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Assessment of water quality and trophic state in Sooriyawewa reservoir in the Southern province of Sri Lanka

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Abstract Trophic state of a reservoir is one of the important factors in limnological perspective in order to understand its healthiness. This study was focused to understand the dynamics of trophic state and water quality in Sooriyawewa reservoir in the Southern province of Sri Lanka. Water quality was evaluated in six sampling sites from August 2014 to March 2015 using standard methods. Significant temporal variation ($p<0.05$) was observed for chlorophyll-a (14.63±14.2 mg L^{-1}), NO_3^- (2.77±1.4 mg L^{-1}), PO_4^{3-}(0.21±0.1 mg L^{-1}), total suspended solids (15.24±10 mgL^{-1}), conductivity (253.75±86.2 μScm^{-1}) and temperature (29.90±0.5°C). PO_4^{3-}, NO_3^- and chlorophyll-a concentrations showed their highest levels in September, October and November respectively. Water Quality Index (WQI) values ranged from 11.62 (December) to 22.78 (November, January, February, March) indicating very poor water quality. The Trophic State Index (TSI) changed from slightly eutrophic to hyper-eutrophic status in October and November respectively coinciding higher chlorophyll-a concentration. Results showed that Sooriyawewa reservoir is not suitable to be used as a drinking water source under conventional treatment and continuous monitoring of water quality parameters should be carried out.

Keywords: trophic state, eutrophication, physic-chemical parameters, chlorophyll-a

INTRODUCTION

Water quality of a reservoir is an important factor due to increased threat of drinking water quality around the world in addition to water scarcity and poor water distribution (Alves et al. 2014). Moreover, increasing industrial pollution, increased demand for water by agriculture and industry, coupled with poor management or a lack of management of water resources deteriorates the water quality (Kharraz et al. 2012). To ensure the quality of drinking water for the public, its suitability for consumption has to be evaluated. Deterioration of the water quality can be identified by the various physcio-chemical parameters such as sediment load, nutrient concentrations, temperature, dissolved oxygen levels, pH and other biological parameters (Swamee and Tyagi 2007). Based on those parameters various indices have been developed (Lumb et al. 2011) and the commonly-used index is water quality index (WQI) that was developed by the National Sanitation Foundation (NSF) in USA (Brown et al. 1970).

Trophic state of a lake/reservoir is a paramount factor that indicates its healthiness, quality and well-being. Carlson (1977) defined the trophic states as “total weight of living biological material (biomass) in a water body at a specific location and time.” As a tool it provides multitudinous support over the management of existing ecosystems. Dodds (2007) stated that the trophic state is the foundation of community integrity and ecosystem function in a lake/reservoir. Trophic state indices (TSI) developed by various authors give a comprehensive idea about the trophic state of a water body (Sharma et al. 2010). The primary importance of the trophic state is to understand how nutrients can be linked to trophic state and how trophic state could reflect system properties that are of interest with respect to ecosystem services (Dodds 2007).

TSI is not a single dimensional index over the water quality of a reservoir since there is no single variable can represent the whole trophic state in a reservoir (Sharma et al. 2010) and it is recommended to use of an array of different methods to estimate it (ARC 2005). However, the most common and widely used method for estimation of the trophic state of a lake is productivity (Murthy et al. 2008). The trophic status refers to the level of productivity in a water body as measured by phosphorous, algae abundance and depth of light penetration (Carlson 1981).

TSI rates individual lakes, ponds and reservoirs based on the amount of biological productivity occurring in the water and it can be used to get a quick idea about the extent of productivity of the water (Hillsborough 2008). The trophic states of lakes can broadly be divided into major segments including oligotrophic, mesotrophic and eutrophic where the trophic states are gradually increasing respectively (Carlson 1977).

