International journal of Advanced Biological and Biomedical Research
ISSN: 2322 - 4827, Volume 1, Issue 4, 2013: 403-420
Available online at http://www.ijabbr.com

Effects of agriculture, tourism and the dam on eutrophic status of the Zerebar Lake, Iran

Tahsin Rahmani [1], Hadi Poorbagher [*1], Arash Javanshir [1], Barzan Bahrami Kamangar [2]

[1]Department of Fisheries, Faculty of Natural resources, University of Tehran, Karaj PO Box 4111, Iran.
[2]Department of Fisheries Sciences, Faculty of Natural Resources, University of Kurdistan, Sanandaj, 416, Iran.

Abstract

The Zerebar Lake is a shallow freshwater lake located in the northwestern Iran. The lake is surrounded by three human activities: agriculture, tourism and dam. The present study aimed to investigate (1) which human activity has the greatest impact on eutrophication of the Zerebar Lake (2) If phytoplankton communities, as the indicator, are correlated with the human activities. Water samples were collected from three selected sites (nearby three human activities) in the Lake every two months, from August 2010 to June 2011. Water variables and parameters of phytoplankton communities (distribution, abundance, biomass and diversity indices) were examined. Agricultural runoff had the main effect on eutrophication of the Lake and the dam deteriorated trophic condition by preventing removal of the nutrients. Although, phytoplankton diversity was affected by nutrients, especially phosphorous, phytoplankton biomass was likely affected by physical parameters, mainly light. The present study suggests that phytoplankton diversity indices are not good indicators for anthropogenic activities around the Lake. However, some phytoplankton genera were more suitable indicators of trophic condition of the lake than others.

Key word: Shallow Lake, Human activities, Eutrophication, Phytoplankton indices.

INTRODUCTION

Eutrophication is the process of water enrichment with nutrients (Istvanovics 2009; Best 1999; Painting *et al*, 2007; Karydis 2009; Scholten *et al*, 2005) that change fauna, flora and water chemistry, food chains and nutrient cycles (Asaeda *et al*, 2001). Eutrophication can be natural, stems from natural processes such as climate variations (Vincent, 2009). The natural eutrophication occurs slowly over a period of many years through the lake aging process (Hill, 2010). Human activities increase nutrient loading and intensify this natural process (Khan and

Corresponding Author: Hadi Poorbagher, Email: poorbagher@ut.ac.ir

Ansari, 2005; Dodds, 2002), which is called cultural eutrophication. The cultural eutrophication is the most important global water quality problem (Glibert *et al*, 2005). As 54% of lakes in Asia, 53% in Europe, 48% in North America, 41% in South America and 28% in Africa are faced eutrophication problems (Nyenje *et al*, 2010). Urbanization, agricultural activities and industry are the main human activities that affect eutrophic status of lakes (Bartsch 1970). Of them, agricultural activities have a great role (Ekholm *et al*, 1997) because it is a key source of phosphorus (P) for water bodies (Bennett *et al*, 2001; Sharpley *et al*, 2003). The agricultural runoff is characterized by agrochemicals, including pesticides, fertilizers and manure, which enhance the productivity and, consequently, organic waste (Okamura *et al*, 2002; Bulut and Aksoy, 2008). Tourism and leisure impact water resources through a variety of water sports and recreational activities (Davenport and Davenport, 2006). While tourism has important effects on coastal and marine resources, there is some evidence that tourism activities also influence eutrophication lakes (Kuo *et al*, 2008). Eutrophication changes physicochemical conditions of water leading to direct and/or indirect impacts on biological quality elements (Toming and Jaanus 2007). Hence, assessment of eutrophication is based on physical, chemical and biological data (Karadžić *et al*, 2010; Kitsiou and Karydis, 2011 and 2000; Ferreira *et al*, 2011). Total phosphorus (TP), Secchi disc depth (SDD) and chlorophyll-a (chl-a) are the variables that indicate eutrophic condition (Cooke et al. 2005). Using these variables, simple models have been developed for eutrophication assessments (e.g. Carlson trophic status index; Carlson, 1977). Phytoplankton, zooplankton, aquatic vegetation, benthic invertebrates, fish, epilithon and epiphyton community parameters are used as biological indicators of water quality (Danilov and Ekelund 2000; Moncheva *et al*, 2002; Yagow *et al*, 2006). Of biological parameters, phytoplankton community changes quickly in response to environmental variables (Szeląg-Wasielewska, 2006). One of the primary effects of eutrophication is the enhancement of phytoplankton growth and changes in phytoplankton community structure (McQuatters-Gollop *et al*, 2009; Touzet, 2011). Hence, relationships between phytoplankton community and eutrophic status are used as an indicator of eutrophication (Solimini *et al*, 2006). Species composition, abundance, dominance, diversity indices (e.g. Shannon- wiener and Margaleff index) and harmful algal blooms are the phytoplankton community parameters that are used to assess the eutrophic status (Rawson, 1956; Kauppila, 2007; Danilov and Ekelund, 1999; Kitsiou and Karydis, 2000; Gao and Song, 2005). In addition, spatial and temporal changes in distribution of physicochemical and biological indicators have been used to compare the eutrophic condition of different ecosystems subjected to different anthropogenic factors (Bianchi *et al*, 2003). The Zerebar Lake is a shallow eutrophic lake (mean depth 3.6 m) in the northwestern Iran (the province Kurdistan, Fig. 1) with an area of about 20 km^2 (Sharifinia *et al*, 2013). Approximately 12 $km^2$of the lake are mainly covered by reed (*Phragmites australis*). The lands around the lake are used for various human activities. Generally, there are three main factors affecting eutrophic status of the lake: first, agricultural runoff from farms that are mainly located in the north of the lake. The river runoff is entered the lake seasonally (from April to December). Second, a dam (length 1770 m and height 4.5 m) in south of the lake, blocking the outflow. Finally, tourism that is mostly focused on eastern side of the lake. These activities have deteriorated water quality of the lake. Eutrophication has increased productivity of aquatic plants in the Lake and has seriously threatened the aquatic life. The first step in eutrophication management is identifying sources of pollution and assessing how different variables are affected by those sources. Therefore, the present study aimed to investigate (1) which human activity has the greatest impact on eutrophication of the Zerebar Lake (2) if phytoplankton communities, as an indicator, are correlated by the three human activities (agriculture, tourism, construction of dam).

