Original Research

Monitoring Stream Water Quality: A Statistical Evaluation

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Abstract

Seydisuyu Stream Basin, known to be exposed to agricultural and domestic pollution, is one of the most important branches of the Sakarya River. In addition to the geologic structure of the basin, Kırka Boron Mine is one of the most important inorganic pollution sources for the system and also for the Sakarya River. In this study, the water quality of Seydisuyu Stream was evaluated by determining some physiochemical (temperature, conductivity, salinity, TDS, pH, ORP, dissolved oxygen, and nitrate) and chemical (boron and arsenic) parameters. Water samples were collected an average of 10 times per month between September 2011-September 2012 from Hamidiye Village, located at the downside of Seydisuyu Stream. All of the data obtained experimentally were compared according to the criteria of 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). Cluster analysis (CA) was applied to the results to classify the seasons according to water quality by using the Past package program. Factor analysis (FA) was applied to the results to classify the affective factors on water quality, and Pearson Correlation Index was applied to the results to determine the relations of parameters by using the SPSS 17 package program. According to the results of FA, four factors explained 84.78% of the total variance and according to the results of CA, three statistically significant clusters were formed. In a macroscopic view, the monitoring station has class I-II water quality in terms of arsenic and class IV water quality in terms of boron. It was also determine that arsenic and boron accumulations in Seydisuyu Stream water were much higher than drinking water limits.

Keywords: arsenic, boron, water quality, monitoring, Seydisuyu Stream, multivariate statistic

Introduction

Fresh water quality is a matter of serious global concern today. Streams are among the most vulnerable water bodies to pollution due to their role in carrying off municipal and industrial wastewater and run-off from agricultural land in their vast drainage basins [1]. It is necessary to evaluate a large number of physico-chemical and chemical water quality data for effective pollution control, and useful water resource management, which is often difficult to interpret and draw meaningful conclusions [2, 3]. The application of multivariate statistical techniques helps in the interpretation of complex data matrices to better understand water environment quality and ecological status of the studied ecosystems [4].

Seydisuyu Stream is one of the most important branches of the Sakarya River and all of the contaminations on Seydisuyu Stream threaten directly the Sakarya, thereby

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threatening the Black Sea. As it is known, Turkey has 70% of the total boron reserve of the world. Kırka county of Eskişehir province, located on the border of Seydisuyu Stream Basin, is one of the most important borate deposits in Turkey [5]. According to the literature, boron content of geological structure is significantly effective on arsenic levels in the region. It is also known that arsenic may accumulate in the environment through use of arsenical pesticides and the application of fertilizers in agricultural activities [6]. In addition to the geological structure of Seydisuyu Stream Basin, intensive agricultural activities, urban discharge, and Kırka Boron Works located on the upside of the stream are the main pollution sources for the basin.

The aim of this study is to monitor the water quality of Seydisuyu Stream by field studies performed very frequently (an average of 10 field studies in a month) and by using some mono (Pearson correlation index, boxplot deviation diagrams) – multi (cluster analysis, factor analysis) statistical techniques.

Material and Method

Study Area and Collection of Samples

Seydisuyu Stream Basin, known to be exposed to significant organic and inorganic pollution, is one of the most important agricultural and mining areas of Turkey. It is located on the border of Eskişehir Province in the Central Anatolia Region of Turkey (between 38.0851-39.0361 north latitude and 30.0161-31.0071 east longitude) [7].

Water samples were collected an average of 10 times per month between September 2011-September 2012 from Hamidiye Village of Eskişehir Province, where is located at the downside of Seydisuyu Stream and may reflect the total pollution load of the basin. A total of 134 field studies were carried out in a total of 13 months in the present study. The map of Seydisuyu Stream Basin and the monitoring station are given in Fig. 1.

Chemical and Physicochemical Analysis

Temperature, conductivity, salinity, TDS (total dissolved solid), pH, ORP (oxidation-reduction potential), and dissolved oxygen parameters were determined using a "Hach Lange Hydrolab DS5 Multiparameter Sonde" device during field studies. The nitrate parameter was determined using a "Hach Lange DR 2800 Spectrophotometer" device.

For determination of element levels in water, 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. 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.

Element accumulations in water samples were determined by an "ICP-OES (Varian 720 ES)" device. The element analysis in water samples were recorded as means triplicate measurements [8, 9]. In the ICP-OES analysis, the following wavelength lines were used; As 193.759 nm, B 249.678 nm.

Statistical Analysis

Cluster analysis and boxplot deviation diagrams were applied to the results by using the "Past" package program. Pearson correlation index, factor analysis, and scatterdot comparison diagrams were applied to the results using the "SPSS 17" package program.

