

HYDROGEOLOGICAL REGIME AND GROUNDWATER OCCURENCE IN THE ANTHEMOUNTAS RIVER BASIN, NORTHERN GREECE

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Abstract

The Anthemountas river basin is located in northern Greece and covers an area of 374 km². The mountainous part of the basin consists of ophiolitic, crystalline and carbonate rocks, whereas the lowlands comprise Neogene and Quaternary sediments. Porous aquifers are developed in neogene and quaternary deposits of confined and/or unconfined conditions. Karstic aquifers are developed in the carbonate rocks and there are aquifers in the Mesozoic and Palaeozoic fissured rocks. The water demands of the basin are mainly met by the exploitation of the porous aquifers through a large number of boreholes (more than 1000). The aquifers of fissured rocks discharge through cold springs without significant flow rate. Thermal hot springs are recorded across the Anthemountas fault discharging a mixture of geothermal fluids and cold water from the karst aquifer. According to their hydrogeological and lithological characteristics, porous aquifers can be divided into the sub-systems of Galatista and Galarinos in the eastern part of the Anthemountas basin, Vasilika-Risio-Thermi and Tagardes-Trilofos in the western part and Peraia-Agia Triada and AUTH farm-Makedonia airport in the coastal area. For the determination of the aquifers (geometry and anatomy), their recharge mechanisms and hydraulic connection, data from geological maps, lithological profiles, geoelectrical soundings and tomographies, pumping tests and groundwater level measurements are used.

Key words: Aquifer systems, Fissured rocks, Springs, Geoelectrical soundings.

Περίληψη

Η λεκάνη του Ανθεμούντα βρίσκεται στη βόρεια Ελλάδα και έχει έκταση 374 km². Στα ορεινά τμήματα της περιοχής συναντώνται οφιολιθικά, ανθρακικά και κρυσταλλοσχηστώδη πετρώματα, ενώ το πεδινό τμήμα αποτελείται από Τεταρτογενή και Νεογενή ιζήματα. Στα τεταρτογενή και νεογενή ιζήματα αναπτύσσονται ελεύθεροι και υπό πίεση υδροφορείς, στα ανθρακικά πετρώματα καρστικοί, ενώ και υδροφορείς στα διερρηγμένα κρυσταλλικά πετρώματα. Οι υδατικές ανάγκες της περιοχής καλύπτονται κυρίως από την εκμετάλλευση των πορώδων υδροφορέων με μεγάλο αριθμό γεωτρήσεων (>1000). Οι υδροφορείς των διερρηγμένων πετρωμάτων εκφορτίζονται από ψυχρές πηγές χωρίς σημαντικές παροχές. Κατά μήκος του ρήγματος του Ανθεμούντα ενοτοπίζονται γεωθερμικές πηγές όπου σε ορισμένες περιπτώσεις εκφορτίζουν νερό από

*ανάμειξη γεωθερμικών ρευστών και ψυχρού από τον καρστικό υδροφόρο. Σύμφωνα με τα υδρογεωλογικά και λιθολογικά χαρακτηριστικά τους οι πορώδεις υδροφορείς χωρίστηκαν στα υποσυστήματα της Γαλάτιστας και του Γαλαρινού στα δυτικά, των Βασιλικών-Ρυσίου-Θέρμης και Ταγαράδων-Τριλόφου στο κέντρο της λεκάνης και της Περαίας-Αγίας Τριάδας και Αγροκλήματος ΑΠΘ-Αεροδρόμιο Μακεδονία στο παράκτιο τμήμα. Για τον καθορισμό της γεωμετρίας και δομής των υδροφορέων, την υδραυλική επικοινωνία και τα υδραυλικά τους χαρακτηριστικά χρησιμοποιήθηκαν δεδομένα από λιθολογικές τομές, δοκιμαστικές αντλήσεις, βυθοσκοπήσεις και ηλεκτρικές τομογραφίες, καθώς και μετρήσεις στάθμης.
Λέξεις κλειδιά: Διαρρηγμένα πετρώματα, Πηγές, Υπόγειοι υδροφορείς, Γεωηλεκτρικές διασκοπήσεις.*

1. Introduction

Groundwater is of major importance in the Anthemountas basin because it is the main supply of water for domestic, irrigation, industrial and livestock uses. Population of the basin is 56,000 people, agricultural land covering 52%, livestock units (about 100) and a large number of industrial and commercial units can describe the main needs of water supply in the area. The water demands are covered by the exploitation of the porous aquifers through a large number of boreholes (greater than 1000). On the other hand a small number of boreholes are drilled in fissured rocks, located mainly in fault zones. Cold springs with no significant discharge are recorded in the wider area.

