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Drinking Water Quality Assessment of Ergene River Basin (Turkey) by Water Quality Index: Essential and Toxic Elements

(Penilaian Kualiti Air Minuman Lembangan Sungai Ergene (Turki) melalui Indeks Kualiti Air: Unsur Penting dan Toksik)

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ABSTRACT

Ergene River Basin is the most significant aquatic habitat for Thrace Region and also one of the most polluted watersheds in Turkey. The objectives of this study were to determine some essential-toxic element accumulations in drinking water of settlement areas located in Ergene River Basin and evaluated the water quality in terms of local public health. Drinking water samples were collected from 30 stations in dry (summer) season of 2018. Cluster Analysis (CA) was used to classify the investigated elements and villages and Weighted Arithmetic Water Quality Index (WAWQI) was used to assess the water quality. According to results of elemental CA, 11 statistically significant clusters were formed in terms of elemental densities and according to results of locational CA, 3 statistically significant clusters were formed in terms of drinking water qualities. According to results of WAWQI, the risk sequence of the elements in drinking water of the system as follows: Se > As > Mo > B > Ba > Cr > Pb > Mn > Ni > Cd > Cu. Although Ergene River Basin is known as a very contaminated freshwater ecosystem, it was determined that the groundwater of the basin has I. - II class water quality, in general. Selenium accumulations detected in almost all the investigated villages exceeded the drinking water limit of 10 ppb. Arsenic, boron and molybdenum accumulations detected in some villages exceeded the drinking water standards. Although concentrations of some elements in some locations were exceed the limit values and recorded as quite high levels, the majority of investigated element concentrations in drinking water of the basin have been found to be in the range of human consumption standards.

Keywords: Drinking water quality; Ergene River Basin; water quality index

ABSTRAK

Lembangan Sungai Ergene ialah habitat akuatik paling signifikan bagi rantau Thrace dan juga salah kawasan tadahan air yang paling tercemar di Turki. Objektif kajian ini adalah untuk menentukan beberapa unsur toksik terkumpul dalam air minuman di kawasan penempatan yang terletak di Lembangan Sungai Ergen dan menilai kualiti air daripada segi kesihatan penduduk tempatan. Sampel air minum telah diambil daripada 30 stesen pada musim kering (musim panas) 2018. Analisis Kelompok (CA) telah digunakan untuk mengkelaskan unsur yang dikaji dan kampung serta Indeks Kualiti Air Aritmetik Berpemberat (WAWQI) telah digunakan untuk menilai kualiti air. Menurut keputusan unsur CA, 11 kelompok penting secara statistik telah dibentuk daripada segi ketumpatan unsur dan mengikut keputusan lokasi CA, 3 kelompok utama secara statistik telah dibentuk daripada segi kualiti air minuman. Menurut keputusan WAWQI, jujukan risiko unsur dalam air minuman sistem ini adalah seperti berikut: Se > As > Mo > B > Ba > Cr > Pb > Mn > Ni > Cd > Cu. Walaupun Lembangan Sungai Ergen dikenali sebagai ekosistem air tawar yang sangat tercemar, telah ditentukan bahawa air bawah tanah di dalam lembangan ini secara umum mempunyai kualiti 1 - II kelas air. Pengumpulan selenium dikesan di hampir kesemua kampung yang dikaji adalah melebihi had air minuman 10 pbb. Pengumpulan arsenik, boron dan molibdebum dikesan di beberapa kampung melebihi piawaian air minuman. Walaupun kepekatan beberapa unsur di beberapa lokasi telah melebihi nilai had dan direkodkan sebagai tahap yang agak tinggi, majoriti kepekatan unsur yang dikaji dalam air minuman lembangan didapati dalam julat piawaian penggunaan manusia.

Kata kunci: Indeks kualiti air; kualiti air minuman; Lembangan Sungai Ergen

INTRODUCTION

Freshwater resources are among the most significant and adversely affected components of the environment. Contamination of freshwater resources causes to reduce the water quality and usage potential (Aris et al. 2014; Çiçek et al. 2013; Köse et al. 2014; Tokatlı et al. 2014). Only about 2.8% of water is fresh and suitable for human consumption and about 30.1% of freshwater are located in underground (Gupta 1997). Groundwater is the most significant source of drinking water supply for numbers of villages and districts. But unfortunately many inorganic pollutants sourced from anthropogenic activities have been identified as strong contaminants found in groundwater (Hudak 1999; Tokatlı 2014). Toxic metals have hazardous effects on the ecological balance of environment and they are significant contaminants for both surface and groundwater ecosystems. Significant quantities of toxic metals, which are being discharged to the aquatic ecosystems in every day, can be strongly accumulated, and biomagnified along water and food chain (Massoudieh et al. 2010; Tokatlı 2017; Yu et al. 2011; Yuswir et al. 2015). Therefore, monitoring groundwater quality and investigating essential and toxic element accumulations in drinking water have a vital importance both for human health and ecosystem health in especially industrial and agricultural zones.

Water quality indices, which are important parameters for the assessment and management of both surface and ground water, are effective tools to communicate information on the quality of water to the concerned citizens and policy makers. Weighted Arithmetic Water Quality Index (WAWQI) is one of the most commonly used drinking water quality indices, which may define as a rating reflecting the composite influence of different water quality parameters. WAWQI is calculated from the point of view of the suitability of groundwater for human consumption (Akter et al. 2016; Mukatea et al. 2019; Tyagi et al. 2013).

