Environ Monit Assess (2007) 130:389–402
DOI 10.1007/s10661-006-9406-3

Assessment of the Water Quality of Troia for the Multipurpose Usages

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Received: 16 March 2006 / Accepted: 18 July 2006 / Published online: 28 October 2006

Abstract The aim of this study was to determine the origin and quality of waters in Troia. For this purpose total of 25 water samples including 2 springs, 14 surfaces and 9 groundwaters, were collected at eight different times. Global positioning system (GPS) was used to determine to coordinates of sampling points. The concentration of 6 minor elements (B, Cu, F, Fe, Pb and Zn), 9 major anions and cations (Na^+, Ca^{2+}, K^+, Mg^{2+}, SO_4^{2-}, PO_4^{3-}, HCO_3^-, Cl^- and, CO_3^{2-}) were determined by spectrometric, colorimetric and volumetric methods. Water pH, EC, DO, ORP and TDS were measured *in situ* using probes. The data showed that the concentrations of most of minor elements were below the EPA and TSE limits except Pb which ranged between 0.001 and 4.832 mg L^{-1}. Statistically significant relationships ($P < 0.01$ and $r > 0.70$) were observed between Fe and Cu, Cu and K^+, Cu and Ca^{2+}, B and Na^+, Na^+ and K^+. Assessing the water based on irrigation using Wilcox model showed that some well waters were not suitable for irrigation. Troia water was found to be highly corrosive and the average corrosion coefficients varied from 0.5 to 4.6. According to the Piper and Schoeller diagrams results, the water in Troia was classified as mixed water type.

Keywords Water quality · Heavy metals · Troia · Anion · Cation · Corrosion coefficient

1 Introduction

Millions of migratory birds connect the continents of Europe, Asia and Africa. The Troia is an important ecological building block within the international migratory bird system. Now, the natural area is in jeopardy due to the increased usage of the land that threatens the function of the Troia as a resting place for migratory birds (Schwaderer, 2003). The agricultural usage of Troia land has become widespread and intensified. The environmental changes in the past four decades have had dramatic effects on migratory birds. This has been directly connected to the depletion of wetlands and also water quality. Water sources are very important for Troia National Park. The Turkish Government has designated a historical national park in 1996 and UNESCO declared the archaeological riches of Troia a world cultural heritage in 1998.

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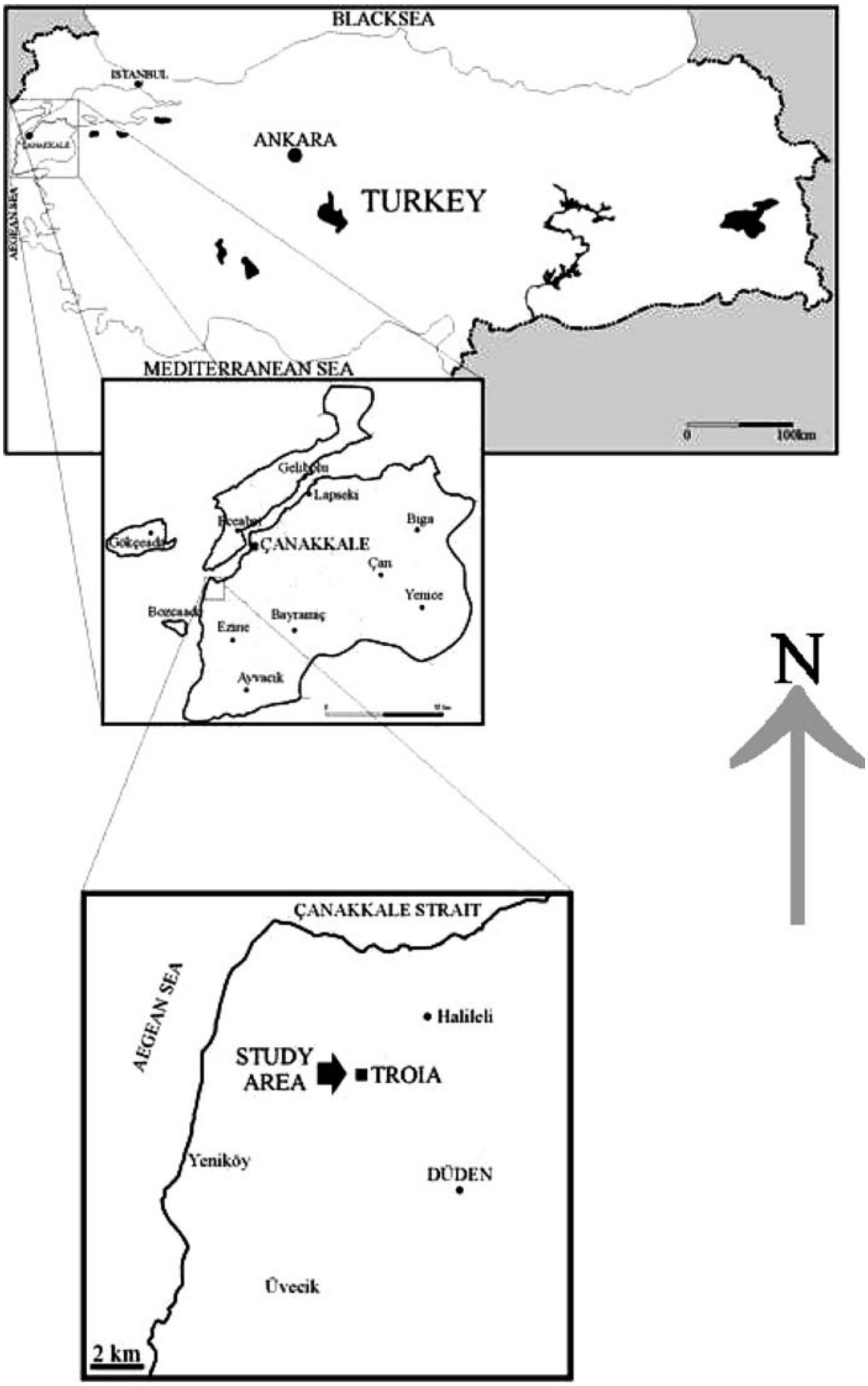
According to topographical map (1:25,000 scale) edited in 1957, majority of lands in Troia were wetlands and swamps. Beside the area around the Kırkgoz springs, some lower lands were also swamp. At the end of 1960s, the constructions of drainage canals and intensive agriculture took place in the area. Irrigation from the 6 to 10 m deep wells caused the decline of groundwater levels (DSI, 1996).

Water is very vital for nature and can be a limiting resource to men and other living beings. Water quality is

Figure 1 Location map of the study area.



influenced by natural and anthropogenic effects including local climate, geology etc., and construction of dams and embankments, irrigation practices (Rahman, Hassan, Islam, & Shamsad, 2000). Understanding the sources, their interaction, and effects of water pollutants is essential for controlling pollutants (Manahan, 1994). One of the most significant contaminants in the waters is heavy metals such as copper, zinc and lead (Chatzoudis & Rigas, 1998; Farid, Atta, Rashid, Munnink, & Platenburge, 1993; Laxen & Harrison, 1977; Mendoza, Cortex, & Munoz, 1996; Selim & Iskandar, 1992). Copper is known as not cumulative systemic poison, however large dose (>100 mg) of copper are harmful to humans and might cause central nervous system disorder and adverse effects on Fe-metabolism that results in liver damage. Excess copper may also be deposited in the eyes, brain, skin, pancreas and myocardium (McAnally, Pinto, & Flora, 1997). Lead is a cumulative poison to humans and its major effects are impairment of hemoglobin and porphyrins synthesis. Zinc cause muscular weaknesses and pain, irritability and nausea (AWWA, 1990).