The aim of this work is the determination of the aquifers type, geometry and anatomy, hydraulic characteristics, recharge mechanisms and their hydraulic connection. These data are necessary to determine groundwater reserves and are useful for rational exploitation in order to avoid future quantitative and qualitative degradation.

2. Geomorphological and Geological Settings

The Anthemountas basin is located in northern Greece at the eastern part of the Thermaikos gulf and covers an area of 374 km² with high hills of semi-mountainous relief, according to Dikau's (1989) classification. The mean altitude and slope of the study area are 259 m and 20%, respectively, with a good developed dendritic drainage network.

From a geological point of view, the Anthemountas basin is a part of the Servo-Macedonian, Circum-Rhodope and Paenonian geotectonic zone (Mountrakis, 1985). The mountainous part of the basin consists of Mesozoic ophiolitic, crystalline and carbonate rocks whereas in the lowlands Neogene and Quaternary sediments represent 65% of the formations. The Neogene sediments are mainly located at the southern part of the area and consist of sandstone-marl (sandstones, marls, sands and gravels), red-clay (clay with lenses of sands) and conglomerate series (conglomerates, gravels, sands). The Quaternary sediments are alluvial deposits (sands, gravels and clays) in the western part of the basin and terrace systems (sands, pebbles) in the east (Figure 1). Carbonate rocks outcrop in the south-central part of the basin near Agia Paraskevi and Tagarades and consist of Triassic limestones. Leucocratic gneiss represents the largest percentage of the metamorphic rocks in the basin. The fault pattern of the study area is quite complex with WNW-ESE to E-W and NE-SW normal faults (Tranos et al., 2004). The Anthemountas fault is the longest in the area (32 km) and is characterised as active (Tranos et al., 2003; Zervopoulou et al., 2007).

3. Materials and Methods

For the determination of the aquifers, their recharge mechanisms and hydraulic connection, data from geological maps, lithological profiles, geoelectrical soundings and tomographies, pumping

tests and groundwater level measurements have been used (Figure 2). The aquifer type and geometry has been determined from the geological maps and lithological profiles (150) of boreholes. From the geoelectrical vertical soundings (47), the material of the vadose zone was defined, while geoelectrical tomographies were used to identify the anatomy of the aquifer layers after calibration with lithological data based on Vargemezis and Fikos' assignment (2010).