Ergene River that is located in the Thrace region of Turkey is one of the most important river basins and known to be exposed to serious pollution due to rapid urbanization and industrialization. Ergene River is one of the most important branches of Meriç River, which is the most important irrigation water source of the Thrace Region of Turkey. It was reported that major sources of pollution in Ergene River Basin are domestic wastes, pollution caused by organized industrial sites, especially sodium and salt containing agricultural derange water pollution and slaughterhouse waste. It was also reported that there are about 2000 industrial enterprises in Çorlu, Çerkezköy, Muratlı and Lüleburgaz districts located in the Ergene River drainage area (DSİ 1997; Hallı et al. 2014; Tokatlı 2018 2017; Tokatlı & Baştatlı 2016).

Therefore, determination of drinking water quality of settlements located in Ergene River Basin, which is known to be exposed to so much contamination pressure, has a great importance both for ecosystem and public health. The aim of this study was to determine the essential and toxic element concentration levels in drinking water of villages located in the Ergene River Basin and evaluate the detected data according to drinking water standards and classify the investigated macro - micro elements in terms of densities in drinking water and classify the investigated villages in terms of drinking water qualities.

MATERIALS AND METHODS

STUDY AREA AND COLLECTION OF SAMPLES

Drinking water samples were collected in dry (summer) season of 2018 from 30 stations from the drill fountains of the villages located in the Ergene River Basin. Drinking water samples were then collected at the outflow of drill pump in polyethylene bottles. Station codes and localities of selected stations are given in Table 1. The map of Ergene River Basin and the selected stations are given in Figure 1.

CHEMICAL ANALYSIS

For determination of macro and micro element levels, pH of drinking water samples of one liter were adjusted to 2 by adding 2 mL of HNO_3 into each. Afterwards, all the samples were filtered (cellulose nitrate, 0.45 μm) in such a way as to make their volumes to 50 mL with ultra-pure water.

The element levels in drinking water samples were determined by using an ICP-MS device in Trakya University Technology Research and Development Application and Research Center (TÜTAGEM). The center has an international accreditation certificate within the scope of TS EN / ISO IEC 17025 issued by TÜRKAK (representative of the World Accreditation Authority in Turkey). The element analyses were recorded as means triplicate measurements (APHA 1992; EPA 2001).

TABLE 1. Location properties of selected stations

Station Code	Location	Station Code	Location	Station Code	Location
S1	Muratlı	S11	Müsellim	S21	Danişment
S2	Sarılar	S12	Düğüncübaşı	S22	Çöpköy
S3	Çorlu	S13	Lüleburgaz	S23	Bayramlı
S4	Velimeşe	S14	Babaeski	S24	Uzunköprü
S5	Çerkezköy	S15	Alpullu	S25	Salarlı
S6	Saray	S16	Karakavak	S26	Kurtbey
S7	Karlı	S17	Kadriye	S27	Yenicegörece
S8	Marmaracık	S18	Çerkezmüsellim	S28	Meriç
S9	Vakıflar	S19	Hayrabolu	S29	Adasarhanlı
S10	Karamusul	S20	Pehlivanköy	S30	İpsala