MATERIALS AND METHODS

The sampling sites were selected according to the three main human activities surrounding the Zerebar Lake (Fig. 1). One was near the inlet of the lake where agricultural runoff enters, the second site was close to the tourism activity and the third site was in the vicinity of a town and dam. Due to presence of phytoplankton in the surface layers, all of samples were collected from the water surface (0.5 m depth). Water was sampled bimonthly from September 2010 to July 2011 using a Ruttner sampler. Samples were preserved in lugol solution, kept in the dark and stored at 4 ºC for later phytoplankton analyses. For each sample, a ten-ml subsample was precipitated in an Uthermohl's tube. A minimum of 1000 individuals of phytoplankton cells were counted in each subsample using an inverted microscope following the Uthermohl's method (1958). Shannon-Wiener ($= -\sum b_i/B \log^2 (b_i/B)$, where b_i is respective abundance of the phytoplankton genus, B is total abundance) and Margaleff ($= (S - 1)/ \ln N$, where S is the number of genus identified and N is total number of individuals) diversity indices and genus richness were calculated using Biodiversity Pro Verion 2.

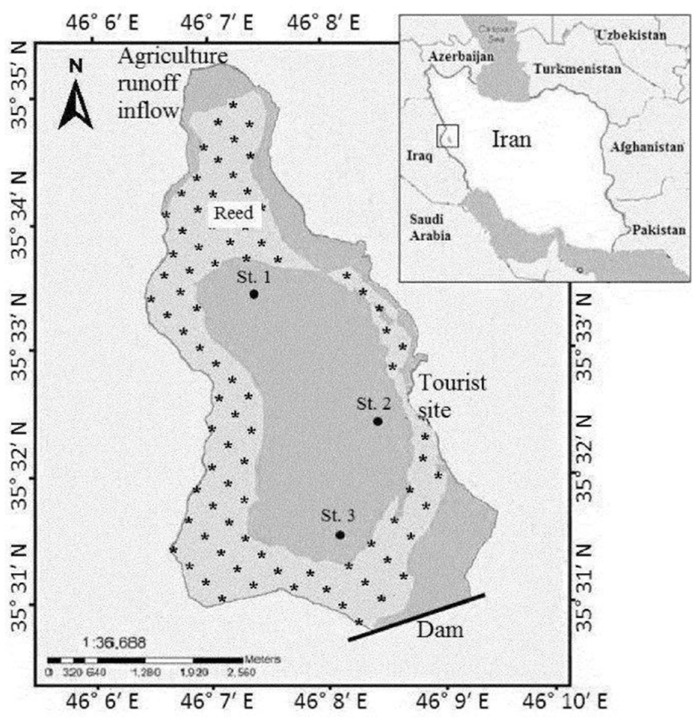


Fig.1 Location of the Lake Zerebar, human activities and sampling stations. Three sampling sites were selected in the vicinity of three major human activities. St.1 (Station 1): agriculture runoff entering, St.2: tourism activities and St.3: town and dam). For NH_3 and TPanalyses, samples were fixed by decreasing pH (< 2) using sulfuric acid. The rest of water samples were preserved using cold. All water samples for chemical analyses were stored in iceboxes and transferred to the laboratory within one hour. Water was analyzed for nitrate (NO_3), ammonia (NH_3), phosphate

(PO_4), TP, and alkalinity using standard methods (APHA 2005). For chl-*a*, water samples were filtered immediately after sampling using 47 mm Whatman GF/C glass fiber filters and kept frozen in -14°C for later analyses. Chl-*a* was measured spectrophotometric ally after extraction in 90% acetone (APHA 2005). Water transparency and depth were measured using a Secchi disc and a string and sinker, respectively. Water temperature, dissolved oxygen (DO), pH and electrical conductivity (EC) were recorded immediately after each water sampling using a portable analyzer (Sibata, number 666224, 666224, 666221 and 666222, respectively).