Drainage from the active and abandoned mines (Emrich & Merritt, 1969), underground or above-ground disposal practices of domestic, municipal, or industrial liquid (Miller, 1980; U.S. EPA, 1977), the use of fertilizers and pesticides in agricultural operations (Hassan, 1974) and, saltwater intrusion (Todd, 1974) can produce a variety of groundwater pollution problems.

In the last century, the impact of changing land use patterns caused stress on all types of water bodies,

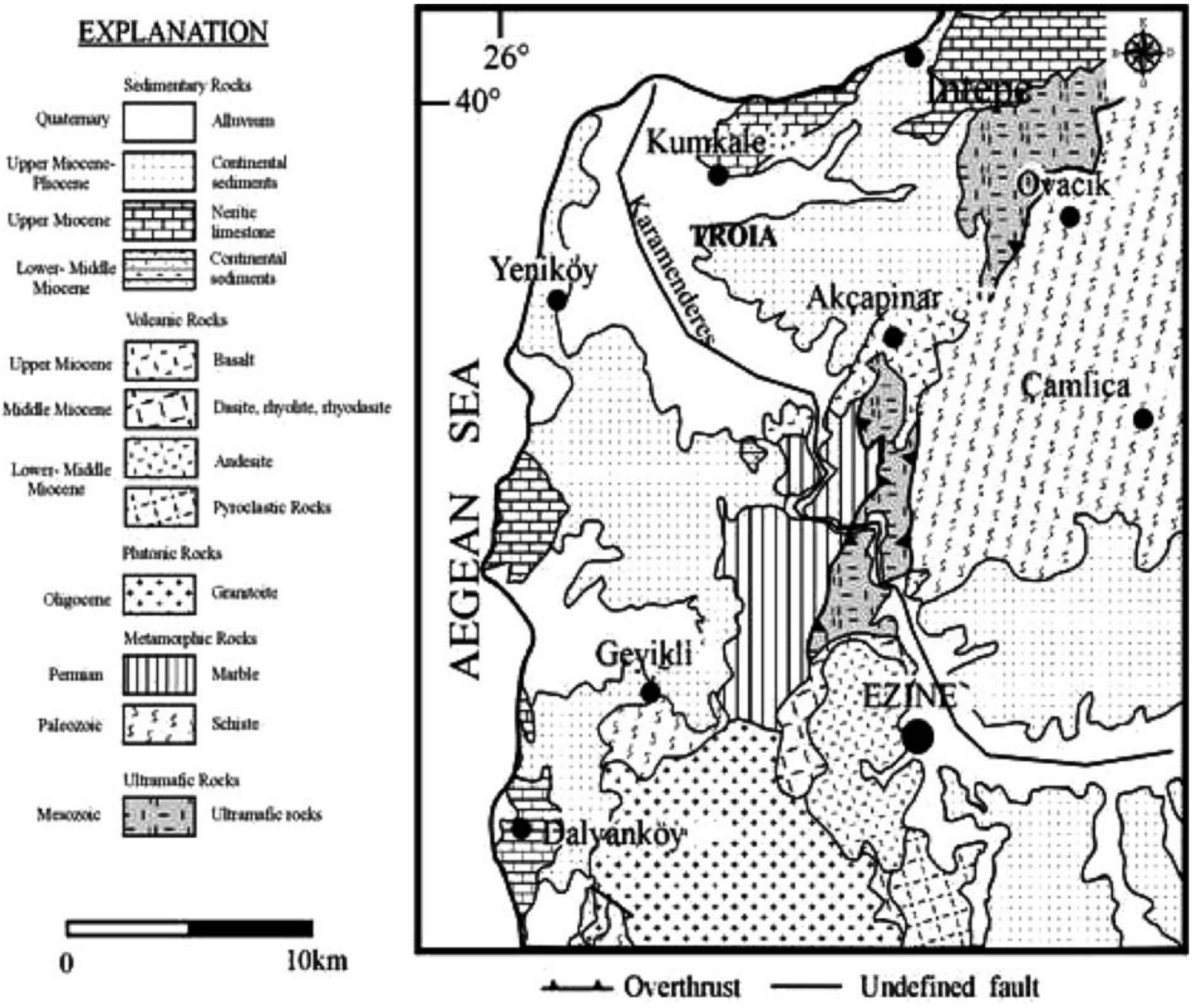


Figure 2 Geological map of the study area (simplified from MTA, 2002).

including those under the ground. Surface water quality monitoring is very important to support terrestrial ecosystem (Ning & Chang, 2003). Water quality pertaining to shallow coastal aquifers has recently been studied worldwide for different purposes (Baba et al., 2001; Babu, Hindi, Da, & Bittencourt, 2002; Malcolm & Soulsby, 2001).

The Troia is very important place in terms of for history, tourism, agriculture, wetland and migratory route of birds. Names of some birds observed at study area were white stork (*Ciciona ciciona*), swallow (*Hirundo rustica*), falcon (*Buteo buteo*) and nightingale (*Luscinia megarhynhos*). The water systems and qualities must be determined and monitored. For this reason, the objectives of this study were;

(a) the preliminary investigation and interpretation of hydrochemical properties of water
(b) to determine the water pollution level in and around Troia National Park

2 Study Area

Study area was one of the oldest and most famous archaeological sites in northwest Turkey at the south entrance of the Dardanelles (Figure 1). The settlement mound of Troy was situated in an excellent strategic position between Europe and Asia continents. Troia is in conjunction with the special conditions of the currents and winds, favored trade and cultural contacts. Study area is in the Troia National Park and surrounded by dried canals, which are Kokona on the east and Kırkgoz (Azmak) on the west.

3 Geology and Hydrogeology

General geology of the area in the vicinity of Troia is presented in Figure 2. Geological structures around the Troia consist of five main rocks groups. Metamorphic crystalline schist and marble constitute the basement rocks of the area. These are unconformably overlain by ultramafic and plutonic rocks. A volcanic formation overlies unconformable the ultramafic and plutonic rocks. These rocks consist of basalt, dasite, rhyolite, rhyodasite, andesite and pyroclastics. The sedimentary rocks overlie unconformably the metamorphic, ultramafic and volcanic rocks. Sedimentary rocks consist of sand, clay and limestone of marine facies (Kayan, 2000). The Quaternary alluvium is the youngest unit and covers a large extension in the study area (Figure 2).

Study area consists of two different physiographical units. These are: flood plain soils (young and old river terraces) and delta soils. Study area is mainly flat and slightly sloped. Top soil texture varies from light to heavy; 46% of these are light, and 27% are heavy and 26% are medium textured soils (DSI, 1996). Because of the alluvial properties of these soils, sand deposits lay below 2 m from the surface. These soils formed on the sediments carried by Karamenderes and Dumrek rivers (Kayan, 2000). Their hydraulic conductivities are high and soil organic matter contents ranges from 0.1% and 4%. The farms in the area range from 0.2 to 7.9 ha in size and primarily produce wheat, cotton, tomato followed by corn, sunflower, alfalfa, pepper, rice or forages.

The Mediterranean climate prevails in the area. The average annual rainfall in Troia is around 600 mm. In last 3 years, minimum rainfall was 439 mm and maximum was 765 mm. Average temperatures of 3 years was 15.8°C and evaporation was 1,266 mm.

