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ORIGINAL RESEARCH PAPER

Assessment of temporal and spatial eutrophication index in a water dam reservoir

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ABSTRACT: Eutrophication is considered as a serious problem in water reservoirs. Awareness about the eutrophic status of each reservoir could help in providing a better understanding of the problem in a global scale. The present study was conducted to assess temporal and spatial eutrophication index in a water reservoir (Sahand dam) in the northwest of Iran. Physico-chemical parametres that are effective on eutrphic condition occurrence were analyzed, and trophic state index was calculated on a scale of 0-100 by measuring Secchi disk depth, chlorophyll a, total phosphorus, total nitrogen, total suspended solids, and phosphorus P/N ratio. Moreover, using the overlapping, the reservoir was mapped based on the mentioned index. Seasonal variation of dissolved solids in the reservoir was recorded due to precipitation and subsequent dilution and evaporation. Thermal stratification was observed during the summer months. The total trophic state index value was calculated as 55.5- 58.07, with minimum value belonging to P/N and maximum value belonging to suspended solids for individual parameters. There were some spatial and temporal differences for trophic state index in the reservoir. It was found that the whole area of the reservoir was in almost moderately upper-mesotrophic condition and in some target stations it was very close to eutrophic condition. The worst condition was observed in Qaranqu River as the main input to the reservoir. Due to the significant impact of suspended particles resulting from erosion of the surrounding lands on TSI value, there is an urgent need for mitigation measures to intercept eutrophication.

KEYWORDS: *Eutrophication; Nutrients; Trophic state index; Water quality; Water resource.*

INTRODUCTION

The increasing need for fresh water and restrictions on the development of water resources reveal, more than ever, the importance of preserving existing water resources (McIntosh and Pontius 2017). Implementation of integrated water resources management has been considered as a target under the water and sustainable development goals (SDGs) by 2030. In the management of surface water resources on a global scale, eutrophication is considered as the most serious problem that affects the quality of

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water in reservoirs (Sechi and Sulis 2009; Wilkinson 2017). Excessive input of nutrients (compounds of nitrogen and phosphorus) to the water body leads to the increased biomass growth of primary producers (Kane *et al.,* 2014) and therefore, causes many issues such as reduction in water dissolved oxygen, water clarity, odor and bad taste, altered fisheries, fish kills and entrance of cyanobacteria (blue-green algea) toxins, resulting in deterioration of water quality and subsequently adverse impacts on human and animal health (Wilkinson 2017). The role of phosphorus in this regard has been studied more (Stow *et al.,* 2014; Lepori and Roberts 2017; Clement and Steinman 2017). Eutrophication of lakes and reservoirs was known as a pollution problem in Europe and North America in the mid-twentieth century and later on became more widespread (OECD 1982; McIntosh and Pontius 2017). Studies have shown that 54% of lakes in Asia, 53% in Europe, 48% in North America, 28% in Africa, and 41% in South America are classified as eutrophic (OECD 1982). In 1982, the OECD lake classification scheme was established, which primarily focused on total phosphorus, chlorophyll and water transparency by considering annual average values. This classification considered five primary trophic classes indicating eutrophication levels. According to a report published in Ireland, considering the percentage of lake area, trophic status was as follows: Oligotrophic/mesotrophic (92.1%), moderately-eutrophic (5.3%), strongly/highly eutrophic (2.4%) and hypertrophic (0.2%) (Martin McGarrigle *et al.,* 2010). Study of water quality and eutrophication processes in rivers, reservoirs and lakes has often been the topic of interest for many researchers in different countries such as China (Akdeniz *et al.,* 2011; Wenqiang Zhang *et al.,* 2017; Li-kun *et al.,* 2017; H. Y. Yan *et al.,* 2016; H. Yan *et al.,* 2016; Ulrich *et al.,* 2016; Chen *et al.,* 2016; Doan *et al.,* 2015, Gharibi *et al.,* 2012), and since 1960s eutrophication has been evaluated using chemical and biological parameters (i.e., biotic and abiotic). For example, the criteria used by different researchers briefly include the following: Secchi disk depth (Uttormark and Wall 1975; Liping Wang *et al.,* 2013; Karadzic *et al.,* 2010; Edna Cabecinha *et al.,* 2009; Carlson 1977); chlorophyll a (Edna Cabecinha *et al.,* 2009; Chrysoula Christia *et al.,* 2014; Liping Wang *et al.,* 2013; Zhixin Hu *et al.,* 2014; Karadzic *et al.,* 2010); total phosphorus (Edna Cabecinha *et al.*, 2009; Jiang Yaping and Zongren 2012; Chrysoula Christia *et al.,* 2014; Liping Wang *et al.,* 2013; Karadzic *et al.,* 2010); total nitrogen (Edna Cabecinha *et al.,* 2009; Liping Wang *et al.,* 2013); lake condition index (LCI) (Uttormark and Wall 1975); phytoplankton, zooplankton, nitrate, ammonia and carbon (Samaei *et al*., 2009); phytoplankton biomass (Zhixin Hu *et al.,* 2014); macrophytobentous and ecological evaluation index (EEI), macrophyte quality index (MaQI), the composite index of macrophytobentous and water quality parameters (transitional water quality index (TWQI)) (Chrysoula Christia *et al.,* 2014); dissolved reactive manganese (DRMn) (Cudowski 2014); and deep-water invertebrates (Guillermo Chalar *et al.* 2011). Eutrophication process modeling (Pauer *et al.,* 2007) and mechanism of its prevalence in lakes and reservoirs have been studied extensively (Liping Wang *et al.* 2013; Weitao Zhang and Rao 2012). Multidimensional nature of the eutrophication phenomenon implies that no single variable can be a representative variable of nutritional status. Therefore, more eutrophication indices are calculated using multivariate analysis. Trophic state index (TSI) introduced by Carlson, 1977 has been accepted as a reasonable method in recent years (Donia and Hussein 2004; Carlson, 1977). Despite great advances, water eutrophication is still a complex problem and the process mechanism may entirely vary for different systems based on the performance and dynamics of each parameter (Donia and Hussein 2004). The present study was conducted in the northwest Iran on Sahand Dam as a multipurpose reservoir. Previous studies have reported concerns about the presence of trace elements, such as arsenic, in this dam (Nadiri *et al.,* 2012; Nadiri *et al.,* 2018). During the recent years, number of studies regarding the status of eutrophication on inland water has considerably increased in Iran (Samaei *et al.,* 2009; Javid *et al.,* 2014; Darvishsefat *et al.,* ; Noori *et al.,* 2011; Salavatian *et al.,* 2010; Asal Pishe *et al.,* 2012; Ghadikolaei and Salehi ; Ghadi and Kianianmomeni 2012; Cheraghpour *et al.,* 2013; Darki 2015; MohsenpourAzary *et al.,* 2010; Mohebbi *et al.,* 2012). Moreover, some of these studies have evaluated water reservoirs, but mostly focused on the other types of water bodies (Cheraghpour *et al.,* 2013; Ahmadi *et al.* 2008). In the current study, trophic status of the reservoir and its temporal and spatial variations through physic-chemical analysis of water were determined along with the calculation of indices. This new approach has not been considered in the previous studies conducted at the study area. In addition, the results of this study can partially help in development of existing knowledge about the status of eutrophication of water resources in a global scale. This study has been carried out in a water reservoir in Sahand Dam located in the northwest of Iran during 2015.

