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Toxic Blue-Green Algal Blooms in Keban Dam Lake and Lake Hazar

Bülent ŞEN , Feray SÖNMEZ*

Fırat University, Fisheries Faculty, Basic Aquatic Sciences Department, Elazığ, Türkiye

ABSTRACT

The blue-green algae are main members of summer phytoplankton in Keban Dam Lake and to some extent in Lake Hazar. Sporadic occurrences of *Microcystis aeruginosa* blooms were noticable in Keban Dam Lake whilst blooms of *Nodularia spumigena* was characteristic in Lake Hazar. Three variants of cyanotoxin namely *microcystin*-RR, *microcystin*-YR and *microcystin*-LR were analyzed in Keban Dam Lake only during *M.aeruginosa* blooms. Their concentrations were determined in the range of *microcystin*-RR 0.27-1.12 µg L^{-1}; *microcystin*-YR 0.12-0.54 µg/L and *microcystin*-LR 0.27-1.15 µg/L respectively. Chlorophyll *a* concentrations were found to range 16-20 µg L^{-1} and 32-36 µg L^{-1} during two blooms of *M. aeruginosa*. *Nodularia spumigena* appeared in the first week of june (2010) with a biomass of 1.368 mg L^{-1} and it proliferated rapidly giving rise to a bloom within two weeks in Hazar Lake. The bloom lasted nearly four weeks and maximum biomass was recorded as 28.4 mgL^{-1}. Chlorophyll *a* concentration was found to be 12-14 µg L^{-1} in the first two weeks of the active multiplication period and increased up to 21-24 µg L^{-1} at the maximum bloom level. *Nodularin* (toxin of *N. spumigena*) was detected in the samples with concentrations varied between 42.3 and 607 µgL^{-1}.

Keywords: Toxic algal blooms, *Microcystis aeruginosa*, *Nodularia spumigena*, Keban Dam Lake, Lake Hazar.

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*** CORRESPONDING AUTHOR**

feraysonmez@gmail.com

Keban Baraj Gölü ve Hazar Gölü'nde Toksik Mavi-Yeşil Alg Çoğalmaları

Öz: : Mavi-yeşil algler, Keban Baraj Gölü ve bir ölçüde Hazar Gölü'ndeki yaz fitoplanktonunun başlıca üyeleridir. Keban Baraj Gölü'nde *Microcystis aeruginosa* bloomları dikkat çekerken, *Nodularia spumigena* bloomları yalnızca Hazar Gölü'nde gerçekleşmiştir. Keban Baraj Gölü'nde *M. aeruginosa* bloomları esnasında alınan örneklerde siyanotoksinin üç varyantı olan mikrosistin-RR, mikrosistin-YR ve mikrosistin-LR analizleri yapılmıştır. *Mikrosistin*-RR konsantrasyonu 0,27-1,12 µg/L; *mikrosistin*-YR konsantrasyonu 0,12-0,54 µg/L ve *mikrosistin*-LR konsantrasyonu 0,27-1,15 µg/L aralığında belirlenmiştir. *M. aeruginosa* bloomları esnasında klorofil *a* konsantrasyonları 16-20 µg/L ve 32-36 µg/L aralığında bulunmuştur. Hazar Gölü'nde *Nodularia spumigena*'nın ilk çoğalmaları, 1.368 mg/L'lik bir biyokütle ile haziran (2010) ayının ilk haftasında ortaya çıkmış ve hızla çoğalmaya devam ederek iki hafta içinde bloom oluşturmuştur. Bloom yaklaşık dört hafta sürmüş ve maksimum biyokütle 28,4 mg/L olarak kaydedilmiştir. Aktif çoğalma periyodunun ilk iki haftasında 12-14 µg/L olarak analiz edilen klorofil *a* konsantrasyonu, maksimum çoğalma seviyesinde 21-24 µg/L'ye kadar yükselmiştir. *Nodularin* (*N. spumigena* toksini) göl suyunda 42,3 ile 607 µg L^{-1} arasında değişen konsantrasyonlarda tespit edilmiştir.

Anahtar kelimeler: Toksik alg çoğalmaları, *Microcystis aeruginosa, Nodularia spumigena,* Keban Baraj Gölü, Hazar Gölü.

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Introduction

Cyanophyta (also refered as cyanobacteria) is conspicuous and common member of phytoplankton of many freshwater ecosystems. Under suitable conditions, they can proliferate rapidly and form blooms. In fact, blooms of blue-gren algae were reported by many authors throughout the world (Paerl et al. 2001; Philips 2007). However one of the major concerns with these blooms is that some of the blue-green algal species have the ability to produce toxins (cyanotoxin) that pose a risk for aquatic ecosystems and to human health (Corus and Bartram 1999). In addition, eutrophication and apperance of cyanobacterial bloom, have become a world-wide problem that can cause serious problems when bloom-forming species release watersoluble toxins (Watanabe and Oishi 1980; Carmichael 1994). There are about 30 species of cyanobacteria that can be associated with toxic water blooms (Skulberg et al. 1993). Reports are available for lakes in at least 44 countries as well as for seas (e.g. the Baltic Sea, Caribbean Sea, Atlantic, Pasific and Indian Oceans) and oceans (Carmichael 1994).

