Hydrogeochemistry and Structural Control of the Area around the Ancient City of Troia, Northwestern Anatolia

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ABSTRACT: *Troia is one of the oldest and most famous archaeological sites, which is located in Biga Peninsula, northwest Turkey. This site is an important point of reference for the chronology of the ancient world from the early Bronze Age through the Roman Empire.*

The purpose of this study is to determine the hydrogeochemistry of waters in Troia. For this aim, total 55 water points around Troia (well, spring, dug and fountain) were monitored for their physical parameters. In addition, 11 water samples were collected for determination of hydrogeochemical properties (major anion, major cation and selected heavy metal concentrations). The pH of water varies from 6.8 to 7.7. The electrical conductivity values range from 161 to 2280 µS cm^{-1}. Generally water samples from aquifers of Troia showed varying properties. Based on the dominant cations and anions, four different water fasies are seen around Troia. First group, Ca-HCO_3 type, comes from springs; second group, Mg-Ca-HCO_3 and Cl type, which originates from alluvium aquifer; third enriched by Ca-Mg-HCO_3-SO_4 affected by volcanic rocks and last group water showed richness of Mg-Ca-Na-Cl and HCO_3 that comes from sedimentary rocks.

KEYWORDS: *Hydrogeology, hydrogeochemistry, Troia, tectonic*

1. INTRODUCTION

Troia is one of the oldest and most famous archaeological sites. The settlement mound of Troia is situated between Asia and Europe. The Troia city is close to the Aeagen Sea which is now within Çanakkale province in northwest Turkey, southwest of the Dardanelles under Mount Ida. This site is an important point of reference for the chronology of the ancient world from the early Bronze Age through the Roman Empire. The Troia site built 5000 years ago was one of the most essential centres of population throughout 3500 years.

An important question about Troia is where the cold and springs described by Homer (Iliad, XXII V.147) could have been located. A set of springs which meet Homer`s characteristics are found near Pınarbaşı, not only two, yet more than eight water outlets near Miocene conglomerates can be found there- all of them bearing more or less the same hydrogeological parameters. One of the first systematic hydrogeological investigations to locate Homer`s cold and hot springs was conducted by Virchow in 1879. He measured the temperatures of several springs and rivers in the north-western Troias (Virchow, 1879; Wolkersdorfer 2003). Since then no regional hydrogeological investigation were conducted in around Troia area. Intensive hydrogeological and geothermal studies were reported from Tuzla. Geothermal studies on Tuzla field have been ongoing since 1966. Ten thermal gradient wells were drilled from 50 to 100 m depth in 1974 based on the result of geological and geophysical surveys. The nature and origin of the thermal springs in Tuzla area have been described by Mutzenberg (1997). Some physical parameters of Pınarbaşı and Kokana springs, which where located south-east of Troia, was measured by Yüzer (1997). Additionally, Kayan (2000) focus on the water supply of Troia. The hydrogeological, hydrogeochemical and environmental properties of the environs of Troia area were described by Baba (2003), Wolkersdorfer (2003), Baba and Özcan (2004), Baba *et al*. (2005), Özcan *et al*. (2006). However, detailed hydrogeochemistry and structural control of the Trioa has not been studied up to now.

The purpose of this paper is to summarize the geological, tectonic and hydrogeochemical characterization and quality of waters in the vicinity of Troia. For this reason, total 55 water points (well, spring, dug and fountain) were monitored for physical parameters (pH, EC, ORP and TDS were measured in situ using probes) four times around Troia. Additionally, 11 water samples were collected for determination of their hydrogeochemical properties (major anion, major cation and selected heavy metal concentrations).

2. STUDY AREA

Study area is one of the most famous archaeological sites in northwest of Turkey. The settlement place of Troia is situated in an important strategic position between Asian and European continents. The study area is located around Kumkale, Halileli, Tevfikiye, Çıplak, Kalafatlı, Gökçali villages within Troia Natural Park, province of Çanakkale (Fig. 1).

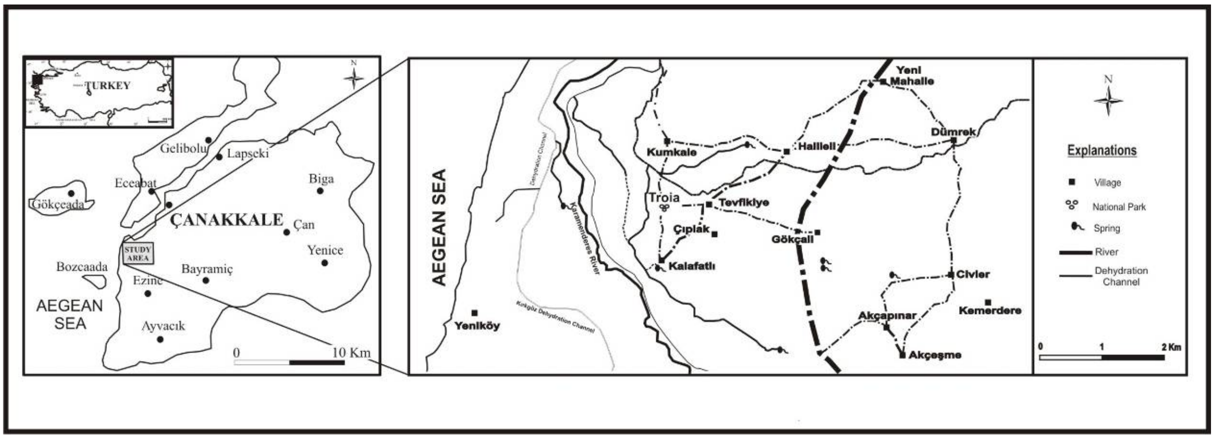

Fig. 1. Location map of study area.

