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Assessment on phytoplankton composition and heavy metal pollution in a drinking water resource: Lake Terkos (Istanbul, Turkey)

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ABSTRACT

In this study, the level of water pollution in Lake Terkos, one of the important drinking water resources of Istanbul Metropolitan, was examined by determining the phytoplankton distribution, some physicochemical parameters, nutrients and heavy metal concentrations. For this purpose, samples were collected from eight sampling stations in March and September from the surface water. 34 taxa, from 8 divisions were categorized as Bacillariophyta (17), Charophyta (2), Chlorophyta (5), Cryptophyta (1), Cyanobacteria (5), Euglenozoa (2), Miozoa (1) and Ochrophyta (1). The habitat of blue-green algae *Anabaena spiroides* (Klebahn), which was found to be dominant in Lake Terkos, was identified as eutrophic as well as stratified signifying shallow lakes with low nitrogen content. Recording high reproduction of *Anabaena spiroides* particularly in autumn demonstrated that the characteristics of the lake was altering from mesotrophic to eutrophic. The measured heavy metal concentrations denote that the Lake Terkos was extremely polluted by some metals/metalloids. Particularly boron (B) and cadmium (Cd) concentrations show a class of 4 water quality. Since it fulfills the demand for drinking water in Istanbul to a large extent, it is crucial to take measures to improve the water quality of Lake Terkos urgently. Also it is considered that, limnological monitoring studies must be carried out continuously at the lake for controlling the water quality.

Keywords: Phytoplankton; Water pollution; Heavy metals; Nutrients; Drinking water resource

1. Introduction

Recently, climate change has attracted great attention in many scientific types of research as an important issue both in daily life and worldwide [1–5]. The fast consumption of available water resources and the contamination for various reasons including climate change effects, make it more difficult for humans to access healthy and safe water [6]. Rapid industrialization and increasing population, excessive urbanization, and unconscious use of natural resources cause water pollution issues [7,8].

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It is known that, depending on all of these reasons, water resources are seriously threatened day by day. One of the most important types of pollution to be considered in waters was reported as heavy metal pollution [9]. Either the presence of certain heavy metals in waters, or their concentrations going over specific levels create a serious threat to all aquatic organisms and finally to mankind who are situated at the top of the food chain. Inorganic compounds such as industrially originating cyanide, copper, mercury, lead, cadmium, arsenic, which combine and leak with wastes into waters, are natural degradation-resistant substances similar to chemical fertilizers, pesticides, and detergents [10]. Therefore, heavy metal pollution is a critical problem that must be solved primarily in aquatic environments [11,12]. The major heavy metals are Cd, Cr, Co, Cu, Fe, Hg, Mn, Ni, Pb, Se, V and Zn [13,14]. Some heavy metals such as As, Cd, Cr, Hg and Pb are toxic to living organisms, even when they exist in quite low concentrations. Natural constituents such as Cu, Fe and Zn are biologically fundamental and they become toxic just when they reach high concentrations [14]. Atmospheric accumulation, geological matrix erosion and anthropogenic activities such as industrial, domestic and mining wastes are known to cause heavy metal pollution in the aquatic environment [11,15].

Phytoplankton is one of the most important biological indicators used in water pollution studies in aquatic systems. Since they react rapidly to changes in water, phytoplankters are used as important bioindicators [16]. They are considered primary producers in aquatic environments and constitute the first ring of the food chain. Moreover, phytoplanktonic organisms may take in and accumulate heavy metals from aquatic environments [17,18]. Therefore, heavy metals accumulate not only in water bodies and sediments but also in phytoplankton in heavy metals contaminated waters. Previously, a few limnological investigations were carried out on zooplankton [19,20], waterborne fungi [21], phytoplankton composition [22], total metal levels in crayfish [23] and parasites on Tench Fish [24] in Lake Terkos. The phytoplankton composition of the lake, the feeding streams including some physicochemical parameters were examined by Yilmaz and Gulecal [25] in an earlier study. Day by day, the improvement and protection of existing water resources is becoming more and more important with the reorganization of usage of the areas. First of all, it is necessary to determine the water quality and pollution level by evaluating biological indicators, physicochemical parameters and heavy metal concentrations collectively in water resources. In this study, it is aimed to designate the level of pollution by examining the accumulation of some heavy metals, some nutrients and phytoplankton composition. Also this is the first paper on heavy metals concentrations on the lake water related to phytoplankton composition in Lake Terkos.

2. Materials and methods

2.1. Study area: Terkos Dam Lake

Terkos Dam Lake is situated on the European side of Istanbul, at a latitude of 40° 19′ N and 28° 32′ E (Fig. 1). The lake has a surface area of 25 km^2 and a maximum depth of 11.5 m [24]. Terkos Dam was built between the Marmara Sea and the Black Sea, to provide drinking water to Istanbul Metropolis. Many streams are feeding the lake and the stream with the highest inflow is Istranca Stream in the west. Although the link between the dam and the Black Sea was terminated in 1881; the water from wells drilled closer to the sea is pumped to Lake Terkos, to meet the increasing need for water because of the drought in recent times. The average yearly flow in Lake Terkos is 196 million m^3 and the lake area is used for recreation, fishery and hunting [25].