One of the more common and widespread bloom-forming blue-green alga associated with toxin production is *Microcystis aeruginosa* (Kutzing) Lemmerman. However, *Aphanizomenon flos-aquae* Ralfs ex Bornet and Flahault, *Dolichospermum spiroides* (Klebhan) Wacklin, L.Hoffmann and Komárek (*Anabaena spiroides* Klebahn) and *Nodularia spumigena* Mertens ex Bornet and Flahault are also included in the list of toxin producing blue-green algae (Carmichael 1994; Paerl et al. 2001). Toxic algae produce two main types of toxin; alkoloid neurotoxins and peptide hepatotoxin (Cood 1994). Contact with water containing toxic blue-green algae can cause various harms to human health such as vomiting, diarrheria, weakness, liver damage and hepatitis (Cood 1994). The occurrence of toxic cyanophytes can also become a major concern for drinking water when they form blooms in water reservoirs (Rositano et al. 2001).

Toxin of *M. aeruginosa* is called microcystin, a hepatotoxin that can negatively affect aquatic animals and human health (Chorus and Bartram 1999; Zurawell et al. 2005). As a result of this, blooms of toxic *M. aeruginosa* has been reported to be responsible for mass mortalities of aquatic animals thus giving rise to destabilization of food web in aqauatic ecosystems (Zurawell et al. 2005). Consumption of microcystin contaminated drinking water was also reported to pose potential human health risks (Chorus and Bartram 1999).

Aphanizomenon flos-aquae was also reported to produce a cyanotoxin called cylindrospermopsin (CYN) (Preussel et al. 2006). This is a tricyclic guanidine alkaloid associated with the production of harmful metabolites and inhibition of protein synthesis (Froscio et al. 2003). It has been linked to gastrointestinal distress, damage to liver in a variety of aquatic animals. CYN has also been shown to be genotoxic, causing DNA strands breakage (Shen et al. 2002).Concerning human health, 148 people were reported to be hospitalized with hepatitis-like symptoms after exposure to CYN-contaminated water (Bourke et al. 1983).

Nodularia spumigena is a flamentous, heterocystous nitrogen-fixing blue-green alga mostly occurring in saline and brakish waters. Filaments are easily recognizable by the short, compressed/disclike cells and heterocysts. The sheath is rather thin and close the filament. Blooms of *N. spumigena* are usually toxic due to hepatotoxin that they produce. Their toxin is called nodularin that is a cyclic pentapeptide. Its structure and biological activity is similar to that of microcystin. This toxin is reported to be hazardous to aquatic animals when dense blooms occurred that can give rise to acute cases. It may cause death through liver failure (Carmichael 1994).

The first report of cyanotoxic bloom of *Nodularia spumigena* was observed in Lake Alexandria (Australia) as early as in 1980s (Hobson et al. 1999). The lake had the characteristic of estuarine salinity at that time. In recent years prominent blooms of *N. spumigena* were reported to have occurred in Baltic Sea (Kahru et al. 1994; Mazur-Marzec 2006). Blooms of *N. spumigena* are usually toxic due to hepatotoxin that they produce. Their toxin is called *nodularin* that is a cyclic pentapeptide. Its structure and biological activity is similar to that of microcystin. These toxins are reported to be hazardous to aquatic animals when dense blooms occurred that can give rise to acute cases. They may cause death through liver failure (Carmichael 1994).

Microcystin and other cyanotoxins have been identified in many freshwater resources in various countries. To our knowledge, the first report related to occurrence of toxic blue-green algal bloom and cyanotoxin (microcystin) production in freshwater ecosystems in Turkey belongs to Albay et al. (1998). Their work on *Microcystis aeruginosa* bloom was performed in Sapanca (meso-oligotrophic) and Taşkışla Lake (eutrophic). They reported that *microcystin-RR* was dominant cyanobacterial microcystin in Lake Sapanca whilst *microcystin*-LR was determined with higher concentration than other types in Taşkışla Lake. *M. aeruginosa* bloom was also observed in Ömerli Dam Lake by the same authors. Several thosound of fish mortalities were reported due to this bloom. In the same geographical region, occasional blooms of *N. spumigena* were observed in Lake İznik (Akçaalan et al. 2008) and more recently a toxic cyanobacteria bloom was reported from Lake Uluabat (Apolyont) (Ulcay et al. 2010).

Keban Dam Lake and Lake Hazar are two significant freshwater resources for Elazığ and neighbouring provinces. The former is a man-made lake whilst the latter is naturally originated. Lake Hazar is known as the second deepest lake in Turkey after Lake Van. The mean depth is calculated as 90 m (Şen et al. 1999).The lake is tectonic in origin and has elopsoid shape with 4 km width and 20 km length. Lake Hazar is categorized as alkaline lake due to its high alkalinity and pH values is 9 or over 9 in most of the year (Koçer and Şen 2014). This features make Lake Hazar as a specialized/extreme ecosystem.

