

Groundwater Quality Analysis in Mygdonia Basin, Greece [†]

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Abstract: The objective of this research is the groundwater quality analysis in Mygdonia basin (North Greece), where intensive agricultural activities take place. Groundwater sampling was carried out in May (17 samples) and in September (26 samples) for the years of 2013 to 2015. In situ physicochemical parameters (pH, EC, T) were tested, whereas major ions (Ca^{2+} , Na^+ , Mg^{2+} , K^+ , NO_3^- , SO_4^{2-} , Cl^- , HCO_3^-) were analyzed in laboratory. Conventional statistical methods were applied for the classification of the groundwater hydrochemical type, and the identification of the prevailing hydrogeological processes. Finally, some recommendations are presented for the protection of groundwater quality.

Keywords: aquifers; groundwater quality assessment; sustainable management; Mygdonia basin; North Greece

1. Introduction

Groundwater is critical to support human well-being and economic development. During the last decades, groundwater is under increasing pressure and the threat of pollution due to agricultural and industrial activities, urbanization, and tourism development. In addition, the climate crisis will affect the parameters of the hydrologic cycle (increase in temperature, reduction of rainfall, droughts, floods), and consequently the natural recharge of the aquifers, as well as the quantity and quality of groundwater resources. In groundwater, dissolved ions and solids are always present. That defines its physical and physicochemical characteristics. When the concentration of pollutants is greater than threshold values, then it is unsuitable for irrigation and/or other uses.

Mygdonia hydrologic basin consists of a rare complex of ecosystems, including the lakes Koronia and Volvi, which constitute an important wetland system of high ecological and international importance (protected by Ramsar Convention), but over the years a degradation, especially of Lake Koronia, was observed (Devlioti, 2016). The main causes of water quality deterioration of Lake Koronia are the water withdrawals and the uncontrollable discharge of untreated domestic and industrial effluents (Ballas, 2007; Malamataris et al., 2020).

This work investigates the groundwater quality of the Mygdonia basin. Conventional statistical methods, hydrogeochemical diagrams along with data reduction methods such as factor analysis, were applied in order to describe groundwater quality, to classify samples according to their water type and identify the prevailing hydrogeological processes that take place in the aquifers of the basin. Some proposals to improve the sustainability of groundwater resources in the Mygdonia basin are presented.

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2. Study Area-Data Collection

2.1. General Characteristics

Mygdonia basin, covering an area more than 2000 km² (650 km² in the lowland), is located in the Thessaloniki Prefecture, central Macedonia, North Greece (Figure 1). It is characterized by the typical Mediterranean and continental climate with wet (October-April) and dry periods (May-September). The mean annual rainfall is 585 mm and the mean annual temperature is 13.5 °C (Chantzi and Dotsika, 2016).

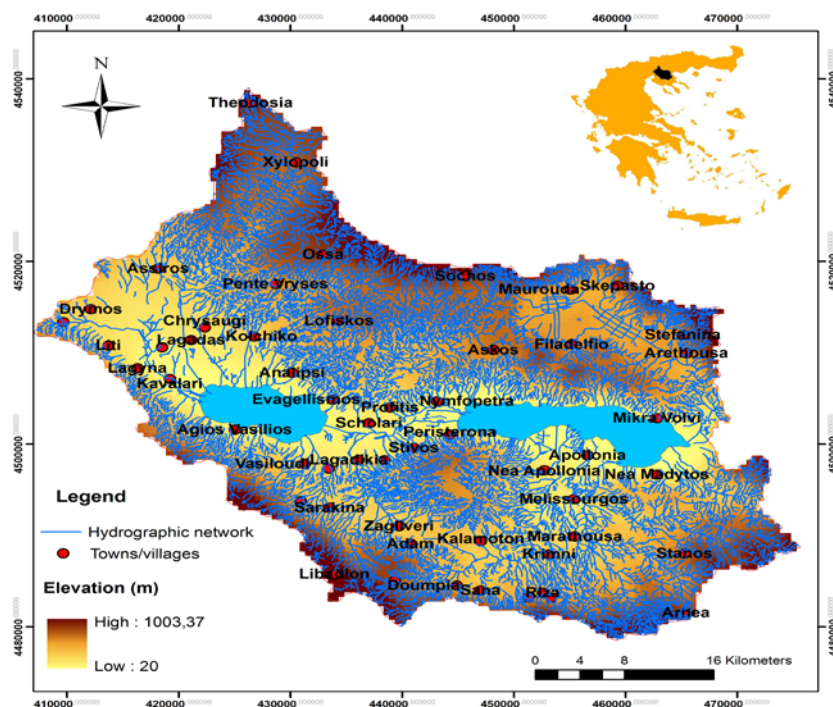


Figure 1. Morphological map of the Mygdonia basin.

