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Assessment of pollution profile in Buyukcekmece Watershed, Turkey

Gokce Tezcanli Guyer · Esra Genç İlhan

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Abstract Buyukcekmece Lake located north of the Marmara Sea coast of Turkey is the third largest water resources among the six main reservoirs of a megacity Istanbul, providing 17% water demand. This study aims to investigate the water quality changes in Buyukcekmece Lake and to classify it in accordance to Turkish Water Pollution Control Regulation for inland surface waters, and assess the impacts of the land-use practices, population density, and settlement in the Buyukcekmece watershed. Physical, chemical, and biological quality of Büyükçekmece Lake has been investigated between December 2007 and June 2008 by collecting samples from the Lake and four streams that feed Büyükçekmece Lake. Land use profile maps of the water basin were created by using ARC-GIS to ensure the quality of drinking water. It was determined that the water quality of Büyükçekmece Lake was still of overall second class, implying that it can be used as a safe drinking water resource following a conventional water treatment scheme; however, it is moving toward the third class. Remarkable portion of the pollution in water basin was attributed to domestic wastewater discharges. Agricultural areas that occupy more than half of the water basin have also adversely affected the water quality.

Keywords Watershed protection · Büyükçekmece Lake · Turkish Water Pollution Control Regulation · ARG-GIS

Introduction

Istanbul, spreading over two continents with its population of over 12 million (Turkish Statistical Institute 2009), is one of the biggest megacities of Europe. Rapid urbanization in the form of population increase and industrialization causes some social and economical problems, together with pollution of surface water bodies in many megacities like Istanbul. In recent years, management strategies to preserve the water quality and the ecosystem of surface waters have been encouraged. Research on the classification of the water quality of surface water reservoirs (Nakashima et al. 2007; Hartig et al. 2009; Baykal et al. 2000; Mallin et al. 2009; Ustun et al. 2006) and effects of land use on water quality have been carried out (Chang et al. 2008; Coskun and Alparslan 2009; Coskun 2006; Lin et al. 2009; Liu et al. 2009).

G. Tezcanli Guyer (✉)
Department of Environmental Engineering, Fatih University, 34500, Buyukcekmece, Istanbul, Turkey
e-mail: gtezcanli@fatih.edu.tr