Irregular occurrence of blue-green algal blooms were observed in lakes situated in Elazığ Province from year to year. Occurrence of *Microcystis aeruginosa* and *Aphanizomenon flos-aquae* blooms were noticable in Keban Dam Lake whilst *Nodularia spumigena* bloom was characteristic only in Lake Hazar. These species have been known to produce toxin under suitable conditions. The cells of these algae contain gas vacuoles (pseudovacuoles) which give them great buoyancy. This naturally accounts for the fact that profuse growths become concentrated at the surface of the lakes where floating scums (constituted by mass of colonies) result.

The present paper emphasizes some significant/interesting findings concerning blooms of toxic blue-green algae *Microcystis aeruginosa* in Keban Dam Lake and *Nodularia spumigena* in Lake Hazar. It is noteworthy that Lake Hazar is the second ecosystem in which the toxic bloom of *N. spumigena* was recorded in our country after Lake İznik.

Materials and Methods

Blue-green algal blooms occurred in summer and early autumn. *Microcystis aeruginosa* blooms occurred in july (2015) and august (2019) in Keban Dam Lake, *Nodularia spumigena* blooms were observed in Lake Hazar during autumn (september) in 2014 and 2016. Blooms of *Aphanizomenon flos-aquae* were also observed in Keban Dam Lake. Blooms were recorded in 2018 (mid september) and 2020 (late september). Toxin analysis were carried out both during *M. aeruginosa* and *N. spumigena* blooms. However such analysis could not be performed for *A. flos-aquae* bloom due to lack of laboratory facilities.

Blooms occurred in littoral regions in both lakes and samplings were carried out only at one station (from the center region of the blooms). Water and algal samples were collected from under the surface of the lakes. Plankton net (20 µm mesh size) and water botttle were used for qualitative and quantitative algal and water collections. Water temperature and pH were measured *in situ* using a multi parameter analizer (YSI 63). Biomass of algae was determined according to method described by Rott (1981). Nitrate and orthophosphate concentrations were analysed following the spectrometric method outlined in APHA (1989). Chlorophyll *a* was determined spectrometrically through aseton method described by Wetzel and Likens (1991) and calculated through monokromatic method (Lorenzen 1967). Toxin analysis was performed at Fisheries Faculty of Istanbul University according to method described by Lawton (1994). The ISO 20179 method was used for microcystin analysis and results were given as Microcystin-LR eq. Micrographs of algae were taken with Nikon Eclipse 80i research microscope and algae were identified from relevant references (Wehr and Sheath 2003; John et al. 2003).

Results

The blue-green algae are main members of summer phytoplankton in Keban Dam Lake and to some extent in Lake Hazar. Blooms of blue-green algal species known potentially to be toxic were observed to occur in these lakes from time to time. When blooms occurred, colonies and/or filaments of algae formed visible thick and wide bands on surface of the lakes. The highest dentisities of filaments and colonies were usually found at first 0.1-1.5 m depth. However filaments and colonies were also found to be suspended in deeper water columns.

Occurrence of *Microcystis aeruginosa* was noticable in Keban Dam Lake whilst occurrence of Nodularia spumigena was characteristic only in Lake Hazar.

Microcystis are characterised as notoriously and overwhemlingly dominant species in many tropical, subtropical and temperate lakes (Fogg et al. 1973; Chorus and Bartram 1999). Sporadic occurrence of *Microcystis aeruginosa* (Figures 1, 2) blooms was also noticable in Keban Dam Lake. When blooms occurred, scums of the alga covered a large part of the lake surface (Figure 3). During the bloom, scums formed visible thick oily surface layers/bands particularly in the littoral region (Figures 4-6). The highest densities of filaments and colonies were usually found at first 0.1-1.0 m depth. However they were also found suspended in smaller numbers up to 1.5-2.0 m. Great density of colonies also changed the colour of lake water to blue-greenish.

Microcystis aeruginosa blooms in Keban Dam Lake did not occur at regular intervals. First bloom was recorded in July 2015 and the second one occurred in August 2019. Density of *M.aeruginosa* during the blooms was estimated as high as 90-95% in overall phytoplankton population. Chlorophyll a concentration was found to range 25-28 µg/L and 32-36 µg/L during the first and the second bloom of the alga respectively. The blooms particularly occurred in Uluova Region of the lake. This region is the most polluted part of the dam lake as city sewage is being discharged into the lake in this part. Thus, high nutrient contents available in Uluova Region could be considered as one of the main reasons for blooms to occur in this part of Keban Dam Lake since no blooms were observed in other parts of the lake.