From a geological point of view (Figure 2), as a tectonically active basin, the lowland of the Mygdonia basin is formed of recent unconsolidated materials, consisting of sands and clay to silty sand sediments (Psilovikos, 1977). The bedrocks are paleozoic gneisses, amphibolites, schists, marbles and granitic intrusions of the Serbomacedonian massif (Mountrakis, 1985).

Within the Quaternary deposits of lowland, aquifer systems are developed, including an unconfined shallow aquifer and deeper confined aquifers. The groundwater level is 0.7–43 m below ground surface. Generally, the highest values are recorded in April (end of wet period) and the lowest in early October (end of dry period).

Groundwater recharge occurs through direct infiltration of rainfall, seepage from torrents, lateral subsurface inflows from mountainous area, and return water flow from irrigation use (OYTH-BRGM 1973; Nimfopoulos 2002).

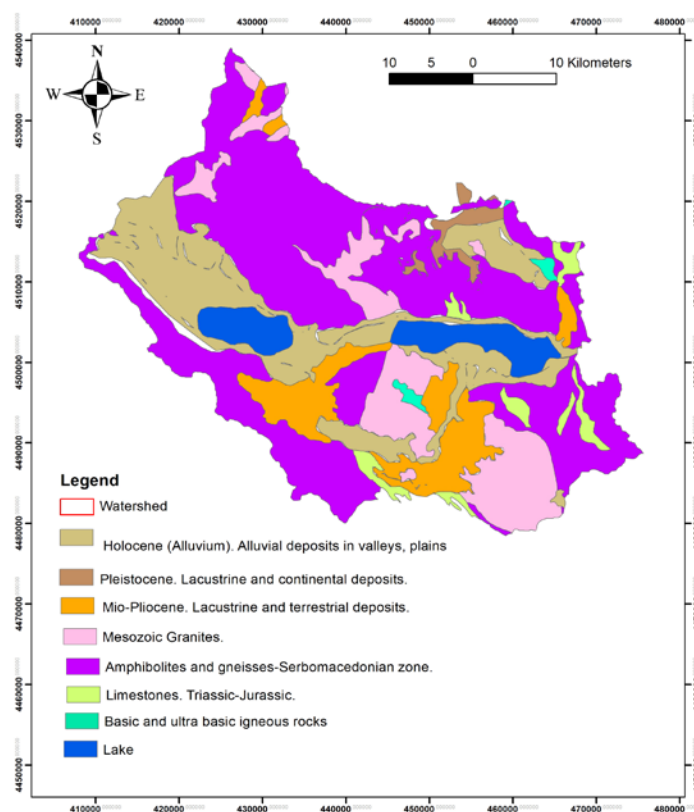


Figure 2. Geological map of the Mygdonia basin.

2.2. Data Collection

Groundwater samples were collected during the wet (May) and dry (September) period over the years 2013 to 2015 showing similar results along with in situ measurements of the physicochemical characteristics. In this work the results of the year 2014 are presented. The samples were analyzed in the Laboratory of Engineering Geology and Hydrogeology, in Aristotle University of Thessaloniki for 8 major ions (Ca^{2+} , Na^+ , Mg^{2+} , K^+ , NO_3^- , SO_4^{2-} , Cl^- , HCO_3^-). Sampling points locations aimed to cover the entire basin. Maps showing the spatial distribution of Electrical Conductivity (EC), temperature (T in $^{\circ}\text{C}$) and pH were created.

The AQUACHEM software was used to create Piper and Durov diagrams and also the S.A.R. (Sodium adsorption ratio) value was calculated. Finally, factor analysis was applied in order to identify main hydrochemical processes and uncover relation between ions.

3. Results of Groundwater Quality Analysis

Summary statistics of the results of chemical analyses are presented in Table 1. The electrical conductivity (EC) mean values are equal to $916.5 \mu\text{S}/\text{cm}$ for May and $889 \mu\text{S}/\text{cm}$ for September. High values are attributed to the intensive agricultural activities, the existence of geothermal fields and human activities in the area. It is known that during the previous decades many textile dyeing units operated in the area. The uncontrolled disposal of the untreated waste in the channels resulted in the degradation of soil and groundwater resources.

pH values range from 6.29 to 8.04 and groundwater temperature range from 16.5°C to 21.8°C (Figure 3). The spatial variation and especially the high temperatures could be caused by the mixing of groundwater with geothermal fluids.

