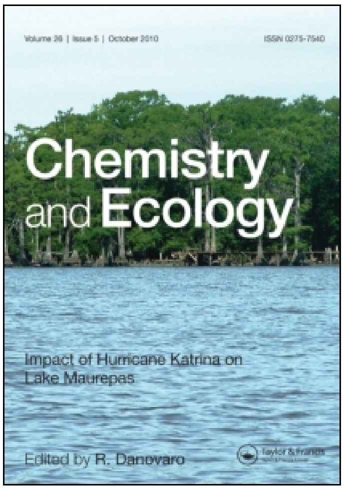

Chemistry and Ecology
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713455114

Factors affecting the current status of a eutrophic shallow lake (Lake Uluabat, Turkey): Relationships between water physical and chemical variables

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To cite this Article Dalkiran, Nurhayat , Karacaolu, Ddem , Dere, Şükran , Şentürk, Engn and Torunolu, Taner(2006) 'Factors affecting the current status of a eutrophic shallow lake (Lake Uluabat, Turkey): Relationships between water physical and chemical variables', Chemistry and Ecology, 22: 4, 279 — 298

To link to this Article: DOI: 10.1080/02757540600856229

URL: http://dx.doi.org/10.1080/02757540600856229

Chemistry and Ecology
Vol. 22, No. 4, August 2006, 279–298

Taylor & Francis
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Factors affecting the current status of a eutrophic shallow lake (Lake Uluabat, Turkey): Relationships between water physical and chemical variables

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(Received 24 October 2005; in final form 5 June 2006)

Lake Uluabat (Apolyont), a protected wetland area, the shorelines of which host urban and industrial sites, is influenced by a high human impact. The lake has eutrophic hardwater characteristics. Temperature, pH value, total dissolved substance, electrical conductivity, dissolved oxygen, biochemical oxygen demand, total hardness, carbonate and bicarbonate alkalinity, nitrate, soluble reactive phosphate, sulphate, soluble reactive silica, secchi disc depth, water depth, water volume, and chlorophyll *a* values were measured. Physical and chemical variables were determined from samples taken monthly at 10 stations from July 1998 to June 1999 to assess the present status of the lake. Significant correlations between physical and chemical variables were observed, and these relationships reflected the interactions among internal nutrient loadings. Two-way ANOVA test results also showed spatial and temporal variations. Internal nutrient loadings have been stimulated by a combination of different factors. Principal-component analyses showed that pH and alkalinity were the major factors that influenced the internal nutrient loadings in the lake. Results also indicated that nitrate, sulphate, and soluble reactive silica concentrations significantly induced the soluble reactive phosphorus loading. Direct or indirect interactions among primary nutrients were important in the nutrient loading in Lake Uluabat. Mustafakemalpaşa stream and its two branches Orhaneli and Emet, which drain into the lake, receive sewage water from households and industry. For this reason, soluble reactive phosphate, sulphate, nitrate, nitrite, ammonia, boron, and suspended solids were determined in samples collected bi-monthly from the Ayazköy station located on the Mustafakemalpaşa stream during the same study period to determine the effects of the main streams on the lake. Results indicated that the pollution load of Lake Uluabat is highly affected by Mustafakemalpaşa stream inflow. In addition, the present nutrient status, compared with previous years' data (1986–1990), collected only during summer months, showed that the physical and chemical characteristics of the lake have changed according to former years. The former and recent years' data also showed that the fluctuation of the water depth also influenced the chemical composition of the lake water. According to qualitative and quantitative observations, the effects of human impact and current status of the lake were determined. The physical and chemical characteristics of the lake water have changed according to human activities and nutrient loadings. Although external nutrient loadings are important because of the inflow of pollutants, internal

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Chemistry and Ecology
ISSN 0275-7540 print/ISSN 1029-0370 online © 2006 Taylor & Francis
http://www.tandf.co.uk/journals
DOI: 10.1080/02757540600856229

nutrient loadings are the major factors that determined the trophic status of the lake. In the light of all findings, the lake balance is going to be disturbed, and some measures must be taken to prevent these circumstances.

Keywords: External nutrient load; Internal nutrient load; Lake Uluabat (Apolyont); Nutrient status; Pollution load; Water depth

1. Introduction

Many lakes have changed from oligotrophic to eutrophic conditions during the last decades because of the nutrient loading from wastewater and fertilizers [1–4]. Physical and chemical characteristics of lake waters and their variations govern the environmental, ecological, and biological status of the lakes. Lakes are also subjected to a high human impact. Many studies examined the physical and chemical status of the lake water [5–12] and demonstrated which factors controlled the water quality, ecologic status and eutrophication patterns.

Pollution has been occurring for many years in Turkey, due to the rapid increase in population and unplanned industrialization, as well as to the pollution of nearby lakes, rivers and streams. Environmental pollution is a major public health concern in the industrialized and urbanized Marmara region, Turkey. Lake Uluabat is one of the most important wetland areas in Turkey and is increasingly threatened by pollution. Organic and inorganic pollution has also affected the nutrient status of the lake, and in this respect, the greatest concern deals with eutrophication. The lake is becoming silted up by increasing sediment accumulation, and a large delta has formed in the mouth of Mustafakemalpaşa stream. The area of the lake has declined at a rate of 12% from 1984 to 1993 [13]. The water depth has also changed importantly during the last decades due to the suspended solids carried into the lake [14]. Climatic conditions and environmental factors are endangering the trophic status of the lake day by day.

As Lake Uluabat is on birds' migration routes coming from the north-west of Anatolia, the lake is a breeding ground for a great number of bird species. It has also attracted attention in recent years because of the associated rich flora and fauna [15, 16]. For this reason, Lake Uluabat was placed under protection by the RAMSAR agreement in 1998 and the living lakes partnership programme of 2002. In this respect, important studies have been carried out in recent years [13, 14, 17–21].

The first observation related to physical and chemical variables in Lake Uluabat was carried out by the State Water Affairs (DSİ), for the period 1968–1977 at only two stations and only in the summer. However, important subsequent research on nutrient status and the water quality of other physical and chemical constituents of the lake was carried out for the period of 1986–1990 by the DSİ 1st Regional Office Environment Service at 10 stations, only in the summer months. Because of the poor temporal scale of investigation, the purpose of the present investigations during 1998–1999 is to assess the current status of the physical and chemical composition of the Lake Uluabat water. In addition, we aimed to compare the recent and previous status of the lake. We also aimed to determine the effects of Mustafakemalpaşa stream water on physical and chemical properties of the lake water. To achieve these, the seasonal and spatial changes of a set of physical and chemical variables have been studied.

Lake Uluabat is an important wetland area and has potentially influenced by the pollution load. Previous investigations hypothesized that physical and chemical variables were responsible for the eutrophication process [22]. To confirm this hypothesis, interactions among the physical and chemical variables were also investigated to assess whether internal nutrient loadings in the lake are as important as external nutrient loadings.

2. Materials and methods

2.1 *Study area and pollution load of the lake*

The location of Lake Uluabat and the sampling stations are shown in figure 1. The coordinates of the sampling stations are given in table 1. The lake is located near the southern part of the Sea of Marmara, in an east–west direction and located in the Bursa district. The lake is the most important part of the Susurluk basin. The lake basin has a water potential of $2060 \times 10^6\,\mathrm{m}^3\,\mathrm{yr}^{-1}$. Lake Uluabat covers an area of between 135 and $155\,\mathrm{km}^2$. The area and depth of the lake change with years and seasons. The depth has changed significantly in previous decades due to suspended solid inputs, and the mean annual depth of the lake is 2.5–3 m, decreasing to 1 m in the summer months.

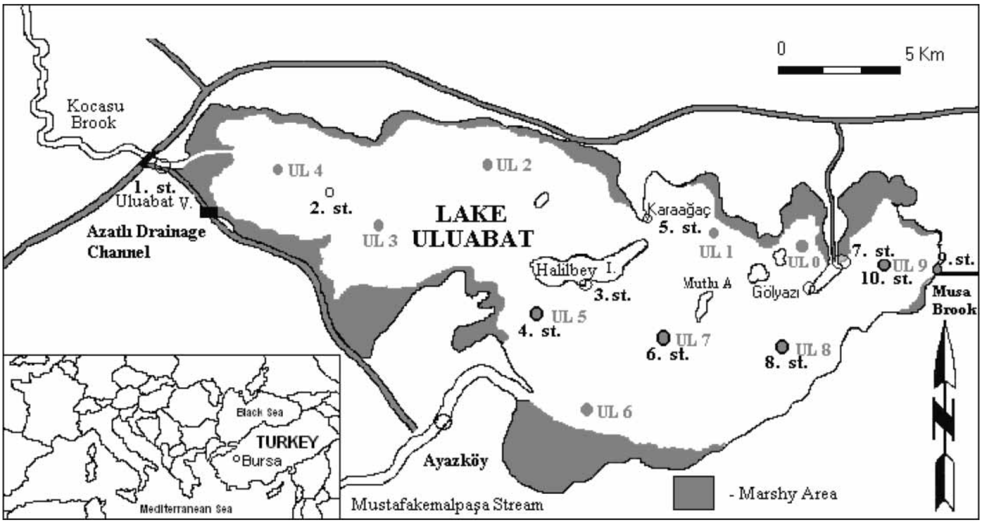


Figure 1. Sampling stations in Lake Uluabat. UL: Stations sampled from 1986 to 1990. St.: stations sampled in the present study.