Europe designates the most valuable regions in terms of biodiversity and in 1999, the surroundings of Lake Terkos was identified as one of the 100 “hot spots” that should be put under protection urgently by means of a project, which was carried out in cooperation with World Wildlife Foundation and the Ministry of Environment and Forestry of Turkish Republic [26]. Lake Terkos and its close surroundings are located on the important bird paths passing through the Bosporus, one of the main migration routes on the earth, where raptors, storks, and thousands of birds pass twice a year and some of them stop and feed. While 57 of the species hosted by Lake Terkos are listed in the list of International Prior Bird Species on the European Scale; 86 species of birds living in the lake and its surroundings are also included in Annex II of the Berne Convention was designated as Important Bird Area (IBA) in 1992 due to these characteristics [26].

Around the lake, a transitional climate between the Mediterranean and Black Sea climates, and also terrestrial climate characteristics are observed. Existence between the European and Asian flora geographically of Lake Terkos has led to the emergence of extremely rich wetland vegetation containing local and rare plant species. More than 50 hydrophytes have been identified in the shallow waters of the lake and the swamps on the lake, including rare distributed species in Turkey such as *Stratiotes aloides* and *Vallisneria spiralis*. Commonly recorded species in the coastal area of the lake are *Phragmites australis*, *Typha* sp., and *Schoenoplectus lacustris*. Lake Terkos is also rich in freshwater fauna. Economically valuable fish species such as *Cyprinus* sp., *Proterorhinus* sp., *Chalcalburnus* sp., *Abramis* sp., *Blicca* sp., *Tinca* sp., *Scardinius* sp., *Rhodeus* sp., *Gobius* sp., *Esox* sp., *Silurus* sp. and *Lucioperca* sp. live in the lake [26].

2.2. Phytoplankton composition

This study was conducted at eight different sampling points, which represented all of the lake in March (spring) and September (autumn) (Fig. 1). Water samples were collected from the surface by using Nansen bottles and afterwards were fixed with Lugol’s iodine solution in the field for phytoplankton identification. Phytoplankton density was forecasted according to Lund et al. [27] using an inverted microscope in the laboratory. Phytoplankton species were defined according to the literature on the subject [28–36]. All identified species at Lake Terkos were checked in Algaebase website [37].

Nygaard’s compound index [38] and Palmer’s index [39] were applied for designating the trophic state of the lake with the recorded phytoplankton species. Nygaard’s

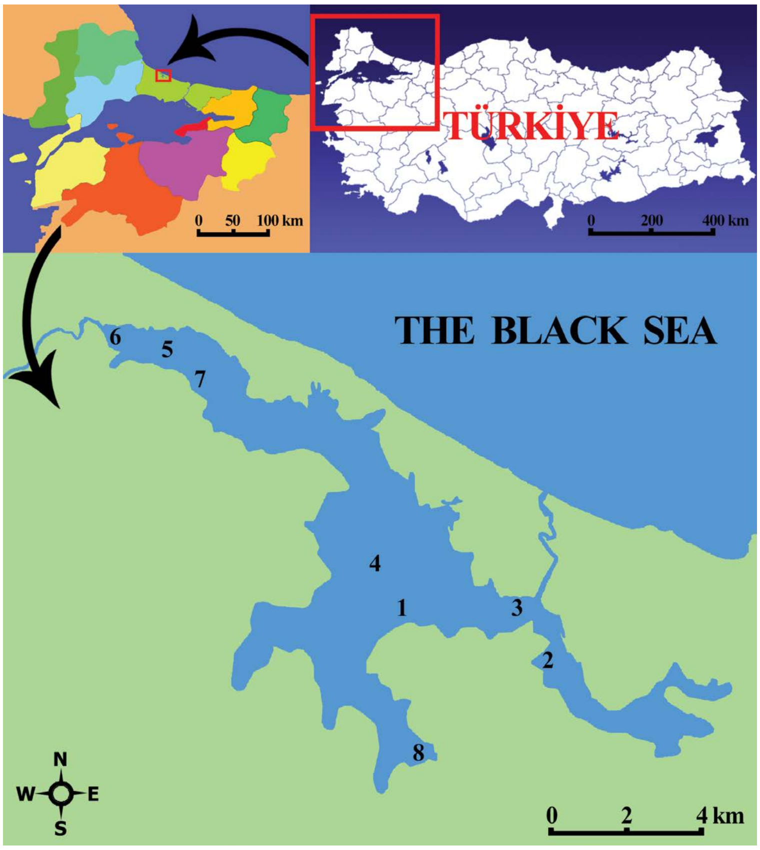

Fig. 1. Map of Lake Terkos and studied locations. 1-Tasliburun, 2-Balaban Village, 3-Dam front, 4-Middle of the lake, 5-Celepkoy Village, 6-Ormanli Creek, 7-Orencik Village, 8-Durusupark Hotel Shoreline.

compound index may figure out as the total species numbers of the groups of Cyanophyceae, Chlorococcales, Centric Diatoms, and Euglenophyceae divided by Desmidiales. While values below 2 indicate oligotrophic, between 2 and 6 weak eutrophic and values above 6 eutrophic lakes [38]. Palmer's index can be calculated according to the presence of phytoplankton genera able to tolerate organic pollution. For this reason, certain scores from 1 to 5 were given to each selected total of 20 organic pollution indicator genus and larger scores refer to higher pollution levels. When scores of recorded genera were multiple according to each species score, 20 and higher values show a high organic pollution load. Values from 15 to 19 indicate that the organic pollution is moderate and values less than 15 refer that there is no organic contamination [39].