3. GEOLOGICAL AND STRUCTURAL PROPERTIES OF STUDY AREA

Western branches of the North Anatolian Fault and West Anatolian graben systems form the geologic grain of the Biga Peninsula. Rocks from Paleozoic to Quaternary ages are combined in varying lithologic and structural settings. These characteristics combine with the regional neotectonic features. Geologic structures around the Troia consist of seven main rocks groups (Fig. 2). Paleozoic metamorphic crystalline schist and Permian limestone constitute the basement rocks of the area. These are inconformably overlain by Triassic ophiolite and Neogene rocks which consist of clastic limestone, shale, marn, sandstone and conglomerate. Miocene volcanic consists of tuff, agglomerate and pyroclastics. The Quaternary alluvium is the youngest unit and covers a large extension in study area.

Two important springs, which are located near Pınarbaşı, were controlled by natural structure. For example, these karstic springs are located at the intersection of the Pınarbaşı fault and other major faults extending NE-SW. Besides, important water source is observed along the fault which extends W-E and NE-SW structural zone.

4. HYDROGEOLOGY

The Mediterranean climate prevails in the area. The average annual rainfall in Troia is around 588.23 mm based on the last 35 years' average. Minimum rainfall was observed to be 413 mm (in 1990) and maximum was recorded as 902.4 mm (in 1980) over the last 35 years. Average temperature is 14.92°C according to the last 35 years' observations. Minimum temperature is observed in January and maximum is recorded in August. Mean evaporation was recorded to be of 1.3 mm based on the last four years' observations.

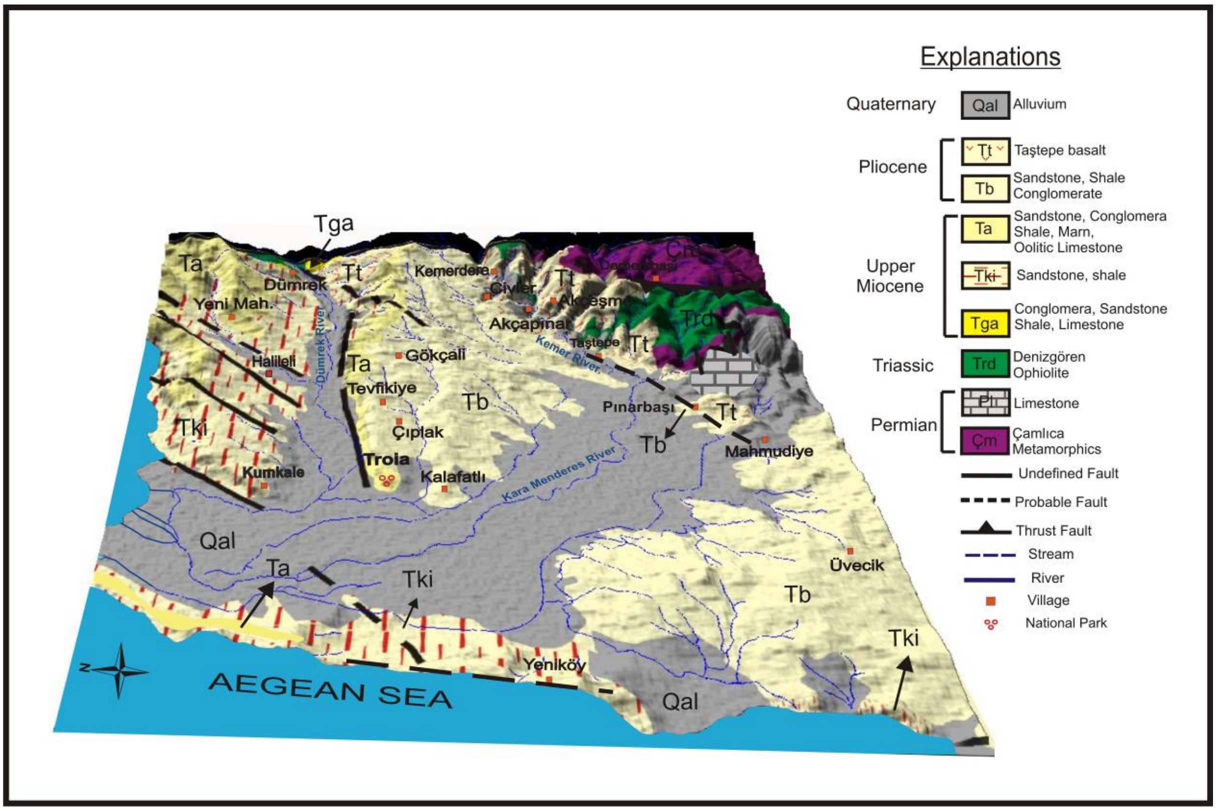

Fig. 2. Geological and location map of Troia archeological site and its surrounding area (modified from Bürkan et.al., 1990)

The most important source of fresh water around Troia is the Karamenderes River which originates in the northern slopes of the Ida Mountains and collects surface waters from the greater part of the Biga Peninsula. It then brings them to the flood-delta plain to the west of Troia. The total catchment area from Ida Mountain to the Dardanelles is nearly 2000 km^2. The Karamenderes River was blocked on the Troia National Park border by a small dam at Araplar Boğazı. This situation affects the hydrological system of the Karamenderes (Schwaderer, 2003; Ozcan *et al*., 2007). Other aquatic sources are wells having 5 to 76 m depths, dugs, fountains and two springs, namely Düden and Kırkgöz. All water sources have been used for various purposes such as irrigation and potable water supply. The springs were controlled by natural structure. For example, these karstic springs are located at the intersection of the Pınarbaşı fault and other major faults extending NE-SW.

