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Original Research

Assessment of the Effects of Large Borate Deposits on Surface Water Quality by Multi Statistical Approaches: A Case Study of Seydisuyu Stream (Turkey)

Cem Tokatli[1]*, Esengül Köse[2], Arzu Çiçek[3]

[1]Department of Laboratory Technology, Ipsala Vocational School, Trakya University, İpsala/Edirne, Turkey
[2]Department of Environmental Protection and Control, Eskişehir Vocational School,
Eskişehir Osmangazi University, Eskişehir, Turkey
[3]Applied Environmental Research Centre, Anadolu University, Eskişehir, Turkey

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Abstract

In the present study, water quality of Seydisuyu Stream Basin were investigated by determining temperature, conductivity, salinity, TDS (total dissolved solid), pH, ORP (oxidation-reduction potential), dissolved oxygen, nitrate (NO_3), nitrite (NO_2), orthophosphate (PO_4), sulphate (SO_4), COD (chemical oxygen demand), BOD (biological oxygen demand), calcium, magnesium, sodium, potassium, arsenic, and boron parameters seasonally in 2012 at 15 stations. All the data obtained were compared with SKKY (Water Pollution Control Regulation in Turkey) and evaluated as drinking water according to the criteria of TS266 (Turkish Standards Institute), EC (European Communities), and WHO (World Health Organization). Some mono (one-way ANOVA test, Pearson Correlation Index) and multi (factor and cluster analysis) statistical techniques were used to evaluate the data properly. Also, the ArcGIS package program was used to make distribution maps of arsenic and boron in order to provide visual summaries of these elements' accumulation in the basin. According to the results of FA, four factors named as "Nutrient," "Agricultural," "Boron," and "pH" explained 77.4% of the total variance, and according to the results of CA, three statistically significant clusters, named "Low," "Moderate," and "High" polluted areas were formed. In a macroscopic point of view, Seydisuyu Stream Basin has class IV water quality in terms of boron; downstream of the basin has class II, upstream has class III water quality in terms of arsenic. It was also determined that arsenic and boron concentrations in Seydisuyu Stream Basin water were much higher than the drinking water limits.

Keywords: arsenic, boron, water quality, Seydisuyu Stream, multivariate statistics, ArcGIS

Introduction

Fresh water quality is decreasing day by day all over the world due to rapid population growth, extreme developments of industry and technology, and lack of environmental awareness in society [1]. Lotic ecosystems that are carrying off municipal and industrial wastewater and runoff from agricultural land in their vast drainage basins are among the most vulnerable water bodies to pollution [2, 3].

Multivariate statistical techniques that are widely used in water quality assessment studies help the interpretation

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*e-mail: tokatlicem@gmail.com

of complex data matrices to better understand the ecological status of the studied ecosystems [4].

The total boron reserve of the world is 885 billion tons, and Turkey, USA, and Russia have the most important boron mines of the world, with Turkey being one of the major boron exporters of the world. Boron mining started in 1861 in Turkey by foreign companies. Then, the mining exploitation rights were transferred to the state sector, namely Etibank. In terms of total reserve basis, Turkey has a share of 72.20% and the most important borate deposits of Turkey are located in the Kırka District of Eskişehir Province [5-7].

Seydisuyu Stream Basin is located in Eskişehir Province, and one of the most important borate deposits of Turkey is located in the basin. Seydisuyu Stream is also one of the most important branches of the Sakarya River and carries all the organic and inorganic pollution to the Black Sea through the Sakarya. In addition to the geological structure of the basin, mining activities, agricultural, and domestic discharges are the major pollution sources for the system.

The aim of this study was to determine the water quality of Seydisuyu Stream Basin by using some mono and multi statistical techniques. When the location of the study area and the anthropogenic pressure on the basin were considered, it can be clearly understood that the investigation of water quality and determining especially arsenic and boron concentrations in water of the Basin have a vital importance for ecosystem and human health.

Materials and Methods

Study Area and Collection of Samples

Seydisuyu Stream Basin is located in the Central Anatolia Region of Turkey between 38.0851-39.0361 north latitude and 30.0161-31.0071 east longitudes. There are many agricultural areas in the basin and one of the most important borate deposits of Turkey is located on the border of basin [8]. Seydisuyu Stream, which has 2 dam lakes on the watershed, is under the significant organic and inorganic pressure.

Table 1. Station properties.

Stations	Location	Coordinates	
		x	y
St. 1	Karaören Village	291678	4344723
St. 2	Kırka District	286648	4350639
St. 3.1	Çatören Dam Lake	289800	4351019
St. 3.2	Çatören Dam Lake	288880	4351531
St. 3.3	Çatören Dam Lake	290654	4355433
St. 4	Akin Village	285940	4356774
St. 5.1	Kunduzlar Dam Lake	287229	4357142
St. 5.2	Kunduzlar Dam Lake	288269	4358041
St. 6	Kesenler Village	296117	4365244
St. 7	Seyitgazi District	300751	4369651
St. 8	Yazıdere Village	320690	4382501
St. 9	Doğançayır	320686	4382502
St. 10	Hamidiye Village	324123	4378834
St. 11	Mesudiye District	329283	4369106
St. 12	Saithalimpaşa Village	338431	4364451

Surface water samples were collected seasonally in 2012 from 15 stations (3 on Çatören Dam Lake and 2 on Kunduzlar Dam Lake). Coordinates of the selected stations are given in Table 1. A map of Seydisuyu Stream Basin and study area are given in Fig. 1.