The most important source of fresh water around Troia is the Karamenderes River. This river 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 catchment area of the river from Ida Mountain to Bayramic dam is 435 km^2 while the total catchment from Ida Mountain to the Dardanelles is 1,962 km^2 (DSI, 1996). The Karamenderes River was blocked on the Troia National Park border by a small dam at Araplar Bogazi. This will affect the hydrological system of the Karamenderes River and it is more than likely that agricultural irrigation of the plains will be intensified (Schwaderer, 2003). Other sources are wells, which have 6 to 10 m depths, two springs (Düden and Kırkgöz) and drainage canals. All water sources are used for irrigation and drinking water for cows, sheep and birds. One of springs is to the south of the Karamenderes River, near Pınarbaşı (Kırkgöz Springs) and the other is the Düden springs to the north (see Figure 3) and about 17 m higher than sea level. These karstic springs are located at the intersection of the Pınarbaşı fault and other major

Figure 3 Sample location map.

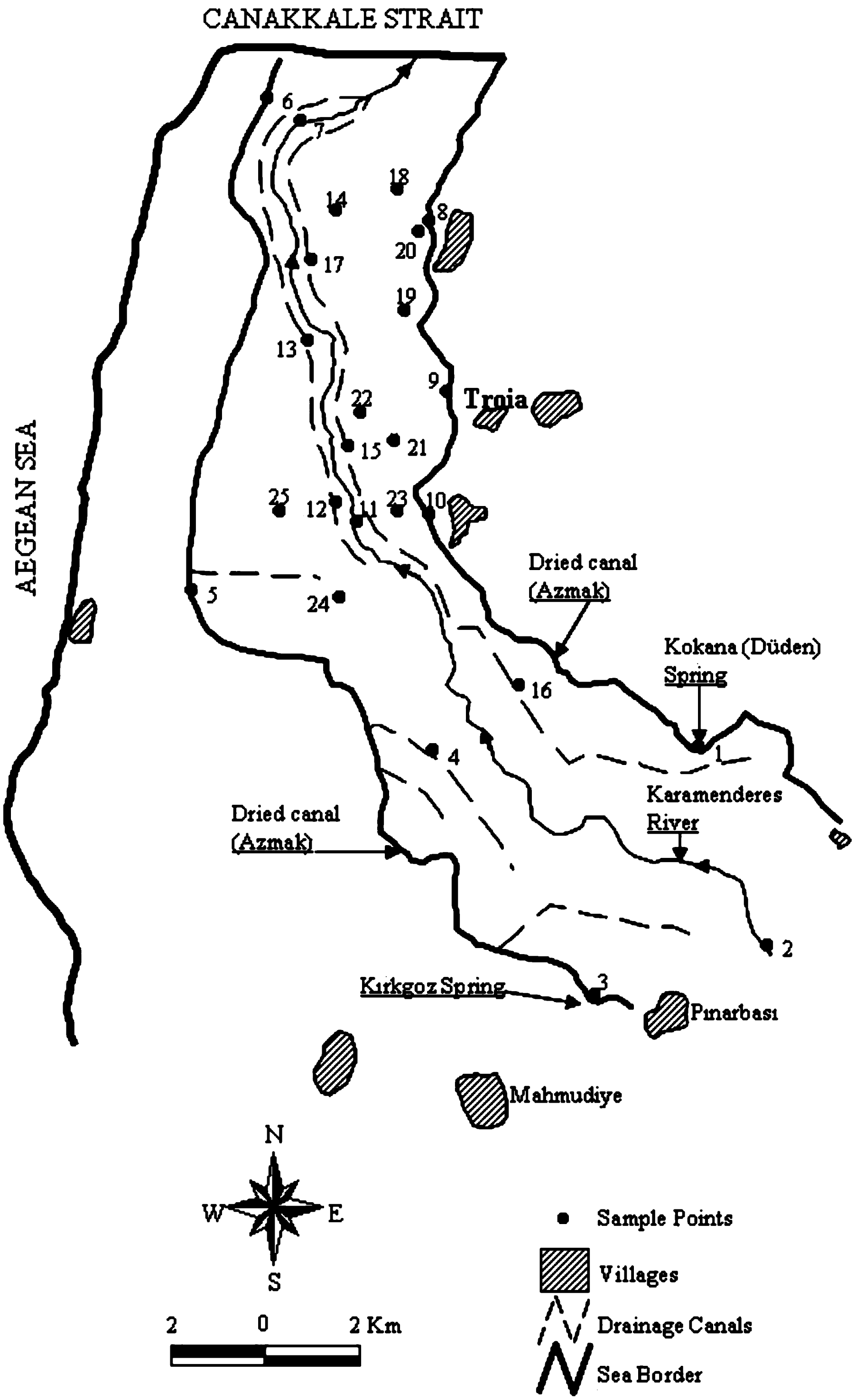


Table I Analytical methods (APHA-AWWA-WCPF 3110, 1992)

Ions	Analytical methods
Na^+, K^+	Flame photometer and ICP
Ca^{2+}, Mg^{2+}	Volumetric and ICP
CO_3^{2-}, HCO_3^-, Cl^-	Volumetric
SO_4^{2-}, F	Colorimetric
Cu, Fe, Zn, PO_4^{3-}	Colorimetric
B, F, Cu, Fe, Pb, Zn, P	ICP-AES

faults extending NW-SE, which form the southern part of the Karamenderes plain (Kayan, 2000).

4 Experimental

4.1 Sampling

A survey was conducted from December 2002 to September 2003 in five water resources and 25 points in Troia (Kumkale Basin), Canakkale, Turkey (Figure 3). Water samples were collected every 2 months during the winter period and every month during the irrigation period. Sampling were done in December 2002, January 2003, March 2003, May 2003, June 2003, July 2003, August 2003 and September 2003. Global positioning system (GPS) was used to determine the coordinates of sampling points.

Water samples were collected from wells where no irrigation infrastructures were available. Total of 14 samples were taken from surface water in each sampling time (Figure 3). Collected water samples were field stored in a cooler on ice and brought to a lab. Any samples that cannot be analyzed in the field or at the lab are transferred to a refrigerator and stored at 4°C. Samples were preserved according to specific test requirements and immediately analyzed for B, F, Cu, Fe, Pb, Zn, PO_4^{3-}, Ca^{2+}, Mg^{2+}, Na^+, K^+, CO_3^{2-}, HCO_3^-, SO_4^{2-} and Cl^- ions according to APHA-AWWA-WCPF 3110 (1992) (Table I). All water samples were filtered through Whatman No: 42 filter papers before analyzing. The pH of water samples for heavy metal analyses was adjusted to pH 2 by nitric acid (HNO_3) addition. Also blank was prepared with double-distilled deionized water contain one to five drops concentrated nitric acid. Concentrations of B, Cu, F, Fe, Pb, and Zn were determined by inductively coupled plasma-atomic emission spectroscopy (ICP-AES) with an axial-view torch (Perkin Elmer Optima 3000 XL). Calibration standards for each analysis were made from certified standards of individual elements acquired from AccuStandard Inc. Sets of three different concentrations of standards were used to establish a calibration curve.

The pH, electrical conductivity (Spcond), dissolved oxygen (DO), total dissolved solid (TDS) and oxidation–reduction potential (ORP) were measured at sampling site using WTW multi-parameter instrument.