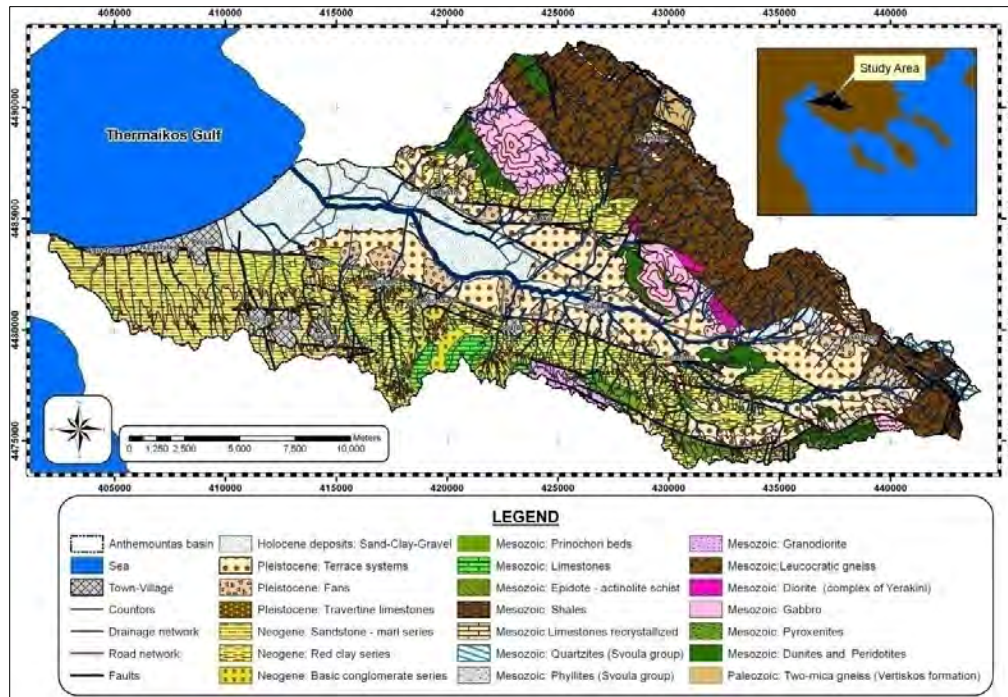


Figure 1 - Geological and topographic map of Anthemountas basin (Modified from IGME, Sheets Thessaloniki, Epanomi, Vasilika, Thermi, Polygiros and Zagliveri).

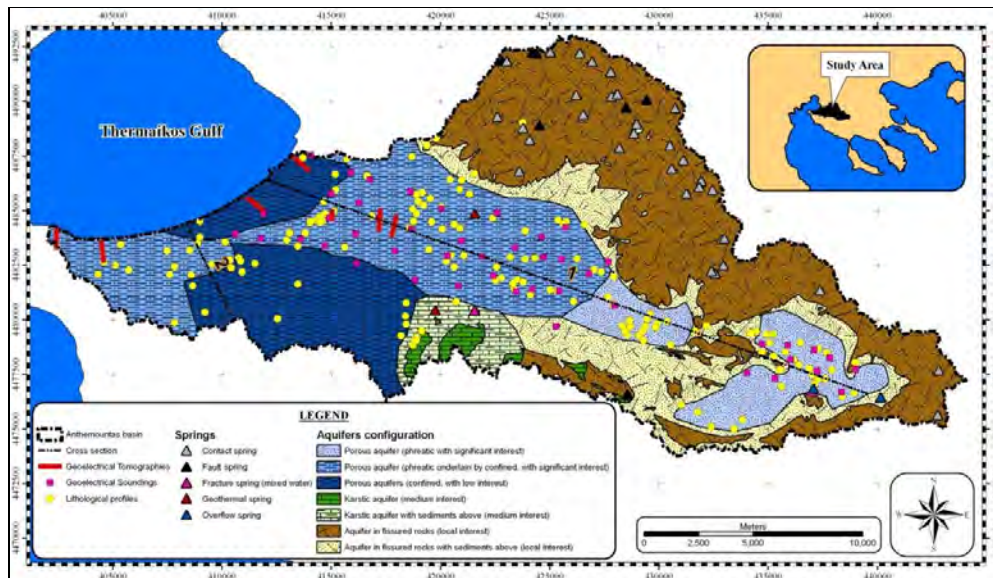


Figure 2 - Aquifers configuration, springs and locations of used data in the Anthemountas basin.

Water level measurements were performed in 136 boreholes for four periods: wet, May 2010-11 and dry, September 2009-2010. Pumping tests were performed in 6 boreholes and pumping data from 135 lithological profiles were used to evaluate the hydraulic characteristics of the porous aquifers. Constant rate pumping tests were used to determine the storativity and specific capacity, which is defined as the ratio of discharge to drawdown at the pumping borehole. Springs were mapped from the geological maps and field investigation. All collected data were stored, analysed, managed and displayed using geographic information systems (G.I.S.).

The Schlumberger array has been applied in order to measure the 47 geoelectrical soundings in the area. The exact location of each VES (Vertical Electric Sounding) can be seen on Figure 2. The distance in between the current electrodes (AB) varied between 30 and 50 meters aiming to get information about the vadose zone. Measurements were taken with Syscal (V11.4) IRIS instrument and the inversion has been done by the use of IPI2WIN software (Alexei et al. 1990-2001). The RMS values varied between 0.5% and 7%.