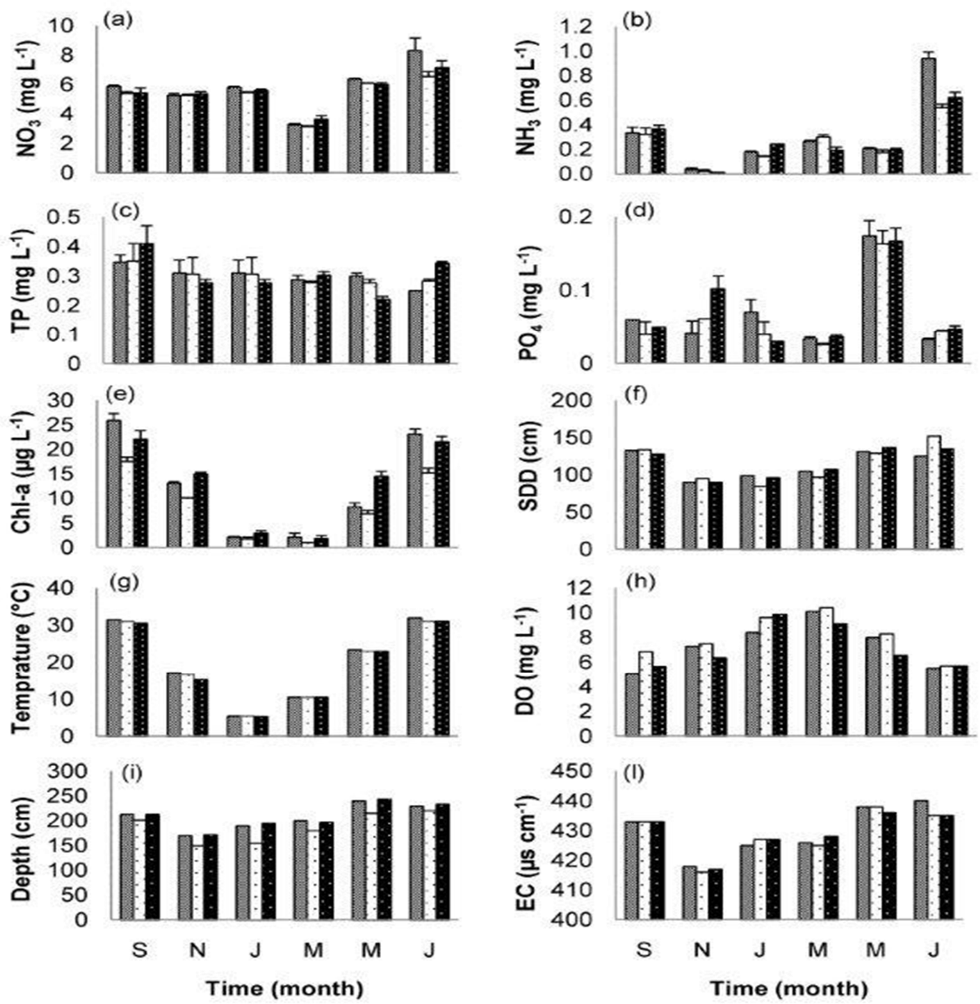
Statistical analyses

The relationships between environmental variables and phytoplankton genera were examined using redundancy analysis (RDA). The analysis was performed on each six sampling times separately. The following variables were included in RDA: NO_3, NH3, PO4, TP, alkalinity, chl-*a*, DO, water temperature, pH, SDD, Depth, and EC as independent factors and abundance of each phytoplankton genus as the dependent factor. RDA was based on correlation matrix with abundance of species being centered and standardized. There was a lot of zero as abundance of various phytoplanktons, therefore, chord transformation was used (Zuur *et al*, 2007). All statistical analyses were performed using Conoco for windows version 4.5.

RESULTS

Environmental variables

Fig.2 Changes in NO_3, NH_3, TP, PO_4, chl-a and DO concentrations and SSD, Temperature, Depth, pH, Alkalinity and EC at different sampling sites. ▩St. 1, ⊡St. 2, ◙St. 3. Each bar indicates mean + SD, (in some case mean only).



