Spatial and Temporal Variation of Physico-chemical Parameters and Primary Productivity in Muruthawela Reservoir, Sri Lanka

H.C.C. De Silva[1*], R.A. Maithreepala[2], H.B. Asanthi[3] and T.Priyadarshana[4]

[1]Department of Limnology, Faculty of Fisheries and Marine Sciences & Technology, University of Ruhuna Matara, Sri Lanka

[2]Department of Limnology, Faculty of Fisheries and Marine Sciences & Technology, University of Ruhuna Matara, Sri Lanka

[3]Department of Limnology, Faculty of Fisheries and Marine Sciences & Technology, University of Ruhuna Matara, Sri Lanka

[4]Department of Limnology, Faculty of Fisheries and Marine Sciences & Technology, University of Ruhuna Matara, Sri Lanka

Corresponding author's email: chandanichalanika [AT] yahoo.com

---

ABSTRACT---- ***Variation of primary productivity in Muruthawela reservoir, a tropical deeper reservoir in lowland of Southern Sri Lanka was determined along the water column in three representative locations throughout one year period. The obtained results were interpreted in relation to the selected environmental conditions including, water depth, secchi depth, water temperature, pH, conductivity, salinity, dissolved oxygen, chlorophyll-a, nitrate and phosphate concentrations. Although, mean water depthwas ranged from 7.16-23.58m during the study period, the secchi depth and euphotic depth were determined as 2m and 4m respectively.The average value of primary productivity were in the ascending order of bottom<surface<middle with 65% of themaximum surface photo-inhibition in December 2012.There were no significant differences ($p > 0.05$) of physico-chemical parametersof each position (surface, middle, aphotic zone) among the three sites.However, significant Pearson correlations were observed between chlorophyll-a, nitrate and phosphate concentrations and conductivity in the reservoir. The maximum mean Gross primary productivity ($1.512 \pm 0.004 mgCL^{-1}h^{-1}$) was recorded in December, 2012 along with the maximum nitrate (0.161mg/L) and phosphate(0.145mg/L) concentrations. The mean Gross Primary Production (GPP) values showed a significant positive correlations between nitrate concentration ($R = 0.84; p < 0.01$), phosphate concentration ($R= 0.87; p< 0.01$), chlorophyll-a concentration ($R= 0.93; p< 0.01$) and Secchi depth ($R= 0.75; p< 0.01$) and it was negativelycorrelated ($R=-0.80; p < 0.01$) with conductivity. The year round variation of primary productivity coincided with the general rainfall pattern which can be caused nutrient runoff from the cultivated catchment in to the reservoir. Further, the progression of trophic state in Muruthawela reservoir has been occurred from Mesotrophic to Eutrophic state as a gradual process. This conversion from one stage to another has been mainly based on the degree of nutrient inflow which triggers by the seasonal variation of rainfall in the study area and ultimately primary productivity of the reservoir.***

Keywords---- Tropical reservoirs, Primary productivity, Nutrients, Rainfall

---

1. INTRODUCTION

Primary productivity or photosynthetic productivity mainly describes the dynamics of fulfilling the photosynthetically available solar radiation in tropical aquatic ecosystems such as reservoirs[1]. It is one of the highly dynamic parameter which contingent on several interconnected physical, chemical and biological factors. In addition, the size of the watershed, reservoir basin morphology, nature and volume of freshwater inflow and the food web structure are also considerable factors [2]. Primary productivity can be used as the index of trophic status and the potential for fishery resources along with chlorophyll content [3]. As a result of the interactions among the physical, chemical and biological parameters, the aquatic environment is subjected to high temporal and spatial variability of primary productivity[4].

Some researchers have found that, light and the nutrient availability are the two main productivity controlling factors[6]. Also, the morphology of reservoirs including area, volume, maximum and average depth are correlated with nutrient cycling, while water chemistry is another important factor of controlling primary productivity [7]. Moreover, reservoir catchment and the catchment land use pattern have an indispensable effect on the nutrient input [8].It has been found that, the abundance and density of phytoplankton is the major factor that controls the productivity along with other environmental variables such as, water depth, euphotic zone depth, atmospheric light, temperature and nutrients such as nitrates and phosphates [9]

