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Trophic Status of a Shallow Lake (North of Iran) Based on the Water Quality and the Phytoplankton Community

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Abstract: This study was carried out on Carlson Trophic State Index (TSI) for assessing trophic status in a shallow wetland (Marzanabad) that located in southwest (SW) of Babol city in north of Iran. The qualitative and quantitative characteristics of phytoplankton community and also environmental variables were determined and compared with the TSI in order to describe the water quality status. In three stations, the water samples were collected in Sept. 2006 through Aug. 2007; except January. In this research, 97 taxa from 6 algal classes such as Bacillariphyta, Chlorophyta, Chrysophyta, Cyanophyta, Dinophyta and Euglenophyta were identified. This wetland water was opened indirectly to Haraz River for 6 months, so phytoplankton composition was different during the year. During the isolation from Haraz overlapping with warm months, the phytoplankton community was dominated by species as *Nitzschia spp*, *Binuclearia tatrana*, *Euglena spp* and specially *Oscillatoria spp*, respectively. But in late Autumn to early spring species as *Dinobryon divergense* and *Gymnodinium paradoxum* were dominated and coinciding with the minimum Shannon-Weaver diversity index that recorded in winter. The Palmer organic pollution index revealed high organic pollution in whole of the year. TSI data and some other criteria indicated that the area has high trophic level.

Key words: Carlson · Trophic State Index · Wetland · Phytoplankton · Palmer · Shannon-Weaver

INTRODUCTION

Shallow lakes and ponds occur in abundance in lowland areas of very gentle relief and the average depths of most of them are less than 3 or 5-7m [1, 2]. In contrast to deep lakes, many shallow lakes (wetland) can switch quite abruptly between different stable states, representing equilibrium alternative, a hypothesis developed and established over the past 20 years [3]. Lake eutrophication has been a major problem for a few decades. It involves a change in lake status from a macrophyte-dominated clear water state to a phytoplankton-dominated muddy state, with detrimental effects to the ecosystem [4]. According to Vollenweider (1976) models, those wetlands with high depths will have lower nutrients concentrations than the others with very low depths [5]. There is evidence that nutrient control may be of greater main concern in eutrophication warm shallow lakes than in similar lakes at higher latitudes [6]. It has been well documented that initial changes in aquatic communities due to increasing eutrophication begin with the successions in the species composition and abundance of phytoplankton, thus the information obtained from phytoplankton communities can significantly contribute to assessing eutrophication levels in aquatic areas [7-10]. Phytoplankton compositions are affected by different environmental factors such as pH, light and temperature [11]. Besides their importance as primary products in food webs and ensuring ecological balance, species of phytoplankton can be useful indicators of water quality [12, 13] So, These phytoplankton have been used as biological indicators of water quality, through their responses to changes in nutrients concentration, water renewal, physical, chemical and biological parameters [14]. In this research, the phytoplankton of Marzanabad shallow wetland was studied for eleven months. This wetland is located in SW of Babol city (Mazandaran province) in north of Iran. The annual mean depth of wetland water is low because of its 6 months isolation from two branches of Haraz River and discharged water from agricultural lands runoff in mid spring too. The objective of present research was to

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assess the trophic status in Marzanabad wetland and to examine spatial and temporal patterns and species diversity of phytoplankton community of this shallow lake.

MATERIALS AND METHODS

Study Area: Marzanabad is located in SW of Babol city (Mazandaran Province) in north of Iran. The longitudes and latitudes of water sampling along wetland were 64°, 71' N and 40° 46' (Fig. 1). The mean and maximum depths of Marzanabad wetland were 2.5 and 5m, respectively. The lake occupies an area of 183 acres. It is useful for agricultural irrigation and to some extent fishing. This shallow wetland is rich with aquatic vegetation and submerged vegetation of Marzanabad is dominated by nutrient tolerant genera as *Ceratophyllum demersum*, *Potamogeton densa* and *Myriophyllum spp*, being the most common. The floating-leaved genera as *Nymphaea* are evenly distributed and occurred in many areas of the lake. The whole bottom of the littoral zone of wetland is almost totally covered by submerged vegetation, dominated by *Myriophyllum* and *Potamogeton*. Marzanabad shallow wetland is also a host to a relatively large number of migratory birds, thus enhancing the conservation value of the lake for Mazandaran Department of Environment (MDOE). Aquatic sources for this shallow wetland are waste waters and specially Haraz River that discharged into marzanabad wetland by two rivers branches since December to June. Therefore, in other months it is isolated from this river. Native fish species of marzanabad wetland are *Esox lucius, Tinca tinca, Cyprinus carpio* and *Carassius carassius*. Some species of Chinese carp as *Cyprinus carpio* and *Ctenopharingodon idella* are living in Marzanabad wetland announced by MDOE (2006) unpublished data.

