

## Investigation of water quality on Gökçekaya dam lake using multivariate statistical analysis, in Eskişehir, Turkey

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Received: 17 July 2009 / Accepted: 14 October 2010 / Published online: 6 November 2010  
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**Abstract** Gökçekaya Dam is one of the dams located on the Sakarya River (Eskişehir) in Turkey and is approximately 38 years old. No study regarding to the water quality of the dam lake has been hitherto made. This study aimed at determining the seasonal variations with physical, chemical, and biological parameters of the water quality of the dam lake. Depth-wise water samples were taken from five selected stations, in seasonal periods during 2005–2008, and analyzed. The quality of water was classified in accordance with the results and taking into consideration many parameters. At the same time, number and type diversities of dissolved heavy metals and algae population were analyzed. Using principal component analysis (PCA) and classification analysis (CA) methods, differences between these parameters and samples from stations have been determined. The analysis showed that Gökçekaya dam lake, formerly an oligotrophic lake, has become a mesotrophic lake. And according to the results thereof the Lake has mezotrophic characteristics due to the sudden

changes (including household waste water inflow and opening the Sarıyar dam lake shutters) in certain periods and in some stations. Hierarchical clustering analysis, revealed no significant difference between the measured parameters. And according to the Water Pollution Control Regulations in Turkey (WPCR) Gökçekaya dam lake is in the first class quality in terms of anions, cations, heavy metals, temperature, and pH values. However, the is of first class quality presence of nitrite reduces the water quality in the lake and causes this lake to be classified in the fourth class quality.

**Keywords** Water quality monitoring · Dam lakes · Classification analysis (CA) · Principal component analysis (PCA) · Eskişehir · Turkey

### Introduction

Turkey is located in the northern hemisphere between the 36°–42° northern parallel and the 26°–45° eastern meridian. Turkey is among the countries which abound in rivers. However, since rivers, lakes and seas are considered as potable and industrial water resources for Turkey, a rapidly developing country. The pollution in these water resources becomes more of an issue. In Turkey, the available amount of water per person is 1,735 m<sup>3</sup>/year, and the water potential is approximately 3,690 m<sup>3</sup>/year. When Turkey is compared with other countries and with the world average in terms of available water per person, it is seen that Turkey is one among the countries which experience water shortage. The number of monitoring studies for determining quality criteria of water resources and for measuring pollution in the current water resources has gradually increased. Especially, determining water pollution values

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caused by anthropogenic sources and climate change has drawn attention in the past few years (Szymanowska et al. 1999).

Water quality monitoring studies require very detailed examinations as they include many physical, chemical, and biological parameters. And also as monitoring process lasts for a long time, a well-designed water quality monitoring plan should be used to preserve the lake water by minimizing the redundancy of nearby monitoring stations and plethora of possible variables monitored, and maximizing the information content of the collected data, as well (Zeng and Rasmussen 2005). Particularly when examining surface waters, it is necessary to take depth-wise samples in monthly and/or seasonal periods. In addition, interpreting many obtained parameters in terms of water quality and taking other factors (surface flow, climate, geological factors, anthropogenic and industrial factors, etc.) into consideration make the interpretation of monitoring studies difficult. Thus, different methods (indicator organisms, remote sensing, statistical studies, etc.) have been used in water quality studies in recent years in order to support analysis studies.

The present study includes research aimed to determine the water quality inventories of lakes' dams (Sarriyar and Gökçekaya) by monitoring depth-wise water quality in a long period, which is a study method used in our country. A lake dam which is not directly exposed to anthropogenic and industrial pollution was chosen as study area. In the lakes' dam formed at the back of the relieved and accumulated structures on the running water. In the running water from the lake's dam, the normal living creatures of the river are changing by the time, because of the cold temperature and low oxygen content of the coming inflow water of the lake dam (Fair et al. 1971). In comparison with natural lakes and marshes, dam lakes have the following features: (1) the water level fluctuates irregularly, which physically destabilizes the lake shoreline, and (2) the hydrogeological setting of dam lakes is complicated and could change easily because the water level is regulated artificially. Therefore, the hydrological and physical environment affects the water quality of a lake dam (Nakashima et al. 2007). In recent years, activities to preserve the water quality and ecosystem of dam lakes have been encouraged. For example, research on the classification of the water quality of dam lakes (De Ceballos et al. 1998) and the effects of its use on land have been carried out (Bhuyan et al. 2003; Brainwood et al. 2004). Also, there has been a growing interest in characterizing the lake water quality such as high-mountain lakes at the landscape (Mosello et al. 1991; Boggero et al. 1993; Stout 1993; Larson et al. 1995), water quality differed between deep and shallow lakes (Larson et al. 1999). Such research compared and

classified the lakes on the basis of various parameters such as carbon, nitrogen, phosphorus, and oxygen (Nakashima et al. 2007).

Multivariate data analysis techniques can be used to assess the complex eco-toxicological processes by showing the relationship and interdependency among the variables and their relative weights (Bartolomeo et al. 2004). The application of different multivariate statistical techniques, such as cluster analysis (CA), principal component analysis (PCA), factor analysis (FA) and discriminant analysis (DA), helps in the interpretation of complex data matrices for a better understanding of water quality and ecological status of the study region (Kazi et al. 2009). For water quality studies particularly on streams, statistical calculation methods are used so as to form a regional multiple sensitivity analysis model and determine the pollution sources in accordance with model outputs (Taylan et al. 2007). In recent years, these methods have been commonly used in evaluating sediment pollutions and heavy metal accumulations in rivers and lakes (Szymanowska et al. 1999; Liu et al. 2003; Zhou et al. 2008).

In the past 10 years, studies on water quality monitoring have been initiated by esteemed institutions and Universities. Anatolian Watershed Rehabilitation Projects initiated by Ministry of Environment and Forestry, aim to protect the water resources in the country with a sustainable planning (Anonymous 2010). Therefore, it is required to evaluate the water quality changes in conformity with the updated data. That monitoring periods in respect of water quality changes are generally short and parameters are not evaluated collectively, which is a major deficiency in this regard. For this study, long-term water quality analysis has been first carried out for a dam lake and many parameter changes have been collectively evaluated. As for this aspect, the study has the distinction of being the first one in Turkey. At the same time it aims at remedying significant deficiency in the international literature through carrying out a water quality monitoring study, which has not been hitherto attempted regarding Gökçekaya Lake Dam.