Table 1. Descriptive statistics of pH, EC, and major ions for groundwater samples.

		μS/cm				mg/L					
		pH	EC	Na	K	Ca	Mg	HCO ₃	SO ₄	Cl	NO ₃
May-14	Mean	7.47	916.47	81.76	3.13	56.78	26.86	307.24	100.47	48.61	33.45
	Max	8.04	1971.00	240.00	5.90	96.00	67.90	580.00	280.00	234.00	110.00
	Min	7.07	444.00	16.00	1.70	20.40	10.00	216.00	26.00	8.00	0.40
Sep-14	Mean	7.49	889.04	66.97	3.03	54.68	33.45	302.31	76.28	38.94	36.00
	Max	8.04	2010.00	233.00	6.10	88.00	72.00	513.00	252.00	217.00	75.20
	Min	6.29	259.00	18.60	0.80	21.20	6.80	158.00	14.00	12.80	4.40

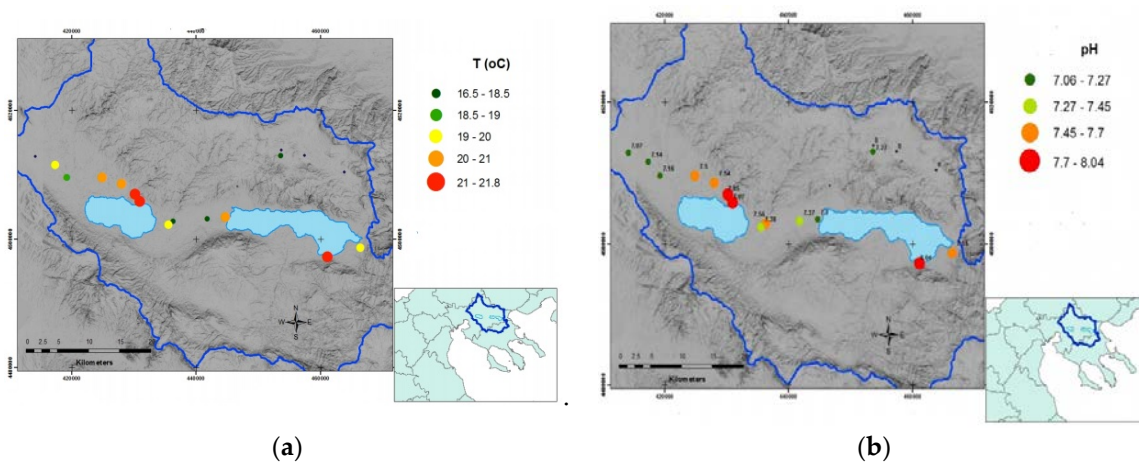


Figure 3. Spatial distribution for (a) Temperature (T) and (b) pH for the period of May 2014.

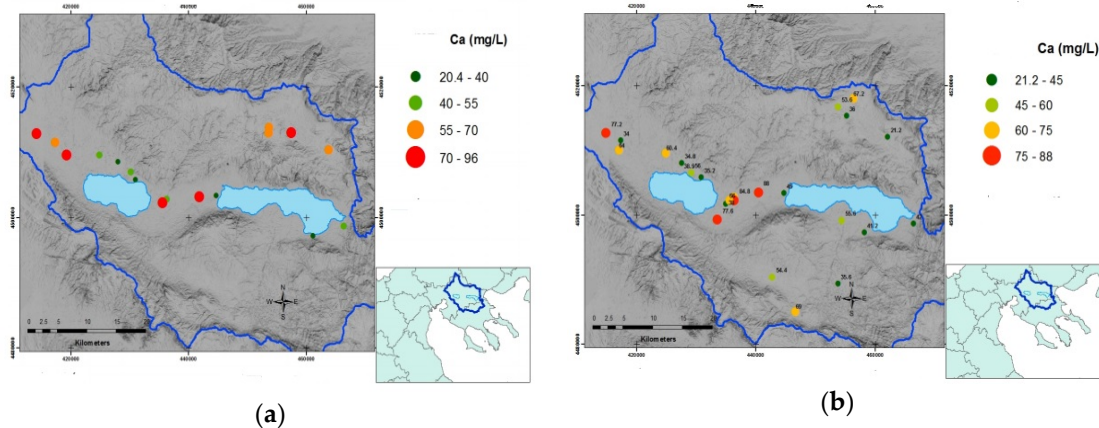


Figure 4. Distribution of Ca²⁺ ions in Mygdonia basin in (a) May 2014 and (b) September 2014.