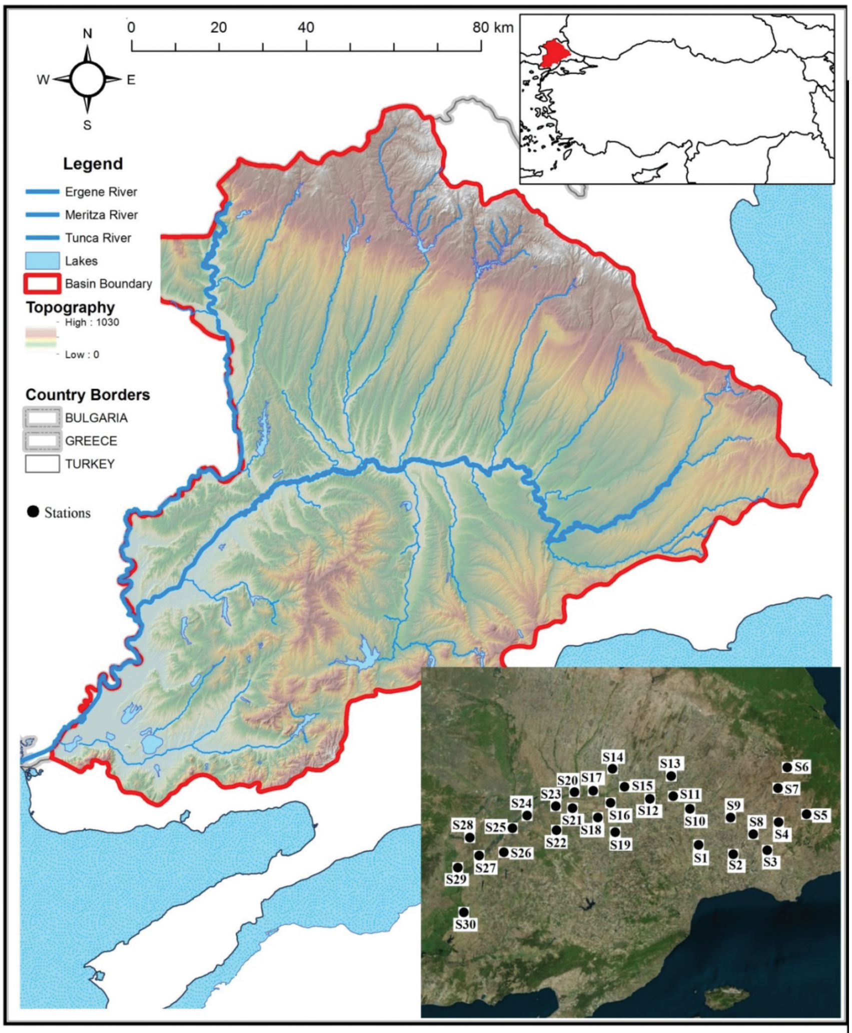

FIGURE 1. Map of Ergene River Basin and selected stations

STATISTICAL ANALYSIS

Cluster Analysis (CA), which is being used to classify the objects, is an important group of multivariate statistical techniques. The primary purpose of CA is assembling objects based on the characteristics they possess. One of the most common approaches in CA is the hierarchical agglomerative clustering, which provides intuitive similarity relationships between any one sample and the entire data set. It is also typically illustrated by a dendrogram in order to provide visual summaries of the clustering processes (Shrestha & Kazama 2007; Tabachnick & Fidell 1996). In this study, Cluster Analysis (CA) according to Bray Curtis was applied to detected data in order to classify the investigated elements and villages by using the 'PAST' statistical package program.

CALCULATION OF WEIGHTED ARITHMETIC WATER QUALITY INDEX

Weighted arithmetic water quality index method classified the water quality according to the degree of purity by using the investigated water quality parameters (Brown et al. 1972). The calculation of WAWQI was made by using the following formula:

$$\text{WAWQI} = \sum QiWi \Big/ \sum Wi$$

The quality rating scale (Qi) for each parameter is calculated by using the following formula:

$$Qi = 100[Vi - Vo]/(Si - Vo)$$

where Vi is the estimated concentration of i^{th} parameter in the analyzed water; Vo is the ideal value of this parameter in pure water (Vo= 0 in general); and Si is recommended standard value of i^{th} parameter.

The unit weight (Wi) for each the water quality parameter is calculated by using the following formula:

$$Wi = K/Si$$

where K is the proportionality constant and can also be calculated by using the following formula:

$$K = \frac{1}{\sum(1/Si)}$$

The rating of water quality according to WAWQI is given in Table 2 (Brown et al. 1972).

RESULTS AND DISCUSSION

ELEMENT ACCUMULATIONS IN DRINKING WATER

The minimum, maximum, average and standard deviation values of investigated macro and micro elements in drinking water of Ergene River Basin are given in Table 3. Element concentration levels in drinking water of Ergene River Basin are given in Figure 2. Sodium, magnesium and calcium were recorded as the densest elements detected in drinking waters, while beryllium, thallium and cadmium were recorded as the rarest elements detected in the basin. According to the results of this study, although macro and micro element concentration recorded in some villages of Ergene River Basin were determined as quite high levels and exceed the limit values, the majority of investigated element levels in drinking water of the basin have been found to be in the range of human consumption standards specified by Turkish Standards Institute (TSI266 2005), European Communities (EC 2007) and World Health Organization (WHO 2011), in general. It was also determined that according to the Water Pollution Control Regulation criteria in Turkey (SKKY 2015), groundwater of Ergene River Basin has I. – II. Class water quality in terms of all the investigated inorganic parameters, in general.

TABLE 2. Water Quality Rating as per Weight Arithmetic Water Quality Index Method

WAWQI Value	Rating of Water Quality	Usage Possibilities	Grading
0 – 25	Excellent water quality	Drinking, irrigation, industrial	A
25 – 50	Good water quality	Drinking, irrigation, industrial	B
50 – 75	Poor water quality	Irrigation, industrial	C
75 – 100	Very Poor water quality	Irrigation	D
> 100	Unsuitable for drinking purpose	Proper treatment is required before use	E

TABLE 3. Some descriptive statistics of investigated elements (ppb)

Elements	Minimum	Maximum	Average	SD
Li	0.657976	23.30859	8.933493	5.770635
Be	0.022133	0.071008	0.042698	0.012301
B	12.3091	779.9541	127.3005	194.3998
Na	16957.5	268483.9	73417.85	61547.75
Mg	984.5241	38029.62	12735.02	11612.78
Al	1.122667	7.316976	2.231947	1.217821
K	358.9549	4830.72	1335.036	879.7073
Ca	1889.025	66368.89	24479.4	20129.7
V	5.227095	17.87227	8.285254	3.641741
Cr	2.188418	5.933415	3.472942	1.141737
Mn	0.146867	41.35737	5.130982	10.22165
Fe	59.63573	105.3472	72.38099	11.13677
Co	0.033332	0.289047	0.120059	0.075208
Ni	0.269512	3.419491	0.893948	0.696307
Cu	0.276136	3.171018	1.115722	0.81151
Zn	1.723641	441.9622	18.734	80.04096
As	0.400401	24.79031	4.012752	4.734796
Se	8.88183	13.42902	10.07833	0.85777
Sr	44.22872	1294.493	426.2309	294.5268
Mo	16.2585	91.90205	19.37231	13.7052
Cd	0.012252	0.178891	0.025752	0.02927
Sb	0.07487	0.470933	0.182658	0.09858
Ba	12.12131	309.6256	80.62264	63.67789
Tl	0.026214	0.070974	0.036786	0.008415
Pb	0.202441	0.394178	0.27556	0.058048