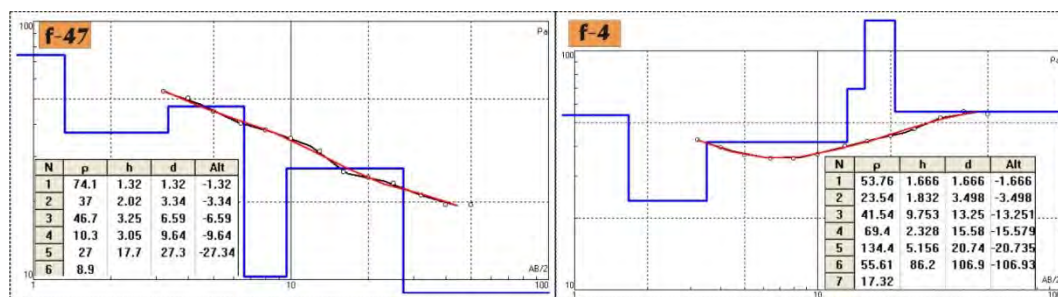


Figure 3 - Example of interpretation for 2 representative VES measured in Nea Raideostos (F-47) and Galatista (F-4).

Some typical examples of the results are presented in Figure 3 where the original measurements (black line with white circles) along with the resulting (by the forward modelling) curve (red colour) and the corresponding table of resistivity (ρ), depth (d) and thickness (h) of each identified layer.

The resistivity values have been calibrated according to geological information revealed from boreholes in the area and geoelectrical layers have been transformed to geological units according to the following table.

Table 1 - Calibration of resistivity values.

Resistivity (Ohm-m)	Geological Unit
0-10	Clay
10-20	Clayey sand
20-30	Sandy clay with thin layers of gravel
30-50	Gravel
50-80	Marl
>80	Conglomerate

According to the calibration table, the distribution of the thickness of the clay layers is shown in the map of Figure 4. The areas with green color are characterized by the absence of clay layers representing unconfined aquifers, while the areas with significant thickness of clay layers (orange and red color) correspond to areas with confined aquifers.

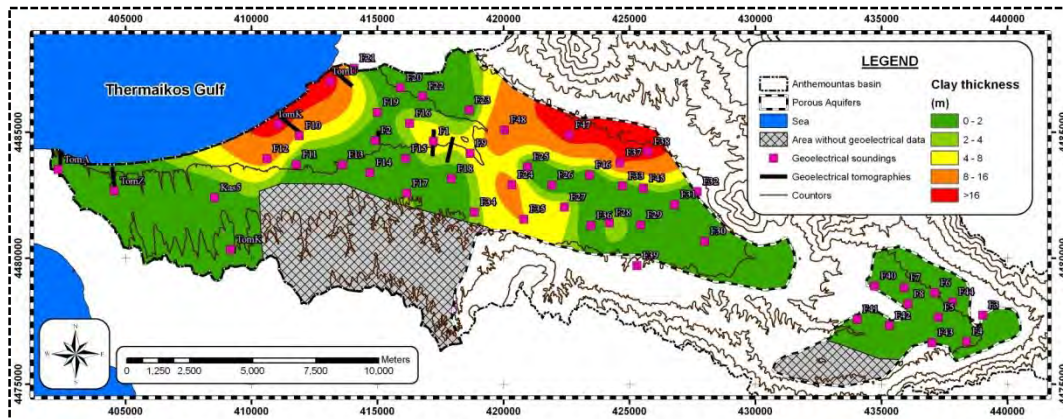


Figure 4 - Distribution of clay layers in vadose zone according to the geoelectrical survey.

4. Results

According to the geological formations, three categories of aquifers have been determined in the Anthemountas river basin, which are: aquifers in fissured rocks, karstic and porous aquifers.

The aquifers of fissured rocks have local interest in fault zones with discharges ranging from 30–80m³/h and covering an area of 177 km² although 52 km² are under sediments. A large number of contact and fault springs (greater than 50) are located in fissured rocks without significant flow rates (1–5 m³/h), which discharge periodically during the winter and spring (Figure 5a).

Karstic aquifers are located in the south-central part of the basin, near to Agia Paraskevi and Tagarades villages, covering an area of 5 km² and 11 km², respectively. Fault springs discharge mixed geothermal and cold water across the Anthemountas fault (Kazakis, 2013); the most well-known is Voskina spring (Figure 5b) near the village of Souroti. According to Nimfopoulos et al. (2002), a karstic aquifer underlies the sediments of the basin and controls the composition of the hosted hydrothermal waters, which are mixed with meteoric water and discharged through.