2.3. Analysis of water samples

Water temperature, pH, dissolved oxygen, salinity, and electrical conductivity were analyzed in the study area by the WTW Multi 340i/set made multiparameter. Water samples, which were put into sterile 50 mL falcon tubes, were filtered through blue band filter paper at the laboratory and transferred to other sterile 50 mL falcon tubes. The dilution process with a ratio of 1/10 was performed in a new falcon tube from filtered samples using 1% HNO_3. After these processes, Al, B, Ca, Cd, Cr, Cu, Fe, K, Mg, Na, Pb, and Zn elements were examined by using multielement ICP standard procedures (Merck) [11,40].

2.4. Applied statistical analysis

Heavy metal and mineral element concentrations are shown in Table 4. These values were obtained using the multivariate analysis of variance (MANOVA) with the Tukey test using the IBM SPSS Statistics 25 software program. A statistically significant difference was assessed at two levels as $^{**}p < 0.01$ and $^{*}p < 0.05$. Sampling stations and seasons were chosen as factors for Manova tests [41].

3. Results

3.1. Phytoplankton composition

A total of 34 taxa in Bacillariophyta (17), Charophyta (2), Chlorophyta (5), Cryptophyta (1), Cyanobacteria (5), Euglenozoa (2), Miozoa (1) and Ochrophyta (1) groups were identified (Fig. 2; Table 1). The blue-green algae *Anabaena spiroides* was determined as the dominant species at the lake. The minimum density of phytoplankton was recorded as 87 individual/cm^3 at station 6 (Ormanlı Creek) in March and maximum phytoplankton density was recorded as 14,697 individual/cm^3 in September at station 3 (dam front).

The Bacillariophyta division was defined as dominant in terms of numbers of the species as they were reported in

Table 1
List of recorded taxa of phytoplankton at Lake Terkos (M: March, S: September).

RECORDED TAXA	St.1		St.2		St.3		St.4		St.5		St.6		St.7		St.8	
	M	S	M	S	M	S	M	S	M	S	M	S	M	S	M	S
DIVISION: BACILLARIOPHYTA																
Amphora ovalis (Kütz.) Kützing										+				*		
Aulacoseira italica (Ehr.) Simonsen	+	+		+		+		+		+		+		*		
Asterionella formosa Hassall		+		+										*		
Cocconeis placentula Ehrenberg	+	+	+		+	+		+		+			+	*	+	
Cyclotella atomus Hustedt	+	+	+	+	+	+				+		+		*	+	+
Cyclotella ocellata Pantocsek	+	+	+	+	+	+	+		+	+	+	+		*	+	+
Cymbella affinis Kützing	+	+	+				+	+	+	+	+		+	*	+	
Cymbella tumida (Bréb.) Van Heurck	+	+	+				+	+	+	+	+		+	*	+	
Diploneis sp.														*	+	
Epithemia sp.									+					*		
Fragilaria crotonensis Kitton	+													*		
Gomphonema clavatum Ehrenberg	+		+						+		+		+	*		
Melosira varians C. Agarth	+	+		+		+	+	+		+		+		*		
Navicula cryptocephala Kützing	+		+				+	+	+	+	+		+	*		
Navicula cuspidata (Kütz.) Kützing	+		+				+	+	+	+	+		+	*		
Ulnaria acus (Kütz.) M. Aboal	+	+	+	+	+				+					*	+	
Ulnaria ulna (Nitzsch) P. Compère	+	+	+		+		+	+	+	+	+		+	*	+	
DIVISION: CHAROPHYTA																
Closterium acutum Brébisson						+		+		+		+		*		
Cosmarium depressum (Näeg.) P. Lundell	+							+	+					*		
DIVISION: CHLOROPHYTA																
Kirchneriella sp.					+									*		
Monoraphidium falcatus (Corda) Ralfs	+								+	+		+		*		
Pediastrum simplex Meyen						+								*		
Scenedesmus quadricauda (Turpin) Brébisson		+		+	+			+		+		+		*		
Scenedesmus sp.		+			+									*		
DIVISION: CRYPTOPHYTA																
Cryptomonas ovata Ehrenberg		+	+	+			+		+			+	+	*	+	+
DIVISION: CYANOBACTERIA (=CYANOPHYTA)																
Anabaena spiroides Klebahn		+		+		+		+		+		+		*		
Aphanizomenon flosaquae Ralfs ex Bornet & Flauhault										+				*		
Merismopedia glauca (Ehr.) Kützing	+		+											*		+
Microcystis aeruginosa (Kütz.) Kützing	+													*	+	
Oscillatoria tenuis C. Agarth ex Gomont		+		+		+		+		+	+	+	+	*		
DIVISION: EUGLENOZOA (=EUGLENOPHYTA)																
Euglena gracilis G. A. Klebs							+							*		+
Trachelomonas hispida (Perty) Stein				+										*		+
DIVISION: MIOZOA (=DINOPHYTA)																
Peridinium bipes Stein	+	+	+	+	+		+	+		+		+		*		+
DIVISION: OCHROPHYTA																
Dinobryon sp.	+													*		

*Phytoplankton species could not be identified due to excessive particulate matter in the samples.