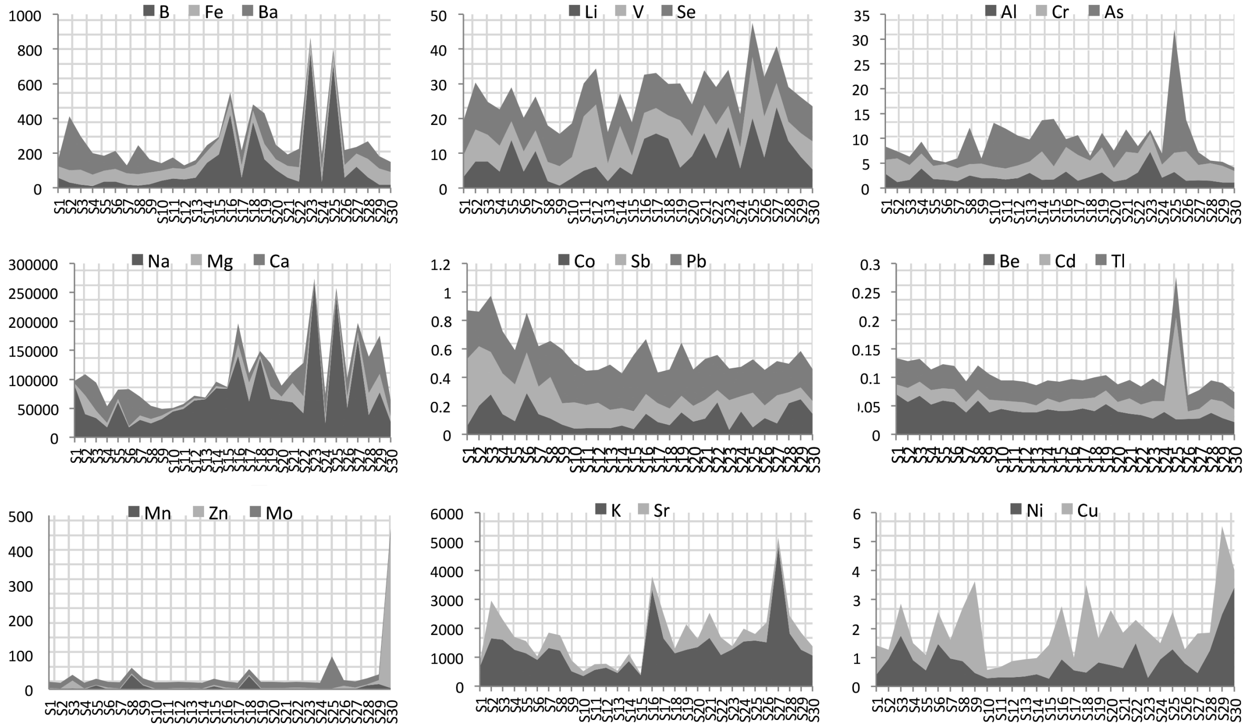

FIGURE 2. Element accumulation levels in drinking of Ergene River Basin (ppb)

RESULTS OF WEIGHTED ARITHMETIC WATER QUALITY INDEX (WAWQI)

Monomial and multinomial risks of B, Cr, Mn, Ni, Cu, As, Se, Mo, Cd, Ba and Pb in drinking water of Ergene River Basin for all the investigated locations were determined by using Weighted Arithmetic Water Quality Index (WAWQI). The quality rating scale values (Qi), which means the results of monomial WAWQI, calculated unit weights (Wi) of investigated parameters and the data of overall WAWQI, which means the results of multinomial WAWQI are given in Table 4.

The results obtained from the present study showed that although the overall WAWQI of drinking water in Ergene River Basin was within the permissible limits (<100) from the entire samples taken, quality rating scale values of selenium was not within the permissible limits (>100) almost in all the region and quality rating scale values of arsenic and boron were not within the permissible limits in a few stations. It was also determined that some regions of Ergene River Basin have 'C - D grade (poor - very poor)' water quality, according to the results of Monomial WAWQI in terms of arsenic and boron accumulations. According to the results of Multinomial WAWQI, Salarlı Village was found to be the riskiest location in terms of drinking water quality and according to the results of quality rating scale values, the risk sequence of the elements in groundwater of the basin used in the Weighted Arithmetic Water Quality Index as follows: Se > As > Mo > B > Ba > Cr > Pb > Mn > Ni > Cd > Cu.

The selenium levels detected in the ground water of the basin were between values of 8.88 - 13.42 ppb. The detected selenium concentrations in almost all the investigated villages exceeded the drinking water limit of 10 ppb (EC 2007; TSI266 2005; WHO 2011). Low levels of selenium can be found in drinking water and selenium concentrations are less than 10 ppb in 99.5% of drinking water sources tested (ATSDR 2003). In the Ergene River Basin, the average selenium accumulation in drinking water was found to be as 10.07 ppb and selenium contents of about 50% of investigated villages were found to be as higher than 10 ppb. It is known that selenium is released to the water via sewage effluent, agricultural runoff and industrial waste water (ATSDR 2003). The quite high selenium contents detected in the upstream of the basin, where is known that not exposed to industrial pollution, suggests that the main source of selenium accumulation in drinking water of the Ergene River Basin may due to sewage wastes and agricultural activities. It should also be noted that farmers living in rural regions may be at higher risk of selenium exposure than people living in urban regions. Because farmers tend to consume a larger proportion of locally grown foods, whereas people in urban areas tend to consume foods grown over a wider geographic area (ATSDR 2003). Therefore, it has a great importance that the selenium concentrations in drinking water of these rural areas in Ergene River Basin must be kept under control in order to protect the health of local people.