Most of the dugs located in the Neogen unit consist predominantly of sandstone, conglomerate, shale and limestone. The Neogen unit constitutes a poor aquifer due to the dominance of fine clastics. Volcanic rocks, fractured aquifers, out crop around Akçeşme and Akçapınar. This rock has specific density joint. Many springs born from volcanic rock dominated areas. Nevertheless, flow rate of these springs are not remarkably high (around 0.01 to 0.5 L s^{-1}).

Alluvium constitutes the major aquifer of the study area. Alluvium, which is most probably derived from sheet wash deposits, fan deposits, coastal and wind blown sediments, are observed along the flat terrain that extends. It is mostly fine-grained (clay, silt, sand and conglomerate) and constitutes the major agricultural fields of the study area. Generally, different confined aquifers are observed on alluvium aquifers (see Fig. 3). The aquifer has been exploited extensively for domestic and irrigation water supply. The average groundwater level in the site area is about 3 m below the surface.

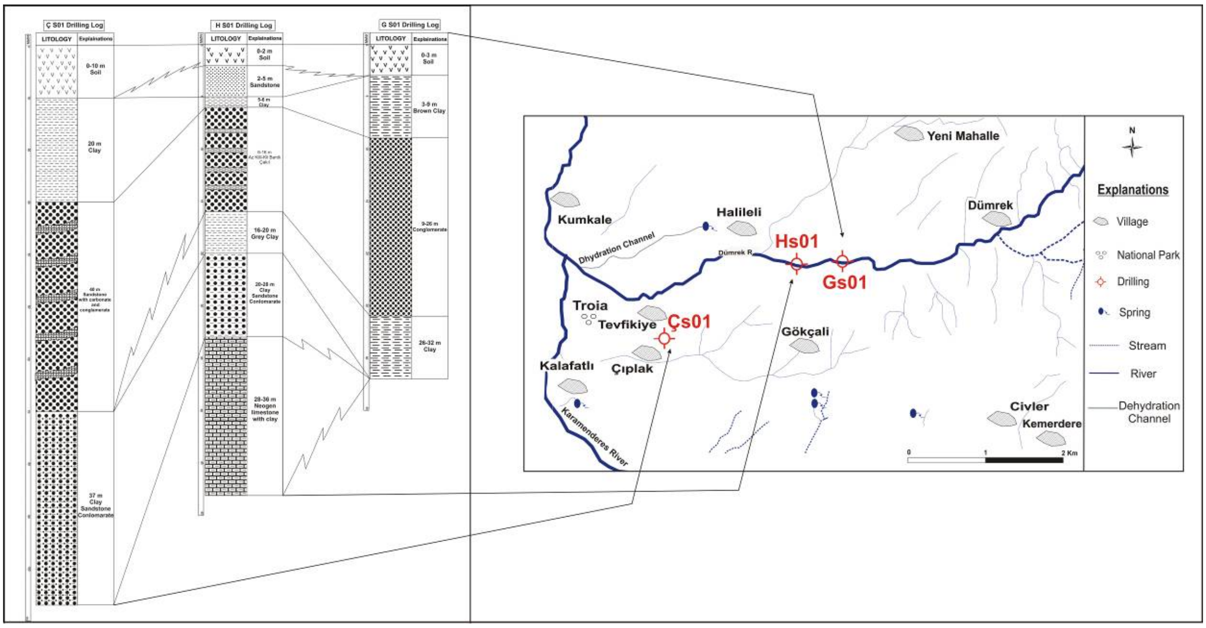

Fig. 3. Lithology of drillings near Troia

5. MATERIALS AND METHODS

A survey was conducted between August 2006 and May 2007 at 55 points in Troia (Kumkale Basin), Çanakkale, Turkey (Fig. 4). Water samples were measured four times during the study period and additional 11 sampling were completed on May 2007. These 11 samples were taken from the following spots; GS02, HS01, ÇS02, ÇS03 from wells and ÇS01, KÇ01, TÇ01, TÇ03, ÇÇ01, CÇ02 and CÇ03 from fountains in order to determine their hydrogeochemical properties. The pH of water samples for heavy metal analyses was completed following to adjustment of pH to 2 by high purity lab grade nitric acid (HNO_3) addition.

The pH, electrical conductivity (Spcond), total dissolved solids (TDS) and oxidation–reduction potential (ORP) were measured at sampling sites using HACH® multi-parameter instrument. LaMotte ® smart colorimeter and its kits were used for SO_4, NH_3, NO_2 and NO_3 analyses. Bicarbonate analyses of water samples were performed according to the method given by Soil Survey Staff (1996).

Analysis of total 72 elements including Al, As, B, Cd, Cu, Pb and Zn were performed on inductively coupled plasma mass spectrometry (ICP-MS) (ACME, Canada).

6. RESULTS AND DISCUSSION

Samples from the Troia area have relatively high electrical conductivity (EC) values (161-2280 μS cm^{-1}). pH values were determined to be between 6.8 and 7.7 (Table 1). Calcium, sodium and magnesium are dominant cations, which vary between 34.93 and 170.84 mg L^{-1}, 26.47 and 137.15 mg L^{-1}, 24.34 and 135.57 mg L^{-1}, respectively. HCO_3 concentrations are around 500 mg L^{-1}. Sulphate ions were measured as high as 189 mg L^{-1}.

Generally water sampled from aquifers of Troia showed varying hydrogeochemical properties. The major ion composition of groundwater is used to classify groundwater into different types based on the dominant cations and anions. For instance, water from Pınarbaşı spring, which originates from limestone (Özcan *et al*., 2007), determines the groundwater that is Ca-HCO_3 type. The composition of the dominant ions is displayed graphically by Schoeller and Piper diagrams (Figs. 5 and 6). Based on the dominant cations and anions, four different water fasies are found around Troia. First group, Ca-HCO_3 type, comes from springs as also noted by Özcan *et al*. (2007); second group, Mg-Ca-HCO_3 and Cl type, which originates from alluvium aquifers; third is enriched by Ca-Mg-HCO_3-SO_4 which are originates from volcanic rocks and last group showed richness in terms of Mg-Ca-Na-Cl and HCO_3 that are affected by sedimentary rocks (Table 2).