## Materials and methods

In the present study, it was both aimed to determine physico-chemical and biological differences in the ecological structure of a dam lake area which is not fed by fresh river waters, and the water quality of Gökçekaya dam lake. Again, it was aimed to explain the differences between heavy metals, algae types, and sample stations using PCA (Helena et al. 2000) and Classification analysis (CA) (Kazi et al. 2009; Gauch 1982).

Study area and climate conditions

Gökçekaya Dam lies 43 km (27 miles) north of Alpu town, 45 km (28 miles) east of province of Eskişehir in central Turkey and is located 60 km (37 miles) downstream of Sarıyar Dam on the Sakarya River which runs into the Black Sea. Sarıyar and Gökçekaya Dams were built by the State Hydraulic Works across the 824-km-long Sakarya River with the aim of producing electricity. Gökçekaya Dam was built by State Hydraulic Works in the area of Sakarya River which is located within the borders of Eskişehir Province with the aim of producing hydro electric energy. The water coming from the upper section of the dam lake belongs to Sarıyar dam lake. Gökçekaya Lake is between Sarıyar Dam and Yenice dam lakes which are situated in the same line of Sakarya River (Fig. 1) (Study area coordinates: 40°06'00"N, 31°04'60"E). The water flowing through the tail gates of Gökçekaya dam lake reaches Yenice dam lake as inflow water. All the technical information on both dam lakes is given in Table 1.

The study area of the project has the characteristics of Central Anatolia climate. In summer, it is hot and dry; in winter, it is cold and wet. The average annual temperature of the area is 28.6°C in summer, -1.3°C in winter, and the average annual temperature is 12.3°C. The dominant wind direction of the area is west (W) and the average annual wind speed is 1.49 m/s. The average annual amount of rainfall of the study area is 291.5 kg/m<sup>2</sup> (Anonymous 2010). Around Yenice, Gökçekaya dam lake seems like a river which meanders through a large valley. While one coastline of the lake which stretches along Sündiken Mountains is surrounded by juniper and pine forests, the

**Table 1** Technical specifications of Gökçekaya and Sarıyar dam lakes (EIE 2008)

Specifications	Gökçekaya	Sarıyar
Place of dam	Eskişehir	Ankara
River	Sakarya	Sakarya
Purpose	Energy	Energy
Year of construction (starting–ending)	1967–1972	1950–1956
Type	Concrete arch	Concrete weight
Dam volume	650.000 m <sup>3</sup>	568.000 m <sup>3</sup>
Height (thalweg)	115.00 m	90.00 m
Lake volume at normal water level	910.00 hm <sup>3</sup>	1,900.00 hm <sup>3</sup>
Lake volume at normal water level area	20.00 km <sup>2</sup>	83.83 km <sup>2</sup>
Power	278 MW	160 MW
Annual production	562 GWh	400 GWh

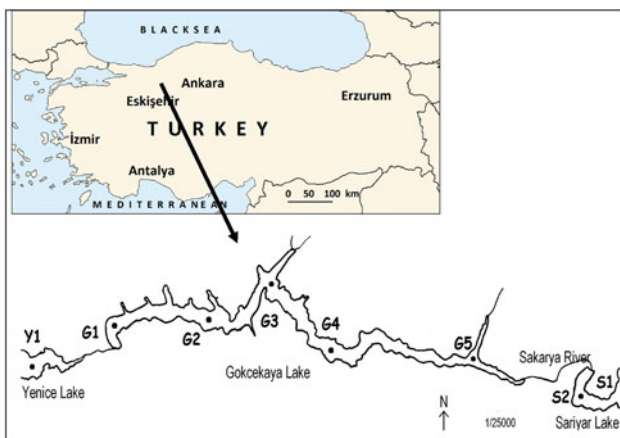
hills and mountainsides on the other side have a quite barren vegetation cover.

Around lakes, particularly around Gökçekaya dam lake, there is a quite rugged topography. This leads rain and snow water to directly reach the lake in the form of flash floods in a short time. Therefore, dam lakes are continually covered with alluvial deposits. Although soil types are generally variegated around lakes dam, the dominant type is volcanic rocks. The brown soil, which is the typical soil in Central Anatolia, covers most of the study area. The chemical reaction and bacterial activities at the bottom of a lake, which emerge as a result of dissolution of minerals forming geological units in a dam lake, affect the chemical structure of lake water (Bhuyan et al. 2003; Brainwood et al. 2004). Gökçekaya dam lake stretches along the valley parallel with Sündiken Mountains. In particular, the dense pine forests located in the slopes, wildlife and the fact that there is no settlement except for a few small villages in the area enable the area to maintain its virginity.

Sampling site

Since the study area is large (the average length is 35 km), the number of stations was restricted to five in Gökçekaya dam lake and two in the outlet of Sarıyar dam lake. In determining the stations, a GPS device was used. Hence, according to the coordinates set during the field work, some samples could be taken from the same stations. The field work and sample stations were determined within the scope of the project, as shown in Fig. 1.

With the field works performed in seasonal periods (spring, summer, autumn, winter) in the determined stations in the dam lakes, 12 field works were uninterruptedly



**Fig. 1** Location of sampling sites in the Gökçekaya and Sarıyar dam lakes (Akin et al. 2008). G1 (40°01'21N, 31°00'55E, mean depth 96m); G2 (40°03'10N, 31°04'55E, mean depth 50m); G3 (40°04'53 N, 31°07'24E, mean depth 45 m); G4 (40°02'52N, 31°11'56E, mean depth 50m); G5 (40°03'38N, 31°17'34E, mean depth 12m); S1 (40°01'45N, 31°27'05E, mean depth 58m); S2 (40°01'12N, 31°24'28E, mean depth 60m)

performed in a total of 3-year observation period during 2005–2006, 2006–2007 and 2007–2008.

### Analytical procedure

In the field studies carried out for determining the water qualities of the dam lakes, water samples were taken from the stations determined in each field study as instantaneous samples. The samples were taken depth-wise and the surface samples were taken from 0.5 m depth. The distance between the points from which the samples were taken was determined as 10 m. In the course of taking the samples, different numbers of sample vessels with different features were used for each analysis group. While taking the samples, pH, DO (dissolved oxygen), TDS (total dissolved solids), temperature, EC (electrical conductivity), depth, and salinity were instantly measured using YSI 6600 Multiple Probe. In conducting these depth-wise measurements, water samples were taken by means of a pump connected to the probe (Akin et al. 2008).