The results of the variables among sampling sites and months in the Zerebar Lake are shown in Fig. 2. There was a high concentration of NO_3 during the summer period. NO_3 concentration decreased in the lake during the other seasons (Fig.2a). Over the year, NO_3 concentration at agriculture site was more than those of other sampling sites. Mean concentration of NH_3 was 0.27 mg L^{-1} over the year (Fig.2b). The maximum of NH_3 was recorded from the agriculture site in July and showed a decreasing trend from July to October and increased, from January to March. The maximum concentration of TP was 0.45 mg L^{-1} in September at St. 3 (nearby dam, Fig.2c). TP decreased gradually from September to May and the minimum TP was recorded as 0.21 mg L^{-1} in May. Unlike TP, there was a peak in PO_4 concentrations in May (Fig.2d). PO_4 had low fluctuation over sampling times but varied greatly among sampling sites. The maximum concentration of chl-*a* was found in vicinity of agriculture site in July and September and decreased during the cold seasons (Fig.2e). While the lowest concentration of chl-*a* was recorded 0.86 µg L^{-1} in March (nearby the tourism siteactivity). The maximum of SDD was recorded at tourism sampling site in September and November and then had an increasing trend from January to July (Fig.2f). During January, March and May SDD at the tourism site were less than other sampling sites. Water temperature was high during summer, and decreased during winter (Fig.2g). Over the year, DO show a high value in the tourism site (Fig.2h). The highest DO was recorded at winter and decreased during spring-summer seasons but increased, again, from summer to winter. The mean depth of the site was 201 cm (Fig.2i). It was low during November and increased during winter-spring season, gradually. Over the year, the mean pH was 7.72 and had low fluctuation among the sampling site and times (Fig.2j). The maximum alkalinity was measured in July and then decreased during other months, generally had for the highest values near St. 3 (the dam Fig.2k). Totally, the amount of alkalinity and pH showed a high alkaline power of the lake. The mean conductivity was 429 $\mu s\ cm^{-1}$ during the year showed partially high dissolved solid (Fig.2l).

Phytoplankton community and Diversity index

Table 1: List of phytoplankton genera of the Lake Zerebar and abbreviations used in RDA graphs (Fig 5). Abbreviations: **Baci**: Bacillariophyceae, **Chlo**: Chlorophyceae, **Chry**: Chrysophyceae, **Conj**: Conjugatophyceae, **Cryp**: Cryptophyceae, **Cyan**: Cyanobacteria, **Dino**: Dinophyceae, **Eugl**: Euglenophyceae, **Xant**: Xanthophyceae

Class	Order	Genus	Ab*	Class	Order	Genus	Ab
Baci.	Centrales	*Melosira*	1	Chry.	Ochromonadales	*Synura*	26
	Centrales	*Aulacoseira*	2		Ochromonadales	*Gonyostomum*	51
	Centrales	*Rhizosolenia*	3	Conj.	Zygnematales	*Spirogyra*	27
	Centrales	*Stephanocostis*	4		Zygnematales	*Zygnema*	28
	Centrales	*Cyclotella*	5		Desmidiales	*Staurastrum*	29
	Pennales	*Navicula*	6		Desmidiales	*Cosmarium*	30
	Pennales	*Cymatopleura*	7	Cryp.	Cryptomonadales	*Cryptomonas*	31
	Pennales	*Surirella*	8	Cyan.	Nostocales	*Cylindrospermopsis*	32
	Pennales	*Cymbella*	9		Oscillatoriales	*Oscillatoria*	33
	Pennales	*Nitzschia*	10		Oscillatoriales	*Spirulina*	34
	Pennales	*Synedra*	53		Nostocales	*Raphidiopsis*	35
Chlo.	Chlorococcales	*Sphaerocystis*	11		Chroococcales	*Microcystis*	36
	Chlorococcales	*Pediastrum*	12		Nostocales	*Anabaena*	37
	Volvocales	*Pandorina*	13		Chroococcales	*Chroococcus*	38
	Chlorococcales	*Ankistrodesmus*	14		Chroococcales	*Aphanocapsa*	39
	Chlorococcales	*Tetraedron*	15		Chroococcales	*Aphanothece*	40
	Chlorococcales	*Chlorella*	16		Chroococcales	*Merismopedia*	41
	Chlorococcales	*Quadrigula*	17		Oscillatoriales	*Lyngbya*	50
	Chlorococcales	*Scenedesmus*	18	Dino.	Peridiniales	*Peridinium*	42
	Chlorococcales	*Golenkinia*	19		Peridiniales	*Glenodinium*	43
	Chlorococcales	*Coelastrum*	20		Peridiniales	*Ceratium*	44
	Volvocales	*Volvox*	21		Peridiniales	*Heterocapsa*	45
	Volvocales	*Eudorina*	22	Eugl.	Euglenales	*Trachelomonas*	46
	Chlorococcales	*Oocystis*	23		Euglenales	*Euglena*	47
	Chlorococcales	*Nephrocytium*	24		Euglenales	*Phacus*	48
	Chlorococcales	*Selenasterum*	52	Xant.	Tribonematales	*Tribonema*	49
Chry.	Ochromonadales	*Dinobryon*	25	* Abbreviation			

A total of 53 phytoplankton genera were identified in the Zerebar Lake (Table 1). Chlorophyceae had the highest diversity but Cryptophyceae and Xanthophyceae had the lowest diversity, presenting only one genus.

