Hydrogeological conditions of the Kotyli springs (N. Greece) based on geological and hydrogeochemical data

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Abstract The Kotyli springs are located in northern Greece on the NW part of Rhodope Mountains, which is the oldest mountain range of the country. The climate is semi-humid with water excess and deficiency during winter and summer, respectively. The area belongs to the Rhodope isopic zone, specifically in Sidironero unit, consisting of a Paleozoic sequence of neritic-sea metamorphosed sediments and plutonic intrusions successed by tertiary plutonic, volcanic and coastal deposits. The fractured granodiorites in valley depression areas gives rise to most of the springs, the discharge values and the overall hydrogeological data being consistent with this scenario. Hydrogeochemical analyses performed on samples showed that the springs are classified to the Na-Ca-Cl-HCO_3 type, except for two of the springs in Pacni area classified to the Na-K-Ca-Cl-HCO_3 type and the Aimonio spring which is classified to the Ca-Cl-HCO_3 type. The low values of the dissolved minerals, expressed in TDS and electric conductivity values indicate a function mechanism, which involves the existence of a shallow aquifer in fractured rock with restricted size and the development of the springs at their current site due to the presence of depressions in the small valleys of the area. However, the function mechanism of the Aimonio spring involves the existence of a shallow aquifer in slightly carstified marbles and the development of the spring at its current site due to the presence of a depression in the small valley of the area.

1 Introduction

The Kotyli springs are the essential source of drinking water for the settlements of the area. They are located, on the NW Thraki, on the mountainous part of Xanthi Prefecture (Fig. 1, 2). The springs are located in the area of the settlements Kotyli, Aimonio, Pachni and Dimario, all being part of the Municipality of Kotyli, in altitudes over 800 m.

In the studied area a dentritic pattern hydrographic network prevails, of a medium density, which is characteristic of a development of streams on hard crystalline rocks (Fig. 1). The springs are located along secondary valleys, some of them of a probable tectonic origin. Along those valleys and at a distance of their axe, rocks are fractured and altered, at a certain depth, subsequently presenting a secondary porosity, which assists the development of an aquifer (Stournaras 2007).

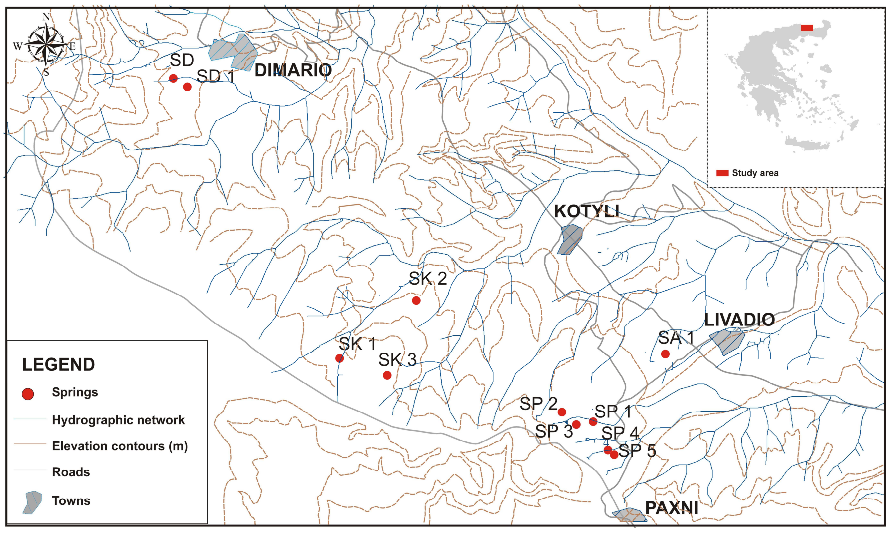

Fig. 1. Map of the hydrographic network of the Kotyli spring area.