The correlation coefficients of the calibration curves were varied between 0.985 and 0.995. In order to minimize matrix effects, blanks and standard solutions were accurately matched with the samples with respect to matrix. Blanks and standards of known concentrations

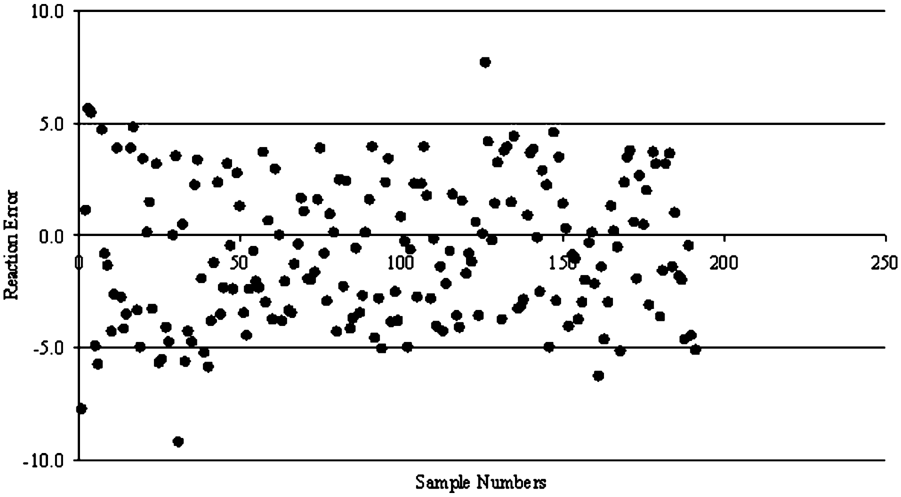


Figure 4 Ionic balance reaction error.

Table II The average value of major element in Troia water resources (mg L^{-1})

Type	Sample number	Na^+	K^+	Ca^{2+}	Mg^{2+}	$S0_4^{2-}$	HCO_3^-	Cl^-	PO_4^{3-}
Spring	1	43.53	3.19	63.46	54.51	27.63	279.35	173.78	1.008
	3	41.53	3.05	86.11	53.72	23.13	353.34	162.49	0.503
Surface water	2	33.32	4.14	46.24	57.40	33.38	238.84	146.28	0.956
	4	106.20	3.08	41.33	58.95	64.38	284.26	199.98	0.862
	5	34.11	2.57	65.57	55.50	30.13	265.83	171.24	0.744
	6	38.16	5.43	48.84	64.75	36.63	276.66	169.73	0.978
	7	40.42	3.30	54.53	45.56	35.75	205.40	141.92	0.934
	8	78.67	4.01	53.86	60.39	41.38	340.34	177.59	2.036
	10	56.80	3.96	47.90	58.93	43.38	205.29	210.13	0.808
	11	43.33	3.10	39.81	53.63	35.50	238.38	131.76	1.049
	12	395.39	5.13	33.40	81.71	76.71	883.36	347.66	1.070
	13	389.30	5.21	49.35	60.59	62.00	456.04	591.69	1.467
	14	77.34	5.48	54.66	45.16	35.90	207.05	223.88	0.712
	15	108.32	3.85	63.92	57.59	58.13	290.40	239.16	0.551
	16	60.29	2.88	69.04	33.28	42.50	224.34	161.53	0.815
	17	76.88	5.34	61.70	48.33	37.13	273.93	200.41	1.946
Groundwater	9	322.80	2.66	83.11	59.76	338.63	405.18	375.66	0.596
	18	432.02	17.26	108.72	88.25	486.29	253.86	698.39	0.787
	19	345.58	17.71	85.38	83.73	552.14	289.44	418.11	1.091
	20	475.94	16.16	178.09	49.23	739.63	275.63	564.03	1.066
	21	224.68	11.55	136.96	56.50	343.14	363.76	316.58	1.018
	22	414.44	13.12	79.12	41.51	13.86	341.73	705.66	0.653
	23	108.73	6.19	56.54	47.25	57.14	277.93	205.81	0.824
	24	234.86	16.02	92.37	49.68	173.29	321.90	392.46	1.429
	25	365.54	9.71	80.80	75.31	256.71	455.33	558.29	1.977

were run periodically throughout the analyses as quality-control checks.

LaMotte smart colorimeter and its kits were used for Cu, F, Fe, SO_4^{2-}, PO_4^{3-} and, Zn analyzing. Chloride, bicarbonate and, carbonate analyses of water samples were performed according to Soil Survey Staff (1996). For all of above analysis, three replicates were analyzed. Any replicate that deviates more than ±10% of the mean was recorded and reanalyzed.

Multiple regression analysis was done for all parameters by using SPSS (1988).

5 Results and Discussion

5.1 Quality of chemical data

It is an important step, before any manipulation of chemical data, to ascertain its quality. The accuracy of chemical data can be checked by computation of ionic charge balance error which is explained below (Lloyd & Heathcote, 1985; Mandel & Shiftan, 1981);

$$ReactionError = \frac{\sum cations - \sum anions}{\sum (cations + anions)} \times 100$$

$\sum$ cations: sum of meq L^{-1} concentrations of cations
$\sum$ anions: sum of meq L^{-1} concentrations of anions

If the reaction error of chemical data set is greater than 10% therefore qualities of analysis questionable. In this study, reaction errors are given in Figure 4. All the reaction errors are within 10% range. Therefore the quality of chemical data is acceptable according to ionic charge balance criteria.

5.2 Anions and cations

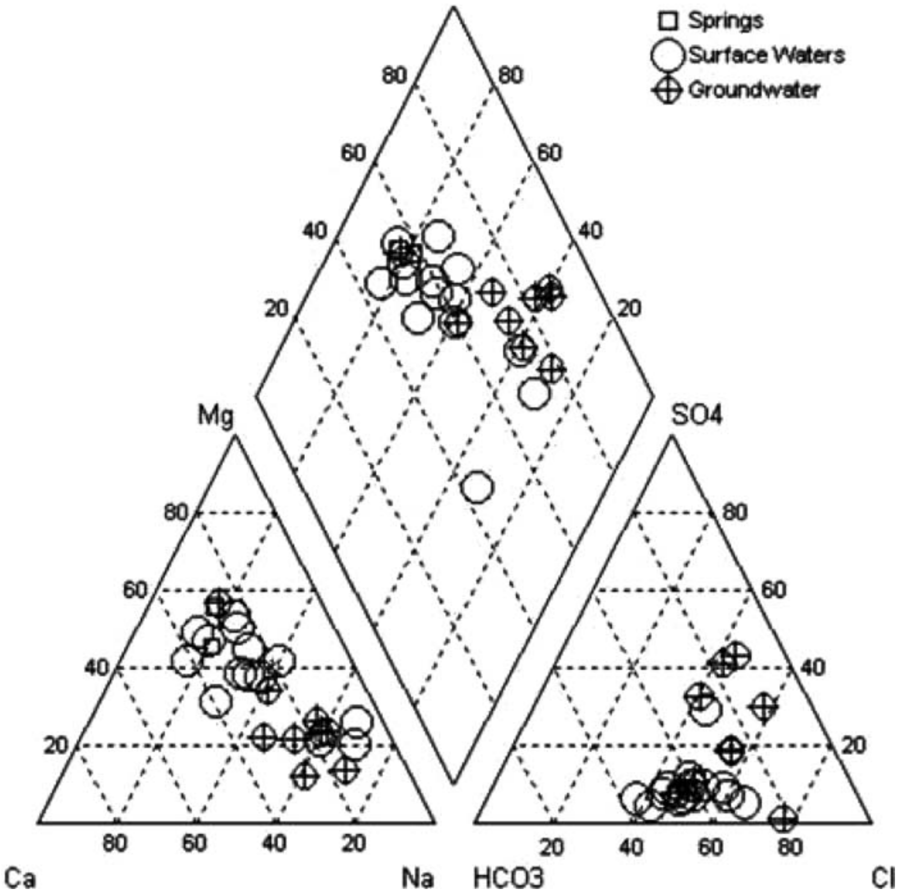
Average values of major anions and cations measured during the 8 months period were presented in Table II. These results were plotted on Scholler and Piper diagrams (Figures 5 and 6). According to Piper diagram (Figure 5) the samples 1, 3, 4, 7 and 8 are rich within Mg^{2+}-Ca^{2+}-Cl^--HCO_3^- ions whereas the samples 5, 6, 10, 13 show major adjacent cations with Mg^{2+}-Na^{+}-Ca^{2+}-Cl^{-}-HCO_3^{-} ions. Well samples 20, 21, 24 are rich with Na^{+}-Ca^{2+}-Mg^{2+}-Cl^{-}-SO_4^{2-} while 18, 19 are rich with Na^{+}-Mg^{2+}-Cl^{-}-SO_4^{2-} and 23, 25 rich with Na^{+}-Mg^{2+}-Cl^{-}-$HCO_3{}^{-}$. According to Piper it can be said that, well waters are rich in Na and Cl. This situation seems to reveal that the wells in the area have been affected by seawater intrusion.