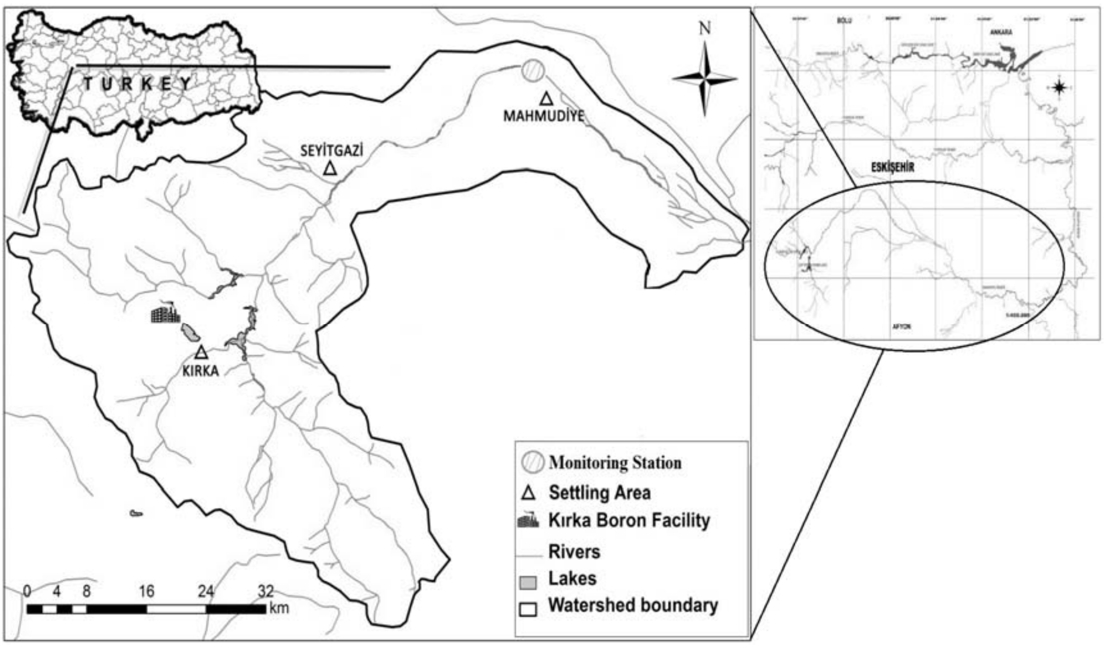

Fig. 1. Seydisuyu Stream Basin and the monitoring point.

Results

Monthly averages of results of physicochemical and chemical parameters with minimum, maximum, mean and standard deviation values are given in Table 1 and the comparing diagrams according to Water Pollution Control Regulations in Turkey [10] are given in Fig. 2.

The highest boron and nitrate levels in water were determined in September 2012 (maximum: 5.05 mg/L for boron; 21.02 mg/L for nitrate) and the highest arsenic accumulations in water were recorded in October 2011 (maximum: 0.122 mg/L). Sudden decreases in the pH of water were recorded in November and December 2011 (minimum: 6.05). Significant increases in conductivity, salinity,