The mean annual precipitation in the area, in the period 1970-2005 (Ministry of Agriculture, 2007), is 1076 mm, the climate being semi-humid with water excess and deficiency during winter and summer, respectively. The hydrological balance of the same period in the area was estimated according to the method of Turc (Kallergis 1999). It is calculated that approximately 63% of the mean annual precipitation in the area returns to the atmosphere through evaporo-transpiration, 34% supplies surface runoff and 3% infiltrates in groundwater. The infiltration coefficient is high enough to recharge the existing low potential groundwater aquifers, but on the other hand is low and explains the low discharge rates of the springs.

The present study took place during the study for the collection of the water of 11 of these springs (July 2008-October 2009), aiming to evaluate the hydrochemical characteristics of the water of the springs, as well as to investigate their hydrogeological conditions with respect to local geology.

2 Geological and hydrogeological setting

Geologically, the area belongs to the Rhodope isopic zone, specifically to the Sidironero unit (Mountrakis 1985, 1994). The lower part of the unit is composed of rocks of medium grade metamorphism, that is gneisses and augen gneisses with intercalations of marbles, while the upper part is composed of rocks of low grade metamorphism (green schist metamorphism), that is gneisses, mica schists, amphibolites and marbles. In the upper part, intrusions of plutonic rocks are observed (granitic intrusions); aging 35 million years or older, but locally even volcanic rocks dating 30 millions years are observed (Mountrakis 1985; Kokkinakis 1980; Kronberg et al. 1970, Kronberg and Eltgen 1973).

These neritic-sea metamorphosed sediments and plutonic intrusions are overlaid by tertiary deposits, consisting of coastal deposits, volcanic deposits and more recent plutonic intrusions.

The studied area is composed of tertiary deposits dating in Oligocene, consisting of volcanic rocks (rhyolites and ignimbrites), coastal deposits (conglomerates and sandstones) and magmatic intrusions (granodiorites and old granodiorites), as well as Paleozoic metamorphic rocks, that is the upper amphibolitic sequence, represented in the studied area by the lower marble – amphibolite series (marbles, amphibolites, schists and gneisses) and the gneiss - augen gneiss - migmatite series. No major faults have been located in the studied area; however the crystalline rocks present two main discontinuity systems (minor faults and joints), dipping 243/32 and 307/87 (Angelopoulos 2009).

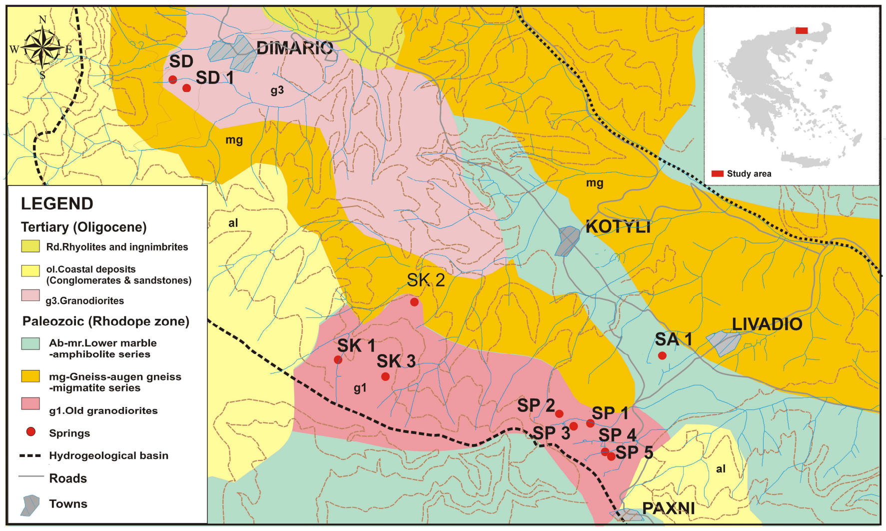

Fig. 2. Geological map of the Kotyli spring area (after IGME (1982), modified).