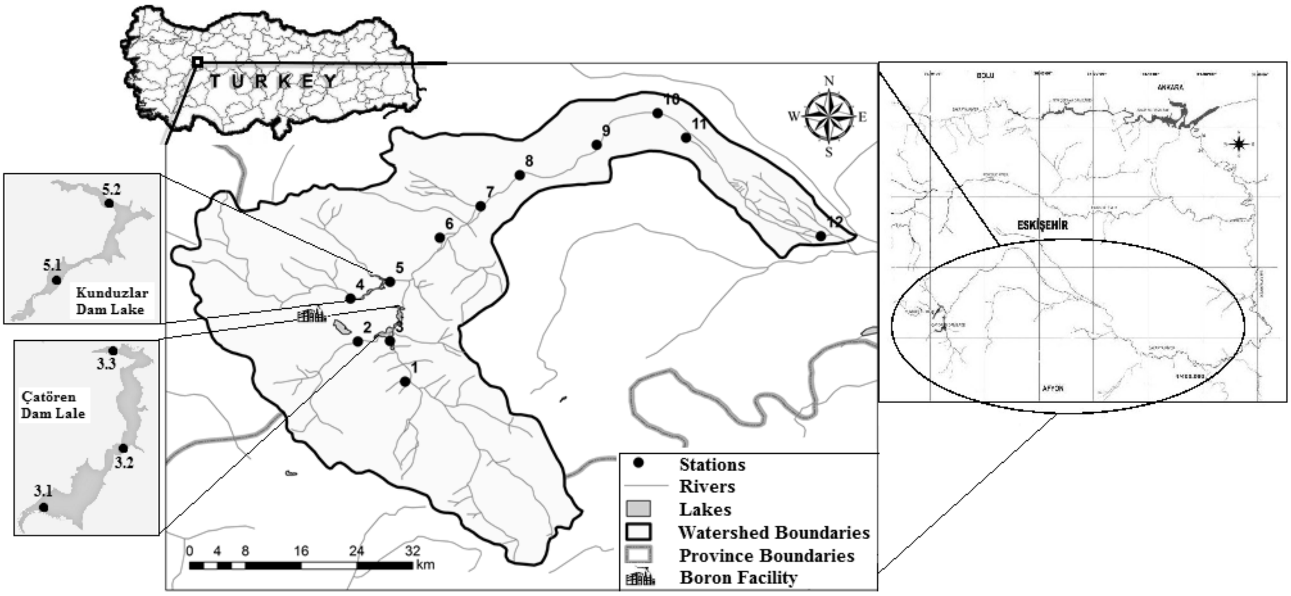

Fig. 1. Seydisuyu Stream Basin and select stations.

Analysis of Water Quality Parameters

Temperature, conductivity, salinity, TDS (total dissolved solid), pH, ORP (oxidation-reduction potential), and dissolved oxygen parameters were determined by using a “Hach Lange Hydrolab DS5 Multiparameter Sonde” device during the field studies. Nitrate (NO_3), nitrite (NO_2), orthophosphate (PO_4), sulphate (SO_4), COD (chemical oxygen demand) parameters were determined using Hach Lange DR 890 Colorimeter and Hach Lange DR 2800 Spectrophotometer devices; BOD (biological oxygen demand) parameter was determined using an Enotek Ref. 100 BOD device during the laboratory studies.

For determination of arsenic (As), boron (B), calcium (Ca), magnesium (Mg), potassium (K), and sodium (Na) concentrations in water of Seydisuyu Stream, water samples of one liter were adjusted to pH 2 by adding 2 ml of HNO_3 into each for determination of arsenic and boron. Afterward, 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. Element contents in water samples were determined by an “ICP-OES (Varian 720 ES)” device. All the element analyses in water samples were recorded as means triplicate measurements [9, 10]. In the ICP-OES analysis, the following wavelength lines were used; arsenic 193.759, boron 249.678, calcium 315.887, magnesium 279.079, potassium 766.491, and sodium 588.995.

Statistical Analysis and Distribution Maps

Cluster analysis (CA) (according to Bray Curtis) was applied to the results using the “Past” package program. Pearson Correlation Index (PCI), factor analysis (FA) and one-way ANOVA test (according to Tukey) was applied to the results by using the “SPSS 17” package program. The distribution maps of arsenic and boron in the basin were made using an “ArcGIS” package program.

Results and Discussion

Annual averages of results with mean and standard deviation values and the results of one-way ANOVA test that compares the water quality parameters detected in different stations are given in Table 2. The distribution maps of arsenic and boron in the basin are given in Fig. 2.