Trophic level of a water body indicates the response of the biological community to the forcing factors such as nutrient additions (Naumann 1931). However, the effect of nutrients is changing with different factors such as seasons, grazing and mixing depth (Sharma et al. 2010). Determination of trophic state index is important to identify current status of water bodies and according to that management and conservation strategies can be applied for prolong utilization of water bodies such as to predict fish yield in lakes and reservoirs. Jayasinghe et al. (2005) have made attempt to classify Sri Lankan non-perennial reservoirs based on trophic state to determine suitability of the reservoir for culture-based fisheries development. The excessive input of sediments from catchment area, industrial waste and sewage disposal, nutrient enriched runoff from agricultural lands and forestry, issues regarding storm water management practices, overfishing, recreation, encroachments and climate change are some factors that result in negative effects on reservoir ecosystems.

Sri Lanka bears a large number of man-made reservoirs, tanks accounting for about 3% of its total land area. There are two major types of reservoirs in the country, namely the seasonal and perennial reservoirs. They are also classified as major, medium and minor scale reservoirs based on the area and water capacity. This innumerable water resource of the country is currently being used for agriculture, hydropower generation, public water supplying, inland capture fisheries and culture-based fisheries. Therefore, it is essential to determine the level of pollution and trophic status of the water bodies to implement management and conservation strategies for enhancing their healthiness.

MATERIALS AND METHODS

Sooriyawewa reservoir (6°30'8.04" N; 81°1'0.12" E) located in Hambantota district was selected for study which was carried out during the period of August 2014 to March 2015. The main irrigation canal arising from the reservoir is Beddewewa Atu Ela and major stream inlets are Habaragala Ara and Mahakadawala Ara. The maximum width is 2.58 km and maximum depth is 53.7 m at the sluice. Its dam is 0.98 km in length and its maximum capacity is about 1.47×10^5 m^3. Six sampling sites were selected for the study (Figure 1). Water samples were collected from three different depths (surface, middle and bottom) at the six sites using the Ruttner sampler on monthly basis. Selected parameters were measured based on the recommended methods summarized (Table 1).

One-way ANOVA was performed to analyze the temporal variations of water quality parameters. Pearson`s correlation coefficient was determined between the water quality parameters. All the statistical analyses were performed using SPSS 16.0 software package and spread sheets of Microsoft Office 2007.

WQI is a commonly used measure of water quality that was developed by the National Sanitation Foundation (NSF) in United States in 1970 (Brown et al. 1970). Ten common water quality parameters [ortho-phosphate, ammonia concentration, total oxidized nitrogen, biochemical oxygen demand (BOD_3), total suspended solids (TSS), temperature, dissolved oxygen (%), pH, conductivity and *E-coli*] and their respective rates for each parameter were used for WQI calculation using the following equation (Brown et al. 1970).

$$\text{WQI}=\frac{\Sigma(\text{Water quality ratings})^2}{100}$$

If there was any missing parameter due to unavoidable reasons, the following equation was used (Brown et al. 1970).

$$\text{WQI}=\sum\frac{\text{Water quality rating x}100}{100-\sum\text{minimum rating of absent parameters}}\text{x}\frac{1}{100}$$

According to National Sanitation Foundation (NSF) grading system, the water quality was determined (Table 2).

Carlson's TSI is widely used measure of eutrophication of the water body. Water transparency (Secchi depth or SD in metres), chlorophyll-a (Chl-a in μgL^{-1}) and phosphate concentration (TP in μgL^{-1}) are basic factors that are considered under this index.

Different components of the TSI were calculated using the following equations (Brown and Simpson 2012).