Although, Sri Lanka has no natural lakes, it has 103 river basins lagoons, tidal flats, mangrove swamps, saline marshes and estuaries cover an area of approximately 1 800 km^2, and man-made freshwater lakes (reservoirs), and perennial or seasonal tanks cover another 1500 km^2[3]. Most of the reservoirs in the dry zone have been primarily constructed in order to reserve the water for the irrigation of paddy and other cultivations.Later on they are becoming the vital sources for culture based capture fishery and distribution of drinking water. Therefore, it is important to study the spatial and temporal variations of primary productivity for understanding thewater quality and the fishery production of the reservoirs[10]. Long-term monitoring of chlorophyll content or the primary productivityhas been carried out only in a few perennial reservoirs in Sri Lanka [11]. Severalstudies have been conducted to investigate theproductivity in Sri Lankan reservoirs including, Tissawewa[12],Prakramasamudraya[13] and the set of perennial irrigation reservoirs [14]. However, Muruthawela reservoir which is located in southern part of the Sri Lanka is not yet to be studied which uses for culture based capture fishery with annual production of 274 Mt and for irrigation and as a source for drinking water supply for around 150 families.

Muruthawela is a relatively deep, man-made reservoir was built with the aim of reducing the water shortage in the cascade system in 1970s. The shore area and the island of the reservoir arebeing used by people foragriculture and live stocks rearing. However, antecedent information reveals that the fish catch is decreasing in the reservoir.Therefore, the objective of the present study was to observe the temporal and spatial variation of primary productivity and the physicochemical parameters in Muruthawela reservoir to predict the variation of fishery production.

2. MATERIALS AND METHODS

2.1. Site description

Muruthawela Reservoir (06° 12' 57.0" N, 080° 43' 32.9"E) is located 10.4 km away from Weeraketiya town in Hambantota district.The average annual rainfall was1000mmfor the period from 1990 to 2010 (data from national Meteorological department, Sri Lanka). The surface area is around 627ha and the maximum and mean depths are 22m and 15m respectively[15].Three sampling sites were selected randomly representing the open water zone of the reservoir during the period of October 2012 to September 2013(**Figure 1**).

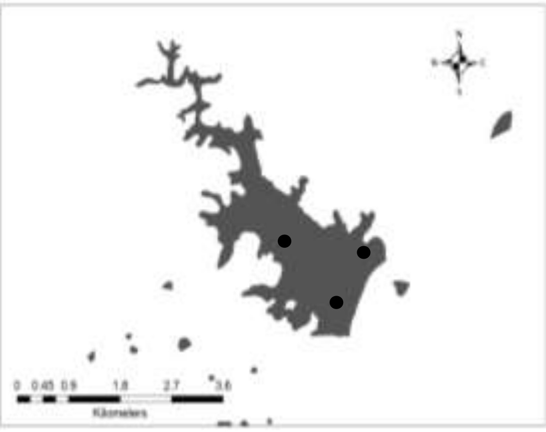

Figure 1: Site map of the study area

2.2. Determination of physico–chemical parameters

Light penetration in water was determined using a standard Secchi disc (diameter, 25 cm), and the depth of the Euphotic zone was calculated by multiplying the secchi depth by a factor of 2.5 to determine the interface between Euphotic and Aphotic zone. Then thewater samples were collected fromsurface (0m), euphotic zone(2m) and aphotic zone(4m) ateach sampling station. Depth was measured by a digital depth gauge(HONDEX-PS-50C 45776, Japan/m). Physico-chemical parameters such as water temperature (Thermometer/^{0}C), pH (AD111 pH/mV/^{0}C Portable Meter), Dissolved Oxygen; mg/L, saturated oxygen; %, salinity; ppt and conductivity; µS/cm (Water quality meter YSI 85, Japan), nitrate and phosphate concentrations (Portable UV spectrophotometer HATCH DR 2800/ mgL^{-1}) were measured. Water samples were filtered atthe field through glass fiber filters (GF/C; pore size 45µm), using a hand – held filterfor the estimation of chlorophyll-a concentration. The filter paper with chlorophyll were kept in opaquevials and stored in a cool box at 4^0C. Chlorophyll wasextracted to 80% ethanol at 72˚C for 5 min within 5hrs after collection in the laboratory.