MATERIALS AND METHODS

The setting

Fig. 1 shows the location of Sahand reservoir on the map (UTM: 37.4° N and 46.8° W). The reservoir is located within 26 km from southwest Hashtrood City. The main purpose of the reservoir construction was to store river waters in the region (the Qaranqu and Almaloo rivers) in order to meet the agricultural, domestic and industrial water demands in the area. Precipitation on Sahand Mountain is the main source of surface water and groundwater in the region. From hydrological aspect, the area of the reservoir is a division of the Caspian Sea basin and Sefidrood river sub-basin. The main catchment of the reservoir belongs to Qaranqu river basin with an area of 820 km^2, where is located in a distance over 51 km away from the reservoir. The reservoir is of soil type containing impermeable clay core, with walls height, length, and width of 47, 405 and 10 m, respectively. The reservoir capacity is about 165,000,000 m^3 with 10 km length and 10 km^2 surface area. The reservoir water level has considerable variation during wet and dry seasons. The highest percentage of land use is devoted to pastures and saline lands, respectively, whereas residential areas have the lowest percentage. Based on the land use map, water entrance to the dam stems is more than irrigated cultivation or pastures areas (Fig. 2). Sampling locations were based on the reservoir shape that has a relatively higher length than width. Five sampling points, as shown in Fig. 1, were considered throughout the reservoir: S_1 (Qaranqu input), S_2 (Almaloo input), S_3 (Conflux of the two inputs), S_4 (Middle of the reservoir), S_5 (Near the dam wall).

Sampling program and analysis

All water samples were collected from near of the surface of the water body (up to 0.5 m); however, temperature was measured both in the surface and in the depth. To evaluate transparency, Secchi disk depth was determind using a standard disk. Temperature and dissolved oxygen (DO) were measured on site using portable equipment (WTW Oxi 330 / SET, Germany). All the samples were preserved in polypropylene and glassy bottles at 4 °C in darkness and transferred to