Schoeller diagram (Figure 6) show that water in the region could be classified into three different groups. Especially samples 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 13, 14, 15 and 16 were similar to each other which were classified as rich with Mg^{2+}-Cl^{-}-HCO_3^{-}. Samples 17, 18, 19, 20, 21, 24 and 25 were rich with Na^{+}-Cl^{-}, and samples 11, 12 and 22 were rich with Na^{+}-HCO_3^{-}.

Groundwater can be rich with any ion depending on the chemical composition of the land. Generally water sampled from aquifers of Kumkale Basin showed different properties. Spatial lithological changes within rocks, change of ions, increase of solubility, reduction of sulphates etc. can partially affect the properties of groundwater. For instance, when samples 9 and 18 are compared it can be seen that concentration of SO_4^{2-}/Cl^{-} is decreasing when groundwater approaches to Dardanelles. Similarly concentration of Ca^{2+}/Mg^{2+} is decreasing by approaching to Dardanelles.

Sulphate concentrations of water wells were found to be very high because of gypsum layers in the alluvium aquifer which were extensively heterogeneous in lithology. Much of the sulphate could be leached by rain because of shallow wells and high groundwater level in the region. Beside that, well numbers 18, 19, 20 and 21 had interesting tectonic morphology and these wells had also high concentrations of Na^{+} and sulphate suggested that these wells could be affected by tectonics movements. Another reason could be the mixing of these waters with hydrothermal fluids (Tuzla and Kestanbol thermal waters are located near the research area).

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



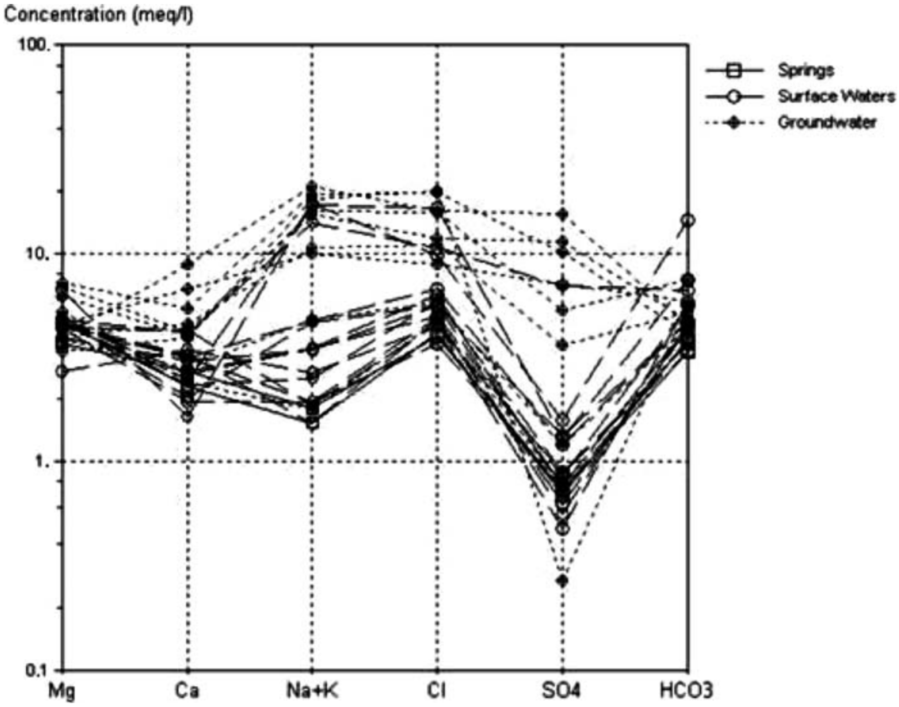


Figure 6 Chemical analysis of water of the study area plotted on Piper diagram.

Table III The average value of EC, pH, TDS, DO, ORP, SAR and Total hardness in Troia water resources (mg L^{-1})

Type	Sample number	EC dS m^{-1}	TDS g L^{-1}	DO mg L^{-1}	pH	ORP mV	SAR	Total hardness mg L^{-1}
Spring	1	0.720	0.469	7.82	7.73	51.63	0.97	383
	3	0.571	0.370	7.31	7.63	57.60	0.87	436
Surface water	2	0.499	0.324	7.61	7.77	56.68	0.79	352
	4	0.798	0.520	7.38	7.74	61.26	2.93	346
	5	0.573	0.370	7.27	7.65	67.24	0.78	392
	6	0.641	0.413	8.09	7.66	62.43	0.85	388
	7	0.550	0.472	7.64	7.81	69.36	0.99	324
	8	0.927	0.602	6.83	7.67	70.43	1.73	383
	10	0.715	0.464	7.31	7.63	68.21	1.30	362
	11	0.616	0.401	8.45	7.93	62.38	1.08	320
	12	1.763	1.148	7.06	8.14	56.48	8.53	420
	13	2.650	1.716	6.33	7.75	63.18	9.59	373
	14	1.052	0.685	6.89	7.72	62.04	1.80	322
	15	1.031	0.663	7.55	7.72	55.46	1.85	353
	16	0.729	0.473	7.71	7.84	67.23	1.55	309
	17	0.677	0.441	7.61	7.66	62.08	2.69	397
Groundwater	9	2.255	1.468	6.10	7.38	83.98	6.64	453
	18	4.599	2.996	5.08	7.27	78.26	6.82	635
	19	2.119	1.380	6.71	7.49	71.35	6.61	558
	20	3.820	2.487	7.39	7.53	62.09	8.73	647
	21	2.861	1.859	6.24	7.56	47.50	4.89	575
	22	3.462	2.305	5.06	7.66	64.81	9.09	368
	23	1.098	0.707	6.54	7.77	47.64	2.64	336
	24	2.375	1.543	6.86	7.54	66.44	5.13	435
	25	2.350	1.529	6.68	7.68	67.89	7.21	512

Kayan (2000) reported that in the Iliad Homer mentioned hot and cold springs although there is no hot springs today in the vicinity of Troia. This could be because of thick alluvial sedimentation along the base of the slope. It could be assumed that some warm-water would have continually come from rather small springs beneath the alluvium, which was about 10–15 m thick in some places. This water could diffuse in the loose alluvium mixing into the present water-table.

The average concentrations of PO_4^{3-} in samples were between 0.503–2.036 mg L^{-1}. The highest concentration of PO_4^{3-} was found in sample number 8 (Table II) which was regularly polluted by the discharges of the Kumkale Village sewage.