2.3. Determination of primary production

Primary productivity was measured monthly according to the Light and Dark Bottle method[16]. Light and dark, bottles (250ml) were filled with water from corresponding depths and suspended between 10.30am and 1.00pm at three different vertical positions at each sampling site, surface (0m), middle (within the euphotic zone, 2m) and bottom (within aphotic zone, 4m). After 2.5 hours incubation, the water samples were fixed with Winkler reagents andafter acidification, titration was done to determine the DO concentrations.Calculations of gross and net primary productivity rates (A) and respiration rate were performed according to the difference of Dissolved Oxygen (DO; X) concentrations in each sampling bottle (Light; L, Dark; D, Initial; I) as described in following two formulas.

$$Gross\ primary\ Production\ = \frac{12}{32}(X_L\ -\ X_D)\ mg\ C\ L^{-1}h^{-1} \ldots\ldots\ldots\ldots\ldots (1)$$

$$Net\ primary\ Production\ = \frac{12}{32}(X_L\ -\ X_I)\ mg\ C\ L^{-1}h^{-1} \ldots\ldots\ldots\ldots\ldots (2)$$

$$Respiration\ = \frac{12}{32}(X_I\ -\ X_D) mg\ C\ L^{-1}h^{-1} \ldots\ldots\ldots\ldots\ldots (3)$$

The difference between the photosynthetic rate at the surface and Amax was calculated and expressed as a percentageof photo-inhibition.

2.4. Determination of primary production

The Trophic State Index (TSI) of Carlson was calculated using the following formulae [17, 18]

$$TSI\ for\ Chlorophyll - a\ (CA)TSI\ = 9.81\ \ln Chlorophyll - a(\mu g/l)\ + 30.6 TSI\ for\ Secchi\ depth\ (SD)TSI$$
$$= 60 - \ln Secchi\ depth\ (m)\ TSI for\ Total\ phosphorous(TP)TSI$$
$$=\ 14.42\ \ln Total\ Phosphorous\ (\mu g/l) + 4.15$$

Where, TSI is Carlson Trophic State Index and ln is natural logarithm

$$Carlson's\ trophic\ state\ index\ (CTSI) = [TSI(TP) + TSI(CA) + TSI(SD)]/3$$

Based on the values of CTSI, the trophic state was classified as Oligotrophy (low productive), Mesotrophy (moderately productive) and Eutrophy (Highly productive). The range of Carlson's trophic state index values and trophic state classification are represented in Table 3.

2.5. Statistical analysis

Data were tested for normality before the analysis using Shapiro Wilk test.Descriptive data analysis (mean, standard deviation, standard error, maximum and minimum values) were carried out using Windows excel 2007 version.. One way ANOVA was carried out to compare the mean primary productivity among the sampling sites and sampling depths further with the Post hoc comparison of means using Turkey's multiple range tests at the significance level. Pearson's correlation value was determined between mean primary productivity, and water quality parameters throughout the sampling period. All statistical analysis was carried out using SPSS software program (SPSS v 16.0).

3. RESULTS AND DISCUSSION

Muruthawela reservoir which has adendritic shape is a comparatively larger and deeper (mean depth-9.1m; maximum depth-36m) reservoir and exhibits low water level fluctuations [19]. The mean values of physico-chemical attributes were illustrated in **Figure2** for the study period. There were no significant differences ($p > 0.05$) of physico-chemical parametersof each position (surface, middle, aphotic zone) among the three sites. Therefore, the mean values at the three sites were considered for studying the temporal variationand the correlations among the physico-chemical parametersand primary productivity.