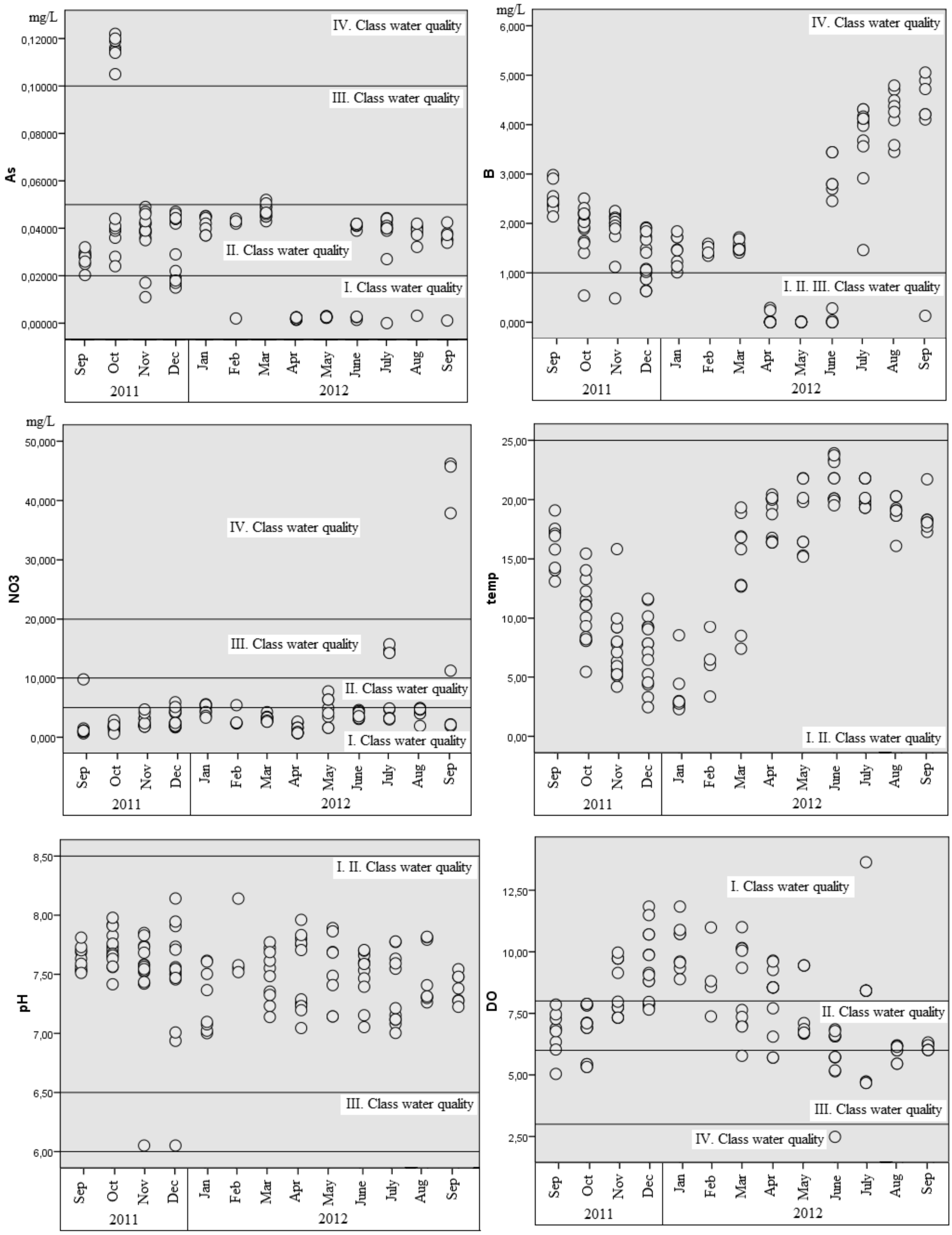

Fig. 2. Scatterdot comparing diagrams and water quality classes (SKKY, 2004).
(temp – temperature; DO – dissolved oxygen)

Table 1. Monthly average values of water quality parameters.

Years	Months		Parameters									
			temp ºC	cond µS/cm	sal ‰0	TDS mg·L^{-1}	pH	ORP	NO_3 mg·L^{-1}	DO mg·L^{-1}	As mg·L^{-1}	B mg·L^{-1}
2011	Sep (n=10)	min	13.11	838.6	0.440	0.437	7.51	246.8	0.652	5.04	0.02030	2.140
		max	19.09	1022.5	0.605	0.670	7.81	418.4	9.765	7.86	0.03200	2.980
		mean	**16.26**	**892.1**	**0.508**	**0.523**	**7.63**	**302.2**	**1.875**	**6.73**	**0.02753**	**2.496**
		SD	1.90	61.4	0.073	0.067	0.10	45.1	2.782	0.79	0.00320	0.260
	Oct (n=14)	min	5.44	847.3	0.450	0.442	7.42	252.1	0.643	5.33	0.02400	0.540
		max	15.45	1064.8	0.670	0.700	7.98	343.8	2.842	7.88	0.12200	2.502
		mean	**10.45**	**963.2**	**0.551**	**0.574**	**7.71**	**301.4**	**1.756**	**6.79**	**0.07593**	**1.894**
		SD	2.76	68.8	0.062	0.084	0.16	24.4	0.550	0.99	0.04191	0.489
	Nov (n=15)	min	4.19	386.7	0.315	0.405	6.05	236.1	1.799	7.33	0.01100	0.482
		max	15.83	1280.6	0.675	0.817	7.85	718.0	4.685	9.97	0.04900	2.250
		mean	**7.55**	**939.7**	**0.509**	**0.628**	**7.50**	**322.8**	**2.504**	**8.42**	**0.03746**	**1.875**
		SD	2.85	209.4	0.078	0.090	0.42	128.6	0.891	1.09	0.01037	0.471
	Dec (n=16)	min	2.45	376.1	0.186	0.222	6.05	181.4	1.681	7.65	0.01500	0.630
		max	11.63	1280.6	0.676	0.817	8.14	718.0	5.913	11.84	0.04700	1.920
		mean	**7.45**	**880.2**	**0.458**	**0.555**	**7.47**	**336.8**	**3.049**	**9.21**	**0.03174**	**1.235**
		SD	2.83	257.3	0.139	0.167	0.49	141.9	1.415	1.40	0.01364	0.469
2012	Jan (n=8)	min	2.29	737.2	0.382	0.500	7.00	215.6	3.294	8.89	0.03700	1.010
		max	8.53	1070.4	0.561	0.680	7.62	257.9	5.569	11.84	0.04520	1.840
		mean	**3.63**	**902.4**	**0.471**	**0.579**	**7.29**	**250.1**	**4.640**	**10.20**	**0.04194**	**1.447**
		SD	2.08	109.5	0.060	0.071	0.27	14.2	0.881	0.99	0.00354	0.302
	Feb (n=4)	min	3.36	536.3	0.271	0.300	7.52	179.0	2.324	7.38	0.00200	1.346
		max	9.25	1139.2	0.599	0.750	8.14	251.5	5.424	10.99	0.04400	1.587
		mean	**6.28**	**880.3**	**0.458**	**0.552**	**7.70**	**229.5**	**3.157**	**8.94**	**0.03275**	**1.467**
		SD	2.41	258.0	0.141	0.189	0.30	34.1	1.512	1.50	0.02052	0.109
	Mar (n=10)	min	7.40	555.7	0.058	0.100	7.14	275.0	2.621	5.78	0.04300	1.410
		max	19.33	716.8	0.370	0.500	7.77	351.8	4.244	11.00	0.05200	1.717
		mean	**14.18**	**670.5**	**0.299**	**0.400**	**7.49**	**306.7**	**3.149**	**8.54**	**0.04734**	**1.532**
		SD	4.09	64.7	0.125	0.133	0.22	21.1	0.496	1.79	0.00278	0.099
	Apr (n=12)	min	16.37	141.7	0.060	0.100	7.05	334.0	0.699	5.70	0.00140	0.000
		max	20.43	640.9	0.330	0.400	7.96	365.0	2.624	9.64	0.00250	0.290
		mean	**18.75**	**488.2**	**0.193**	**0.258**	**7.51**	**357.1**	**1.404**	**8.08**	**0.00195**	**0.047**
		SD	1.71	141.0	0.105	0.124	0.32	9.8	0.776	1.38	0.00038	0.102
	May (n=8)	min	15.19	640.3	0.330	0.400	7.14	235.1	1.597	6.67	0.00220	0.000
		max	21.81	3861.4	2.101	2.500	7.89	360.2	7.750	9.45	0.00300	0.016
		mean	**18.36**	**1548.4**	**0.828**	**0.991**	**7.54**	**296.9**	**4.512**	**7.80**	**0.00258**	**0.005**
		SD	2.82	1424.5	0.784	0.917	0.29	53.2	2.260	1.37	0.00029	0.005

