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The Coastal Karstic Aquifer of Vlora (Albania)

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ABSTRACT
The coastal karstic aquifer of Mt. Oyramanges (1864 m asl) is located in the Vlora Bay, along the Adriatic coast. The quality of the spring water there is so high that it is used to supply the drinking supply of the second largest Albanian town, Vlora. Starting from a geological and tectonic conceptualization of the area, a GIS approach based on long-term rainfall, temperature and river yield time series has been used to define hydrologic balance. The assessment of recharge and the measurement of sub-aerial spring discharge permit the rough assessment of submarine groundwater discharge. The definition of the flow domain and of groundwater chemical features is pursued with an on-going survey which includes chemical and isotopic analyses of rainfall, groundwater and sea water.

INTRODUCTION
Albania, has a surface of 28,748 km² and a perimeter of 720 km. The coasts, along the Adriatic and Ionian Seas extend for 362 km. 70% of the territory is mountainous with peaks higher than 2700 m asl. Along the coast, alluvial plains, 16 km in width as per the mean value, represent the unique flat areas. Despite the massive land reclamation for agricultural purposes, about 109 km^2 of coastal wetlands or lagoons still exist, especially along the Adriatic coast (Cullhaj et al. 2005).

The Albanian climate is subtropical Mediterranean. The mean annual temperature ranges from 7˚ to 15˚, while the mean annual rainfall ranges from less than 600 mm to more than 3,000 mm (1,500 mm as mean). The mean national value is about 1,500 mm. Groundwater is the only source for drinking water in the whole country (Ministry of Environment 2002). A lack of detailed knowledge on groundwater availability and recharge and the non-systematic monitoring cause management problems where discharge is high and localized, as in some coastal areas in which seawater intrusion can also be observed.

The paper describes the study of the large karstic coastal aquifer of the Oyramanges Mt. (1864 m asl), located near Vlora (South-western Albania). Two main groups of springs are fed by the aquifer; one of which is of a coastal type. Spring groundwater fills the drinking supply of the town; the total spring discharge is roughly 4 m^3/s. A series of surveying campaigns has allowed for the characterization of hydrogeological balance and chemical-physical characterization. The study has been realised for the CISM project (www.cismalbania.it), an Italian-Albanian research project supported by INTERREG III.

GEOLOGICAL AND HYDROGEOLOGICAL FRAMEWORK
The analyzed aquifer is formed by carbonatic rocks of the large Tragjasi anticline, the periclinal of which is located in the S and SW parts of the study zone. The anticline is about 22 km in length and 6-10 km in width, with an asymmetric structure, inverted toward the West. Moving from the core, the anticline is composed of Upper Triassic (T_3) dolostone and limestone, Jurassic (J), Cretaceous (Cr) and Paleocene–Eocene (Pg_1–Pg_2^{1-2}) limestones, dolostones, and limestones with cherts. The carbonatic aquifer is bounded on the E, N and NW sides by Paleogene-Neogene flysch formations (claystones, siltstones and sandstones) (Meçaj et al. 2005); the area hosting aquifer outcrop is 147 km^2. The leakage from the aquifer is null, also due to a continuous outcrop

of quaternary clayey soils, locally including sands and gravels, which extend almost along the entire W side of the aquifer. The inland portion of the aquifer shows karstic features (Fig. 1).

On the western side, the carbonatic rocks and flysch come into transgressive contact with angle discordance placed in the Dukati valley. The relief of the left valley side constitutes the Acrocerauni belt which includes the carbonatic cretaceous relieves of the Karaburuni and Mali I Kanalit Mountains. The Karaburuni Mountain, where small bays and caves can be observed, creates a peninsula which closes the Vlora Bay. In the Dukati plain a shallow aquifer of Quaternary gravel, sand and poorly consolidated boulders can be distinguished. This aquifer, about ten meters thick, lies on hundreds of meters of impervious soils and rocks. The recharge is mainly due to the leakage of the Dukati River. On the left side of the coastal plain, the Orikumi Lagoon completes the environmentally precious bay. On the other side of the aquifer, we come across the hilly Shushica River valley, where Neogenic soils, mainly claystones siltstones and marlstones, which are hundreds of meters thick, outcrop. The discharge from the aquifer occurs as a result of the springs located near or immediately below the margin of outcropping limestone. There are no wells in the area where limestone outcrops but only in the valley of the Dukati River or where Quaternary soils outcrop.