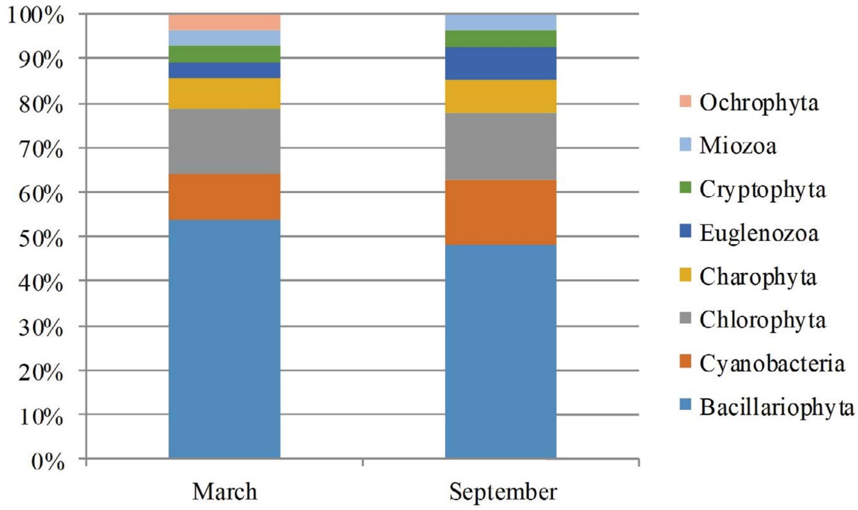

Fig. 2. Percentage distribution of phytoplankton groups in Lake Terkos according to the sampling periods.

many investigations carried out in Turkish lakes [25,42–45]. Bacillariophyta was represented by 17 species. The *Cyclotella atomus* and *Cymbella ocellata* of Stephanodiscales order were of most frequently recorded species and this genus indicated mesotrophic lakes with species sensitivity to the onset of stratification in many investigations [46,47]. *Aulacoseira italica*, a member of mesotrophic and eutrophic waters [48], was found generally in samples that were collected in September. A characteristic inhabitant of eutrophic and inorganically turbid shallow lakes, the *Ulnaria ulna* was one of the most recorded taxa in Terkos Dam Lake. It was stated that *Ulnaria acus*, frequently found in lakes and mostly in shallow, enriched turbid waters, was sensitive to nutrient depletion [44,46,48,49]. In this study, it was identified generally in March samples in stations 1, 2, 3, 5, and 8. *Cocconeis placentula* was recorded in all sampling points except station 6. *Cymbella affinis* and *Cymbella tumida* were found in all sampling points except station 3. *Navicula cuspidata* and *Navicula cryptocephala* were found at all stations, except stations 3 and 8. A species of mixed, eutrophic small and medium lakes, the *Asterionella formosa* [48] was recorded only at stations 1 and 2 in September. This species was defined to be dominant in Sapanca Lake, which has mesotrophic characteristics [43]. *Aulacoseira italica*, *Ulnaria ulna* and *Cocconeis placentula* of diatoms were recorded as dominant in Lake Kaz [42].

Charophyta was represented by *Closterium acutum* and *Cosmarium depressum* of the Desmidiales order. According to Palmer [39], most species of desmids could exist in oligotrophic waters and very few in eutrophic waters [44]. *Cosmarium depressum* was registered at stations 3, 4, 5, and 6 in low numbers, which indicated mesotrophic waters [48]. Members of Desmidiales order are very sensitive to chemical variations of water and generally prefer acidic waters and used as indicators in aquatic systems [50]. During the study period, desmids were found rarely in low numbers as they were catalogued in many oligotrophic, mesotrophic, and eutrophic lakes in Turkey [43–45]. Chlorophyta members usually exist extensively in mesotrophic and eutrophic lakes [47]. In this study, Chlorophyta division was represented by five species. *Monoraphidium falcatus* were recorded at stations 1, 5, and 6; *Scenedesmus* sp. at stations 1 and 3; *Scenedesmus quadricauda* at all stations except for stations 7 and 8. It is known that *Monoraphidium* species are found to be dominant in oligotrophic and mesotrophic lakes; *Scenedesmus* species are prominent in shallow, highly enriched systems and they are frequently dominant in freshwater lakes and rivers [48]. Also, it has been reported that *Scenedesmus* species are abundant in oligo-mesotrophic reservoirs and in eutrophic lakes in Turkey [44].