Table 1. Coordinates of sampling stations in Lake Uluabat.

UL0: 40° 05′ 17″ latitude; 28° 41′ 59″ longitude
UL1: 40° 05′ 17″ latitude; 28° 41′ 59″ longitude
UL2: 40° 11′ 34″ latitude; 28° 34′ 25″ longitude
UL3: 40° 11′ 42″ latitude; 28° 31′ 18″ longitude
UL4: 39° 58′ 11″ latitude; 28° 46′ 47″ longitude
UL5 and 4th st: 40° 08′ 09″ latitude; 28° 35′ 43″ longitude
UL6: 40° 07′ 49″ latitude; 28° 35′ 07″ longitude
UL7 and 6th st: 40° 10′ 32″ latitude; 28° 37′ 07″ longitude
UL8 and 8th st: 40° 08′ 53″ latitude; 28° 39′ 14″ longitude
UL9 and 10th st: 40° 10′ 36″ latitude; 28° 42′ 14″ longitude
1st st: 40° 12′ 20″ latitude; 28° 26′ 08″ longitude
2nd st: 40° 12′ 14″ latitude; 28° 28′ 50″ longitude
3rd st: 40° 10′ 06″ latitude; 28° 35′ 14″ longitude
5th st: 40° 11′ 09″ latitude; 28° 36′ 46″ longitude
7th st: 40° 10′ 04″ latitude; 28° 40′ 51″ longitude
9th st: 40° 10′ 39″ latitude; 28° 43′ 24″ longitude
Ayazköy: 40° 10′ 52″ latitude; 28° 40′ 20″ longitude
Azatlı drainage: 40° 12′ 13″ latitude; 28° 26′ 38″ longitude
Kumkadı drainage: 40° 10′ 05″ latitude; 28° 29′ 50″ longitude

Demir *et al.* [23] reported that 16 urban sites are found on the lake shoreline. The villages of Eskikaraağaç and Gölyazı (Apolyont) are found on two peninsulas on the southern part of the lake, where stations 5 and 7 are also located.

The Azatlı drainage channel system (figure 1), which partly drains several waste waters (and whose main use is to collect excess irrigation water), enters the lake on the western side. The Kumkadı drainage channel also joins the lake on the south-eastern side and causes local pesticide pollution [24]. The Musa brook joins the lake on the eastern shoreline and drains urban and partly treated industrial wastes from the town of Akçalar.

The Mustafakemalpaşa stream is the major water contributor to the lake. The Emet and Orhaneli streams are joined in Camandar, forming the Mustafakemalpaşa stream. This system drains an area of 10 555 km^2, a large part of the southern Marmara and northern Aegean regions. Demir *et al.* [23] reported that 67 urban sites are found along this system. The three streams represent the most important pollution sources of Lake Uluabat. One of the main urban sites, the Tavşanlı district, discharges the canalization systems into the Orhaneli stream without any treatment. The Tunçbilek thermal power station and a lignite company are also important pollution sources, with wastes treated only physically, joining the Orhaneli stream.

The main part of the canalization systems of Mustafakemalpaşa district and 54 companies in the leather-processing industrial area (the former having a physical treatment station) also discharge organic and inorganic pollutants into the Mustafakemalpaşa stream at three different locations [23]. In addition, organic wastes from 27 cheese companies and slaughterhouses are discharged into the Mustafakemalpaşa stream without any treatment [23]. Station 4 is close to the mouth of the Mustafakemalpaşa stream, reflecting pollution by the stream.

The Mustafakemalpaşa stream and its two branches carry significant amounts of suspended solids in addition to organic and inorganic wastes. The mouth of the Mustafakemalpaşa stream is embanked due to the silt forming a large delta. Suspended solid loads typically increase in the last 20–25 km of the Mustafakemalpaşa downstream (figure 1). Aksoy and Özsoy [13] reported that the Mustafakemalpaşa stream delta, which is a large and expanding delta covering an area of 3747.6 ha in 1998, has been formed by silt deposition, around the stream mouth in the south-western section. Research carried out in 1984 by DSİ reported that the formation of this delta was caused by a lignite company, located in the middle of the Orhaneli stream. Sand companies, around the Camandar and Mustafakemalpaşa districts, also increased suspended matter loads. Landsat images taken in 1984, 1993, and 1998 showed that the surface and volume of the lake are continuously decreasing by 12% over a 14 yr period [13]. In addition, Kazancı *et al.* [14] found that the sedimentation rate in the lake reached 0.44 cm yr^{-1} in the 20th century. They also added that the suspended sediment load of the Mustafakemalpaşa stream has been about 1 258 143 tons yr^{-1} in the last 30 yr [14].

Boron mineral (mostly colemanite) has been the major pollutant in recent years. The world's most important boron beds (50% of the world's total reserve) are found in Turkey and two important boron beds are found in Hisarcık-Emet and Kestelek-Orhaneli districts [25, 26]. Boron mineral is also found in the soil around the stream basins, and carried into Lake Uluabat by erosion. Physical treatment condensers were constructed upon DSİs insistence before 1985. Therefore, boron concentration decreased in Mustafakemalpaşa stream at 3 mg l^{-1} and in Lake Uluabat 1 mgl^{-1}.

Lake Uluabat is drained by Kocasu brook into Simav (Susurluk) River and the water flow is high in winter months. Reverse current is formed in Kocasu brook at several locations, therefore the pollutants which originate from the Azatlı drainage channel, are also carried into the lake. Demir *et al.* [23] reported that the pollutants originating from Nilüfer Stream, which also join Simav River, are carried inside the lake because of the reverse current. However, these two pollution sources are not hindered.

Lake water is also used as an irrigation source for the Mustafakemalpaşa plateau. The Mustafakemalpaşa stream delta is one of the most important wetland areas, and is also used for agricultural purposes. Erdoğan *et al.* [27, 28] stated that 19.37×10^6 m^3 and 22.95×10^6 m^3 water were used for irrigation in 1998 and 1999, respectively. The Mustafakemalpaşa stream is the major inflow of the lake; however, the amount of water clearly changes with climate conditions (precipitation quantity). Artüz and Korkmaz [15] reported that the quantity of water carried by Mustafakemalpaşa changed from 500×10^6 m^3 to 4000×10^6 m^3 (30 yr means for 1939–1969).

2.2 *Physical and chemical variables*

Physical and chemical variables have been determined from samples taken monthly at 10 stations from July 1998 to June 1999, and studies were carried out at the Uludağ University Hydrobiology Research Laboratory to assess the present status of the lake. The sampling stations are shown in figure 1. The dissolved oxygen (DO) concentrations were measured at the sampling sites using a field-type YSI 55 model apparatus. For biochemical oxygen demand (BOD_5) analyses, water samples were brought to the laboratory and analysed according to the Winkler method [29]. Electrical conductivity (EC), total dissolved substance (TDS) and water temperature (T, °C) were measured synoptically using a field-type WTW LF95 apparatus, and pH was measured using Hanna HI 8314 apparatus.

The total hardness (TH), French hardness (F°), and alkalinity (HCO_3^- and CO_3^{2-}) were determined by titration methods [29, 30]. Nitrate ($N{-}NO_3^-$) was determined by the cromatrophic acid method, soluble reactive phosphate (SRP) by the zinc chloral method, sulphate (SO_4^{2-}) by the turbidimetric method, and soluble reactive silica (SRSi) by the molibdosilicate method [29, 30]. Chlorophyll a (Chl a) concentrations were also determined in accordance with Richards and Thompson's [31] method, using 90% acetone as solvent. A 1 l water sample was filtered by Whatman GF/A filtered paper and samples were steeped for at least 2 h at 4 °C in the dark. Chl a analyses were determined in only five open water stations. The Secchi disc depth was also measured. The monthly mean water depth and water volume amounts were compiled by DSİ based on Eskikarağaç station. The water depth represents the deepest point of the lake (Station 2).