Table 1. Continued.

Years	Months		Parameters									
			temp ºC	cond µS/cm	sal ‰0	TDS $mg·L^{-1}$	pH	ORP	NO_3 $mg·L^{-1}$	DO $mg·L^{-1}$	As $mg·L^{-1}$	B $mg·L^{-1}$
2012	June (n=11)	min	19.51	183.1	0.330	0.400	7.05	229.8	3.093	2.49	0.00140	0.000
		max	23.91	759.7	0.393	0.500	7.71	364.0	4.593	6.85	0.04190	3.441
		mean	**21.59**	**608.3**	**0.361**	**0.447**	**7.50**	**296.1**	**3.777**	**5.76**	**0.02696**	**1.630**
		SD	1.73	209.4	0.023	0.048	0.22	51.2	0.577	1.25	0.01963	1.530
	July (n=11)	min	19.31	632.2	0.323	0.400	7.00	439.5	3.015	4.68	0.00000	1.461
		max	21.80	709.5	0.370	0.500	7.78	479.0	15.699	13.64	0.04430	4.309
		mean	**20.44**	**665.1**	**0.342**	**0.418**	**7.36**	**453.9**	**8.682**	**7.54**	**0.03639**	**3.695**
		SD	1.11	29.8	0.018	0.040	0.30	14.5	5.776	2.72	0.01295	0.845
	Aug (n=8)	min	16.09	672.0	0.349	0.400	7.26	391.8	1.901	5.45	0.00316	3.447
		max	20.28	745.5	0.387	0.500	7.82	462.0	4.937	6.20	0.04195	4.789
		mean	**18.92**	**692.5**	**0.357**	**0.442**	**7.50**	**422.5**	**4.245**	**5.95**	**0.03402**	**4.217**
		SD	1.31	23.8	0.014	0.038	0.26	28.0	1.012	0.32	0.01281	0.488
	Sep (n=7)	min	17.27	649.7	0.330	0.400	7.22	446.7	1.873	6.01	0.00110	0.130
		max	21.71	704.3	0.360	0.500	7.54	468.5	46.205	6.32	0.04250	5.053
		mean	**18.49**	**672.8**	**0.344**	**0.414**	**7.38**	**461.0**	**21.025**	**6.15**	**0.03184**	**3.902**
		SD	1.46	26.7	0.015	0.038	0.12	7.0	21.224	0.14	0.01385	1.704

n – number of sampling in the month,
temp – temperature, cond – conductivity, sal – salinity, DO – dissolved oxygen,
min – minimum, max – maximum, SD – standard deviation

and TDS values were observed in May 2012. Also, significant increases in ORP values and decreases in oxygen values were observed during the summer.