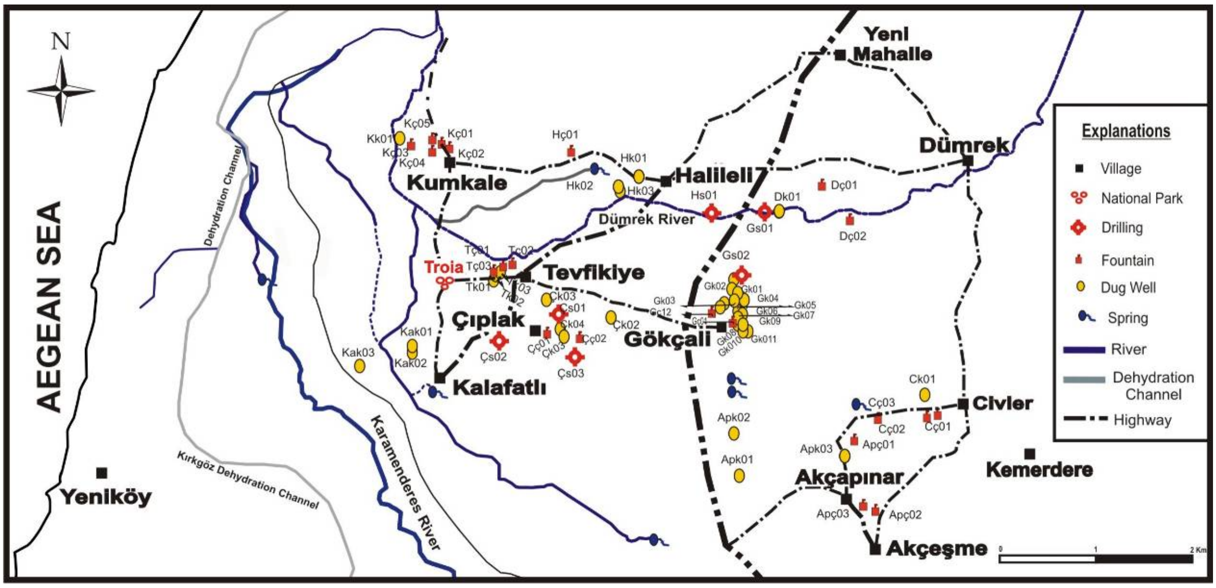

Fig. 4. Sample location map

The concentrations of As, Cr, Pb, Se and Zn range from 1 to 7 µg L^{-1}, from 0.6 to 21.3 µg L^{-1}, from 0.1 to 0.8 µg L^{-1}, from 0.7 to 9.8 µg L^{-1} and from 1 to 66.2 µg L^{-1}, respectively (see Table 2). The concentration of As is maximum in Gökçali drilling. The concentration of Cr is the highest in HS01 which is used by many villagers (Fig. 7). In addition, the concentration of Se is the highest in (TÇ01) that is situated Tevfikiye village, next to Troia ruin site. In general, the concentration of other heavy metals such as Al, Cd and Hg is under limit of U.S. EPA (2003) drinking water in groundwater sources around Troia.

Characteristics of many waters around Troia are that high NO_3 contents of up to 20.9 ppm found. Distribution map of NO_2, NO_3 and NH_3 are given in Figs 8 to 10. Many agrarian activities exist around Troia area. Many farmers use notable amounts of pesticides and fertilizers in this area even uncontrollably. Such activities are expected to lower water quality in the area. Yet, further water quality analyses should be performed especially in terms of groundwater quality.

Numerous lineaments related to faults detected in the study area. Northeast trending several faults located near Kumkale, north of ancient Troia and northeast of Tevfikiye mapped in the region (Perinçek and Karslıoğlu 2007). Fault system partially controlling distribution of Quaternary units and springs. Eastern and southern limits of quaternary sediments control by faults are located respectively near Kumkale and ancient Troia.

The springs were controlled by fault. For example these karstic springs are located in the vicinity of the Pınarbaşı Fault and other major faults extending NE-SW. Another spring located close to Halileli is on the NE-SW trending fault zone. Also, important water outlets can be seen along the fault which extended W-E fault zone.

According to Homers (Iliad, XXII V.147-156) hot spring existed within Troia border. In addition, Kayan (2000) emphasized that structural control is closely related with hot spring. Until now, no relationship on that has been determined based on our studies. But, some of important hot spring such as Tuzla, Kestanbol, Tepekoy, Bardakcilar can be seen around Troas area.

Table 1: Physical parameters of water around Trioa

	pH				EC (µS/cm)				T (^{0}C)			
	August 06	**January 07**	**March 07**	**May 07**	**August 06**	**January 07**	**March 07**	**May 07**	**August 06**	**January 07**	**March 07**	**May 07**
GS02	7,24	7,47	7,74	7,6	548	161,1	810	766	23,6	15,7	19,8	20,8
ÇS01	7,1	7,27	6,94	7,41	356	175,8	872	877	17,6	18,2	18,7	21,5
HS01	7,22	7,25	7,3	7,43	959	181	875	1036	16,1	16,2	15,9	17,2
ÇS02	7,3	7,12	6,81	7,07	1065	817	1013	1903	19,8	19	19,2	20,3
ÇS03	7,3	7,35	7,2	7,27	950	250	867	1470	19,6	18,6	18,5	21,3
ÇÇ01	7,03	7,02	6,96	7,08	1793	340	400	2033	23,5	13,5	13,6	19,4
TÇ01	7,57	7,45	7,25	7,6	1874	344	1957	2042	17	15,7	15,8	17,7
ÇÇ02	7,02	7,05	7,67	7,08	1794	351	2000	2022	21,7	13,1	13,1	18,8
CÇ03	6,82	7,01	6,64	6,95	1256	255	1436	1487	18,6	16,1	15,8	17,9
KÇ01	7,15	7,23	7,24	7,18	1718	328	1746	1757	17,9	17	16,7	17,5
TÇ03	7,28	7,25	7,02	7,29	521	409	390	2280	16,1	15,8	15,6	17,5