The highest arsenic and molybdenum values were recorded in Salarlı village at 24.79 and 91.90 ppb, respectively. These detected levels were about 2.5 times higher than the arsenic standards of TSI, EC and WHO (10

TABLE 4. Values of quality rating scale values (Qi), unit weights (Wi) and overall WAWQI

Stations	B	Cr	Mn	Ni	Cu	As	Se	Mo	Cd	Ba	Pb	Overall WAWQI
	Used Elements in WAWQI											
	Wi											
	0.0029	0.029	0.0036	0.0207	0.0007	0.145	0.145	0.0207	0.4833	0.002	0.145	
	Qi											
S1	11.90	5.65	0.39	0.58	0.05	27.09	**100.57**	24.91	0.55	4.48	3.41	20.03
S2	6.14	9.52	0.04	1.35	0.02	13.77	**134.29**	24.06	0.82	44.23	2.43	23.15
S3	3.72	6.16	0.57	2.51	0.05	16.10	**95.04**	23.36	0.83	27.67	3.93	17.89
S4	2.46	6.08	0.04	1.28	0.03	23.32	**104.38**	23.50	0.86	17.67	2.95	20.11
S5	7.46	5.26	2.76	0.78	0.03	12.50	**97.49**	24.36	0.71	12.37	2.40	17.38
S6	7.28	6.23	0.07	2.08	0.06	4.00	**96.35**	23.41	0.76	14.86	2.76	16.09
S7	3.86	5.38	0.05	1.37	0.03	18.94	**97.81**	24.00	0.61	6.54	2.81	18.36
S8	2.70	4.60	10.34	1.25	0.09	73.22	**104.21**	24.82	0.65	23.81	2.54	27.21
S9	4.17	5.85	2.74	0.66	0.16	10.64	**92.47**	24.15	0.74	10.76	3.79	16.60
S10	8.10	4.57	0.12	0.41	0.01	**87.82**	**96.67**	24.79	0.49	6.04	2.74	28.11
S11	10.76	4.38	0.04	0.45	0.02	**80.36**	**94.76**	25.14	0.55	8.96	2.40	26.75
S12	9.86	5.16	0.45	0.46	0.03	**59.77**	**103.38**	24.47	0.57	2.88	2.32	25.01
S13	11.71	4.65	0.47	0.49	0.03	44.06	**88.82**	24.07	0.41	3.34	3.17	20.63
S14	28.91	11.50	0.12	0.61	0.03	**62.35**	**92.92**	24.36	0.64	5.03	2.42	24.15
S15	38.65	5.23	2.08	0.39	0.06	**95.04**	**96.33**	25.10	0.51	1.73	3.94	29.41
S16	**84.28**	9.94	0.30	1.33	0.09	16.18	**109.77**	24.06	0.70	6.98	3.85	20.25
S17	11.97	10.44	0.05	0.79	0.02	40.14	**100.55**	23.47	0.57	12.27	2.16	21.88
S18	**75.96**	6.49	9.44	0.68	0.15	10.22	**91.64**	23.40	0.79	4.98	2.73	16.51
S19	33.05	10.01	0.30	1.19	0.04	29.41	**105.99**	25.10	0.80	25.06	3.72	21.56
S20	20.78	5.52	0.08	1.05	0.09	34.54	**91.15**	23.90	0.57	11.93	2.54	19.65
S21	11.64	11.15	0.05	0.90	0.06	44.44	**100.58**	23.44	0.91	9.35	2.85	22.79
S22	7.43	7.79	0.06	2.14	0.04	13.50	**107.83**	23.41	0.60	14.91	2.47	19.07
S23	**155.99**	7.29	0.09	0.42	0.08	7.57	**103.47**	24.77	1.01	2.17	2.22	18.12
S24	6.75	5.41	0.05	1.32	0.03	21.56	**96.49**	23.63	0.65	13.17	2.07	18.47
S25	**141.97**	7.77	0.05	1.83	0.06	**247.90**	**97.00**	**131.29**	5.96	3.32	2.34	**56.65**
S26	11.78	11.87	0.08	1.13	0.02	**63.35**	**113.04**	24.26	0.45	12.20	2.49	27.12
S27	24.65	6.15	0.39	0.66	0.07	25.61	**105.54**	24.61	0.56	5.57	2.39	20.44
S28	12.29	6.99	2.68	1.77	0.03	5.74	**99.28**	23.83	0.80	14.62	2.02	16.73
S29	3.67	6.73	3.75	3.56	0.15	7.50	**103.94**	23.36	0.96	10.00	2.55	17.81
S30	3.92	4.61	0.85	4.88	0.03	7.13	**101.77**	23.23	0.73	8.62	2.24	17.23
Min	2.46	4.38	0.04	0.39	0.01	4.00	88.82	23.23	0.41	1.73	2.02	16.09
Max	155.99	11.87	10.34	4.88	0.16	247.90	134.29	131.29	5.96	44.23	3.94	56.65
Mean	25.46	6.95	1.28	1.28	0.06	40.13	100.78	27.67	0.86	11.52	2.76	22.17

Index values of ">50 (>poor water quality)" are given in bold

ppb) and about 1.5 times higher than the molybdenum standard of WHO (70 ppb) (EC 2007; TSI266 2005; WHO 2011).