The samples were carried to the laboratory in storage boxes which comply with the Standard Methods and appropriate conservation criteria (cooler storage boxes, acidification, etc.). The experimental studies within the scope of the Project were carried out in the second phase. Some of them were conducted in situ and some of them

were conducted under laboratory conditions. In performing analyses, the international standard methods (APHA 2005) were used. The analyses performed and the methods used within the scope of the project are given in Table 2. Except for the instantaneous in situ measurements, heavy metals and physico-chemical parameters were analyzed in the Hacettepe University Hydrogeology Application and Research Laboratory. Microbiological analyses were performed in the Gazi University Department of Biology Education Microbiology Laboratory, and the algae were analyzed in the Gazi University Microalgae Biotechnology Laboratory.

### Statistical analysis

All statistical calculations, including PCA, CA, and Hierarchical Classification analysis (HCA) and linear regression, were conducted using Statistica for Windows Ver. 4.5 and SPSS for Windows Ver. 15 (SPSS 2007). PCA provides information on the most meaningful parameters which describe the whole data set interpretation, data reduction and summarize the statistical correlation among constituent in the water with minimum loss of original information (Helena et al. 2000). In this study, PCA was applied to summarize the statistical correlation among components in the lake water samples. PCA is designed to

**Table 2** The methods used for the analyses

Analysis	Analytical methods	
pH (pH unit)	In situ	YSI-multiple probe
Dissolved Oxygen, DO (mg/l)	In situ	YSI-multiple probe
Electrical conductivity, EC (dS/cm)	In situ	YSI-multiple probe
Temperature, T (°C)	In situ	YSI-multiple probe
Total dissolved solids, TDS (g/l)	In situ	YSI-multiple probe
Salinity (ppm)	In situ	YSI-multiple probe
Chemical oxygen demand, COD (mg/l)	Dichromate reflux method	Spectrophotometric
<i>Ortho</i> -phosphate, PO <sub>4</sub> -P (mg/l)	Molybdate ascorbic acid method	Spectrophotometric
Ammoniac nitrogen, NH <sub>4</sub> -N (mg/l)	Nessler's reagent	Spectrophotometric
Nitrate nitrogen, NO <sub>3</sub> -N (mg/l)	Brucine method	Spectrophotometric
Nitrite nitrogen, NO <sub>2</sub> -N (mg/l)	Diazotization method	Spectrophotometric
Total suspended solids, TSS (mg/l)		Gravimetric
Heavy metals <sup>a</sup> (ppb)		ICP
Hardness (FS)	EDTA complexometry titration	Titrimetric
Chlorophyll <i>a</i> (mg/l)	Pigment analyse method	Spectrophotometric
Turbidity (NTU)		Spectrophotometric
CO <sub>3</sub> , HCO <sub>3</sub> (mg/l)	Acid titration method	Titrimetric
Na, K, Ca, Mg (mg/l)		AAS
Cl (mg/l)		Ion selective electrode
F (mg/l)		Ion selective electrode
SO <sub>4</sub> (mg/l)	Barium sulphate turbidity method	Spectrophotometric
Coliform analysis (cfu/100ml)		Vacuum membrane pump

<sup>a</sup> The following metals were analyzed: B, Al, Si, P, S, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, Ge, As, Br, Se, Rb, Sr, Mo, Pd, Ag, Cd, Sn, Sb, Te, I, Cs, Ba, Ce, Pr, Nd, Sm, Eu, Au, Hg, Pd, Th, U

convert the original variables into new, uncorrelated variables (axes), called the principal components which are linear combinations of the original variables (Kazi et al. 2009).

## Results and discussion

The water quality of Gökçekaya and Sarıyar dam lakes

Gökçekaya dam lake water quality changes were monitored in seasonal periods. They did not show a significant change in the 3-year period between 2005 and 2008. Given the structural nature of Gökçekaya and Sarıyar Lakes Dam, it can be said that seasonal water quality changes result from temperature changes and fresh water intake. Gökçekaya dam lake receives limited fresh water intake. Its inflow is mainly from Sarıyar dam lake and includes seasonal water intake also from a few short rivers. Due to the fact that most of the rivers flowing to the Lake during the monitoring period dried up (because of the drought periods), it was observed that the water level of the lake decreased especially during summer (depending on the decrease in the rainfall of the area in recent years). Water quality values (temperature, pH, DO, etc.) also decreased due to the lack of fresh water inflow. These depth-wise changes caused the biological diversity (algae) in the area to change.

The water quality parameters, which were measured depth-wise in the 3-year monitoring period in Gökçekaya and Sarıyar dam lakes according to the seasonal period averages, are given in Table 3. The quality criteria depending on the classes of continental water resources stated in the Water Pollution Control Regulations in Turkey (WPCR 2004) are examined. Upon examination, it is seen that both Lakes are of the first quality class in terms of heavy metal pollution. According to the same classification, Gökçekaya dam lake is in the first class quality in terms of anions, cations, temperature, and pH values. However, the presence of nitrite reduces the water quality in both Lakes and causes these Lakes to be classified in the 4th quality class. According to the seasonal averages, it is seen that Gökçekaya dam lake has been lacking in nutrient (nitrogen and phosphorus compounds) for many long years. The analysis showed that Gökçekaya dam lake, which was formerly an oligotrophic lake, has become a mezotrophic lake (Lind 1990) and the Lake has mezotrophic characteristics due to the sudden changes (including household waste water intake and the opening of Sarıyar dam lake shutters) in stations in certain periods.

TDS and EC values did not vary significantly in both lakes during the seasonal periods when water quality was monitored. TDS and Conductivity values in the Gökçekaya Baraj Lake varied between 0.61–0.8 g/l and 0.74–1.2 dS/

cm and in Sarıyar dam lake between 0.45–0.61 g/l and 0.66–0.86 dS/cm. TDS values in the Gökçekaya dam lake were measured at lower levels (0.76 g/l) in summer in comparison with autumn. EC and salinity values increased in summer period in comparison with winter and autumn. One of the most important reasons behind the increase of salinity in summer is the increase of evaporation rate (Tepe 2009). In this case, decrease in salinity in summers in comparison with winters and partial contribution of increase in biological activity (Tuğrul and Polat 1995) hereto has increased the TDS amount. pH changes for Gökçekaya dam lake varied between 8.01 and 9.15 and for Sarıyar dam lake between 7.57 and 8.93 during the course of monitoring. For both dam lakes, while depth increases, the temperature decreases at an average of 10 m below the surface, where DO value decreases below 1.0 mg/l. DO value naturally decreases depending on decrease in the depth-wise temperature and photosynthetic activity (Galal-Gorchev et al. 1993). pH value decreased due to the increase in anoxic and anaerobic conditions since DO level decreased depending on depth.

