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Determining the Eutrophication State of Ecbatan Reservoir using Carlson Index

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Abstract: Reservoirs are vital and necessary resources of potable water. Different sectors such as agriculture, industry and fishery are dependent on these resources which need high quality water. Water quality is mainly evaluated using different parameters such as pH, temperature and turbidity which are easily measured. Also there are some more complicated parameters such as eutrophication degree of a water body. This study was accomplished to investigate the trophic state of Ecbatan reservoir in dry and wet seasons. Water sampling was accomplished in July and January to compare the trophic state of the reservoir in two critical situation of a hydrologic dry year. 15 stations were selected in different points of the reservoir. Different parameters of water quality were measured such as temperature, pH, Secchi Disk (SD), Total Nitrate (TN), Total Phosphate (TP) and chlorophyll-a (chla). The trophic state was estimated for all stations using Carlson index. Results of the study show that trophic state of the lake is mild mesotrophic in July and acute mesotrophic in January. Also Phosphorous is the limiting nutrient in this reservoir. This research showed that eutrophication is a serious problem in Ecbatan reservoir and managerial strategies are required to prevent water quality deterioration.

Keywords: Carlson Index, Dry Year, Ecbatan Reservoir, Eutrophication, Trophic State Index (TSI), Water Quality

Introduction

Iran is a dry country located in the Middle East. Fresh water resources are very important for surrounding environment and society in this country. Many reservoirs have been built to supply clean and healthy water. These resources are used to supply potable water for urban and rural areas, industry, agriculture and recreation purposes. All of these sectors need a healthy resource of water.

Natural and artificial lakes such as reservoirs are exposed to more pollution as a result of their geometry and characteristics of water bodies. Nutrients have more opportunity to settle and remain in these systems. Consequently the possibility of eutrophication phenomenon is higher in such ecosystems. Many studies have been accomplished on the eutrophication of reservoirs. These studies are mainly accomplished to investigate the quality of water in reservoirs and could ultimately lead to practical solutions to protect the quality of these resources.

Any increase in eutrophication rate increases the biomass of algae in water bodies such as rivers, ponds, coastal areas and reservoirs (Camargo *et al*., 2005; Kurz *et al*., 2005). Nitrogen (N) and Phosphorus (P) are main nutrients which affect the growth of algae and increase the amount of chla directly (Smith, 2003). Based on the ratio of eutrophication in a water body N or P could be the limiting factor. Li *et al*. (2015) determined the limiting nutrient in Yuqiao reservoir and controlled the amount of nutrient entrance to a threshold that prevented eutrophication. P was identified as the limiting factor in this reservoir.

Science Publications

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Eutrophication limits the application and consumption of water, since algae clog filtration equipment and suction pipes in refineries, change the taste and odor of water and cause some disease (Domagalski *et al*., 2007; Smith *et al*., 2005). Excessive growth of algae and water plants reduces the amount of Dissolved Oxygen (DO) (Zhang *et al*., 2007; Arheimer *et al*., 2004). As a result fishes will die and biological species will be reduced. Some algae species which are created in reservoirs are poisonous and harmful to human and aquatic creatures (Gurung, 2007; Chapra, 1997). Also industrial usage of water might be restricted because many industries need high quality water.

Sharma *et al*. (2010) Investigated the Trophic State Index (TSI) of Mansi Ganga Lake in India. They showed that the rate of water quality degradation is high in this lake. It was oligotrophic in 2006 and changed to meso-trophic in 2008. Trophic state of a lake from oligotrophic to eutrophic is a gradual progress and it is necessary to monitor this state in a long term. However, sometimes the trophic state of a lake changes from month to month (Mahesh *et al*., 2014).

Reservoirs are resources of fresh water and many researches focus on water quality of this important resource. Yang *et al*. (2012) investigated the trophic state of 11 subtropical reservoirs in Fujian province during summer 2010. All 11 reservoirs showed symptoms of eutrophication. Results from trophic studies on lakes and reservoirs could identify the limiting nutrient which is helpful in applying managerial strategies to reduce the rate of water quality degradation.

Mahesh *et al*. (2014) investigated the trophic state of Dantaramakki Lake in February, March and April. The lake showed meso-trophic symptoms in February and March and eutrophic symptoms in April.

Many studies focused on eutrophication of lakes, ponds and reservoirs in Iran (Javid *et al*., 2014; Jalilzadeh *et al*., 2013). This country is located in an arid geographical region and protection of water resources is necessary to maintain fresh water.

Ecbatan reservoir is a resource of drinking water for Hamedan city and is exposed to eutrophication problem (Norouzi *et al*., 2011). The concentration of nutrients is considerable in this lake (Samarghandi *et al*., 2013).