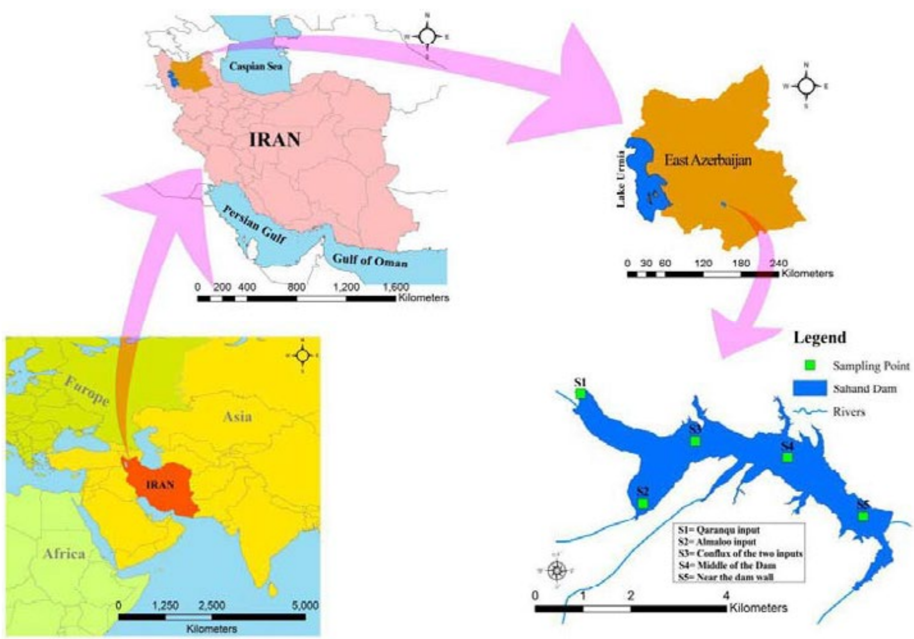

Fig. 1: Geographical location of the study area showing the sampling points

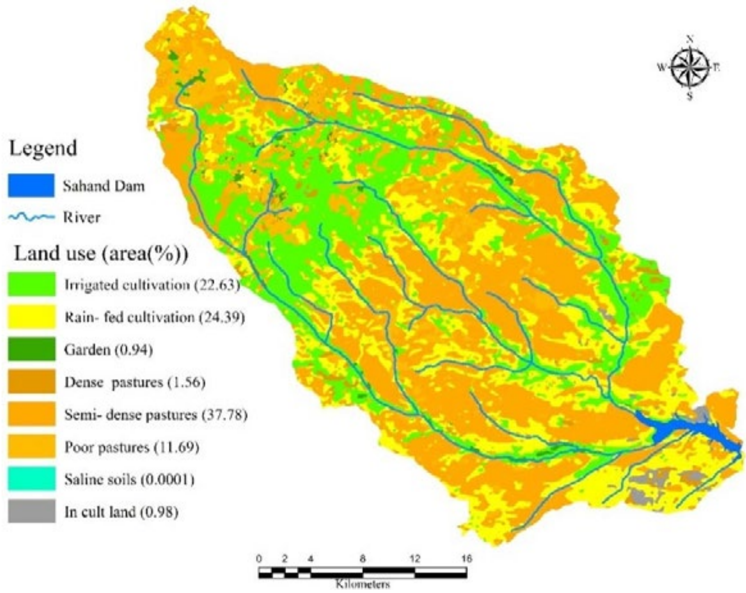

Fig. 2: Land use types (%) in the catchment area of Sahand reservoir

the laboratory. The main studied parameters were nutrients [NH_4^+, NO_2^-, NO_3^-, total nitrogen (TN), PO_4^{-3}, and total phosphorus (TP)] and Chlorophyll-a (Chl-a) concentrations that were analyzed according to the standard methods (APHA 1998). All chemicals used in the study were of analytical grade and purchased from the manufacturing company, MERCK. Turbidity, electrical conductivity (EC) and pH were measured using a nephelometric turbidimeter (AQUA-COND model of EC meter) and a 230 Senso Direct pH meter (Germany), respectively. TN was measured by the persulfate digestion method in an autoclave at a temperature of 100-110 °C followed by absorption measurement at 220 nm. TP was determined using ascorbic acid spectrophotometry and absorption measurement at 880 nm (APHA 1998). To prepare the samples, they were filtrated and extracted with acetone 90% and reading the absorbance using a spectrophotometer UV/VIS model of OPTIZEN 2120 UV (MECASYS, Korea), 10 mm light path, and 3.5ml quartz cell at four wavelengths of 630, 647, 664, and 750 nm. Then, the concentration of chlorophyll was measured in vitro according to the method described in the book on standard methods for quantitative and qualitative analyses of water and wastewater. The Concentration of chlorophyll was calculated based on the absorbance of the samples (APHA 1998). Due to the cold climate of the study area, the reservoir began to freeze during December, January and February and this affected the sampling program. Sampling and measurements were conducted during March (winter), May, June (spring), July, August, September (summer), October and December (autumn). Some of the water quality parameters were measured in all seasons, while some others were just measured during the summer and the fall, including TOC, chlorophyll a, TSS and $N\text{-}NH_3$. Also, the results reported for TN and TP did not comprise winter. Results were presented by descriptive statistics including minimum, maximum, mean and standard deviation. ANOVA test and paired sample t-test were used for seasonal variation and comparison of the two seasons, respectively, and $p < 0.0$ was considered significant. Moreover, Shapiro-Wilk coefficient was calculated for determination of data normality.

Eutrophication index

In order to assess the reservoir eutrophic states, the related index was calculated using the results obtained over a period of one year through the laboratory analysis. Eutrophication zoning maps of the reservoir were provided using Arc GIS based on the ordinary Kriging method (Fig. 5). For interpolation, different approaches are available such as inverse distance weighting, global polynomial interpolation, local polynomial interpolation, radial basis function and ordinary Kriging method. The last method is one of the most common and strong interpolation techniques, predicting a variable with the least error that combines both the spatial and the dependence correlations (Seyedmohammadi *et al.*, 2016). The validation of the developed model was tested via cross validation technique. Estimation is performed by exiting one sample out and using the remaining data. The interpolation values are compared to the real values using root mean square error (RMSE). RMSE is calculated as Eq. 1.

$$\mathrm{RMSE} = \left[\frac{1}{n}\sum_{i=1}^{n}(Pi - Oi)2\right]1/2 \qquad (1)$$

Where, n is the number of validation points, p_i is predicted value at point i, o_i is observed value at point i.

Carlson nutritional index (Carlson 1977) was also used as a quantitative index for classification of the reservoir eutrophication. Furthermore, assessment of each parameter was performed based on the available thresholds for eutrophication of lakes belonging to Japan's (Aizaki *et al.,* 1981) and China's environment (Huo *et al.,* 2013). The standards are shown in Table 1. As the values measured for both TP and P/N were not in the range of calculation based on Table 1, individual TSI values for P/N and TP were calculated by Eqs. 2 and 3, respectively (MPCA, 2016; Karadzic *et al*., 2010 and Kratzer, 1980)

$$TSI_{(P/N)} = 9.81\ln(10)^{P/N} + 30.6 \qquad (2)$$

$$TSI_{(TP)} = 4.15 + 14.42[\ln(TP)] \qquad (3)$$

Eventually, Eq. 4 was used to compute eutrophication ranks for each qualitative factor (Xu *et al.*, 2001).

$$TSI_i = [(TSI_{i,k-1}) + |(C_i - S_{i,k-1}) / (S_{i,k} - S_{i,k-1})| \times (TSI_{i,k} - TSI_{i,k-1})] \qquad (4)$$

Where, C_i represents concentration of the i-th indicator including TP, TN, SD and Chl-a; $TSI_{i,k}$ and $TSI_{i,k-1}$ are the k-th and (k−1)-th levels of the i-th indicator; and $S_{i,k}$ and $S_{i,k-1}$ are assessment standards of the k-th and (k−1)-th levels of the i-th indicator (Table 1). Eq. 5 was also used to overlap the thematic maps.

$$TSI_{total} = \Sigma TSI_i \times W_i \qquad (5)$$ (Xu *et al.,* 2001)

Where, TSI_{total} is the calculated total nutritional level, TSI_i is the value revealing the trophic levels of the SD, Chl-a, TP, TN and other parameters for each sampling point, and W_i is the weight factors for the indicator parameters. In this study, the value of W was considered as 1/n for each parameter, where n is the number of used parameters.