SRP, SO_4^{2-}, $N{-}NO_3^-$, nitrite ($N{-}NO_2^-$), ammonia ($N{-}NH_3$), boron (B), and suspended solids (SS) were determined bimonthly at the Ayazköy station and carried out at the DSİ I Regional Head Environmental Laboratory from May 1998 to July 1999 to determine the effects of the main streams on the lake. The first three analyses were performed as above and $N{-}NO_2^-$ by the colorimetric method, $N{-}NH_3$ by the phenate method, B by the carmine method, and SS gravimetrically often desiccated at 103–105 °C [29, 30]. Mustafakemalpaşa stream inflow amounts in Ayazköy were measured at the same time in the field by DSİ.

The water-quality results for the 1986–1990, for the summer months only, at 10 stations, were compiled by DSİ. The stations from the previous study are also given in figure 1. The lake-water depth measurements in this former study were measured at all stations.

2.3 *Statistical procedures*

The relationships between physical and chemical variables were analysed using the Spearman rank correlation. The spatial and temporal (seasonal) changes of all physical and chemical variables were estimated by means of a two-way ANOVA. When significant differences were observed, the posthoc pairwise comparison test with the least significant difference (L.S.D.) was used to determine differences among groups [32]. The statistical tests were performed with SPSS version 11.0 [33], and the threshold for statistical significance was set at $P = 0.05$. Ordination of physical and chemical variables of the water quality by principal-component analysis (PCA) was performed on standardized data, based on a correlation matrix [34]. The PCA was performed using Minitab version 13.1 statistical software [35].

3. Results

The mean annual physical and chemical features of Lake Uluabat are listed in table 2. Two-way ANOVA results on the seasonal variability of physical and chemical variables are given in table 3. The physical and chemical variables revealed significant seasonal changes, and results also showed that the seasonal fluctuations are important (table 3). The L.S.D. test results are also given in figure 2. In this figure, empty squares indicate equal months, and full squares indicate significant differences.

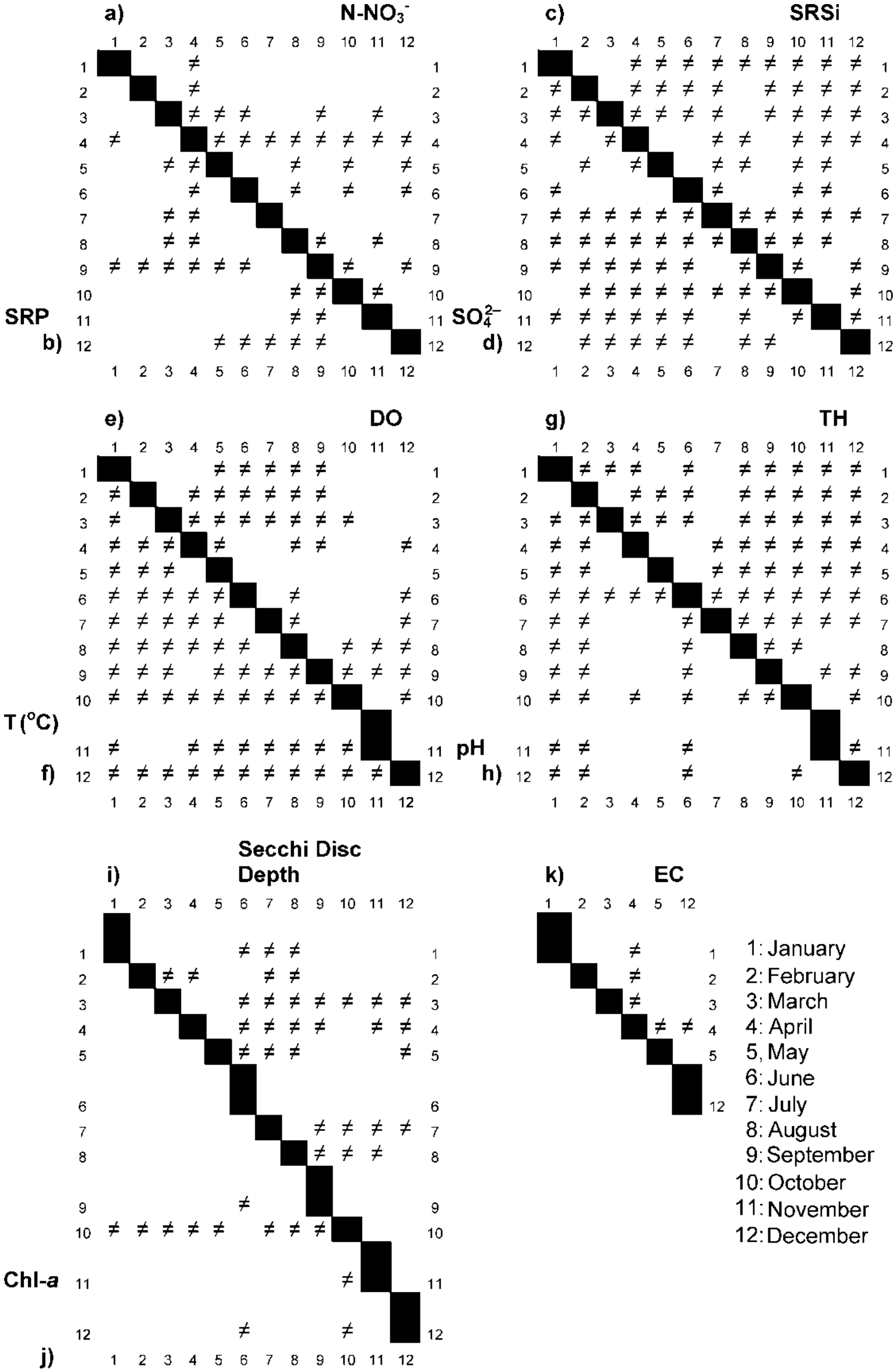
Table 2. Mean annual values of physical and chemical variables in Lake Uluabat.

Variables	n	Min.	Max.	Mean ± S.D.
T (°C)	118	3.90	34.40	18.37 ± 8.13
DO (mg l^{-1})	118	1.15	12.30	7.73 ± 2.22
BOD_5 (mg l^{-1})	87	0.69	11.80	4.31 ± 2.09
pH	118	7.30	10.10	8.42 ± 0.54
EC (mμohm cm^{-1})	58	286	626	456.71 ± 7.75
TDS (mg l^{-1})	48	284	542	415.30 ± 45.21
CO_3^{2-} (mg $CaCO_3$ l^{-1})	118	0.00	60	11.99 ± 11.95
HCO_3^- (mg $CaCO_3$ l^{-1})	118	16	290	131.71 ± 32.39
TH (F°)	118	6	34.90	18.91 ± 5.00
$N{-}NO_3^-$ (mg l^{-1})	118	0.00	5.51	0.99 ± 1.39
SO_4^{2-} (mg l^{-1})	118	26.6	171	89.29 ± 32.89
SRP (mg l^{-1})	118	0.002	0.14	0.022 ± 0.02
SRSi (mg l^{-1})	118	0.13	4.48	2.07 ± 0.99
Chl a (mg m^{-3})	59	0.87	51.96	11.31 ± 11.33
Secchi disc depth (cm)	59	18	168	85.11 ± 46.79
Water depth (m)	12	2.31	5.04	3.31 ± 0.95
Water volume (m^3 s^{-1}) 3; cubic	12	229×10^6	683×10^6	$387 \times 10^6 \pm 156.15 \times 10^6$

Table 3. Seasonal two-way ANOVA results of physical and chemical variables.