According to the criteria of SKKY identified for Turkey (Water Pollution Control Regulation in Turkey), the monitoring station located on the downside of the Seydisuyu Stream Basin has class I-II water quality in terms of temperature and pH (except 2 data recorded in November and December 2011) during the monitoring period (13 months). It has class II water quality in autumn, class I water quality in winter, class I-II water quality in spring, and class II-III water quality in summer in terms of the dissolved oxygen (DO) parameter. Minimum DO value was recorded in June 2011 as 2.49 mg/L, which is lower than even the limit value of class IV water quality (<3 mg/L). In general, the monitoring station has class I-II water quality in terms of nitrate during the monitoring period. But sudden increases in nitrate levels were determined in July and September 2012 and water quality has fallen to class III-IV in these months in terms of nitrate levels (class III limit is 10 mg/L and class IV limit is 20 mg/L). In general the monitoring station has class I-II water quality in terms of arsenic during the monitoring period, except October 2011. Extreme increases of arsenic values were observed in October 2011 and Seydisuyu Stream has class IV water quality in these peak times in terms of arsenic (>0.1 mg/L). Significant increases in boron accumulations were recorded in summer and the monitoring station has class IV water quality in terms of boron, even in months having the lowest average boron accumulations (Fig. 2) [10].

Fig. 3 is a boxplot diagram that shows the range and mean values and the deviations of detected parameters in Seydisuyu water. According to the boxplot diagrams, temperature values of the water showed significant deviations mainly because of seasonal differences. Also, arsenic and boron values of water showed significant deviations, mainly because of point discharge sources of these elements in the basin. The highest deviation between the maximum value and upper quartile (Q3) of the boxplot was observed for the nitrate parameter and the highest deviation between the minimum value and lower quartile (Q1) of the boxplot was observed for pH parameter.

Pearson Correlation Index

The relationships between temperature, conductivity, salinity, TDS, pH, ORP, nitrate, dissolved oxygen, arsenic, and boron levels in Seydisuyu Stream water were calculated by the Pearson correlation index (n=134 for all parameters) and all recorded significant relations are given in Table 2.

Table 2. Pearson correlation index coefficients.

	temp	cond	sal	TDS	pH	ORP	NO_3	DO	As	B
temp	1									
cond	-0.162	1								
sal	-0.162	0.959**	1							
TDS	-0.155	0.958**	0.968**	1						
pH	0.021	0.088	0.129	0.085	1					
ORP	0.328**	-0.126	-0.154	-0.143	-0.404**	1				
NO_3	0.181*	-0.004	-0.014	-0.011	-0.051	0.285**	1			
DO	-0.559**	0.030	0.014	0.049	-0.147	-0.143	-0.130	1		
As	-0.274**	0.014	0.052	-0.012	0.118	-0.063	-0.072	-0.052	1	
B	0.175*	-0.112	-0.098	-0.117	-0.092	0.412**	0.234**	-0.276**	0.311**	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)

It was found that the relations between temperature – ORP (+), dissolved oxygen (-) and arsenic (-); conductivity – salinity (+) and TDS (+); salinity – TDS (+); pH – ORP (-); ORP – nitrate (-) and boron (+); nitrate – boron (-); dissolved oxygen – boron (-); and arsenic – boron (+) parameters were directly proportional at the 0.01 level (p<0.01). And the relationships between temperature – nitrate (+) and boron (+) parameters were directly proportional at the 0.05 level (p<0.05).

Factor Analysis (FA)

Factor Analysis is a powerful multivariate statistical technique that facilitates the interpretation of large data sets and is widely used in water quality assessment studies in especially recent years [11-15]. In the present study, FA was used to determine the effective varifactors on Seydisuyu Stream by using correlated variables. Uncorrelated variables were removed to increase the reliability of FA, and a