The pH values of water were between 7.03 (surface)–8.88 (well) (Table III). The mean values of dissolved oxygen (DO) were high at all stations. Minimum value was 1.40 mg L^{-1} in well water and 12.08 mg L^{-1} in surface water. Average DO values were between 5.06–8.45 mg L^{-1} (Table III). It is expected that DO value should be around 10 mg L^{-1} in non-polluted waters. As dissolved oxygen levels in water drop below 5.0 mg/l, aquatic life is put under stress. Oxygen levels that remain below 1–2 mg L^{-1} for a few hours can result in large fish kills (Anonymous, 2004). The electrical conductivity is a valuable indicator of the amount of material dissolved in water; and its values ranged from 0.571 to 4,599 dS m^{-1} (Table III). The recommended value of EC for potable water is 2.5 dS m^{-1} (WHO, 1993). The high electrical conductivity values in some well water samples showed that they were unsuitable for human consumption and irrigation. Total dissolved solids (TDS) indicate the general nature of water quality or salinity. Water samples containing less than 0.5 g L^{-1} of TDS is considered the Ist class water and over 5.0 g L^{-1} is the IVth class water according to inland water resource quality criteria (DSI, 2001). TDS values were between 0.229 and 4.486 in Troia water samples therefore they can be classified between the 1st and IVth class.

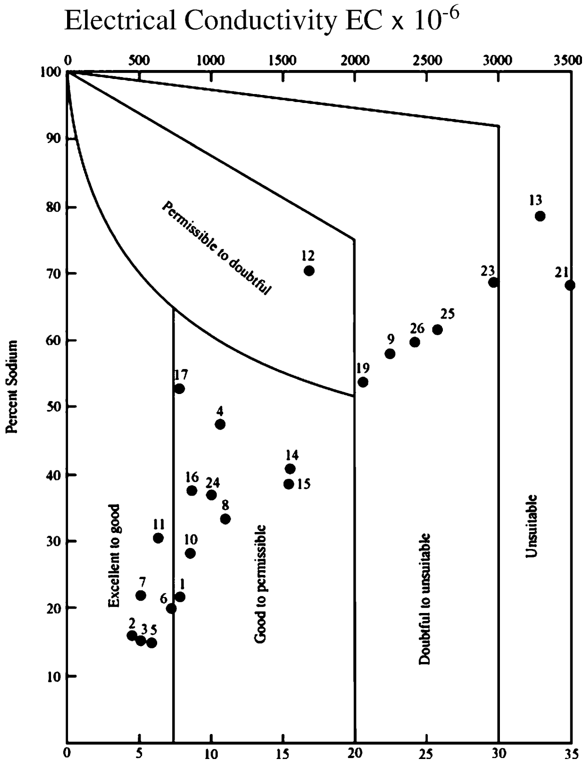


Figure 7 Wilcox diagram for irrigation classification of the water (summer seasons).

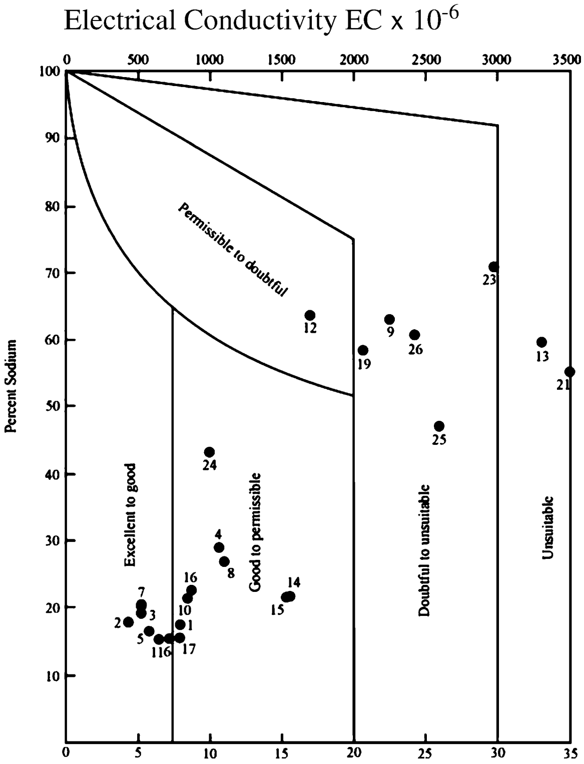


Figure 8 Wilcox diagram for irrigation classification of the water (winter seasons).

EC values over 5 dS m^{-1} are not suitable for livestock and over 7 dS m^{-1} is not suitable for poultry. Our results show that EC values of water were suitable for poultry. Average values of EC were less than 5 dS m^{-1} (Table III), however due to temporal variations during the year; these values can be lower or higher than limit value.

Table IV The average value of minor element in Troia water resources (mg L^{-1})

Type	Sample number	B	Zn	Pb	F	Cu	Fe
Spring	1	0.180	0.108	0.087	0.203	0.021	0.151
	3	0.198	0.097	0.468	0.156	0.039	0.053
Surface water	2	0.125	0.102	0.574	0.094	0.063	0.076
	4	0.225	0.087	0.150	0.149	0.029	0.078
	5	0.131	0.076	0.182	0.218	0.043	0.068
	6	0.211	0.150	0.145	0.189	0.029	0.168
	7	0.344	0.089	0.152	0.136	0.031	0.054
	8	0.340	0.076	0.136	0.238	0.117	0.122
	10	0.178	0.110	0.626	0.216	0.017	0.135
	11	0.412	0.119	0.122	0.184	0.023	0.084
	12	0.631	0.253	0.497	0.543	0.063	0.111
	13	0.772	0.179	0.243	0.397	0.064	0.254
	14	0.297	0.336	0.419	0.170	0.025	0.064
	15	0.313	0.323	0.291	0.270	0.028	0.068
	16	0.449	0.127	0.135	0.207	0.041	0.072
	17	0.464	0.145	0.161	0.164	0.091	0.129
Groundwater	9	0.357	0.171	0.234	0.406	0.019	0.261
	18	0.659	0.620	0.100	0.127	0.517	4.656
	19	0.379	0.125	0.344	0.249	0.048	0.487
	20	0.456	0.144	0.741	0.603	0.629	2.229
	21	0.479	0.484	0.083	0.253	0.048	0.529
	22	0.465	0.323	0.158	0.340	0.160	1.281
	23	0.356	0.136	0.133	0.309	0.022	0.220
	24	0.671	0.629	0.086	0.140	0.291	0.091
	25	0.926	0.471	0.207	0.357	0.057	0.239
U.S. EPA (2003)		–	5	0.015	4	1.3	0.3
WHO (1963)		–	5	0.05	–	1	0.3
TSE (1997)		2	5	0.05	1.5	3	0.2

Average sodium absorption ratios (SAR) were between 0.78 and 9.59 in the area (Table III). Generally the values of SAR in groundwater samples were higher than those of surface water.

Oxidation–reduction potential (ORP) provides a measurement of the oxidizing or reducing properties of the water. The oxidizing nature of water has implications in its ability to support life. Average oxidation and reduction potentials (ORP) were between 47.50 mV and 83.98 mV in the study area (Table III).

The hardness of water can naturally range from zero to hundreds of milligrams per liter (or parts per million). Waters with a total hardness in the range of 0 to 60 mg L^{-1} are termed soft; from 60 to 120 mg L^{-1} moderately hard; from 120 to 180 mg L^{-1} hard; and above 180 mg L^{-1} very hard (Ayyildiz, 1983). In this study water samples can be classified as very hard (Table III).

5.3 Trace elements and heavy metals

B, Cu, Fe, F, Pb and Zn analysis of water samples were done and compared with standard values for potable water suggested by U.S. EPA (2003), WHO (1963) and TSE (1997) (Table III). B, Cu, F and, Zn values were lower than the standard values for potable water. However, Pb concentration was above the US. EPA limits ranging from 0.001 to 4.832 mg L^{-1}. Industries do not exist in the catchment area but altered volcanic rocks are widespread in the study area. These altered rocks have some ore deposits minerals such as lead that could be washed around the area and accumulated in the Kumkale Plain. The minimum average Pb value (0.086 mg L^{-1}) was 6 times and the maximum average Pb value was 50 times greater than those permitted by EPA (0.015 mg L^{-1}) for drinking water.