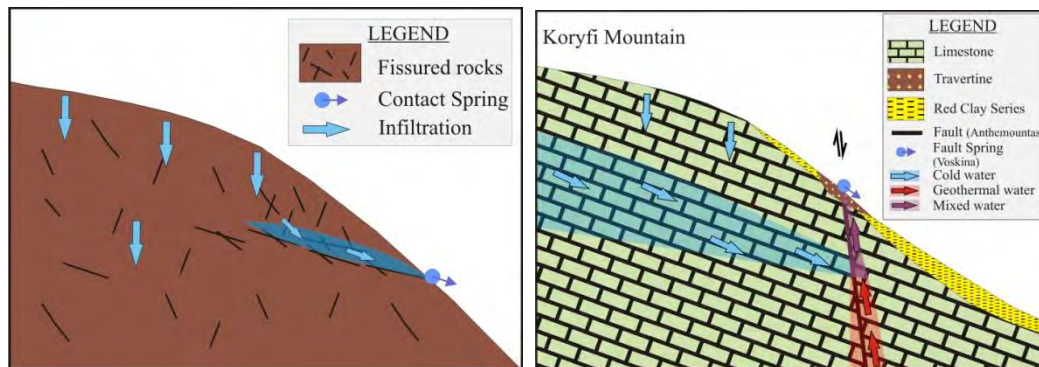


Figure 5 - (a) Contact spring in fissured rocks, (b) Fault spring with mixed water in Karst.

Porous aquifers cover an area of 181 km² and are developed mainly in the lowlands. According to their hydrogeological and lithological characteristics, porous aquifers can be divided into the sub-systems of Galatista and Galarinos in the eastern part of the Anthemountas basin, Vasilika-Risio-Thermi and Tagarades-Trilofos in the western part and Peraia-Agia Triada and AUTH farm-Makedonia airport in the coastal area (Figure 2). The sub-systems are described below and their hydraulic characteristics represented in Table 2.

- **Galatista:** Located in the western part of the Anthemountas basin, the Galatistas sub-basin covers an area of 24 km². An unconfined aquifer underlain by a confined aquifer is developed in the centre of the basin (Theodosiou and Latinopoulos, 2006). Its thickness ranges from 15 to 100 m, consisting of pebbles, gravel and sand. Groundwater level varies from 8 m below ground surface (b.g.s.) in the centre to 100 m (b.g.s.) in the southern part. The sub-system is hydraulically isolated from the other systems, because it is surrounded by crystalline rocks. The unconfined aquifer is recharged from directly infiltrating precipitation, percolation water from streams and the Anthemountas River and from fissured aquifers, whereas the confined aquifer is recharged from both unconfined and fissured aquifers.
- **Galarinos:** This is placed between the villages of Galarinos and Vasilika and has an area of 9 km². The thickness of the sediments varies from 140 to 180 m. The main aquifer is unconfined with a small confined aquifer below. Its thickness ranges from 40 to 80 m. The materials of the aquifer system consist of gravel, sand and sandy clay. Groundwater level varies from 60 m in the eastern part to 25 m in the western part. Groundwater recharge in this aquifer occurs via the following mechanisms: direct infiltration from rainfall, percolation from the Anthemountas River and lateral subsurface inflows from the aquifers of the fissured rocks. Aquifers of the fissured rocks are detected below the porous aquifers of the sub-system, as a result of the small thickness of the sediments. This is the main difference to the Vasilika-Risio-Thermi sub-system, with which it is in direct hydraulic contact.