E. G. İlhan
Eyüp Municipality, Istanbul, Turkey

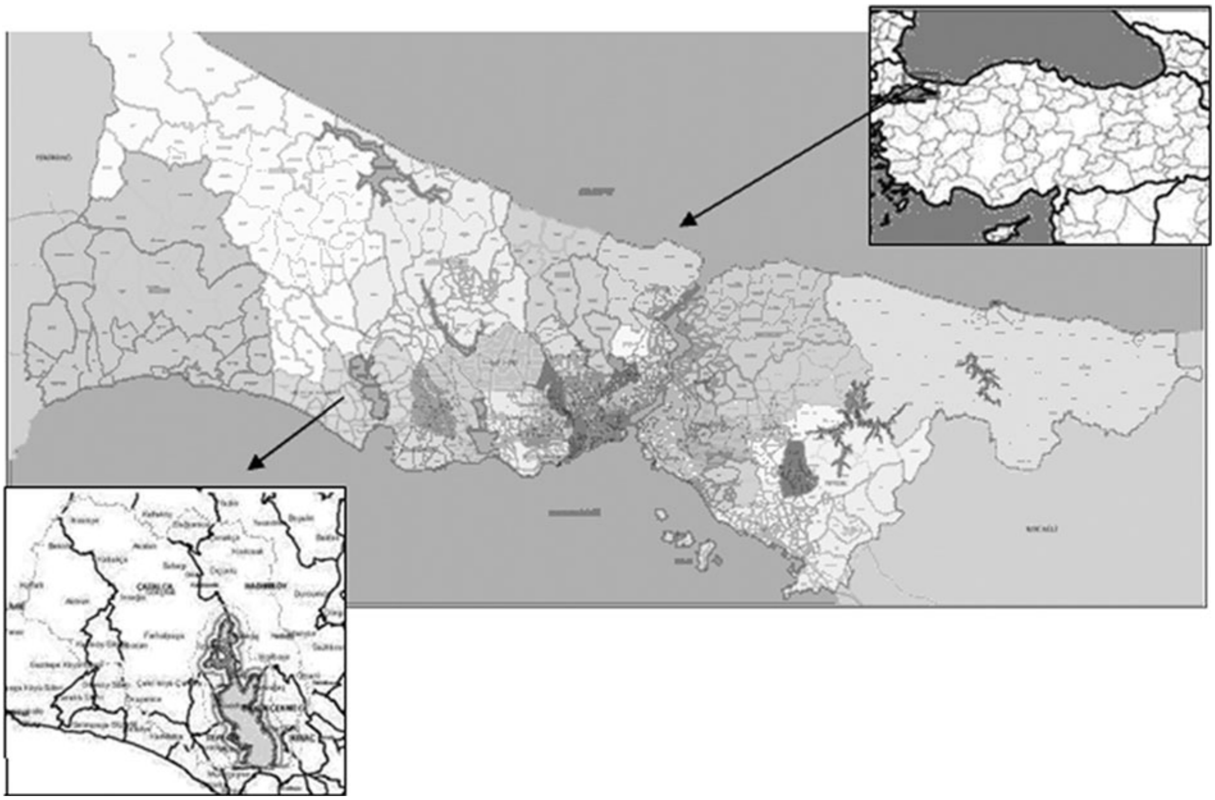

Fig. 1 Location of Buyukcekmece watershed, Istanbul, Turkey

Today, nearly 97% of Istanbul's drinking water is supplied from surface sources which are active lakes and dams (Istanbul Master Plan Consortium 2006). Drinking water catchment basin covers an extensive area; nearly 53% of Istanbul is located within the drinking water catchment basins (Istanbul Water and Sewerage Administration 2005). Rapid population (500,000 capita/year) and industrialization increase in Istanbul have resulted in a near-parallel rapid deterioration of the reser-

Table 1 Water quality classification of inland surface waters (Turkish Water Pollution Control Regulation 2004, TWPCR)

Water quality classes				
Water quality parameters	I	II	III	IV
Physical and inorganic-chemical parameter				
Temperature (°C)	25	25	30	>30
pH	6.5–8.5	6.5–8.5	6.0–9.0	>6.0–9.0
D.O. (mg/L)	8	6	3	<3
NO_2-N (mg/L)	0.002	0.01	0.05	>0.05
NO_3-N (mg/L)	5	10	20	>20
Total P (mg/L)	0.02	0.16	0.65	>0.65
Organic parameters				
COD (mg/L)	25	50	70	>70
BOD_5 (mg/L)	4	8	20	>20
TKN (mg/L)	0.5	1.5	5	>5
Bacteriological parameters				
Fecal coliform (EMS/100 mL)	10	200	2,000	>2,000
Total coliform (EMS/100 mL)	100	20,000	100,000	>100,000

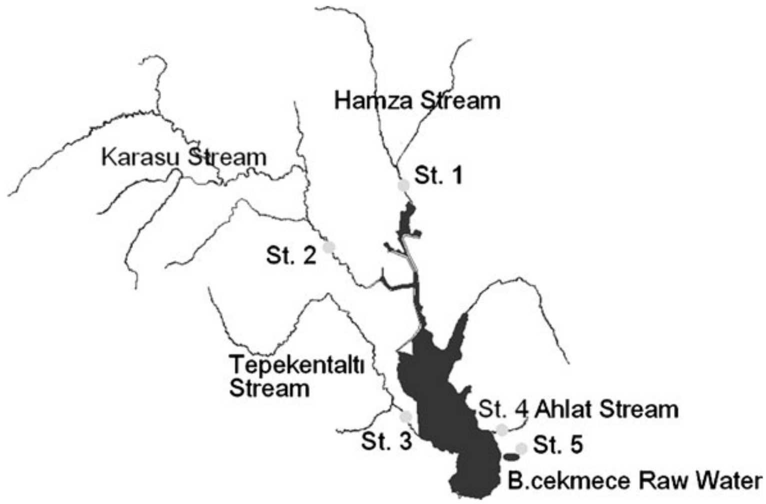

Fig. 2 Sampling sites in Buyukcekmece watershed

voir catchments. Büyükçekmece Lake, which has a drainage area of 620 km^2, is the third largest water resources of Istanbul, and is under great risk of contamination. It is located 35 km to the southwest of Istanbul, which is the most significant historic, cultural, and economic center of Turkey (Fig. 1).