Variables	F	F	d.f.
T (°C)	174.13	0.000	20
DO (mg l^{-1})	5.01	0.000	20
pH	11.23	0.000	20
EC (mμohm cm^{-1})	12.29	0.000	14
TH (F°)	21.18	0.000	20
$N{-}NO_3^-$ (mg l^{-1})	9.23	0.000	20
SO_4^{2-} (mg l^{-1})	10.56	0.000	20
SRP (mg l^{-1})	3.81	0.000	20
SRSi (mg l^{-1})	12.26	0.000	20
Chl a (mg m^{-3})	2.38	0.013	15
Secchi disc depth (cm)	5.54	0.000	15

Note: L.S.D. test results are shown in figure 2.



a) N-NO$_3^-$ (upper) / b) SRP (lower)

	1	2	3	4	5	6	7	8	9	10	11	12
1	■			≠								
2		■		≠								
3			■	≠	≠	≠			≠		≠	
4	≠			■	≠	≠	≠	≠	≠	≠	≠	≠
5			≠	≠	■			≠		≠		≠
6				≠		■		≠		≠		≠
7			≠	≠			■					
8			≠	≠				■	≠		≠	
9	≠	≠	≠	≠	≠	≠			■	≠		≠
10								≠	≠	■	≠	
11								≠	≠		■	
12					≠	≠	≠	≠	≠			■

c) SRSi (upper) / d) SO$_4^{2-}$ (lower)

	1	2	3	4	5	6	7	8	9	10	11	12
1	■			≠	≠	≠	≠	≠	≠	≠	≠	≠
2	≠	■		≠	≠	≠	≠		≠	≠	≠	≠
3	≠	≠	■	≠	≠	≠	≠		≠	≠	≠	≠
4	≠		≠	■			≠	≠		≠	≠	≠
5		≠		≠	■		≠	≠		≠	≠	
6	≠					■	≠			≠	≠	
7	≠	≠	≠	≠	≠	≠	■	≠	≠	≠	≠	≠
8	≠	≠	≠	≠	≠	≠	≠	■	≠	≠	≠	
9	≠	≠	≠	≠	≠	≠		≠	■	≠		≠
10		≠	≠	≠	≠	≠	≠	≠	≠	■		≠
11	≠	≠	≠	≠	≠	≠		≠		≠	■	≠
12		≠	≠	≠	≠	≠		≠	≠			■

e) DO (upper) / f) T (°C) (lower)

	1	2	3	4	5	6	7	8	9	10	11	12
1	■				≠	≠	≠	≠	≠			
2	≠	■		≠	≠	≠	≠	≠	≠			
3	≠		■	≠	≠	≠	≠	≠	≠	≠		
4	≠	≠	≠	■	≠			≠	≠			≠
5	≠	≠	≠		■							
6	≠	≠	≠	≠	≠	■		≠				≠
7	≠	≠	≠	≠	≠		■	≠				≠
8	≠	≠	≠	≠	≠	≠		■		≠	≠	≠
9	≠	≠	≠		≠	≠	≠	≠	■	≠	≠	≠
10	≠	≠	≠	≠	≠	≠	≠	≠	≠	■		≠
11	≠			≠	≠	≠	≠	≠	≠	≠	■	
12	≠	≠	≠	≠	≠	≠	≠	≠	≠	≠	≠	■

g) TH (upper) / h) pH (lower)

	1	2	3	4	5	6	7	8	9	10	11	12
1	■	≠	≠	≠		≠		≠	≠	≠	≠	≠
2		■		≠	≠	≠		≠	≠	≠	≠	≠
3	≠	≠	■	≠	≠	≠		≠	≠	≠	≠	≠
4	≠	≠		■			≠	≠	≠	≠	≠	≠
5	≠	≠			■		≠	≠	≠	≠	≠	≠
6	≠	≠	≠	≠	≠	■	≠	≠	≠	≠	≠	≠
7	≠	≠				≠	■	≠	≠	≠	≠	≠
8	≠	≠				≠		■	≠	≠		
9	≠	≠				≠			■		≠	≠
10	≠	≠		≠		≠		≠	≠	■		≠
11	≠	≠				≠					■	≠
12	≠	≠				≠				≠		■

i) Secchi Disc Depth (upper) / j) Chl-*a* (lower)

	1	2	3	4	5	6	7	8	9	10	11	12
1	■					≠	≠	≠				
2		■	≠	≠			≠	≠				
3			■			≠	≠	≠	≠	≠	≠	≠
4				■		≠	≠	≠	≠		≠	≠
5					■	≠	≠	≠				≠
6						■						
7							■		≠	≠	≠	≠
8								■	≠	≠	≠	
9						≠			■			
10	≠	≠	≠	≠	≠		≠	≠	≠	■		
11										≠	■	
12						≠				≠		■

k) EC

	1	2	3	4	5	12
1	■			≠		
2		■		≠		
3			■	≠		
4				■	≠	≠
5					■	
12						■

1: January
2: February
3: March
4: April
5, May
6: June
7: July
8: August
9: September
10: October
11: November
12: December

Figure 2. L.S.D. test results of physical and chemical variables.

Seasonal changes of some physical and chemical variables are also given in figure 3. All values except lake water volume and depth show the average values of 10 stations for each month. Mean Chl *a* and Secchi disc-depth values also represent only the five open water stations.

Average N–NO_3^- concentrations peaked in the highest mean value in April 1999 and down to undetectible values in May 1999 (figure 3a). L.S.D. test results indicated that the N–NO_3^- concentration was significantly different in April 1999 (figure 2). Average SRP concentrations also showed wide temporal fluctuations with significant peaks in September (figures 2 and 3b). According to annual mean values, the highest mean N–NO_3^- concentration is shown at station 1 (2.34 ± 0.74), while the lowest concentrations are shown at station 4 (0.72 ± 0.28) and station 9 (0.75 ± 0.23), respectively. The highest SRP concentrations are also shown at station 1 (0.038 ± 0.009) and station 9 (0.036 ± 0.01), while the lowest concentration is at station 8 (0.013 ± 0.002).

The highest mean SRSi concentrations were measured in July 1998, gradually decreasing to the lowest mean value in October 1998 (figures 2 and 3d). The highest mean SO_4^{2-} concentration was 132.55 mg l^{-1} in August, while significantly but gradually decreasing during the first half of the study period to half the highest value (figures 2 and 3c). Similarly, the mean HCO_3^- concentration was highest in August, and then fluctuated greatly and gradually decreased during the second half of the study period (figure 3f). However, two-way ANOVA test results do not reveal any significant differences among months and HCO_3^- concentrations.

The average Secchi disc depth also increased gradually during July 1998 to 1999, while the highest value was in March 1999 (figure 3e). L.S.D. test results indicated that the Secchi disc depth was significantly different in March 1999 (figure 2). The average Chl *a* concentration fluctuated widely during the study period, but the highest mean value was found in October 1998 (figure 3e). The L.S.D. test also indicated that Chl *a* concentration was statistically significant in October 1998 (figure 2).

The average seasonal water temperatures fluctuated from 4.80 °C (December) to 29.08 °C (June), while the average DO concentrations fluctuated between 5 and 10 mg l^{-1} (figure 3g). The average BOD_5 values did not exceed 6 mg l^{-1} (figure 3g). The average pH values varied from 7.5 to 9.0. The average TH and pH also fluctuated widely (figure 3 h). The water depth and volume were highest in March 1999, because of the rainy period (figure 3j). Temperature and TH values showed significant differences for all months (figure 2). The DO value was significantly different in August 1998 (figure 2). In addition, pH values were significantly different in January, February, and June 1999 (figure 2). However, two-way ANOVA test results indicated that BOD_5 values did not show any significant differences among months.

Results of the Spearman rank correlation analysis are given in table 4. Water depth was correlated with most of the tested physical and chemical variables. Results indicated that SRP, SRSi, SO_4^{2-}, and N–NO_3^- showed significant relationships with chemical features of the lake water.

The PCA using standardized data for 10 variables is mentioned in figure 4. According to PCA analysis (figure 4), CO_3^{2-}, HCO_3^-, and pH accounted for 28.6%, whereas SO_4^{2-}, DO, and TH accounted for 24.4% of the total variation. The PCA results (figure 4) indicate that CO_3^{2-}, HCO_3^-, and pH are the most important variables measured in the study period. SRP are not weightly represented on the PCA axis, which might be masked by the effects of CO_3^{2-}, HCO_3^-, and pH.

