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Hydrogeochemical and hydrodynamic characterization of Aghia Sub-Basin, Thessaly, Central Greece

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The Aghia Sub-Basin (ASB) is located at the eastern boundary of the River Pinios Basin and covers an area of approximately 45 km^2 (Fig. 1). According to the hydrolithological map presented in Fig. 1b, there are three dominant hydrolithological units identified: 1. Fractured formations of low- to medium-permeability (HA2) consisted mainly of gneiss, gneiss-schists, and ultrabasic formations (amphibolites and prasinites). Within these units, groundwater flow occurs predominantly through their tectonically driven fractures (secondary porosity) and to a lesser extent through the primary porosity. 2. Alluvial deposits of variable permeability (HP1) consisted mainly of recent deposits of variable texture, including lateral screes that fill the basin at the southern plain part of Aghia sub-basin watershed in which a groundwater system of medium potential is formed. 3. Old talus cones and scree of variable permeability (HP4) favor direct infiltration of precipitation compared with the alluvia.

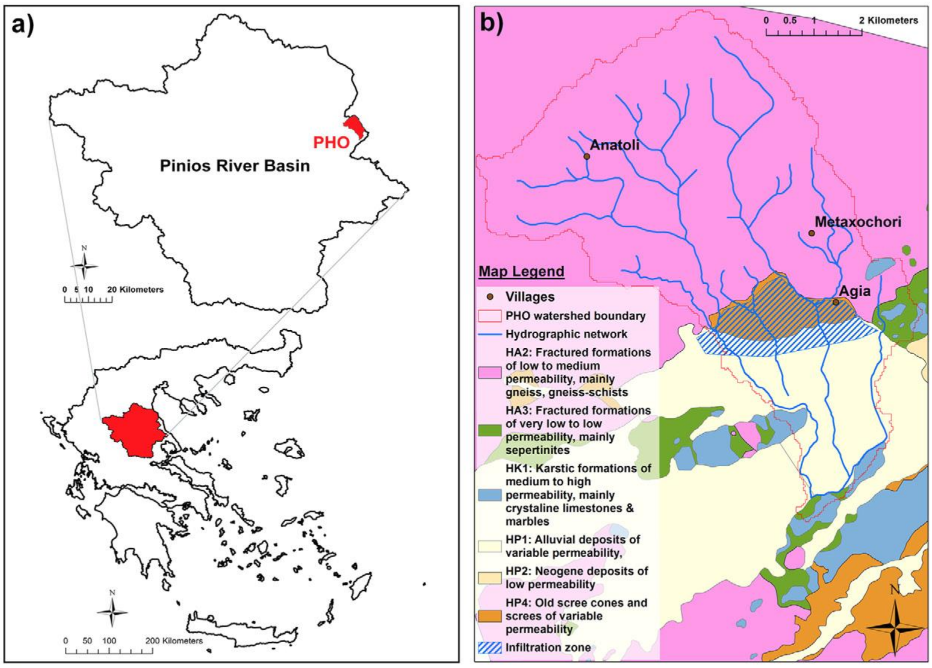

Figure 1: Location of ASB and hydrolithological map (after Pisinaras et al., 2018)

According to previous hydrogeological studies (Hellenic Ministry of Agricultural Development and Food, 2012), lateral crossflows from the adjacent weathered crystalline rock formations at the northern parts of the basin (HA2) and the extensive transition zone that has developed along the same front of the basin (HP4), constitute the major groundwater recharge mechanism of the aquifer system that develops within the alluvium (HP1). Direct recharge through precipitation is important at the infiltration– transition zone (HP4) and occurs over the entire extent of the basin; however, its importance is reduced considerably there. The mountainous weathered crystalline rock formations (HA2) are not used for water production, and therefore no production wells exist in this system.

The overexploitation of groundwater reserves, especially along the downstream southern part of the area, is indicated by the fact that the localized artesian phenomena reported in the past decades (Hellenic Ministry of Agricultural Development and Food, 2012) do not occur any longer, except for a limited number of cases and periods over exceptionally wet hydrological years. Regarding water resources management status, irrigation constitutes the major water consumer for the watershed, and demands are almost exclusively covered by groundwater. According to Tziritis et al. (2016), agriculture constitutes a dominant factor for the hydrogeochemical conditions of the wider area, as reflected by the locally high NO_3 concentrations observed in the alluvial groundwater system. Moreover, the irrational irrigation practices applied, are reflected by locally increased salinization, which is attributed to irrigation water return.

Two groundwater sampling campaigns (n=24) were conducted in June and October 2017, corresponding to the wet and dry hydrological periods, respectively. Totally 22 parameters (physicochemical, major-minor ions, trace elements) in situ and at the accredited laboratory of the Soil and Water Resources Institute (SWRI). Results (median values) revealed that groundwater is circum-neutral (pH=7.3), and EC is 508 μS cm−1, indicating good quality for irrigation water. The dominant cation is Ca^{2+}, followed by Mg^{2+} and Na^{+}, in descending order. The dominant anion in groundwater is HCO_3^-, followed by NO_3^- and Cl^-. The presence of nitrates among the dominant anions is indicative of the anthropogenic impact due to agricultural activities; however, its median concentration is relatively low (17 mg L^{-1}), and the impact is mainly observed locally (concentrations up to 86.5 mg L^{-1}). The concentrations of heavy metals/metalloids are low and fall within the typical margins of natural groundwater (Hem, 1985). No significant variations were observed among the two sampling periods. Nevertheless, sulfates are rather low in the first period, probably indicating a temporal reducing environment affecting their concentration.