The management of Istanbul water basin is being carried out by a local authority, Istanbul Water Works and Sewerage Administration (ISKI). ISKI provides water and sewerage services for 12.5 million people (Çodur et al. 2007), which is about the 18% of the total population in Turkey. The principal regulations that are based on the protection of the drinking waters of Istanbul are as follows: Turkish Water Pollution Control Regulation (TWPCR) enforced by the Ministry of Environment and Forestry (2004), and Drinking Water Basins Regulation (DWBR) established by ISKI (2006). The regulations include the quality classification of the respective bodies of water, as well as the restrictions in the protection zones formed in the planning of the settlement and industrial and agricultural areas within the water catchment basins. Parameters for the classification are grouped under four headings: (1) physical and inorganic chemical parameters, (2) organic parameters, (3) inorganic pollution parameters, and (4) bacteriological parameters. TWPCR demands that "inland surface water quality scale" exists out of four classes: (1) first class: high-quality water, can be consumed for drinking, swimming, and trout production purposes after disinfection, (2) second class: slightly polluted water, can be consumed for drinking, recreation, irrigation, and fish production purposes after advanced or efficient treatment, (3) third class: polluted water, can be consumed for industrial purposes except for those like food, textile, and pharmaceutical industry, only after an appropriate treatment, (4) fourth class: severely polluted water, any water of lower quality. According to the regulation, only classes 1 and 2 may be used for water supply purposes after efficient treatment. Note that, the lowest quality value determines the quality class for a given group of parameter. Water quality criteria for classification and some selected limit values for inland surface waters are presented in Table 1. Within the context of DWBR, protection zones are defined around the water reservoir, as: absolute protection zone (0–300 m), short-range protection zone (300–1,000 m), middle-range protection zone (1,000–2,000 m), and long-range protection zone (2,000 m–watershed boundary). In summary, permanent settlements and industrial activities are prohibited in absolute and short-

Table 2 Coordinates of the sampling stations

Coordinates stations	*X* (m)	*Y* (m)
Station 1 (Hamza Stream)	376,152	4,562,369
Station 2 (Karasu Stream)	371,758	4,558,566
Station 3 (Tepekentaltı Stream)	376,427	4,548,342
Station 4 (Ahlat Stream)	381,068	4,548,421
Station 5 (Buyukcekmece raw water)	381,730	4,546,446

Table 3 Flowrates of the sampling streams

Monthly flowrates of the streams (Q m^3/s)								
Stations	Months							
	December 2007	January 2008	February 2008	March 2008	April 2008	May 2008	June 2008	July 2008
Station 1	0.5	0.3	0.3	0.2	0.2	0.5	0.2	0.1
Station 2	0.2	0.8	0.5	0.4	0.4	0.8	No water	No water
Station 3	0.4	0.2	0.1	0.1	0.1	0.1	No water	No water
Station 4	0.16	0.1	0.1	0.1	No water	0.1	No water	No water

range protection zones. Very low densities of houses are permitted in the middle-range zone. Existing industries may be permitted to work in the long-range zone under special precautions, but new developments are banned. In order to achieve a sustainable management of the drinking water catchment watersheds of Istanbul, the water quality in the reservoirs and the impact of the watershed should be assessed together.

The main objective of this study is to investigate the water quality changes in Buyukcekmece Lake, to classify it in accordance to TWPCR, and to assess the impacts of the land-use practices, population density, and settlement in the watershed. The effects of industrial, domestic, settlement, infrastructure, agricultural, and other land use activities on reservoir water quality was determined in each protection zones of the basin and the pollution profile maps were created.