The low phosphatic rate, which is a restrictive nutrient in terms of eutrophication in fresh water, particularly in lakes (0–1.7 mg PO<sub>4</sub>-P/l), shows that the eutrophication risk in the lake is very low (Table 3). During the 3-year study period, it was observed that each parameter was very low and the phosphate concentration increased in spring and autumn (in an average of 0.7 mg/l). This change which occurred especially in the deep stations of the lake (G1–G2) may have arisen from the fact that a water cycle may have developed during these seasonal periods. Especially in autumn and spring, groundwater was replaced by surface water in the deeper stations due to the thermal stratification evolved from the changes in temperature. *Ortho*-phosphate value in the lake decreased particularly in summers when chlorophytes increase in autumn months when Bacillariophyta is intensive. It results from the fact that phosphate and nitrate are used intensively in summer, whereas the phosphate is infrequently used in autumn months. In this case, the phosphate amount in the bottom sediments causes the phosphate value in water to increase. Since G1 and G2 stations are deeper, there is no settlement around these stations, there is no fresh water inflow around these stations, and other parameters changed similarly (DO, pH, algae population, etc.).

Nitrate-nitrogen value varied between 2.31 and 8.04 mg/l during the period of monitoring in Gökçekaya dam lake. While nitrate concentration reached its maximum values particularly in springs, it decreased towards minimum levels in autumn. This case can be related to the ammonium rate increasing during the degeneration stage following rapid propagation the phytoplankton. Nitrate concentration in the lake has been found to be higher than

**Table 3** Water quality changes in Gökçekaya and Sarıyar dam lakes in the 3-year period

Parameter	Gökçekaya			Sarıyar		
	Max.	Min.	Avr.	Max.	Min.	Avr.
Temperature (°C)	14.35	8.35	11.90	15.17	7.85	12.34
EC (dS/cm)	1.2	0.74	0.95	0.86	0.66	0.73
TDS (g/l)	0.80	0.61	0.68	0.79	0.58	0.68
Salinity (ppm)	620	470	520	610	450	520
DO (mg/l)	3.27	0.02	2.20	5.03	0.43	1.60
pH	9.15	8.01	8.33	8.93	7.57	8.16
Secchi disk (m)	6.69	1.32	3.91	8.75	1.20	3.20
F <sup>-</sup> (mg/l)	0.69	0.28	0.47	0.51	0.11	0.38
Cl <sup>-</sup> (mg/l)	95.07	52.79	63.33	107.68	52.10	63.19
NO <sub>2</sub> (mg/l)	0.87	0.00	0.27	2.44	0.00	0.50
NO <sub>3</sub> (mg/l)	8.04	2.31	5.55	9.89	2.03	6.45
PO <sub>4</sub> (mg/l)	1.72	0.00	0.70	2.30	0.00	0.79
SO <sub>4</sub> (mg/l)	257.18	199.45	221.61	246.70	202.12	218.68
CO <sub>3</sub> (mg/l)	44.32	0.00	19.88	37.76	0.00	13.14
HCO <sub>3</sub> (mg/l)	309.79	215.95	250.96	332.88	197.80	260.34
Li (mg/l)	0.06	0.04	0.05	0.06	0.02	0.04
Na (mg/l)	103.74	68.94	84.25	108.60	72.20	80.34
NH <sub>4</sub> (mg/l)	3.86	0.00	0.59	3.42	0.00	0.50
K <sup>+</sup> (mg/l)	9.76	5.74	7.37	9.17	5.85	6.94
Mg <sup>+2</sup> (mg/l)	53.31	42.92	45.40	47.43	39.16	43.91
Ca <sup>+2</sup> (mg/l)	98.87	73.76	81.72	88.25	73.63	81.81
TSS (mg/l)	53.29	1.72	8.87	4.99	1.26	2.90
Turbidity (NTU)	5.86	0.28	185	2.89	0.28	1.26
Hardness (FS)	46.59	36.33	39.04	41.52	34.48	38.47
COD (mg/l)	51.33	18.39	32.49	51.33	17.00	32.22
Total coliform (cfu/100ml)	4.5 × 10 <sup>6</sup>	1 × 10 <sup>6</sup>	2.2 × 10 <sup>6</sup>	8.7 × 10 <sup>5</sup>	0.00	2.4 × 10 <sup>6</sup>
Fecal coliform (cfu/100ml)	0.5 × 10 <sup>6</sup>	0.00	1.4 × 10 <sup>4</sup>	3 × 10 <sup>3</sup>	0.00	1.2 × 10 <sup>6</sup>
B (ppb)	1,389.40	446.60	715.19	1,449.50	469.50	725.26
Al (ppb)	1,088.06	3.46	233.43	1,215.40	0.00	256.34
Si (ppb)	19,604.00	950.71	10,381.45	21,785.00	350.15	8,295.65
P (ppb)	2,687.80	212.80	949.03	6,404.50	81.19	1,377.98
S (ppb)	3,234,800.0	6,920.75	1,174,766.41	3,076,000.00	844.10	819,679.72
V (ppb)	19.23	4.01	7.19	8,379.00	3.92	704.44
Cr (ppb)	25.13	0.28	5.68	14.55	0.04	3.02
Mn (ppb)	94.45	0.00	22.96	58.77	0.00	23.10
Fe (ppb)	432.40	38.25	255.34	389.05	18.66	185.04
Co (ppb)	1.05	0.02	0.50	116.30	0.00	10.14
Ni (ppb)	11.07	0.00	1.88	11.91	0.00	1.77
Cu (ppb)	44.65	0.00	14.21	57.20	0.00	10.08
Zn (ppb)	270.74	0.00	56.78	90.83	0.00	29.82
Ga (ppb)	5.14	0.92	2.45	5.38	0.00	1.97
Ge (ppb)	0.59	0.02	0.26	0.90	0.01	0.30
As (ppb)	21.92	7.28	12.70	22.89	0.00	10.99
Br (ppb)	334.20	33.07	149.45	375.45	13.61	124.17
Se (ppb)	37.99	0.00	10.63	34.67	0.00	9.45
Rb (ppb)	9.24	4.58	6.67	11.61	1.43	6.48
Sr (ppb)	2,101.60	763.89	1,503.48	2,188.00	6.73	1,197.85