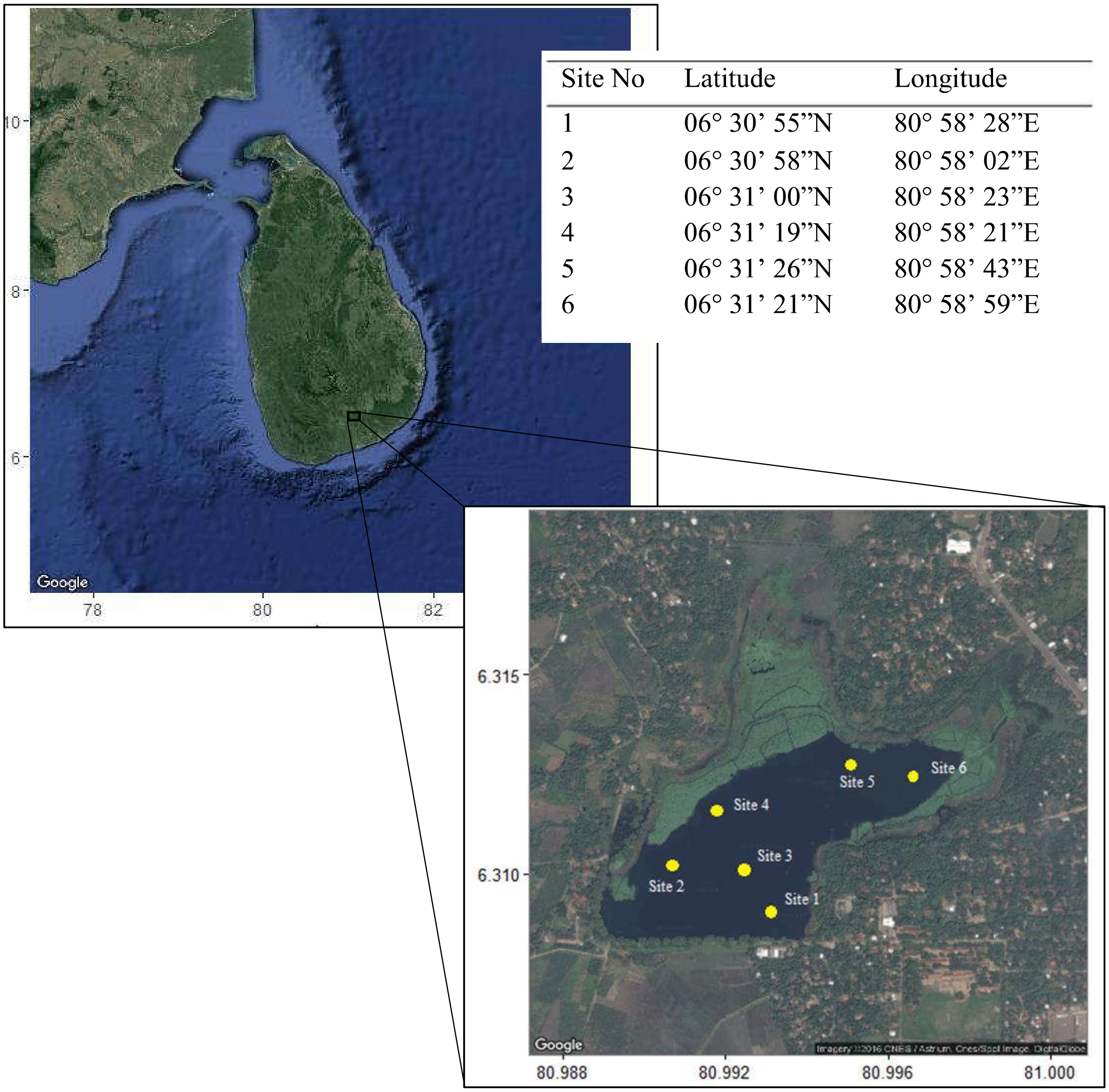
$\mathrm{TSI(TP)} = 14.42 \,\mathrm{Ln}\, [\mathrm{TP}]+4.15$

$\mathrm{TSI(Chl\text{-}a)} = 30.6 + 9.81 \,\mathrm{Ln}\, [\mathrm{Chl\text{-}a}]$

$\mathrm{TSI(SD)} = 60 - 14.41 \,\mathrm{Ln}\, [\mathrm{SD}]$

$\mathrm{CTSI} = \frac{1}{3}[\mathrm{TSI\ (TP)}+\mathrm{TSI\ (Chl\text{-}a)}+\mathrm{TSI\ (SD)}]$

where TSI is Trophic State Index and CTSI is Carlson's Trophic State Index. CTSI is regarded as the most representative index in the classification of water quality.