Arsenic known as a toxic chemical is naturally found in the environment. It is a proven carcinogen for humans, when exposed thru oral, dermal, and inhalation pathways. Arsenic contamination in drinking water is of great concern for public health (Brown & Ross 2002; Gündüz et al. 2010). In recent years, exposure to high levels of arsenic through consumption of contaminated drinking water (concentrations above 10 ppb) has been associated with the development of a number of chronic human health effects (Kwok 2007; Tseng 2008; Zheng et al. 2014). Salarlı Village is located in the downstream of Ergene River Basin and very close to the river. This may be the cause of the detected high arsenic contents in drinking water of this village. Researchers in U.S. reported that drinking water indicate that about 80% of water supplies have less than 2 ppb of arsenic and 2% of supplies exceed 20 ppb of arsenic in U.S. (ATSDR 2005a) In this study, about 43% of drinking water of Ergene River Basin have less than 2 ppb of arsenic and 3% of drinking water of the basin exceed 20 ppb of arsenic. It is known that use of pesticides, which are known to be intensively used in the region, contains significant quantities of arsenic (ATSDR 2005a; Çiçek et al. 2013; Tokatlı 2017). Agricultural activities conducted around the basin may be the cause of quite high arsenic levels in especially drinking water of Marmaracık, Karamusul, Müsellim, Düğüncübaşı, Babaeski, Alpullu, Salarlı and Kurtbey Villages.

The average boron accumulations detected in the groundwater of Ergene River Basin was recorded as 127.30 ppb. The highest boron levels were recorded in Bayramlı Village as 779.95 ppb and in Salarlı Village as 709.83 ppb. These detected data were significantly higher than the limit boron value of WHO (500 ppb) (WHO 2011). Accumulations of boron in drinking water have been reported in a range of 7 - 200 ppb in the U.S. and England and it was also reported that boron accumulations up to 400 ppb have been found in most drinking water samples (ATSDR 2010). In this study, boron levels of about 13.3% of investigated villages in Ergene River Basin were higher than the maximum detected value of 200 ppb in U.S. and England and boron contents of about 90% of groundwater of the basin were lower than 400 ppb.

The minimum cadmium accumulation was recorded in drinking water of Lüleburgaz District as 0.012 ppb and the maximum cadmium accumulation was recorded in drinking water of Salarlı Village as 0.178 ppb. There was a 15-fold difference between these cadmium concentrations detected in groundwater of the basin. Cadmium is an agricultural origin toxic metal. It can easily emit to soil and water by application of phosphate fertilizers, which are known to be intensively used in the region. It has been also reported that elevated cadmium levels in water resources may base on from cadmium-emitting industries in the vicinity (ATSDR 2007). The reason of the large cadmium differences found in the groundwater of Salarlı Village is thought to be that the village is located in the vicinity of Ergene River and the intensive agricultural activities carried out around the settlement.

The highest zinc level in drinking water of the Ergene River Basin was detected İpsala District and there was a 250-fold difference between the minimum (1.72 ppb) and maximum (441.96 ppb) zinc accumulations in the basin. Fertilizers being used in especially paddy fields have a significant impact on zinc transition to the soil (ATSDR 2005b). Rice production has a signifiaxcnt place in İpsala District, which is known as 'Rice Land' in Turkey, and the reason of recorded extreme differences on zinc accumulations in groundwater of İpsala District may be intensive paddy cultivation conducted around this settlement area.

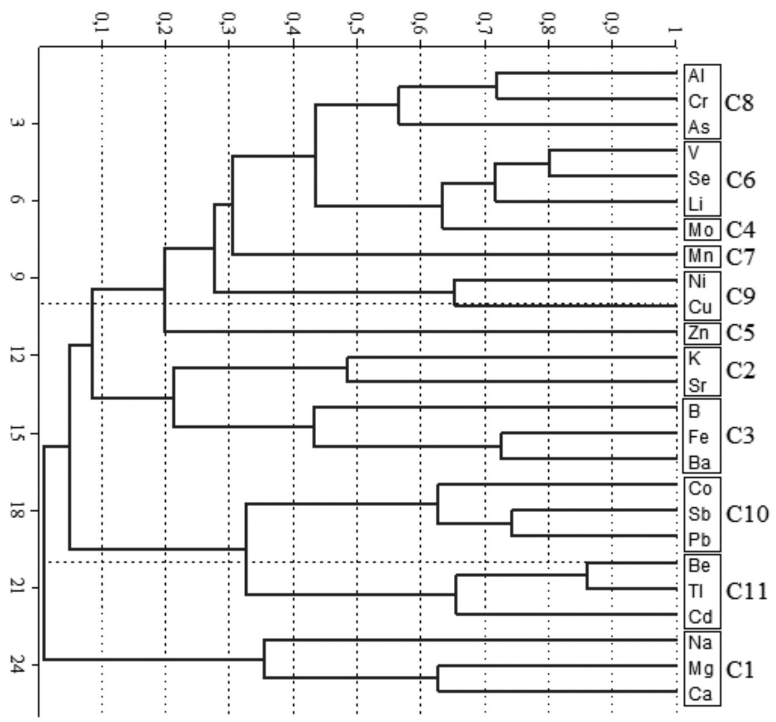

FIGURE 3. Elemental CA diagram

CLUSTER ANALYSIS (CA)

The diagram of elemental CA calculated by using all recorded macro - micro element values is given in Figure 3 and the diagram of locational CA calculated by using the results of weighted arithmetic water quality index values is given in Figure 4. Also essential and toxic element concentration rates in villages located in the Ergene River Basin classified by using the results of elemental CA are given in Figure 5.