Materials and methods

Selection of sampling points

Büyükçekmece Lake has an area of 12 km^2 with shallow waters and deepest section is about 6 m, fed by Karasu, Hamzadere, Tepekentaltı, and Ahlat streams which are connected with other streams (Fig. 2). Water quality analyses were performed in the samples that were collected from Buyukcekmece drinking water treatment facility influent, and four streams feeding the lake. The stations were selected in accordance with their

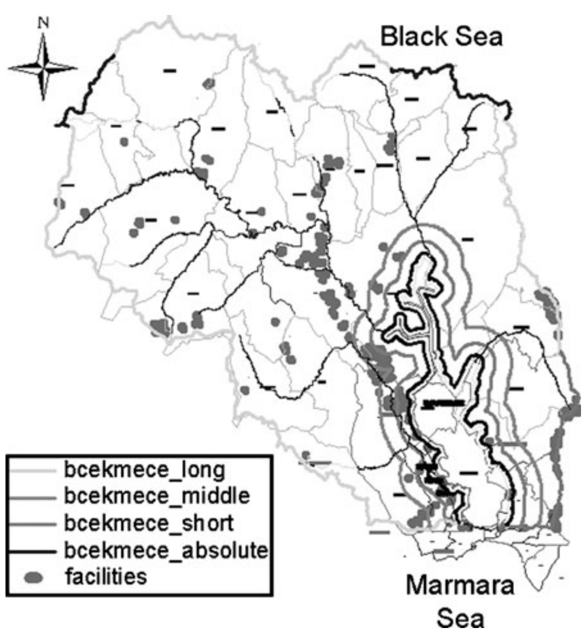

Fig. 3 Distribution of facilities in Buyukcekmece watershed (number of facilities in absolute-range protection zone, 16; short-range protection zone, 23; middle-range protection zone, 13; long-range protection zone, 77)

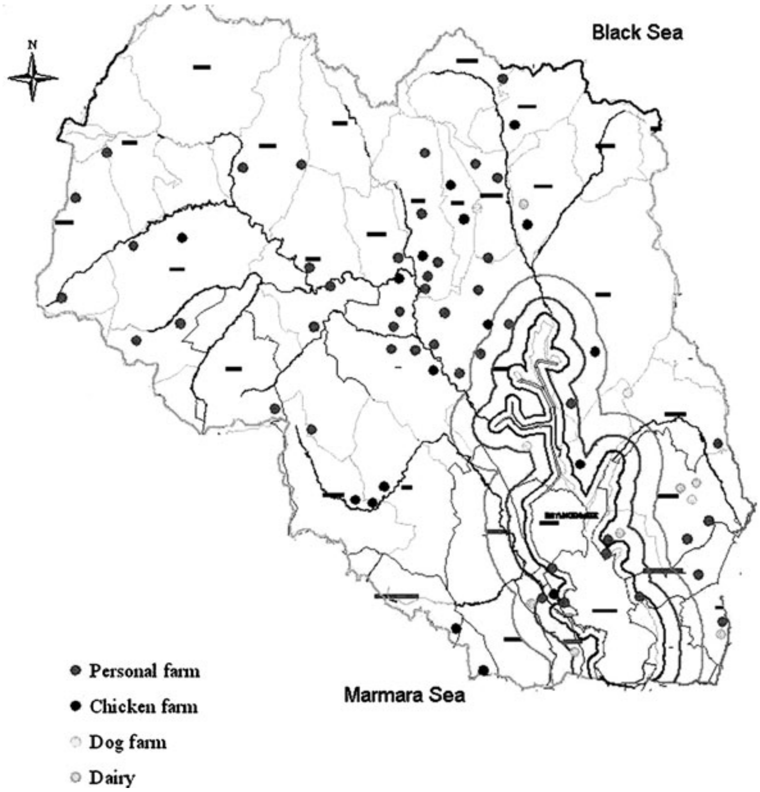

Fig. 4 Distribution of livestocks, personal-chick farms in Büyükçekmece watershed

flow rates compared to other streams that feed the reservoir. Coordinates were determined by using 'Garmin etrex vista' model GPS in the field. Coordinates of the sampling points and the flow rates of the streams are given in Tables 2 and 3, respectively.

Methods of analysis

Water samples were collected monthly from the preselected stations between December 2007 and July 2008. All experiments were conducted in accordance with Standard Methods (APHA/AWWA/WPCP 1998).

The pH, temperature, and dissolved oxygen were measured on site. BOD_5, TSS, fecal coliform, and total coliform analysis were performed within 2 h. The rest of the samples were acidified with 1 M nitric acid and stored in the dark at 4°C, prior to analysis. pH, temperature, and dissolved oxygen analysis were conducted by Merck pH meter.