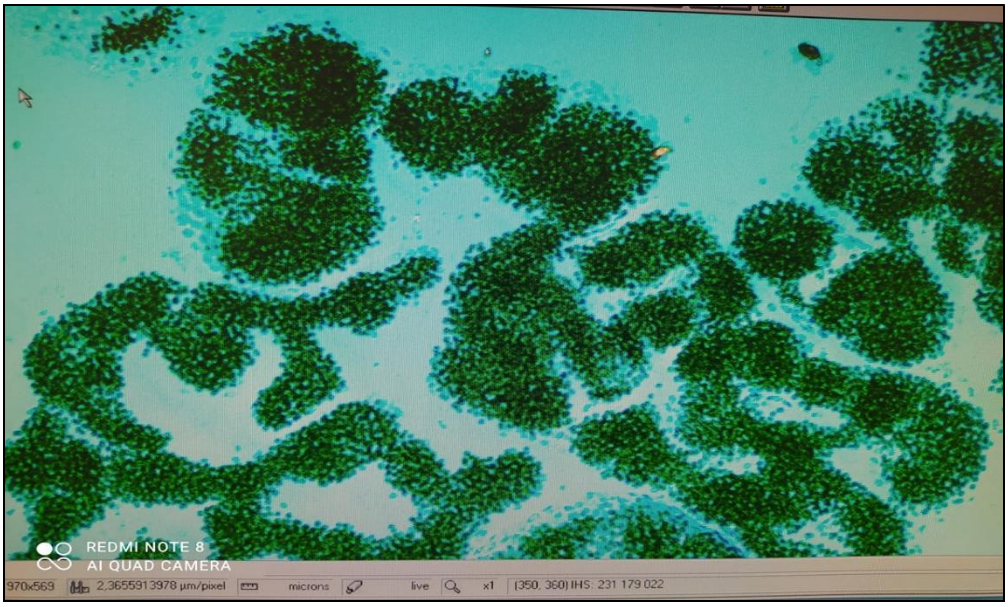

Figure 1. The general appearance of *Microcystis aeruginosa* colonies under the microscope.

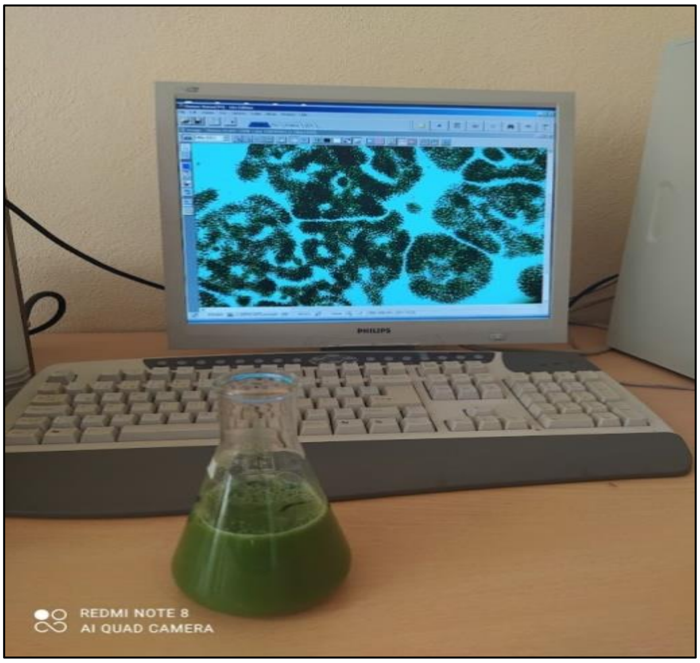

Figure 2. The microscobic appearance of *Microcystis aeruginosa* colonies as stored in a computer attached to microscope. **Note:** Notice the thick, dense mass of *M. aeruginosa* colonies in the conical flask collected from Keban Dam Lake.

Figure 3. General view of *Microcystis aeruginosa* bloom on the surface of Keban Dam Lake. **Note:** Notice how scums covered almost the whole surface of the lake.

Figure 4. The bloom-band of *Microcystis aeruginosa* visible on the surface of Keban Dam Lake

Figure 5. Thick oily scums of *Microcystis aeruginosa*

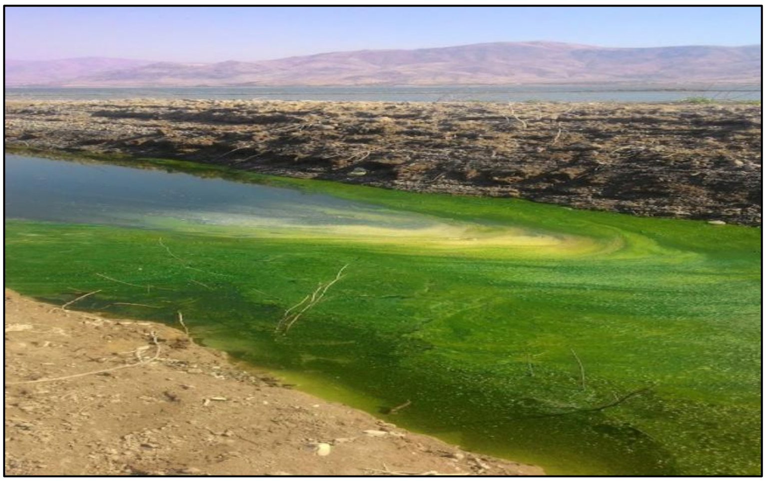

Figure 6. Blue-greenish oily scums of *Microcystis aeruginosa* in a indentation of Keban Dam Lake.