Cryptophyta were represented by *Cryptomonas ovata* rarely in very low numbers. It was stated that *Cryptomonas ovata* generally existed in small enriched lakes and low light tolerance was found in low numbers [48,49]. Cyanobacteria were represented by five taxa and members of this group usually prefer eutrophic environments [51]. In this study, *Anabaena spiroides* of blue-green algae, the organism that produces toxin, was found to be the dominant species. It was recorded at all sampling points except stations 7 and 8. *Aphanizomenon flos-aquae* was present only at station 5 in September. *Merismopedia glauca*, a characteristic of summer epilimnia in mesotrophic lakes [48], was detected only at stations 1, 2, and 8. *Oscillatoria tenuis* was encountered at all stations except station 8; *Microcystis aeruginosa* was registered at stations 1 and 8 in March. Species belonging to *Oscillatoria* and *Microcystis* genera are known as the cause of excessive blooms. *Microcystis aeruginosa*, a cyanobacterium that usually inhabits eutrophic waters, is responsible for the formation of toxic water blooms. Shallow, warm as well as eutrophic reservoirs maintain ideal conditions for the development of *Microcystis aeruginosa* [48,49]. It is stated that *Microcystis* is danger to public health, all aquatic organisms, and migratory birds by secreting toxin in the lake ecosystem.

Euglenozoa (newly named instead of Euglenophyta) was represented very rarely in low numbers by *Euglena gracilis* and *Trachelomonas hispida*. It is noted that, *Euglena gracilis* exist mainly in waters with high organic pollution and *Trachelomonas hispida* typically are found in shallow mesotrophic lakes [48,49]. Miozoa (newly named instead of Dinophyta) was represented only by *Peridinium bipes*.

According to Reynolds et al. [48], the habitat of *Peridinium* is summer epilimnia in mesotrophic lakes. *Peridinium bipes*, which was recorded frequently in the current study may cause excessive blooms called red-tide under suitable conditions. This species is known to be judged as one of the harmful algae in aquatic systems [52]. Ochrophyta division was represented by *Dinobryon* sp., which was found only at station 1 in March in very low numbers. It is stated that this is a species of oligotrophic waters.

3.2. Physicochemical parameters and heavy metal concentrations

During the study period, the measured dissolved oxygen concentrations ranged from 3.41 to 8.44 mg L^{-1}, the temperature varied from 13.8°C to 15.8°C, pH fluctuated between 7.62 and 8.74, electrical conductivity shifted between 286 and 482 μS cm^{-1} (Table 2). The maximum dissolved oxygen concentrations were recorded in spring (March) at station 8, which was selected from the shoreline of a hotel called Durusupark Hotel. Also the highest pH was measured in spring at station 3, located in front of the dam bent. No salinity concentrations were measured in spring and autumn water samples at all stations.

The lowest and highest concentrations of heavy metal and mineral nutrients of water samples calculated were; Al (0.210–0.272 mg L^{-1}), B (0.864–1.407 mg L^{-1}), Ca (221.625–315.326 mg L^{-1}), Cd (0.004–0.013 mg L^{-1}), Cr (0.013–0.038 mg L^{-1}), Cu (0.009–0.026 mg L^{-1}), Fe (0.216–0.331 mg L^{-1}), K (100.877–175.828 mg L^{-1}), Mg (122.997–216.514 mg L^{-1}), Na (160.377–240.528 mg L^{-1}), Pb (0.007–0.021 mg L^{-1}), and Zn (0.127–0.202 mg L^{-1}).

In this study, values of electrical conductivity were evaluated in the standard limits (150–500 μS cm^{-1}) of the protocols allocated to protect surface water sources from pollution [53]. It was determined that the water of Terkos Dam is slightly alkaline (within normal limits) and the water is of class I and II quality according to the calculated pH results (Table 2). B and Cd concentrations were gauged at a much higher level than permitted by the United States Environmental Protection Agency [54] (Table 3) and Water Pollution Control Regulations of Turkey [55].

In terms of Cr and Zn concentrations, the dam is of class I; in terms of Al, Cu, Fe, and Pb concentrations and the water quality is of class I and II. The dam has IV water quality characteristics according to B and Cd concentrations. Ca and Na concentrations of the lake assessed indicate a class of III water quality. The appraised K (100.877–175.828 mg L^{-1}) and Mg (122.997–216.514 mg L^{-1}) concentrations were found to be higher than the class of I and II water quality characteristics specified by EPA [54].

In parallel, when the minimum phytoplankton density was recorded in March in station 6; the minimum concentrations of Al, Cd, and Pb were also calculated. This may be an indicator of heavy metal accumulation of phytoplankters from aquatic environments. Whilst the maximum concentrations of Al, B, Cu, Pb, and Zn were registered at station 8 in September; there were only seven taxa of phytoplankton: *Cyclotella* species of diatoms, *Cryptomonas ovata* of Cryptophyta, *Merismopedia glauca* of blue-green algae, *Peridinium bipes* of Miozoa, *Euglena gracilis* and *Trachelomonas hispida* of Euglenozoa divisions. We can say that these species have resistance to these high heavy metal concentrations in Lake Terkos. The highest concentrations of Cd and Fe were measured at station 2 in September.