Supporting computer programs

In this study different computer programs were used such as ArcGIS, ArcMap for creating maps, AutoCAD for editing maps, and Microsoft Office Excel for mathematical manipulation.

Table 4 Number of livestock and farms in protection zones

Livestock–farm types	Absolute preservation zone	Short preservation zone	Middle preservation zone	Long preservation zone
Personal farm	4	3	2	36
Chicken farm	–	2	1	14
Dog farm	–	1	–	3
Dairy	–	2	1	5

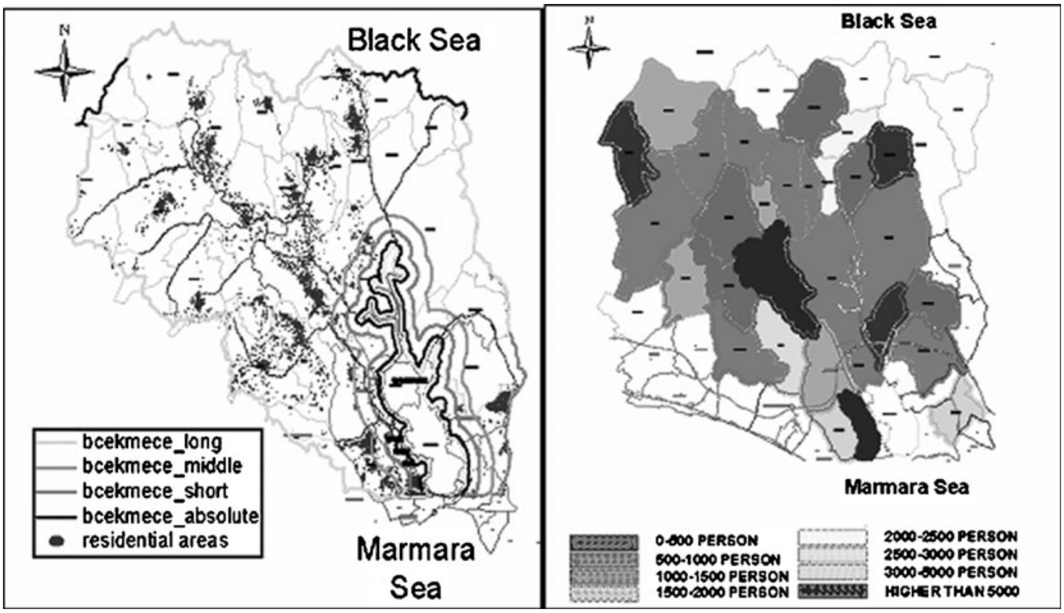

Fig. 5 **a** Settlement, **b** compactness of population in Buyukcekmece watershed

Results and discussion

Evaluation of the land use practices in Buyukcekmece watershed

Buyukcekmece basin is accepted as an important and attractive area by industry financiers and investors because of its nearness to Ambarli harbor, and residential areas containing workforce. That is why there are small industrial facilities in protection zones (Fig. 3).

Besides, there are a lot of livestocks, personal-chick and dog farms in the basin (Fig. 4). And the number of them with respect to protection zones is shown in Table 4.

The increase of the work power around the region resulted in rapid population and irregular urbanization arise. Figure 5 shows the residential areas and the compactness of population in Büyükçekmece watershed.

Population of Istanbul is increased by 300,000–500,000 people in every year by immigration. While 5.3% population increase in 1985–1990 was recorded, 19.79% increase in watersheds was recorded (Turkish Statistical Institute 2009; Yuksel et al. 2004). That shows how urbanization affects the watersheds. Table 5 shows the velocity of population increase of Buyukcekmece watershed year by year.

Velocity of population increase is calculated by using the following equation:

$$r = \frac{\ln\left(\frac{P_s}{P_i}\right)}{t}$$

where r, rate of population increase, t, year, P_s, last population, and P_i, previous population.