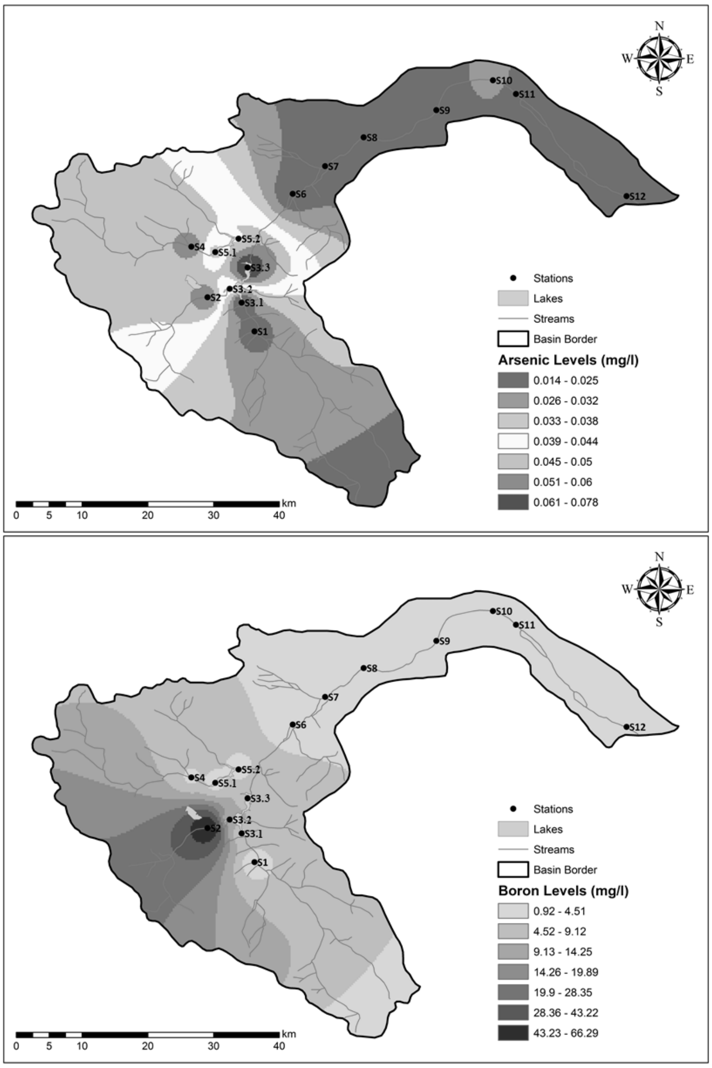

Fig. 2. Arsenic and boron distributions in the basin.

Table 2. Seasonal averages of detected parameters and results of one-way ANOVA test.

Parameters		Stations*														
		1	2	3.1	3.2	3.3	4	5.1	5.2	6	7	8	9	10	11	12
temp ºC	mean	16.04a	15.96a	17.76a	18.12a	15.01a	14.97a	15.46a	16.57a	14.34a	14.16a	13.36a	14.18a	13.59a	13.73a	15.07a
	SD	6.77	6.40	8.72	9.34	8.70	5.58	7.53	8.07	6.05	5.22	5.11	5.15	4.74	5.04	6.13
cond µS/cm	mean	414.9a	546.3a	345.3a	365.3a	416.1a	644.1a	351.0a	362.4a	437.1a	451.8a	621.4a	724.6a	772.8a	800.1a	904.8a
	SD	70.0	320.2	80.2	124.7	130.9	333.6	162.7	225.5	180.7	210.2	215.8	279.8	265.0	426.4	345.4
sal ‰	mean	0.21a	0.51a	0.17a	0.18a	0.21a	0.32a	0.18a	0.18a	0.23a	0.25a	0.32a	0.37a	0.40a	0.42a	0.47a
	SD	0.04	0.29	0.04	0.07	0.07	0.19	0.09	0.12	0.10	0.12	0.12	0.15	0.14	0.23	0.19
TDS mg·L^{-1}	mean	0.26a	0.37a	0.23a	0.24a	0.26a	0.39a	0.25a	0.24a	0.29a	0.28a	0.40a	0.46a	0.52a	0.51a	0.58a
	SD	0.05	0.21	0.05	0.07	0.09	0.21	0.10	0.16	0.10	0.15	0.14	0.20	0.16	0.26	0.23
pH	mean	7.67ab	8.05ab	8.40a	8.55a	8.43a	7.80ab	8.08ab	8.20ab	7.95ab	7.91ab	7.74ab	7.55b	7.34b	7.42b	7.68ab
	SD	0.37	0.24	0.41	0.21	0.21	0.28	0.20	0.21	0.39	0.10	0.16	0.22	0.56	0.36	0.39
ORP	mean	343.2a	341.8a	334.4a	339.0a	376.4a	297.8a	320.2a	331.6a	316.4a	318.0a	309.9a	310.1a	334.0a	332.5a	324.6a
	SD	63.4	35.0	49.3	46.6	46.2	83.0	48.7	65.3	85.6	86.9	93.0	92.5	93.8	94.3	88.6
DO mg·L^{-1}	mean	7.94ab	7.30ab	10.45ab	11.07a	11.18a	8.68ab	8.13ab	7.74ab	7.86ab	7.48ab	7.30ab	7.27ab	7.24ab	6.19b	6.12b
	SD	1.08	1.61	3.24	2.57	2.63	1.15	1.38	0.98	1.58	0.96	0.81	0.81	1.75	1.15	3.16
BOD mg·L^{-1}	mean	0.88a	5.31a	4.77a	4.38a	1.88a	1.80a	2.38a	3.66a	2.18a	2.90a	1.96a	2.55a	1.09a	1.96a	3.06a
	SD	1.03	4.53	4.76	1.55	1.29	2.00	1.43	2.38	1.00	1.17	0.57	1.26	1.11	2.68	1.07
COD mg·L^{-1}	mean	14.63a	56.68b	26.33a	24.28a	20.58a	13.35a	15.12a	18.52a	19.43a	20.39a	12.44a	14.32a	11.85a	12.94a	20.96a
	SD	2.08	29.66	16.84	6.52	6.56	8.37	7.79	12.36	11.46	6.63	5.57	2.51	5.27	3.46	10.52
NO_3 mg·L^{-1}	mean	9.72a	28.68b	22.31ab	22.61ab	13.06a	11.52a	10.29a	3.01a	3.54a	23.37ab	5.74a	5.26a	4.67a	3.20a	2.68a
	SD	15.30	54.09	43.43	43.71	24.29	19.51	18.73	4.29	3.48	36.47	5.23	4.60	4.50	2.62	3.14
NO_2 mg·L^{-1}	mean	0.007a	0.034b	0.010a	0.009a	0.018a	0.016a	0.003a	0.013a	0.035b	0.016a	0.019a	0.029ab	0.009a	0.011a	0.021a
	SD	0.005	0.033	0.013	0.010	0.009	0.020	0.004	0.011	0.041	0.019	0.015	0.035	0.005	0.013	0.017
PO_4 mg·L^{-1}	mean	0.308a	1.343b	0.653a	0.330a	0.772ab	0.326a	0.225a	0.632a	0.793ab	0.622a	0.390a	0.333a	0.502a	0.593a	0.739ab
	SD	0.215	1.137	0.527	0.249	1.320	0.260	0.206	1.035	1.048	0.644	0.341	0.277	0.447	0.692	0.803