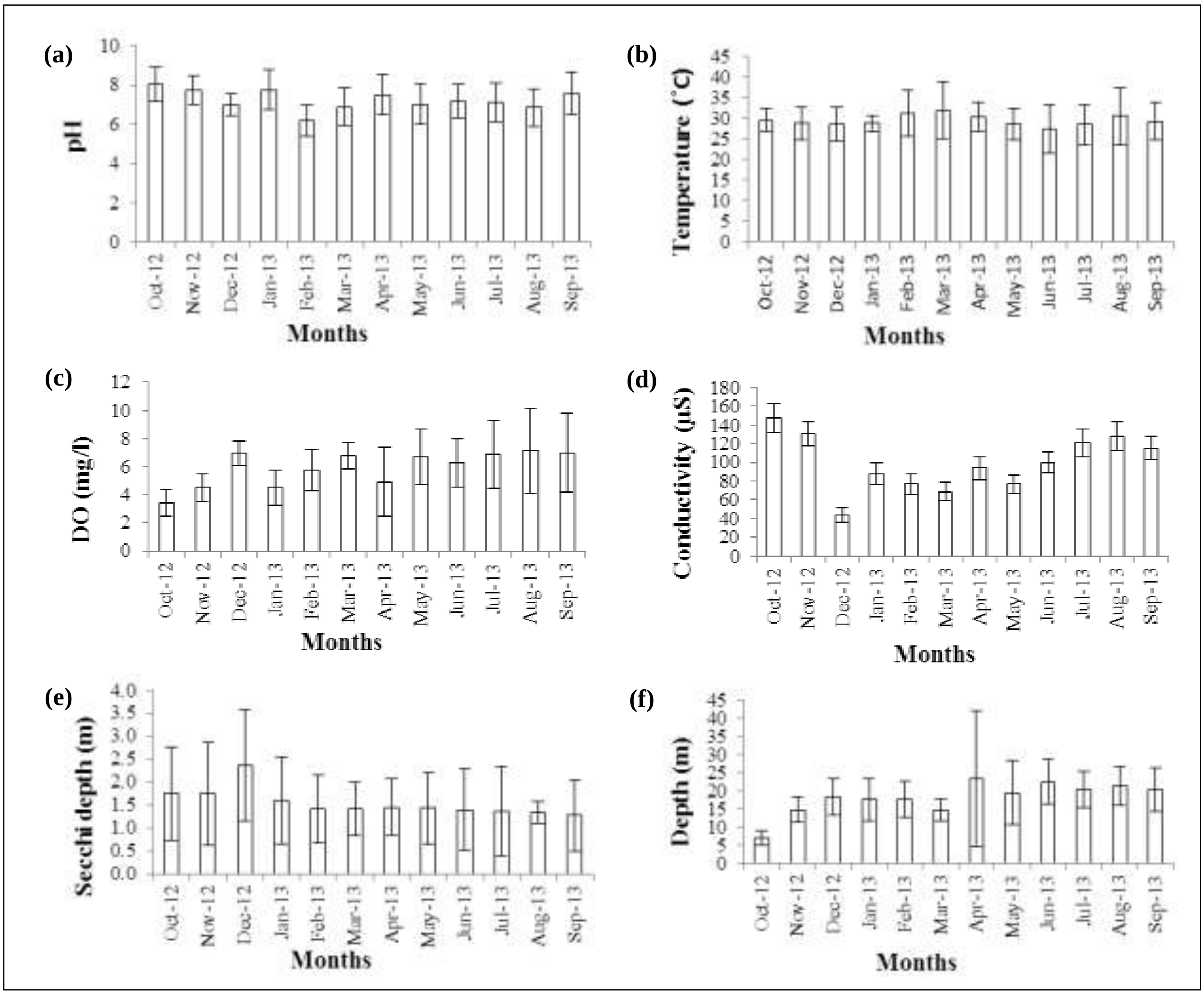

Figure 2: Monthly variation of mean values in pH (a), Water Temperature (b), Dissolved Oxygen (c), Conductivity (d), Secchi depth (e) and Depth (f) from October, 2012 to September, 2013 in Muruthawela reservoir

Water pH which ranged from 6.20 (February) to 8.05 (October) was from slightly acidic to alkaline side. [20] has reported that, pH is one of the crucial factor for the phytoplankton mediated primary productivity in water bodies. [21] has revealed that, while pH in ranged of 5.0-8.5 is favorable for plankton growth, pH more than 8.8 is harmful for plankton.The alkaline nature in Sri Lankan dry zone irrigation reservoirs has been observed by [22].Water temperature was recorded within the range of 27.45˚C (January) to 31.91˚C (March) during the sampling duration and there were no significant differences among the temperatures of three water levels.Muruthawela reservoir did not show clear thermal stratification during the sampling period, though it has a higher depth range (7.16-23.58 m). The possible reasons may be the mixing of water column owing to the higher wind along the reservoir and the stirring up by the freshwaterinput.

