

Determination of some major and trace elements in the lower Sakarya River water by ICP-MS

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Abstract: In this paper, water and sediment samples were collected along the Lower Sakarya River basin for a twelve month period between February 2007 and January 2008. The samples were analysed for trace elements (31 elements in sediment and 33 elements in water) using the ICP-MS technique as pollution indicators. The results indicated that the Sakarya River water was polluted by sources of beryllium and thallium which exceeded the limits set by US Environmental Protection Agency (USEPA 2003). Sediments were polluted by Antimony, Tin, Rhodium and Selenium. The results also provide useful data for the conservation of the Black Sea where it is joined by the Sakarya River.

Keywords: Sakarya river; river water; sediment; heavy metal; ICP-MS; environmental. © 2018 ACG Publications. All rights reserved.

1. Introduction

The Sakarya River is one of the most important watersheds in the northwest part of Turkey and is a water source for irrigation, wastewater dilution, and industries. The watershed consists of three parts: the Upper, Middle, and Lower Sakarya River Basins. In this paper the lower part of the river basin was studied. There are five provinces within the Sakarya River Basin namely, Ankara, Kutahya, Eskisehir, Bilecik, and Sakarya, where the river drains into the Black Sea.

Various studies have been carried out in the major rivers of Turkey, such as the Buyuk Menderes and Gediz [1], Kizilirmak [2], Yeşilirmak [3], Firat [4], Tigris (Dicle) [5], and Mert Irmağı [6]. Water, the most important natural resource in the world, has the unique property of dissolving and carrying in suspension a huge variety of chemicals; hence, water can easily become contaminated [7]. Among the inorganic contaminants of river water, heavy metals [8,9] are important because of their non-degradable nature. Although some papers on the assessment of water quality based on physico-chemical and biological parameters have been published [10,11] very little information is available about the status of heavy metal contamination of the river Sakarya. With this background an investigation was initiated.

In an aquatic environment many anthropogenic pollutants are bound or absorbed by particulate matters. Depending on river conditions, suspended particles can settle and become part of the bottom sediments. Many studies reported the release of contaminants from surface sediments [12,13] depending on the aquatic conditions. A source of contaminants can make sediment chemistry and toxicity key

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components of aquatic system quality. Moreover, such concentrations are often highly variable because of several interacting factors, such as source characteristics, the flow regimes of the river and receiving waters, as well as their mixing dynamics [13].

The three main objectives of this paper are as follows: (a) The first goal was to obtain a comprehensive description of the physical, chemical properties and trace metal contents of the Lower Sakarya River water and trace metal contents of sediments. Only a few previous studies examined this river, always from a few sites of interest or single “hot spots”. (b) The second aim was to assess whether hazardous conditions may derive from the sediments and threaten the aquatic community. Only limited, scattered information is available on the risk posed by sediments. (c) The third main objective was to evaluate the usefulness of the different indicators (and approaches) to discriminate the quality changes along the Lower Sakarya River. To accomplish these three major objectives, water and sediment samples were collected from various locations of the river [14,15], and according to a defined procedure, they were concurrently examined for a range of physical, chemical and trace metal contents. The present study describes and discusses the principal results of the Lower Sakarya River water and sediment analysis.

2. Experimental

2.1. Sampling and analysis

In total, 240 river water samples were collected throughout the Lower Sakarya River during a twelve month period. Water samples were collected at selected sites (Çardak (1), Alifuatpaşa (2), Doğançay (3), Adliye (4), E-5 Sakarya Köprüsü, Rüstemler (5), Sinanoğlu (6), Adatepe (7), Tuzla (8), Karasu (9)) all located along the Lower Sakarya River (Figure 1 and Table 1).