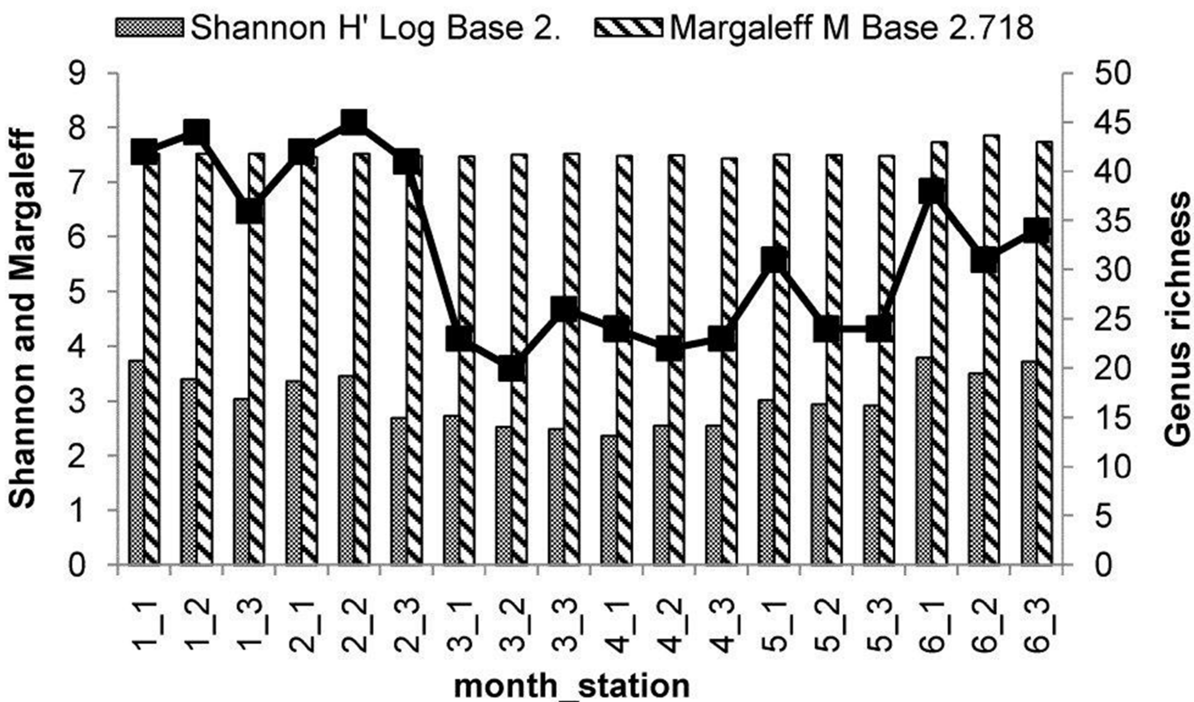


Fig.3 The variation of Shannon and Margaleff diversity indices and genus richness during the year. the first number on x-axis is sampling times from (1) September, (2) November, (3) January, (4) March, (5) May, (6) July , and the second number is the sampling station: (1) is agriculture, (2) tourism and (3) town and dam station. The maximum and minimum richness were recorded at the tourism site. Maximum richness was recorded during September and November (Fig. 3) and minimum richness (20 genera) was found in March. Genus richness increased gradually from March to May at all sampling sites. The Margaleff index did fluctuate greatly among sites or over months (Fig. 3). The Shannon index had the highest values in the site close to agriculture site in March, May and July and to tourism station during September and November.