Table 2. Continued.

Parameters		Stations*														
		1	2	3.1	3.2	3.3	4	5.1	5.2	6	7	8	9	10	11	12
SO_4 mg·L^{-1}	mean	33.21ac	115.41b	16.08ac	15.51ac	16.09ac	10.62a	13.86a	10.53a	16.35ac	16.03ac	40.71ac	50.66ac	79.13bc	110.54b	138.59b
	SD	31.31	72.27	2.57	2.40	3.91	2.82	2.18	3.04	8.89	12.86	22.48	36.55	27.81	84.88	85.99
As mg·L^{-1}	mean	0.020a	0.056a	0.040a	0.078a	0.014a	0.053a	0.044a	0.036a	0.021a	0.020a	0.024a	0.021a	0.027a	0.023a	0.019a
	SD	0.015	0.040	0.037	0.131	0.009	0.033	0.033	0.022	0.015	0.011	0.014	0.014	0.016	0.013	0.013
B mg·L^{-1}	mean	0.910a	66.407b	10.386c	5.911ac	3.706a	3.610a	2.809a	2.104a	2.775a	1.967a	2.047a	1.480a	1.979a	2.098a	1.791a
	SD	0.322	12.345	7.410	1.589	2.658	2.000	2.104	1.269	2.758	2.226	2.055	0.884	1.690	1.850	0.737
Ca mg·L^{-1}	mean	56.26a	52.25a	23.48a	26.25a	20.83a	34.35a	32.03a	19.01a	22.96a	42.51a	38.67a	30.13a	76.43a	124.64a	152.87a
	SD	41.67	39.76	13.42	18.06	14.98	27.35	27.07	11.11	20.27	33.13	32.43	19.61	81.25	173.40	223.45
Mg mg·L^{-1}	mean	31.96a	52.60a	26.17a	21.47a	20.75a	18.80a	18.90a	15.54a	22.41a	27.73a	33.11a	41.53a	44.71a	52.76a	58.15a
	SD	26.04	48.87	17.75	9.31	11.07	9.59	8.17	5.71	20.04	10.37	20.92	36.30	35.40	46.48	47.67
K mg·L^{-1}	mean	24.82a	17.75a	11.65a	17.20a	25.27a	6.32a	24.02a	23.57a	8.54a	14.99a	21.93a	27.81a	60.73a	35.77a	38.08a
	SD	28.42	11.62	6.70	11.46	28.93	3.23	31.05	33.05	7.83	11.98	30.36	31.37	62.57	31.01	30.63
Na mg·L^{-1}	mean	12.03a	44.05a	9.49a	9.24a	8.62a	5.98a	7.08a	6.71a	9.88a	8.20a	14.82a	16.03a	18.82a	27.83a	30.25a
	SD	17.12	67.57	12.50	11.14	10.56	6.67	8.14	7.95	12.61	9.20	20.17	26.02	27.38	43.29	48.66

*The values marked with different letters in the same line are statistically different ($p<0.05$).

Conductivity, salinity, and TDS values of water detected downstream were found to be significantly higher than upstream. The highest conductivity, salinity, and TSD levels were recorded as 1,373 µS/cm, 0.726‰, and 0.9 mg·L^{-1}, respectively, in the S12 station in winter.

In general, upstream of the basin has alkaline water characteristics, and pH values detected in the upstream were significantly higher than those detected in the downstream. According to the ANOVA results, statistically significant differences were identified between S3.1, S3.2, and S3.3 stations with S9, S10, and S11 stations in terms of pH levels ($p<0.05$). According to the criteria of SKKY identified for Turkey (Water Pollution Control Regulation in Turkey), all stations selected on the Seydisuyu Stream Basin have class I-II water quality in terms of pH values (6.5-8.5) [11].