Because of rapid population increase, problems of infrastructure also increased at that region. There is a village located in the southwest part of the watershed, where most part of it exists on absolute and short protection zones. This is contrary to the TWPCR that prohibit the any type of settlement in absolute and short-range protection zone. The amount of settlements in the absolute and

Table 5 Average population rate of increase in Buyukcekmece watershed (Turkish Statistical Institute 2009)

	1965–1970	1970–1975	1975–1980	1980–1985	1985–1990	1990–2000	2000–2007
% increase	2.05	3.09	2.71	4.44	9.53	3.76	26.37

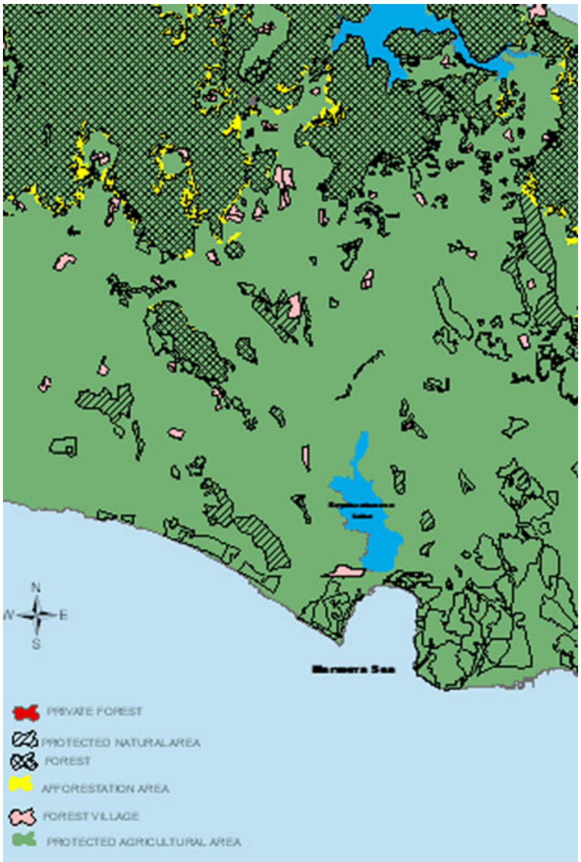

Fig. 6 Land use patterns in Buyukcekmece watershed

short-range protection zones are 6% and 9%, respectively. Sixteen percent of lives in the medium range and 69% of the catchment area population lives in the long-range protection zone. There are some villages discharging their wastewaters directly to the streams without any treatment. Current significant problems associated with protection zones include the lack of municipal plan controlling development and construction within an area. The current land use in the watershed indicates that the 65% of the area is devoted to agricultural activities; 19% of the catchment area is covered by forests and meadows (Fig. 6); 10% consists of settlements, livestocks, and farms and the very limited small industrial activities; and the rest is devoted to the lake itself (Istanbul Master Plan Consortium 2006). Especially southwest part of the catchment area (Tepecik) has experienced an uncontrolled and impressive urbanization, with an increase of population as large as 77% between the years 2000 and 2007. That pressure to the protection zones of the water resources threatens both lake itself and agricultural areas. The consumption of fertilizers and pesticides is important for the watershed where residuals of the fertilizers in the soil can leak to groundwater or transfer to the streams by surface runoff, especially during the rainy seasons. To decrease the toxic effects of the fertilizers, the less harmful fertilizers which are more soluble should be chosen.

Experimental determination of current water quality

The average annual physical, chemical, and bacteriological water quality concentrations are presented in Table 6.

Table 6 Average annual water quality parameter concentrations at sampling stations

Parameter	Station 1	Station 2	Station 3	Station 4	Station 5
pH	7.8 ± 0.2	7.9 ± 0.1	8.1 ± 0.1	8.2 ± 0.1	8.2 ± 0.1
Temprature (°C)	13.5 ± 6.2	12.5 ± 6.1	12.8 ± 6.3	14.30 ± 5.7	16.30 ± 8.6
D.O. (mg/L)	9.01 ± 2.9	11.01 ± 2.7	11.05 ± 1.7	11.36 ± 1.8	9.95 ± 1.7
TSS (mg/L)	28.33 ± 22.2	26 ± 11.4	50 ± 34.6	64 ± 71.9	93.30 ± 112.0
COD (mg/L)	<25	<25	<25	<25	<25
BOD_5 (mg/L)	<8	<8	<4	<8	<4
T-P (mg/L)	1.32 ± 0.9	0.1 ± 0.5	0.1 ± 0.4	1.00 ± 0.2	1.00 ± 0.2
TKN (mg/L)	2.00 ± 1.2	1.00 ± 0.4	0.78 ± 0.3	1.12 ± 0.9	1.00 ± 1.2
NO_2-N (mg/L)	0.37 ± 0.4	0.36 ± 0.5	0.56 ± 0.6	0.38 ± 0.1	0.17 ± 0.1
NO_3-N (mg/L)	1.40 ± 1.1	0.69 ± 0.4	0.26 ± 0.1	1.33 ± 1.3	0.63 ± 0.6
Fecal coliform (EMS/mL)	2,800	8,263	1,433	7,250	337
Total coliform (EMS/mL)	3,300	10,025	975	7,500	400