The mean Dissolved Oxygen (DO) concentration varied from 3.45 mg/L in October – 7.21 mg/L in August. The lower DO values has been recorded due to high temperature as high temperature decreases the Oxygen holding capacityof water and it triggers the rate of organic matter decomposition in water. [23] has indicated that, water with DO levelhigher than 5 mg/L is more productive for culturing fish.Electrical conductivity was ranged in comparatively wide range (43.97-147.40µS) in Muruthawela reservoir during sampling duration. [24] has illustrated that, relatively higher electrical conductivity values are coincide with the edaphic factors based on his works related to the Aruvi Aru and Moderagam Aru in Sri Lanka.So, the bio chemical conditions within the soil in surrounding watershed area may have a significant impact on the reservoir water quality, particularly conductivity. During the sampling period, it has been observed that, there are agricultural lands and livestock farming in the reservoir catchment. This may be the possible reason for increment of electrical conductivity in water.

Although, mean water depth was ranged from 7.16-23.58m during the study period, the Secchi depth and Euphotic depth were limited to about 2m and 4m respectively. Secchi disc transparency is a standard indicator of water clarity, which is strongly correlated with biomass and annual productivity of suspended algae [25].This is also closely related to the amount of sandy clay, detritus and organic matter suspended in water and quantity of dissolved elements in water [26].

However, low values of water transparency may be the results of increasing turbidity due to the bottom stirring up of the reservoir by the freshwater input from Urubokkuoya. [12] have indicated that, increment of wind speed and conventional mixing of water column may be the profound factor for recording lower secchi depth transparency with their works on "Tissawewa" reservoir, Sri Lanka.

Phosphates and nitrates are the most important nutrients and pre-dominant factors for the maintenance of lake fertility. During the present study, phosphate concentration has been varied between 0.01mg/L to 0.145mg/L while nitrate concentration was varies from 0.020-0.161mg/L. The highest values of both nitrate and phosphate were recorded in December 2012 during the Monsoon season (175mm). The anthropogenic inputs of super phosphates applied to agriculture field around the reservoir may be the main source of inorganic phosphate.Nitrate is the highly oxidized form of nitrogen in water and biological oxidation of nitrogenous organic matter with both autochthonous and allochthonous origin is the main source of nitrate. During the sampling protocol, it has been observed that, there islivestock farming around the Muruthawela reservoir and they may be the possible sources for entering the nitrogenous organic matters in to water.

Pearson correlations and significance values among physico-chemical parameters during one year period in Muruthawela reservoir have been represented in **Table 1**.

Table 1: Pearson correlations (R) among physico-chemical parameters in Muruthawela reservoir (* $P<0.05$)

	pH	**Temp**	**DO**	**Cond**	**Sal**	**NO_3^-**	**PO_4^{3-}**	**Chl-a**	**S.D.**
Temp	-0.42	-							
DO	-0.65*	0.04	-						
Cond	0.54	-0.13	-0.40	-					
Sal	0.72*	-0.40	-0.78*	0.42	-				
NO_3^-	-0.26	-0.16	0.38	-0.70*	-0.43	-			
PO_4^{3-}	-0.45	0.12	0.29	-0.94*	-0.35	0.70*	-		
Chl-a	-0.28	-0.04	0.21	-0.92*	-0.24	0.73*	0.96*	-	
S.D.	0.18	-0.25	-0.21	-0.34	0.14	0.71*	0.50	0.58*	-
Depth	-0.38	-0.18	0.59*	-0.29	-0.42	-0.04	0.23	0.26	-0.37

*indicates significant at 0.05 level

Temp-Temperature (˚C); DO-Dissolved Oxygen (mg/L); Cond-Conductivity (µS); Sal-Salinity (ppt); NO^-_3-Nitrate concentration (mg/L); PO_4^3-Phosphate concentration(mg/L); Chl-a-Chlorophyll-a concentration; S.D.-Secchi depth (m); Depth-Water depth (m).

Significant positive correlations for chlorophyll-a concentration have been obtained with both inorganic nutrients; nitrates and phosphates. These two nutrients are the main factors that increase the algal growth and thereby they affect to increase the chlorophyll content.

The average primary productivity rates were in the ascending order of bottom<surface<middle in the present study (**Table 2**). The minimum productivity was observed as 0.176 ± 0.0048 g C $L^{-1}h^{-1}$ in July, 2013 and the maximum productivity was 1.512±0.0045 g C $L^{-1}h^{-1}$in December, 2012. There were significant differences of Gross Primary Production in middle layer with reference to that of surface ($p<0.05$) and aphotic zone ($p<0.01$). However, significant difference did not observe for Gross Primary Production between middle (Euphotic zone) and bottom (Aphotic zone).

