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Assessment of eutrophication in the Lake Zribar, Western Iran: analysis of temporal trophic variations

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Abstract

Lake Zribar, which is located in Kurdistan province, is one of the most productive lakes in Iran. Due to concerns about potential pollution resulting from watershed sources and adjacent agricultural lands, a study of the trophic state of Lake Zribar was conducted during the period December 2005 to October 2012. Total nitrogen (TN), total phosphorus (TP), Secchi disc depth (SD), Chemical Oxygen Demand (COD) and chlorophyll a (Chl a) were analyzed in order to assess the trophic state of the lake. The results indicated that COD, TN and TP are the key factors controlling the lake's TSI level. The eutrophication level of the lake has been increasing and has reached the hypereutrophic level. Changes in N:P mass ratio indicated that phosphorus was the limiting nutrient for the algae proliferation at 65% of the sampling times; suggesting Bacillariophyta were the dominant taxonomic group. Soil analysis results showed that agricultural lands, especially tobacco farms, have a major contribution of nitrogen and phosphorus supply to the Lake.

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Introduction

Eutrophication is becoming one of the main problems in water deterioration (Manojlovic *et al*., 2007; Choi *et al*., 2008). This process can be evaluated by determining the limiting nutrients and by calculating trophic state indices (Elmaci *et al*., 2009). Since the 1960–70s, a number of attempts have been made to quantitatively evaluate the trophic state of lakes using single-variable trophic indices or multi-parameter approaches (Xu *et al*., 2001). The single-variable trophic indices can be divided into abiotic and biotic aspects (Xu *et al*., 2001).

The multidimensional nature of the eutrophication phenomenon means that no single variable is representative of the eutrophication status of a given water body (Shannon and Brezonik, 1972b; Carlson, 1977; Cruzado, 1987). Among the abiotic parameters, plant nutrients (phosphate, nitrate), oxygen demanded (BOD, COD) and transparency were usually used to assess lake trophic levels (Vollenweider, 1968; Dobson *et al*., 1974; Vollenweider, 1976; Schindler, 1977; Chapra, 1980; Ritter, 1981; Gregor and Rast, 1982; Persson and Jansson, 1988; Thornton and Rast, 1988; Alvarez *et al*., 1992; Boers *et al*., 1993).

The trophic state index (TSI) based on several biological, chemical and physical indicators, especially the Carlson-type TSI offers the most suitable and acceptable method for evaluating lake eutrophication (Xu *et al*., 2001).

The change in nitrogen and phosphorus loadings to lakes led to changes in the biogeochemical cycles of these nutrients in lakes. However, the cycling of N is expected to be more affected by external loadings due to the open characteristic of the N cycle (Quirós, 2003). Human activities such as direct discharge of domestic wastewaters to the lake (point pollution) and the pollution resulting from agricultural lands (non-point pollution) are the major causes of reduced water quality and increased eutrophication in Lake Zribar. The objectives of this study were (1) to explore Eutrophication trend of Lake Zribar during 2005 to 2012; (2) the trophic level of the lake (3) the pollution sources that cause trophic condition.

Materials and methods

Description of the study area

Lake Zribar is located in (46°7′ E, 35°32′ N) at an altitude of 1290 meters and situated 3 km from northwest of Marivan city, Kurdistan province, western Iran. This area is characterized by a Mediterranean climate with cold, snowy winters, an average annual rainfall of 800 mm and an average annual temperature of 13 °C (for the period 1993 to 2003 at Marivan Station). No permanent surface water (river) pours into the lake except rainwater; the main water supply of the lake is the bottom springs which their average annual discharge is 12.91 million m^3. The average depth of the lake is 3.4 meters and its volume of stored water is estimated 22 to 47 million m^3 in drought and high rainfall years respectively; in different seasons, lake area fluctuates between 13 to 23 km^2. Average annual water inflow to the lake is 54 million m^3 of which 41 million m^3 is supplied by surface runoff and 13 million m^3 by springs. The watershed area is about 88 km^2. The outlet water enters into Zribar River and pours into Darbandikhan Dam in Iraq and then enters the Tigris River and finally pours into the Persian Gulf.

Land use pattern in the lake catchment

Orchard is the dominant land use around the lake. Cultivated areas include a total of 29% of the lands around the lake (Fig.1). Low-height residential sites near the Lake Zribar include 12% of total land uses around the lake. A sparse oak forest (*Quercus brantii*) covers the mountains around the lake (16% of the total area around the lake).