Site No	Latitude	Longitude
1	06° 30' 55"N	80° 58' 28"E
2	06° 30' 58"N	80° 58' 02"E
3	06° 31' 00"N	80° 58' 23"E
4	06° 31' 19"N	80° 58' 21"E
5	06° 31' 26"N	80° 58' 43"E
6	06° 31' 21"N	80° 58' 59"E

Fig. 1 Locations of the sampling sites in Sooriyawewa reservoir

Table 1 The methods applied to determine the water quality parameters

Parameter	Analyzing method
pH	pH meter (AD111 pH/ mV/°C meter)
Temperature	Water quality meter (Model: YSI 85, Geo Scientific Ltd, Canada)
Dissolved Oxygen	Water quality meter (Model: YSI 85, Geo Scientific Ltd, Canada)
% Dissolved Oxygen	Water quality meter (Model: YSI 85, Geo Scientific Ltd, Canada)
Conductivity	Water quality meter (Model: YSI 85, Geo Scientific Ltd, Canada)
Total Dissolved Solids	Gravimetric method (APHA 2012)
NO_3^-	Spectrophotometric method (APHA 2012)
PO_4^{3-}	Spectrophotometric method (APHA 2012)
Secchi depth	Secchi disc
Chlorophyll content	Spectrophotometric method (APHA 2012)

The Burns model is dependent on total phosphorus concentrations (TP), total nitrogen concentration (TN), total chlorophyll-a concentrations (Chl-a), and Secchi depth (SD). The model is comprised of a series of empirical equations that can be used to calculate a value for Total Trophic Status Index (TTSI) (Burns et al. 1999). Trophic state of reservoir was calculated as follows:

$$TS(P) = 0.218+2.92 \log (\text{TP in ppb})$$
$$TS(N) = -3.61+3.01 \log (\text{TN in ppb})$$
$$TS(S) = 5.10+2.60 \log (1/SD-1/40)$$
$$TS(\text{Chl-a}) = 2.22\ 2.54 \log (\text{Chl-a in ppb})$$
$$TTSI = \tfrac{1}{4} [TS(P)+TS(N)+TS(S)+TS(\text{Chl-a})]$$

Classification criteria for water quality based on CTSI and TTSI are given in Table 3.

Table 2 Water quality classification criteria based on water quality index (WQI) (Brown et al. 1970)

WQI value	Water quality
90-100	Excellent
70-90	Good
50-70	Medium
25-50	Bad
0-25	Very bad

Table 3 The classification of TSI according to Carlson's Trophic State Index (CTSI) and Total Trophic Status Index (TTSI)

Classification	CTSI	TTSI
Strongly Oligotrophic	$TSI<27$	$TSI<2.0$
Oligotrophic	$27\leq TSI>33$	$2.0 \leq TSI <2.7$
Slightly Oligotrophic	$33\leq TSI <38$	$2.7\leq TSI< 3$
Slightly Mesotrophic	$38\leq TSI<43$	$3.0 <TSI \leq 3.3$
Mesotrophic	$43\leq TSI <49$	$3.3 <TSI \leq 3.7$
Strongly Mesotrophic	$49\leq TSI <54$	$3.7 <TSI \leq 4.0$
Slightly Eutrophic	$54 \leq TSI <58$	$4.0 \leq TSI < 4.5$
Eutrophic	$58\leq TSI >62$	$4.5 \leq TSI <5.0$
Strongly Eutrophic	$62 \leq TSI < 65$	$5.0 \leq TSI < 5.5$
Slightly hyper Eutrophic	$65\leq TSI <70$	$5.5 \leq TSI< 6$
Hyper Eutrophic	$70\leq TSI$	$6.0<TSI$