Table V Correlation coefficients among parameters

	F	Cu	Fe	PO_4	Spcond	pH	B	Zn	Pb	Na	K	Ca	Mg	SO_4	HCO_3	Cl
F	1															
Cu	0.282	1														
Fe	0.117	0.818**	1													
PO_4	0.080	0.085	−0.127	1												
Spcond	0.464*	0.738**	0.778**	0.080	1											
pH	0.113	−0.489*	−0.579**	0.110	−0.544**	1										
B	0.407*	0.347	0.310	0.515**	0.650**	−0.033	1									
Zn	−0.010	0.414*	0.466*	0.101	0.640**	−0.389	0.646**	1								
Pb	0.384	0.214	0.022	−0.202	0.008	0.067	−0.201	−0.254	1							
Na	0.691**	0.586**	0.584**	0.126	0.910**	−0.325	0.714**	0.494*	0.155	1						
K	0.198	0.709**	0.650**	0.137	0.816**	−0.560**	0.492*	0.629**	0.033	0.709**	1					
Ca	0.342	0.720**	0.568**	−0.038	0.697**	−0.632**	0.252	0.398*	0.164	0.528**	0.691**	1				
Mg	0.155	0.144	0.373	0.175	0.336	−0.204	0.312	0.274	0.090	0.455*	0.336	0	1			
SO_4	0.426*	0.688**	0.627**	0.036	0.730**	−0.626**	0.334	0.32	0.250	0.691**	0.755**	0.817**	0.416*	1		
HCO_3	0.628**	−0.063	−0.093	0.203	0.234	0.384	0.486*	0.173	0.133	0.505*	0.008	−0.106	0.459*	0.022	1	
Cl	0.498*	0.612**	0.673**	0.113	0.933**	−0.444*	0.704**	0.585**	0.039	0.934**	0.737**	0.509**	0.367	0.582**	0.296	1

$^{*}p<0.05$; $^{**}p<0.01$

When we investigated water analysis results in terms of drinking water by livestock, upper limit for Cu is 0.5 mg L^{-1}and Pb 0.1 mg L^{-1}. Especially in some well waters (18 and 20) Cu values were higher than the upper limit. Most of the water samples had higher copper contents than upper limit values which were not suitable as a drinking water sources for livestock (Ayers & Wescot, 1976; E.S.B., 1972).

Fe values of well numbers 18, 19, 20, 21 and 22 were above the limits. Iron contents of water were between 0.01 mg L^{-1} (spring) and 14.5 mg L^{-1} (well). The first reason for high Fe contents in wells were fertilizer use and possibly the second was hot water which was mentioned above for the sulphate.

Water samples taken in summer and winter seasons were evaluated for irrigation using Wilcox graphs (Figures 7 and 8). According to these graphics samples were classified as follows: 13, 18, 21 and 22 not suitable for the irrigation; 9, 19, 23, 25 and 26 from doubtful to unsuitable; 12 from permissible to doubtful; 1, 4, 8, 10, 14, 15, 16, 17 and 24 from good to permissible; 2, 3, 5, 6, 7 and 11 from excellent to good.

Multivariate statistical techniques were used to analyze relationships among all parameters presented in Tables II and IV. Table V shows that the correlations among the average values resulting from 8 months of investigations. The maximum correlation was found between sodium and chloride ($P < 0.01$ and r = 0.934). The higher negative correlation was found between calcium and pH ($P < 0.01$ and r = −0.632). Statistically significant positive relationships $P < 0.01$) were found between F and Na^{+}, F and HCO$_3^{-}$; Cu and Fe, Cu and EC, Cu and Na^{+}, Cu and K^{+}, Cu and Ca^{2+}, Cu and SO$_4^{2-}$, Cu and Cl^{-}; Fe and EC, Fe and Na^{+}, Fe and K^{+}, Fe and Ca^{2+}, Fe and SO$_4^{2-}$, Fe and Cl^{-}; PO$_4^{3-}$ and B; B and Zn, B and Na^{+}, B and Cl^{-}, B and EC; Zn and K^{+}, Zn and Cl^{-}, Zn and EC; Na^{+} and K^{+}, Na^{+} and Ca^{2+}, Na^{+} and SO$_4^{2-}$, Na^{+} and Cl^{-}, Na^{+} and EC; K^{+} and Ca^{2+}, K^{+} and SO$_4{}^{2-}$, K^{+} and Cl^{-}, K^{+} and EC; Ca^{2+} and SO$_4{}^{2-}$, Ca^{2+} and Cl^{-}, Ca^{2+} and EC; SO$_4{}^{2-}$ and Cl^{-}, and were found negative relationships between pH and EC, pH and Fe, pH and K^{+}, pH and Ca^{2+}, pH and SO$_4^{2-}$.

5.4 Corrosion coefficient (K)

A very important parameter for water quality evaluation in Troia is corrosion coefficient (K). It was used because it evaluated the quality of water regarding to

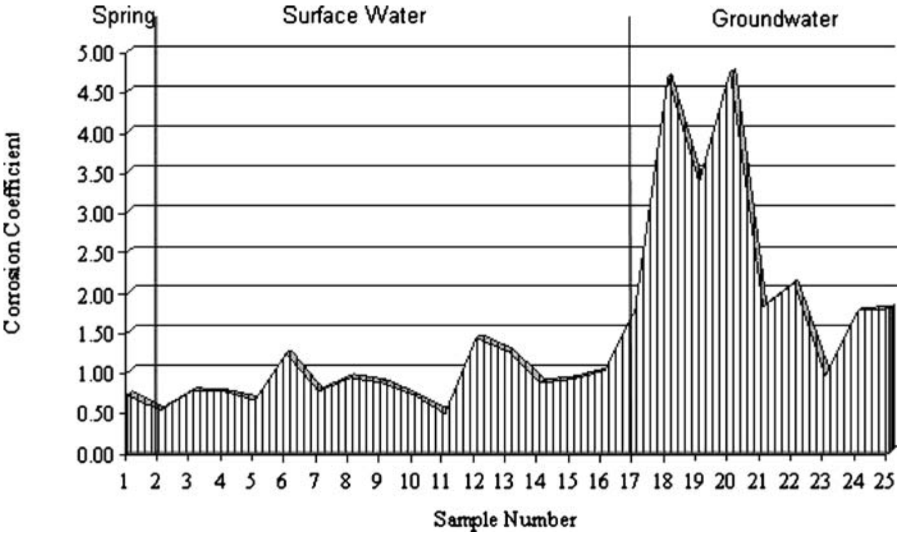


Figure 9 The average corrosion coefficient of Troia waters.

the variations of chloride and sulphate concentration. Corrosive tendency was calculated by corrosion coefficient (K) as below;

$K = (Cl^- + SO_4^{2-})/HCO_3^-$ (Alkalinity) (Larson & Scold, 1958).

The neutral pH range (7 to 8), with dissolved oxygen ratios equal to or below 0.25, indicates general resistance to corrosion, while higher ratios generally indicate more corrosive waters which damage the water supply systems (Stambuk-giljanovic, 1999). The average K value of Troia water resources was presented in Figure 9. As it is seen in the Figure 9, all waters are corrosive especially groundwater have higher corrosivity than other water sources.

6 Conclusion

Generally water sampled from aquifers of Troia showed different properties. Piper diagram showed that, well waters were rich in Na^+ and Cl^-. This situation seems to reveal that the wells in the area have been affected by seawater intrusion.

Some of the heavy metal concentrations values were above EPA limits such as lead. The minimum average Pb value (0.086 mg L^{-1}) was 6 times and the maximum average Pb value was 50 times greater than those permitted by EPA (0.015 mg L^{-1}) for drinking water.