HYDROLOGICAL BALANCE AND RECHARGE

Monthly data (covering a 20 to 32-year time-frame) concerning rainfall P, temperature T, (six gauges) and river flow yield R (1 gauge) were used to define the hydrological balance. Both rainfall and temperature show a statistically relevant straight-line correlation with altitude. On the basis of a DEM (cell size 40 m), the spatial variability of rainfall and temperature was assessed. The real or actual yearly evapotranspiration Er was calculated in each cell using Turc's

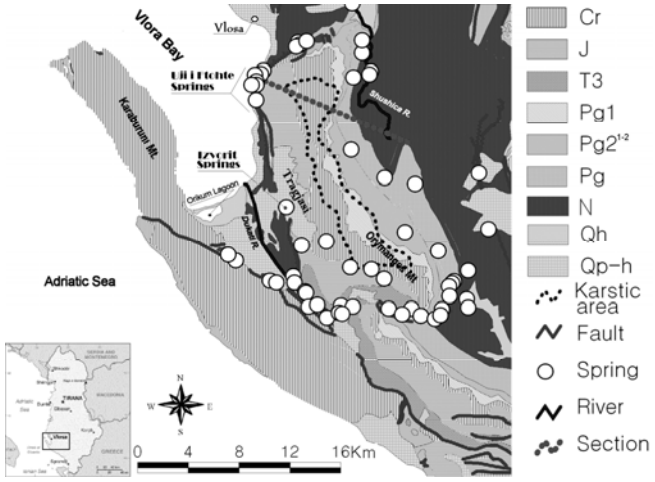
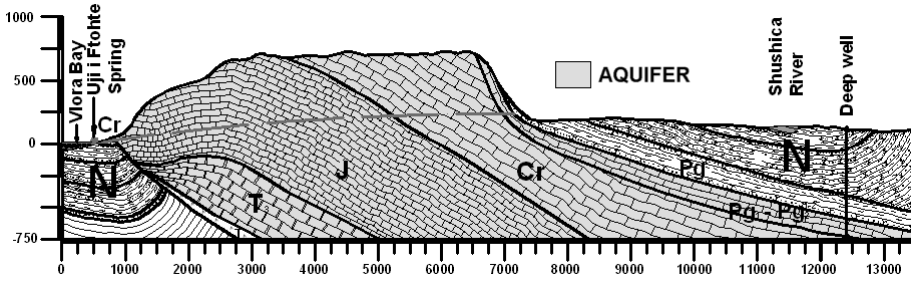


Figure 1. Geological and hydrogeological schematic map and section. Main aquifer: Cr, J, T_3, Pg_1 and Pg_2^{1-2} respectively are Cretaceous fissured and karstified limestones, dolomitic limestones and dolostones, Triassic fissured dolostones and Paleogene-Eocene limestones and limestones with cherts. Impervious formations: Pg and N respectively are Paleogenic and Neogenic soils and rocks, mainly claystones, silts and marlstones. Secondary aquifer: Qp-h and Qh respectively are Quaternary gravel, sand and poorly consolidated boulders, covered by shallow clay in the former case.



formula; the amount of net rainfall Pn was thus calculated as Pn=P-Er. On the basis of the map of hydrogeological complexes, which defines an infiltration coefficient Ci for each complex, the infiltration I is assessed in each cell as I=Pn Ci. The basin of the Shushica River was used to calibrate the hydrologic model. At the Drashovice gauge, the Shushica drainage basin is 587 km^2; while the mean river yield is 19.8 m^3/s, due to mean annual rainfall equal to 1840 mm. At the end of calibration, the mean river yield was assessed as being equal to 17.1 m^3/s. On this basis, the annual net recharge on the karstic aquifer outcrop is equal to 1,127 mm which corresponds to 5.2 m^3/s.