**Table 3** continued

Parameter	Gökçekaya			Sarıyar		
	Max.	Min.	Avr.	Max.	Min.	Avr.
Mo (ppb)	34.26	3.66	9.23	1,436.00	3.67	138.37
Pd (ppb)	80.70	0.31	1.57	71.50	0.25	18.41
Ag (ppb)	0.60	0.00	0.14	0.38	0.00	0.09
Cd (ppb)	8.90	0.00	0.77	7.87	0.00	1.21
Sn (ppb)	3.04	0.00	1.29	5.49	0.00	1.54
Sb (ppb)	0.51	0.00	0.30	0.52	0.00	0.25
Te (ppb)	0.18	0.00	0.07	0.39	0.00	0.10
I (ppb)	13.90	4.29	9.19	13.74	0.11	8.30
Cs (ppb)	1.47	0.01	0.33	4.17	0.05	0.76
Ba (ppb)	71.75	22.5	48.65	60.88	0.13	42.42
Ce (ppb)	0.06	0.00	0.03	51.05	0.00	5.13
Pr (ppb)	0.01	0.00	0.00	0.06	0.00	0.01
Nd (ppb)	0.02	0.00	0.01	0.02	0.00	0.01
Sm (ppb)	0.01	0.00	0.00	0.01	0.00	0.00
Eu (ppb)	0.03	0.00	0.01	0.02	0.00	0.01
Au (ppb)	37.42	1.21	19.35	39.59	0.00	14.48
Hg (ppb)	2.96	0.00	0.65	2.31	0.00	0.57
Pb (ppb)	14.82	0.00	4.07	305.03	0.00	33.37
Th (ppb)	0.03	0.00	0.01	0.03	0.00	0.01
U (ppb)	9.02	2.52	4.73	5,271.08	0.01	443.06

in some other lakes in our country.  $\text{NO}_3\text{-N}$  change value for some lakes in Turkey has been determined as 0–0.09 mg/l for Keban, 0.004–2.55 mg/l for Kurtboğazi, 0–0.19 mg/l for Çubuk-I (Taş 2006), 0.69–3.90 mg/l for Ömerli, 10–25 mg/l for Mumcular (Yılmaz 2004).

Gökçekaya dam lake receives household waste water directly from Gökçekaya Dam Enterprises Facilities and Sarıyar Municipality which is close to the main inflow of the Lake. Although the main inflow rate of the Lake is low, *E. coli* and COD values in G4 and G5 stations increase in summer because the depth of these stations are low and the lake bed extends through a narrow valley. One of the reasons behind the water quality variation in these stations is that the water discharge gates of Sarıyar dam lake are not regularly opened. Therefore, the quality of the water (DO, pH, temperature, etc.) flowing to Gökçekaya dam lake deteriorates as it stays stagnant back in Sarıyar Dam water gates for a long time. The increase in the COD values resulted in a decrease in the dissolved oxygen level of the Lake water (Rittmann and McCarty 2001). DO value in aquatic environments may vary according to temperature, photosynthesis rate and trophic levels of lakes (Akbulut and Yıldız 2001). This is an expected result depending on the biological activity to occur.

The analysis revealed that the total number of coliform in the stations G4 and G5 in Gökçekaya dam lake was

higher in the surface (Table 3). These stations are located close to the area where the administrative and social facilities of the General Directorate of dam lake Electricity Enterprises are located. The household waste water produced in these facilities is discharged directly into the Lake without being exposed to any refining operation. The number of Coliform varies depending on the amount of water discharged into the lake from the facilities.

Gökçekaya dam lake extends through the valley for approximately 35 km like a large river bed. Both sides of the Lake have a topographic structure covered with rocks and trees. It was observed that the suspended solid values were low in terms of water quality due to the low surface flow rate and the high depth of the Lake. Therefore, the turbidity value of the water was quite low. The average turbidity value of the Lake water varied between 0.28 and 5.86 NTU in the 3-year period. The average sechi disk value varied between 3.9 and 6.7 m in the 3-year period. The reason why the TSS and turbidity values increase especially in the depths close to the lower base is that there is a mud structure on the lower base and also the water pumping may vacuum the bottom sediments.

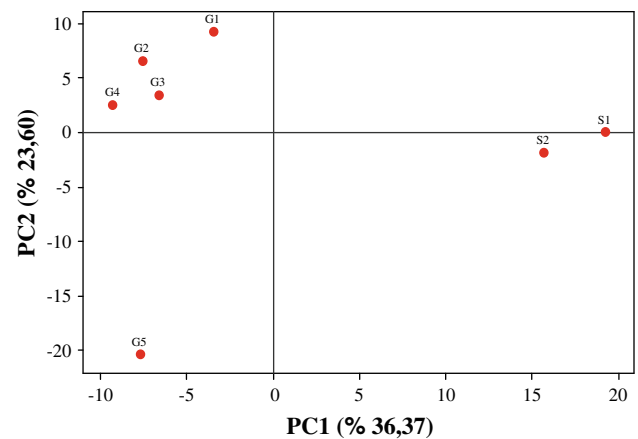
The analysis carried out in the Lake showed that  $\text{Ca}^{+2}$  and  $\text{Mg}^{+2}$  ion values of the water were high and that the average calcium value was around 82–99 mg/l and the average magnesium value was around 45–53 mg/l in the

3-year period (Table 3). Having especially high  $\text{Ca}^{+2}$  values can be related to the morphological structure of the region. In studies done in the region it was observed that limestone structures are very common (Varol and Kazancı 1981). When the entire lake is taken into consideration, it is seen that  $\text{Ca}^{+2}$  and  $\text{Mg}^{+2}$  values have not changed very significantly. Along the horizontal axis, differences of 4–7 mg/l in  $\text{Ca}^{+2}$  values and 1.5–4 mg/l in  $\text{Mg}^{+2}$  values are seen. At the same time, vertically, increases of 8–10 mg/l in  $\text{Ca}^{+2}$  values and 2–4 mg/l in  $\text{Mg}^{+2}$  values are seen. That is to say,  $\text{Ca}^{+2}$  and  $\text{Mg}^{+2}$  values increase with depth, even though very small in amount. When we consider that the anthropogenic factors are close to zero, it can be said that amounts of these minerals are varying according to the geological formations. The average water hardness values calculated according to these values were calculated as 39–46°FS in the 3-year period. Calcium and magnesium bicarbonates give temporary hardness, chloride, nitrate, sulfate, phosphate, and silicate thereof gives permanent hardness (Ünlü et al. 2008). The results of the analysis showed that the water quality of Gökçekaya dam lake was considered as “hard water”.