Field and laboratory methods

Water samples were taken from the lake center on seventeen times from December 2005 to September 2012. Prior to laboratory analysis, the water samples stored at 4°C. Physicochemical parameters of water samples from the center of the lake were measured. Turbidity, pH, electrical conductivity (EC), dissolved oxygen (DO) and temperature were measured during sample collection. Total phosphorus (TP) was measured by colorimetric method (Ebina *et al*., 1983), total nitrogen concentrations by Kjeldahl method (Mackereth *et al*., 1978) and nitrate concentrations by the (Golterman *et al*., 1978) method. The amount of chlorophyll a was determined with spectrophotometer after filtration of water with GF-C filter and extraction of chlorophyll by acetone 90% (Lorenzen, 1967). The amount of Chemical Oxygen Demand (COD) was measured by alkaline potassium permanganate method.

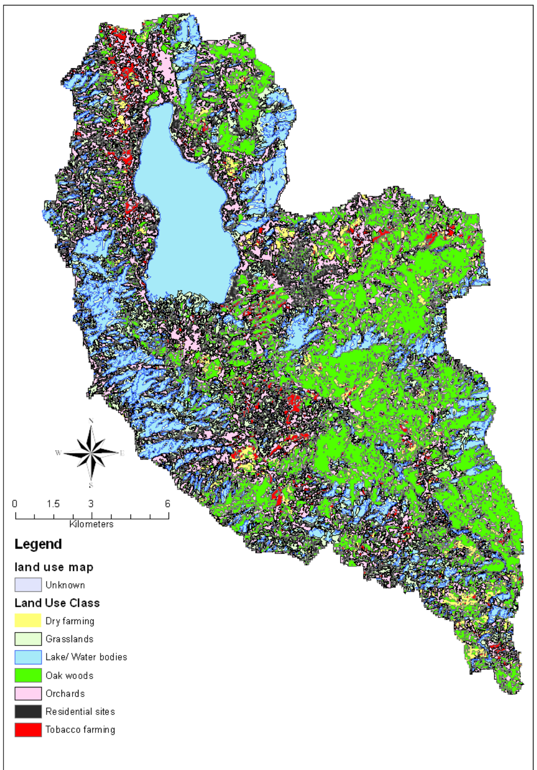

Fig. 1. Land use map of the study area

Trophic state index (TSI)

Trophic state index (TSI) introduced by Carlson (1977) and Porcella *et al*. (1980) was used to evaluate Lake Zribar in terms of trophic level and eutrophication status. TSI scale is divided from 0 to 100. TSI calculation is based on total phosphorus (TP, mg/l), total nitrogen (TN, mg/l), chemical oxygen demand (COD, mg/l), the depth of Secchi disk (SD, m) and chlorophyll a concentration (Chl-a, μg/l).

The 0 to 100 scale is divided into oligotrophic (0-30), slightly mesotrophic (30-40), mesotrophic (40-50), highly mesotrophic (50-60), eutrophic (60-70), hypereutrophic (70-80) and highly hypereutrophic (80-100). The standards for assessment of each parameter is based on the defined standards for eutrophication of lakes (OECD, 1982), standards of the National Institute for Environmental Studies of Japan (Aizaki *et al*., 1981) and a study conducted on Tai Lake in China (Jin *et al*., 1990).

The following formula is used to calculate TSI for each parameter (Xu *et al*., 2001).

$$TSI_i = [(TSI_{i,k-1}) + \left|\frac{C_i - S_{i,k-1}}{S_{i,k} - S_{i,k-1}}\right| \times (TSI_{i,k} - TSI_{i,k-1})] \quad (1)$$

Where C is the ith measured amount of concentration of Chl-a, COD, TN, TP and SD parameters, $S_{i,k}$ and $S_{i,k-1}$ are the upper and lower standard values for i parameter and $TSI_{i,k}$ and $TSI_{i,k-1}$ are the standard TSI values for $S_{i,k}$ and $S_{i,k-1}$ respectively.

$$(2) \quad TSI_{overall} = \sum_{i=1}^{n} TSI_i \times W_i$$

$TSI_{overall}$ is the eutrophication level obtained from the total TSI of Chl-a, COD, TN, TP and SD parameters and W is the weight of each parameter which is the identical weight of 0.2.