Table2: Primary productivity (Mean±SE) from October 2012 to September 2013 in Muruthawela reservoir (g C L^{-1} h^{-1})

Sampling date	**Primary productivity ($g\ C\ L^{-1}h^{-1}$)**		
	Surface	Middle	Aphotic zone
Oct-12	0.302 ± 0.000	0.340 ± 0.053	0.189 ± 0.053
Nov-12	0.378 ± 0.070	0.378 ± 0.157	0.302 ± 0.000
Dec-12	0.529 ± 0.000	1.512 ± 0.004	0.491 ± 0.035
Jan-13	0.378 ± 0.000	0.554 ± 0.000	0.378 ± 0.005
Feb-13	0.403 ± 0.003	0.428 ± 0.007	0.378 ± 0.001
Mar-13	0.428 ± 0.005	0.604 ± 0.008	0.201 ± 0.047
Apr-13	0.428 ± 0.078	0.680 ± 0.001	0.327 ±0.009
May-13	0.277 ± 0.005	0.655 ± 0.005	0.327 ± 0.008
Jun-13	0.302 ± 0.007	0.579 ± 0.004	0.327 ± 0.000
Jul-13	0.226 ± 0.008	0.579 ± 0.009	0.176 ± 0.005
Aug-13	0.226 ± 0.008	0.478 ± 0.006	0.252 ± 0.008
Sep-13	0.226 ± 0.110	0.529 ± 0.098	0.277 ± 0.005

The depressed photosynthetic rate at the surface of a water body is a common feature of photosynthesis-depth profiles of phytoplankton in tropical lakes [1] due to photo-inhibition and presence of excess photons. The total photosynthetic process in Muruthawela has been restricted to the layers near the surface with a single sub-surface maximum and this is the characteristic pattern of light limitation of deeper waters [19]. A similar variation of primary productivity profile has been obtained for several Sri Lankan reservoirs including Udawalawe, Chandrika wewa, Minneriyawewa, ParakramaSamudra and Kaudulla [14].

The mean Gross Primary Production (GPP) values showed significant positive correlations betweennitrate concentration (R = 0.84; p <0.01), phosphate concentration (R= 0.87; p< 0.01), chlorophyll-a concentration (R= 0.93; p< 0.01) and Secchi depth (R= 0.75; p< 0.01). Itwas negativelycorrelated(R=-0.80; p <0.01) with conductivity.

Figure 2 illustrates thevariation of mean GPP, nitrate and phosphate concentration with respect to the variation of mean monthly rainfall in Muruthawela reservoir

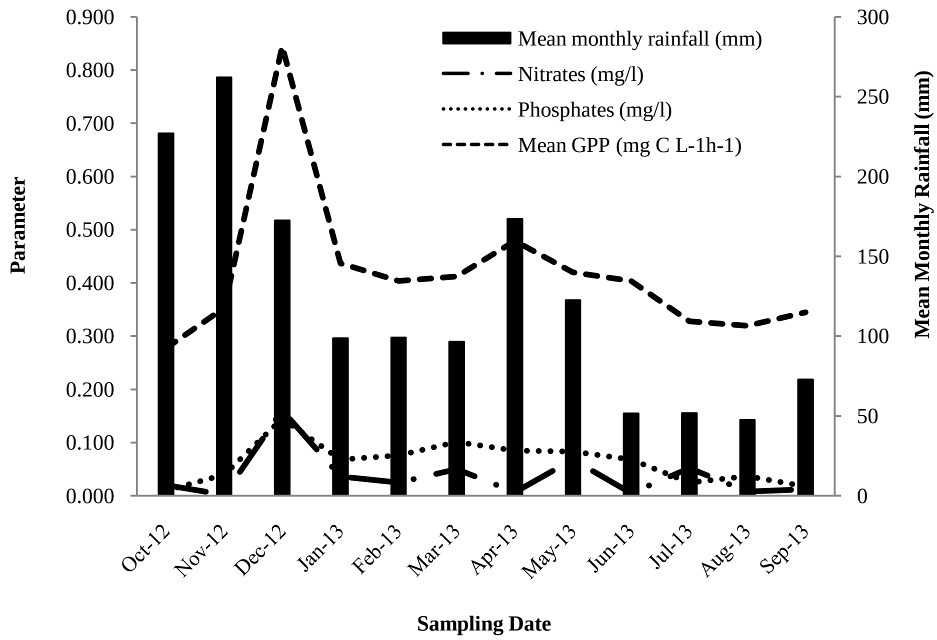

Figure2: Year round variation of mean GPP, nitrate and phosphate concentration with respect to the variation of mean monthly rainfall in Muruthawela reservoir.