Table 2: Analysis result of sample waters around Troia (May 2007, µg L-1)

Age	***Quaternary***	***Neogene***									
Litology	**Alluvium**	**Sedimentary**								**Volcanic**	
Element / Sample Number	**HS01**	**ÇS01**	**ÇS02**	**ÇS03**	**ÇÇ01**	**GS02**	**TÇ01**	**TÇ03**	**KÇ01**	**CÇ02**	**CÇ03**
Al	5	8	7	11	6	16	16	3	3	10	7
As	2	4	4,5	5,3	5,3	7	5,6	6,2	4,8	1	2,8
B	25	54	51	61	59	135	61	126	95	18	27
Ba	64,82	92,86	208,48	117,21	254,22	129,1	105,65	125,1	148,05	11,51	58,24
Be	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05
Br	209	156	743	679	1110	225	906	742	887	119	635
Ca	74717	66072	153493	92023	130900	34933	132068	165617	103548	131853	170841
Cd	<.05	<.05	<.05	<.05	<.05	0,09	<.05	<.05	<.05	<.05	<.05
Ce	0,02	0,03	0,03	0,04	0,03	0,04	0,02	0,01	0,01	0,01	0,03
Cl	51000	46000	263000	213000	329000	67000	304000	276000	245000	34000	178000
Co	<.02	<.02	<.02	0,05	<.02	0,09	0,32	0,03	<.02	<.02	<.02
Cr	21,3	3,4	0,6	0,6	0,9	1,3	0,8	<.5	0,9	1	2
Cs	<.01	0,56	0,68	1,17	0,42	0,24	0,06	0,05	0,01	0,44	0,41
Cu	10,2	1,2	1,1	3,9	0,9	1,7	1,2	2	0,5	8,4	0,7
Dy	0,01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	0,02	<.01
Fe	12	20	48	297	<10	<10	19	15	<10	<10	<10
Hg	<.1	<.1	<.1	<.1	<.1	0,1	<.1	<.1	<.1	<.02	<.02
K	1482	2734	2054	3904	1473	7603	4996	15000	1689	1072	1478
La	0,02	0,02	0,02	0,03	0,02	0,02	0,01	<.01	0,01	0,03	0,01
Li	5,8	20,8	18,2	28,4	19,4	75,9	24,2	22,9	19,1	6,6	10,4
Lu	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
Mg	99020	73428	108258	102232	129424	34323	132117	135566	108959	24337	71570
Mn	0,25	1,63	1,49	8,17	2,54	1,93	0,72	0,25	0,25	0,28	1,04
Mo	0,4	1,5	0,3	0,8	0,5	0,6	2	1,1	0,8	0,2	0,1
Na	26472	39227	91770	86713	137151	83734	112690	104657	118656	27532	51501
Ni	4	0,4	4,6	0,2	0,3	20,4	64,2	0,7	<.2	<.2	<.2
P	28	27	<20	21	<20	<20	21	27	<20	<20	26

Table 2: Continued-Analysis result of sample waters around Troia (May 2007, µg L-1)

Age	***Quaternary***	***Neogene***									
Litology	**Alluvium**	**Sedimentary**								**Volcanic**	
Element / Sample Number	**HS01**	**ÇS01**	**ÇS02**	**ÇS03**	**ÇÇ01**	**GS02**	**TÇ01**	**TÇ03**	**KÇ01**	**CÇ02**	**CÇ03**
Pb	0,7	0,2	0,2	0,1	0,4	1,1	0,1	0,1	0,1	0,8	0,2
Rb	0,54	4,25	6,29	8,88	3,51	6,05	8,24	7,51	0,98	1,18	3,4
Re	0,01	0,02	0,04	0,03	0,01	0,01	0,19	0,09	0,03	<.01	0,01
S	0,013	0,008	0,025	0,016	0,023	0,008	0,044	0,051	0,024	0,007	0,02
Sb	0,07	0,06	<.05	<.05	0,11	<.05	0,06	0,1	0,07	<.05	<.05
Sc	3	3	2	2	2	2	2	2	2	2	4
Se	2,3	2,2	5,1	5,8	6,8	2,6	9,8	5,2	6,8	0,7	4,1
Si	15016	11513	10181	10260	9609	8713	8840	8202	6588	7285	16865
Sm	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02
Sn	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05
Sr	257,59	1042	1380	2019,3	1220,5	1427	1828,2	1294	1019,59	277,9	917,88
Tl	<.01	0,05	0,05	0,08	0,01	0,03	0,03	0,07	<.01	0,03	0,01
U	1,87	4,69	5,26	7,31	6,11	4,36	8,78	7,24	6,64	0,64	2,15
V	3,9	4,4	8,3	6,5	11,1	17,3	5	7,1	5,2	0,8	8,6
W	<.02	0,02	<.02	0,83	<.02	0,04	0,06	<.02	<.02	<.02	<.02
Y	0,08	0,02	0,05	0,04	0,07	0,02	0,01	0,01	0,01	0,22	0,02
Yb	0,01	<.01	<.01	<.01	0,01	<.01	<.01	<.01	<.01	0,01	<.01
Zn	17	5,6	3,4	3	1,8	12,3	4,5	1	1,2	66,2	1,8
Zr	<.02	<.02	0,02	<.02	0,04	0,02	0,02	<.02	<.02	<.02	0,02
HCO_3	546544	455700	364540	394910	516420	303800	455670	584800	443024	370906	313906
SO_4	62000	21000	68000	47000	56000	23000	180000	189000	102000	80000	52000
NO_3	3300	830	12500	4900	5500	160	9600	20900	12200	2500	13000
NO_2	27	0.0	85	11	47	28	58	26	26	34	30
NH_3	290	700	910	500	170	140	650	160	310	180	190
Water Type	Mg-Ca-HCO3	Mg-Ca-HCO3	Mg- Ca- Na-Cl HCO3	Mg- Ca- Na-Cl HCO3	Mg- Ca- Na-Cl HCO3	Na- Mg-Ca- HCO3	Mg- Ca- Na-Cl- HCO3	Mg- Ca-HCO3-	Mg-Ca-Na-HCO3- Cl	Ca-Mg-HCO3	Ca-Mg-HCO3