RESULTS AND DISCUSSION

General quality of water resource

Water quality in the reservoir is a function of water quality of the inputs (rivers and drainages) and internal conditions of the reservoir including geology and a variety of chemical and biological events occurring in the reservoir (Wilkinson 2017). The input water quality is considerably impacted by precipitation and characteristics of the basin. A significant difference for concentration of analyzed parameter except for BOD_5 and $N\text{-}NO_2$ was observed during different seasons (P< 0.05). With respect to the dissolved solids, annual mean of electric conductivity of the reservoir was determined as 730 ± 78 µs/cm. Fig. 3 illustrates the water belonging to Class II (< 750 µs/cm) and Class

Table 1. Standard (S) eutrophication index TSI for different parameters

Water body class (TSI range (unit less))	TSS (mg/L)	TN (mg/L)	SD (m)	Chl-a (µg/L)	TSI
Oligotrophic (0-30)	0.04	0.010	48	0.10	0
	0.09	0.020	27	0.26	10
	0.23	0.040	15	0.66	20
	0.55	0.079	8.0	1.6	30
Lower-meso trophic (30-40)	1.3	0.16	4.4	4.1	40
Mesotrophic (40-50)	2.1	0.31	2.4	10	50
Upper-meso trophic (50-60)	7.7	0.65	1.3	26	60
Eutrophic (60-70)	19	1.2	0.73	64	70
Hyper eutrophic (70-80)	45	2.3	0.40	160	80
Extremely hyper eutrophic (80-100)	108	4.6	0.22	400	90
	260	9.1	0.12	1000	100

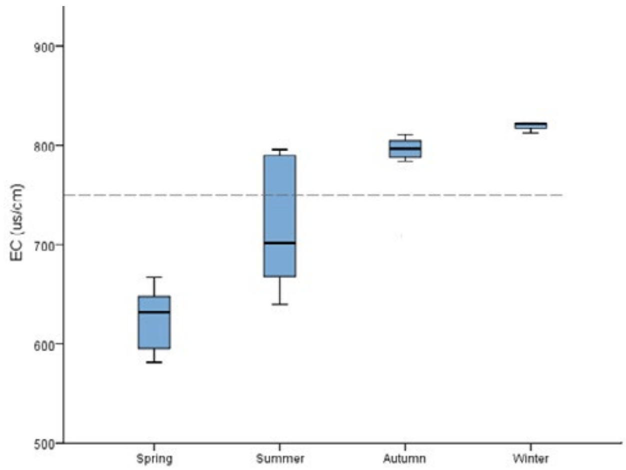

Fig. 3: Seasonal variation of EC of the studied reservoir (EC 750 µs/cm ≈ TDS 500 mg/L as desired limit of drinking water standard)

III (750 – 1500 µs/cm) in different seasons. The lowest EC level was recorded in spring (581µs/cm), whereas the highest level was recorded in autumn (830µs/cm). The highest average of EC was 820 ± 4µs/cm belonged to winter. There was an increasing trend for EC from spring to winter. Temperature of the reservoir was recorded between 3.1 and 27 ºC. The seasonal mean water temperatures were 14.5 ± 4.3 ºC, 19.9 ± 5 ºC , 7.1 ± 3.8 ºC and 4.2 ± 0.74 ºC respectively belong to spring, summer, autumn and winter (the mentioned temperature in winter was recorded at late winter). During December, January and February the reservoir was frozen. Fig. 4 shows the variation of temperature in different depths of the two selected stations of the reservoir. It can be seen that thermal stratification occurred in the reservoir during summer (June, July and August). However, in March and November, temperature profile indicated a mixed condition in the reservoir where thermal stratification was dismantled. The two stations had almost a similar condition. Annual mean of pH was 8.3 ± 0.31 with a minimum of 7.35 and a maximum of 8.39. Moreover, pH decreased from spring to summer and then, had an increasing trend toward winter. In water bodies with appropriate buffered capacity, basically in the pH value, there is no considerable fluctuation. However, large fluctuations of pH values are observed in eutrophic ecosystems (Javid *et al.,* 2014). Despite the eutrophic condition in Sahand reservoir, large fluctuations were not observed in the pH value. This may be justified by the influence of

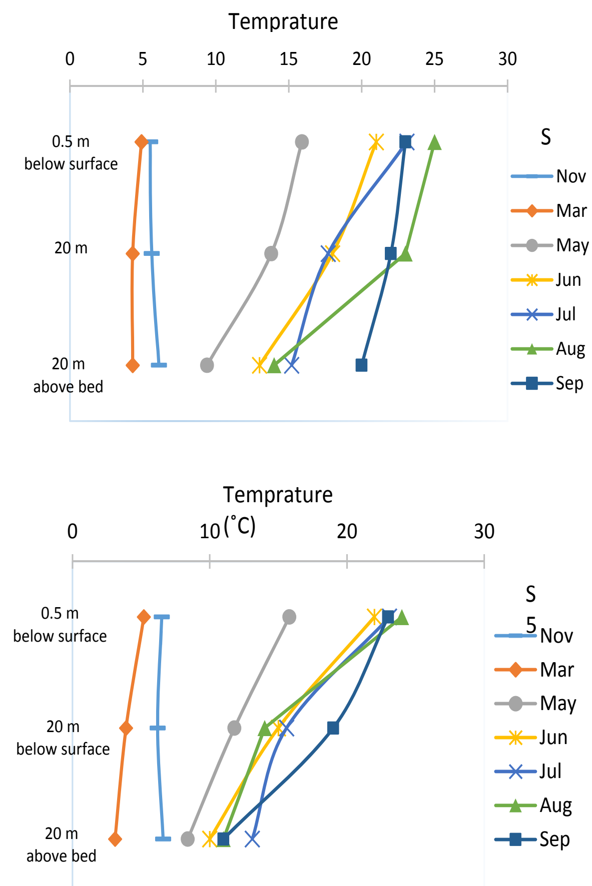

Fig. 4: Variation of temperature in the two stations (S3 and S5) of the studied reservoir at three depths (0.5 m from the surface, 20 m below the surface and 20 m above the bottom of the reservoir)