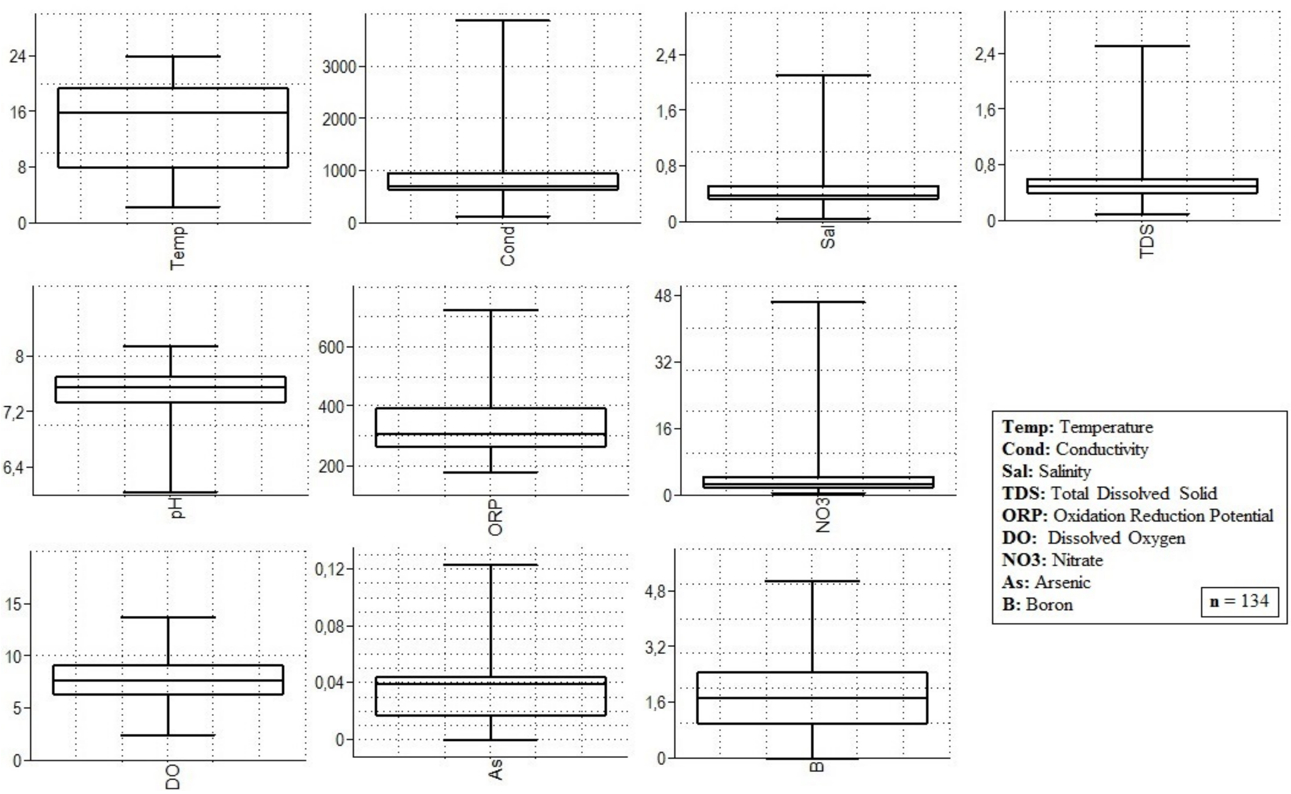

Fig. 3. Boxplot deviation diagrams.

Table 3. Extracted values of FA parameters.

Component	Initial eigenvalues			Extraction sums of squared loadings (unrotated)			Rotation sums of squared loadings (rotated)		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
1	3.093	34.367	34.367	3.093	34.367	34.367	2.934	32.602	32.602
2	1.830	20.337	54.704	1.830	20.337	54.704	1.765	19.615	52.216
3	1.365	15.169	69.873	1.365	15.169	69.873	1.556	17.284	69.500
4	1.342	14.913	84.785	1.342	14.913	84.785	1.376	15.285	84.785
5	0.554	6.159	90.945						
6	0.424	4.709	95.653						
7	0.318	3.534	99.187						
8	0.044	0.491	99.678						
9	0.029	0.322	100.000						

Table 4. Parameter loadings for component matrix and rotated component matrix.

	Component Matrix				Rotated Component Matrix			
	Component				Component			
	1	2	3	4	1	2	3	4
TDS	0.949				0.985			
sal	0.952				0.984			
cond	0.944				0.983			
temp		0.670				0.864		
DO		-0.694	0.506			-0.853		
pH			-0.804				-0.828	
ORP		0.593	0.532				0.806	
As				0.909				0.875
B		0.573		0.555				.706

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

total of nine variables were used to determine the varifactors (n=134 for all parameters). The result of KMO (Kaiser-Meyer-Olkin) measurements of sampling adequacy test was 0.682 and this value means that the sampling adequacy was at a good level for the present application [11]. Eigenvalues higher than one were taken as criterion to evaluate the principal components required to explain the sources of variance in the data (Fig. 4).

The percentage variance counted, cumulative percentage variance and component loadings (unrotated and rotated) are given in Table 3. According to rotated cumulative percentage variance, four factors explained 84.78% of the total variance.

The parameter loadings (higher than 0.5) for four components before and after rotation are given in Table 4. Liu [11] classified the factor loadings according to loading val-

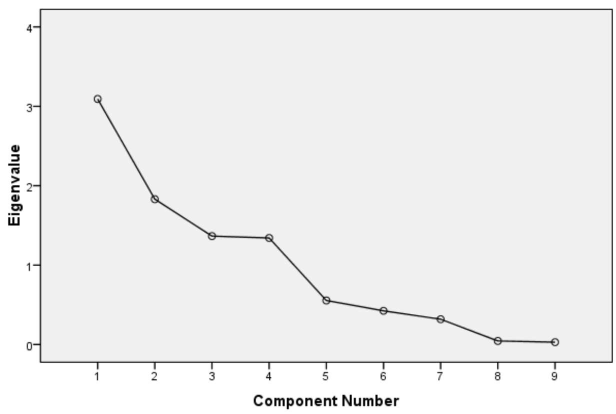

Fig. 4. Scree plot of factor analysis.

Table 5. Similarity-distance coefficients of months.