Ecbatan Dam is a drinking reservoir located in Hamadan city, which has eutrophication potential (Norouzi *et al*., 2011; Taheri and Ghahghaie, 2016). In this study, the eutrophication state of Ecbatan reservoir is investigated in July, 2014 and January, 2015. Considering that summer season is critical in terms of algae growth (more temperature and light in the environment).

Previous studies show that TSI is highly dependent on air temperature and precipitation. More light and temperature is available in summer which can increase the rate of eutrophication. Also stratification is complete in Ecbatan reservoir during summer while there is a full circulation of water in winter. Any information about the response of water quality to environmental factors helps to change the withdraw rule of the reservoir and choose the proper decision to prevent severe water quality degradation. The aim of this study is to investigate and compare the trophic state of Ecbatan reservoir in dry and wet seasons as the most critical time in a year in terms of precipitation and temperature which can change the trophic state of the reservoir.

Materials and Methods

The Study Area

Hamedan is a mountainous city located in west of Iran. It is the center of Hamedan Province. The city is located in the hillside of Alvand Mountain in 1800 masl and has a cold climate. Abshine River originates from Alvand Mountain and enters to Ecbatan reservoir. Ecbatan Dam is located in south west of Hamedan on Abshine River where two branches of Yalfan and Abru join together. This Dam is located between 34°45'24"N and 48°36'10"E. The area of the reservoir at normal level is 1.75 km^2. Figure 1 shows the location of the study area and Fig. 2 shows the sampling points in July and January.

Primary structure of this dam was first built in 1963 to supply agriculture and potable water for Hamedan. The rate of erosion is high in Ecbatan watershed and a huge amount of sediment settled in the reservoir. The height of the dam was increased 25 m in 2008.

15 points were determined for sampling in Ecbatan Lake. Coordinates of all points were determined using Global Positioning System (GPS). These points were selected so that cover all parts of the lake. Summer sampling was accomplished in July 2014 and winter sampling was done in January 2015.

The Characteristics of sampling points for July and January are shown in Table 1.

Sampling was accomplished in 30 cm of water depth. Temperature, pH, Sechi disk, Total Phosphate (TP), Total Nitrate (TN) and chla were sampled and measured in this research.

Samples were analyzed in water and waste water laboratory of Hamedan. TP and TN were measured in laboratory using the standard method. Also the concentration of chla was determined in plant physiology laboratory of science faculty in Bu Ali Sina University, using NMM method (Huang and Cong, 2007).

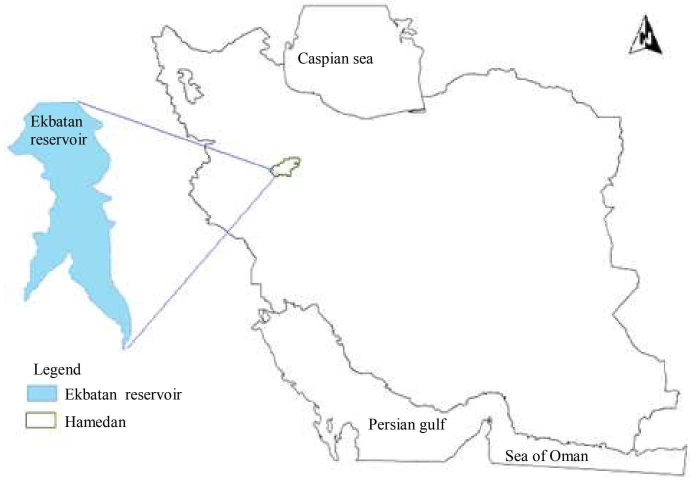

Fig. 1: Ecbatan reservoir

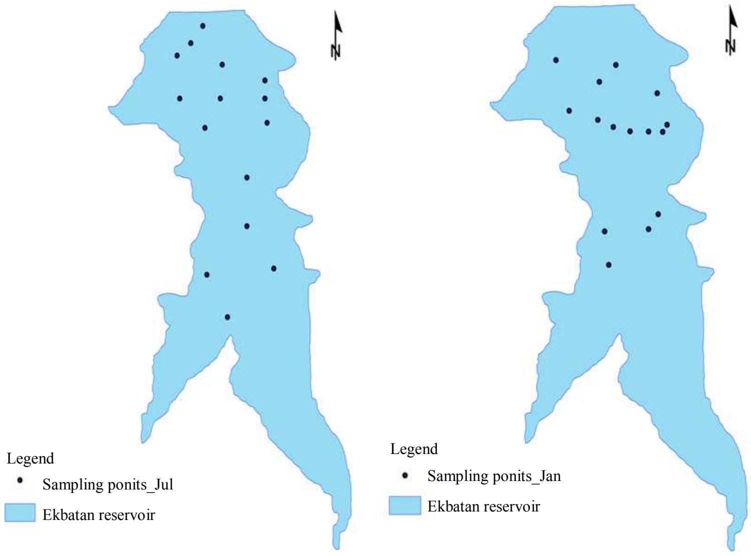

Fig. 2: Sampling points in July 2014 (a) and January 2015 (b)