different factors on pH (e.g., type of dissolved solids as a function of basin water, erosion and upstream bed leaching). A study conducted by Vaezi *et al.* (2009) has already shown that the rocks in the basin floor are mostly of limestone type. Considering the organic matter presence, the amount of COD parameter was determined as 25 ± 7 mg/L (annual mean) with a minimum of 12.8 mg/L and a maximum of 40.8 mg/L. The level of $BOD_{5,}$ and its minimum and maximum were 3.7 ± 2.7 mg/L, 2 mg/L and 12.3 mg/L, respectively. The COD to BOD ratio was about 6.75. The highest level of TOC was observed in summer, during which the concentration ranged between 1.47 and 6.57 mg/L with a mean of 2.94 mg/L. Significant correlation was observed between TOC and TN (r= -0.654, p = <0.05). However, there was no significant correlation between TOC and other parameters. Annual mean of DO was calculated as 6.2 ± 1.8 mg/L with a minimum rate of 3.1 mg/L and a maximum rate of 10.1 mg/L. Comparison of seasonal mean of DO level led the order: autumn> winter> spring> summer. Clarity (transparency) of water during the study varied between 75 and 180 cm with an average of 125 ± 32 cm and the minimum clarity belonging to summer. A decreasing trend for clarity was observed from spring to winter. Also, a negative significant correlation was observed between clarity and turbidity of water (r= -0.752, p = <0.05). Turbidity varied from 4.9 to 43.8 NTU with an annual average of 12.9 ± 7.6 NTU. Both the minimum and maximum turbidities were recorded in summer. TSS ranged from 2 to 38.4 mg/L with the annual mean of 17.2 ± 14 mg/L. Mean concentrations during summer and autumn were 28.4 ± 10 mg/Land 6 ± 6 mg/L, respectively. Seasonal differences of TSS were significant (p < 0.05). The annual mean concentration of Chlorophyll a was measured as 2634 ± 1314 µg/m^3 with a minimum of 204.6 µg/m^3 and maximum of 5360 µg/m^3, both being recorded in summer. The minimum concentration during autumn was eight times higher than that during summer. At 95% confidence interval, seasonal differences (between summer and autumn) were significant (p< 0.05) and the trend seemed to be decreasing from summer to autumn. The minimum and maximum TN were 0.5 and 3 mg/L, respectively. For TP, the minimum and maximum values were 0.04 mg/L and 0.7 mg/L, respectively. Moreover, the mean values of TN and TP were 1 ± 0.68 and 0.12 ± 0.14 mg/L, respectively. Shapiro-Wilk significant coefficients in test of normality were 0.032 and 0.559 for TN and TP, respectively, indicating non-normal distribution of TN.

Eutrophication index

Table 2 provides a comparison of analyzed parameters and calculated TSIs in 5 stations. The total TSI value was between 55.5 and 58.07, with the minimum and maximum values belonging to S_2 (Almaloo river input) and S_1 (Qaranqu river input) (Fig. 5). For individual parameters, the minimum TSI value belonged to P/N and the maximum value belonged to TSS. The corresponding TSI for TSS varied between 76.1 and 82.27, with the minimum and maximum values belonging to S_4 (middle of the

Table 2: Water quality parameters and calculated eutrophication index in the stations

Parameter (station code)	pH	EC (µs/cm)	Turbidity (NTU)	TSS (mg/L) (TSI)	SD (cm)	Chl a (µg/m^3) (TSI)	TP (mg/L) (TSI)	TN (mg/L) (TSI)	P/N (TSI)	TSI-$_{Total}$	
S_1	8.32	752	8.27	19.4 (80.15)	102 (59.64)	5417.2 (47.18)	0.075 (66.4)	1.88 (63.52)	0.040 (31.5)	58.0	Nutritional class Upper-mesotrophic
S_2	8.32	794.5	8.44	20.2 (80.46)	115 (57.99)	1758.3 (36.14)	0.075 (66.4)	1.50 (60.3)	0.050 (31.73)	55.5	
S_3	8.29	719.3	15.48	17.0 (78.23)	110 (58.63)	2945.6 (41.20)	0.125 (73.77)	0.82 (51.45)	0.154 (34.08)	56.2	
S_4	8.44	725.4	12.44	14.6 (76.1)	127 (56.5)	3806.4 (43.71)	0.070 (65.4)	1.54 (60.68)	0.045 (31.62)	55.7	
S_5	8.22	767.2	10.0	24.9 (82.27)	141 (55)	1953.6 (37.17)	0.138 (75.2)	0.95 (53.66)	0.1469 (33.90)	56.2	
S.D. (all stations)	0.31	77.6	7.75	13.89	31.719	1313.8	0.142	0.679	_		

reservoir) and S_5 (near the dam wall), respectively. The corresponding TSI for SD varied between 55 and 59.64, with the minimum and maximum values belonging to S_5 and S_1, respectively. Also, the corresponding TSI for chlorophyll a varied between 36.14 and 47.18, with the minimum and maximum values respectively belonging to S_2 and S_1. The corresponding TSI for TP varied between 66.4 and 75.2, with the minimum and maximum values belonging to S_1, S_2 and S_5. The corresponding TSI for TN varied between 51.45 and 63.52, with the minimum and maximum values belonging to S_3 and S_1, respectively. The corresponding TSI for P/N varied between 31.5 and 34.08, with the minimum and maximum values respectively belonging to S_1 and S_3. As shown in Fig. 5, S_1 station had the maximum value of total TSI likewise TSI for SD, Chlorophyll a and TN. S_2 station had the minimum value for total TSI as well as TSI for Chlorophyll a and TP. However, in all stations, the nutritional class was upper meso-trophic. In terms of temporal variation of the total TSI, the maximum value was observed during May, while the minimum value was seen in August. According to Fig. 6, TSI values showed the following sequence during the studied period: May> Jun> Dec> Sep> Jul> Aug. According to the testing results of validation, calculated