Years		2011				2012								
	Months	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep
2011	Sep	1.00												
	Oct	0.97	1.00											
	Nov	0.97	0.98	1.00										
	Dec	0.98	0.95	0.97	1.00									
2012	Jan	0.97	0.95	0.95	0.95	1.00								
	Feb	0.96	0.93	0.94	0.95	0.98	1.00							
	Mar	0.90	0.87	0.87	0.89	0.86	0.86	1.00						
	Apr	0.78	0.75	0.77	0.80	0.74	0.73	0.87	1.00					
	May	0.78	0.81	0.80	0.77	0.77	0.75	0.69	**0.59**	1.00				
	June	0.86	0.83	0.83	0.85	0.83	0.83	0.96	0.90	0.66	1.00			
	July	0.84	0.81	0.83	0.85	0.80	0.80	0.92	0.86	0.66	0.89	1.00		
	Aug	0.86	0.83	0.85	0.88	0.83	0.83	0.93	0.86	0.67	0.90	0.97	1.00	
	Sep	0.83	0.81	0.82	0.85	0.80	0.80	0.92	0.85	0.65	0.88	**0.99**	0.97	1.00

ues as "strong (>0.75)," "moderate (0.75-0.50)," and "weak (0.50-0.30)." Component plot in rotated space, which shows the related variables of two factors, was given in Fig. 4.

- The first factor (F1), named as "Nutrient Factor," explained 23.6% of total variance and was related to the variables of TDS, salinity, and conductivity values of water. All parameters were highly loaded with this factor.
- The second factor (F2), named as "Climatic Factor," explained 19.6% of total variance and it was related to the variables of temperature and dissolved oxygen values of water. Temperature parameter was strong positively and dissolved oxygen parameter was negatively loaded with this factor.
- The third factor (F3), named as "pH Factor," explained 17.2% of total variance and it was related to the variables of pH and ORP values of water. pH parameter was strong negatively and ORP parameter was strong positively with this factor.
- The fourth factor (F4), named as "Inorganic Factor," explained 15.2% of total variance and it was related to the variables of arsenic and boron values of water. The arsenic parameter was strong and the boron parameter was moderately positively loaded with this factor.

Cluster Analysis (CA)

Cluster analysis is also a widely used multivariate statistical technique in water quality assessment studies that provide a facility in order to classify the objects according to similar characteristics [1, 7, 16-18]. In the present study, CA was used to determine the similarity groups between the months and seasons.

The diagram of CA calculated by using temperature, conductivity, salinity, TDS, pH, ORP, nitrate, dissolved oxygen, arsenic, and boron levels in Seydisuyu Stream water is given in Fig. 5. According to the CA, three statistically significant clusters were formed:

- Cluster 1 corresponded to November, October, September, December 2011, and February, January 2012
- Cluster 2 corresponded to April, August, September, July, June, and March 2012
- Cluster 3 corresponded to May 2012.

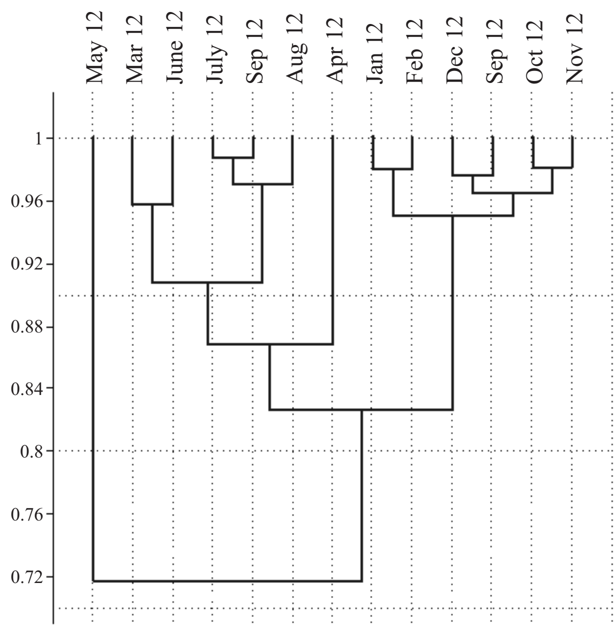

Fig. 5. Diagram of cluster analysis.

The highest similarity was determined between July and September 2012 (99%) and the lowest similarity was determined between April and May 2012 (59%) (Table 5).

Discussion

Multivariate statistical techniques are used widely to evaluate surface water quality and provide valuable data. These techniques include especially cluster and factor analysis, providing easy explaining and valuable data, and they are being used in large numbers of countries in order to evaluate many different freshwater habitats for a better understanding of ecological status of the systems [19, 20].

In a study performed in Xiangjiang watershed in China, FA and CA were used to evaluate the water quality as similar to the present study. CA grouped 34 sampling sites into three clusters based on the similarity of water quality characteristics, and FA reduced the data sets in four latent factors for three different sites accounting for 71.62%, 71.77%, and 72.01% of the total variance [17]. In another study performed in Uluabat Lake in Turkey, FA and CA were used to assess water quality. According to FA, 77.35% of variances explained by 3 factors and CA grouped 12 sampling sites into 2 clusters of similar water quality [12].