The highest dissolved oxygen level was recorded at the S3.1 station in autumn (15.22 mg·L^{-1}), and the lowest dissolved oxygen level was recorded in the S12 station in summer (3.65 mg·L^{-1}). According to the ANOVA results, statistically significant differences were identified between S3.2 and S3.3 stations with S11 and S12 stations in terms of dissolved oxygen levels ($p<0.05$). According to the criteria of SKKY, Çatören Dam Lake (S3.1, S3.2, and S3.3 stations), Akin Village (S4 station), and the input of Kunduzlar Dam Lake (S5.1 station) have class I (>8 mg·L^{-1}); all the other stations have class II (>6 mg·L^{-1}) water quality in terms of the dissolved oxygen parameter [11].

In general, BOD and COD concentrations detected in the S2 station and Çatören Dam Lake (S3.1, S3.2, and S3.3 stations) were significantly higher than the other stations. The highest BOD and COD levels were recorded as 11.93 mg·L^{-1} and 78.9 mg·L^{-1}, respectively, at the S2 station in autumn. According to the criteria of SKKY, S2 and S3.1 stations have class II (4-8 mg·L^{-1} for BOD and 25-50 mg·L^{-1} for COD) water quality in terms of BOD and COD levels; S3.2 station has class II water quality in terms of COD levels; all other stations have class I (<4 mg·L^{-1} for BOD and <25 mg·L^{-1} for COD) water quality in terms of BOD and COD levels [11].

According to the ANOVA results, statistically significant differences were identified between station S2 and all stations except S3.1, S3.2, and S7 stations in terms of nitrate levels; between S2 and S6 with all stations except S9 in terms of nitrite levels; between S2 with all stations except S3.3, S6, and S12 stations in terms of phosphate levels; and between S2, S11, and S12 with all stations except S10 in terms of sulfate levels ($p<0.05$). According to the criteria of SKKY, S5.2, S6, S10, S11, and S12 stations have class I (<5 mg·L^{-1}); S1, S8, and S9 stations have class II (5-10 mg·L^{-1}); S3.3, S4, and S5.1 have class III (10-20 mg·L^{-1}); and S2, S3.1, S3.2, and S7 have class IV (>20 mg·L^{-1}) water quality in terms of nitrate contents. S1, S3.1, S3.2, S5.1, and S10 have class II (0.002-0.01 mg·L^{-1}); all the other stations have class III (0.01-0.05 mg·L^{-1}) water quality in terms of nitrite contents [11].

The highest boron concentrations in all seasons were determined in S2 (with an annual average of 66.4 mg·L^{-1}). According to the ANOVA results, boron accumulations recorded at S2 station were statistically significantly higher than those recorded in all other stations. Apart from a few commercially exploitable deposits, boron is present at low concentrations in rocks (15-300 mg·kg^{-1}), soils (10-20 mg·kg^{-1}), surface water (0.1-0.5 mg·L^{-1}), and sea water (5 mg·L^{-1}) [12, 13]. The detected extreme boron concentrations at S2 have class IV water quality (>1 mg·L^{-1}) according to the criteria of SKKY, even in the stations not exposed to any point discharge (Fig. 2) [11].

In a macroscopic point of view, arsenic accumulations detected in the upside of the basin, including dam lakes, were significantly higher than those detected in the downstream of the basin. According to the criteria of SKKY, S3.3 and S12 stations have class I (<0.02 mg·L^{-1}); downstream of the basin (except S12) has class II (0.02-0.05 mg·L^{-1}); 1. station, input of Çatören Dam Lake (S3.1 station) and Kunduzlar Dam Lake have class II (0.02-0.05 mg·L^{-1}); all the other stations have class III (0.05-0.1 mg·L^{-1}) water quality in terms of arsenic concentrations (Fig. 2) [11].

According to drinking water standards specified by the World Health Organization (WHO), European Communities (EC), and Turkish Standards Institute (TS266), arsenic and boron accumulations in water of Seydisuyu Stream Basin were much higher than the drinking water limits (>0.01 mg/L for As; >0.5 mg/L (WHO) and >1 mg/L (TS266, EC) for B) [14-16].

Pearson Correlation Index (PCI)

The relationships between the physico-chemical water quality parameters detected in the Seydisuyu Stream Basin were calculated by the Pearson Correlation Index (PCI) ($n = 60$ for all parameters). Significant positive and negative relationships were recorded between the detected parameters at the 0.01 and 0.05 levels. All relationships with PCI coefficients are given in Table 3.

Arsenic and boron are both soluble minerals found in hydrothermal-volcanic deposits and they are often correlated in the environment. According to literature knowledge, boron contents of geological structure significantly affect arsenic levels [17]. In a study performed in groundwater of the same study area (Seydisuyu Basin), significant relations were reported between As and B concentrations at the 0.05 significance level [8]. In another study performed in groundwater of Türkmen Mountain (in the border of Seydisuyu Basin), significant relations were reported between As and B concentrations at the 0.01 significance level [18]. In contrast to these literature information and studies, no significant relation was recorded between As and B contents in water of Seydisuyu Stream in the present study. All these results reflect the fact that point discharge of boron in the surface water of the basin has more effect on water quality than the geological structure of the basin.

Factor Analysis (FA)

Factor analysis (FA) is a powerful multivariate statistical technique and widely used to evaluate the surface water quality in especially recent years [18-23].