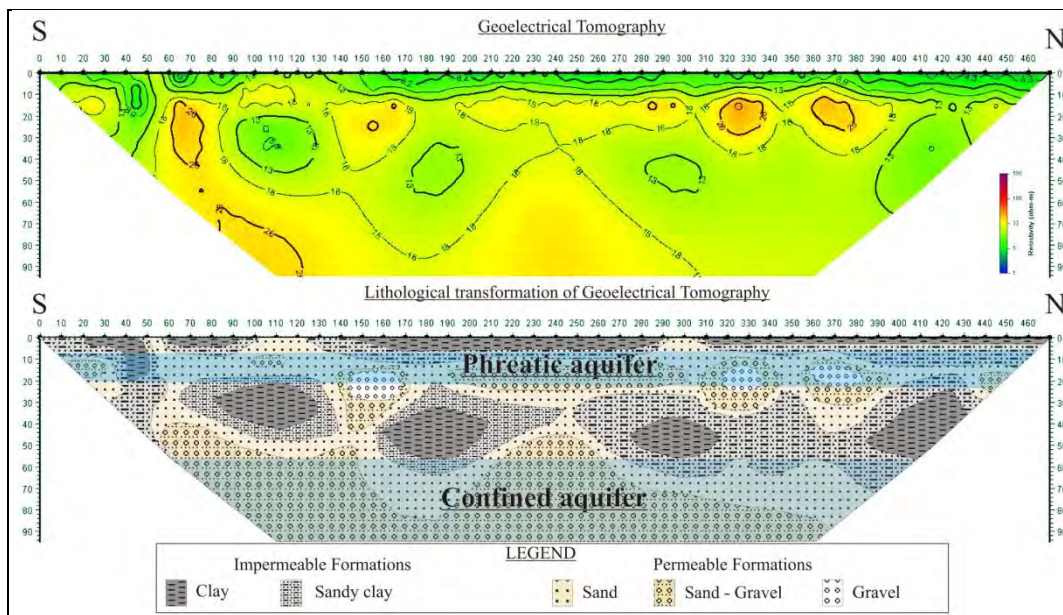


Figure 6 - (Up) Goelectrical tomography of Vasilika-Risio-Thermi sub-system, (Below) lithological cross section based on goelectrical tomography and lithological profiles.

- **Vasilika-Risio-Thermi:** This is located in the centre of the basin between Vasilika, Neo Risio and Thermi with a total area of 70 km². The thickness of the sediments is greater than 800 m in Vasilika (Vargemesis and Fikos, 2010) and greater than 1000 m near to Neo Risio (Thanassoulas, 1983). Quaternary deposits are up to 300 m thick and the aquifers developed within them contain fresh water; geothermal fluids are found beneath these deposits (Kolios et al., 2007). A phreatic aquifer was detected at a depth of up to 30–40 m (Nagoulis, 1998) with hydraulic connection with the confined aquifer through the

discontinuities of the clay lens (Figure 6). Furthermore, the construction of boreholes, exploiting both two aquifers favours the connection. The phreatic aquifer is converted to confined conditions in places, due to surface clay layers, mainly in the centre of the sub-system. The material of the aquifers consists of sand, sand-silt and gravel. Recharge of the sub-system occurs via infiltration of rainfall water, percolation from the Anthemountas River and torrents (Tagarades, Trilofos) and lateral inflows from the karstic aquifer in the southern part and the fissured rocks aquifer in the north. Groundwater level of the phreatic and confined aquifers ranges from 8–20 m in the western part to 25–40 m in the eastern part. Both aquifers are united in the area of Vasilica village, which constitutes the boundary with the Galarinos sub-system.

- **AUTH farm-Makedonia airport:** The phreatic aquifer of the Vasilika-Risio-Thermi sub-system is confined in the coastal area with the exception of some parts of AUTH farm (Fikos, 2000). For this reason, it is separated from the Vasilika-Risio-Thermi sub-system, although the two aquifer systems are in hydraulic connection. This sub-system covers an area of 7 km² in the northern coastal part and is recharged by infiltration of rainfall and from the Vasilika-Risio-Thermi. Groundwater level varies from 5 to 20 m below ground surface or from 10 to 20 m below sea level and shows negative piezometry due to overexploitation of the aquifer. The aquifer materials consist of sands and gravels.

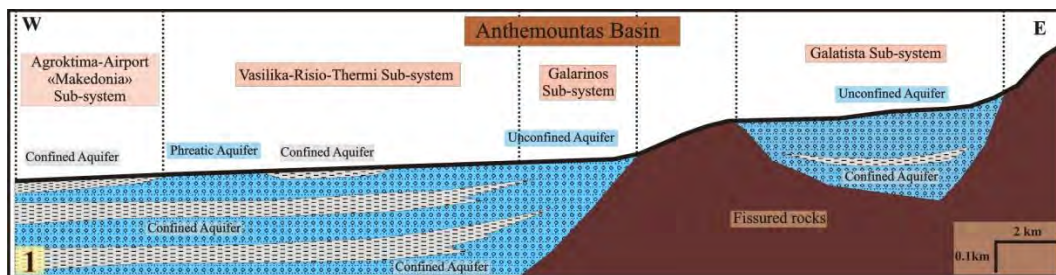


Figure 7 - Hydrogeological cross section from Galatista to Coastal area (1).