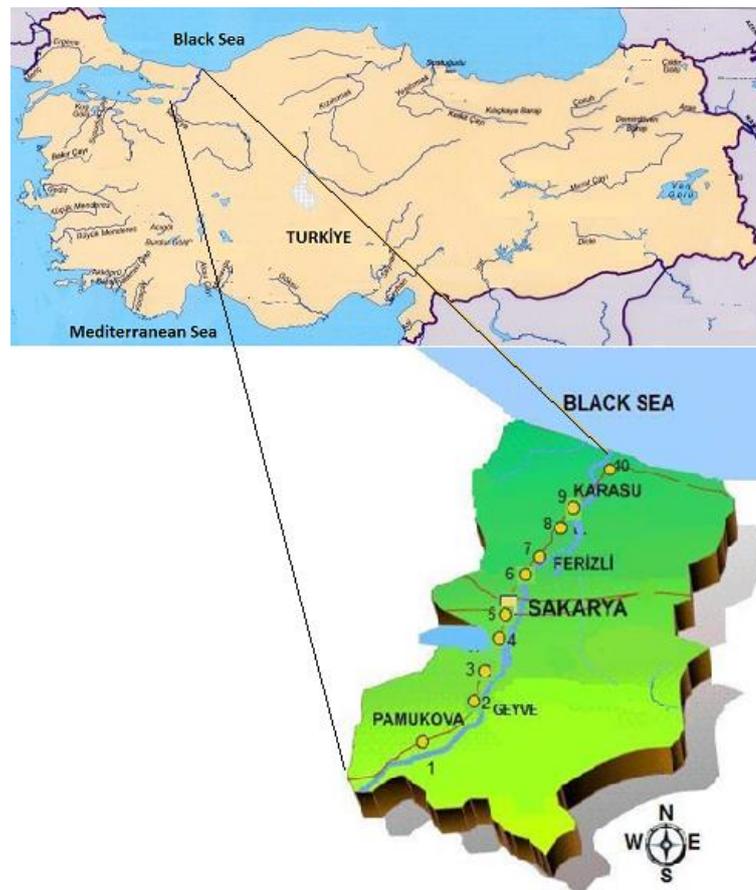


Figure 1. Schematic representation of Lower Sakarya River Water [14]

The samples were taken in duplicate, in 0.5 L polyethylene plastic bottles, using a Nansen type water sampler, between February 2007 and January 2008. After collection, the water samples destined to metal analysis were acidified with HNO₃. Sample properties (pH, temperature, dissolved oxygen, biological oxygen demand, salinity, alkalinity, etc.) were recorded according to Turkish standards (TS 5089, TS 5090, and TS 5106). Sulfate (TS 5095), Phosphate (TS 4082), Nitrate (TS 7890), and Chloride (TS 4164) in water samples were analysed in the laboratory. A coloured soft water from Quebec (Trois-94) was used for validation of the water analysis. River water reference material for trace metals, SLRS-4 were used for validation of the water analysis.

In total, 200 sediment samples were collected during a 10-month period between February 2007 and January 2008. Surface sediment samples were collected at selected sites (Table 1) on the Lower Sakarya River [14,15].

Table 1. Coordinates of the sampling sites in the Lower Sakarya River [15]

Sampling Stations		1	2	3	4	5	6	7	8	9	10
Coordinates (° ' ")	East	30 09 34	30 17 49	30 19 52	30 22 44	30 25 20	30 26 12	30 30 32	30 36 08	30 38 38	30 38 47
	North	40 28 09	40 32 06	40 37 29	40 40 16	40 44 22	40 47 76	40 57 52	41 01 30	41 04 51	41 07 08

The samples were collected in duplicate, in 250mL polyethylene bottles using an Ekman-Birge type grab sampler, [TS 9547 ISO 5667-12 method (Water quality-sampling section 12: Guide to bottom sediment sampling)]. After collection, sediment samples were digested in graphite crucible (ASTM D 4698). Samples were not collected in July and August due to the loss of an Ekman-Grab bottom sampler. Sediment samples were sieved using sieves with pore sizes below 0.074 mm. Sediments were used in elemental analysis within one week of collection.

Sediment samples were digested using TS 9265 [Water quality-Total digestion of sediment samples before chemical analysis of various metals (ASTM D 4698)] standard before elemental analysis. Trace metals in sediment samples were analysed by using ICP-MS technique.

River sediment reference material for trace metals are; STSD-1, chinese stream sediment, and NCS DC73312, were used for validation of the sediment analysis. Samples were digested using TS 9265 [Water quality-Total digestion of sediment samples before chemical analysis of various metals (ASTM D 4698)] standard before elemental analysis.