Table 3. Results of Pearson Correlation Index and PCI coefficients.

	temp	cond	sal	TDS	pH	ORP	DO	BOD	COD	NO_2	NO_2	PO_4	SO_4	As	B	Ca	Mg	K	Na
temp	1																		
cond	-0.354**	1																	
sal	-0.199	0.779**	1																
TDS	-0.349**	0.989**	0.761**	1															
pH	0.191	-0.261*	-0.221	-0.258*	1														
ORP	0.367**	-0.253	-0.229	-0.253	0.029	1													
DO	-0.038	-0.200	-0.281*	-0.208	0.596**	0.119	1												
BOD	0.409**	-0.054	0.024	-0.058	0.258*	0.410**	0.207	1											
COD	0.350**	-0.213	-0.068	-0.173	0.203	0.370**	0.090	0.619**	1										
NO_3	0.414**	-0.064	-0.067	-0.082	0.220	0.378**	0.346**	0.701**	0.510**	1									
NO_2	-0.110	0.341**	0.260*	0.356**	-0.057	0.004	0.019	0.159	0.258*	0.138	1								
PO_4	-0.356**	0.343**	0.295*	0.373**	0.053	-0.265*	0.099	0.133	0.267*	0.022	0.388**	1							
SO_4	-0.221	0.638**	0.637**	0.669**	-0.225	-0.058	-0.168	-0.031	0.217	-0.080	0.357**	0.377**	1						
As	0.380**	0.000	0.144	0.001	0.232	0.160	0.315*	0.440**	0.235	0.568**	0.180	0.049	-0.014	1					
B	0.091	-0.023	0.346**	-0.004	0.129	0.135	-0.039	0.432**	0.714**	0.292*	0.262*	0.287*	0.298*	0.253	1				
Ca	0.280*	0.121	0.138	0.086	-0.259*	0.519**	-0.296*	0.175	0.103	0.085	-0.140	-0.277*	0.101	0.016	0.021	1			
Mg	-0.397**	0.600**	0.595**	0.634**	-0.129	-0.381**	-0.027	-0.216	-0.010	-0.233	0.395**	0.479**	0.835**	-0.021	0.151	-0.192	1		
K	-0.256*	0.581**	0.465**	0.595**	-0.129	-0.148	-0.015	-0.087	-0.144	-0.064	0.190	0.347**	0.497**	0.114	-0.072	-0.066	0.540**	1	
Na	-0.394**	0.509**	0.453**	0.550**	-0.020	-0.068	0.134	-0.024	0.242	-0.060	0.463**	0.529**	0.805**	0.061	0.277*	-0.128	0.863**	0.440**	1

temp – temperature, cond – conductivity, sal – salinity, DO – dissolved oxygen

*correlation is significant at the 0.05 level ($p<0.05$)

**correlation is significant at the 0.01 level ($p<0.01$)

In the present study, FA was used to obtain the effective varifactors on Seydisuyu Stream using correlated variables. Uncorrelated variables were removed to increase the reliability of FA and a total of 15 variables were used to determine the varifactors (n = 60 for all parameters). The result of the KMO (Kaiser-Meyer-Olkin) measurement of sampling adequacy test was 0.726 and this value means that the sampling adequacy was at a good level for the present study (>0.7) [19]. Eigenvalues higher than one were taken as criterion for evaluating the principal components required to explain the sources of variance in the data. According to rotated cumulative percentage variance, four factors explained 77.4% of total variance (Fig. 3).

The factor loadings are classified according to loading values as strong (>0.75), moderate (0.75-0.50), and weak (0.50-0.30) [19]. Parameter loadings higher than 0.3 for four components after rotation are given in Fig. 4.

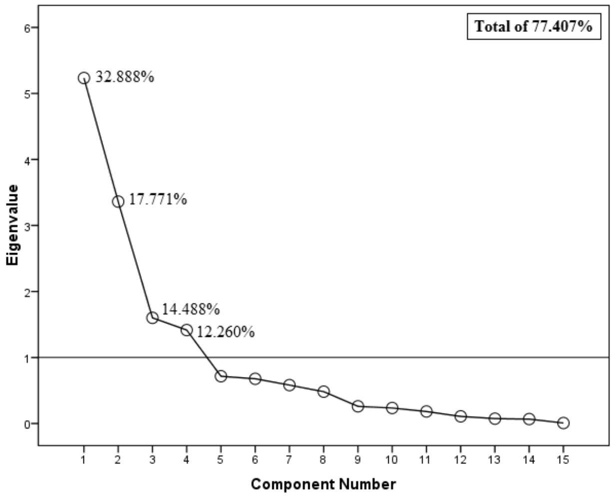

Fig. 3. Scree plot of FA.

The first factor (F1), named "Nutrient Factor," explained 32.8% of total variance and it was related to the variables of TDS, conductivity, magnesium, salinity, sulfate, sodium, potassium, and temperature. TDS, conductivity, magnesium, salinity, and sulfate parameters were strong; sodium and potassium parameters were moderate positively loaded with this factor. The temperature parameter was weakly negatively loaded with this factor (Fig. 4). As known, nutrient salts in the water affect the parameters of conductivity, salinity, and TDS [24]. In a study performed in northern Greece to evaluate water quality, conductivity was positively loaded with the nutrient factor (0.82) [25]. In another study performed in the Seydisuyu Basin to evaluate groundwater quality, conductivity and salinity were strong positively loaded with the nutrient factor (0.99, 0.98, respectively) [8].