According to the results of elemental CA, a total of 11 clusters were determined. 1. Cluster was formed by the elements of Na, Mg and Ca (most intense elements); 2. Cluster was formed by the elements of K and Sr (second most intense elements); 3. Cluster was formed by the elements of B, Fe and Ba (third most intense elements); 4. Cluster was formed by the element of Mo (fourth most intense elements); 5. Cluster was formed by the element of Zn (high-moderate intense elements); 6. Cluster was formed by the elements of V, Se and Li (moderate intense elements); 7. Cluster was formed by the element of Mn (low-moderate intense elements); 8. Cluster was formed by the elements of Al, Cr and As (fourth rarest elements); 9. Cluster was formed by the elements of Ni and Cu (third rarest elements); 10. Cluster was formed by the elements of Co, Sb and Pb (second rarest elements); 11. Cluster was formed by the elements of Be, Tl and Cd (rarest elements). According to the results of locational CA, a total of 3 clusters were identified as higher risk regions, moderate risk regions and lower risk regions. Higher Risk Cluster was formed by the station of S25 (Salarlı); Moderate Risk Cluster was formed by the stations S16 (Karakavak), S18 (Çerkezmüsellim) and S26 (Bayramlı); Lower Risk Cluster was formed by the stations of S1 (Muratlı), S2 (Sarılar), S3 (Çorlu), S4 (Velimeşe), S5 (Çerkezköy), S6 (Saray), S7 (Karlı), S8 (Marmaracık), S9 (Vakıflar), S10 (Karamusul), S11 (Müsellim), S12 (Düğüncübaşı), S13 (Lüleburgaz), S14 (Babaeski), S15 (Alpullu), S17 (Kadriye), S19 (Hayrabolu), S20 (Pehlivanköy), S21 (Danişment), S22 (Çöpköy), S23 (Bayramlı), S24 (Uzunköprü), S27 (Yenicegörece), S28 (Meriç), S29 (Adasarhanlı) and S30 (İpsala).

Cluster Analysis (CA) is a significant multivariate statistical technique. The primary purpose of CA is classifying the objects based on their similar characteristics (Shresta & Kazama 2007). In the present study; CA was used to determine the similar groups among the investigated elements and locations according to accumulation levels of macro and micro elements and drinking water qualities of villages. In two studies performed in the same river basin, CA was used in order to classify the element accumulations in sediments of Meriç - Ergene River Basin and classify the element bioaccumulations in tissues of fishes living in Meriç River Delta. According to the results of these studies, 5 statistically significant clusters were formed and as similar to the present study, they were named as “most intense elements”, ‘second most intense elements’, ‘moderate intense elements’, ‘second rarest elements’ and ‘rarest elements’ (Tokatlı 2018; Tokatlı & Baştatlı 2016). In another study performed in Langkawi Geopark in Malaysia, as similar to the present study, CA was used to identify the similarities in sampling sites. As a result of this study, CA generated 2 main clusters in terms of similar water qualities (Aris et al. 2013).