Scums of *M. aeruginosa* constituted thick oily layer on the surface water particularly near the shore (Figures 6, 7) in Keban Dam Lake. This region is better protected from strong wind effect therefore it offers a calm/unwindy water conditions for the colonies to accumulate and proliferate.

Naturally this gives rise to the formation of thick-oily scums. Blooms of the alga usually lasted 3-4 weeks with varying densities. Colonies proliferated and spreaded rapidly to form massive scums on the surface of the lake. They usually spreaded slowly from littoral region towards open water part. However thicker scums were always in the littoral. It was also possible to observe blue coloured remains of scums on the shore after water level decreased towards the end of summer (Figure 7).

Figure 7. Conspicuous blue coloured remains/residues of *Microcystis* scums on the lake shore after water level decreased.

Toxin of *M. aeruginosa* is called microcystin. Three variants of microcystin namely ***Microcystin-RR***, ***Microcystin-YR*** and ***Microcystin-LR*** were analyzed in lake water during the blooms. Their concentrations were determined in the following range; microcystin-RR 0.27-1.12 µg/L, microcystin-YR 0.12-0.54 µg/L and microcystin-LR 0.27- 1.15 µg/L (Table 1).

Table 1. Microcystin values determined in Keban Dam Lake during *Microcystis aeruginosa* blooms.

Bloom 1	Microcystin-YR	0.12-0.52 µg/L
	Microcystin-LR	0.27-1.13 µg/L
Bloom 2	Microcystin-RR	0.27-1.12 µg/L
	Microcystin-YR	0.12-0.54 µg/L
	Microcystin-LR	0.27-1.15 µg/L

Table 2. Mean values of some physical and chemical parameters of Keban Dam Lake during *Microcystis aeruginosa* blooms.

	Littoral	**Open water**
pH	8.1	8.3
Water temperature (°C)	25.6	28.4
Dissolved oxygen (mg O_2/L)	7.8	8.3
Electrical conductivity (µS/cm)	290	284
Orthophosphate (µg/L)	110	80
Nitrate (µg/L)	2100	1120
Total hardness (mg$CaCO_3$/L)	144	142

(table continues…)		
Chlorine (Cl)	24.1	21.9

In recent years blooms of *Aphanizomenon flos-aquae* was also observed in Keban Dam Lake. Blooms were recorded in 2018 (mid september) and 2020 ((late september) that never coincided with the bloom years (2015, 2019) of *M. aeruginosa*. During the bloom, *A. flos-aquae* filaments constituted the almost 90 % of the whole phytoplankton population. Many individual filaments of *A. flos-aquae* gather together to form free-floating flakelike bundles (Figure 8) which were easily visible scattered/spreaded on surface of the lake at first 0.1-1.5 m depth. Toxin analysis during the bloom of *A. flos-aquae* could not be performed due to lack of laboratory facilities.

Figure 8. General appearance of filaments of *Aphanizomenon flos-aquae* under the microscope. **Notice** flakelike bundles of the alga.

Blooms of *Nodularia spumigena* (Figure 9) are usually toxic due to hepatotoxin called nodularin. First bloom of *N. spumigena* in Lake Hazar was reported by Şen et al. (2010). The high densities of filaments were usually found at 0.1-0.5 m water column. The first apperance of the alga was observed in the first week of june (2010) with a biomass of 1.368 mg/L (1368 µg/L) and it multiplied rapidly giving rise to a bloom within two weeks. The bloom lasted nearly 4 weeks with varying densities. The maximum biomass was recorded as 28.4 mg/L (28400 µg/L). At this stage, a thick band caused by dense filaments of the alga was visible on the surface of the lake (Figure 10). Chlorophyll a concentration was found to range 12-14 µg/L in the first two weeks of the active multiplication period and increased up to 22 µg/L at the maximum bloom level. During the first bloom of *N. spumigena* (2010), the concentration of the toxin of the alga (nodularin), was detected to vary in a range of 42.3 - 607 µg/L. On the onset of the bloom, concentration of nodularin was determined as 42.3 µg/L and it increased up to 607 µg/L at maximum bloom level.

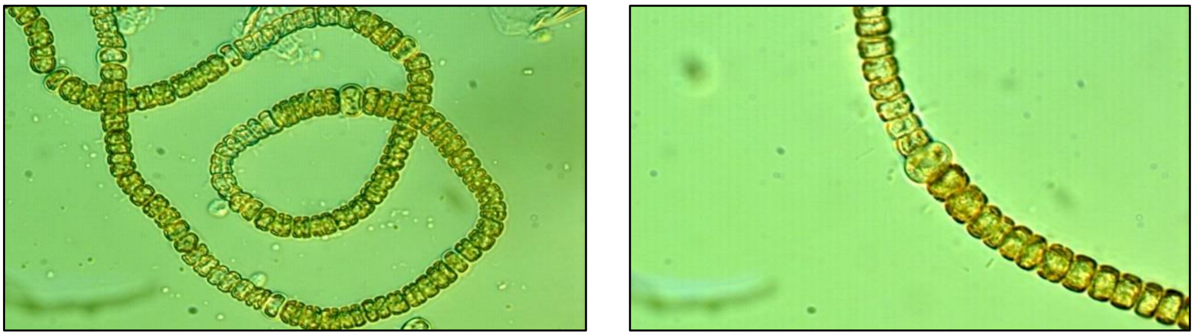

Figure 9. Micrograph of *Nodularia spumigena* observed in Lake Hazar.