A total of 33 elements in water (vanadium, chromium, manganese, iron, cobalt, nickel, copper, zinc, aluminium, boron, cadmium, arsenic, selenium, antimony, lead, calcium, magnesium, thorium, molybdenum, barium, strontium, beryllium, lithium, sodium, potassium, gallium, wolfram, tantalum, bismuth, titanium, rhodium, thallium, silicon) and sediment samples (vanadium, chromium, manganese, iron, cobalt, nickel, copper, zinc, aluminium, arsenic, selenium, antimony, lead, calcium, magnesium, thorium, molybdenum, barium, strontium, beryllium, cesium, sodium, potassium, gallium, germanium, tin, wolfram, tantalum, bismuth, titanium, rhodium, thallium, silicon) (as above, except for boron, lithium and cadmium) were analysed by inductively coupled plasma mass spectrometry.

2.2. Apparatus and chemicals

Determinations of all elements have been performed by using an Agilent 7500A model Inductively Coupled Plasma-Mass Spectrometer. The pH of solutions was adjusted by adding HCl and NaOH solutions and controlled with a Schott CG 840 pH-meter. A distilled deionized Ultra High Quality water (chemical resistivity: 18 MΩ cm⁻¹ at 25 °C) obtained from a Milli-Q Plus water system (Millipore, Bedford, MA, USA) was used throughout the experiments. All chemicals, obtained from Merck (Germany), were of analytical reagent grade. YSI 556 model multiparameter instrument was used to determine physico-chemical parameters such as pH, temperature, dissolved oxygen.

2.3. Data analysis

2.3.1. Enrichment factor

Enrichment Factor (EF) was shown for elements using:

$$EF = \frac{(C_n / C_{Al})_{Sample}}{(C_n / C_{Al})_{Crust}}$$

Where $(C_n/C_{Al})_{sample}$ is the ratio of the concentration of the element of concern (C_n) to that of Al (C_{Al}) in the sediment sample and $(C_n/C_{Al})_{crust}$ is the same ratio in an unpolluted reference sample [15]. Here, Al was chosen as a reference element [16].

EF can provide information about anthropogenic source from a natural origin. EF close to 1 point to a crustal origin while those greater than 10 are considered to have a non-crustal source. EF can also assist determination of the degree of metal contamination [17]. Table 2 gives 5 contamination categories based on EF values.

Table 2. Contamination categories based on EF values [17]

Factor	Mean
EF<2	Deficiency to minimal enrichment
EF=2-5	Moderate enrichment
EF=5-20	Significant enrichment
EF=20-40	Very high enrichment
EF>40	Extremely high enrichment

2.3.2. Geoaccumulation index

In order to quantify metal accumulations and their contamination degree in the sediments, the geoaccumulation index (I_{geo}) was calculated. This index is described by the equation, where C_n is the total concentration of metal n in the silt/clay fraction, B_n is the geochemical background value of element n, and 1.5 is a correction factor due to lithogenic effects. The I_{geo} is classified [18] with seven grades (0 to 6), ranging from no pollution to very high pollution [17,19].

$$I_{geo} = \ln \frac{C_n}{1.5B_n}$$

3. Results and discussion

River water and sediment samples were collected during a 12-month time period (10 months for sediment samples) throughout the Lower Sakarya River. Sediments, based on their heavy metal content, have shown a toxic effect depend on the collection points. For example, iron concentrations in sediment appeared to be an important factor for controlling toxicity. When iron levels were increased or exceeded relative to the combined total of other metals, toxicity was reduced. Thus, the iron chemistry of sediments is known to control heavy metal bioavailability. In order to quantify metal accumulations and their contamination degree in the

sediments, the geoaccumulation index (I_{geo}) was calculated and compared with the data given in Table 3.