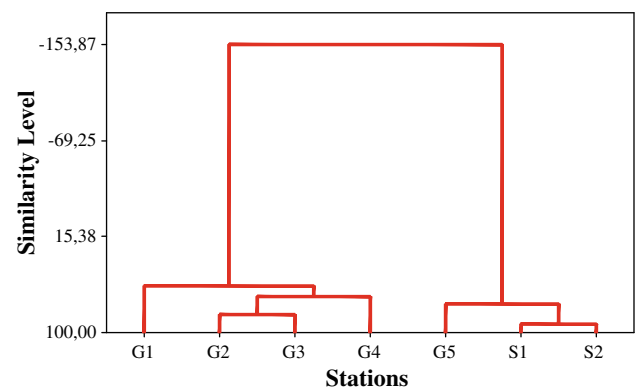
#### Heavy metal changes

Water samples were taken from the seven stations in Gökçekaya and Sarıyar dam lakes. In order to understand the correlation (relationship) between the heavy metal levels therein, within the scope of the present work and basic statistics and these sources in terms of heavy metals, PCA was applied (Kazi et al. 2009). PCA transforms original variables (heavy metal levels) into new and less variables among which there is no relationship. It is possible to see that the figure of the object scores obtained from the analysis is so close to the inspected objects (Zhou et al. 2008). Ultimately, clustering analysis was used in order to evaluate the similarities of the stations in terms of heavy metals. The Ward method was used as connection method for the data which were applied hierarchical clustering method (Ward 1963). The Euclidean distance criteria were also used as distance criteria (Zeng and Rasmussen 2005). Dendrogram was obtained using clustering analysis so that the classification can be visually and easily seen.

In the last phase of statistical studies on heavy metals, the differences between sources in terms of the average heavy metal values in the 3-year period and the seasonal and annual changes in the heavy metal levels were determined and interpreted by one-way variance analysis (Kruskal 1952). As evident from in Fig. 2, sources S1 and S2 are very close to each other in terms of heavy metal levels according to the 1st basic component (PC1). G1, G2, G3, and G4 stations are close to one another according to



**Fig. 2** According to the first two basic components, heavy metals, which were obtained by PCA explain approximately 60% of the total variance



**Fig. 3** The Dendrogram obtained by hierarchical clustering method which is applied using ward connection method and euclidian distance criteria

the second basic component (PC2). That is, there is no difference in the heavy metal levels of these stations. Station G5 which is seen alone in this graphic is close to the group including the stations G1, G2, G3, G4, and G5 according to the first basic component. The same is also seen close to the group including the stations S1 and S2 according to the second basic component. It is understood that station G5 is associated with both groups. In order to understand this grouping well, a clustering analysis was carried out.

Thanks to the heavy metal measurements obtained from the samples from sampling stations, the Dendrogram which shows the similarities between the stations in terms of heavy metals is given in Fig. 3. According to the figure, water sources can be classified as follows: Stations S1, S2, and G5 are in one group; stations G1, G2, G3, and G4 are in another group. Given the average heavy metal levels in the 3-year period, one-way variance analysis showed that there is no difference between the sampling stations.



Relationship between chlorophyll *a* values and total organism

All autotrophic living creatures perform photosynthesis by means of their chlorophylls, carotenoids and photosynthetic pigments. Since Chlorophyll *a* often found in all algae divisions, it is one of the methods used to determine algae biome indirectly in lacustrine environment (Costelloe et al. 2005; Kobbia et al. 1992).

When Chlorophyll *a* values' monthly seasonal distribution according to the stations was analyzed, the highest Chlorophyll *a* value was determined as 3.742 mg/l at the end of the summer in 2007. In the beginning of the spring in 2007, a decrease at Chl-*a* value was seen. The monthly distribution of the Chlorophyll *a* amount and the total organism number are given in Fig. 4 comparatively. The reason why Chl-*a* value is high in some seasons is the increase in the production of phytoplankton. In Gökçekaya Dam, especially Bacillariophyta members grab attention as the dominant group. Chlorophyta, Cyanophyta, and others follow them, respectively. Chl-*a* was at the same level in 2005 and 2006, and in 2007 it reached the highest and the lowest levels. In particular, according to the data in 2008, although there were significant statistical increases in the division of Bacilariophyta, Chl-*a* did not reach the maximum level. However, Chlorophyta levels increased during the same dates and this caused an increase in Chl-*a* values. Such changes reveal that increase in chlorophyll *a* value is an inevitable result through increase in the photosynthetic activity in springs and summers.

Chl-*a* and species diversity vary seasonally and some varieties are observed in accordance with the phytoplankton distribution. The reason why the organism number in Gökçekaya dam lake is low can be explained with water movements at the bottom of the dam and the use of the previous ground water as spring water. Throughout the study, the species of *Gomphonema lanceolatum*, *Cymbella*

*amphicephala*, *Cyclotella ocellata*, *Synedra ulna*, *Nitzschia palea*, *Chlorella vulgaris*, and *Scenedesmus communis* were observed in almost all seasons during the year and they were determined as dominant organisms. The statistical increases of these species affect the amount of Chl-*a*.

Change in algae diversity depending on water quality

Principal component analysis and hierarchical clustering analysis were used in investigating the change in algae diversity in the lake depending on the measured water quality parameters. As parameters: pH, temperature, EC, TDS, DO, TSS, turbidity, Na<sup>+</sup>, K<sup>+</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup>, total hardness, F<sup>-</sup>, Cl<sup>-</sup>, SO<sub>4</sub><sup>2-</sup>, Sechi dischi, Chl-*a*., Nitrite, Nitrate, Ammonia, Ortho-phosphate, and COD were used. First, the relationship between the sample stations in the lake and the values of these parameters was determined. According to the results of the hierarchical clustering analysis, there was no significant difference among the parameters measured in the stations. In other words, there was a slight difference among all the stations. The changes in the water quality showed similar tendencies in the 3-year period (Fig. 5).