Figure 10. Thick bloom-bands of *Nodularia spumigena* spreading on the surface of Lake Hazar.

The second bloom was observed during summer of 2016. Biomass of the alga showed similarity to that of the first bloom. On the onset of the bloom (mid July), biomass was determined as 1.204 mg/L (1204 µg/L) and finally reached to a maximum biomass of 19.2 mg/L (19200 µg/L) in August. Chlorophyll a concentration was 17.2 µg/L at maximum bloom level. Concentration of nodularin was determined to vary minumum 34.6 µg/L (on the onset) and maximum 544 µg/L. No fish mortalities were observed during both blooms.

Concentrations of nitrate (NO3) and orthophosphate (PO4) generally ranged 0.361- 0.581 mg/L (361-581 µg/L) and 0.008- 0.017 mg/L (8-17 µg/L) respectively during the summer seasons in Lake Hazar (Table 3).

Table.3 Summer physical and chemical water properties of Lake Hazar

Parameters	Minimum	Maksimum
pH	9.0	9.2
Water Temperature (°C)	24.1	26.0
Electrical Conductivity (µS/cm)	2161	2439
NO_2 (µg/L)	48	61
NO_3 (µg/L)	361	581
TN (µg/L)	740	1010
PO_4 (µg/L)	8	17
TP (µg/L)	14.1	21.4
Cl (mg/L)	231	314

N. spumigena has never been observed and/or was reported from Keban Dam Lake. On the contrary, blooms of *Microcystis aeruginosa* and Aphanizomenon flos-aquae never occurred in Lake Hazar. Higher contentrations of nodularin in Lake Hazar compared those of microcystin detected in Keban Dam Lake was noticable.

Discussion

The blue-green algae are main members of summer phytoplankton in Keban Dam Lake and to some extent in Lake Hazar. Occurrences of *Microcystis aeruginosa* and *Aphanizomenon flos-aquae* were noticable in Keban Dam Lake whilst occurrence of *Nodularia spumigena* was characteristic only in Lake Hazar. These species have been known to produce toxins under suitable conditions.

Microcystis is characterised as notoriously and overwhemlingly dominat species in many tropical, subtropical and temperate lakes. Sporadic occurrence of *Microcystis aeruginosa* blooms was also noticable in Keban Dam Lake. The blooms of the toxic blue-green alga *M. aeruginosa* occurred particularly in Uluova Region of Keban Dam Lake. This region is the most polluted part of the dam lake. City sewage is discharged into this part and there are many agricultural lands in the vicinity where fertilizers are used extensively. Thus one may think that, main reason for blue-green algal blooms to occur in this part of the dam lake could be the high nutrient concentrations available for the algae due to nutrient loading. This finding is in harmony with that of Roxas and Salgados (2014). Uluova Region of the lake has moderately alkaline and moderately hard water characteristics. Thus, it may be posssible to suppose that these properties of the lake water may also favour the cyano-blooms to occur in the region.

Blue-green algae (cyanobacteria) are widespread. Fogg et al. (1973) reported that the major factors influencing their growth are light, temperature, chemical composition of lake water and dissolved oxygen concentration.

Planktonic species such as *Aphanizomenon, Anabaena, Coelosphaerium, Gloetrichia, Microcystis* and *Oscillatoria* were shown to have a preference to warm water condition (temperature ranging 17-20 °C) for their growth (Fogg et al. 1973; Walsby 1975). In addition, it is also considered that higher temperatures over 20 °C seem to favour the formation of blooms. Reynolds (1984) emphasized that 20 °C is the most suitable water temperature for the optimal growth of most blue-green algae occurring/known in lakes of temperate regions.

Present study supported above findings since cyanobacteria blooms in Lake Hazar and Keban Dam Lake usually occurred during summer when water temperaturee were high. *M. aeruginosa* and *N. spumigena* bloom showed a clear relation with water temperature since occurrence of blooms always coincided with temperatures over 20 °C (usually 20-26 °C). It is also worth to mention that Albay et al. (2005) reported that microcystin production in Lake Küçük Çekmece occurred between 16-25 °C and maximum production was recorded at 24-28.5 °C. Considering most of the blooms occurring at high temperatures, it may be possible to suggest that summer water conditions, particularly high water temperatures, also favour the growth and bloom formation of cyanobacteria both in Lake Hazar and Keban Dam Lake. However, it should be noted that active multiplication of *Aphanizomenon* also occurred at lower (16-18 °C) water temperatures.