Table 3. Seven classes of the geoaccumulation index [18]

Class	Value	Sediment quality
0	$I_{geo} \leq 0$	Practically uncontaminated
1	$0 > I_{geo} < 1$	Uncontaminated to moderately contaminated
2	$1 > I_{geo} < 2$	Moderately contaminated
3	$2 > I_{geo} < 3$	Moderately to heavily contaminated
4	$3 > I_{geo} < 4$	Heavily contaminated
5	$4 > I_{geo} < 5$	Heavily to extremely contaminated
6	$I_{geo} > 5$	Extremely contaminated

In Table 4, Boron (530.77 ng/mL), Iron (Total) (130.56 ng/mL), Calcium (65840 ng/mL), Magnesium (29231 ng/mL), Potassium (8974 ng/mL), Silicon (6484 ng/mL), Sodium (61991 ng/mL), and Strontium (737.25 ng/mL) were recorded as the highest elemental concentrations in the Lower Sakarya River water. The highest concentrations seen in the river water belonged to the alkaline and earth alkaline elements, except for Boron which is a useful element responsible for vegetables growing to maturity.

Table 4 shows the elemental analysis results of the Lower Sakarya River sediment samples as mg/kg. When Table 4 was compared with Ontario Sediment Quality Guidelines [18] Arsenic, Mercury, Silver, Cadmium, and Cobalt showed the value below the lowest effected level. Copper indicated limits above the severe effect level, except for April and October. Zinc showed a level above the severe effect level only in January. However, the data obtained in March and October showed the data under the lowest effect level. Iron indicated data under the lowest effect level only in June and October. However, in all other months, iron showed levels under the lowest effect level. The Lead element was found below the lowest effect level in April, May and October. For other months, it showed levels above the lowest effect level. Manganese was obtained above the lowest effect level in May. Other months were shown below the lowest effect level. Finally, Nickel showed a level below the severe effect level in February and March. Other months showed the level above the severe effect level.

According to the I_{geo} levels given in Table 4 Antimony (3.05), Bismut (3.56), Tin (2.51), Rhodium (8.11), and Selenium (2.81) showed the I_{geo} levels above 2. Based on the data shown in Table 4 the river was moderately to heavily contaminated with Tin and Selenium, heavily contaminated with Antimony and Bismut, and extremely contaminated with Rhodium.

The Lower Sakarya River sediments were moderately contaminated with Copper (1.35), Lead (1.13), and Thallium (1.13). Arsenic (0.71), Zinc (0.91), Molybdenum (0.71), Tantalum (0.72), and Thorium (0.40) elements were classified as uncontaminated to moderately contaminated.

Table 4 (on dry basis) also gives the enrichment factors of the river sediments. According to the enrichment factors in the table Antimony (113.62), Bismut (189.85), Tin (66.09), Rhodium (17978.12), and Selenium (89.89) showed the EF levels above 40 [17], which indicates extremely high enrichment and a non-crustal source of contamination. High enrichment of a sediment means that the sediment is highly contaminated. Arsenic, Copper, Beryllium, Zinc, Molybdenum, Thallium, and Thorium also showed EF levels as significant enrichment. Apart from natural contributions, heavy metals may be incorporated into the aquatic system from anthropogenic sources, such as the solid and liquid wastes of industries [20].

Table 4. Comparison of metal contents in surface water and sediment from Lower Sakarya River (mean, minimum, maximum concentrations, I_{geo} and EF Levels, n = 6)