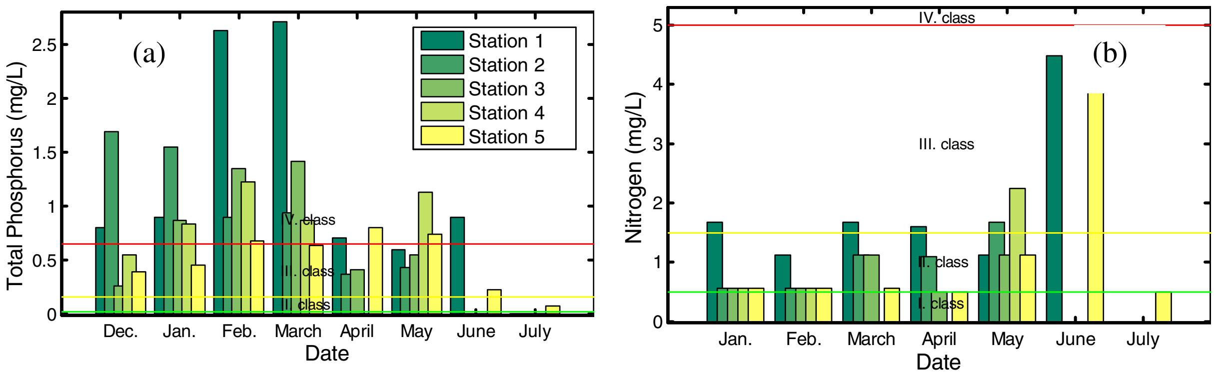

Fig. 7 **a** Monthly total phosphorus, **b** monthly total Kjeldahl nitrogen concentration at sampling points

Table 6 reveals that the most critical group of pollutants is nutrients and bacteriological parameters that exceed second class in accordance to Table 1. The water quality data are in good agreement with land use practices (Figs. 4, 5, and 6).

Although the pH, dissolved oxygen, and temperature analysis results of all stations (during all test period) was first class, the lower quality values of nitrogen and phosphorus determined the quality class for a given group of physical and inorganic chemical parameters. Nutrient pollution regarding pesticides and fertilizers has adverse effect on water quality in terms of eutrophication. Total phosphorus and TKN concentrations are presented in Fig. 7. The highest P concentration increase was obtained during months of winter.

The high phosphorus concentration can be attributed to point sources of domestic origin, whereas high nitrogen concentration arises from non-point sources such as agricultural activities and forests and meadow (see Figs. 5 and 6). As can be seen in Fig. 8, higher nitrogen (also phosphorus) concentrations in the first station can be attributed to the localization of agricultural (Fig. 6) and residential areas (Fig. 5) around this sampling station. Nitrogen also arises from point sources of domestic origin. The remarkable increase in population rate and the lack of infrastructure around the stations of interest results in decreased water quality.

High number of animal farms around the stations can cause bacteriological pollution. The high fecal coliform population in streams can be explained by livestock and domestic waste water discharges around them. When Fig. 4 was examined, personal chicken-farms and livestocks around the sample collecting points were observed. Animal wastes that come from livestocks and farms may be the reason of high fecal coliform concentrations. Daily fecal coliform load for animals are shown in Table 7.

Although the fecal coliform populations in all streams are third and fourth class, the water quality of Buyukcekmece raw water is third class.