RESULTS AND DISCUSSION

Significant temporal variation of chlorophyll-a concentration was observed and highest chlorophyll-a concentration was recorded in November. The highest Secchi depth (71.1 cm) was observed in August 2014 while the lowest chlorophyll-a concentration was recorded in the same month (1.48 mgL^{-1}). Lee and Jones-Lee (N.D.) also indicated that Secchi depth is inversely related with the phytoplankton biomass. Jayasinghe et al. (2005) reported mean Chl-a concentration in 14 non-perennial reservoirs in Hambantota district ranged as 86.6±31.7–3.45±0.9 mgL^{-1} and the lower limit of the range represented Chl-a values in the present study. The dissolved organic matter concentration in productive waters is high and in addition, the algae and submerged angiosperms secrete large quantities of organic compounds during photosynthesis, senescence and lysis (Wetzel 2001). The increment of PO_4^{3-} and NO_3^- levels and reduction of Secchi depth are used as an indication of poor water quality by different authors (Trivedi and Goel 1986). However, TP of some reservoirs in Hambantota district, Sri Lanka reported by Jayasinghe et al. (2005) were comparatively higher (579.1±26.5–207.9±28 mgL^{-1}) than the observed values in Sooriyawewa reservoir.

The lowest NO_3^- concentration (1.68 mgL^{-1}) was recorded in January 2015 while the highest concentration (5.04 mgL^{-1}) was recorded in October 2014. The significant temporal variation of PO_4^{3-} concentration was also recorded with the highest value (1.60 mgL^{-1}) in September 2014. The TSS also varied significantly with the highest value (47 mgL^{-1}) in February 2015 and the lowest value was in November 2014 (4.50 mgL^{-1}). The lowest and the highest conductivity values were observed in December and March respectively. Table 4 gives the means of surface, middle and bottom values of physicochemical parameters.

The water quality index (WQI) values for the eight months with the rating values are given in Table 5 and these indicated very bad water quality. While WQI based on physico-chemical parameters showed that Sooriyawewa reservoir is a polluted water body, Chironomidae larva which is a biological indicator for organic pollution was also observed in the bottom substrate of the reservoir at a density of 1 x 10^4 m^{-2} (Figure 2). These Chironomidae larvae are used by different authors as indicators of poor water quality (Saether and McLean 1972; Saether 1979). These biological indicators are also necessary for total evaluation of a water body. They give information which may not be obtained by merely chemical methods even approximately (Saether 1979). The trees on the bank of the reservoir are roosting places for large number of bats and their fecal matter provides large amount of organic matter on the bottom which results in increased organic pollution. This allochthonous organic matter provides a nutrient enriched environment and other animal species such as fruit bats and birds including cormorants may deteriorate the water quality further (Silva 2007; Gunaratne et al. 2015).

Table 4 Mean ± SD of physcio-chemical parameters in Sooriyawewa reservoir from August 2014 to March 2015