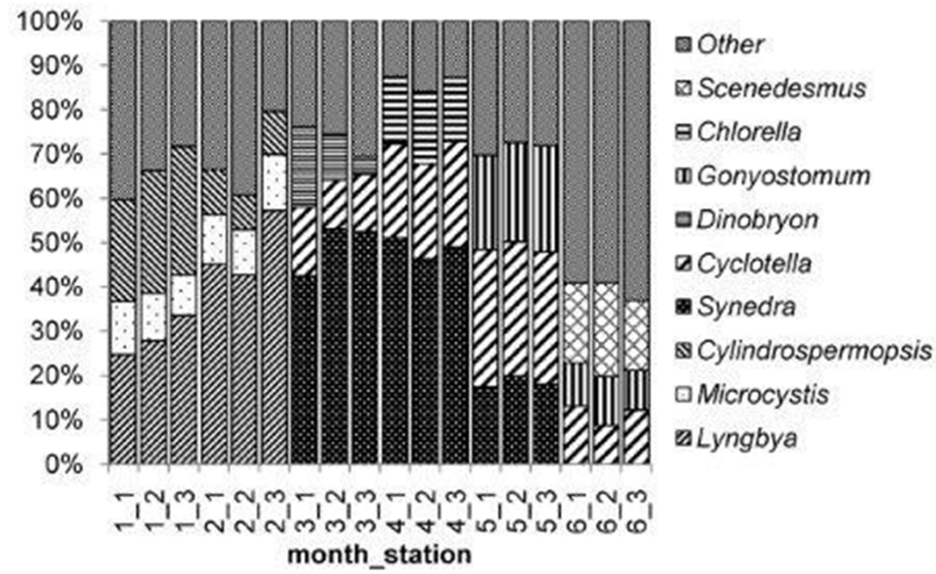


Fig.4 The percentage of dominant phytoplankton genera at different sampling times and sites during the year. the first number on x-axis is sampling times from (1) September, (2) November, (3) January, (4) March, (5) May, (6) July , and the second number is the sampling station: (1) is agriculture, (2) tourism and (3) town and dam station. There were three dominant genera at each sampling time in the lake which formed notable abundance of phytoplanktons (Fig. 4). *Lyngbya*, *Cylindrospermopsis* and *Microcystis* were the dominant genera at September and November and had high abundance at the vicinity of the dam except *Microcystis* that had a high abundance at station 1 (agriculture site) in September. *Dinobryon* and *Gonyostomum* from Chrysophyta were the other dominant genera. The highest abundance of *Dinobryon* recorded in January at the agriculture site, tourism and dam, respectively. In May, *Gonyostomum* was found, in descendant order, around the dam, tourism, and agriculture site. *Cyclotella* and *Synedra*, from diatoms were the most abundant genera in the Zerebar Lake and fluctuated greatly among the sampling sites. *Cyclotella* had the lowest abundance in September and increased gradually by May and declined onwards. *Chlorella* and *Scenedesmus* were the only green algae with a high abundance in March and July, respectively, especially at tourism site. *Peridinium*, *Aphanocapsa* and *Nephrocytium* emerged only in warm months and fluctuations of some genera such as *Melosira* did not follow any particular trend. Some genera, such as *Spirogyra*, *Anabaena,* Aphanothece, Merismopedia and *phacus*, were found only in September and November. Some genera, such as *Selenastrum*, *Heterocapsa* and *Ceratium* were rare in the lake and were found in a very limited number.

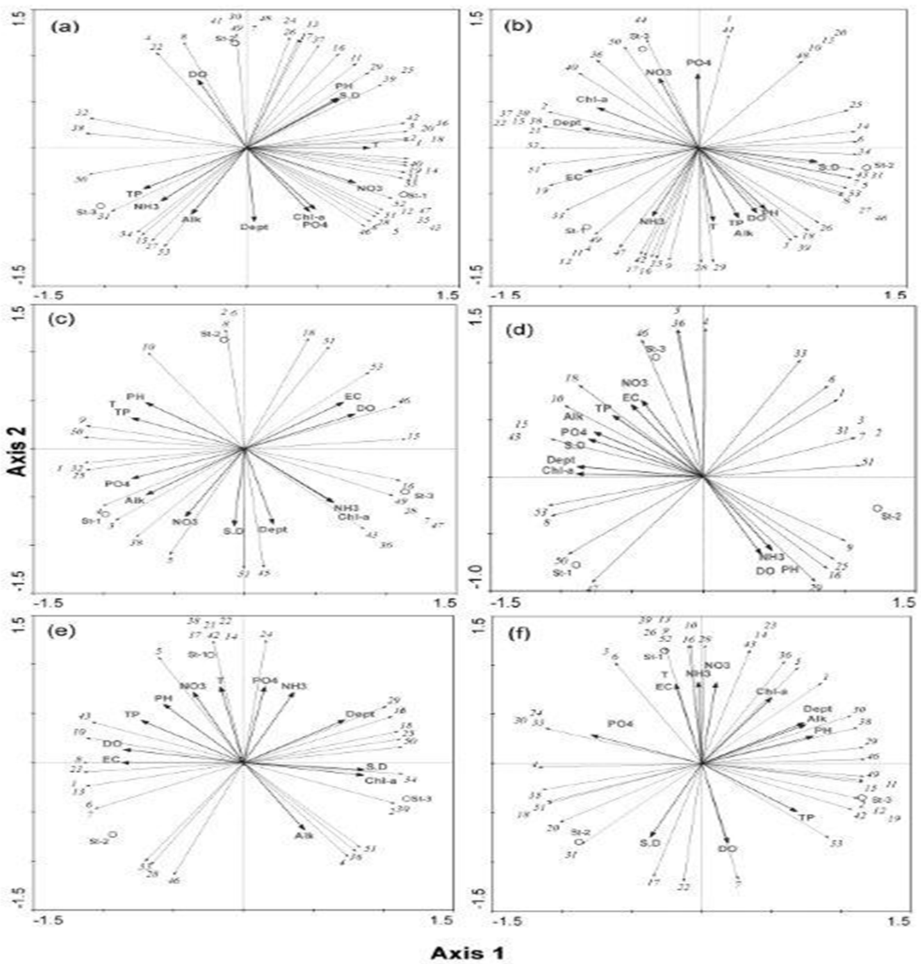


Fig.5 Ordination triplot of RDA of phytoplankton data and environmental variable. (a) September, (b) November, (c) January, (d) March, (e) May, (f) July, the circles represent the station, NH_3 (NH3), NO_3 (NO3), TP (TP), PO_4 (PO4), Chlorophyll a (chl-*a*), Alkalinity (Alk), Temperature (T), EC (EC), depth of stations (Dept), pH (pH), SDD (S.D), the number from 1 to 53 is the number of phytoplankton (table 1). RDA revealed that the first two axis of the RDA explained 100% of the species–environment relationship for each sampling time. In addition, the eigen values of first two axes and total variance was one. NH_3, NO_3 and PO_4 concentrations showed a high correlation with the first sampling site (agriculture site) in May, July and September (except NH_3 in September that was correlated to the third sampling site, Fig. 5) and had a high fluctuation among stations during other months. There were a positive correlation between TP concentration and the third sampling site (the dam) in March, July and September and to the first sampling site in November, January and May. Chl-*a* concentration had a high fluctuation among sites. It was correlated with the first sampling site in March, July and September and to the third sampling site in November, January and May. Depths of sites was positively correlated with the first and third sampling sites and negatively correlated with the second sampling site. There was a positive correlation between DO and the second sampling site. pH showed a high negative correlation with the third sampling site from September to May. Changes of alkalinity did not follow any pattern over the sampling sites. There was a strong