In contrast, Cu, F and, Zn values were lower than the standard values for potable water. Iron contents of water were between 0.01 mg L^{-1} (spring) and 14.5 mg L^{-1} (well). The reason for high Fe contents in wells was fertilizer use and possibly presence of hot water in the area. Some of the water samples had higher Cu and Pb contents than upper limit values which were not suitable as a drinking water sources for livestock.

The corrosion coefficient (K) in Troia waters varied based on water sources. It was lower than 1 in springs; it was about 1 in surface waters whereas it was over 1 in the groundwater. The K value in groundwater in Troia showed that these waters were considerably corrosive; it reached up to 8 and average of 4.5. Results of the chemical analysis showed that the water could be related with hot water. So, it is urgently recommended that the further researches should be done to determine the source of water by isotope analysis and the relationships between source of water and tectonics need to be explained.

These results showed that the water in the area is probably going to be affected by sea water therefore the abstracted water should be under regulations. Also people have to be aware for corrosion effects of well waters in the area.

Up to now we have not some important environmental problem in Troia, but some of the water analysis results showed that some heavy metals such as Pb exceeded EPA limits. This can effect on living organisms in the area. For instance some birds are very sensitive to it. Therefore more cautions must be taken into consideration for agriculture and habitats in the area.

Acknowledgment This research covered a part of the project supported by The Scientific and Technical Research Council of Turkey (Project Number: 102Y031).

References

Anonymous (2004). http://www.state.ky.us/nrepc/water/wcpdo.htm.

APHA-AWWA-WPCF 3110 (1992). *Standard methods for examination of water and waste water* (18th ed). Washington, DC: APHA-AWWA-WPCF.

AWWA (American Water Works Association) (1990). *Water quality and treatment: A handbook for community water supplies* (4th ed.). New York, NY: McGraw Hill.

Ayers, R. S., & Wescot, D. W. (1976). *Water quality for agriculture*. Rome: Food and Agriculture Organization of the United Nations.

Ayyildiz, M. (1983). *Irrigation water quality and salinity problems* (Agricultural Faculty Publication No: 879, p. 282.). Ankara University, Ankara, Turkey (in Turkish).

Baba, A., Birsoy, Y. K., Ensari, E., Andiç. T., Baykul, A., & Langeranli Y. (2001). Groundwater quality of Izmir. In *Groundwater and environmental symposium* (pp. 149–158). Izmir, Turkey.

Babu, S. D., Hindi, E., Da, R. F. E., & Bittencourt, A. (2002). Characteristics of Valadares Island aquifer, Paranagua coastal plain, Brazil. *Environmental Geology, 41*, 954–959.

Chatzoudis, G. K., & Rigas, F. P. (1998). Polymeric conditioners effects on leaching of nitrogen fertilizers in soil columns. *Journal of Environmental Science and Health, Part A, 33*, 765–782.

Emrich, G. H., & Merritt, G. L. (1969). Effects of mine drainage on groundwater. *Groundwater, 7*, 27–32.

Environmental Studies Board (1972). *Water quality criteria*. National Academy of Science, National Academy of Engineering.

Farid, M. S. M., Atta, S., Rashid, M., Munnink, J. O., & Platenburge R. (1993). Impact of reuse domestic wastewater for irrigation on ground water quality. *Water Science and Technology, 27*, 147–157.

Hassan, A. A. (1974). Water quality cycle – reflection of activities of nature and man. *Groundwater, 12*, 16–21.

Kayan, I. (2000). The water supply of Troia. In *Studia Troica* (pp. 135–144). Mainz am Rhein: Verlag Philipp von Zabern.

Larson, T. S., & Scold, R. W. (1958). Laboratory studies relating mineral quality of water to corrosion of steel and cast iron. *Corrosion, 16*, 285.

Laxen, D. P. H., & Harrison, R. M. (1977). The highway as a source of water pollution, an appraisal with the heavy metal lead. *Water Research, 11*, 1–11.

Lloyd, J. W., & Heathcote, J. A. (1985). *Natural inorganic hydrochemistry in relation to groundwater. An introduction* (p. 295). Oxford: Clarendon Press.

Malcolm, R., & Soulsby, C. (2001). Hydrogeochemistry of groundwater in coastal wetlands: Implications for coastal conservation in Scotland. *Science of the Total Environment, 265*, 269–280.

Manahan, S. E. (1994). *Environmental chemistry* (6th ed, pp. 179–180). Florida: Lewis Publishers.

Mandel S., & Shiftan Z. L. (1981). *Groundwater resources* (p. 269). New York: Academic.

Mcanally, A., Pinto, A., & Flora, J. (1997). Evaluation of lead and copper corrosion control techniques. *Journal of Environmental Science and Health, Part A, 32*, 31–53.

Mendoza, C. A., Cortes, G., & Munoz, D. (1996). Heavy metal pollution in soils and sediments of rural developing district 063 Mexico environment. *Environmental Toxicology and Water Quality, 11*, 327–333.

Miller, D. W. (1980). *Waste disposal effects on groundwater*. Berkeley, CA: Premier Press.

MTA (2002). *Geological map of Turkey*. General Directorate of Mineral Research and Exploration, Ankara, Turkey.

Ning, S. K., & Chang, N. B. (2003). Optimal expansion of water quality monitoring network by fuzzy optimization approach. *Environmental Monitoring and Assessment, 91*, 145–170.

Rahman, M. M., Hassan, M. Q., Islam, M. S., & Shamsad, S. Z. K. M. (2000). Environmental impact assessment on water quality deterioration caused by the decreased Ganges outflow and saline water intrusion in southwestern Bangladesh. *Environmental Geology, 40*, 31–40.

Schwaderer, G. (2003). Proposal for an effective protection concept for the Troad – A strategy for the preservation of an important ecological building block in the international system of bird migration. In G. A. Wagner, E. Pernicha, H. P. Uerpmann (Eds.), *Troia and the Troad – Scientific approaches* (pp. 285–291). Berlin: Springer Verlag.

Selim, M., & Iskandar, I. (1992). *Engineering aspects of metal-waste management*. London: Lewis Publishers.

Soil Survey Staff (1996). *Soil survey laboratory methods manual*. Soil Survey Investigation Report No. 42, Version 3.0.

SPSS (1988). *SPSS/PC, +,V.9.0.* Base Manual for the IBM PC/XT/AT and PS/2, Marija and Moruis. SPSS Inc.

Stambuk-giljanovi´, C. N. (1999). Water quality evaluation by index in Dalmatia. *Water Research, 33*, 3423–3440.

State Hydraulic Works (DSI) (1996). *Karamenderes Project, Kumkale Plain irrigation and drainage survey and land classification report* (Project no: 401). State Hydraulic Works, Turkey (in Turkish).

State Hydraulic Works (DSI) (2001). *Technical agenda*. State Hydraulic Works, Ankara, Turkey (in Turkish).

Todd, D. K. (1974). Salt water intrusion and its controls. *Journal of AWWA, 66*, 180–187.

TSE (1997). *Water intended for human consumption* (TS 226/Nisan 1997). Turkish Standard Institute, Ankara.

U.S. EPA (1977). *Waste disposal practices and their effects on groundwater* (pp. 81–107). United State Environmental Protection Agency, Report to Congress.

U.S. EPA (2003). *Groundwater and drinking water, drinking water standards*. United State Environmental Protection Agency. http://www.epa.gov/safewater.

WHO (1963). Drinking water standards (In Rahn P. H., 1996). In *Engineering geology: An environmental approach* (2nd ed, pp. 256–257). Prentice Hall PTR.

WHO (1993). *Guidelines for drinking-water quality. Volume 1. Recommendations* (2nd ed, p. 188). Geneva: World Health Organization.