Mature mode of nutrition of blue-green algae is autotrophic. They have ability to survive the extreme light conditions of summer season at the water surface (Mur and Beijsdorf 1978). Present study supported this as cyanoblooms both in Keban Dam Lake and Lake Hazar occurred in summer when high-light conditions were prevaling. Oppositely, cyanobacteria are also reported to be able to sustain biomass under low-light conditions better than eukaryotic algae. The main reason for that was explained with their low maintenance energy requirements at low light levels (Mur and Beijsdorf 1978). Occurrence of *A. flos-aquae* in Keban Dam Lake supported this finding since the alga also grew well in late-winter and spring. However it is noteworthy that the alga never formed a bloom in this period of the year.

Many cyanobacteria cannot survive high light intensities over long period. This may limit their distribution to more turbid eutrophic ecosystems. However *Microcystis* spp. are less sensitive to high light intensities because buoyancy regulation enables them to find light conditions that are optimal for their growth (Fogg et al. 1973; Walsby 1975). This means that the presence of *Microcystis* spp. cannot be related strictly to the level of eutrophication. This genus therefore can be found in mesotrophic, eutrophic and hypertrophic waters. However, it is logical to consider that amounts of biomass that this species attain depends on the level of eutrophication. In Keban Dam Lake, *M. aeruginosa* and *A. flos-aquae* blooms only occurred in the most polluted part (Uluova Region) of the lake where nutrient concentration is possibly higher than in other parts. It is evident that high nutrients contents naturally favours the cyanotoxic algal blooms. It is also noticable that no blooms were observed in other parts of the lake probably due to insufficient nutrient concentrations. Thus, occurrence of cyanotoxic species only in polluted part of Keban Dam Lake that has eutrophic water properties clearly supports the findings of Chorus and Bartram (1999).

Most *Microcystis* blooms are found in lakes with summer chlorophyll *a* concentration of 20-50 µg /L (Chorus and Bartram 1999). The present study is in harmony with the finding of these authors as chlorophyll *a* concentration in Uluova region of Keban Dam Lake was found to range 16-36 µg/L during *Microcystis aeruginosa* blooms. In addition, chlorophyll *a* concentration during the bloom of *Nodularia* in Lake Hazar was found to range 12-14 µg/L in the first two weeks of the active multiplication period and increased up to 22 µg/L at the maximum bloom level. In addition *Nodularia spumigena* blooms in Lake Hazar coincided with chlorophyll *a* concentrations over 20 µg/L.

Blue-green algae are sometimes predominant in waters poor in nutrients. Maxima tend to occur some weeks after the nutrients decreased (Fogg et al. 1973). These algae may store previously available nitrogen that they use under nitrogen-limiting conditions. Akçaalan et al. (2008) determined the concentration of nitrogen ($NO_2 + NO_3$) as 81.9 µg/L (0.081 mg/L) during the bloom *of Nodularia* in Lake İznik. Concentrations of nitrate (NO_3) and orthophosphate (PO_4) generally ranged 361-372 µg/L (0.361-0.372 mg/L) and 8-12 µg/L (0.008-0.012 mg/L) respectively during *Nodularia spumigena* blooms in Lake Hazar. Occurrence of *Nodularia* bloom at low nitrogen concentrations in lake İznik and Lake Hazar appears to support the finding of Fogg et al. (1973). However, concentrations of nitrate were always high (ranged 2.1-4.6 mg/L) to support the rapid multiplication of *Microcystis aeruginosa* in Keban Dam Lake where nitrate and orthophosphate concentrations were 5-6 folds of those recorded in Lake Hazar and Lake İznik.

Cyanotoxic blooms of *Nodularia spumigena* were observed in lakes (Hobson et al. 1999) as well as in seas (Kahru et al. 1994; Mazur-Marzec 2006). However toxic bloom of the alga was reported only from a freshwater lake (Lake İznik) in Turkey so far. Lake Hazar is the second ecosystem in which the toxic bloom *N. spumigena* was recorded in our country.

Akçaalan et al. (2008) reported that maximum filament concentrations of *N. spumigena* occurred in August in Lake İznik. Present study is in harmony with these authors since first bloom of *N. spumigena* in Lake Hazar occurred late-July and the second one was observed in early-August. Therefore it may indicate that blooms of *N. spumigena* tend to occur in summer like that of *M. aeruginosa* in this geographical region.

Akçaalan et al. (2008) analysed chlorophyll *a* concentration as 11.4 µg/L during the bloom of *Nodularia spumigena* in Lake İznik. Similarly, chlorophyll *a* concentration was found to range 14-18 µg/L during the blooms of the same alga in Lake Hazar. Level of pH in lake İznik was reported to be 8.99 (Akçaalan et al. 2008) that is almost as high as that of Lake Hazar.

A direct reletionship between *N.spumigena* blooms and high phosphate and low nitrogen content in brakish waters was found by Lehtimaki et al. (1994). However, the present study is partly in harmony with this finding since active growth of *N. spumigena* coincided with low concentrations of both nutrients in Lake Hazar.