negative correlation between DO and chl-*a* (except in January). Over the year, there was not significant positive correlation between TP with chl-*a* (except in March). In addition, there was a strong correlation between TP and PO_4 only in January, March and May. No relationship was observed between pH and other environmental variables. The dominant Cyanophytes (*Lyngbya* and *Cylindrospermopsis*) had positive correlations with the third sampling time in September and November, and *Microcystis* only in November. Other dominant genera were mainly correlated with the first and third sampling sites. Most green algae were positively correlated to the first and third sampling sites, and negatively to the third sampling site. There was no correlation between Chrysophyta with other classes or environmental variables. Most diatoms showed positive correlation with DO and negative correlation with temperature. However, no understandable pattern was observed between dominant diatom (*Synedra* and *Cyclotella*) and other genera or variables. The fluctuation of the green algae had no clear pattern in correlation with environmental variables and other phytoplankton groups.

DISCUSSION

The Zerebar Lake is a shallow eutrophic lake located in the northwest of Iran. There are three main human activities around the Zerebar Lake: agriculture, tourism and, town and dam. The present study investigated effects of three human activities on phytoplankton communities and water physicochemical characteristics of the Zerebar Lake as indicators of the eutrophic status.

Environmental variable

A significant increase in nitrate, ammonia, phosphate concentrations, EC, and a decrease in DO and SDD were coincided with the peak of agricultural activities (in May, July and September) especially in north of the lake (agriculture site). These results were expected as agricultural runoff has a low DO and high electrical conductivity (Rodusky et al. 2008). It is rich in nitrogenous and phosphorous compounds (Arbuckle and Downing, 2001) and has an important effect on eutrophication (Ekholm *et al*, 1997).

TP had a low fluctuation over the year compared with phosphate and other nutrients. In addition, at most sampling times, the correlation between phosphate and chl-a was stronger than that of TP and chl-*a*. Although P is an important factor for increase of phytoplankton primary production (Reynolds, 2006), the present study suggests that TP was not a controlling factor in the Zerebar Lake. This may be related to the form of P because phytoplanktons' absorbable form of P is inorganic (Valk, 2006). Estimating chl-*a* concentration using empirical models and TP show that concentration of chl-*a* in the Zerebar Lake is much lower than that predicted by models. As an example, based on lakes model of Søndergaard *et al*, (2011), concentration of chl-*a* was estimated 127 $\mu g\ l^{-1}$ while in the Zerebar Lake was $< 0.5\ \mu g\ l^{-1}$ suggesting that a major part of P was not used by phytoplanktons. Lack of a positive correlation between P and chl-*a* concentration in the Zerebar Lake suggest that factors other than nutrients, which are related to surrounding human activities, may control phytoplankton's growth.

In addition to nutrients, primary production is dependent on various parameters including temperature (Chen *et al*, 2003), light (Smith, 1986) and zooplankton and planktivorous fish grazing (Liu *et al*, 2010). In the Zerebar Lake, SDD and temperature increased from January to the end of summer and decreased onwards. SDD had a positive correlation with chl-*a* in winter and early spring but negative relationship in summer. While a high photosynthesis rate in summer may evacuate the epilimnion from nutrients in the Zerebar Lake, a lower chl-*a* concentration in summer was not related to nutrient deficiency or low temperature but light. Since no correlation was detected between chl and N and P compounds but chl-*a* was positively correlated with depth and SDD. Temperature was positively correlated with chl-*a* in the summer and was not limiting.

Hence, our results suggest that source of water turbidity in the cold season in the Lake is not related to increased primary production and phytoplankton self-shading but most likely to river runoff or re-suspension from the substrate owing to increased rainfall and wind. In summer, river runoff decreases and thermocline is established, which prevents turn-over and re-suspension of particles from the substrate. Therefore, summer increase of chl-*a* in the Lake, accompanied with a low SDD, was due to intensification of primary production and subsequent turbidity by phytoplankton growth.

At the present study, majority of phytoplankton abundance was correlated with the highest TP (in September) were related to non-edible Cyanophyta. Therefore, it is unlikely that top-down control has been very important factor on primary production (chl-*a*) of the Zerebar Lake, at least in September when the peak of chlorophyll concentration was found.

Unlike NO_3, NH_3, PO_4, EC, DO and chl-*a*, changes of TP concentration were not associated with agricultural runoff. The highest concentration of TP was found in summer in the vicinity of the dam (south of the lake) where SDD decreased and reached to the minimum value in November. As degradation of aquatic plant lead to increase P concentration (Asaeda *et al*, 2001) and in the Zerebar Lake the amount of aquatic plants was very high, it is likely that TP was originated from aquatic plant at the end of their growing season. As a result, P levels increased and SDD declined in the vicinity of the dam. Therefore, outlet of the dam may be an important parameter causing fluctuations of key environmental variables especially concentration of TP, by preventing removal of organic matters.