Sampling and Analysis: Water sampling was carried out since September 2006 to August 2007 (except in January because of bad climate condition) for eleven times at three stations with 3 sub-samples (Fig. 1). All samples were collected by a one litter Ruttner sampler in one meter depth. The samples were kept in polyethylene bottles and placed on ice. Selection of stations was based on difference in aquatic vegetation and their position.

The evaluation of water quality was based on physico-chemicals parameters. Temperature, Dissolved Oxygen (DO) and pH were measured in 1 meter depth of water. Water samples for nutrients (DIN, DIP, TP), chemicals and biological analysis with 1 liter were collected at the same depth and preserved in cold and dark condition for transferring to laboratory. All the methods were in accordance with those recommended by standard methods [15]. For determination of Chl-a, water samples were filtered through watman GF/C glass fiber filters and pigment extraction was performed using 90% acetone. The pigment concentration was measured by spectrophotometer and calculation done according to standards methods procedures [15]. The Phytoplankton samples were collected in 3 stations with 3 frequencies in 1liter bottles and preserved using buffered formaldehyde

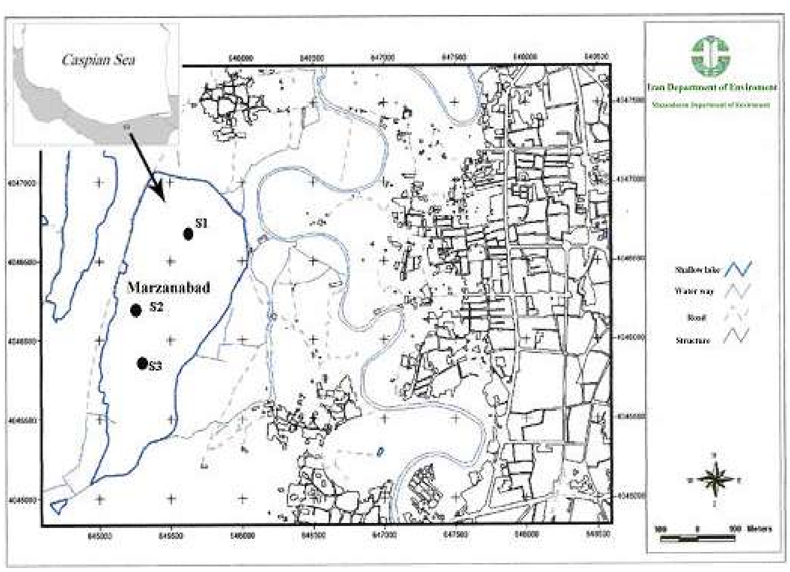

Fig 1: Map of the Marzanabad shallow wetland and sampling stations are show by dots

(4%). In laboratory, the identification and enumerating of phytoplankton cells were done at 20 magnifications with an invert microscop (Hund, GmbH, wetzlar 21) in 3 sub-sample of 1ml using a sedjwick- rafter. The phytoplankton community in each site was analyzed in terms of taxonomic composition, abundance and diversity [16]. The Phytoplankton species identification was carried out based on a few studies [17-20]. Statistical tests were done between parameters among stations and months and their interaction by means of one-way Anova and Pearson correlation analysis using SPSS: version 11.5. In this study, trophic state index (TSI), the classical freshwater TSI of Carlson (1996) and vollenweider and OECD (Organization for Economic Cooperation and Development) criteria were used to assess the trophic status. TSI is based on algal biomass as the basis for trophic state classification and 3 variables are used to independently estimate algal biomass, as Chl-a (CHL), Secchi Depth (SD) and Total Phosphorus (TP). The trophic index (TSI) is scaled from 0 to 100. The TSI values less than 30 indicates oligotrophic condition, while values between 50-70 and more than 70 indicate high level of trophic status as eutrophic and hypereutrophic condition [2, 21].