Parameter	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Chlorophyll (mgL^{-1})	1.48 ± 1.56^{a}	4.45 ± 3.86^{a}	4.02 ± 1.44^{a}	45.18 ± 7.83^{b}	11.84 ± 4.94^{a}	9.15 ± 1.14^{a}	20.72 ± 1.86^{b}	20.27 ± 1.22^{b}
NO_3^- (mgL^{-1})	3.36 ± 0.58^{b}	3.90 ± 1.76^{b}	4.93 ± 1.56^{b}	2.67 ± 0.21^{b}	3.51 ± 2.20^{b}	1.68 ± 0.82^{a}	1.05 ± 1.32^{a}	1.08 ± 1.41^{a}
PO_4^{3-} (mgL^{-1})	0.17 ± 0.16^{a}	0.53 ± 0.59^{b}	0.04 ± 0.01^{a}	0.15 ± 0.01^{a}	0.40 ± 0.39^{b}	0.33 ± 0.72^{b}	0.06 ± 0.01^{a}	0.04 ± 0.06^{a}
TSS (mgL^{-1})	13.16 ± 12.70^{ab}	8.16 ± 6.08^{a}	12.33 ± 12.56^{ab}	4.50 ± 4.22^{a}	6.00 ± 4.42^{a}	18.33 ± 8.31^{abc}	32.00 ± 10.86^{c}	27.50 ± 14.08^{bc}
BOD_3 (mgL^{-1})	3.97±1.33	3.25±1.41	2.80±2.40	1.71±2.88	5.37±1.61	3.97±1.33	3.20±0.79	3.14±0.81
Temperature (°C)	29.4 ± 0.2^{ab}	30.2 ± 2.5^{ab}	30.0 ± 0.9^{ab}	30.0 ± 0.7^{ab}	30.1 ± 2.5^{ab}	28.9 ± 0.9^{a}	30.2 ± 1.3^{ab}	30.5 ± 1.3^{b}
Conductivity (μScm^{-1})	283.4 ± 2.8^{c}	186.2 ± 12.2^{b}	263.2 ± 10.4^{c}	157.7 ± 11.2^{b}	129.7 ± 25.7^{b}	306.5 ± 18.3^{c}	353.3 ± 12.1^{a}	350.1 ± 5.1^{a}

In each row values with different superscript letters are significantly varied among the columns ($p<0.05$), the rows without superscript letters are also significantly varied.

Table 5 Monthly variation of the rating values and WQI in Sooriyawewa reservoir from August 2014 to March 2015. As WQI was less than 25 (see Table 2), water quality was very bad throughout the study period.

Month	Rating for NO_3^-	Rating for PO_4^{-3}	Rating for NH_3 (absent)	Rating for TSS	Rating for BOD	Rating for conductivity	Rating for pH (absent)	Rating for temperature	Rating for *E. coli* (absent)	Sum of present parameters	Sum of absent parameters	WQI
Aug	5	5	12	6	10	6	0	3	12	35	24	21.21
Sep	4	0	12	7	11	6	0	2	12	30	24	15.58
Oct	3	7	12	6	12	6	0	2	12	36	24	22.43
Nov	5	4	12	7	14	6	0	2	12	38	24	25.0
Dec	4	0	12	7	7	6	0	2	12	26	24	11.7
Jan	6	1	12	5	10	6	0	3	12	31	24	16.64
Feb	7	6	12	3	11	6	0	2	12	35	24	21.21
Mar	7	7	12	4	11	6	0	2	12	31	24	16.64

Fig. 2 Chironomidae larvae at the bottom of the tank near raw water pumping point of Sooriyawewa water treatment plant (growing on 25 cm^2 asbestos sheet during one-month period)

According to the Carlson trophic state index Sooriyawewa was eutrophic in August 2014, February 2015 and March 2015 and hyper eutrophic in November 2014 (Table 6). Carlson trophic state index, based on total phosphorus [TSI (TP)] was higher in September and December 2014 than in other months (Table 6). The lowest TSI (TP) was recorded in January 2015. The mean values of TSI (TP) of some reservoirs in Hambantota district have been reported as the range between 95±3-80±2 indicating hyper eutrophic condition due to non-algal turbidity (Jayasinghe et al. 2005). TSI (Chl-a) was highest in the November 2014 with the lowest values of TSS and BOD_3 and it was lowest in August 2014 (Table 6) at the eutrophic condition. Silva (2007) explained that the progressive increase in Chl-a content with decrease of water clarity in Kandy lake from 1994 to 2004. Use of TSI (Chl-a) for the classification of trophic status in reservoirs of Sri Lanka was suggested to be more reliable especially for the purpose of development of culture based fisheries (Jayasinghe et al. 2005).