A high percentage of the groundwater samples (25%) exceeds the maximum permissible limit for drinking purposes set by the Directive 2006/118 EC, the Joint Ministerial Decision 39626/208/E130 and the Ministerial Decision 1811/2011 (Official Government Gazette 3322 B/2011). This is associated with the use of nitrogen fertilizers in agriculture. It is pointed out that the common fertilizers in the area contain nitrogen, phosphate, sulfate and potassium.

Sodium values exceed the threshold value of 150 mg/L in seven out of forty-four samples. The high sodium values are recorded at boreholes close to the geothermal field and at livestock units. Groundwater quality regarding sodium could be affected by the geothermal fluids and the use of salt in the livestock units could locally increase the sodium concentration in water samples.

Typically, the distribution of calcium (Ca^{2+}) ions for the two sampling periods, is shown in the maps of Figure 4, constituting a typical example given that calcium is one of the most important dissolved ions in water, as the content of groundwater is directly linked to the geological environment through which the groundwater moves from the moment of its infiltration up to the entire period of its storage in the aquifer. Its highest concentrations are concentrated in areas where water remains for a long time in the aquifer, as for example the area between Koronia and Volvi lakes. High values of sulfate are locally recorded and should be attributed to the use of fertilizers and/or the mixing with geothermal fluids.

Hydrochemical diagrams were created providing information about the water type. In Figure 5, Durov diagrams for both sampling periods were created showing that all samples belong to bicarbonates in terms of anions. Regarding cations, samples belong to calcium and sodium, while based on anions and cations (square), several of them belong to bicarbonate, sulfate, and chloride. It is, therefore, concluded that the groundwater type is calcium-bicarbonate (Ca-HCO_3), while some samples are a mixture of different hydrochemical types of water.

Concerning Piper diagrams, all samples, regarding anions, belong to bicarbonate, while in terms of cations, samples belong to calcium and sodium ones. Based on anions and cations (diamond), the majority belongs to the category of water coming from mixing processes with increased values of sodium. There are no dominant ions (Figure 6).

The SAR index proposed by the salinity laboratory of the U.S. Department of Agriculture defines the degree of Na^+ adsorption by soil because this ion influences the soil permeability (Tizro and Voudouris, 2010). SAR values range between 0.15 and 0.5, indicating that the water is suitable or permissible for irrigation use.

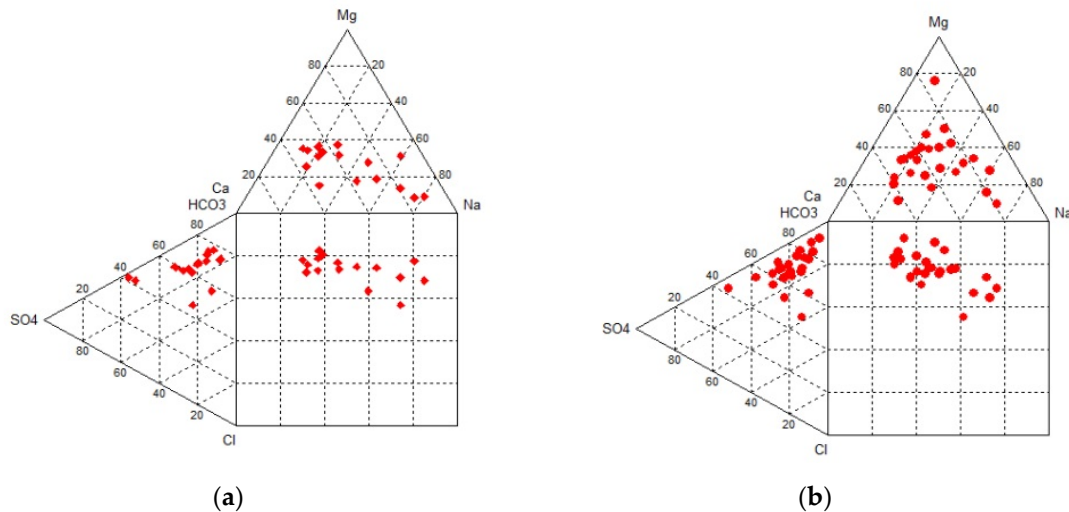


Figure 5. Durov diagrams including all samples for Mygdonia basin (a) May2014 and (b) September 2014.