The mean annual physical and chemical features at the Ayazköy station are listed in table 5. Temporal changes for N$-NO_3^-$, N$-NO_2^-$, N$-NH_3$, SO_4^{2-}, pH, CO_3^{2-}, HCO_3^-, DO, BOD_5, EC, TDS, SS, B, and Mustafakemalpaşa stream inflow are also given in figure 5. N$-NO_3^-$ input gradually increased after July 1998, and the highest value was measured (>1.4 mg l^{-1}) in July 1999 (figure 5a). SRP concentrations were usually below 0.15 mg l^{-1} in the study period but,

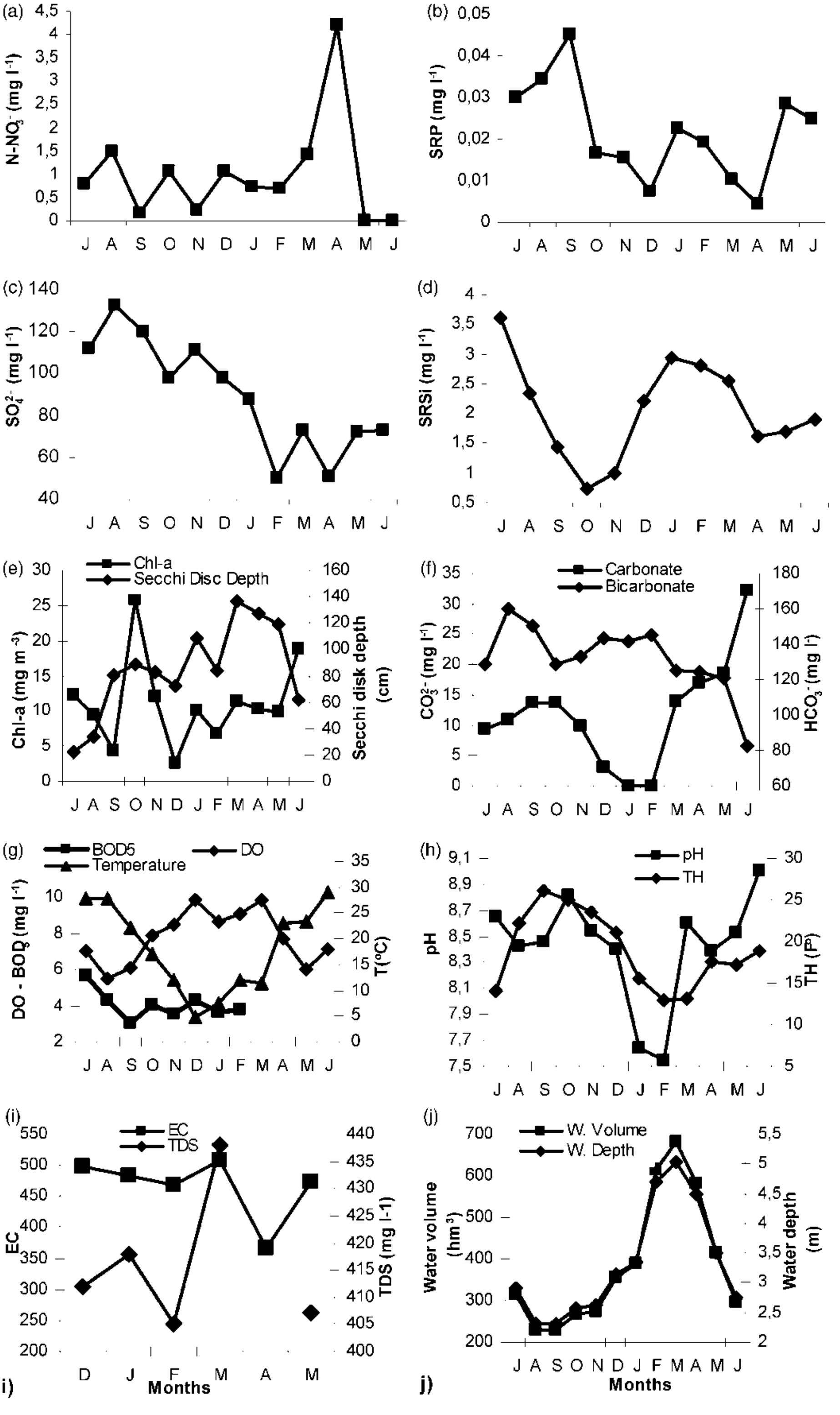


Figure 3. Variation in measured physical and chemical variables in Lake Uluabat.

Table 4. Spearman rank correlation results among physical and chemical variables (**P < 0.01, *P < 0.05).

Variables	pH	DO	TH	CO_3^{2-}	HCO_3^-	$N{-}NO_3^-$	SRP	SO_4^{2-}	SRSi	Secchi disc depth	Chl *a*	Water depth
T	0.444**	−0.524**	n.s.	0.437**	−0.252**	−0.331**	0.356**	n.s.	n.s.	−0.396**	n.s.	−0.363**
pH	1	n.s.	0.242**	0.803**	−0.425**	−0.260**	−0.216*	n.s.	−0.404**	n.s	0.387*	−0.315**
DO		1	–0.335**	n.s.	n.s.	0.299**	–0.366**	–0.237**	n.s.	n.s.	n.s.	0.352**
TH			1	n.s.	0.233*	n.s.	0.202*	0.567**	–0.545**	n.s.	n.s.	–0.782**
CO_3^{2-}				1	–0.558**	–0.243**	n.s.	n.s.	–0.384**	n.s.	n.s.	n.s.
HCO_3^-					1	0.319**	n.s.	0.457**	0.218*	n.s.	n.s.	n.s.
$N{-}NO_3^-$						1	–0.349**	–0.191*	n.s.	n.s.	n.s.	0.247**
SRP							1	0.277**	0.184*	–0.529**	n.s.	–0.477**
SO_4^{2-}								1	n.s.	–0.259*	n.s.	–0.660**
SRSi									1	n.s.	n.s.	0.336**
Secchi disc depth										1	n.s.	n.s.
Chl *a*											1	n.s.
Water depth												1

	Axis 1	Axis 2
T	0.224	0.373
DO	0.177	- 0.452
pH	0.500	0.181
HCO_3^-	-0.470	0.126
CO_3^{2-}	0.517	0.138
TH	-0.036	0.491
SO_4^{2-}	-0.145	0.432
SRSi	-0.296	- 0.191
$N\text{-}NO_3^-$	-0.044	- 0.113
SRP	-0.261	0.335

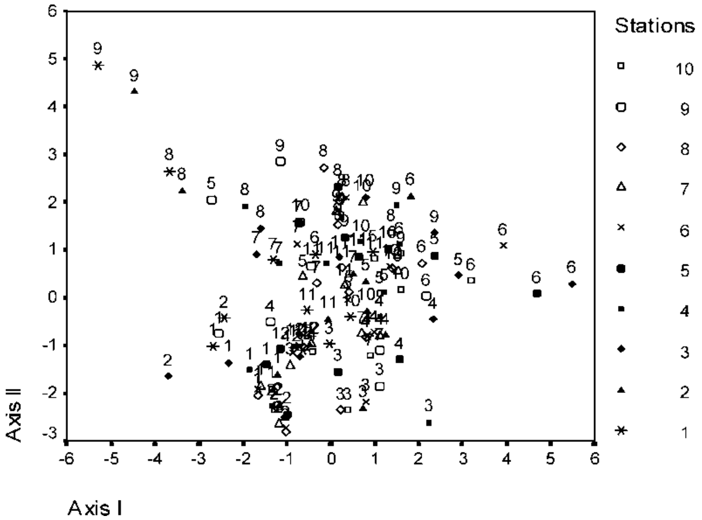


Figure 4. Physical and chemical variables in the PCA axis. Axis I accounted for 28.6%, and axis II accounted for 24.4% of the total variance. 1: January; 2: February; 3: March; 4: April; 5: May; 6: June; 7: July; 8: August; 9: September; 10: October; 11: November; 12: December.

in March 1999, peaked at 0.5 mg l^{-1} (figure 5a). $N\text{–}NH_3$ temporal pattern was also similar to the out of SRP (figure 5b). $N\text{–}NO_2^-$ concentrations displayed a similar temporal pattern of $N\text{–}NO_3^-$; the highest concentration was measured in July 1999 (1.4 mg l^{-1}) and the lowest in July 1998 (0.9 mg l^{-1}) (figure 5b). The SO_4^{2-} concentration fluctuated from 60 to 100 mg l^{-1} and decreased down to 20 mg l^{-1} in March 1999 (figure 5c).

The pH varied from 7.4 to 8.1 (figure 5d). HCO_3^- concentrations fluctuated widely, with the lowest value being measured in January (figure 5d). Water temperature ranged from 5 to 25 °C in the study period (figure 5e). The DO concentration ranged between 8 and 12 mg l^{-1}, with the highest value being in March 1999 (figure 5e). The BOD_5 values did not exceed 4 mg l^{-1} (figure 5e).

The boron concentration fluctuated from 0.5 to 1.5 mg l^{-1} with the highest value being in June 1999 (2.0 mg l^{-1}) (figure 5g). The water velocity fluctuated by approximately 10 $m^3\,s^{-1}$,

Table 5. Mean annual values of physical and chemical variables at Ayazköy station.