Table 1: Characteristics of sampling points in January and July

Characteristics of sampling points in January			Characteristics of sampling points in July		
Point no.	Long.	Lat.	Point no.	Long.	Lat.
1	48°35'54.6"	34°45'15.48"	1	48°36'4.32"	34°45'15.5"
2	48°35'57.1"	34°45'7.6"	2	48°36'12.2"	34°45'12.9"
3	48°36'2.1"	34°45'6.1"	3	48°36'12.2"	34°45'10.1"
4	48°36'4.7"	34°45'5.0"	4	48°36'3.9"	34°45'10.1"
5	48°36'7.9"	34°45'4.3"	5	48°35'56.4"	34°45'10.1"
6	48°36'11.1"	34°45'4.3"	6	48°36'12.9"	34°45'6.5"
7	48°36'13.7"	34°45'4.3"	7	48°36'1.1"	34°45'5.4"
8	48°36'14.4"	34°45'5.4"	8	48°35'58.7"	34°45'19.1"
9	48°36'12.6"	34°45'10.4"	9	48°35'55.7"	34°45'17.3"
10	48°36'5.4"	34°45'14.8"	10	48°36'0.7"	34°45'21.9"
11	48°36'2.5"	34°45'12.2"	11	48°36'9.0"	34°44'57.5"
12	48°36'3.2"	34°44'48.5"	12	48°36'9.0"	34°44'49.9"
13	48°36'3.9"	34°44'43.1"	13	48°36'14.0"	34°44'43.1"
14	48°36'11.2"	34°44'48.9"	14	48°36'1.4"	34°44'42."
15	48°36'12.9"	34°44'51.4"	15	48°36'5.4"	34°44'35.1"

Table 2: Classification of eutrophication (Ebrahimpour *et al.*, 2012)

No.	Eutrophic state	Range
1	Oligotrophic	0<TSI<30
2	Mild Mesotrophic	30<TSI<40
3	Mesotrophic	40<TSI<50
4	Acute Mesotrophic	50<TSI<60
5	Eutrophic	60<TSI<70
6	Hypertrophic	70< TSI <80
7	Acute Hypertrophic	80<TSI<100

In this study Carlson trophic index (Carlson, 1997) was used to determine the eutrophication state of the lake. The value of TSI is calculated using three quality parameters such as chla, TP (μg L^{-1}) and SD (m) based on Equation 1 to 3:

$$TSI_{(SD)} = 10\left(6 - \frac{\ln SD}{\ln 2}\right) \quad (1)$$

$$TSI_{(SP)} = 10\left(6 - \ln\frac{\frac{48}{TP}}{\ln 2}\right) \quad (2)$$

$$TSI_{(CI-a)} = 10\left(6 - \frac{2.04 - 0.69\ln(CI-a)}{\ln 2}\right) \quad (3)$$

The units of chl-a and TP concentration is μgl-1 and the unit of SD is m in these equations.

Total amount of TSI is the average of TSI (Chla), TSI (SD) and TSI (TP). The value of TSI varies between 1 and 100. Based on this index the trophic state of the lakes could be categorized to oligotrophic, mesotrophic, eutrophic and hypertrophic.

Also there are other classifications based on this value which categorizes a water body into seven classes (Ebrahimpour *et al.*, 2012; Yang *et al.*, 2012) in a more accurate classification (Table 2).

In this research chla concentration, SD and TP concentration were used to calculate the value of TSI at each individual sampling point for two seasons. The results of study are presented in results and discussion section.

Results and Discussion

After analysis of the samples, bar graphs of pH, SD, TP, TN, temperature and chla were plotted. These charts show changes in water quality parameters of Ecbatan reservoir at the sampling points both for January and July.

SD changes is presented in Fig. 3. SD has an inverse relationship with turbidity. Consequently, stations with a greater value of SD display less chla and turbidity at the measurement point. A comparison between SD values in January and July shows that this value has decreased in January. In other words the water is more turbid in January.

Variations of pH are shown in Fig. 4. This parameter varies between 6.2 and 7.6 at sampling points for both months. Figure 4 shows that the value of pH has increased in January. This is true for chla concentration as shown in Fig. 5. There is a big difference in the values of chla concentration for January and July. Figure 6 shows the variation of temperature at different sampling points.