$$\begin{cases} TSI(SD) = 60 - 14/41\ Ln(SD)(m) \\ TSI(CHL) = 9/81\ Ln(chl.a) + 30/6(\frac{\mu g}{L}) \\ TSI(TP) = 14/42\,Ln(TP) + 4/15\ (\frac{\mu g}{L}) \end{cases}$$

The Shannon-Weaver diversity index (H′) was used to determine the diversity of species. Some of the trophic classifications are based on phytoplankton community as shown by a report [22] introduced the list of algae that are important in eutrophic lakes. This index values (I_{genus}) are scaled between 1-6 for 10 genus and 20 specific species of phytoplankton (according to Palmer's genus index of organic pollution tables [22]. Higher values reveal more tolerant species in high organic pollution [22].

$$\sum I_{genus} \begin{cases} <15 \rightarrow \text{ low organic pollution} \\ 15\text{-}19 \rightarrow \text{ Medium organic pollution} \\ >20 \rightarrow \text{ heavy organic pollution} \end{cases}$$

RESULTS

Water Quality Parameters: A combination of the condition in the shallow lake is given in (Table1), which reports the average values of the physico chemicals parameters. The maximum and minimum degrees of Marzanabad wetland water temperatures related to summer and winter seasons were 29 and 8.9°C, respectively. The annual mean transparency of water was low (53.5±31.45cm) and also with max. and min. transparency occurred in April and Sept. were 88 and 14cm, respectively. The rainy period started since December 2006 and lasted until May 2007, in these months Haraz River water is also flown into Marzanabad wetland, so according to achieved data, the annual mean depth of this shallow lake was (mean±SD) 214.3 ±119.11cm. The maximum and minimum depths occurred in spring and summer was 363 and 65cm, respectively. The transparency correlation with water depth was very high significant ($p< 0.01$). The maximum and minimum values of dissolved oxygen were 14 and 1.8 ppm, respectively that measured in spring and summer seasons (Table 1). The correlation between DO concentration and variation of water depth in Marzanabad shallow wetland was very significant ($p<0.01$). The annual DO mean is higher in middle spring. The pH levels ranged from 7.3 to 8.3. In 2006-2007, the concentration of the dissolved inorganic nitrogen (DIN) compound was fluctuated between 798.3 and 3301.3µg/l. The maximum value of DIN compound was observed during the warm months and this may attributed to chemical fertilizers input from around agricultural lands. The most important form of DIN was the nitrate. The annual dissolved inorganic phosphorus (DIP) and total phosphorus (TP) fluctuation measured in same period were between 123.2 to 201 and 308 to 500µg/l, respectively. The ratio of DIN/DIP fluctuated between 5.13 and 25.55 with an average value of 11.22, which indicates that primary production of the shallow lake may be limited by nitrogen, slightly. The annual mean concentration of Chl,a was 42.5µg/l and the highest values were recorded during the warm periods. The value of Chl,a demonstrate that the trophic classification of the lake is eutrophic [23].

Trophic State Index: The trophic state index of Carlson was determined. The TSI of Chlorophyll a (TSI_{CHL}) and TSI of Secchi Depth (TSI_{SD}) were presented lower values than the TSI that determined by TP concentration (TSI_{TP}). The TSI_{CHL} and TSI_{SD} were minimum in May 2007 (48.17 and 59.76) and maximum in September 2006 (78.35 and 88.33), respectively. The Mesotrophic and Hypereutrophic matching each other during the year, but most of the samples values are indicated as eutrophy position (TSI_{CHL} = 67.38, TSI_{SD} = 69.01). The lowest value of T SI_{TP} was calculated in June 2007 (86.77) and the

Table 1: Summary of environmental and biological variables and TSI

	Temp.	DO	pH	SD	DIN	DIP	TP	DIN/DIP	Chl-a	TSI
Mean	20	8.4	7.9	0.535	1856	157.98	394.9	11.22	42.5	75.06
S.D.	7.18	5	0.37	0.314	972.94	29.34	73.34	6.37	34.8	5.4
Min.	8.9	1.8	7.3	0.14	798.3	123.2	308	5.13	6	65.7
Max.	29	16	8.3	1.017	3301.3	201	500	25.55	130.6	84.71

Units in µg/l for all nutrients and Chl-a: Temp.(Temperature) in °C; DO(Dissolved Oxygen in mg/l; SD(Tranparency,secchi depth) in meter; TSI-Trophic State Index for Marzanabad; SD-Standard deviation; Min- minimum; Max- maximum; pH- power of hydrogen; DIN- Dissolved Inorganic Nitrogen; DIP- Dissolved Inorganic Phosphorus; TP- Total Phosphorus.