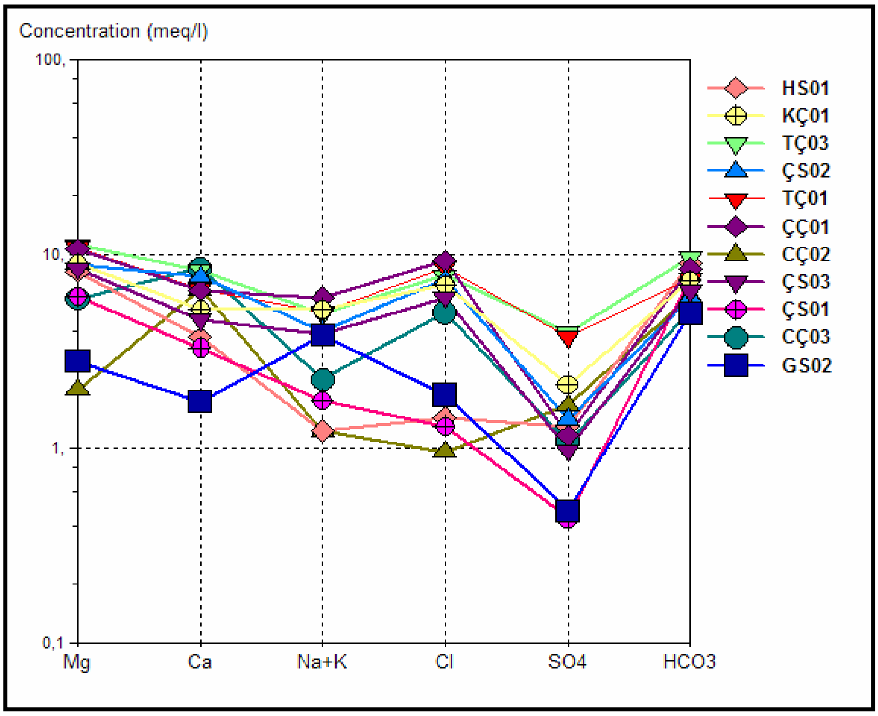

Fig. 5. Chemical analysis of water the study area plotted on Schoeller diagram.