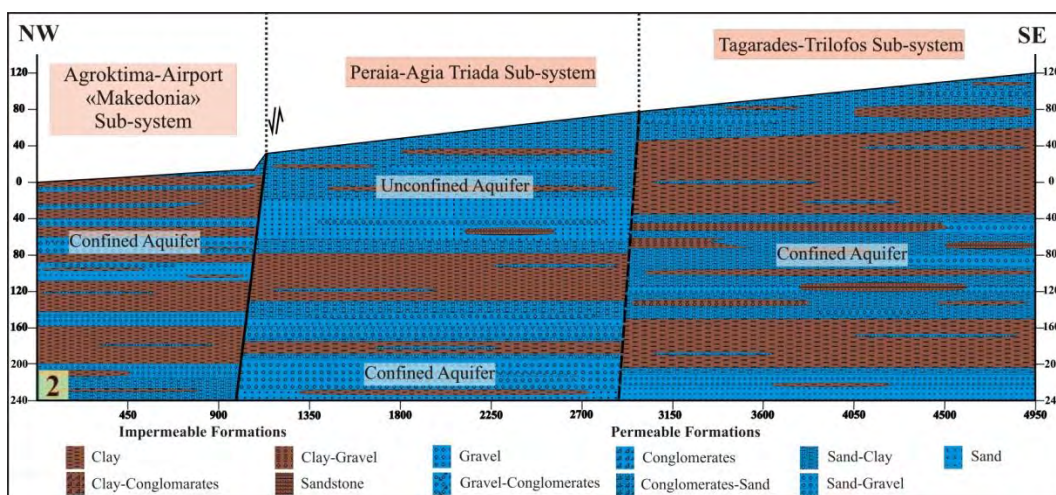


Figure 8 - Hydrogeological cross section (2) of the south-west part of Anthemountas basin.

- **Tagarades-Trilofos:** This is located in the north-western part of the basin and covers an area of 42 km². The Anthemountas fault form the boundary with the Vasilika-Risio-Thermi

sub-system. The aquifer consists of a small thickness (15-20 m) of parallel layers of sand with clay and gravel under confined conditions. The yield of the boreholes ranges between 4 and 10 m³/h, while groundwater level varies from between 60 to 120 m b.g.s. without significant variation between the dry and wet periods. The sub-system is recharged mainly by infiltration of rainwater and by the percolation from streams and from the karst aquifer in the east.

- **Peraia-Agia Triada:** It covers an area of 22 km² located in the south-western part from the coast to the Tagarades-Trilofos sub-system. The aquifer system is divided to the upper unconfined aquifer with a mean thickness of 80 m and the deeper confined aquifer below 200 m. The two aquifers have the same piezometric head (Koumantakis, 2006) with negative values due to overexploitation (Voudouris and Kazakis, 2011). The unconfined aquifer consists of sand and some layers of gravel with groundwater level varying from 10 m near to the coast to 100 m in the hills of the southern part. The sub-system is recharged via infiltration, percolation from streams and inflows from the Tagarades-Trilofos sub-system.

In Figure 9, the spatial distribution of groundwater heads (metres above sea level) for the period of May 2010 is given. The groundwater flow direction in the Galatistas sub-system is mainly from west to east and southwest to northeast in the southern part revealing a hydraulic connection and recharge from the aquifer of the fissured rocks. In the western part of the study area the direction of groundwater is northwest to southeast in the north and from northwest to southeast in the south, whereas in the coastal area it is from the sea towards the mainland, which is due to seawater intrusion from overexploitation and the low natural recharge of the aquifer.

In Table 2, the hydraulic characteristics of the Anthemountas river basin sub-systems are shown. Hydraulic conductivity values range between 1.5×10^{-6} m/s and 5×10^{-6} m/s. The value of storativity (S) varies from 10^{-4} to 3×10^{-1} . The values of specific capacity range between 2–270 m²/h. The effective porosity varies from 15% to 26%.