Table 3
Trace element based freshwater classification

	I	II	III	IV
Al μg L^{-1}	300	300	1,000	>1,000
B μg L^{-1}	1,000	1,000	1,000	>1,000
Ca mg L^{-1}	75	200	800	–
Cd μg L^{-1}	3	5	10	>10
Cr μg L^{-1}	20	50	200	>200
Cu μg L^{-1}	20	50	200	>200
Fe μg L^{-1}	300	1,000	5,000	>5,000
K mg L^{-1}	20	50	–	–
Mg mg L^{-1}	50	150	–	–
Na mg L^{-1}	125	125	250	>250
Ni μg L^{-1}	20	50	200	>200
Pb μg L^{-1}	10	20	50	>50
Zn μg L^{-1}	200	500	2,000	>2,000

Sources: United States Environmental Protection Agency (EPA) [54] and Water Pollution Control Regulations of Turkey [55].

Table 2
Some measured physicochemical parameters of Lake Terkos

	Dissolved O_2 (mg L^{-1})		pH		Temperature (°C)		Electrical conductivity (μS cm^{-1})	
Sampling stations	March	Sept.	March	Sept.	March	Sept.	March	Sept.
St.1: Tasliburun	6.86	4.22	8.58	8.55	13.8	15.6	340	292
St.2: Balaban Village	7.33	4.29	8.57	8.55	14.1	15.7	301	288
St.3: Dam front	7.72	3.87	8.74	8.34	14.9	15.1	290	288
St.4: Middle of the lake	6.07	4.16	8.52	8.51	14.6	15.4	286	286
St.5: Celepkoy Village	6.31	5.13	8.08	8.36	15.4	15.7	277	385
St.6: Ormanli Creek	6.86	3.41	8.33	7.83	15.8	14.3	305	482
St.7: Orencik Village	7.37	4.21	8.14	8.47	15.7	14.5	420	288
St.8: Durusupark Hotel Shoreline	8.44	4.27	7.62	8.50	15.1	14.9	325	289

There were recorded 12 taxa of phytoplankton: *Aulacoseira italica*, *Asterionella formosa*, *Ulnaria acus*, *Melosira varians*, *Cyclotella atomus* and *Cyclotella ocellata* of Bacillariophyta; *Scenedesmus quadricauda* of Chlorophyta, *Cryptomonas ovata* of Cryptophyta; *Anabaena spiroides* and *Oscillatoria tenuis* of Cyanobacteria; *Trachelomonas hispida* of Euglenozoa and *Peridinium bipes* of Miozoa divisions. These phytoplankters are established as the resistant species to Cd and Fe pollution in Lake Terkos.

In addition to the element values of Lake Terkos water samples shown in Table 4, Manova-Tukey HSD test results are presented. When these results are examined; the test results of Al, B, Ca, K, Mg, and Na elements reveal a significant difference ($p < 0.01$ and 0.05). Our study took place at a total of eight stations: For Al; while stations 1-2-8 formed one group, stations 3-4-5-7 constituted a second group and station 6 comprised a third group independent of the other two. For B; stations 1-2-8 formed a group, stations 3-4 composed a second group and stations 5-6-7 were combined to form a third group independent of the other two. For Ca; stations 2-8 formed one group, stations 1-3-4 a second group and stations 5-6-7 a third group independent of the other two. For K; stations 2-8 formed one group, stations 1-4 a second group and stations 3-5-6-7 formed a third group independent of the other two. For Mg; stations 1-2-8 formed one group, stations 3-4 a second group, stations 5-6 stations a third group independent of the other two. However, the 7th station was included in the same class with 3-4-5-6 stations. For Na; stations 1-2-8 were combined to form one group, stations 3-4-5 a second group and stations 6-7 a third group independent of the two. This study was carried out at 8 stations and the test results of Al, B, Ca, K, Mg, and Na elements revealed that three types of content differed fundamentally from each other.

Phytoplankton of the lake includes diatoms, blue-green algae *Anabaena spiroides* and green algae members. When we compared our study with that of Yilmaz and Gulecal [25], no significant change in species diversity according to phytoplankton groups was observed; only a few increases in diatom species diversity were identified. While the cyanobacterium *Anabaena spiroides* was observed as the dominant species in the current study, the *Aulacoseira italica* of diatoms were found to be the dominant species in the earlier study carried out by Yilmaz and Gulecal [25]. The habitat of *Anabaena spiroides* is known to be eutrophic, stratified as well as shallow lakes with low nitrogen content. Significant high reproduction of this species particularly in autumn suggested that the trophic structure of the lake is changing from mesotrophic to eutrophic. Increased nutrient input to the lake, especially N and P, affected the biological productivity of the lake [56]. The seasonal and yearly concentration changes of N and P were dependent on both the river water runoff and intensity of phytoplankton development [57]. Also it is supported by the presence of other mesotrophic and eutrophic species and by high levels of some heavy metals and nutrients.