There was no conspicuous evidence on the impact tourism on the trophic status of the Zerebar Lake. Since the peak of tourism activities (May, July and September), concentrations of nutrients and chl-*a* had no significant difference with adjacent sampling sites (the agriculture site and the dam). There was a high concentration of DO in the vicinity of the tourism site which was often high than those of other sampling sites. This could be due to aeration by rowing and boating (Honey and Krantz, 2007). In summer, SDD in tourism site was higher than other sampling sites indicating lower phytoplankton primary production at this site. Therefore, compared with other human activities, tourism activities have lower effect on the trophic status of the Zerebar Lake.

Phytoplankton assemblage

The dominant phytoplankton genera of Lake Zerebar (Cyanophyta and diatoms) were indicators of eutrophication. Their dominance was resulted from high concentration of nutrients originated from human activities. Eutrophication changes the species composition and increases the abundance of dominant species (Tepe *et al*, 2006) and probability of toxic algal bloom (Camargo

and Alonso 2006). *Lyngbya*, *Cylindrospermopsis* and *Microcystis* were the dominant toxic genera of the lake in August and November. Cyanophyta become dominant when TN: TP>17 and the limiting effect of P increases (Reynolds, 1998). The value of TN: TP in the Zerebar Lake was 17.27 (considering NH_3 and NO_3 instead of TN). Availability of NH_3 and NO_3 is an important factor in determining what cyanobacteria species to be the dominant (Chorus and Bartram, 1999). At the present study, *Lyngbya* and *Cylindrospermopsis*, which were the most abundant species, were found near the dam where ammonium and nitrate levels were not higher than the other sampling sites. Since these species are nitrogen fixing, nitrogenous compounds were not as controlling as P.
In addition to Cyanophyta, diatoms from the genera *Synedra* and *Cyclotella* were found in a high density. Diatoms are dominant in nutrient-rich lakes of the temperate regions (Liu *et al*, 2010) because of their resistance to low temperature and light (Bellinger and Sigee 2010) in cold seasons. Although human activities increase the nutrient and then the temporal distribution of the diatoms, their spatial distribution did not follow a specific pattern in the Zerebar Lake, indicating that human activity had no major influence on their distribution.

The green algae, *Scenedesmus*, were one of the dominant genera in July and the most abundant genus near the tourism site. It creates a high biomass in the nitrogen-rich lake due to agricultural fertilizers (Reynolds, 2006). Temporal distribution of *Scenedesmus* spp was highly correlated with ammonia and nitrate in Zerebar Lake. Its high abundance in the vicinity of tourism activity station is likely due to favorable conditions to green algae such as higher SDD (higher light) than other areas of the lake.
Dinobryon, from Chrysophyta, was the dominant genus in December and with highest densities, in descendent order, adjacent to the agriculture, tourism and the dam, which was correlated with P concentration. Dominance of *Dinobryon* had been reported previously in lakes that were affected by P from agricultural and urban activities (Reynolds, 2006), and in lakes with cool water temperature (Lehman, 1976). Thus, low water temperature (≈ 5 °C) and availability of P led to dominance of *Dinobryon* in the January.

Phytoplankton diversity indices (genus richness, Shannon and Margaleff) showed that the spatial distribution of the indices did not follow a specific pattern according to human activity. Also, based on the Shannon index and according to Shanthala *et al*, (2009), the Zerebar Lake is classified as a lake with low pollution (3> H '> 4.5). However, based on Margaleff index (M >6) and according to Bellinger and Sigee (2010), the lake is classified as a lake with very low concentration of nutrient while we found very high concentration of nutrients in the Lake. Therefore, the indices values much lower those of ours. Pei *et al*, (2011) reported similar results on the Shannon index in a nutrient-rich lake. He discussed that when nutrients are available, only physical factors control phytoplankton diversity. Chalar, (2009) stated that change in availability of limited resources increases the diversity as in a flourishing water resources condition, phytoplankton diversity reaches to its maximum. Therefore, lack of competition over food had been an important factor to increase phytoplankton diversity in the Zerebar Lake. Spatharis *et al*, (2011) declared that due to structural changes in phytoplankton communities, diversity indices show similar value in low and high ranges of trophic spectrum. Our results are consistent with Danilov and Ekelund, (1999) who demonstrated that phytoplankton diversity indices are not an appropriate measurement of trophic status.

In conclusion, the main cause of the eutrophic condition in the Zerebar Lake is high nutrient amounts of agricultural runoff. Although, phytoplankton diversity was affected by nutrient, especially phosphorous, phytoplankton biomass was likely affected by physical parameters, mainly light. Our study also showed that human activities, such as boating that causes physical changes in the lake, can make undesirable eutrophic condition. The present study suggests that phytoplankton diversity indices are not good indicators of eutrophic conditions and effects of anthropogenic activities around a lake. Some phytoplankton genera are more suitable indicators of trophic condition of the lake.

Acknowledgement

The Authors wish to thank the Kurdistan department of environment, and also personnel of the university of Kurdistan for their help during sampling.

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