Results and discussion

Ecological status of the lake is affected by physical environments and water conditions. Annual average, maximum, minimum and standard error of the measured parameters are shown in Table 1. The results showed that during the years 2005 to 2012, the amount of dissolved inorganic nitrogen (DIN) in Lake Zribar water varied between 0.326 mg/l to 6.52 mg/l. The extent of the variation of soluble reactive phosphorus (SRP) was between 0.023 mg/l to 0.320 mg/l. The annual average concentrations of chlorophyll a during the study period was 9.691 μg chl-a/l and the minimum and maximum was recorded 2.220 μg chl-a/l in January 2011 and 22.940 μg chl-a/l in September 2010, respectively.

Table 1. Some physicochemical parameters of Lake Zribar (December 2005 – October 2012)

Parameter	Mean ± SE	Range
Temperature (°C)	18.07 ± 2	3.34 - 31.08
pH	7.75 ± 0.084	7.15 - 8.41
COD (mg/l)	33.20 ± 2.72	14 - 57
TN (mg/l)	4.88 ± 0.54	0.44 - 7.85
DIN (mg/l)	4.28 ± 0.46	0.33 - 6.52
SRP (mg/l)	0.140 ± 0.018	0.023 - 0.320
TP (mg/l)	0.326 ± 0.050	0.051 - 0.827
DIN/SRP	38.450 ± 5.290	1.019 - 80.125
TN/TP	19.332 ± 2.573	0.527 - 37.358
N/P	8.73± 1.16	0.24- 16.87
Secchi Disk(m)	1.263 ± 0.043	0.985 - 1.57
Chl-a (μg/l)	9.691 ± 1.289	2.22 – 22.94

Land use pattern-lake relationship

The measured parameters of soil samples taken from different land uses are shown in Table 2. Mean values of the parameters %CaCO3, %OM, pH, EC (ds/m), P concentration (mg/kg) and NO_3^- (mg/kg) were 3.92, 2.05, 7.32, 0.62, 1.13 and 0.27, respectively.

Table 2. Statistical summary of soil properties taken from the Lake Catchment

Parameter	Mean ± SE	Range
$CaCO_3$ (%)	3.93 ± 1.29	0.25 - 29.50
OM (%)	2.05 ± 0.08	0.66 - 4.94
pH	7.32 ± 0.04	6.90 – 7.72
EC (ds/m)	0.62 ± 0.05	0.29 - 1.28
P (mg/kg)	1.13 ± 0.14	0.20 - 2.18
NO_3 (mg/kg)	0.27 ± 0.04	0.11 - 1.08

OM: organic matter

Of the total area around the Lake, 47.27% is under cultivation soils (farm and garden) and 12% is residential site. The measured amounts of soil properties in six types of land use were compared using one-way ANOVA (Table 3).

Table 3. ANOVA statistical results of soil properties under the six land uses

		Land use (sample numbers)						F	Sig
		Dry wheat (6)	Grassland (3)	Lake beach (3)	Oak wood (3)	Orchard (7)	Tobacco farms (3)		
$CaCO_3$ (%)	Mean	4.02**a**	0.875**a**	5.09**a**	3.13**a**	5.93**a**	1.08**a**	0.334	0.885
	CV	0.77	0.61	0.04	1.22	1.77	0.35	-	-
OM (%)	Mean	1.78**a**	1.87**a**	3.64**b**	1.20**a**	2.16**ab**	2.21**ab**	1.835	0.159
	CV	0.31	0.12	0.51	0.26	0.49	0.49	-	-
pH	Mean	7.27**a**	7.45**ab**	7.64**b**	7.26**a**	7.34**ab**	7.15**a**	1.810	0.165
	CV	0.03	0.02	0.01	0.04	0.02	0.03	-	-
EC (ds/m)	Mean	0.545**ab**	0.821**b**	0.643**ab**	0.436**a**	0.566**ab**	0.926**b**	2.495	0.072
	CV	0.26	0.42	0.26	0.38	0.32	0.34	-	-
P (mg/kg)	Mean	1.09**bc**	0.469**ab**	0.537**ab**	0.219**a**	1.564**cd**	1.918**d**	11.087	0.000
	CV	0.52	0.14	0.11	0.07	0.18	0.12	-	-
NO_3(mg/kg)	Mean	0.195**a**	0.304**a**	0.203**a**	0.189**a**	0.227**a**	0.603**b**	2.911	0.045
	CV	0.41	0.14	0.51	0.34	0.37	0.73	-	-

Means with the same letter are not significantly different at p<0.05 (Duncan's multiple range test)

The results showed that the impact of land use was quite significant on nitrate and phosphorus concentrations. The highest amount of nitrate and phosphorus was found in tobacco-growing soils. This may be due to the application of agricultural fertilizers to increase crop yields (De López Camelo *et al.*, 1997). The lowest amount of nitrate and phosphorus was found in oak forest soils. According to Ebrahimpour *et al.* (2007), surface runoff from agricultural lands and residential waste waters entering the lake increased the nutrient concentrations and changes trophic state of the lake.