The springs in Kotyli area (SK) and in Pachni area (SP) discharge through discontinuities present in the old granodiorites, while those in Dimario (SD) area through discontinuities in the rhyolites and that in Aimonio (SA) area through carstic discontinuities in marbles of the lower marble – amphibolite series (Angelopoulos 2009) (Fig. 2).

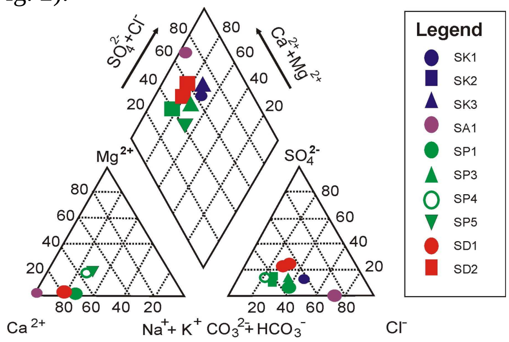

Fig. 3. Piper diagram.

The springs discharge was monitored in June 2008 and, using older data (Community of Kotyli, 2008) as well, is considered to be generally low, consistent with the low infiltration rates of the area as mentioned above (Table 1).

Table 1. Discharge of Kotyli springs

Springs	Number of springs	Monitored (mean) discharge (m^3/h)	Minimum estimated discharge (m^3/h)	Maximum estimated discharge (m^3/h)
Kotyli springs	3	10.0	7.5	12.0
Aimonio spring	1	3.0	2.0	4.0
Pachni springs	5	4.0	2.5	5.0
Dimario springs	2	10.5	7.5	12.0

The spring discharge values of the Table 1 concern the total of every group of springs, measurements being possible only in the cistern of every settlement.

The hydrogeological basin of the springs is included between the watershed of the main valley (Small River Valley) and the course of the river, and is estimated to be about 30 km^2 (Fig. 2).

3 Hydrogeochemical characteristics and classification

Water samples were collected in October 2009 for chemical analyses. According to the Piper diagram, the hydrochemical type of the springs is Na-Ca-Cl-HCO_3, with the exception of the springs SP4 and SP5 in Pachni area displaying Na-K-Ca-Cl-HCO_3 type and the Aimonio spring, which displays Ca-Cl-HCO_3 type (Fig. 3).

It is evident that the Aimonio spring samples display a different type to the others being consistent with its different origin.

According to Schoeller diagram all the springs present the same chemical pattern, except for Aimonio spring which presents higher concentration of Ca, lower of Mg and lack of SO_4, while the Pachni springs SP4 and SP5 presents higher concentration of Ca, Na and K (Fig. 4).

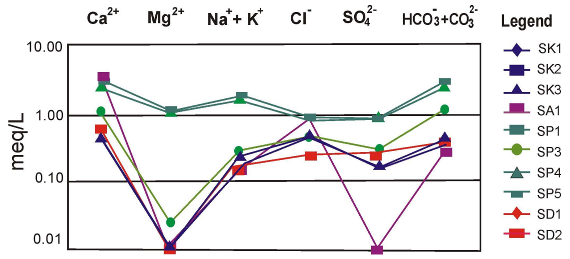

Fig. 4. Schoeller diagram.

The pH values range between 7.0 and 8.0, while the electric conductivity values (ρ_α) range between 49 and 590 μS/cm, the springs SA1, SP4 and SP5 presenting the higher values. The TDS value range between 75 and 431 mg/L, the same as aforementioned springs presenting the higher values.

The concentration of all ions, as represented of the values of electric conductivity (ρ_α), in the water of the springs is very low and very close to that of rain water. Only the two springs in Pachni area and that of Aimonio, to a lesser extent, present concentrations close to the values of that of the Komotini - Xanthi Plain groundwater (Angelopoulos 2010) (Fig 5).