Also Fig. 7 and 8 show the variation of TP and TN at sampling points respectively. The values of TP has increased in January at different sampling points. However TN values has decreased in some points. The ratio of N/P has declined for the majority of samples in this January (Fig. 9). This ratio has decreased mainly since water level of the reservoir has declined and the amount of TP is readily available in the reservoir in January. It is obvious that the limiting factor of eutrophication is TP in this lake.

Figure 10 shows the variations of TSI for January and July. After analysis of samples the value of TSI was determined based on three parameters of chla, TP and SD. The value of TSI for different sampling points varies between 35.7 and 50.7 in July. TSI values vary between 55.1 and 58.6 in January. Figure 9 shows this variation in different sampling points both for July and January.

Also radar graph of TSI values is shown in Fig. 11. This graph shows that 13 stations in Ecbatan reservoir are mild mesotrophic and two stations are mesotrophic (points 13 and 15) in July. Based on the average value of total TSI for the lake in July and January the state of the lake is mild mesotrophic and acute mesotrophic in July and January respectively. Although we expected more eutrophication in summer as environmental factors such as higher temperature, longer daytime and less rain increase the rate of eutrophication. Also stratification of this reservoir is completed in summer while in winter a complete circulation happens and no stratification happens in the reservoir (Weysi *et al.*, 2013).

The results show that the quality of water in reservoir has changed from mild mesotrophic in July to acute mesotrophic in January. On the contrary found that the quality of water in winter is more convenient (TSI = 46, mesotrophic) than summer (TSI = 53.7, acute mesotrophic).