Changes in biotic and abiotic parameters

Monthly changes in physicochemical parameters are shown in (Fig. 2 and Fig. 3). During the study period (December 2005 to October 2012), despite the monthly fluctuations, the overall trend in the concentration of Dissolved Inorganic Nitrogen (DIN) has been increased (Fig. 3). DIN varied between 0.326 mg/l and 6.52 mg/l. The highest concentration of DIN is recorded in autumn (November and October) and the lowest in spring (May and March). This is due to the use of nitrogen fertilizers in agricultural lands in watershed of the lake in the early autumn (October) and nitrate leaching and consequently, its entrance into the lake. The DIN concentration in the lake water is affected by the characteristics of the lake's watershed, the amount of nitrogen in the watershed soils, denitrification and atmospheric precipitation (Kopacek *et al.*, 2005).

Measurement of SRP concentrations during the same period indicated that changes not have a specific trend (Fig. 3) and its concentration fluctuates between 0.023 mg/l and 0.19 mg/l. The highest values are recorded in spring. The highest amount of SRP in the lake water was observed in 2006, which is due to the start of cultivation of tobacco vegetables and use of phosphate fertilizers by farmers (Ebrahimpour *et al.*, 2011).

The DIN:SRP ratio by mass, varied between 0.283 and 29.548. The average of DIN:SRP in the entire period was 17.354 which is higher than 10:1 ratio and shows a high deficiency of phosphorus (Havens *et al.*, 2003). Akkoyunlu and Ileri (1998) stated that phosphorus tends to be the limiting factor when N:P mass ratio is greater than 7:1. If not, nitrogen tends to be the limiting factor. Phosphorus was found to be the primary limiting nutrient in Lake Zribar according to the calculated N:P mass ratios (mean 8.73 ± S.E 1.16) (Table 1). In addition, 35% of calculated N:P ratios was found to be less than 7:1 suggesting that cyanobacteria were the dominant taxonomic group, whereas Bacilloriphyta is dominant in other months (N:P>7:1).

The changes in the water temperature followed the typical seasonal pattern of a shallow Mediterranean lake (Fig. 3). Summer epilimnetic temperature fluctuates between 17 and 31°C, while winter temperature ranging between 3.4 and 5.8°C.

Visible depth of Secchi disk (SD) showed a characteristic seasonal variation. The lowest value of SD was recorded in high rainfall months (autumn and winter), which indicates the entrance of suspended particles by runoff into the lake and reduction of water clarity (Fig. 3).

The highest of chlorophyll a values were found in warm months (September 2010 and July 2011) (Fig. 2). Despite the obvious seasonal variation of chlorophyll a, its concentration increased from 5.26 µl/ml at 2005 to 14.06 µl/ml at 2012.

The amount of total phosphorus (TP) during the study period (December 2005 to September 2012) had high fluctuations in different months which are shown in Fig. 2. The highest value of total phosphorus was recorded in May 2006; which might be related to starting tobacco and vegetables cultivation (2006 – 2007) and intensive application of phosphate fertilizers and subsequent leaching of phosphorus into the lake (Ebrahimpour *et al.*, 2011). Most external P-reduction studies in shallow lakes have shown a long recovery hysteresis (Jeppesen *et al.*, 1991; Beklioglu *et al.*, 1999; Villena and Romo, 2003). Moreover the response time can be highly variable in shallow lakes due to internal loading, the magnitude of the former external loading and the hydraulic retention time (Jeppesen *et al.*, 1991; Sondergaard *et al.*, 1993).

Regarding to changes in total nitrogen (TN), despite the monthly fluctuations, the overall trend was increasing and the highest value of TN was observed in November 2008 (Fig. 2). TN ranged from 0.436 to 7.846 mg/l, abrupt increasing in TN value was observed in 2008 due to intensive N fertilizers application and subsequent leaching into the lake (Ebrahimpour *et al.*, 2011).