Burn's trophic state model also showed the variability of key components of trophic state index during the study period (Table 7). TSI based on total phosphorus content [(TSI (TP)] was similar to that of Carlson model where the peak value was recorded in September 2014. TSI (SD) showed symmetrical distribution during the study period. NO_3^- concentration is a factor considered only for Burn's model and a symmetrical distribution of TSI could be seen for TSI (TN) (Table 7).

The temporal variation of the eutrophication status in Sooriyawewa reservoir can be explained by the two models. However, ordinary temporal variability is familiar to any lake with recurring seasonal patterns and short-term responses to storm (Knowlton and Jones 2006) and these temporal variations are needed to invoke or interpret lake management practices.

Major stream inlets to the reservoir included Habaragala Ara, Mahakadawala Ara and Urusita wewa. All these are associated with large number of agricultural lands and therefore the highest TSI (TP) value was recorded in September 2014 during the Maha agricultural season (August-October). Increased amount of total phosphorous level and consequently increased TSI (TP) was also shown by Zaimes and Schutlz (2002). Izumi and Ranatunga (1974) have shown that in the Maha season, farmers use comparatively higher amount of phosphorus rich fertilizers which give high yields of paddy. The phosphate level peaked in September and in the following month nitrate level peaked. The highest chlorophyll-a level was observed in November. Due to the reduction of phosphate and nitrate in December and January, chlorophyll-a concentration reduced (Table 4). It is a fact that although both phosphate and nitrate act as major nutrients for phytoplankton growth in aquatic ecosystems, generally TP has higher correlation with Chl-a than TN especially in eutrophic freshwater lentic ecosystems (Wetzel 2001; Lv et al. 2011).

CONCLUSION

The temporal variation of eutrophic condition in Sooriyawawa reservoir was observed during the study period. It became hyper eutrophic in September, November, and December according to the Burn's model. Similarly, highest trophic condition was shown in the same three months according to Carlson model. Since the WQI indicated very bad water quality throughout the study period of eight months it is fair to recommend not to use this reservoir as a water source for drinking. Water treatment plant in Sooriyawewa is of conventional treatment plant type. If it is continued to be used as a water source in future, granular activated carbon filters have to be used after rapid sand filters.

Table 6 Carlson Trophic State Index (CTSI) of Sooriyawewa reservoir from August 2014 to March 2015. TSI – Trophic state index; TP – Total phosphorous; SD – Secchi depth; Chl-a – Chlorophyll-a

CTSI value	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
TSI (TP)	78.45	94.86	58.51	77.13	90.68	54.59	63.42	64.42
TSI (SD)	71.05	67.51	66.58	67.01	58.65	62.54	60.28	61.43
TSI (Chl-a)	34.44	45.26	44.24	67.98	54.84	52.31	60.33	60.11
CTSI	61.31	69.21	56.44	70.70	68.05	56.48	61.34	61.98
Trophic State	Eutrophic	Slightly hyper eutrophic	Slightly eutrophic	Hyper eutrophic	Slightly hyper eutrophic	Slightly eutrophic	Eutrophic	Eutrophic

Table 7 Burns Trophic State Index (TTSI) of Sooriyawewa reservoir August 2014 to March 2015. TSI – Trophic state index; TP – Total phosphorous; SD – Secchi depth; Chl-a – Chlorophyll-a; TN – Total nitrogen

TSI value	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
TSI of TP	6.75	8.19	4.99	6.63	7.82	4.65	5.44	5.51
TSI of SD	5.97	5.68	5.60	5.64	4.96	5.27	5.09	5.18
TSI of Chl-a	2.65	3.86	3.75	6.42	4.94	4.98	5.56	4.93
TSI of TN	7.01	7.20	7.06	6.70	7.06	6.10	5.58	5.53
TTSI	5.59	6.23	5.35	6.34	6.19	5.25	5.41	5.28
Trophic State	Slightly hyper eutrophic	Hyper eutrophic	Strongly eutrophic	Hyper eutrophic	Hyper eutrophic	Strongly eutrophic	Strongly eutrophic	Strongly eutrophic

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