Variables	n	Min.	Max.	Mean ± S.D.
T(°C)	8	5.90	25.30	16.53 ± 7.17
DO (mg l^{-1})	8	7.49	12.02	9.69 ± 1.72
BOD_5 (mg l^{-1})	8	1.34	3.43	2.43 ± 0.71
pH	8	7.40	8.10	7.65 ± 0.23
EC (mμohm cm^{-1})	8	533	792	645.25 ± 74.77
TDS (mg l^{-1})	8	375	499	437.50 ± 47.82
HCO_3^- (mg $CaCO_3$ l^{-1})	8	192.31	300	266.38 ± 36.61
$N\text{–}NO_3^-$ (mg l^{-1})	8	0.87	1.30	1.12 ± 0.14
$N\text{–}NO_2^-$ (mg l^{-1})	8	0.87	1.30	1.12 ± 0.15
$N\text{–}NH_3$ (mg l^{-1})	8	0.01	0.09	0.034 ± 0.02
SO_4^{2-} (mg l^{-1})	8	19.20	103.20	73.80 ± 29.32
SRP (mg l^{-1})	8	0.00	0.46	1.14 ± 0.13
SS (mg l^{-1})	7	23.20	280	84.06 ± 89.82
B (mg l^{-1})	8	0.45	1.83	0.93 ± 0.44
Stream inflow ($m^3\,s^{-1}$) 3; cubic^{-1}; upper symbol	8	8.20×10^6	56.70×10^6	$22.97 \times 10^6 \pm 19.49 \times 10^6$

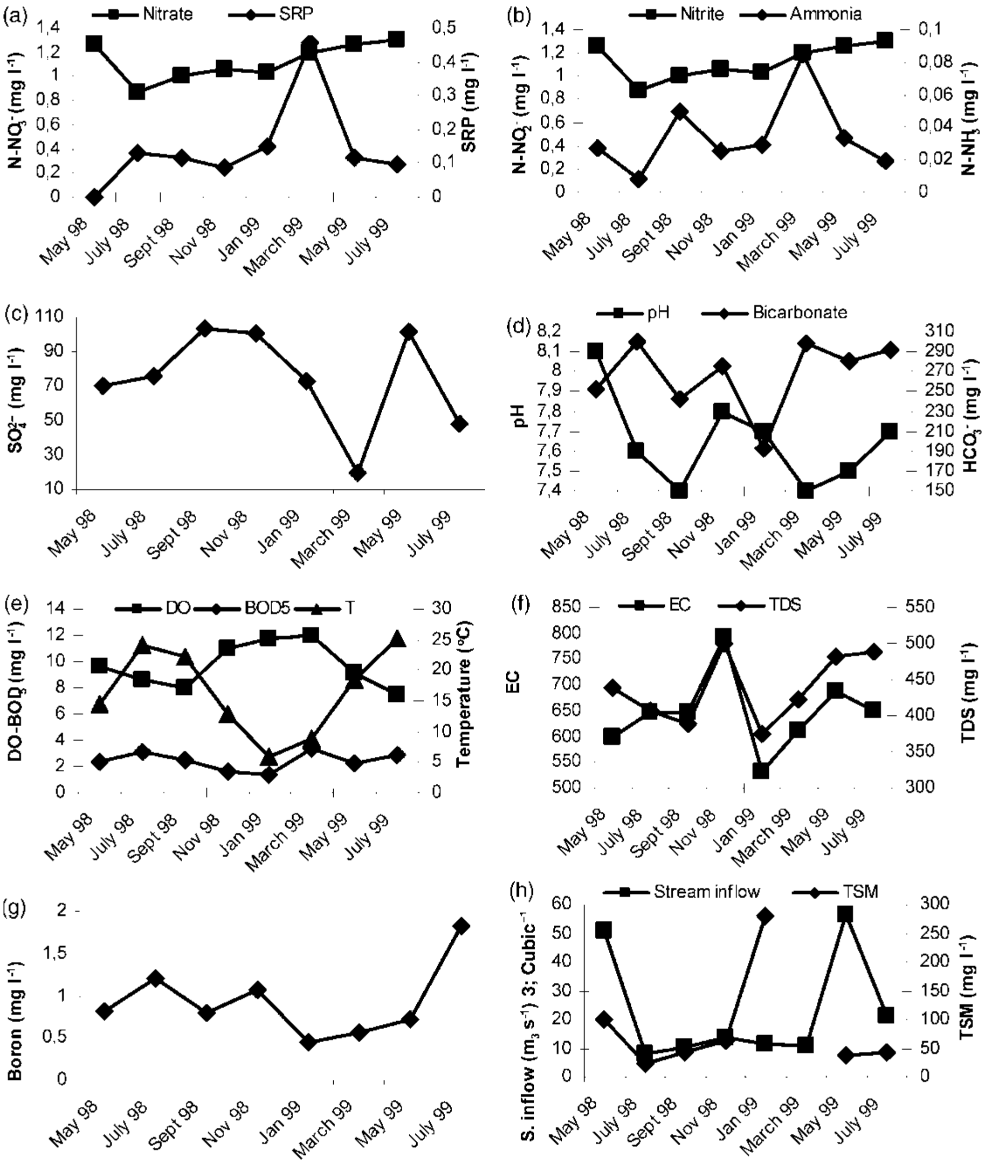


Figure 5. Variation in measured physical and chemical variables in the Ayazköy station.

Table 6. Several chemical constituents entering the lake at Ayazköy station.

Variables	Ayazköy
$N–NO_3^-$ (tonnes yr^{-1})	0.839
$N–NO_2^-$ (tonnes yr^{-1})	0.022
$N–NH_3$ (tonnes yr^{-1})	0.026
SO_4^{2-} (tonnes yr^{-1})	55.199
SRP (tonnes yr^{-1})	0.108
SS (tonnes yr^{-1})	62.839
B (tonnes yr^{-1})	0.701

Table 7. Previous research results, sampled from1986 to 1990.

Sampling dates Variables	September 1986 Mean ± S.D.(*n*)	June 1987 Mean ± S.D.(*n*)	May 1988 Mean ± S.D.(*n*)	June 1988 Mean ± S.D.(*n*)	July 1988 Mean ± S.D.(*n*)	June 1990 Mean ± S.D.(*n*)	July 1990 Mean ± S.D.(*n*)
T (°C)	19.45 ± 0.61(8)	25.58 ± 2.19(20)	18.74 ± 1.27(20)	26.77 ± 0.63(10)	28.31 ± 0.39(10)	16.07 ± 0.98(10)	23.89 ± 0.22(6)
pH	–	8.39 ± 0.24(20)	7.97 ± 0.12(20)	8.54 ± 0.05(10)	8.53 ± 0.09(10)	8.10 ± 0.001(10)	8.23 ± 0.05(6)
TDS (mg l^{-1})	–	243.91 ± 69.40(20)	218.55 ± 80.42(20)	–	291.6 ± 23.75(10)	296.00 ± 2.83(5)	303.30 ± 11.01(6)
Turb NTU	–	70.02 ± 107.48(20)	16.43 ± 8.72(20)	43.70 ± 53.83(10)	142.00 ± 92.53(10)	49.25 ± 15.44(10)	256.67 ± 107.50(6)
N–NH_3 (mg l^{-1})	0.12 ± 0.08(8)	1.16 ± 2.93(20)	0.12 ± 0.08(20)	0.18 ± 0.08(10)	0.21 ± 0.15(10)	0.15 ± 0.13(10)	0.07 ± 0.08(6)
N–NO_2^- (mg l^{-1})	0.04 ± 0.01(8)	0.01 ± 0.01(20)	0.005 ± 0.005(20)	0.003 ± 0.001(10)	0.00(10)	0.002 ± 0.001(10)	0.016 ± 0.003(6)
N–NO_3^- (mg l^{-1})	0.17 ± 0.06(8)	0.05 ± 0.05(20)	0.05 ± 0.05(20)	0.18 ± 0.11(10)	0.08 ± 0.04(10)	0.47 ± 0.25(10)	0.12 ± 0.03(6)
SRP (mg l^{-1})	–	0.07 ± 0.06(20)	0.04 ± 0.05(20)	0.12 ± 0.04(10)	0.16 ± 0.08(10)	0.14 ± 0.19(10)	0.61 ± 0.14(6)
SO_4^{2-} (mg l^{-1})	142.72 ± 110.01(8)	44.12 ± 3.20(20)	37.01 ± 10.82(20)	37.61 ± 10.56(10)	37.20 ± 8.48(10)	45.80 ± 7.98(10)	73.98 ± 18.16(6)
Cl^- (mg l^{-1})	17.11 ± 0.59(8)	12.40 ± 4.76(20)	8.58 ± 0.91(20)	12.25 ± 0.97(10)	12.15 ± 1.82(10)	13.15 ± 0.83(10)	16.09 ± 1.04(6)
Fe^{3+} (mg l^{-1})	4.35 ± 2.65(8)	0.29 ± 0.16(20)	0.26 ± 0.11(20)	0.49 ± 0.58(10)	0.93 ± 0.76(10)	0.49 ± 0.27(10)	2.73 ± 1.21(6)
Na^+ (mg l^{-1})	19.13 ± 0.84(8)	9.88 ± 2.97(20)	13.23 ± 13.72(20)	16.88 ± 1.12(10)	18.61 ± 1.68(10)	9.84 ± 0.56(10)	14.61 ± 0.35(6)
K^+ (mg l^{-1})	4.32 ± 0.35(8)	2.49 ± 0.40(20)	3.48 ± 1.35(20)	3.52 ± 0.21(10)	3.31 ± 0.24(10)	2.38 ± 0.09(10)	3.68 ± 0.26(6)
Ca^{2+} (mg l^{-1})	37.99 ± 0.80(8)	44.86 ± 8.62(20)	45.85 ± 3.56(20)	35.83 ± 5.40(10)	42.44 ± 7.32(10)	37.99 ± 2.94(10)	37.75 ± 4.99(6)
Mg^{2+} (mg l^{-1})	42.13 ± 1.69(8)	36.52 ± 5.22(20)	36.55 ± 2.77(20)	33.91 ± 2.56(10)	32.92 ± 3.26(10)	38.36 ± 2.28(10)	44.48 ± 4.29(6)
B (mg l^{-1})	0.97 ± 0.21(8)	0.84 ± 0.63(20)	0.60 ± 0.41(20)	0.87 ± 0.10(10)	0.55 ± 0.20(10)	0.36 ± 0.23(10)	1.79 ± 0.17(6)
SRSi (mg l^{-1})	0.03 ± 0.02(8)	12.52 ± 17.61(20)	0.03 ± 0.02(20)	–	0.13 ± 0.03(10)	0.13 ± 0.04(10)	–
Chl *a* (mg m^{-3})	58.25 ± 16.99(5)	17.48 ± 9.27(10)	23.66 ± 11.79(10)	21.83 ± 7.35(10)	46.85 ± 12.43(5)	19.39 ± 12.94(5)	22.02 ± 12.57(6)
SS (mg l^{-1})	120.35 ± 30.64(8)	50.07 ± 29.88(20)	49.77 ± 28.04(20)	–	–	55.28 ± 29.86(5)	222.67 ± 92.02(6)
Water depth (m)	0.75 ± 0.27(7)	1.99 ± 0.43(10)	2.43 ± 0.59(10)	1.45 ± 0.09(10)	1.38 ± 0.75(5)	1.97 ± 0.16(5)	1.23 ± 0.14(6)