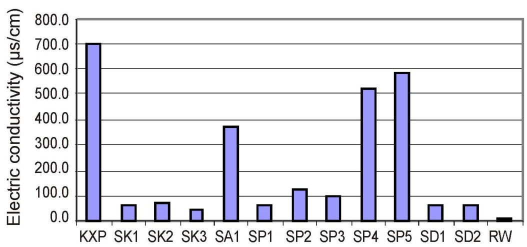

Fig. 5. The values of electric conductivity of the springs comparatively to that of rainwater (RW) and the Komotini-Xanthi Plain groundwater (KXP).

4 Discussion

According the way the springs discharge through rocks suggests that the springs can be considered as fracture springs, while the Aimonio spring can be considered as carstic spring (Kallergis 2000, Todd and Mays 2005).

The geochemical characteristics of spring water and especially the very low TDS and ρ_α values indicate that rain water infiltrates through rock fractures and having a high flow rate discharge through joints at small valley depressions. Is it possible that the low values of TDS and ρ_α, combined to the reduced solubility of the formations and the fact that they are under conditions of lack of extended ruptures, the limited depth of the discontinuities do not permit a groundwater extended circulation.

According to hydrodynamic conditions described above, the springs can be considered as contact springs (Stournaras, 2007), inasmuch the whole of the water of the aquifers is located in altitudes higher than those of the springs, as all available data suggest (Fig. 6).

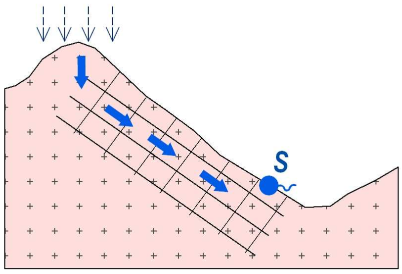

Fig. 6. Schematic representation of the fracture springs function mechanism.

Although the case of the springs to be of the overflow springs type, the water of the aquifers being located in altitudes higher and lower than those of the springs, cannot be excluded, due to the lack of spring hydrographs and geophysical data, but the concentrations of dissolved minerals is rather low, hence the model of contact springs being the most probable.

The same pattern applies for the Aimonio spring, the only difference being geochemical characteristics, which indicate infiltration and rapid flow in carstic cavities, being considered as carstic spring.

The very low TDS and, consequently, ρ_α values are justified from the very shallow extent of the fractures, perhaps less than 50 m and the high flow rate in them, so as the time for the water to be in contact with the fractured media and dissolve minerals is extremely short.

In the case of the two springs in Pachni area with higher values of TDS and ρ_α it is supposed that the time for the water to be in contact with the fractured media is prolonged, permitting in this way the water to dissolve a significant amount of minerals and indicating a possibly deeper extend of the fractures

As far as the Aimonio spring is concerned, the fact that marbles are intercalated in amphibolites restricts the circulation in carstic cavities and thus limiting the necessary time for the water to be in contact with the fractured media in order to dissolve a significant amount of minerals.

5 Conclusions

The Kotyli springs are hosted in the tertiary volcanic and plutonic rocks of the West Rhodope zone, being considered as fracture springs. Exception to this is the Aimonio spring which is hosted in the Paleozoic upper amphibolites sequence, in the marbles intercalating amphibolites, considered as carstic spring. All springs however are considered, as far as hydrodynamic behaviour is concerned, as contact springs.

The Aimonio spring displays a different chemical composition than the rest of the springs in the area, justified from the different host rock. The relatively high concentration of SiO_2, almost identical with that of the other springs varying between 9.0 and 14.8 mg/L, indicates the contribution of amphiboles in its chemical composition.

The hydrogeochemical data suggest a shallow, very limited in size aquifer in fractured rock, which flows rapidly, having low dissolution of various elements, and discharges, at very low discharge rates, at valley depressions, while concerning the Aimonio spring the same function model applies, with the difference of a carstic aquifer present instead of one in fractured rock.

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