TDS (total dissolved solids) is defined as the quantity of dissolved material in water and it depends mainly on the solubility of rocks and soils that the water contacts. Salinity is the total of all salts dissolved in water and conductivity is a measure of the ability of water to pass an electrical current, and it is affected by the presence of dissolved solids. TDS and salinity levels in water are closely related to conductivity levels. If the TDS and salinity value in water rise, the conductivity value will also increase. Although these parameters do not identify specific water pollution, they may indicate general water quality and discharges to water can change the TDS, salinity, and conductivity levels. Sewage wastes and irrigation practices could raise the levels of these parameters because of the presence of chloride, phosphate, and nitrate [21, 22]. In the present study, significant relations were determined between these three parameters at the 0.01 significance level. According to the results of FA, the first factor (F1) that was related to the variables of TDS, salinity, and conductivity was the most effective factor on Seydisuyu Stream (explaining 23.6% of total variance). It was also observed that these three variables were the most dominant parameters used in the classifying seasons on the CA application. The main reason for the recorded peak values of TDS, salinity, and conductivity is thought to be runoff from agricultural lands and the sewage discharges from residential areas in the basin.

Dissolved oxygen is one of the most important parameter for monitoring the exchange of water quality [21]. Despite the detected low dissolved oxygen levels during the summer, Seydisuyu Stream has a fairly good level of oxygen values in a macroscopic view. The amount of dissolved oxygen in water depends on the current temperature, density of dissolved salts, and biological processes of the aquatic ecosystem. As it is known, dissolved oxygen in water is closely related to the temperature parameter and solubility of oxygen in water decreases with increasing temperature [22]. So detected low oxygen levels in summer in Seydisuyu Stream were an expected situation and, as similar to the literature, significant negative correlations were recorded between dissolved oxygen and temperature parameters ($p<0.01$). According to the results of FA, temperature parameter was positively strong and dissolved oxygen parameter was negatively strong with the second factor (F2), which explained 19.6% of total variance.

pH and ORP (oxidation reduction potential) parameters are different measurements, but they are closely related. When the acidic water is positive in ORP, alkaline water contains negative ORP, which is also known as antioxidant [22]. Detected significant negative correlations between pH and ORP levels in the present study ($p<0.01$) and the third factor (F3) determined in FA that was related to the variables of pH (strong positively loaded) and ORP (strong negatively loaded) parameters prove the literature information.

Pesticide applications in agricultural areas and mining activities have an important place for the release of arsenic to the environment from anthropogenic sources [23]. It is known that boron contents of geological structure significantly affect the arsenic levels, and arsenic and boron are often correlated as they are both soluble minerals found in hydrothermal – volcanic deposits [24]. In the present study, significant positive correlations recorded between boron and arsenic levels in water ($p<0.01$). Also, the fourth factor (F4) determined in FA was positively related to the variables of arsenic and boron parameters. But determined quite low arsenic accumulations in summer, when the peak values of boron accumulations recorded indicate another nonpoint discharge than Kırka Boron Works for arsenic in the basin. It is thought that the most important source of arsenic in water of Seydisuyu Stream could be the intensive pesticide applications carried out around the basin as a result of agricultural activities.

According to drinking water standards specified by the Turkish Standards Institute, European Communities, and the World Health Organization, arsenic and boron accumulations in Seydisuyu Stream water 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) [25, 26, 27].

Emet-Hisarcık Districts of Kütahya Province are other important boron deposits of Turkey. In a study performed in Emet Stream that is directly under pressure by the Emet Boron Works, arsenic and boron accumulations in water greatly exceeded the limit values for drinking water, especially around the close stations to the boron mine (maximum arsenic: 1 mg/L and maximum boron: 74 mg/L) [28]. If we compare the two large boron deposit areas, arsenic and boron accumulations in Emet Stream water were much higher than those detected in Seydisuyu Stream, and it can be concluded that the pressure of the boron mine on Emet Stream is significantly higher than the pressure on Seydisuyu Stream.

Conclusion

In the present study, different multivariate statistical applications were used to evaluate variations in Seydisuyu Stream water quality. Factor analysis helped to identify the effective factors on water quality variations in the basin by using a large number of physico-chemical and chemical water quality data that were not clearly visible from an examination of the analytical data in the tables, and were difficult to evaluate without using any multivariate statistical technique. Cluster analysis grouped 13 sampling seasons into three clusters of similar water quality characteristics, and according to data obtained from CA, it may be possible to design an optimal sampling season, which could reduce the number of field studies. The present study indicates the usefulness and necessity of using multivariate statistical techniques for the interpretation of complex data sets, identification of pollution sources, and understanding variations in water quality. The main cause of degradation of Seydisuyu Stream is the discharge of agricultural wastes, municipal sewage water from settlement areas, and mineral washing activities by Kırka Boron Works (especially in summer). According to data observed, arsenic and boron accumulations detected in Seydisuyu Stream were at critical levels. Unless any measures are taken in the basin as soon as possible, this inorganic pollution may be a significant limiting factor on aquatic life in the region and may also adversely affect human health in the immediate future.

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