Since eutrophication depends on the entering of limiting nutrients into the lake, the most important step in controlling eutrophication and restoration of the lake is controlling the amount of nutrients entering the lake (Xu *et al.*, 2001). The ratio of nitrogen to phosphorus in inputs is thought to be a logical starting point in examining the factors controlling nutrient limitation (Elmaci *et al.*, 2009). If the amount of nitrogen and phosphorus is not under the control of biogeochemical processes, then N:P mass ratio would be an appropriate estimate of the limiting nutrient in the lake (Howarth, 1988; Anonymous, 2000).

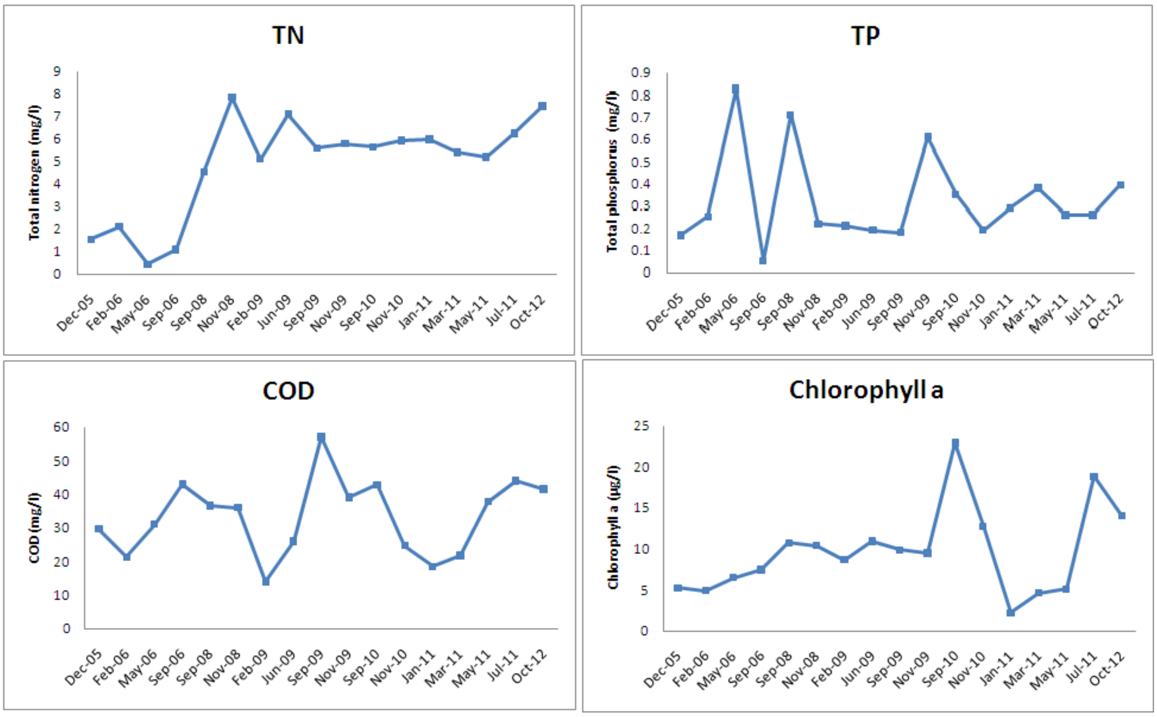

Fig.2. Monthly variations of hydro-chemical parameters; Total Nitrogen (TN), Total Phosphorus (TP), Chemical Oxygen Demand (COD) and Chlorophyll a

TSI values calculated on the basis of total nitrogen, chemical oxygen demand, total phosphorus, chlorophyll a and secchi disc depth, showed a characteristic seasonal variation (Fig. 3). The mean values of, TSI_{TN}, TSI_{COD}, TSI_{TP}, $TSI_{Chl\text{-}a}$ and TSI_{SD} during the study were, 82.73, 92.56, 82.03, 59.11 and 60.91, respectively. The results indicated that the overall trophic level of the lake ($TSI_{overall}$) has increased (from 74.35 to 79.98) during the study period (2005 to 2012) and has risen to hypereutrophic level.

Lower values of TSI (50-60) refer lower boundary of classical eutrophy, TSI 60-70 shows dominance of blue-green algae and possible occurrence of algal scum and higher values of TSI (70-80) indicates very eutrophic conditions along with heavy algal blooms throughout the summer period (Carlson, 1977).