The second factor (F2), named "Agricultural Factor," explained 17.7% of total variance and it was related to the variables of magnesium, nitrate, BOD, arsenic, temperature and COD. Nitrate and BOD parameters were strong; arsenic and temperature parameters were moderate; COD was weakly positively loaded with this factor. The magnesium parameter was weakly negatively loaded with this factor (Fig. 4). Arsenic and boron elements are often correlated as they are both soluble minerals found in hydrothermal-volcanic deposits and boron content of geological structure is significantly effective on arsenic concentrations [17, 18]. In contrast to this literature knowledge, no significant relation was recorded between As and B accumulations in water of Seydisuyu Stream in the present study. The results point to arsenic and boron elements being released to the environment from different anthropogenic sources in the basin. Pesticide applications in the agricultural activities have an important place for the release of arsenic to the environment [26]. As a result of intensive agricultural activities carried out on the basin, pesticides could be the most

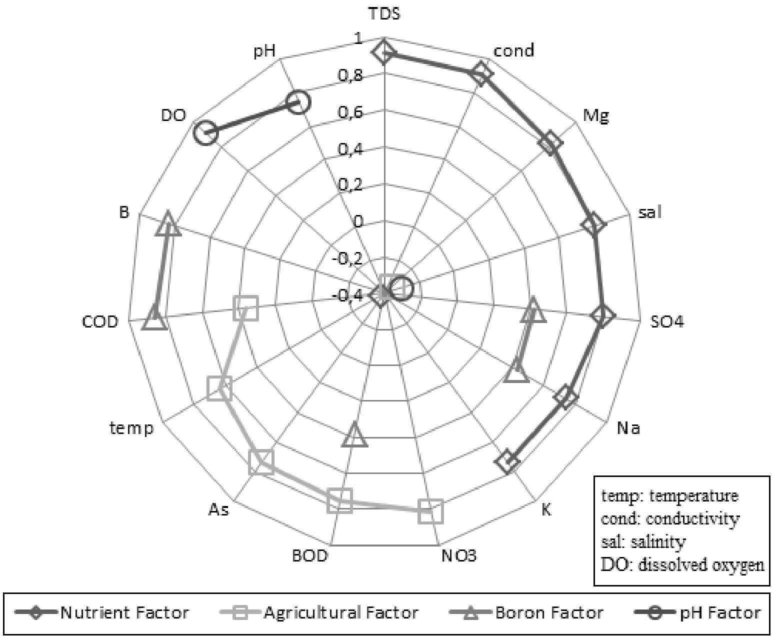

Fig. 4. Rotated component matrix.

Table 4. Similarity – Distance coefficients of stations.

Stations*	1	2	3.1	3.2	3.3	4	5.1	5.2	6	7	8	9	10	11	12
1	1.00														
2	0.75	1.00													
3.1	0.85	0.74	1.00												
3.2	0.84	0.74	**0.96**	1.00											
3.3	0.86	0.72	0.90	0.93	1.00										
4	0.80	0.69	0.78	0.80	0.82	1.00									
5.1	0.83	0.70	0.90	0.93	0.91	0.81	1.00								
5.2	0.80	0.66	0.88	0.90	0.89	0.80	0.93	1.00							
6	0.84	0.68	0.87	0.88	0.88	0.84	0.89	0.90	1.00						
7	0.83	0.68	0.85	0.87	0.87	0.84	0.88	0.88	0.91	1.00					
8	0.84	0.70	0.78	0.79	0.81	0.82	0.80	0.80	0.86	0.86	1.00				
9	0.81	0.72	0.74	0.75	0.78	0.83	0.75	0.76	0.81	0.81	0.93	1.00			
10	0.77	0.73	0.68	0.70	0.73	0.78	0.70	0.70	0.75	0.77	0.88	0.92	1.00		
11	0.72	0.71	0.65	0.66	0.68	0.75	0.67	0.68	0.72	0.72	0.83	0.87	0.90	1.00	
12	0.70	0.73	**0.62**	0.63	0.66	0.75	0.63	0.64	0.68	0.70	0.79	0.84	0.88	0.94	1.00

*The most and least similar coefficients are highlighted in bold.

effective factor on As contents in water. Recorded significant positive relations between As with BOD and NO_3 levels at the 0.01 significance level in the basin and the results of FA (agricultural factor) clearly prove this prediction.

The third factor (F3), named "Boron Factor," explained 14.4% of total variance and it was related to the variables of sulfate, sodium, BOD, COD, and boron. COD and boron parameters were strong; sulfate, sodium, and BOD parameters were moderate positively loaded with this factor (Fig. 4). Increases of boron compounds in the aquatic ecosystem may cause increases of required oxygen for the chemical and biological cleavage [27]. According to the results, boron accumulation in water is primarily effective on BOD and COD values in the Seydisuyu Stream Basin. Boron is found in the environment primarily combined with oxygen in compounds called borates, including boric acid, borax, and boron oxide [28]. The boron ore is found as sodium tetraborate compounds (borax) in the basin and one of the major products produced by the facility from boron is boric acid. The manufacturing process of the boric acid basically consists of the insertion reaction of colemanite with sulfuric acid [7, 29]. Detected significant positive relations between boron with sodium and sulfate ($p<0.05$) and the results of FA (Boron Factor) confirm this information and prove the reliability of the data observed in the present study. We also detected a significant positive relationship between sodium with sulfate values at the 0.01 significance level reflecting the same discharge source point for these parameters.