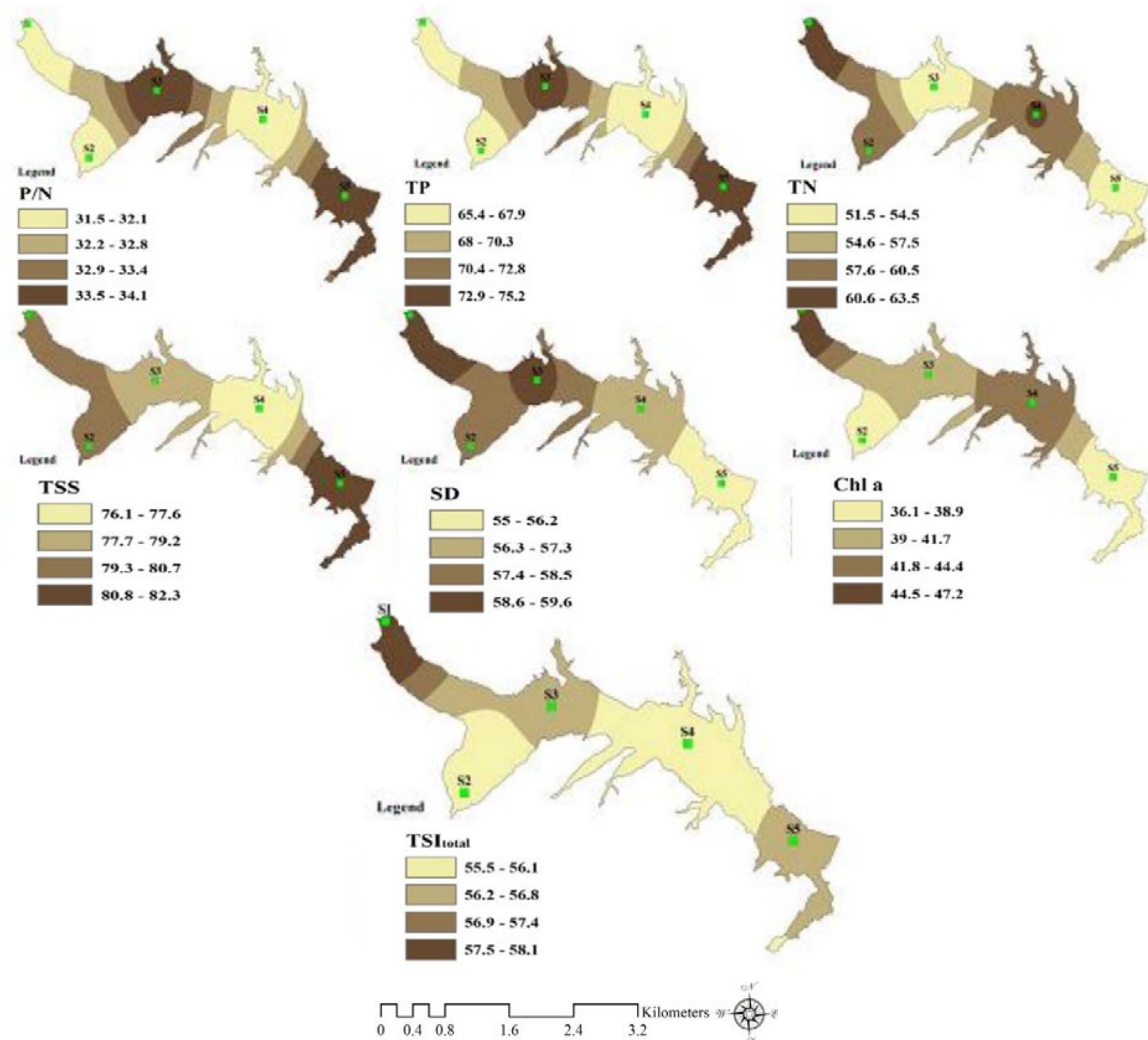

Fig. 5: Spatial distribution of the TSI index for individual parameters and total eutrophication index

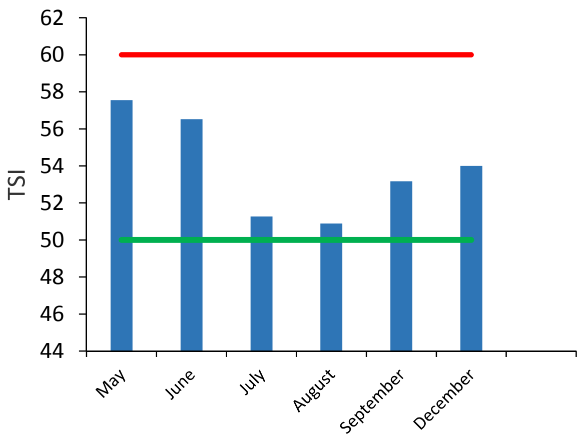

Fig. 6: Temporal distribution of the total TSI index in different months (between red and green lines = upper-mesotrophic area)

root mean square error in ordinary Kriging method for SD, TN, TP, Chl a, TSS, P/N and TSI_{total} are 0.94, 1.0, 1.0, 0.90, 1.0, 0.91 and 0.96, respectively.