Salinity was reported to be one of the main factors for blooms of toxic cyanobacteria to occur (Kahru et al. 1994; Mazur-Marzec 2006; Akçaalan et al. 2008). However effect of salinity in the present study was obscure since chlorine concentration were too low to affect strongly the occurrence of cyanotoxic blooms in Keban Dam Lake. However this may hold true for the bloom of *Nodularia spumigena* in Lake Hazar that is a characteristic lake with high alkalinity and pH level. In fact, chlorine (Cl) concentration was found to range 200-300 mg/L in Lake Hazar (Koçer and Şen 2014) that is almost 10 folds of that recorded (21.9-24.1 mg/L) in Keban Dam Lake.

It is noteworthy to emphasize that *N. spumigena* was never observed and/or reported from Keban Dam Lake. On the contrary, blooms of *M. aeruginosa* and *A. flos-aquae* never occurred in Lake Hazar. This is most probably due to different water quality characteristics of the two lakes. In fact, it is possible to consider that specialized environmental features of Lake Hazar (such as high alkalinity and pH) may prevent *Microcystis* and *Aphanizomenon* from occurring in in this lake. This may be true as it was reported that considerably high and low degree/concentration of any environmental variables may become a restricting factor for algal growth in the ecosystems (Rai and Gaur 2001).

Concentrations of cyanotoxins produced by *Nodularia spumigena* and *Microcystis aeruginosa* were considerably different although both algae formed thick bloom bands when blooms occurred. In fact, higher concentration of *nodularin* in Lake Hazar was noticable compared to that of *microcystin* detected in Keban Dam Lake. Different water properties of the two lakes may be taken as one of the reasons for this. It is a well-known fact that dam lakes have different water properties and dynamics than those of highly alkaline and less dynamic lakes like Lake Hazar. Different trophic status of these lakes should also be taken into consideration to explain the difference related to toxin production.

Albay et al. (1998) studied *M. aeruginosa* bloom occurred in Sapanca (meso-oligotrophic) and Taşkışla Lake (eutrophic). They reported that *microcystin-RR* was dominant cyanobacterial microcystin in Lake Sapanca whilst *microcystin*-LR was determined at higher concentration than other variant of microcystin in Taşkışla Lake. All three variants of microcystin were also determined in Keban Dam Lake during *Microcystis aeruginosa* bloom and amount of microcystin-RR and microcystin-LR were also higher than that of microcystin-YR. Albay et al. (2005) reported that highest microcystin production occurred when ratio of TN/TP was over 7. High concentration of nitrate in Keban Dam Lake also appeared to support the cyanotoxin production.

Blooms in Keban Dam Lake and Lake Hazar usually commenced to occur in the littoral regions. Nutrient concentrations in littoral regions are always higher than those in open water parts of the lakes. This may be one of the the main reason for blooms to occur in the littoral regions. In addition, wind and water movements push the filaments and colonies of the blue-green algae to accumulate in a much smaller volume of water to form dense populations. Naturally, this may give rise to an increase in number of individuals/colonies in the littoral.

Fortunately, fish mortalities were not observed during the blooms of both *M. aeruginosa* and *N. spumigena.* This is most probably due to the low concentrations of the cyanotoxins in these lakes. Both lakes have enormous water volume that most probably contribute a rapid dilution of cyanotoxins. In addition, fishes probably prefer to gather in colder deep water rather than staying in warm surface water during summer. This creates a good alternative for fishes to keep themselves awayfrom the effect of harmful toxic blooms that always occurred on the surface waters (at 0.1-1.5 m water column). However, it was reported that the longevity of the effects of toxic*M. aeruginosa* in different ecosystems depend on factors that can accelerate the degradation or dilution of the toxin, such as ultraviolet radiation, strong oxidizers, naturally occurring bacteria which deactivate or otherwise eliminate microcystin (Watanabe et al. 1992). Hydrologic consideration such as tidal flushing and water residencetime should also taken into consideration to define the rate of dilution of both toxic cells and extracellular toxin.

Abundance of cyanobacteria is usually closely linked to eutrophication. In fact, it is a significant observation considering the fact that cultural eutrophication of surface waters resources has increased with the world-wide occurrences of putatively toxic algal blooms. The same threat is also valid for Keban Dam Lake and to some extent Lake Hazar. It should always be noted that continous nutrient loading from catchment area will definitely give rise to a change in the trophic status of these lakes in the long term. It is a well-known fact that, shifting trophic status of the lakes from oligomesotrophy to eutrophy with increasing nutrients will be inevitable in future. At that stage, unfortunately it may be possible to witness more frequent and more intensive toxic blooms of cyanophyta/cyanobacteria in Keban Dam Lake and Lake Hazar, possibly resulting in fish deaths.

Because of potential harmful effects of *M. aeruginosa, A. flos-aquae* and *N. spumigena,* occurrence of these algae in Keban Dam Lakeand Lake Hazar should be monitoredreqularly. In addition external nutrientloads of diffuse and point resources in these lakes from their vicinity should be estimated
and controlled carefully. It should be an urgent issue for local govermental authorities thatthese algae should become a focus of efforts to control harmful algal blooms in these ecosystems. Preventing bloom of harmful algae is extremely significant to maintain their sustainable use for fisheries, irragation and recreational purposes. It should always be remembered that toxic algae naturally cause a serious damage to the sustainable use of the lakes.

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