As mentioned above, the measured B and Cd concentrations showed that Lake Terkos belonged to class 4 of water quality. Literature indicated that Cd accumulation was dependent on the chemical properties of aquatic environments. Also, Cd accumulation occurred in a concentration-dependent manner and furthermore some ions such as Ca^{2+} and Mg^{2+} have protective effects on aquatic organisms against Cd toxicity [58,59]. The competition of these ions with Cd suppressed its toxicity [59,60]. As a result of the chemical similarities, there is an antagonism between Ca^{2+} and Cd^{2+} cations and they compete with each other in both uptake and accumulation processes in plants [61]. Although Cd and its compounds have better solubility in water than other metals, the relatively higher concentrations of Ca and Mg in the Lake Terkos could be an advantage for living organisms in the lake. Nevertheless, this could be problematic for people when used as drinking water for humans.

Like many heavy metals, natural (soils and rocks, coal, volcanic eruptions) and below-mentioned anthropogenic sources release Cd to the environment. Some important sources of anthropogenic cadmium pollution include industrial processes (manufacturing of batteries, plastics and metal coatings, pigments, and the industry of electroplating), urban traffic, incineration of solid waste, cement factories, mining, smelting, smoking, phosphate fertilizers, pesticides and sewage water used for irrigation [62,63]. There have been some reports on Cd-caused skeletal demineralization, renal dysfunction, endothelial dysfunction as well as carotid intima-media thickness and formation of atherosclerotic plaques in hearth, acute central and peripheral neurotoxicity [64–66]. Also, cadmium compounds were categorized as carcinogenic in humans especially for lung, prostatic and renal cancers [67–69]. In the study area, near Lake Terkos although there is not much, the area is under the pressure of almost 20,000,000 residents of Istanbul and anthropogenic activities such as traffic and farming could be the major reason of the high Cd concentrations in the Lake.

Natural boron sources are volcanic and hydrothermal activities, physical and chemical weathering, high-temperature hydrothermal vents, fluids from subduction zones and sedimentation. The main anthropogenically derived B sources to the environment are mining, biomass burning, deforestation, charcoal, combustion of agricultural remains, manmade fires, incineration of wastes and (iii) fossil fuel combustion including coal combustion [70]. Natural as well as anthropogenic sources together could be the sources of the higher B in the Lake.

Boron in the boric acid form dissolves rapidly in body water of humans and animals and can pass across the mammalian placenta. It also equally localizes to the blood, adrenals, brain, epididymis, kidneys, liver, muscle, seminal testes and vesicles [71,72]. Furthermore, boron sources such as boric acid and sodium borates have been shown to have a toxic effect on reproduction and development in animal studies in high doses. Also there are some reports suggesting negative effects of boron on developmental, male and female reproductive toxicity [72] as well as on congestion, inflammation, exfoliative dermatitis, renal epithelial cells degeneration, edema and swelling. In the risk assessments data on diet or water level, it is stated that high levels of sodium borate and boric acid in diet and water cause toxicity [73,74].

Nygaard's compound index [38] and Palmer's index [39] are accepted as the main biological indices used to determine the trophic status of lakes according to the phytoplankton

Table 4
Heavy metal and mineral nutrient concentrations (mg L^{-1}) according to sampling sites in Lake Terkos