Table 8. Spearman rank correlation results between water depth and physical and chemical variables, studied from 1986 to 1990.

	Water depth (m)		
Variables	ρ	P	n
T (°C)	−0.376	0.000	84
pH	−0.547	0.000	76
TDS (mg l^{-1})	n.s.		
Turb NTU	−0.471	0.000	76
N–NH_3 (mg l^{-1})	n.s.		
N–NO_2^- (mg l^{-1})	n.s.		
N–NO_3^- (mg l^{-1})	−0.331	0.002	84
SRP (mg l^{-1})	−0.488	0.000	76
SO_4^{2-} (mg l^{-1})	−0.353	0.001	84
Cl^- (mg l^{-1})	−0.590	0.000	84
Fe^{3+} (mg l^{-1})	−0.518	0.000	84
Na^+ (mg l^{-1})	−0.575	0.000	84
K^+ (mg l^{-1})	−0.491	0.000	84
Ca^{2+} (mg l^{-1})	0.379	0.000	84
Mg^{2+} (mg l^{-1})	n.s.		
B (mg l^{-1})	−0.523	0.000	84
SRSi (mg l^{-1})	n.s.		
Chl a (mg m^{-3})	−0.348	0.022	43
SS (mg l^{-1})	−0.423	0.001	56

but the highest values were found in May 1999 and May 1998, respectively (figure 5h). The SS concentration fluctuated widely, with the highest value being in January 1999 (270 mg l^{-1}; figure 5h).

Several chemical consitituents entering the lake at Ayazköy station (tonnes yr^{-1}) are listed in table 6. The SS value is the most important variable in Lake Uluabat. We found that the SS loading to Lake Uluabat via Mustafakemalpaşa stream was 62.84 tonnes yr^{-1} in the study period (table 6). SO_4^{2-} is the second most important pollutant, followed by $N{-}NO_3^-$ and B.

The mean results of physical and chemical variables in previous research (1986–1990) at 10 stations are also shown in table 7. These results are important to compare the recent and previous status of the lake. Table 8 also reveals significant negative relationships between water depth and physical–chemical variables except calcium, in the former study. Tables 7 and 8 show that the physical and chemical variables are changed and fluctuated significantly according to sampling date and water depth.

4. Discussion

Because of human activities, Lake Uluabat has been eutrophicated in recent decades. Bellemakers and Maessen [22] suggested that eutrophication could be caused directly by eutrophic inlet water, which has a high nitrogen and phosphorus concentration (external eutrophication). While internal eutrophication is another important factor, the macro-ion composition may cause increased mobilization of nutrients from the sediment because of chemical reactions [22].

4.1 *Internal nutrient loadings in Lake Uluabat*

Lake Uluabat is located in a Mediterranean climate region and is closely surrounded by karstified limestone [14]. The lake shows hardwater characteristics, and this characteristic of the lake affects the internal nutrient loadings. Multivariate analysis results indicate that the hardwater characteristics of the lake water are the greatest factor affecting the biochemical loadings, while bivariate analysis results emphasize a one-to-one effect for chemicals in Lake Uluabat water.

The DO played an important role in the physical and chemical characteristics of lake water (table 4). Correlation analysis results indicate that DO decreased SRP and SO_4^{2-} loadings while increasing $N{-}NO_3^-$ loading in the water column. De Medina *et al.* [36] demonstrated that aerobic conditions favoured rapid transformation of $N{-}NH_3$ to $N{-}NO_3^-$. Sass *et al.* [37] stated that SO_4^{2-} reduction is inhibited by traces of oxygen, and no SO_4^{2-} reduction has been observed in the presence of oxygen in pure cultures. Because of the importance of the eutrophication pattern, many more studies have been carried out to determine the effects of DO on phosphorus loading. Periodic anoxia in the water column intensifies sediment phosphorus release, resulting in increased phosphorus loading into surface waters [1]. Some experimental designs have shown that the hypolimnion was aerated with oxygen gas that increased the binding surfaces for sediment phosphorus [38]. However, anoxic conditions in the water column were not observed in the study period. This is because considerable amounts of phosphorus also released under aerobic conditions [39] implicated the possibility of bacterial involvement [40]. DO is one of the important components in biochemical oxidation and reduction processes in aquatic environments. Releasing or binding important nutrients such as $N{-}NO_3^-$, SRP, or SO_4^{2-}, related to DO concentration, are important in internal nutrient loadings.

High pH concentration decreased $N{-}NO_3^-$ and SRP concentrations in the water column in Lake Uluabat. The nitrification process is sensitive to pH and occurs less rapidly at a low pH [36]. In addition, at a high pH, phosphate concentrations favour precipitation of metal phosphates at the sediment surface [41]. Kamp-Nielsen [42] explained the reason for the phenomenon, as the change in pH with sediment could strongly influence the sorption and solubility of phosphate. Holtan *et al.* [41] also added that diagenetic processes transform the sedimentary phosphorus according to biological activity, redox conditions, and pH of the final sediment composition. However, different findings have also been found. Koski-Vähälä and Hartikainen [43] found that high pH when linked with intensive resuspension may markedly increase the internal phosphorus risk. As for chemical factors affecting phosphorus mobilization, the equilibrium phosphorus concentration followed the order: pH 7 < pH7 anoxic <pH9 [43]. Statistical tests revealed significant negative pH–SRP relationships, as discussed above (table 4), while the pH range in the water column of Lake Uluabat (table 2) indicated that SRP loading occurred at high pH values. This complex situation may occur when all the interactions among all chemicals are observed, and the effects of other chemicals may change the situations.