Two main flow paths go from the high karstic plateau of Mt. Oyramanges to two spring areas. These areas are placed at a distance of 10 km on the western side of the aquifer, where it outcrops at the lowest altitude. The former is the group of coastal springs of Uji i Ftohtë, located at sea level. The main coastal group of springs is called Uji i Ftohtë. The group includes three springs tapped by short tunnels and used for the Vlora aqueduct. The mean spring yield discharged in these tapping works is roughly equal to 2.0 m^3/s. The second group of springs is called Izvorit and it is located at about 40 m asl, in the Tragjasi Village. The springs are placed along a straight portion of the outcrop limit between carbonatic rocks ($J\text{-}T_3$) and clays of Neogene. The springs of both groups are roughly placed along a straight N-NW S-SE tectonic line. A low percentage of the Izvorit spring outflow rises up to some villages; the rest was measured with tracer tests. The whole mean outflow of the spring group is roughly equal to 1.8 m^3/s.

The difference between total spring outflow and recharge, roughly equal to 1.4 m^3/s, can be considered equal to groundwater submarine discharge, since the well discharge is almost null. The groundwater submarine discharge is concentrated near the Uji i Ftohtë spring area, where the carbonate aquifer is directly bordered by the sea. The hydrological relevance of groundwater submarine discharge was highlighted by a surveying cruise executed in the Vlora Bay, in which temperature, salinity, pH and dissolved oxygen of the sea water were measured (www.cismalbania.it).

Characteristics of the Uji i Ftohtë spring group

The tunnel of I Jonufrës Cape, 1,700 m in length, connects the outflow of 32 coastal springs, which taps in different sectors along the coastal line. Moving from North to South, the first sector includes tapping from the tunnel road which is 185 m in length. The mean annual discharge is roughly 0.40 m^3/s. Unexploited springs, some of them submarine, are placed from the end the of tunnel road to a maximum distance of about 300 m. From this point to the lighthouse, another tunnel is able to tap a mean discharge equal to 0.64 m^3/s. From the lighthouse to the Castle, about 400 m, four unexploited small springs can be observed. The last sector includes the old road tunnel where 11 tapped springs are placed, for a mean total discharge of 0.94 m^3/s. The chemical and physical characteristics of groundwater tapped springs are almost identical. On the basis of preliminary results (the first of two years of surveying has almost been completed), the spring groundwater is weakly alkaline (pH 7.6) and almost fresh (TDS roughly equal to 0.2 mg/l); the mean chloride concentration is 26 mg/l, but a relevant seasonal variation is observed (peak value equal to 50 mg/l). The hydrochemical type is HCO_3-Ca-Mg. There neither evidence of contamination nor relevant effects of seawater intrusion. The insignificant presence seawater intrusion effects can be tied to the high rate of groundwater flow, the favorable stratigraphical conditions and the Venturi effect (Fleury et al. 2007). The primary exception is due to small springs, mainly located near the first sector, where salinity rises up to 0.3-0.4 mg/l, the nitrate concentration (20-25 mg/l) becomes relevant and chloride is about

double the amount than the value observed in the main springs. This seem to be the result of contamination due to the recent diffuse house building, carried out upward the spring area yet where there are no sewage systems.

RESULTS

The study shows the peculiarities of this carbonate coastal aquifer and the importance of its groundwater which is the chief water resource for the second largest Albanian town. The amount of recharge and discharge was verified together with the conceptual model.Further investigations are necessary to assess groundwater degradation risks and to define management criteria for reducing these risks.

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