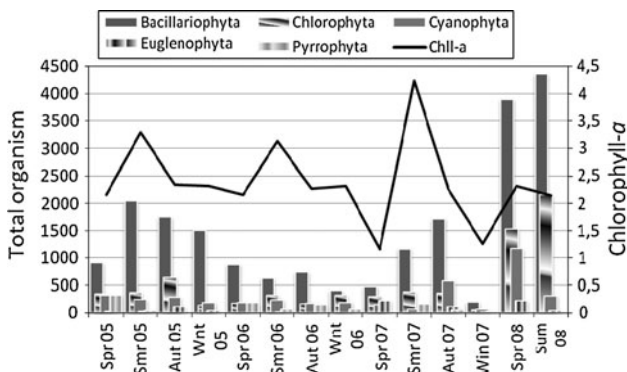


Fig. 4 Gökçekaya dam lake. Comparison between the seasonal distribution of Chlorophyll *a* amount and total organism number in the 3-year period

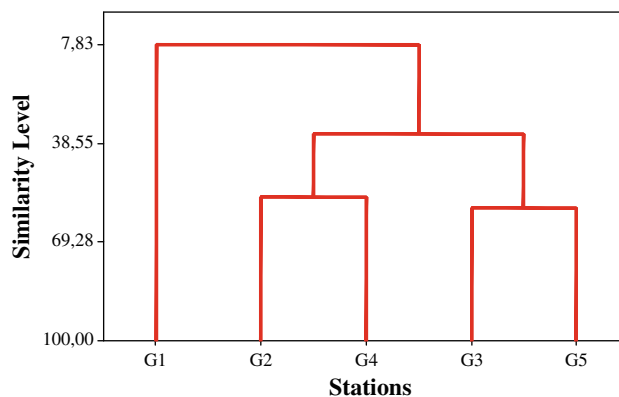


Fig. 5 Dendrogram obtained by hierarchical clustering method

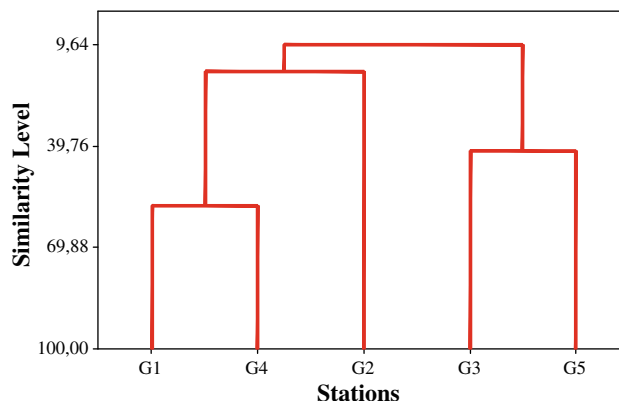
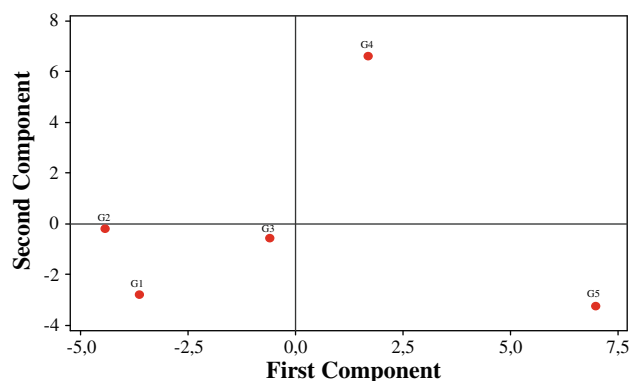


Fig. 6 The Dendrogram obtained by hierarchic clustering method



**Fig. 7** The scores of the two components which were obtained using principal component analysis between the algae types and the measured water quality parameters of the five sampling stations

Hierarchical clustering analysis was also used to determine whether the algae diversity differed from one station to another. Accordingly, it was seen that there was no significant statistical difference in the algae diversity depending on the stations (Fig. 6).

In order to explain the relationship between all the algae types observed in the stations and the measured water quality parameters, PCA was used. All the algae types and all the parameters were included in the analysis (Fig. 7). The analysis showed that there was no difference between the stations G1, G2, and G3 in terms of both components and these components (algae types and parameters) differed in the stations G4 and G5. This may have arisen from the fact that the stations G4 and G5 received household waste water inflows and that the stations were close to the tail gates of Sarıyar dam lake. Therefore, water quality values changed.

## Conclusions

In the present study in which experimental and multivariate statistical approaches were used, it was aimed to examine how water quality of a Lake is changed by an inflow from another dam lake's tail gates using a monitoring study. Water quality monitoring studies were carried out for 3 years in seasonal periods. They revealed that the water quality of Gökçekaya dam lake varied depending on normal bedding and seasonal conditions which can be seen in lakes. It was also seen that there was no significant difference between the stations in terms of heavy metal concentrations. Inflow water does not greatly affect heavy metal changes. According to the results thereof the algae diversity and populations differed a little in the stations which were close to the inflow water. There was no difference in other stations. Statistical methods effective in determining the effect of inflow water on water quality of a

Lake and in interpreting many parameters obtained by the analysis were used in the present study (PCA, CA). However, the sediment structures and the pollution which may arise from them should be determined in order to interpret the effect of inflow water properly.

**Acknowledgments** The research was supported by The Scientific and Technical Research Council of Turkey (TUBITAK) by the project No: 104Y067.