Element	Surface Water ng/mL			Element	Sediment $\mu\text{g/g}$			Crust ($\mu\text{g/g}$)	I_{geo}	EF
	Min	Max	Mean		Min	Max	Mean			
Aluminum	5.00	75.11	18.31	Aluminum	7367.50	35175.00	22805.50	82000	0	1.00
Antimony	3.51	5.00	4.88	Antimony	6.25	6.64	6.32	0.2	3.05	113.62
Arsenic	3.73	13.51	8.88	Arsenic	1.68	7.49	4.74	2.1	0.41	8.12
Barium	40.83	89.83	68.24	Barium	110.16	237.84	172.16	340	0	1.82
Beryllium	0.10	19.08	7.51	Beryllium	0.13	7.87	2.70	1.9	0	5.11
Bismuth	1.00	1.11	1.02	Bismuth	1.25	1.65	1.32	0.025	3.56	189.85
Boron	145.90	2327.00	530.77	Germanium	0.63	1.36	0.84	1.4	0	2.16
Cadmium	0.10	5.69	0.61	Tin	8.79	83.89	40.44	2.2	2.51	66.09
Calcium	30150	79300	65840	Calcium	13104.50	60327.50	34272.45	50000	0	2.46
Chromium(Total)	0.96	1.77	1.07	Chromium (total)	57.93	279.63	126.15	140	0	3.24
Cobalt	0.50	2.18	0.96	Cobalt	2.48	8.83	6.16	30	0	0.74
Copper	0.50	8.54	1.83	Copper	58.09	1558.73	394.19	68	1.35	20.84
Gallium	0.50	2.42	1.50	Gallium	0.63	9.22	5.50	19	0	1.04
Iron(Total)	54.13	224.50	130.56	Iron (total)	5716.25	26187.50	15486.13	63000	0	0.88
Lead	0.10	1.44	0.43	Lead	15.12	144.15	46.52	10	1.13	16.73
Lithium	11.99	160.91	88.89	Cesium	0.13	2.26	1.50	1.9	0	2.84
Magnesium	10403	39080	29231	Magnesium	2068.75	7961.25	5498.13	29000	0	0.68
Manganese	6.44	54.85	24.13	Manganese	195.50	475.00	344.37	1100	0	1.13
Molybdenum	1.36	37.59	6.14	Molybdenum	1.25	10.54	3.36	1.1	0.71	10.98
Nickel	2.42	6.80	4.35	Nickel	53.55	166.23	104.05	90	0	4.16
Potassium	1931	50800	8974	Potassium	1727.50	5750.00	4279.50	15000	0	1.03
Rhodium	0.10	19.20	8.53	Rhodium	0.13	10.73	3.50	0.0007	8.11	17978.12
Selenium	1.00	5.00	1.67	Selenium	1.25	1.25	1.25	0.05	2.81	89.89
Silicon	1590	14140	6484	Silicon	60725	200500	144256	270000	0	1.92
Sodium	1713	87660	61991	Sodium	128.75	4937.50	2851.38	23000	0	0.45
Strontium	301.14	1160.15	737.25	Strontium	62.06	149.44	112.38	360	0	1.12
Tantalum	0.01	12.80	3.68	Tantalum	0.01	16.58	5.23	1.7	0.72	11.06
Thallium	0.10	12.40	7.00	Thallium	0.13	7.93	2.45	0.530	1.13	16.62
Thorium	0.50	14.86	7.56	Thorium	0.63	23.15	13.47	6	0.40	8.07
Titanium	1.00	5.63	1.79	Titanium	1.55	4048.75	1110.54	6600	0	0.61
Vanadium	1.26	6.10	3.34	Vanadium	21.78	70.48	43.57	190	0	0.82
Wolfram	1.00	6.97	1.66	Wolfram	1.19	4.98	2.56	190	0	0.05
Zinc	5.00	20.16	7.41	Zinc	46.24	1064.00	295.43	79	0.91	13.45

Concentrations of Antimony in water reached the standards established by the international and national authorities (Table 5). Chromium concentration was recorded under the limit seen in Table 5. Maximum Boron concentration surpasses national and international standards. The only standard found in the literature for Thallium was established by the US-EPA Standard. The mean Thallium concentration exceeded by more than three times the US EPA standard level. The Beryllium element also exceeded almost double the concentration limit set by US-EPA.

Table 5. Comparison of lower Sakarya River water with national and international Standards (mg/L)