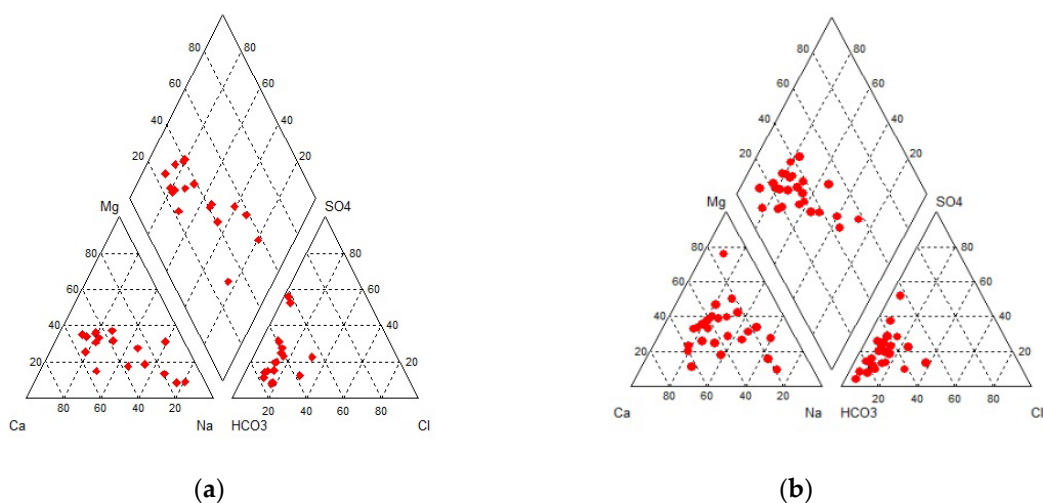


Figure 6. Piper diagrams including all samples for Mygdonia basin (a) May 2014 and (b) September 2014.

Statistical Analysis

Application of factor analysis (Voudouris et al., 1997; Voudouris et al., 2000; Busico et al., 2018) in all the chemical analyses of the period 2014–2016 showed that three factors, explaining 71% of the total variance, could describe the main hydrogeological and hydrochemical processes which take place in the Mygdonia basin. The first factor accounts for 32.6% of the total variance of the data and has high loadings on Mg, Na, EC, HCO_3 and Cl. This factor correlates to the mixing activities of water.

The second factor accounts for 21.5% of the total variance and exhibits high loadings with respect to calcium (dissolution of carbonates) and the third factor (16.8% of the total variance) shows high loadings on sulfate indicating an origin from fertilizers and/or geothermal fluids (Poutoukis and Ntotsika, 1994).

4. Conclusions and Discussion

Hydrochemical analysis was carried out, in order to draw conclusions about the groundwater quality of Mygdonia basin. From the analysis, possible connection with geothermal fluids emerged. More specifically, regarding temperature values, in some places they were slightly increased (values up to 21.8 °C), which is probably connected to the existence of geothermal field, while SO_4^{2-} appear elevated along the northern coastline of Lake Koronia, which may also be due to their mixing with geothermal fluids. Alongside, nitrate ions show high concentration values in the lowland part of the Mygdonia basin, probably due to the intense agricultural activity and the use of fertilizers.

Based on Piper and Durov diagrams, it follows that the groundwater of the area has calcium and sodium as its main cations and bicarbonate as its main anion. That is, the dominant hydrochemical type of groundwater is Ca- HCO_3 and mixing water types. Based on SAR values, the water is suitable for irrigation. Large number of samples exceed the upper permissible limit of 50 mg/L (EU Council) for drinking water.

A set of measures, including monitoring (water quality, groundwater level, level of lakes, climatic data, water abstractions, etc.), should be applied for the protection of water quality and the sustainability of aquifers as well as for the socio-economic development of the wider area. The application of rational fertilization waste-water treatment plants, as well as the delineation of protection zones around the boreholes and springs for water supply, will contribute to water quality protection.

Further investigation on the role of the geothermal field on groundwater quality should be implemented at the area of the boreholes in which high-temperature values

were recorded. The continuous monitoring of groundwater quality characteristics is essential for the rational and sustainable management of groundwater in the Mygdonia basin.

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