Lake Terkos		Station 1		Station 2		Station 3		Station 4		Station 5		Station 6		Station 7		Station 8	
		Ave.	St.D.(±)	Ave.	St.D.(±)	Ave.	St.D.(±)	Ave.	St.D.(±)	Ave.	St.D.(±)	Ave.	St.D.(±)	Ave.	St.D.(±)	Ave.	St.D.(±)
Al	March	0.235^{a}	0.005	0.246*^{a}	0.007	0.221*^{b}	0.010	0.218**^{b}	0.003	0.213*^{b}	0.005	0.210*^{c}	0.005	0.214**^{b}	0.005	0.249**^{a}	0.005
	September	0.259^{a}	0.007	0.271*^{a}	0.006	0.241*^{b}	0.003	0.235**^{b}	0.004	0.222*^{b}	0.005	0.225*^{c}	0.007	0.231**^{b}	0.004	0.272**^{a}	0.008
B	March	1.132^{a}	0.023	1.241**^{a}	0.037	1.025*^{b}	0.044	1.032*^{b}	0.012	0.864**^{c}	0.022	0.921*^{c}	0.021	0.878*^{c}	0.019	1.246*^{a}	0.023
	September	1.302^{a}	0.034	1.369**^{a}	0.028	1.165*^{b}	0.013	1.156*^{b}	0.022	1.025**^{c}	0.023	1.103*^{c}	0.033	1.032*^{c}	0.018	1.407*^{a}	0.043
Ca	March	265.331^{b}	5.387	283.624**^{a}	8.569	241.320**^{b}	10.382	246.947*^{b}	2.976	221.625**^{c}	5.603	230.312*^{c}	5.373	225.764*^{c}	4.834	291.614*^{a}	5.414
	September	301.218^{b}	7.926	315.326**^{a}	6.402	270.696**^{b}	3.032	280.784*^{b}	5.229	250.911**^{c}	5.599	250.447*^{c}	7.425	245.629*^{c}	4.292	311.454*^{a}	9.410
Cd	March	0.009	0.000	0.012	0.000	0.007	0.000	0.008	0.000	0.004	0.000	0.004	0.000	0.005	0.000	0.010	0.000
	September	0.012	0.000	0.013	0.000	0.009	0.000	0.010	0.000	0.005	0.000	0.006	0.000	0.007	0.000	0.012	0.000
Cr	March	0.025	0.001	0.031	0.001	0.021	0.001	0.019	0.000	0.013	0.000	0.015	0.000	0.014	0.000	0.029	0.001
	September	0.033	0.001	0.038	0.001	0.026	0.000	0.024	0.000	0.019	0.000	0.020	0.001	0.018	0.000	0.035	0.001
Cu	March	0.016	0.000	0.019	0.001	0.013	0.001	0.015	0.000	0.010	0.000	0.009	0.000	0.010	0.000	0.020	0.000
	September	0.020	0.001	0.023	0.000	0.016	0.000	0.018	0.000	0.013	0.000	0.011	0.000	0.015	0.000	0.026	0.001
Fe	March	0.291	0.006	0.305	0.009	0.271	0.012	0.265	0.003	0.216	0.005	0.220	0.005	0.218	0.005	0.284	0.005
	September	0.315	0.008	0.331	0.007	0.282	0.003	0.276	0.005	0.224	0.005	0.231	0.007	0.229	0.004	0.302	0.009
K	March	121.621^{b}	2.469	132.625*^{a}	4.007	112.326*^{c}	4.832	120.847*^{b}	1.456	103.629**^{c}	2.620	100.877*^{c}	2.353	109.646**^{c}	2.348	139.668**^{a}	2.593
	September	151.326^{b}	3.982	160.388*^{a}	3.257	130.574*^{c}	1.463	140.277*^{b}	2.613	121.625**^{c}	2.714	118.664*^{c}	3.518	115.602**^{c}	2.020	175.828**^{a}	5.312
Mg	March	162.284^{a}	3.295	169.625**^{a}	5.125	150.306**^{b}	6.466	146.958**^{b}	1.771	122.997**^{c}	3.110	130.457**^{c}	3.044	135.699**^{bc}	2.905	173.625**^{a}	3.223
	September	206.645^{a}	5.438	211.958**^{a}	4.304	198.124**^{b}	2.219	190.177**^{b}	3.542	152.732**^{c}	3.408	156.242**^{c}	4.632	160.914**^{bc}	2.812	216.514**^{a}	6.542
Na	March	201.330^{a}	4.088	213.625*^{a}	6.454	182.326*^{b}	7.844	190.312**^{b}	2.293	175.326*^{b}	4.433	169.625*^{c}	3.957	160.377**^{c}	3.434	208.228**^{a}	3.866
	September	232.619^{a}	6.121	240.528*^{a}	4.884	212.214*^{b}	2.377	216.657**^{b}	4.035	202.301*^{b}	4.514	198.635*^{c}	5.889	190.041**^{c}	3.321	235.881**^{a}	7.127
Pb	March	0.013	0.000	0.015	0.000	0.010	0.000	0.011	0.000	0.007	0.000	0.007	0.000	0.008	0.000	0.018	0.000
	September	0.017	0.000	0.019	0.000	0.013	0.000	0.013	0.000	0.009	0.000	0.010	0.000	0.011	0.000	0.021	0.001
Zn	March	0.164	0.003	0.175	0.005	0.156	0.007	0.161	0.002	0.147	0.004	0.131	0.003	0.127	0.003	0.180	0.003
	September	0.181	0.005	0.188	0.004	0.169	0.002	0.175	0.003	0.159	0.004	0.148	0.004	0.140	0.002	0.202	0.006

The mean difference is significant at **p < 0.01 and *p < 0.05 level by the Tukey's test (a, b, c) and MANOVA.

species recorded. Nygaard's compound index was found to be 8 for Lake Terkos, indicating eutrophic waters. Palmer's index for Lake Terkos was estimated as 25 revealing the high organic pollution of the lake.

4. Conclusion

As a result, the phytoplankton community of Lake Terkos mainly consists of blue-green algae, diatoms, and green algae members. The dominance of the blue-green algae *Anabaena spiroides* and measured high concentrations of B and Cd shows that the lake is exposed to pollution. An important part of Istanbul's water demand is provided by the Terkos Dam Lake, which is one of the sensitive wetlands of Turkey. Since the basin is under threat due to pollution, it should be protected through the environmental regulations. Also, detailed studies should be conducted on phytoplankton as well as physicochemical parameters, heavy metal and nutrient concentrations to control the water quality in the lake. Additionally, Lake Terkos falls within the realm of the "Canal Istanbul Project", which is to connect Black Sea and Sea of Marmara along a line parallel to the Bosphorus by a channel. Because of this project, it is expected to be exposed to some environmental effects to Turkey and also other neighboring countries such as Bulgaria, Romania, Ukraine, Russia, Georgia, and Greece. For this reason, the data obtained from this research have a significant value.

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