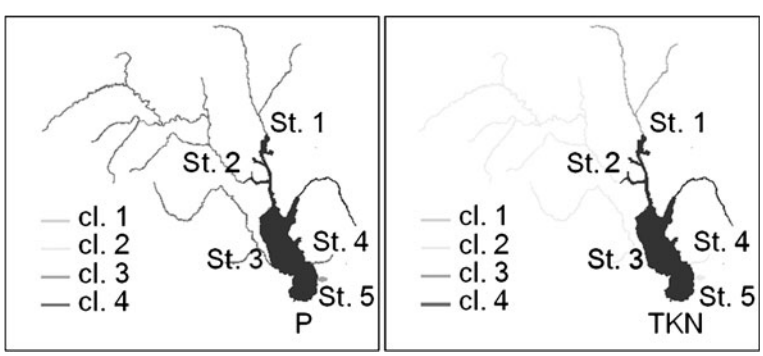

Fig. 8 The classification of water quality of streams feeding Büyükçekmece Lake. **a** Total phosphorus, **b** total Kjeldahl nitrogen

Table 7 Pollution load for animals capita-day (Chapra 1997)

Animals	Fecal coliform pollution load (FC/capita day)
Chicken	240×10^6
Cow	540×10^6
Duck	$11,000 \times 10^6$
Pig	$8,900 \times 10^6$
Sheep	$18,000 \times 10^6$
Turkey	130×10^6

The reason of lower fecal coliform population in the lake may be the higher death rate of coliform bacteria during the way to the lake. It is well known that physical factors such as photo-oxidation, adsorption, sedimentation, and temperature can affect the coliform population in surface waters resulting in an apparent decrease. Fecal coliform may be mentioned as temporary pollution. Uncontrolled domestic wastewater discharges around stations where there are cesspools instead of sewer system can be the reason of high total coliform populations. It is known that 0.3×10^6 total coliform is discharged per capita per day.

The average monthly water quality data of sampling points are classified in accordance to Table 1. Remember that, to implicate the water resource in a class, "all" water quality parameters of a water resource should be consistent with any of the class' parameters, and the lowest quality value determines the quality class for a given group of parameters. Table 8 presents the water quality classification of Buyukcekmece Lake and its streams.

As can be seen in Table 2, streams have relatively low flowrates. Their mass loadings have minor importance when the total volume of Buyukcekmece Lake was considered. Therefore, the results of stream classification do not significantly affect the total water quality classification of Buyukcekmece Lake.

Conclusions and recommendations

Between the months of December 2007 and July 2008, water samples were collected from Buyukcekmece raw water influent and four streams that feed the lake. Water quality was determined by experimental study and the results were evaluated in accordance to TWPCR and the results were associated with self-compiled land use profile maps of the watershed. The following results were obtained:

- In Büyükçekmece Lake, pollution was already noticeable. The total water quality of Buyukcekmece Lake was second class in accordance to TWPCR for inland surface water quality classification, and tended to move toward the third class, which is a sign for the urgent need of an appropriate management strategy concentrating on urbanization, land use, and effective protection practice implementation.
- The results of stream classification (third and fourth class) did not significantly affect the total water quality classification of Buyukcekmece Lake due to their lower mass loadings when the total volume of the Lake was considered.
- Exhaustive bacteriological analyzes results showed that the most part of the total pollution in the basin was originated from livestocks

Table 8 Water quality classification of Buyukcekmece Lake and its streams according to TWPCR

Parameters	Station 5 (Buyukcekmece Lake)	Station 4	Station 3	Station 2	Station 1
Physical and inorganic chemical parameters: temperature, pH, D.O, nitrite, nitrate, total-P	II	III	III	III	IV
Organic parameters: BOD_5, COD, TKN	II	II	II	II	III
Bacteriological parameters fecal coliform, total coliform	III	IV	III	IV	IV

and residential areas located around the sampling stations. Therefore, transportation of wastewater to the streams must be prevented by constructing collectors in residential areas.

- High nutrient concentration was attributed to agricultural areas that occupy more than half of the watershed, forests and meadows, and residential areas. Greenhouse facilities inside the preservation zones must be forbidden to decrease fertilizer consumption, and farmers must be conscious for applying organic agriculture.
- Buyukcekmece watershed can be used as a source of drinking water, but it is important to note that the Lake and its watershed are under risk of over pollution. The rapid increase of population, urbanization, unconscious, and excess use of fertilizers in agricultural areas are the major causes of pollution. Due to the factors mentioned above, Buyukcekmece watershed could not be considered as a source of drinking water in the near future.

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