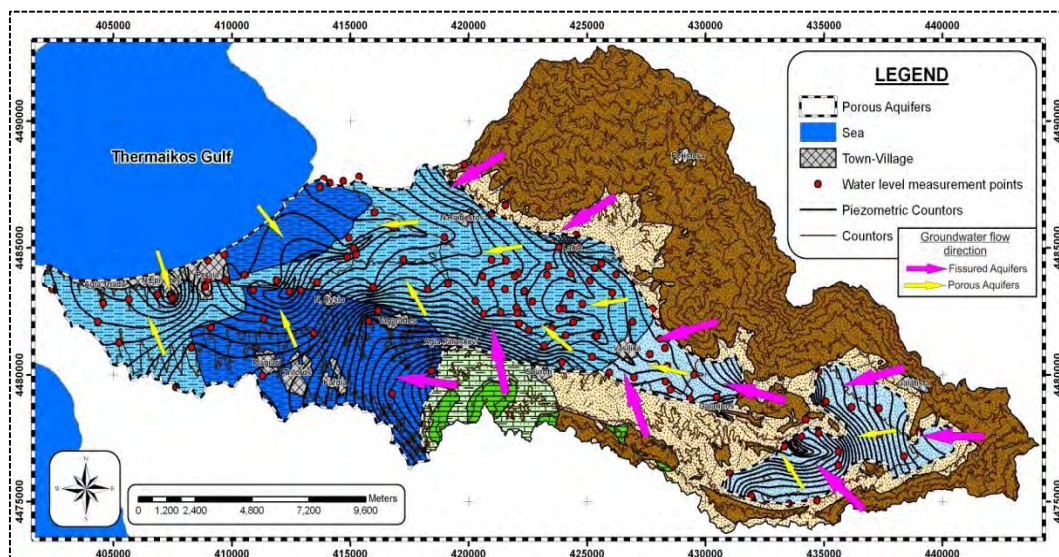


Figure 9 - Piezometric map and groundwater flow of porous aquifers of Anthemountas basin (May 2010).

Table 2 – Hydraulic characteristics of Anthemountas basin sub-systems.

Sub-system	Aquifers Thickness (m)	Yield of boreholes (m³/h)	Specific Capacity (m²/d)	Hydraulic Conductivity (m/d)	Storativity (%)	Effective porosity (%)
Galatista	15-100	25-80	28-60	1.3-3.5	0.1-10	15-23
Galarinos	15-80	30-160	15-270	0.3-8.6	1-30	17-24
Vasilika-Risio-Thermi	15-170*	20-160	28-270	1.3-43.2	0.01-5	16-26
Tagarades-Trilofos	15-50*	4-10	2-20	0.1-0.5	0.01-0.1	15-19
Peraia-Agia Triada	45-120*	30-60	28-230	1.7-10.4	0.05-5	19-24
AUTh farm-Macedonia airport	50-100*	30-80	60-250	1.7-13.8	0.01	19-26

*Until the depth of 300 m

5. Conclusions

From the analysis of hydrogeological and geophysical data in the Anthemountas river basin (North Greece), the following conclusions can be drawn:

Porous aquifers are divided into the sub-systems of Galatista, Galarinos, Vasilika-Risio-Thermi, Tagarades-Trilofos, Peraia-AgiaTriada and AUTh farm-Makedonia airport. In the sub-systems of Galatista, Galarinos and Peraia-AgiaTriada the main aquifer is phreatic and the yield of the boreholes varies from 25 to 160 m³/h.

The confined aquifer is the most important in the Vasilika-Risio-Thermi and AUTh farm-Makedonia airport sub-systems with significant values of yield from boreholes ranging between 15–170 m³/h. The Tagarades-Trilofos sub-system consists of parallel confined aquifers without significant discharge due to the low thickness of the aquifers and the mix of clay in the aquifer media.

Fissured rock aquifers and karstic aquifer discharge groundwater through springs. Piezometric maps reveal the subsurface hydraulic connection between the aforementioned aquifers and porous aquifers. The main direction of groundwater flow in the Anthemountas river basin is E-W, while overexploitation in the coastal area has caused an inversion of the flow from the sea towards the mainland.

6. Acknowledgements

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