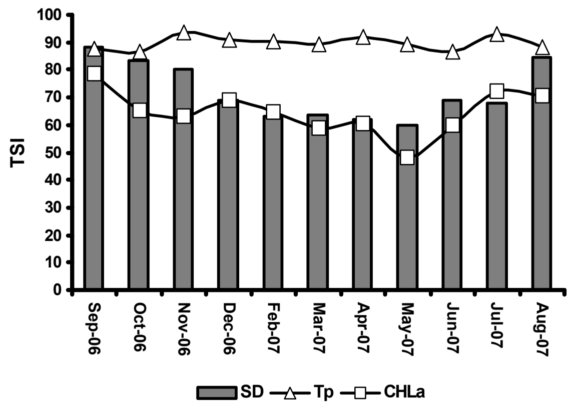

Fig. 2: Changes in the TSI_{TP}, TSI_{CHL} and TSI_{SD} in Marzanabad wetland (2006-07)

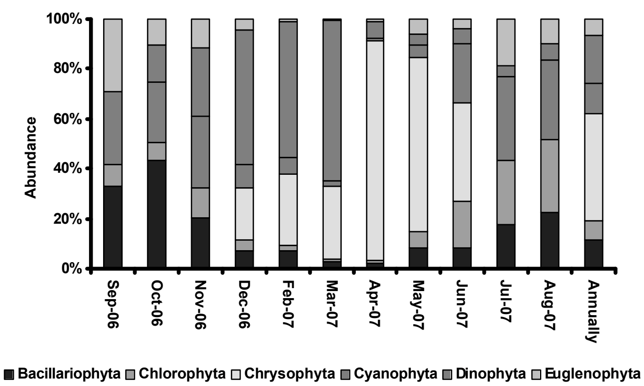

Fig. 3: Monthly trend in relative abundance of each group in Marzanabad wetland (2006-07)

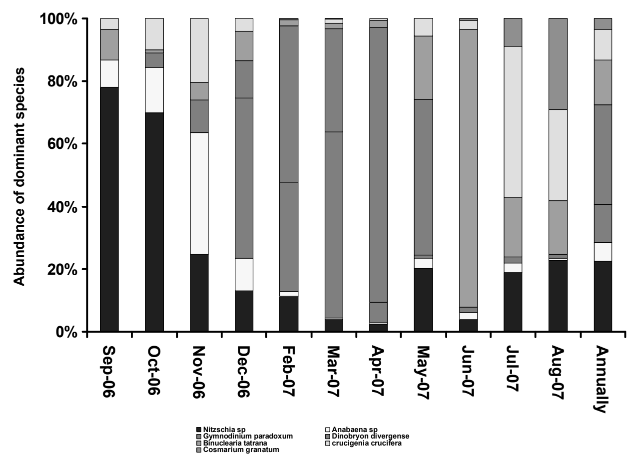

Fig. 4: Monthly trend in abundance of dominant phytoplankton species in Marzanabad wetland (2006-07)

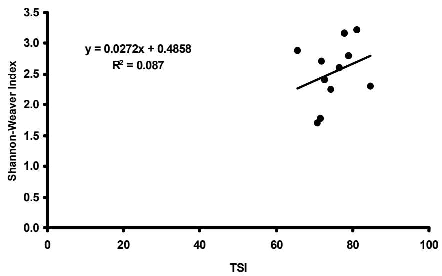

Fig. 5: Plot of the Shannon-weaver index against the corresponding TSI values

highest in November 2006 (93.76) (Fig. 2). These values correspond to Hypertrophic systems and whole of samples presented this condition.

