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Hydrogeological research on water supply conditions in a mountainous region of NE Greece

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Abstract. This paper deals with the investigation of the aquifer system of Myki Municipality in the mountainous area of Xanthi Prefecture, NE Greece, within the context of the development and management of groundwater of the study area for meeting drinking water supply needs. The work included, during spring, summer and autumn of 2021-2022, measurements of discharge from a selected network of fifty-two (52) points (springs and groundwater wells), sampling of groundwater from all springs and wells, chemical analyses, as well as relevant analysis, elaboration, presentation of the produced results and composition of related proposals regarding the improvement of water supply conditions at Myki Municipality. The research resulted in calculating the water supply values for each settlement (L/capita/day) and the surplus or deficit supply values with respect to the private special consumption value for domestic use of 250 L/capita/day. It was found that the available water resources to meet water needs of the Myki Municipality are partially insufficient. The observed water shortage can be attributed to the limited capacity of aquifers in some places, some bad groundwater recovery facilities, as well as water losses in the water supply system.

Keywords: hydrogeology, mountain aquifers, water supply, Myki Municipality, NE Greece

1. Introduction

Groundwater flow in mountains areas has been a topic of research for several decades, spanning regional flow characterization (Freeze and Witherspoon, 1967; Forster and Smith, 1988b), interaction with mountain and valley bottom streams (Constantz, 1998; Winter et al., 1998, 2003; Kimball and Stolp, 2004; Wilson and Guan, 2004; Covino and McGlynn, 2007) and mountain block recharge (Manning and Solomon, 2003, 2005; Wilson and Guan, 2004).

Somers and McKenzie (2020) state that groundwater processes in mountain regions differ from lower relief areas in three main ways: (a) water table position and hydraulic gradients are much higher which influence the dominant local flow paths and discharge rates (Forster and Smith, 1988a), (b) the near surface hydrogeologic stratigraphy is very complex due to the high energy depositional environment and glacial deposition processes (Cairns, 2014), and (c) the high relief of the surface topography drives deeper groundwater circulation, recharging regional and even continental scale flow systems and potentially allowing the geothermal temperature gradient to affect flow (Forster and Smith, 1988a).

Silar (1990) comments that a look at a geological section of mountainous system shows the complexity of the groundwater flow in the bedrock, as well as in the covering formations. Very often, it also explains the irregularities and anomalies observed in hydrological processes.

This paper deals with the investigation of the aquifer system of Myki Municipality in the mountainous area of Xanthi Prefecture, NE Greece, within the context of the development and management of groundwater of the study area for meeting drinking water supply needs.

2. Study area

The Municipality of Myki is located in the northern mountainous area of Xanthi Prefecture, NE Greece and belongs to the Administrative Region of Eastern Macedonia and Thrace (Figure 1). The area of the Municipality is 633.3 km^2 and its population is 15,540 people according to the 2011 census. The municipality is a mountainous area with many problems, among them being water supply. The relief morphology of the wider area appears intensely diverse with a dense hydrographic network, a characteristic of the impermeable rocks, which constitute the largest area of the mountain mass. Marbles appear cracked and slightly karstified, while the springs, which appear in the area of the marbles, are usually of low potential discharge. The crystalline formations of the mountain zone are considered impermeable, except for the weathered parts or the presence of discontinuities, where low-potential aquifers may appear. The springs, which appear in these formations, are usually of low potential and intermittent form. For this reason, they are often not enough to cover the water supply needs of the various settlements during the summer months and especially during dry years. Exceptions are the volcanic and granodiorite rocks formations, which due to their composition, have formed favorable aquatic conditions resulting in hosting several springs suitable for exploitation (Diamantis et al. 2003, Empliouk et al., 2022).