The general trend of TSI_{SD} index is decreasing; this index declined from 62.28 in 2005 to 60.35 in 2012. $TSI_{Chl\text{-}a}$ index increased from 51.971 (2005) to 64.065 (2012). The estimated annual average of TSI_{COD} indicates increasing trend from 90.99 (2005) to 95.37 (2012).

Considering the changes in TSI_{TP} index, the status of the lake from hypereutrophic (74.143) in 2005 has reached highly hypereutrophic (84.83) in 2012. During the study period, the TSI_{TN} index increased from eutrophic (60.05) in December 2005 to highly hypereutrophic (95.285) in October 2012, which indicates increased entering of nitrogen and its great impact on the lake's eutrophic conditions.

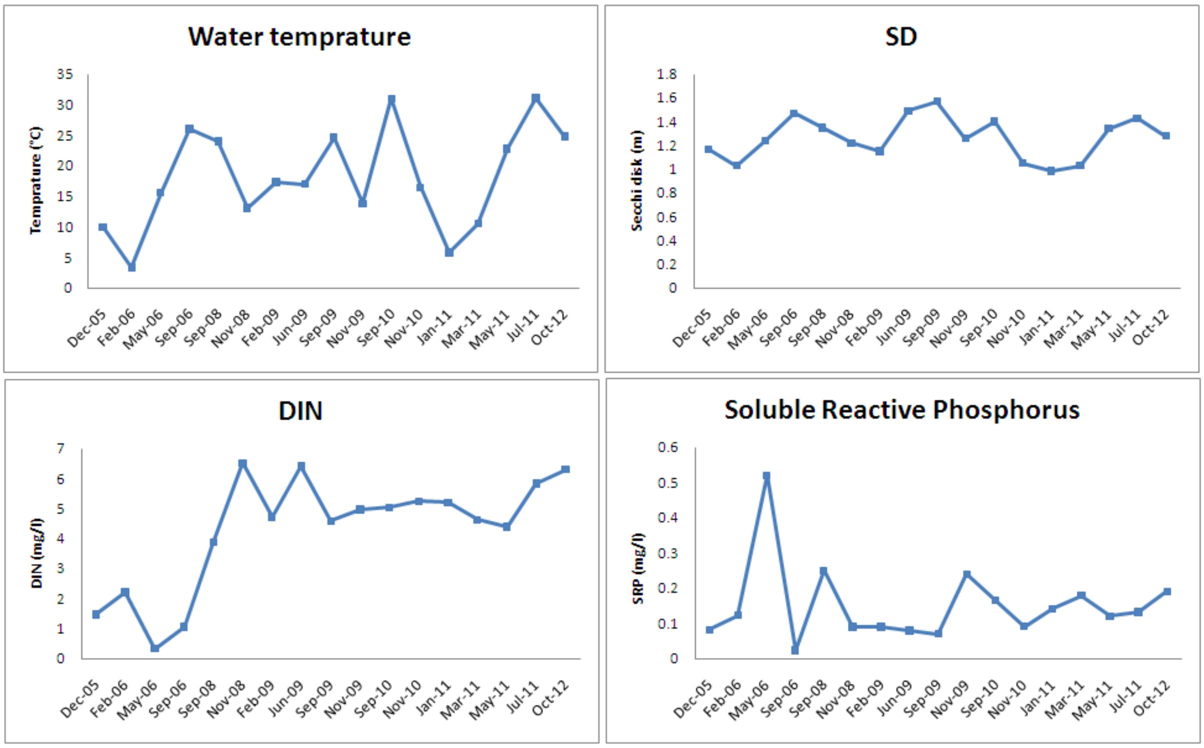

Fig.3. Monthly variations of hydro-chemical parameters; Water Temperature, Secchi Disk Depth (SD), Dissolved Inorganic Nitrogen (DIN) and Soluble Reactive Phosphorus (SRP)

Conclusion

The Lake Zribar of Kurdistan Province has problems with eutrophication related to nitrogen and phosphorus input. The main source of nutrients is the load of runoff from agricultural lands and untreated sewage from numerous sources in the rural villages.

The results of physicochemical analyses indicated that the water quality is decreasing and requires strategies for reducing the trophic conditions in the lake. The overall evaluation of this study indicated that clear signals of eutrophication were observed in the lake. Due to its importance as being a Ramsar site, management solutions must be urgently developed in order to avoid the destruction of the lake. Two main strategies for nutrients load reduction for lake are: (a) decreasing the amount of untreated domestic and poultry sewage volumes from the catchment area; (b) control of soil erosion in areas with highly erodible soil.

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