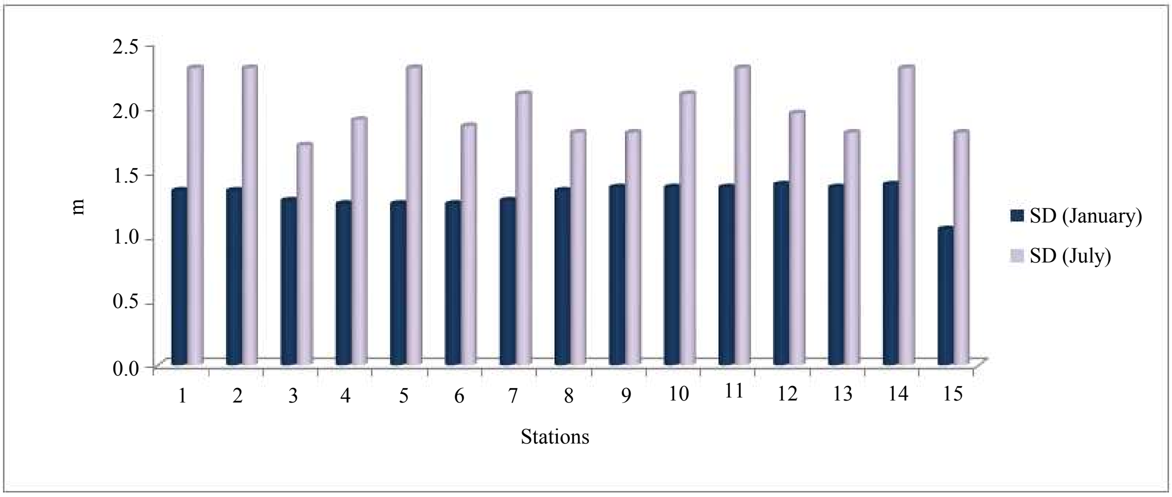

Fig. 3: SD variation at sampling points for January and July

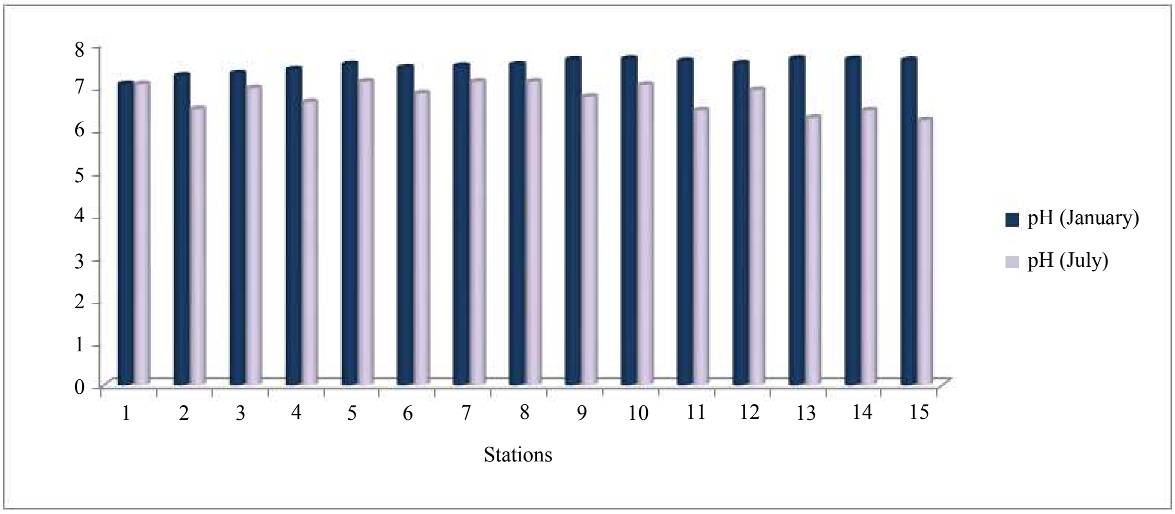

Fig. 4: pH variation at sampling points for January and July

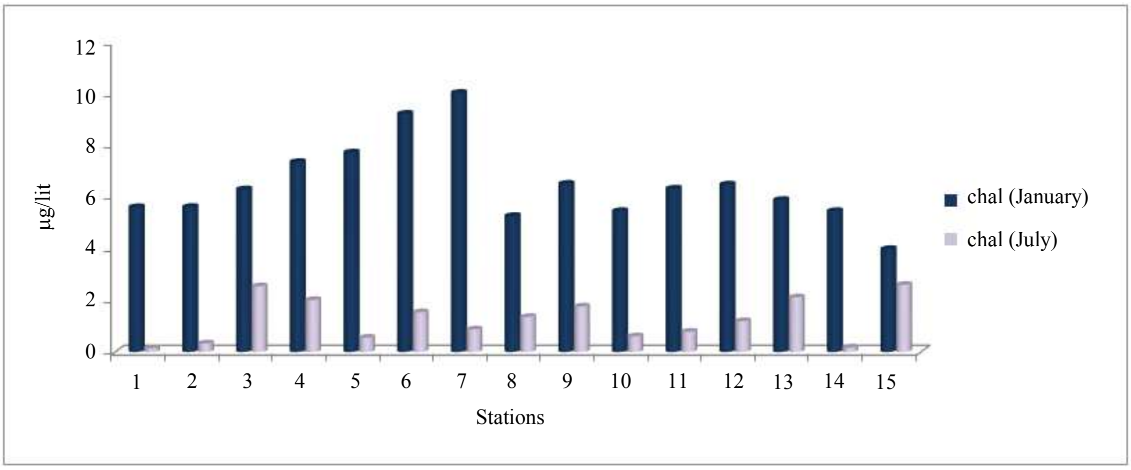

Fig. 5: Chla variation at sampling points for January and July

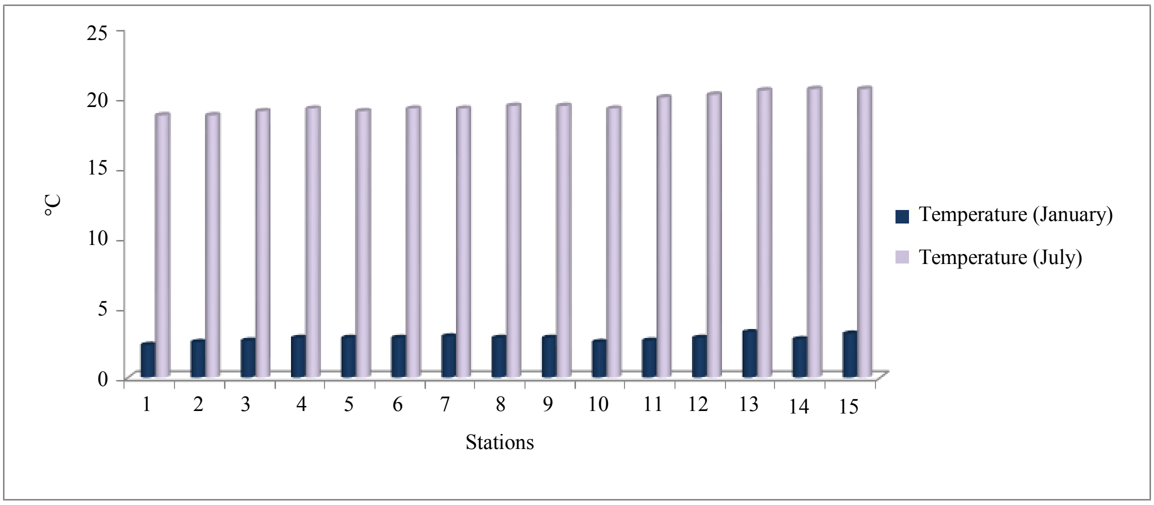

Fig. 6: Temperature variations at sampling points for January and July

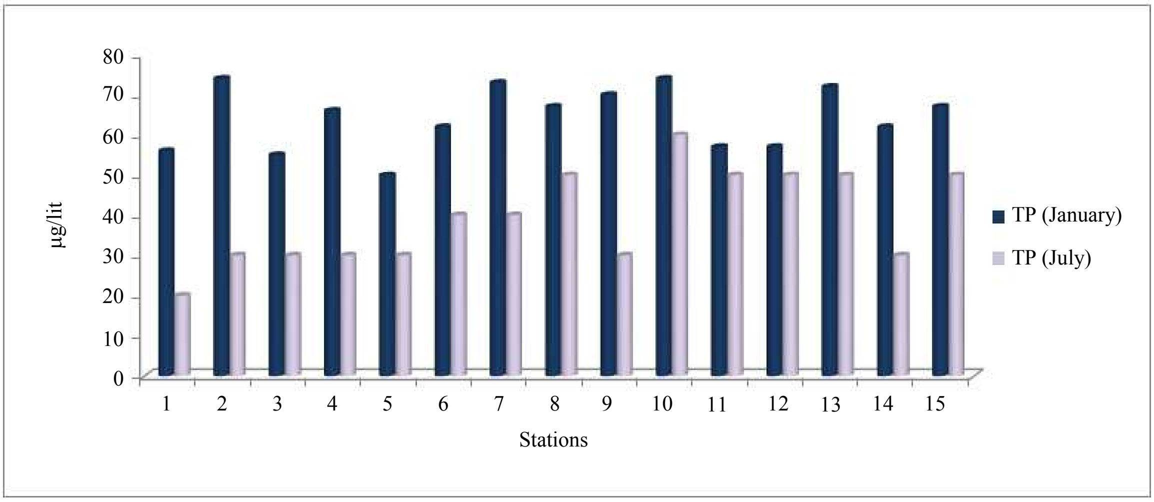