Phytoplankton Composition, Abundance and Ecological Index: At the present study, 97 species of six different algal phylla, Bacillariophyta (9.0%), Chrysophyta (41.13%), Chlorophyta (8.36%), Dinophyta (21.49%), Euglenophyta (7.02%) and Cyanophyta (12.47%) were identified (Fig. 3). Bacillariophyta and Chlorophyta were the most important groups in species number with 31 and 39 species, respectively. In term of numbers of species, Chlorophyta (40.2%) and in abundance, chrysophyta (41.13%) were dominant. The Chrysophyt *Dinobryon divergense* (21%), the diatom *Nitzschia spp* (15%), the Chlorophyts *Binuclearia tatrana* (9%) and *Crucigenia crucifera* (6%), the Dinophyt *Gymnodinium paradoxum* (8%) and the Cyanophyts *Oscillatoria spp* (8%) and *Anabaena sp* (4%) were dominant in major phytoplankton species, annually (Fig. 4). The chlorophyt *Scenedesmus* had the most species number (6 species). The data set of 3 selective stations did not indicate significant difference during sampling period (p>0.05). At the beginning of the study in September 2006, Bacillariophyta, specially *Nitzschia spp* (39% of major species abundance), were the most important phylla in northen and middle parts of Marzanabad wetland in stations 1 and 3, followed by Euglenophyta, Cyanophyta and Chlorophyta, respectively. The most common genera were *Nitzschia spp*, *Oscillatoria spp*, *Euglena acus* and *Binuclearia tatrana*. The Euglenophyts indicated the most mean abundance (7482±703cell/liter). The most common genus group was *Euglena spp* (11% of major species abundance) was correlated very high significant both with water temperature and DIN (p<0.01).

The mean annual abundance of Bacillariophyta (10146±979cell/l) indicated significant difference in October 2006 and other months of the year (p<0.05). The genus *Nitzschia spp* (54% of major species abundance) was correlated very high significant both with water temperature and DIN (p<0.01). The most common genera were *Nitzschia spp*, *Anabaena spp*, *Phacus spp*, *C. crucifera* and *G. paradoxum* in October.

In November 2006, Cyanophyta was the most important group, especially in western and central parts of the lake. The most common genera be present at during sampling in Nov. were *Anabaena spp* (30% of major species abundance), *Nitzschia spp*, *C. crucifera*, *G. paradoxum* and *Phacus angulatus*. In December 2006, the rainy period started and continued along 6 months, so, the depth of water and the transparency were increased. An important taxa which is not predictable in eutrophic positions, *Dinobryon* (2 species) from Chrysophyta, was attended in lake and they revealed the annual maximum density (43809±21154cell/l). The most abundant species in December 2006 was *Gymnodinium paradoxum* (34% of major species abundance) in all 3 stations. In winter (February 2007), an increase was noted in terms of Chrysophyta (*Dinobryon* species) density except the north and central parts of the shallow lake. The most important genera attended in this month, were *D.divergense* (34% of major species abundance), *G.paradoxum*, *Oscillatoria spp*, *Nitzschia spp*, *Gonium pectorale* and *Trachelomonas spp*. March 2007 was another significant month in which, the most annual mean of Dinophyta (22890±3437cell/l) was recorded. The most common genera were G.*paradoxum* (49% of major species abundance), *D. divergense*, *Nitzschia acicularis*, *Oscillatoria spp*, *Crucigenia fenestrate* and *Thrachelomanas spp*. Throughout the sampling period, April 2007 was the month in which total phytoplankton reached its maximal values (annual mean:101593± 73985 cell/l) in density, specially in north parts of shallow lake (station 1). The Chrysophtes *D. divergense* (74% of major species abundance) and *D. cylindricum* contributed to the high density records due to their colonial shape, also, they were correlated very high significant with transparency (p<0.01). The data set is indicated significant difference in Chrysophyta in terms of Chlorophyta and Euglenophyta (p<0.05). The major composition of phytoplankton in May, in addition of *D.divergense* (29% of major species abundance), was belonged to *Binuclearia tatrana* and *Nitzschia spp*. In June sampling, a significant decrease was recorded in density of Chrysophyta which coincided with stop in raining and arrival of water from Haraz River. Both Chlorophyta (8903±640 cell/l) and Cyanophyta (13288± 1192 cell/l) were revealed their high annual mean of density in June 2007. The typical genera of these two groups were *B.tatrana* (38% of major species abundance) and *Oscillatoria spp* (31% of major species abundance). The Chlorophyta and Cyanophytes were correlated very high significant with water temperature ($p<0.01$). The most important group of phytoplankton in early and middle summer were Chlorophyta, which the most common species of this phylla belonged to *Crucigenia crucifera* (21.3% of major species abundance) and *Casmarium granatum* (20.1% of major species abundance) during July and August 2007, respectively.