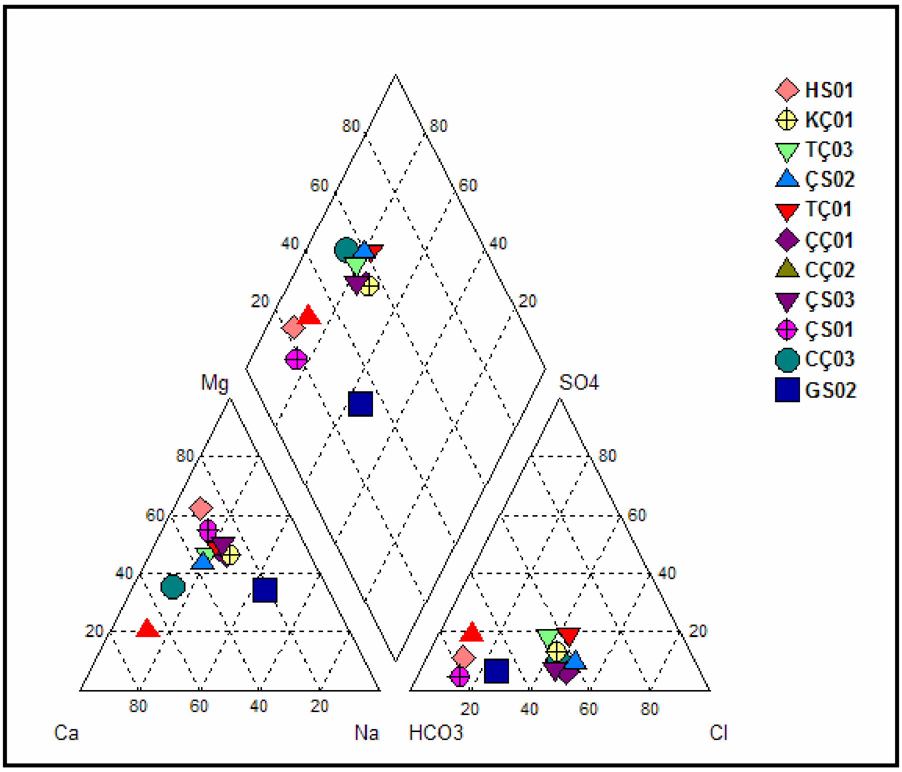

Fig. 6. Chemical analysis of water from study area plotted on Piper diagram

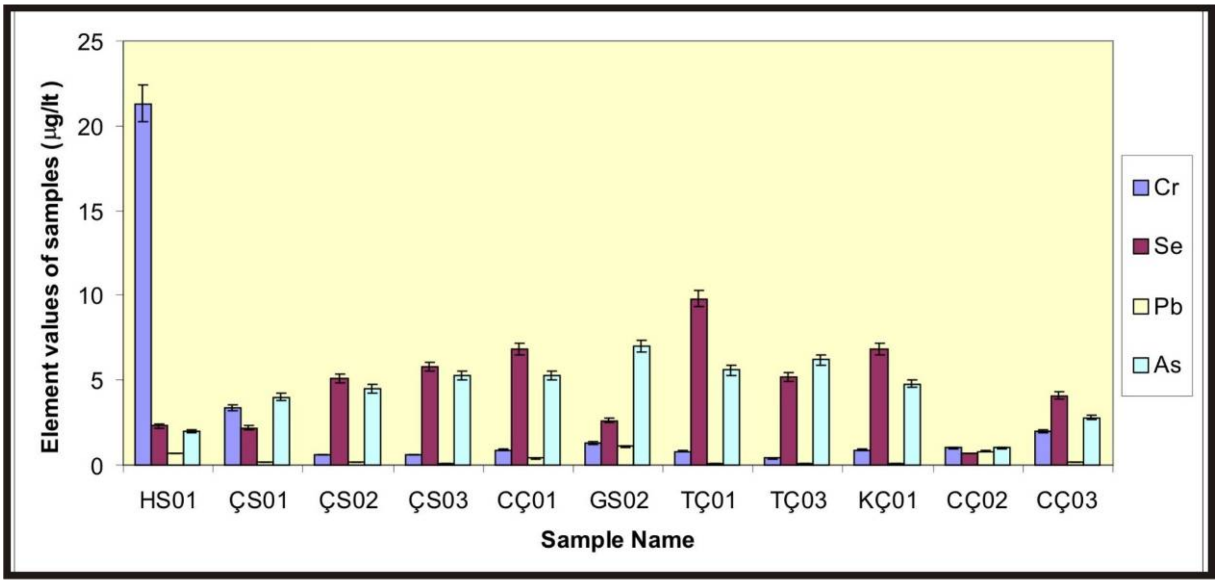

Fig 7. Concentration of As, Cr, Pb and Se (μg L^{-1}) around Troia

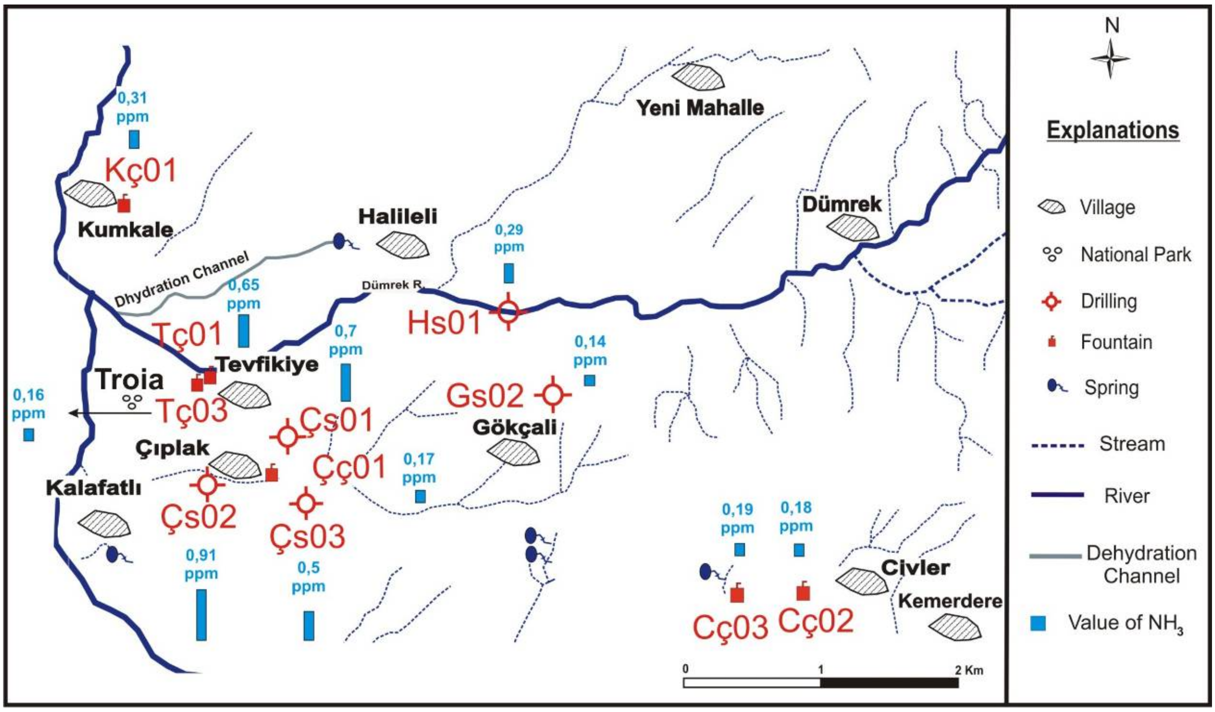

Fig. 8. Distribution of NH_3 in water source around Troia

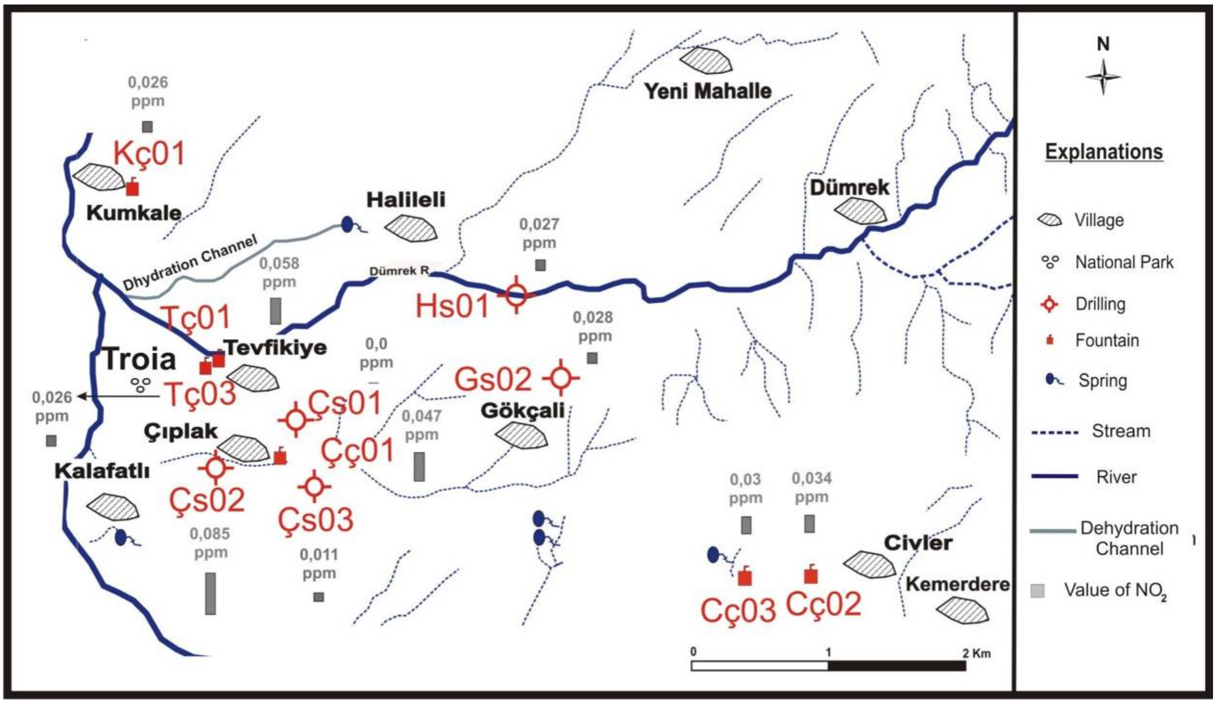

Fig. 9. Distribution of NO_2 in water source around Troia

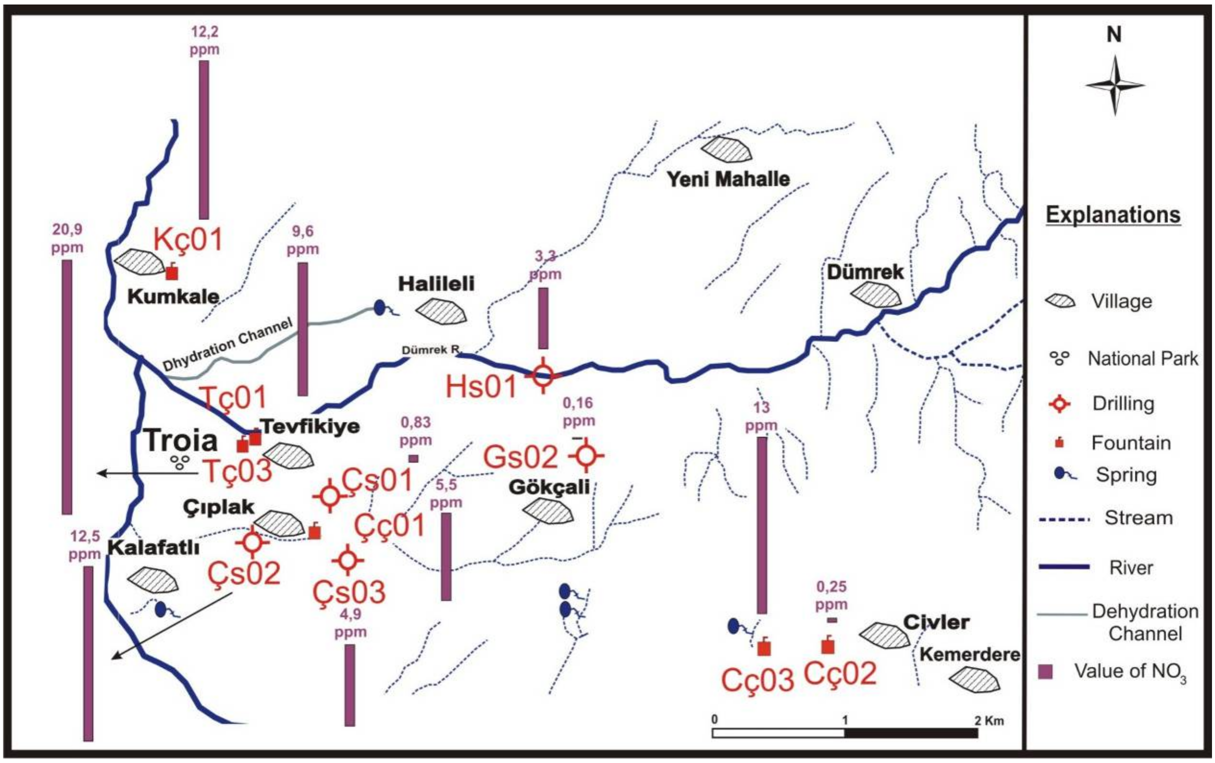

Fig. 10. Distribution of NO_3 in water source around Troia

6. CONCLUSION

Remarkable increase in population, urban expansion and economic development, specifically agriculture related ones, have persistently raised the demand of water supply and consequently, greatly increased the exploitation of fresh water resources around Troia in the last several decades. This area is one of the important tourist sites in Turkey. Therefore, this area will most probably experience expansion in the near future. This study shows that there are not crucial groundwater problems in Troia and its surroundings yet some of the water analyses showed that pollution parameters, such as NO_3 exceeded U.S. EPA limits. Therefore, remediation and conservation measures should be immediately applied to protect water sources around Troia area. Also, it is important to measure isotopes in water samples for determine source and age of water.

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