Fig. 7: TP variation at sampling points for January and July

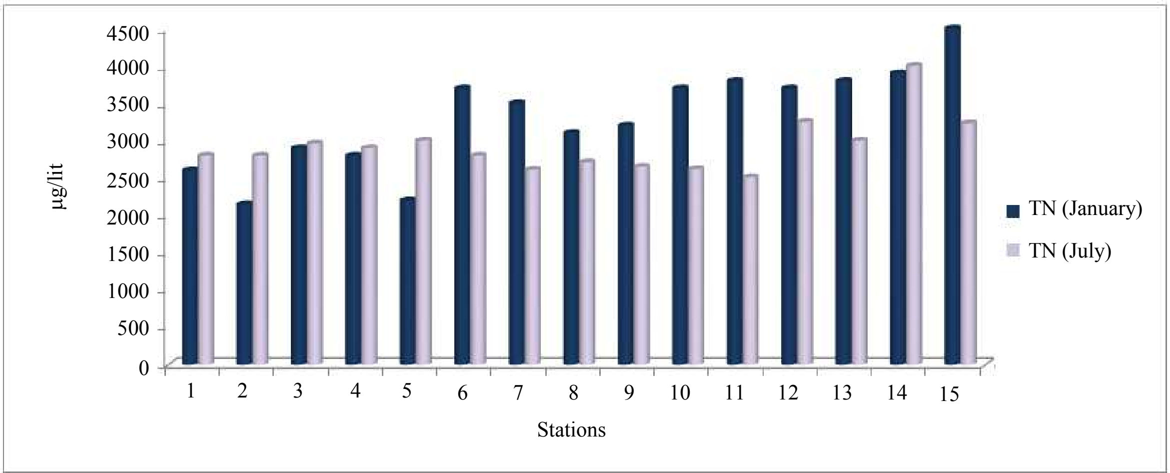

Fig. 8: TN variation at sampling points for January and July

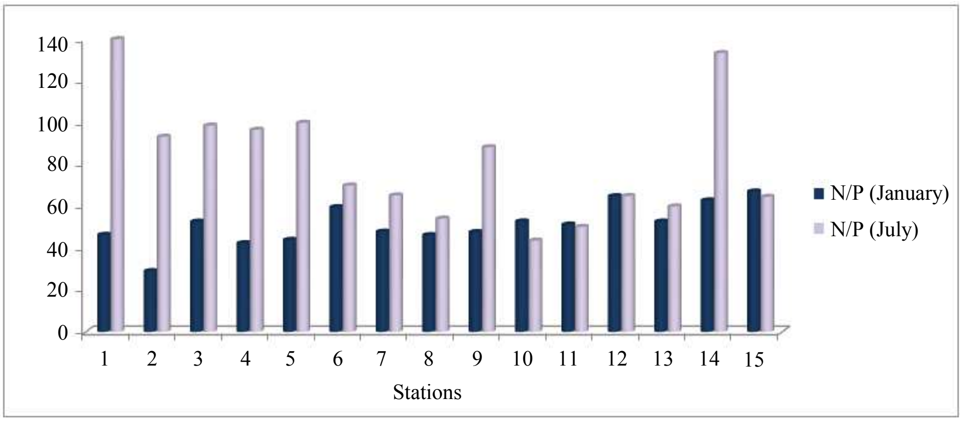

Fig. 9: Variation of N/P ration at sampling points for January and July

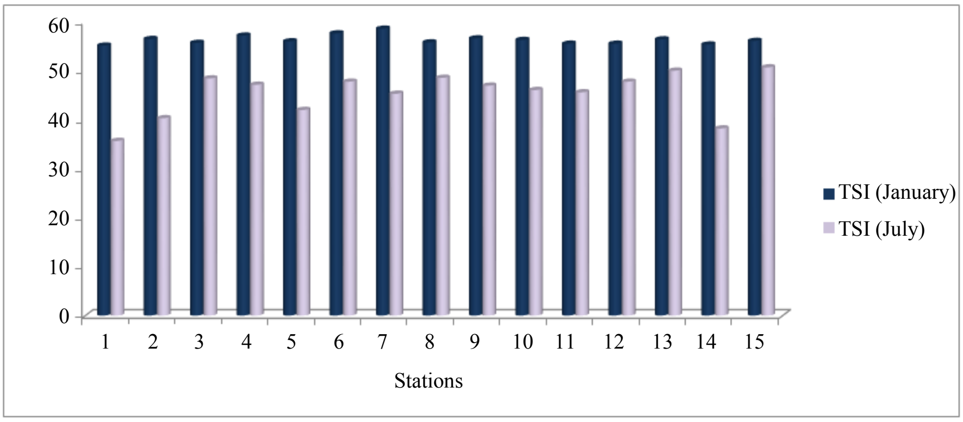

Fig. 10: Carlson index at sampling points for July and January

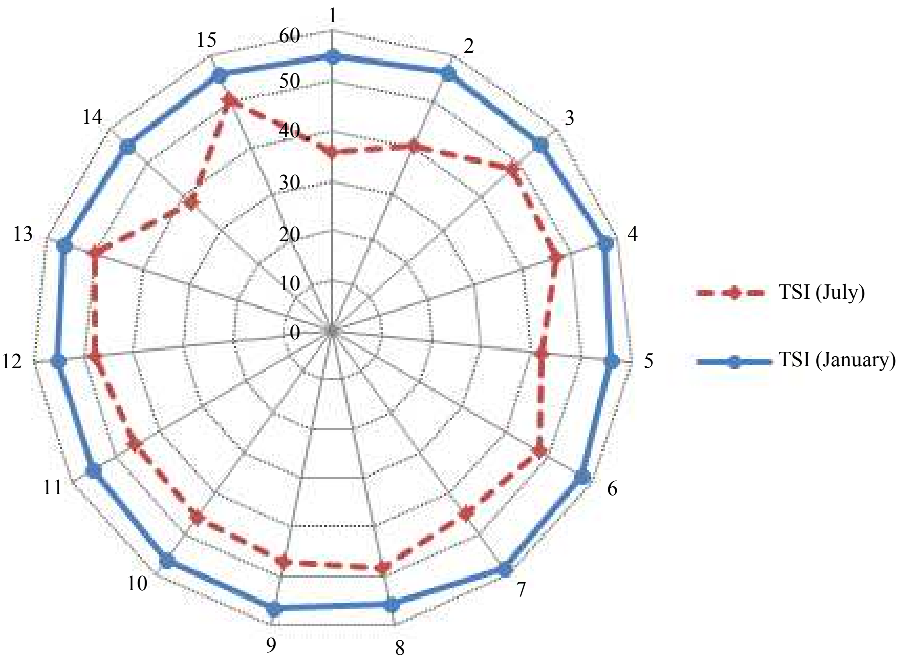

Fig. 11: Radar Graph of TSI values at sampling points in July and January

Therefore we referred to water volume of reservoir in summer and winter for both 2015 and 2010. The volume of water in reservoir was about 30 and 16.4 MCM in July, 2010 and January, 2011 respectively. The reservoir was in a normal year in 2010. Also the volume of water in the reservoir was 17.7 and 5.3 MCM in July, 2014 and January, 2015 which is a hydrological dry year.