Biologic Indices: According to Organic Pollution Palmer index, 14 of 20 determined genera were attended in the shallow lake and the index value was recorded 32. The annual Shannon-Weaver diversity index was calculated 2.52. Shannon-Weaver diversity index was determined between 1.7 and 3.21.The analysis of data did not indicate significant difference between stations ($p>0.05$).The most number of phytoplankton species (56) was observed in August 2007 and the fewest (36) was in March 2007. The diversity index revealed minimum values in the bloom periods of the dominant species. The Figure 5 shown that the correlation between TSI and Shannon-Weaver index values was positive but weak ($r=0.29$, $p<0.05$).

DISCUSSION

Many lakes are highly eutrophic because of high nutrient loads from sewage and agricultural activities. The relationship between the external nutrient loading and in-lake nutrient concentration depends on processes occurring within the lake and thus on physico-chemicals and biological parameters [4]. It has been well documented that initial changes in aquatic communities due to increasing eutrophication begin with the successions in the species composition and abundance of phytoplankton [9]. It is almost completely accepted that trophic state is one of the main factors which influence phytoplankton structure [24]. Marzanabad shallow lake is the region most seriously affected by eutrophication. Some of authors have developed different indicators for the classification of trophic levels of the freshwater and coastal water systems, based on concentration of phosphorus and nitrogen compounds as well as Chl-a [21, 23, 25]. These different criteria were used to assess the trophic and water quality status of the Marzanabad shallow lake. A report [23] shown that the OECD criteria and on the basis of data collected along the project, TP values in the study lake are characteristic of hypereutrophic lakes,also Marzanabad will be in eutrophic status based on Chl-a values. Considering the Carlson Trophic State index as proposed by [21], the condition in the Marzanabad during sampling, corresponds to the eutrophic status based on Chl-a and transparency values and hypereutrophic status based on TP values. In present study, TSI_{TP} was more than TSI_{CHL} and TSI_{SD}. According to deviation concept of Carlson, other factors except phosphorus as nitrogen limitation or high grazing of Macro-zooplanktons could be as a limiting factor for algal growth and low annual mean abundance. Also one of key factor which influences on phytoplankton community is the abundance of macrophyts which was massive in its habitat. In shallow lakes, the relationship between phytoplankton biomass and TP concentrations is influenced by submerged macrophytes. Meso to eutrophic shallow lakes may have low or high phytoplankton biomass depending on the presence or absence of well-developed submerged macrophyte vegetation [26]. The lowest TSI_{CHL} and TSI_{SD} were recorded in May 2007, but TSI data calculated along the project revealed no significant difference between sampling months and stations ($p>0.05$) [21]. As well known from researchers [27-29], some environmental variables seem to play an important role to determination of phytoplankton community succession and then diversity, favoring or limiting the growth of different groups of phytoplankton. The N:P ratio of Redfield has long been used as a predictor of phytoplankton nutrient limitation in aquatic ecosystems [9]. The Redfield mean annual of Marzanabad is 11.22, so it could reveal the nitrogen limitation slightly according to Redfield ratio (N/P=16/1), some groups of phytoplankton in this shallow lake were correlated with DIN [30]. In present study, 97 phytoplankton species of six phyla were identified Bacillariophyta, Chrysophyta, Chlorophyta, Dinophyta, Cyanophyta and Euglenophyta. Chlorophyta and Chrysophyta were more dominant groups in terms of species number and density, respectively, than the other taxonomic groups. The Maximum abundance of phytoplankton community was in station 1 which was close to agricultural run off and waste water. Bacillariophyta (Diatoms) included 9.0 % of total abundance and peak of diatoms abundance recorded in October 2006. In Pamvotis shallow lake in Greece, diatoms peak abundance was observed in early autumn and spring [31]. The main species of this group in early autumn was *Nitzschia spp,* while the water depth was significantly low. *Nitzschia* is capable to move among silts and it is also, resistant in enrichment condition and high eutrophy rather than other diatoms [32]. The Chlorophyta included 8.36 % of