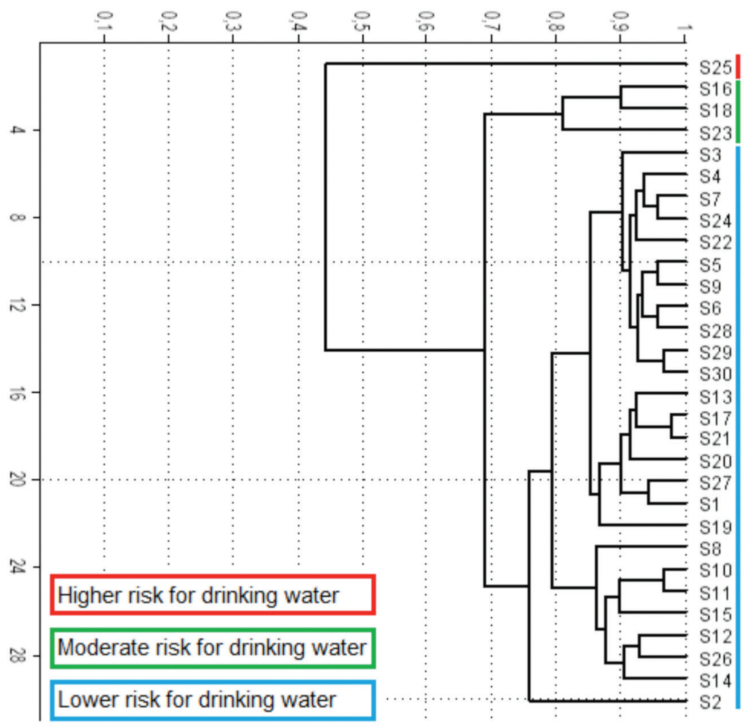

FIGURE 4. Locational CA diagram

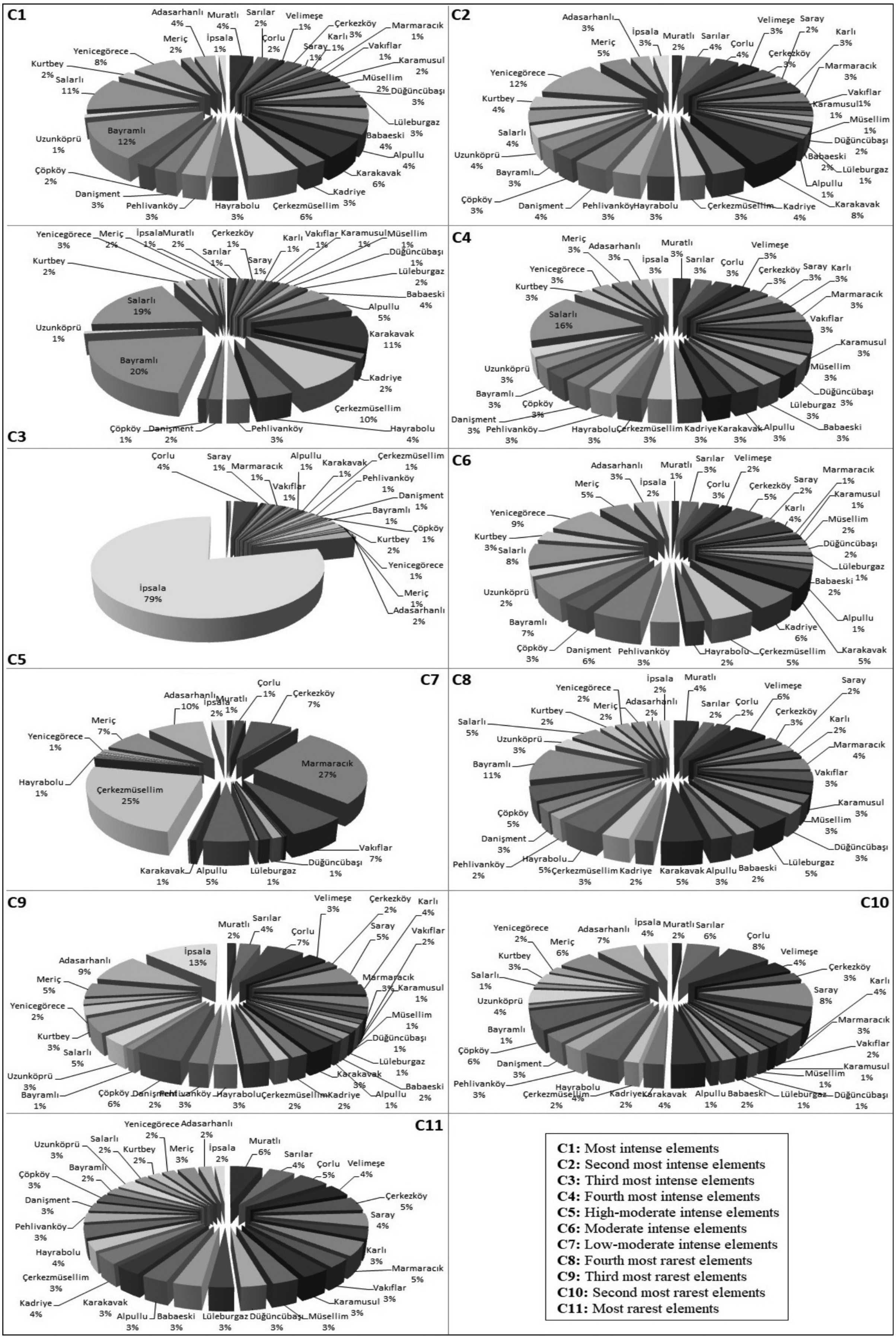

FIGURE 5. Element accumulation rates in drinking of Ergene River Basin

Conclusion

In the present study, some macro and micro element concentrations in drinking water of settlement areas located in Ergene River Basin (Thrace Region of Turkey) were investigated. Cluster Analysis (CA) and Weighted Arithmetic Water Quality Index (WAWQI) were used to evaluate the detected data.

Elemental CA was grouped 25 essential and toxic elements into 11 clusters of similar accumulation characteristics in groundwater of the basin; 'Most intense elements', 'Second most intense elements', 'Third most intense elements', 'Fourth most intense elements', 'High-moderate intense elements', 'Low-moderate intense elements', 'Moderate intense elements', 'Fourth rarest elements', 'Third rarest elements', 'Second rarest elements' and 'Rarest elements'. Locational CA was grouped 30 settlement areas into 3 clusters of similar water quality characteristics in drinking water of the basin; 'Higher Risk Cluster', 'Moderate Risk Cluster' and 'Lower Risk Cluster'.

According to detected data, the elements of arsenic and selenium were found to be as the riskiest elements in drinking water and Salarlı Village was found to be as the riskiest settlement area in the basin. Selenium contents detected in almost all the investigated villages exceeded the drinking water standards. It was determined that drinking water of Salarlı Village is not suitable for human consumption in terms of boron, arsenic and molybdenum levels and drinking water of Bayramlı Village is not suitable for human consumption in terms of boron levels. It was also determined that zinc accumulations detected in groundwater of İpsala District were found to be 100 times higher than the basin average.

According to the results of WAWQI, Se, B, As and Mo were found to be the riskiest elements for drinking water of the basin and groundwater of 3.3% of the investigated regions were not suitable for drinking in terms of multinomial WAWQI. It was also determined that 80% of investigated locations for Se, 6.6% of investigated locations for B, 3.3% of investigated locations for As and Mo were not suitable for drinking in terms of monomial WAWQI.

In conclusion, although levels of some elements in some villages of the basin were determined as quite high levels and exceed the limit values, the majority of investigated toxic element contents in drinking water of the basin have been found to be in the range of human consumption standards. As many researchers indicated, Ergene River is one of the most polluted river ecosystems in Turkey and it has IV. Class water quality in terms of many parameters. In this study, it was determined that the quality of groundwater is much higher than the surface water of the basin. It is thought that these toxicants cannot leak into the groundwater of the basin because of the region has a clayey soil structure.

The detected data clearly showed that agricultural runoff caused from especially paddy fields around the basin and the industrial discharges caused from Ergene River are the main risk factors for the groundwater of the basin. If such contamination persists, concentrations of inorganic toxicants in drinking water may reach the critical levels and may adversely affect the human health in the near future.

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