Ecbatan reservoir receives a significant amount of sediment from upstream watershed and transparency of this water body is affected by suspended materials. Therefore Equation 1 might cause misleading results in determining the trophic class of reservoir. Cigagna *et al.* (2016) neglected the Equation 1 because the case study of their research was a reservoir affected by turbidity of suspended materials. Also Lorenzen (1980) proved that this equation doesn't show the net effect of algae and other suspended materials could influence this value .We modified the results by removing Eq. 1 and used Carlson's classification to determine the trophic state of the reservoir. Table 3 shows TSI values based on chla, TP and SD.

Besides if two indices show the same trophic class for the environment, the degree of limitation is normal. When TSI (chla) ranks the environment in a class higher than TSI (TP), the degree of limitation is low since the situation is convenient for phytoplankton productivity. On the contrary if the value of TSI (TP) ranks the environment in a higher class of eutrophication, the degree of limitation is high (Lamparelli, 2004).

In this study TSI (TP) value is higher than TSI (chla) both for dry and wet seasons indicating that the degree of limitation is high. Table 4 shows the range of TP, chla and TSI of Ecbatan reservoir for both seasons.

Also min, max and the average values of TSI for dry and wet seasons with/without considering TSI (SD) are shown in Table 5.

Trophic state of the reservoir varies between oligotrophic and mesotrophic for 15 stations in dry season neglecting TSI (SD) while it varies between mild mesotrophic and mesotrophic considering TSI (SD). Also for wet season no difference was observed for trophic state of the reservoir between the results of considering TSI (SD) and neglecting this value.

Table 3: Carlson classification of trophic state (Carlson, 1977)

TSI	SD (m)	Surface TP (µg/lit)	Surface chla (µg/lit)
0	64.000	0.75	0.04
10	32.000	1.50	0.12
20	16.000	3.00	0.34
30	8.000	6.00	0.94
40	4.000	12.00	2.60
50	2.000	24.00	6.40
60	1.000	48.00	20.00
70	0.500	96.00	56.00
80	0.250	192.00	154.00
90	0.120	384.00	427.00
100	0.062	768.00	1183.00

Table 4: The range of TP, chla and TSI for Ecbatan reservoir in January and July

	Wet season		Dry season	
	TP (µg/lit)	chla (µg/lit)	TP (µg/lit)	chla (µg/lit)
Min	50	4	20	0.1
Max	74	10	60	2.6
TSI	60-70	40-60	40-70	10-50

Table 5: TSI mean value for dry and wet seasons with/ without considering TSI (SD)

TSI		**With SD**	**Min**	**55.1**
			Max	58.6
			Average	56.3
	Wet Season	Without SD	Min	54.5
			Max	59.6
			Average	56.4
		With SD	Min	35.7
			Max	50.7
	Dry Season		Average	45.4
		Without SD	Min	29.5
			Max	50.3
			Average	43.1

Different factors such as nutrients entrance, the volume of water in the reservoir, precipitation and the amount of release from the reservoir affect the trophic state of a water body. The results of this study are in agreement with (Prasad and Siddaraju, 2012) that the trophic state of a reservoir might change from year to year and it can show significant changes from season to season. Also in some regions precipitation and water increase in a reservoir might deteriorate the state of eutrophication. Since more nutrients are carried to water bodies through surface streams (Cigagna *et al*., 2016).

Conclusion

Ecbatan reservoir is a resource of drinking and agriculture water for Hamedan city. This study investigated the trophic state of Ecbatan Dam Lake using Carlson index. In this study, 15 stations in the reservoir were identified and sampling from these points was carried out in July, 2014 and January, 2015.

The results of this study showed that Ecbatan reservoir has a serious problem of eutrophication. Trophic state of a lake from oligo-trophic to eutrophic or hypertrophic is a gradual progress. Consequently it is necessary to choose a period for monitoring the quality of reservoirs so that it covers the normal, wet and dry periods because the trophic state of a reservoir is a function of different environmental conditions and operational rules. Especially in a situation like Ecbatan reservoir where a high amount of sediment occupies a considerable volume of the lake and water level decline can increase the rate of eutrophication due to readily available P in the environment.

Due to the fact that drinking water supply in Hamadan is one of the objectives of Ecbatan reservoir, it is necessary to prevent water quality decline in reservoir using managerial strategies in the upstream of the basin.

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We thanks all participants and authors that cooperate in the presents study.

Author's Contributions

Maryam Ghashghaie and Mohammad Reza Serajian Maralan: Write manuscript and analyzed data.

Kaveh Ostad-Ali-Askari: Write manuscript and revise it.

Saeid Eslamian, Vijay P. Singh and Nicolas R. Dalezios: Design the study and revise manuscript.

Ethics

This study was approved by Water Resources Engineering Department, Faculty of Agriculture, Bu-Ali Sina University, Hamedan, 6517833131, Iran.

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