Elements	This Study	Drinking and Usage Water Regs Standard Levels (22)	Institute of Turkish Standards (TS 266) (2005)(23)	European Union (EC) (1998)(24)	World Health Organization (WHO) (2003)(25)	US Environmental Protection Agency (USEPA) (2003)(21)
Aluminum	0.0183	0.2	0.2	0.2	0.2	0.2
Antimony	< 0.0049	0.005	0.005	0.005	0.02	0.006
Arsenic	0.0089	0.01	0.01	0.01	0.01	0.01
Barium	0.0682				0.70	2
Beryllium	0.0072					0.0040
Bismuth	<0.0010					
Boron	0.5308	1	1	1	0.5	0.6
Cadmium	0.0006	0.005	0.005	0.005	0.003	0.005
Calcium	65.84					
Chromium (total)	0.0011	0.05	0.05	0.05	0.05	0.1
Cobalt	0.0010					
Copper	0.0018	2	2	2	2	1.3
Gallium	0.0015					
Iron (total)	0.13	0.2	0.2	0.2	0.3	0.3
Lead	0.0004	0.025	0.01	0.01	0.01	0.015
Lithium	0.089					
Magnesium	29.23					
Manganese	0.0241	0.05	0.05	0.05	0.4	0.05
Molybdenum	0.0061				0.07	
Nickel	0.0044	0.02	0.02	0.02	0.02	
Potassium	5.135					
Rodium	0.0085					
Selenium	0.0017	0.01	0.01	0.01	0.01	0.05
Silicon	6.4849					
Sodium	61.99	200	200	200	200	
Strontium	0.7373					
Tantalum	0.0037					
Thallium	0.0070					0.0020
Thorium	0.0076					
Titanium	0.0018					
Wolfram	0.0017					
Vanadium	0.0033					
Zinc	0.0074					5

The mean physical and chemical parameters, such as Sulfate, Nitrate, Total Phosphorus, Chloride concentrations of the Lower Sakarya River Water samples in 12 sampling sites, are shown in Table 6, which indicates quality classifications of river water. The mean level of Sulfate ion was 272.82 mg L⁻¹, Chloride ion was 65.51 mg L⁻¹, Nitrate nitrogen was 5.18 mg L⁻¹, and Total Phosphorus was 0.25 mg L⁻¹. The water quality of the River is reported as 2nd class water.

Table 6. Quality classifications of Lower Sakarya River water

Water Quality Parameters	This Study	Water Quality Classifications			
		I	II	III	IV
Temperature (°C)	15.64	25	25	30	> 30
pH	7.83-8.43	6.5-8.5	6.5-8.5	6.0-9.0	Outside 6.0 - 9.0
Dissolved Oxygen (mg O ₂ /L)	8.97	8	6	3	< 3
Oxygen Saturation (%)	88.53	90	70	40	< 40
Chloride Ion (mg Cl ⁻ /L)	65.51	25	200	400	> 400
Sulfate Ion (mg SO ₄ ⁼ /L)	272.82	200	200	400	> 400
Nitrate Nitrogen (mg NO ₃ ⁻ -N /L)	5.18	5	10	20	> 20
Total Phosphorus (mg P /L)	0.25	0.02	0.16	0.65	> 0.65
Total Dissolved Solid (mg /L)	644.25	500	1500	5000	> 5000
Biochemical Oxygen Demand (BOD ₅) (mg/L)	4.92	4	8	20	> 20

Based on Table 7, the mean concentration of most elements is well below the limits for either continuous or short term use of river water for irrigation purposes. The important thing is the concentration of the Boron element which approaches the limit for continuous irrigation.

Table 7. The use of Lower Sakarya River water for Irrigation Purposes (µg/L)

Water Quality Parameters	This Study (Mean Values)	Usage (maximum allowable levels)	
		Continuous	Short term
Aluminum	18.00	1000	20000
Arsenic	8.90	1000	10000
Boron	530.77	750	2000
Cadmium	0.61	5	50
Chromium (total)	1.07	5000	20000
Cobalt	0.96	200	10000
Copper	1.83	200	5000
Lead	0.43	5000	20000
Nickel	4.35	500	2000
Manganese	24.13	2000	20000
Selenium	1.67	50	50
Vanadium	3.30	10000	10000
Zinc	7.41	5000	5000

Water Pollution Control Regulations:31 Dec. 2004 (Official paper).