All groundwater samples have the same water type (Ca-HCO_3), which is evident from their common hydrodynamic characterization, which classifies them as recharge waters. Their common hydrogeochemical signature is also clearly identified in the Piper diagram in Fig. 2. These observations are in line with the geological and hydrogeological regime of the ASB, confirming that the area constitutes a recharge window, where the lateral crossflows from the metamorphic bedrock recharges the alluvium plain through a general north–south direction. Along the same direction, EC values and NO_3^- concentrations increase with distance from the transition zone. Hence, EC values vary from 0.49 to 0.62 mS cm−1 and NO_3^- concentrations from 8.8 to 31.5 mg L^{-1}, which may suggest the contribution of excellent water quality lateral crossflows from the transition zone to the alluvial groundwater system.

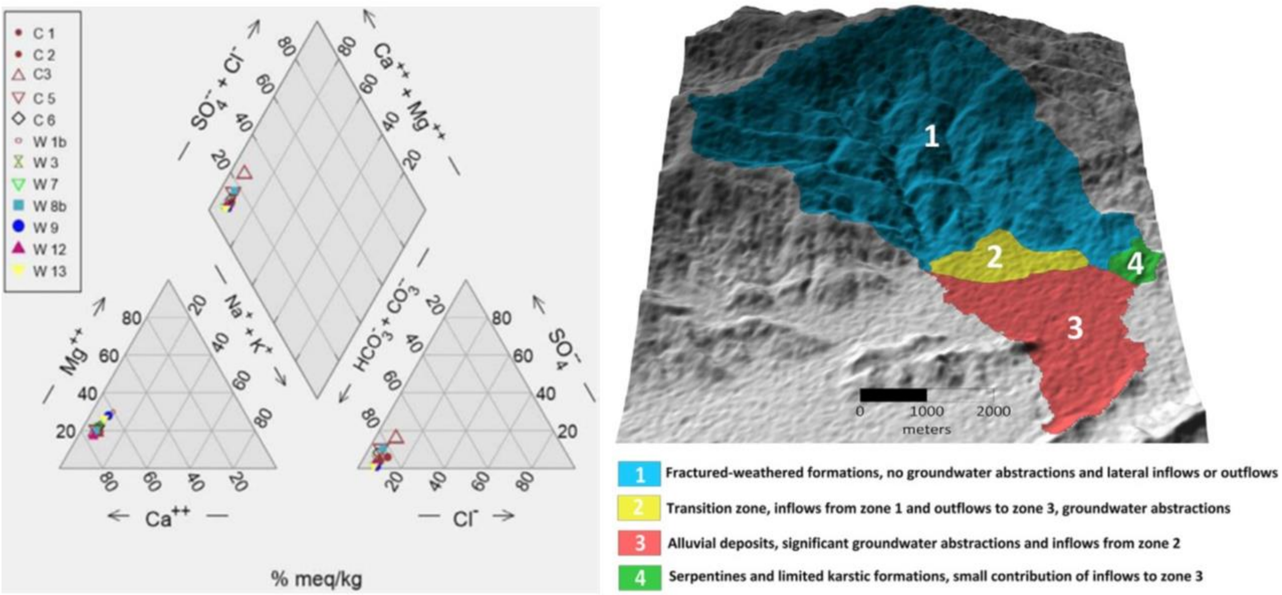

Figure 2: Piper diagram for groundwater samples (average values of periods) and spatial distribution of the major hydrodynamic zones in ASB.

Based on the calculated saturation indices (logQ/K) for the main mineral phases expected, calcite and dolomite are oversaturated in all samples; hence, these phases are the main precipitates that are deposited in the aquifer matrix. The molar ratios of Ca/HCO3 of all samples are <0.5 (range 0.28–0.38). Considering the overall geological regime, the primary source of calcium is possibly attributed to the ion exchange process (Hounslow, 1995; Tziritis et al., 2016). Specifically, Na+, which is enriched in solute due to metamorphic rocks, exchanges with Ca2+, which is hosted in Ca-rich feldspars such as anorthite (CaAl2Si2O8). This process also explains the relatively low Na+ concentrations in groundwater, contradictory to those expected according to bedrock geology. Calcium may also originate from the weathering of Ca-rich silicate minerals (e.g., diopsidic pyroxene [CaMgSi2O6]), which are abundant in the metamorphic bedrock.

Based on the combined evidences of hydrogeology and hydrogeochemistry, 4 different hydrodynamic zones (Z) may be identified (Fig.2). Specifically, Zone 1 is composed by fractures-weathered formation, with no groundwater abstractions and lateral crossflows. Zone 2 is a transition zone with groundwater abstractions, which receives inflows from Z1 and discharges outflows to Z3. Zone 3 is consisted of alluvial deposits, with significant groundwater abstractions and inflows from Z2. Finally, Zone 4 is mainly composed by serpentines and limited karst formations and a relatively small contribution of inflows to Z3.

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