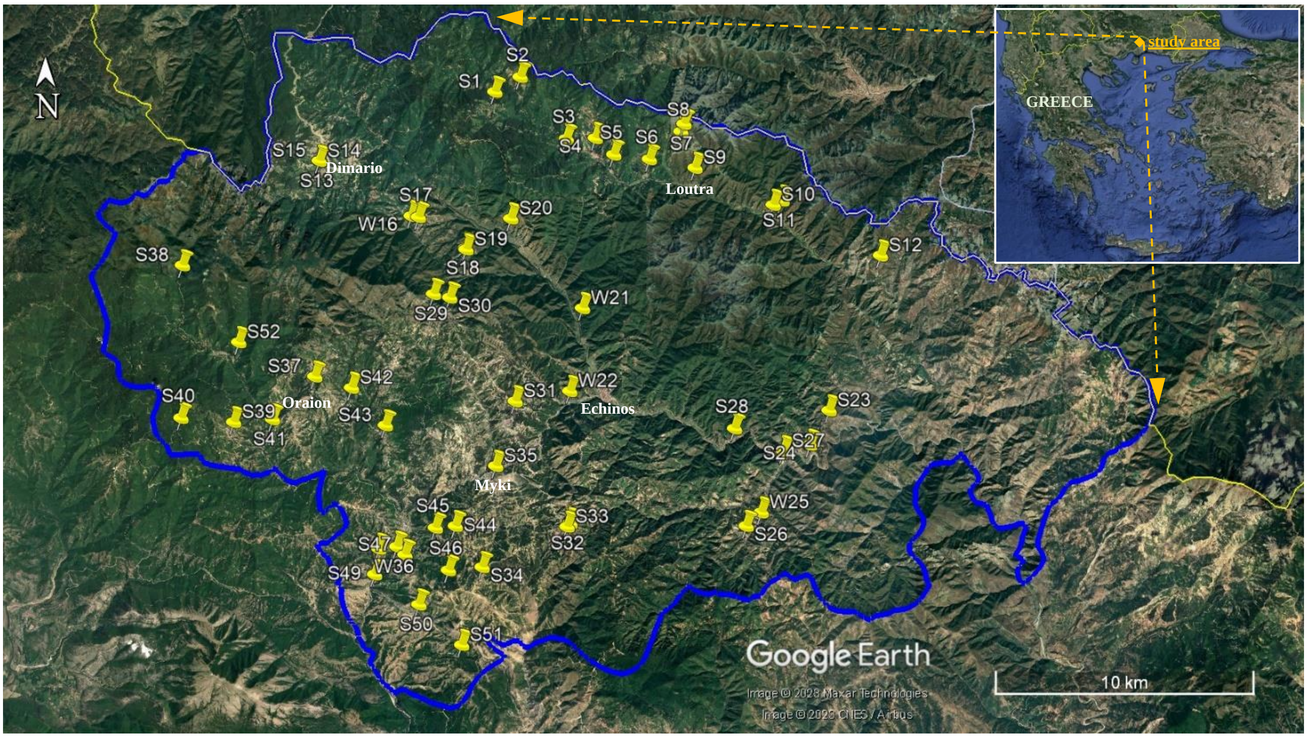

Figure 1. Study area, locations of water springs (S) and groundwater wells (W).

3. Hydrogeological research

The research work included, during October 2021 and April 2022, measurements of discharge from a selected network of fifty-two (52) points (fourty seven (47) springs and five (5) groundwater wells), sampling of groundwater from all springs and wells, chemical analyses, as well as relevant analysis, elaboration, presentation of the produced results and composition of related proposals regarding the improvement of water supply conditions at Myki Municipality (Figure 1). Decrease in the respective discharge values of the two measurement periods was observed ranging from 0.40 to 21.34 m^3/h.

The following parameters were measured in situ: pH (range of values: 6.02-8.27), Electrical Conductivity (range of values: 71.4-6270 μS/cm), and Temperature (range of values: 12.2-18,3 °C).

Groundwater sampling of the 52 water points of the study area was carried out. Chemical analyzes of the samples followed in the Laboratory of Engineeing Geology and Groundwater Research of the Department of Civil Engineering, DUTH, where the following parameters were examined: Total Hardness, Alkalinity P, Alkalinity M, Ca^{2+}, Mg^{2+}, Na^{+}, Mn^{2+}, $Fe^{2+,}$ NH_4^{+}, HCO_3^{-}, PO_4^{3-}, Cl^{-}, SO_4^{2-}, NO_3^{-}, NO_2^{-}. Low values of Electrical Conductivity were recorded, which is due to the karst origin of the waters of the area, while the percentage distribution of the values of Electrical Conductivity, for the most part (87%) does not exceed the indicative limit of 500 μS/cm.

Nitrate ion concentration values are lower than the maximum permissible limit of 50 mg/L with a percentage distribution of 86.54% for values of 0.0-10.0 mg/L (variation of values: 0.0-41.8 mg /L).

The quality characteristics of the examined water samples of the study area are within the permissible limits regarding their concentrations of calcium, magnesium and sodium ions. The good quality of the water samples in the area is highlighted, in terms of their concentrations in carbonate and bicarbonate ions, as well as in chlorides and sulfates. It is worth noting that there was no sample with an increased amount of chlorides at any of the sampling points (variation of values: 0.0 – 16.67 mg/L).

In the context of processing the measured supply values of the springs, the possibility of meeting the water consumption for water needs was investigated based on the reference value of 250 L/capita/day (Official Gazette 174/B΄/26-3-1991).

Table 1, based on October 2021 and April 2022 springs and wells discharge measurements, and the population of each settelement from the 2021 census, presents a grouping of groundwater discharge values for each settlement in the study area (L/capita/day) and the values of surplus [+] (green color) or deficit [-] (red color) supply with respect to 250 L/capita/day.

It is pointed out that not all of the examined springs end up in water supply reservoirs and, moreover, there are springs that provide water to a few settlements outside the study area.