The results of the TSI values illustrated that the reservoir condition was moderately upper-mesotrophic and also in some target stations, such as Qaranqu river input, it was very close to eutrophic condition in all seasons. In other words, the whole area (~10 km^2) of Sahand reservoir was found to be almost in moderately upper-mesotrophic condition. Qaranqu river has annual water volume of 95 million cubic meters and is originated from the eastern slopes of Sahand Mountains. The river may receive different types of organic and inorganic pollutants along its route. In the study area, rainfalls began during the late March and continued until April and May. As a result, according to seasonal variation of EC, dissolved solids content of the reservoir decreased due to dilution in wet seasons. Nonetheless, with the cessation of rainfall during dry seasons and effect of evaporation, amount of solute increased during summer until re-precipitation in late autumn. This temporal trend could be common in such areas of the world where their climatic conditions are similar to those of a country like Iran. Change of water dissolved solids or salinity may contribute to the eutrophication phenomenon. Along with the increase of dissolved solids content, thermal stratification also occurred in the reservoir, which was stronger in deeper locations. The highest calculated eutrophication index belonged to TSS compared to the other parameters. This may reveal the major contribution TSS to the development of eutrophication in the reservoir and likely, confirms its great importance in control and management of eutrophication. Based on field observations and satellite map, surrounding lands of the reservoir are devoted to rainfed agriculture. Plowing the lands for cultivation of rainfed barley and wheat leads to production of heavily polluted agricultural drainage during rainfall, which contains high levels of particulate matter due to erosion of plowed lands. The drainages enter into the reservoir through other routes except for the two main rivers that decrease water quality with respect to suspended solids. High suspended solids near Sahand dam wall could be attributed to the entrance of a stream named “Shoordarreh” close to the end of the reservoir (Fig. 1). It has been reported that agricultural runoff can lead to re-eutrophication of lakes, which was observed in the Great Lakes basin despite earlier success of water quality protection (Kerr *et al.,* 2016). Despite the similarity of eutrophication classes, it was found that there were spatial and temporal differences in TSI. However, variation of the overall temporal index, such as spatial variations in different seasons, may not be considered significant. According to the results, the total TSI index was observed to be higher in May and lower in August, as compared to other months. Increase of the index value in spring and to a lesser extent in fall can be attributed to the increase of TSS due to greater precipitation, high turbidity and TSS content of the input rivers and intense mixing and turbulence of the reservoir during these seasons, which consequently led to the reduced clarity and Secchi disk depth. Ali and Khairy (2016) reported that the transparency of Lake Idku varied from 45 cm to 134 cm. In Lake Zribar in Western Iran, Secchi disk depth was 98.5 - 157 cm (Karimi Nezhad *et al*., 2014). In this study, the transparency was found to be between 75 and 180 cm. Seasonal differences of TSS, which could affect transparency, were significant ($p < 0.05$). In a study performed by Yan *et al.* (2016), significant temporal differences among eutrophication phenomena in Da’ning river were reported, as eutrophication was less serious in autumn, higher in spring and in its highest rate in summer. The results obtained in this study are largely consistent with those obtained by Yan *et al.* (2016). Critical values for eutrophication have been reported as N > 0.2 mg/L and total phosphorus > 0.02 mg/L in reservoirs. In a study carried out by Ali and Khairy (2016) in Egypt, nitrite in the lake was observed to be 84 mg/L, while inorganic phosphate fluctuated between 0.2 and

0.43 mg/L. In a study conducted by Karimi Nezhad *et al.,* (2014), TN, TP and TN/TP were obtained to be in the range of 0.44 and 7.85 mg/L, 0.051 and 0.827 mg/L and 0.527 and 37.358, respectively. In the present study, mean values of nitrogen and phosphorus were 1.34 mg/L and 0.097 mg/L, respectively, proving to be less than those in the above mentioned studies. However, these values indicate the proper condition of the reservoir for the growth of algae in terms of nutrients. During the sampling period, the concentration of nutrients in Sahand reservoir was more than the established critical values of them for eutrophication, and the reservoir was in the eutrophic status in terms of nutrients. This could be justified by the effect of catchment area and anthropogenic or natural sources of nutrient inputs form Qaranqu river. It should be noted that chemical properties of water in the reservoir are influenced by the characteristics of the catchment area such as geology of the basin, soil type and its compounds, vegetation, erosion and human activities (e.g., agriculture, animal farming, cottages around the lake, sanitary wastewater disposal, etc.). Such factors may also explain the trophic status of the reservoir in terms of nutrients. It has been reported that awareness of phosphate and nitrate concentrations is essential for providing an appropriate management strategy to control the eutrophication phenomenon (Parham *et al.,* 2007). If the growth of algae and microorganisms is high in reservoirs, nutrients are consumed and as a result, the concentration of nutrients declines in the reservoir output as compared to the reservoir input. This was observed in the TN concentration in Sahand reservoir rather than in the TP concentration. It is likely for TP to be influenced by the release of total phosphorus from sediments under different hydrologic conditions in the reservoir (Isazadeh *et al*., 2005; Son *et al*. 2015). When the P/N ratio is between 0.1 and 0.2, all the nutrients can be limiting (Donia and Hussein 2004). In Sahand reservoir, this ratio was in the range of 0.1 and 0.2 in the middle of the lake, indicating that the nutrients may be limiting. However, the values obtained from the input stations indicated phosphorus limitation. According to the results, the minimum and maximum concentrations of chlorophyll a were 0.205 mg/m^3 and 5.36 mg/m^3, respectively. These concentrations were significantly lower than those obtained from Lake Idku, in which the minimum and maximum concentrations were reported as 39.9 mg/m^3 and 104.2 mg/m^3, respectively (Ali and Khairy 2016). Also, in a study done by Zhang (2016) in Taihu Lake-connected channels in Yixing City, the highest and the lowest values of Chla were found as 64.26 mg/m^3 and 14.48 mg/m^3 respectively (Zhang 2016). In Lake Zribar, Western Iran, concentrations of chlorophyll a were recorded to be in the range of 2.22 μgchl-a/l to 22.94 μgchl-a/l (Karimi Nezhad *et al.,* 2014). Based on the modified version of the OECD, if annual concentration of chlorophyll a is less than 8 mg/m^3, lake trophic category becomes oligotrophic (Martin McGarrigle *et al.,* 2010). Considering the calculated TSI value of chlorophyll a, eutrophic status was upper-mesotrophic in this study. This suggests that different indices result in different classes of trophic state, which should be considered in classification of lakes. In this study, the value of TSI for chlorophyll a was calculated to be in the range of 36.14 - 47.18 which was lower than other parameters. In a study conducted by Jarosiewicz *et al.* (2011) on eight lakes in Poland, Carlson-type TSI (Chl) was obtained to be in the range of 37 to 79 which was similar to the range of TSI obtained in this study. In the study on Lake Zribar, the mean value of $TSI_{Chl\text{-}a}$ was reported as 59.11 (Karimi Nezhad *et al*., 2014). Maximum concentration of chlorophyll a was recorded in summer, during which more algal growth was observed. Seasonal differences between the concentrations in summer and autumn were significant with a decreasing trend from summer to autumn. TSI_{SD} with an upper-mesotrophic class was in the range of 50-60 at all of the stations. Since the eutrophication index of SD and TP was higher than that of chlorophyll a, it can be concluded that non-algal particles or water-soluble colored materials may prevent light transmission and reduce clarity. In a study carried out by Jarosiewicz *et al.* (2011), TSI (SD), TSI (TN) and TSI (TP) were reported as 31.9-75.1, 44.9-74.1 and 59.4-97.5, respectively. In the current study on Lake Zribar, the mean values of TSI_{TN}, TSI_{TP} and TSI_{SD} were reported as 82.73, 82.03 and 60.91, respectively (Karimi Nezhad *et al.,* 2014). TSI values for SD, TN and TP were calculated as 55-59.64, 51.45- 63.52 and 66.4-75.2, respectively. Values obtained in this study are consistent with those reported by Jarosiewicz *et al.* (2011), but less than those obtained in Lake Zribar. However, for TSI (SD), the minimum value was higher than the minimum value obtained in the study conducted by Jarosiewicz