The fourth factor (F4), named "pH Factor," explained 12.2% of total variance and it was related to the variables of salinity, dissolved oxygen, and pH. Dissolved oxygen parameter was strong; pH parameter was moderately positively loaded with this factor. Salinity parameter was weakly negatively loaded with this factor (Fig. 4). According to literature knowledge, acidic water has a higher oxidation reduction potential (ORP) than alkaline water, which is known as an antioxidant in general with negative ORP [27]. Therefore, high oxygen content in alkaline water with low oxidation potential is an expected situation. One of the important factors effective on dissolved oxygen in water is the salinity parameter. Solubility of oxygen in fresh water decreases with increasing salt concentration [30]. Detecting a significant negative relationship between dissolved oxygen with salinity ($p<0.05$) and the results of FA (pH Factor) confirm this information.

Cluster Analysis (CA)

One of the most widely used multivariate statistical techniques to evaluate surface water quality is cluster analysis (CA), which provides the facility to classify objects according to similar characteristics [2, 8, 18, 31-33].

In the present study, CA was used to obtain the similarity groups between the stations according to water quality status. A diagram of CA calculated using all the detected parameters in Seydisuyu Stream water is given in Fig. 5 and the similarity coefficients of stations are given in Table 4. According to the results of CA, three statistically significant clusters were formed: cluster 1 corresponded to stations S3.1, S3.2, S3.3, S5.1, S5.2, S6, S7, S1, and S4 that were uncontaminated areas of the basin; cluster 2 corresponded to stations S8, S9, S10, S11, and S12 that were moderately con-

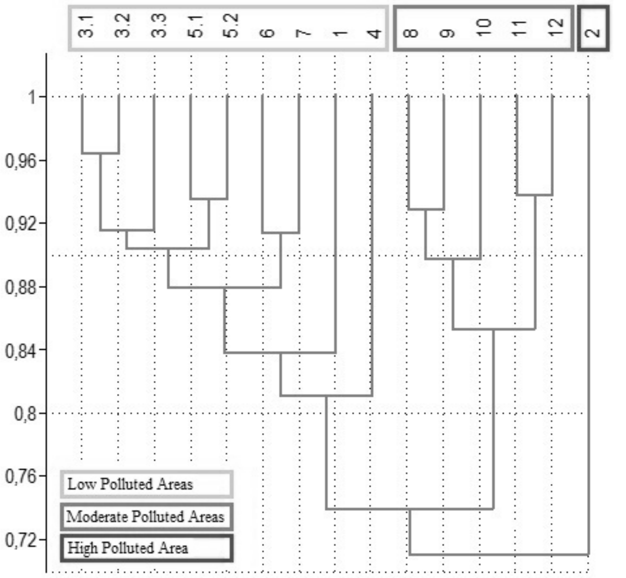

Fig. 5. Tree diagram of CA.

taminated areas of the basin; cluster 3 corresponded to station S2, which was the most contaminated area of the basin.

The highest inorganic and organic pollution was observed in S2, which was the closest station to the Boron Mine and located in the Kırka District. In addition to the inorganic pollution pressure of the mine, the sewage of Kırka District is also discharged into the system from this location. According to results of CA, this location of the basin formed a separate cluster, which was named as “High Polluted Area” (Fig. 5).

The polluted runoff from special agricultural areas draining into Seydisuyu Stream adversely affects the downstream of the basin. According to results of CA, downstream sections of Seydisuyu Stream formed a separate cluster, which was named as “Moderate Polluted Areas” (Fig. 5).

In a macroscopic point of view, As and B concentrations and organic contents of water have significantly decreased in the lenthic sections (Çatören and Kunduzlar Dam Lakes) of the basin due to the resting of the water in the reservoirs. These results point to dam lakes of the basin haveing a significant cleaning capacity for the system in terms of especially boron levels. Similar to results of the present study, it was stated that Porsuk Dam Lake constructed on Porsuk Stream (Sakarya River Basin) has an important cleaning capacity for the basin, and water quality of Porsuk Stream was significantly improving at the stations, which were close to the output of the reservoir [34]. According to the results of CA, output of the reservoirs, the source of Seydisuyu Stream, and lenthic sections of the basin formed a separate cluster that was named “Low Polluted Areas” (Fig. 5).

Conclusion

In this study, different multivariate statistical techniques were used to evaluate water quality and the organic-inorganic pressures of a contaminated aquatic ecosystem. According to results of FA, four effective factors on water quality of the Seydisuyu Stream Basin were identified by using a large number of physical and chemical water quality data. According to results of CA, three clusters of similar water quality characteristics were identified for the Seydisuyu Stream Basin. According to data observed, arsenic and boron concentrations in water of the basin were detected at significantly high levels and exceeded the critical limits. Especially boron levels were rising after the discharge of the boron facility to the system (at the input of Çatören Dam Lake) and this adverse situation caused significant decreases of water quality for Seydisuyu Stream Basin. The data of the present study clearly reveals that agricultural runoff caused from especially intensive pesticide applications, municipal sewage water caused from especially intensive settlement areas, and the mineral washing activities conducted by the boron facility were the main pollution sources for Seydisuyu Stream. The present study also indicates that the multivariate statistical techniques are very useful and necessary for the water quality assessment studies in order to interpretat complex data sets and identify pollution sources.

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