## References

- Akbulut A, Yıldız K (2001) Mogan lake (Ankara) and the distribution of planktonic Bacillariophyta members. *GU J Sci* 14:1081–1093
- Akin BS, Atici T, Katircioglu H (2008) Physicochemical, toxicological and ecological analysis of Gökçekaya dam lake. *Afr J Biotechnol* 7:444–449
- Anonymous (2010a) National watershed rehabilitation project. Workshop for National Watersheds Management Strategy Scope Determination Ministry of Environment and Forestry, Ankara
- Anonymous (2010b) Turkey's weather report statistics. Turkish State Meteorological Service, Ankara
- APHA (2005) Standard methods for the examination of water and wastewater, 21st edn. American Public Health Association, Washington, p 6710
- Bartolomeo AD, Poletti L, Sanchini G, Sebastiani B, Morozzi G (2004) Relationship among parameters of lake polluted sediments evaluated by multivariate statistical analysis. *Chemosphere* 55:1323–1329
- Bhuyan SJ, Koellikler JK, Marzen LJ, Harrington JA (2003) An integrated approach for water quality assessment of Kansas water shed. *Environ Model Softw* 18:473–484
- Boggero A, Barbieri A, Conedera M, Marchetto M, Mosello R, Tartari GA (1993) Land cover as a factor influencing the chemistry of mountain lakes in the western Alps. *Verh Int Verein Limnol* 25:772–775
- Brainwood A, Surgin S, Maheshwari B (2004) Temporal variations in water quality of farm dams: impacts of land use and water sources. *Agric Water Manag* 70:151–175
- Costelloe JF, Powling J, Reid JRW, Shiel RJ, Hudson P (2005) Algal diversity and assemblages in arid zone rivers of the lake Eyre basin, Australia. *River Res Appl* 21:337–349
- De Ceballos BSO, König A, De Oliveira JF (1998) Da reservoir eutrophication: a simplified technique for a fast diagnosis of environmental degradation. *Water Res* 32:3477–3483
- EIE (2008) Annual report. General Directorate of Electrical Power Resources Survey and Development Administration, Turkey
- Fair GM, Geyer JC, Okun DA (1971) Elements of water supply and wastewater disposal. 2nd edn ABD, p 513
- Galal-Gorchev H, Ozolins G, Bonnefoy X (1993) Revision of the WHO guidelines for drinking water quality. *Ann Institutionali Super Sanit* 29:335–345
- Gauch HG Jr (1982) Multivariate analysis in community ecology. In: Grieg-Smith P, Cambridge University Press, London, p 298
- Helena B, Pardo R, Vega M, Barrado E, Fernandez JM, Fernandez L (2000) Temporal evolution of groundwater composition in an alluvial aquifer (Pisuerga river, Spain) by principal component analysis. *Water Res* 34:807–816
- Kazi TG, Arain MB, Jamali MK, Jalbani N, Afridi HI, Sarfraz RA, Baig JA, Shah AQ (2009) Assessment of water quality of polluted lake using multivariate statistical techniques: a case study. *Ecotoxicol Environ Saf* 72:301–309

- Kobbia IA, Zaki MZ, Gad YM (1992) Ecology of phytoplankton in estuarine regions of Abua Tarfaia drain in Lake Quarun (Egypt). *Mansoura Sci Bull Egypt* 19:141–165
- Kruskal WH, Wallis WA (1952) Use of ranks in one-criterion variance analysis. *J Am Stat Assoc* 47(260):583–621
- Larson GL, McIntire MC, Karnaugh-Thomas E, Hawkins-Hoffman C (1995) Limnology of isolated and connected high-mountain lakes in Olympic National Park, Washington State, USA. *Arch Hydrobiol* 134:75–92
- Larson GL et al (1999) Integrating physical and chemical characteristics of lakes into the glacially influenced landscape of the Northern Cascade Mountains, Washington State, USA. *Environ Manag* 24:219–228
- Lind OT (1990) Reservoir eutrophication. *Arch Hydrobiol Beih Ergebn Limnol* 33:701–770
- Liu WX, Li XD, Shen ZG, Wang DC, Wai OWH, Li YS (2003) Multivariate statistical study of heavy metal enrichment in sediments of the Pearl River Estuary. *Environ Pollut* 121:377–388
- Mosello R, Marchetto A, Tartari GA, Bovio M, Castello P (1991) Chemistry of alpine lakes in Aosta Valley (N. Italy) in relation to watershed characteristics and acid deposition. *Ambio* 20:7–12
- Nakashima S, Yamada Y, Tada K (2007) Characterization of the water quality of dam lakes on Shikoku Island, Japan. *Limnology* 8:1–22
- Rittmann BE, McCarty PL (2001) *Environmental biotechnology: principles and applications*. McGraw Hill International Editions, UK
- Stout VM (1993) A comparison of high mountain lakes at different altitudes in southwest New Zealand. *Verh Internat Verein Limnol* 25:890–893
- Szymanowska A, Samecka-Cymerman A, Kempers AJ (1999) Heavy metals in three lakes in west Poland. *Ecotoxicol Environ Saf* 43:21–29
- SPSS (2007) <http://www.spss.com> Accessed 15 July 2007. Version 15
- Taş B (2006) Investigation of water quality of Derbent dam lake (Samsun). *Ekoloji* 61:6–15
- Taylan S, Arslan A, Yüksel O (2007) Surface water quality modeling: Yeşilirmak. 7th. National Congress of Environmental Engineering, İzmir, Turkey Congress Proceeding Book, pp 24–27
- Tepe Y (2009) Determination of the water quality of Reyhanlı Yenişehir Lake (Hatay). *Ekoloji* 70:38–46
- Tuğrul S, Polat ÇS (1995) Quantitative comparison of the influxes of nutrients and organic carbon into the Sea of Marmara both from anthropogenic sources and from the Black Sea. *Water Sci Technol* 34:115–121
- Ünlü A, Çoban F, Tunç MS (2008) Investigation of Lake Hazar water quality according to physical and inorganic chemical parameters. *J Fac Eng Arch Gazi Univ* 23:119–127
- Varol B, Kazancı N (1981) The Htho-and Mofacies properties of the Upper Jurassic/lower cretaceous carbonate sequence, in Nallihan-Seben (Bolu) region. *Bulletin of the Geological Society of Turkey* 24:31–38
- Ward JH (1963) Hierarchical grouping to optimize an objective function. *J Am Stat Assoc* 301:236–244
- WPCR (2004) Water pollution control regulations, Number: 25687, Ministry of Environment and Forests, Turkey
- Yılmaz F (2004) Physicochemical characterizations of Mumcular dam lake (Muğla-Bodrum). *Ekoloji* 50:10–17
- Zeng X, Rasmussen TC (2005) Multivariate statistical characterization of water quality in lake Lanier, Georgia, USA. *J Environ Quality* 34:1980–1991
- Zhou J, Ma D, Pan J, Nie W, Wu K (2008) Application of multivariate statistical approach to identify heavy metal sources in sediment and waters: a case study in Yangzhong, China. *Environ Geol* 54:373–380