Fig. 5: Spatial distribution of the TSI index for individual parameters and total eutrophication index

Author (year)	Country	Studied lake	Reported TSI	Nutritional class
Jarosiewicz *et al.* (2011)	Poland	Rybiec	77.1-80.2 (TSI_{TP})	Hyper eutrophic
			59.8-74.1 (TSI_{TN})	Upper mesotrophic hper eutrophic
		Niezabyszewo	74.4-81.8 (TSI_{TP})	Hyper eutrophic
			53.2-57.4(TSI_{TN})	Upper mesotrophic
		Czarne	65.4-79.0 (TSI_{TP})	Eutrophic hyper eutrophic
			49.1-61.7 (TSI_{TN})	Mesotrophic eutrophic
		Chotkowskie	71.0-86.1 (TSI_{TP})	Hyper eutrophic extremely hyper eutrophic
			47.0-61.9 (TSI_{TN})	
Karimi Nezhad *et al.* (2014)	Iran	Zaribar (Kurdistan)	74.143-84.83 (TSI_{TP})	Hyper eutrophic extremely hyper eutrophic
			60.05- 95.285 (TSI_{TN})	Eutrophic extremely hyper eutrophic
Present study	Iran	Sahand reservoir (East Azerbaijan)	54.4-75.2 (TSI_{TP})	Upper mesotrophic hyper eutrophic
			53.66- 63.52 (TSI_{TN})	Upper mesotrophic eutrophic

et al. (2011). According to Carlson (1977), TSI of 50-60 indicates lower boundary of classical eutrophy, whereas TSI of 60-70 demonstrates dominance of blue-green algae and likely occurrence of algal scum. Moreover, TSI of 70-80 illustrates very eutrophic conditions and heavy algal blooms. Comparison between some selected lakes and Sahand reservoir for TSI_{TP} and TSI_{TN} is presented Table 3.

CONCLUSION

The results obtained from the current study and TSI calculated for different parameters revealed the deterioration of water quality and occurrence of eutrophication in Sahand reservoir. This becomes more important as the reservoir is considered as a drinking water resource and used for multi-purposes. The entire reservoir was upper meso-trophic in terms of nutritional class. However, some temporal and spatial variations were observed for the TSI value in different sampling points. Considering the temporal variation, maximum and minimum values of TSI_{total} were observed in May and August, respectively. Increased rate of TSS due to rainfall and flood regime of input rivers, particularly entrance of drainages from the surrounding agricultural lands, had an important effect on the TSI value during spring. Considering the spatial variation, the worst condition was observed in Qaranqu river as the main input to the reservoir, which could be attributed to the land use and characteristics of the catchment area. During the dry seasons, thermal stratification was formed in the reservoir, which had its own effects on the water quality. Concentration of nutrients in the reservoir was high as compared to the established critical values as a function of both natural and anthropogenic activities such as agriculture in the basin and catchment area of the reservoir and deterioration of the reservoir input rivers. This indicated an urgent need for mitigation measures in order to intercept the current increasing trend and prevent eutrophication. Limited number of analyses performed in the present study can be considered as the main shortcoming. Since, nutrients are particularly from the soil adjacent to the reservoir, erosion details about the seasons are required to be considered along with the general parameters used to investigate the intensity of eutrophication index in the reservoir. Comprehensive water monitoring program is recommended at least for five years to enhance the public awareness about behavior of water body and adoption of integrated water resources management to achieve sustainable development goals.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this manuscript.

ABBREVIATIONS

BOD	Biochemical oxygen demand
°C	Centigrade degree
Chl-a	Chlorophyll-*a*
COD	Chemical oxygen demand
cm	Centimeter
DO	Dissolved oxygen
DRMn	Dissolved reactive manganese
EC	Electrical conductivity
EEI	Ecological evaluation index
GIS	Geographic information system
km	Kilometer
L	Liter
LCI	Lake condition index
m	Meter
MaQI	Macrophyte quality index
mg	milligram
µg	microgram
µs	microsiemens
ml	milliliter
mm	millimeter
m^3	Cubic meter
N	Nitrogen
nm	nanometer
° N	North degree
NTU	Nephlometric turbidity unit
OECD	Organization for Economic Cooperation and Development
RMSE	Root mean square error
P	Phosphorus
S	Station
SD	Secchi disk
SD	Standard deviation
SDGs	Sustainable development goals
TDS	Total dissolved solids
TN	Total nitrogen
TOC	Total organic carbon
TP	Total phosphorus
TSI	Trophic state index
TSS	Total suspended solids
TWQI	Transitional water quality index
UTM	Universal transverse mercator
° W	West degree
%	Percentage

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