Table 8. Comparison of lower Sakarya River water with national surface waters

	Temp	pH	Conductivity	DO	TDS	BOD ₅	NO ₃ -N	PO ₄ -P	Chloride	SO ₄ ²⁻	Fe	Mn	Na	Mg	B
	°C		µS/cm	<-----Mean Values----- mg L ⁻¹ ----->											
This Study	15.64	8.02	816.77	8.97	644.25	4.92	5.18	0.76	65.51	272.82	0.13	0.024	61.99	29.23	0.53
Middle Sakarya River [26]	15.50	8.00	1014.00	10.60	681.00	2.90	2.28	1.82	61.60	208.40	0.32	0.090	71.00	40.40	0.40
Upper Sakarya River [10]	15.80	6.80	1123.70	9.10	-	-	-	-	-	-	-	8,36	-	-	-
Aksu River [27]	15.09	8.24	353.30	8.60	-	4.17	2.79	3.16	16.86	61.25	-	-	-	-	-
Büyük Menderes River [1]	19.00	8.20	1645.00	11.65	-	6.20	-	-	-	-	-	0.094	-	-	-
Gediz River [1]	19.50	8.10	1590.00	11.75	-	6.10	-	-	-	-	-	0.052	-	-	-
Yeşilırmak River [20]	-	7.89	515.00	-	-	-	-	-	23.75	-	-	-	23.22	-	0.96

Comparison of Lower Sakarya River Water with National Surface Waters is shown in Table 8. Based on pH data given in Table 8 the Upper Sakarya River is the most acidic river. The lowest conductivity was observed in the Aksu river; this indicates the un-polluted river amongst other rivers in Table 8. The conductivity levels of the Sakarya river are seen to decrease from the Upper Sakarya river to the Lower Sakarya river. These results indicate that the pollution of the Sakarya river is decreasing. Total Dissolved Solid levels are seen to decrease because of the Sariyer Dam. However, Nitrate nitrogen levels were seen to increase by comparison to the Middle Sakarya river. It is beneficial to lower the phosphate levels in the river. The Sulphate level is the highest in comparison to other rivers. The Boron level is increased from the Middle Sakarya to the Lower Sakarya and exceeded the standard value established by WHO in Table 5 [25].

Table 9 indicated that Lower Sakarya River Water can be used for irrigation purposes and is classified mainly as C₂S₁ quality, 1st and 2nd Class water. Briefly, river water can be used for plants sensitive to Boron levels between 0.4-0.6 mg/L, such as Peach, Apple, Pear, and Onion (Table 9). Long term irrigation of farm lands could make soils rich in Boron and result in poor or unsuitable soils.

Table 9. Agricultural Irrigation Quality Parameters of Lower Sakarya River Water.

	This Study	Water Quality Classifications				
		I. Class (Excellent)	II. Class (Good)	III. Class (Fair)	IV. Class (Poor)	V. Class (Unsuitable)
EC _{25x10⁶}	816.77	0-250	250-750	750-2000	2000-3000	>3000
Sodium Adsorption Rate (SAR)	0.61	<10	10-18	18-26	>26	
Chloride (mg/L)	65.51	0-142	142-249	249-426	426-710	>710
Total Salinity	490	0-175	175-525	525-1400	1400-2100	>2100
Boron (mg/L)	0.54	0-0.5	0.5-1.12	1.12-2.0	>2.0	
Irrigation Classification	C ₂ S ₁	C ₁ S ₁	C ₁ S ₂ , C ₂ S ₂ , C₂S₁	C ₁ S ₃ , C ₂ S ₃ , C ₃ S ₃ , C ₃ S ₂ , C ₃ S ₁	C ₁ S ₄ , C ₂ S ₄ , C ₃ S ₄ , C ₄ S ₄ , C ₄ S ₃ , C ₄ S ₂ , C ₄ S ₁	
NO ₃ ⁻ (mg /L)	5.18	0-5	5-10	10-30	30-50	>50
BOD ₅ (mg /L)	4.92	0-25	25-50	50-100	100-200	>200
pH	8.02	6.5-8.5	6.5-8.5	6.5-8.5	6.0-9.0	<6 or >9
Water Temp.(°C)	15.64	< 30	30	35	40	>40

4. Conclusions

In conclusion, the Sakarya River water was affected by the construction of a highway, the connection of small creeks which carry pollution to the river, and by industrial and municipality pollution. The effects of these pollution sources can be minimised by recycling, stopping construction, decreasing sewage discharge. Lower Sakarya River water can be used for continuous irrigation purposes, but not for a long term use. Ontario Sediment Quality Guidelines was used for River sediments. Physical and inorganic-chemical parameters indicate that river water is represented as 2nd class water. Water pollution parameters, such as Thallium and Beryllium, exceeded the US EPA standards.

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