4. Conclusions

Based on the results obtained from the relevant calculations presented in the Table 1, it was found that the available water resources to meet water needs of the Myki Municipality are partially insufficient. In a total of thirty four (34) settlements, in twelve (12) (35.3 %) settlements, the total disharge per settlement values (L/capita/day) show deficit [-] (red color) supply values with respect to the reference value of 250 L/capita/day ranging from to 81.94 to 220.53 L/capita/day. In the remaining twenty-two (22) (64.7 %)) settlements, the total disharge per settlemnt values (L/capita/day) show a surplus [+] (green color) supply with respect to the reference value of 250 L/capita/day ranging from 74.18 to 46070 L/capita/day (Table 1).

The observed water shortage can be attributed to the limited capacity of aquifers in some places, some bad groundwater recovery facilities, as well as water losses in the water supply system. These shortages are mainly located in the central and southern part of the study area, while in the northern part, there are springs, which can be allocated to satisfy the water supply of the various settlements.

Regarding the necessary actions to improve and upgrade the existing water infrastructures in the study area and to avoid significant water loss and quality degradation problems, the following are proposed: protection of the narrow area of the springs, protection of the water supply system, construction of new groundwater recovery systems in the locations of selected springs.

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Table 1. Total groundwater discharge values for each settlement (L/capita/day) and surplus [+] (green color) or deficit [-] (red color) supply values with respect to 250 L/capita/day

		October 2021		April 2022	
Settlement	**Springs (S) and Wells (W)**	**Discharge (L//)**	**Total discharge per settlement (L/capita/day)**	**Discharge (L/d/resident)**	**Total discharge per settlement (L/capita/day)**
DIASPARTO	S1	381.43	+350.00	683.57	+748.57
DIASPARTO	S2	107.14		192.86	
DIASPARTO	S3	111.43		122.14	
ANO THERMES	S4	474.95	+224.95	919.63	+669.63
MESES THERMES	S5	2582.17	+2332.17	2530.12	+2280.12
KATO THERMES	S6	1349.22	+1099.22	1432.54	+1182.54
KIDARI	S7	288.98	+788.37	1665.31	+3521.43
KIDARI	S8	749.39		2106.12	
LOUTRA	S9	46320.00	+46070.00	92640.00	+92390.00
MEDOUSA	S10	325.66	-91.24	565.66	+408.66
MEDOUSA	S11	69.45		262.38	
KOTTANH	S12	89.30	-160.70	396.28	+146.28
DIMARIO	S13	463.29	+1475.57	546.84	
DIMARIO	S14	1103.54		1913.92	
DIMARIO	S15	158.73		238.10	
KOTYLI	W16	936.84	+1523.16	936.84	+1588.95
KOTYLI	S17	836.32		902.11	
AIMONIO	S18	312.00	+167.60	1032.00	+908.40
AIMONIO	S19	105.60		126.40	
MELIVOIA	S20	500.00	+250.00	763.27	+513.27
ECHINOS	W21	162.09	+74.18	162.09	+74.18
ECHINOS	W22	162.09		162.09	
GIANNOCHORI	S23	1015.38	+765.38	1661.54	+1411.54
KALOTYCHO	S24	384.00	+134.00	640.00	+390.00
TEMENOS	W25	995.85	+840.46	995.85	+894.23
TEMENOS	S26	94.61		148.38	
SATRES	S27	28.80	-145.20	129.60	-32.40
SATRES	S28	76.00		88.00	
PACHNI	S29	232.31	+154.90	364.50	+242.96
PACHNI	S30	172.59		128.45	
GLAFKI	S31	168.06	-81.94	365.79	+115.79
KENTAVROS	S32	3.94	-220.53	6.23	-232.36
KENTAVROS	S33	25.53		11.41	
ACHLADIA	S34	8208.00	+7958.00	12336.00	+12086.00
MYKI	S35	103.67	-146.33	289.32	+39.32
SMINTHI	W36	1983.47	+1733.47	1983.47	+1733.47
THEOTOKOS	S39	2632.26	+2986.13	4041.29	+4511.29
THEOTOKOS	S40	603.87		720.00	
ORAION	S37	735.38	+545.21	955.99	+773.51
ORAION	S41	18.38		26.41	
ORAION	S42	41.45		41.11	
KYKNOS	S43	118.55	-131.45	167.71	-82.29
OASI	S44	119.07	-130.93	349.77	+99.77
KIRRA	S45	967.06	+717.06	2202.35	+1952.35
KOTINO	S46	100.84	-36.22	169.41	+179.58
KOTINO	S47	112.94		260.17	
CHRYSO-SMINTHI	S48	118.94	-131.06	237.88	-12.12
ALMA	S49	66.62	-183.38	69.65	-180.35
TRIGONO	S50	286.03	+36.03	325.48	+75.48
SIROKO	S51	62.70	-187.30	103.78	-146.22
REMA	S38	2105.90	+4353.01	1179.19	+2039.02
REMA	S52	2497.11		1109.83	