total abundance, this group and specially *B.tatrana* indicated the most mean annual abundance in June 2007. In Alte donau shallow lake in Austeria, Chlorophyta dominated in late spring and early summer [33]. The Chrysophyta (*D.divergense, D.cylindricum*) were the most abundant group in Marzanabad especially in April 2007. Chrysophyta found in cold fresh water lakes and ponds are reported to make frequently water blooms in spring months [34]. Alte donau shallow lake, also, indicated high abundance of Chrysophyta in early spring [33]. The Chrysophyta members found in fresh waters and pools are mostly present in winter. The maximum amount reach in spring and autumn months, when *Dinobryon spp* compared with other species, it has quite high tolerance to low temperature [35]. *Dinobryon* was found to be correlated with transparency. This taxon is only observed in transparent waters and oligotrophic condition [36]. The presence of this taxon in Marzanabad, in high abundance, indicated significant difference in water quality of isolated shallow lake from Haraz River, during June to November and other months. The most common genus of Cyanophyta was *Oscillatoria spp* that revealed the most annual mean abundance in June 2007, when coincided with high temperature [1]. Dinophyta presented their maxima contributions to density during the *Gymnodinium* develop. Dinophyta are potentially mixotroph and dependant on bacterial nutrition. Some genus included in the phytoplankton communities as *Dinobryon*, *Gymnodinium*, *Peridinium* and *Cryptomonas* were defined as mixotrophic algae in literature [35]. In late winter 2007, the death of aquatic plants which are massive in Marzanabad due to low and high temperature in depth water creates a lot of organic matters and high bacterial loading [37, 1]. The most common genus of Euglenophyta is *Euglena* (4 species) in Marzanabad which is optional heterotroph and resistant in aerobic condition. The most annual mean of this group was in late summer, corresponding to low water, dissolved oxygen and the highest value of TSI [1, 38]. The seasonal differences in species composition may be related to rainfall because the amount of rainfall can alter water chemistry including pH [39]. Studies on phytoplankton diversity are an important contribution to the understanding of the system dynamic [9]. Phytoplankton diversity is normally low in very oligotrophic waters. It increases as the the trophic status moved to a mesotrophic condition and high values of more than 2bits/cell (Shannon-Weaver diversity index) are obtained in both meso-trophic and slightly eutrophic waters [8]. Low diversity generally corresponds to low species richness or with the bloom of the dominant species. The diversity index revealed minimum values during the bloom periods of the dominant species [14]. In late autumn, an impressive increase in the abundance of *G. paradoxum* was mainly responsible for the peak in Dinophyta abundance, coinciding with the minimum Shannon-Weaver diversity index. At the present study, the correlation between the TSI and the Shannon-Weaver diversity index and number of species ($r= 0.29$, $p<0.05$) is reasonably consistent with the above concepts. Also, Species richness was increased during summer months (August 2007), while it decreased during late autumn and winter months. It can be consequence of decreasing in water temperature, because the Shannon-Weaver index was related with water temperature in Marzanabad ($r= 0.42$, $p<0.05$) [39]. The phytoplankton palmer index showed heavy organic pollution in Marzanabad, according to its correlation with transparency ($r= 0.39$, $p< 0.05$), high organic matters accumulation may be due to wide presence of aquatic vegetation, specially submerged vegetation.

CONCLUSION

The phytoplankton community structure, species diversity, abundance and dominance according to phisico-chemical variables presented different condition of trophism in this shallow lake. The frequency of water was renewal through the artificial opening of the shallow lake to rivers. It might have contribution with minimization of the effects caused by nutrients accumulation, while the shallow lake was isolated. So, although this shallow lake puts in high eutrophic state according to Carlson index and Vollenweider or OECD trophic criteria, but phytoplankton community presented a relatively high diversity, low mean annual abundance and an extensive range of Trophism. The phytoplankton biomass was related not only to the higher nutrient inputs, but also to the presence of submerged macrophytes.

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