It is generally known that phosphorus concentrations in summer are often much higher than in winter [44, 45]. L.S.D. test results indicate that September 1998 was the most important month when the highest mean SRP concentration was determined. This situation may be due to three main reasons in Lake Uluabat. The first concerns SRP relationships among other chemicals. The mean pH value showed a slight decrease in this month, although this decrease was statistically insignificant, and the mean pH value was already high. The highest mean TH value and the second highest mean SO_4^{2-} concentrations were determined in this month. Results indicate that TH is one of the important factors that affected SRP loading in hardwater lakes. Koschel [46] mentioned that hardwater lakes could regulate sediment phosphorus release into the water column. SO_4^{2-} is one of the important chemicals, and the SO_4^{2-}–SRP relationships are discussed below. The second reason may because of the SRP utilization by primary producers. The highest phytoplankton biomass was observed in summer, during the study period [18]. A high phytoplankton biomass may reduce the SRP in the water column, and the highest SRP concentrations may not be observed in summer. The third reason is due to the influence of elevated pH, resulting from photosynthetic activity, and reduced phosphorus concentrations [47, 48]. The highest nutrient loadings which can occur are formed only when suitable conditions are observed, and these feedback reactions are also complicated and miscellaneous. The fact that the interactions among nutrients have not been completely solved may be because not all of these interactions have been fully observed in all studies and/or the effects of these interactions may be masked by other compounds, chemicals and activities of living organisms.

Our data showed that SO_4^{2-} showed a significant positive interaction among SRP and HCO_3^- (table 4). Many investigators agree that a reductive process such as SO_4^{2-} reduction, which is generated in the lake alkalinity, stimulates mineralization and phosphorus mobilization [22]. Enhanced availability of phosphate occurs as a result of SO_4^{2-} reduction in alkaline environments [22]. In addition, Bellemakers and Maessen [22] stated that enhanced SO_4^{2-} fluxes to sediments play a crucial role in the internal eutrophication process in lakes. Roelofs [49] stated that internal eutrophication is partly regulated by the macro-ions HCO_3^- and SO_4^{2-}. Holmer and Storkholm [50] added that substantially altering the cycling of elements such as carbon, nitrogen, phosphorus, and iron in lakes might stimulate SO_4^{2-} reduction of the sediment. Results indicate that alkalinity–pH−TH relationships are the most important factors affecting internal nutrient loadings in Lake Uluabat.

The interactions of SRP−$N-NO_3^-$ and SRP–SRSi, as for other chemicals, are of considerable interest in the internal nutrient load in Lake Uluabat (table 4). Research has revealed positive relationships between SRP and $N-NO_3^-$ [51, 52] but our results could not confirm this finding. However, Andersen [53] suggested that NO_3^-, by oxidizing the sediment, suppressed the release of sediment phosphorus. Jenson and Andersen discussed the possibility that blooms of blue-green algae, which are often associated with low $N-NO_3^-$ levels in the lakes, decreased the sedimentation of particulate phosphorus [52]. The highest cyanobacterial biomass was observed during the summer in the study period [18], and the negative relationships between SRP and $N–NO_3^-$ may originate from this situation. Research indicates that SRSi stimulates phosphorus loading. Silicate anion is also capable of competing with phosphate anions for sorption sites [54]. Both anions are sorbed by the same specific ligand-exchange mechanism onto Fe, Al oxides [54, 55], and Mn oxides [39]. These have also been suggested to be involved in the phosphorus mobility from the sediment [39]. Interestingly, Koski-Wähälä *et al.* [54] found that elevated pH combined with the high SRSi promoted phosphorus desorption. On the other hand, a reverse relation between pH and SRP is well known, which our statistical results support, as discussed above. Results suggest that different chemicals have synergetic effects on one another. Moreover, some evidence shows that interactions among nutrient-inhabiting organisms are important. This may be one of the reasons why the biogeochemical cycles of primary nutrients are strongly associated with the dynamics of primary producers [56]. For example, phosphorus release from sediments follows the demise of a diatom bloom [57]. Gibson *et al.* [58] also added that diatoms take up large amounts of phosphorus in the spring and are the main route whereby both phosphorus and SRSi are transported to the sediment. Our results and other research results indicate that direct or indirect interactions among primary nutrients are important in the nutrient loadings. Interactions among various biogeochemical cycles are crucial for an understanding of the dynamics of aquatic ecosystems [56]. Moreover, nutrient loadings have been stimulated by a combination of different factors such as nutrients among primary producers and bacteria interactions and/or interactions among different biochemicals.

It is clear that the sediment is one of the most important factors as a nutrient reserve in water bodies. However, if suitable conditions are not formed, the nutrient oscillations are limited. Nutrient loadings are induced at different times under different suitable conditions. In deep lakes, these increases are mostly observed in spring and autumn mixing conditions.

Because of the shallow characteristic of Lake Uluabat, thermal stratification is not observed in summer time. Wind-induced mixing is observed in all seasons in the lake. These two factors seem to be important in nutrient oscillation from the sediment to the water column.

Internal nutrient loadings have been observed to be very dynamic processes in Lake Uluabat. Many investigations have proven that nutrient release from the sediment to the water column exists only under suitable conditions such as favourable DO, pH, T, alkalinity, and redox potential. These situations occur under different suitable conditions for different nutrients. Results indicate that such suitable conditions as these exist for many nutrients in Lake Uluabat.

4.2 *External pollution load in Lake Uluabat*

Large temporal fluctuations in physical and chemical variables were determined in the study period. These variations originated from two main factors. The first is internal nutrient loading, which was discussed above. The second is the external pollution load that affected the eutrophication status of the lake. Two major external pollution sources were found in the lake. Results indicate that the Mustafakemalpaşa stream carries high proportions of nutrients into the lake. We emphasize that a high pollution load, entering Lake Uluabat via the Mustafakemalpaşa stream, is one of the important reasons for the external pollution load. The Azatlı drainage channel also greatly influences the physical and chemical composition of the lake. The channel collects Mustafakemalpaşa province domestic waste in addition to accumulated excess irrigation water, joining above station 1. This station also reflects the pollution load entering the lake via Azatlı drainage channel. Unfortunately, the pollution load of Azatlı drainage channel, an important pollution source joining the lake, is not known.

Increased soil erosion has increased sedimentation, a large delta has formed in Mustafakemalpaşa stream mouth (figure 1), and water depth has decreased. Our data show that the SS load entering Lake Uluabat via the Mustafakemalpaşa stream has caused rapid sedimentation in the lake. Satellite observations support the fact that the surface area of the lake has decreased daily [13].

Table 8 shows the boron input joining the lake via Mustafakemalpaşa stream. This higher-than-normal level originates from the boron-mining companies near the Orhaneli and Emet streams. Çöl and Çöl [26] found that the mean level of boron concentration was approximately 10 mg l^{-1} in one of these areas, and this value is much higher than the determined limits. A previous investigation also showed that the boron concentration of the lake was at undesirable levels (table 7).

According to these findings, we emphasize that high nutrient loads, joining the lake from the Mustafakemalpaşa stream, the Azatlı drainage channel, and some companies near the lakeshore, have increased the external pollution load and have changed the trophic status of the lake.

4.3 *Effects of lake-water depth on physical and chemical composition in Lake Uluabat*

Irrigational use of the lake water for Mustafakemalpaşa plain and around the lake basin has reduced the water depth, especially in the summer months. An increase in vaporization and decrease in precipitation intensity are the other two factors that have also decreased the water level. However, the water-level decrease has affected the nutrient status and internal and external nutrient loadings. Søndegaard *et al.* [59] stated that lake morphometry influences the patterns of change in nutrient concentrations on both a seasonal and interannual basis. Because of the shallow characteristics of the lake, the absence of thermal stratification, together with wind-induced mixing in summer time, seems to have affected nutrient concentrations.

Statistical results prove that the chemical composition of the lake water was highly influenced by the lake-water-level fluctuation. Similar results have also been determined between nutrients and water-level fluctuations in other studies [5, 6, 11]. According to the present findings and the comparison of former and present results, we emphasize that water depth has significantly affected the chemical composition of the lake water.

5. Conclusions

Results indicate that there are three major factors which designate the nutrient status of the lake: internal and external nutrient loadings, and the hydrologic cycle related to the climatic response of the lake. Alkalinity, pH, and DO have affected the internal nutrient loadings which affect the nutrient composition in Lake Uluabat. The SRP$-$SRSi$-$N$-$$NO_3^-$$-pH-$DO–alkalinity relationships indicate that internal nutrient loadings in Lake Uluabat show miscellaneous interactions. High proportions of nutrients carried by the Mustafakemalpaşa stream and Azatlı drainage channel have caused significant fluctuations in the chemical composition of the lake, which reflects the high human impact. The water-level fluctuation related to climate variations has also influenced the concentration of chemicals in the lake water. The physical and chemical variables have also changed according to former years. According to all findings, we emphasize that the trophic status of Lake Uluabat, which is a very important RAMSAR site, is endangering the lake balance, which is going to be disturbed, and some measures must be taken to prevent these circumstances.

Acknowledgements

We are grateful to the State Water Affairs (DSİ) 1. Region Head Office for their support and help. We also thank the anonymous reviewers for comments on an earlier draft of this paper.

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