Figure 2 reveals that, there was a significant effect of the amount and intensity of rainfall on productivity in the reservoir. Also, the highest mean gross primary production and the highest concentrations of major nutrients (nitrates and phosphates) were observed just after the highest rainfall in the area (December)which creates a surface runoff that carries a lot of nutrients through the catchment the beginning of rainy season. The rain induced higher levels of primary productivity has been observed as a common ecological phenomena in tropical reservoirs. For instance, the first rain after the start of the rainy season, which carry the a lot of nutrients into the reservoir is the effective factor for the high primary productivity [1, 27].

The trophic state indices for each parameter and CTSI for sampling duration in Muruthawela reservoir are represented in **Table 3** and the graphical representation inthe temporal variation of CTSI is represented in **Figure 3**.

Table 3: Carlson's Tropic State Index during sampling period in Muruthawela reservoir

Sampling Date	TSI (Chl)	TSI (SD)	TSI (TP)	CTSI	Tropic State
Oct-12	52.97	51.94	37.35	47.42	Mesotrophic
Nov-12	60.39	51.87	57.34	56.53	Eutrophic
Dec-12	69.38	47.64	75.91	64.31	Eutrophic
Jan-13	64.46	53.15	65.00	60.87	Eutrophic
Feb-13	63.09	54.98	66.60	61.56	Eutrophic
Mar-13	64.15	54.93	70.70	63.26	Eutrophic
Apr-13	65.16	54.65	68.21	62.67	Eutrophic
May-13	64.46	54.83	67.87	62.38	Eutrophic
Jun-13	62.30	55.14	65.00	60.81	Eutrophic
Jul-13	57.66	55.52	50.57	54.58	Eutrophic
Aug-13	56.18	55.71	56.22	56.03	Eutrophic
Sep-13	58.51	56.48	45.83	53.61	Eutrophic

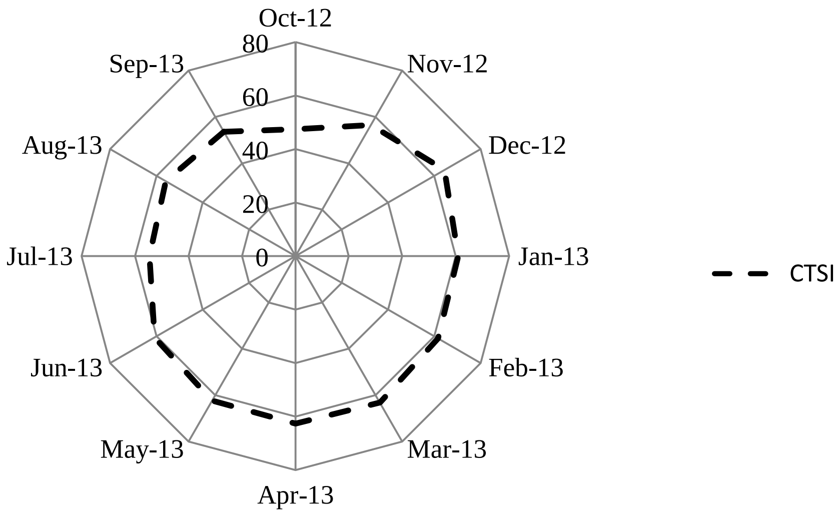

Figure3: Radar diagram of temporal variation in Carlson's trophic state index (CTSI) of Muruthawela reservoir (October 2012 to September 2013)

Based on the results of CTSI values, comparatively higher values were recorded in December, 2012 which is highly compatible with the results of primary productivity. Reservoir showed a little fluctuation of average CTRI values which in between 56 and 65 from November, 2012 to September, 2013. During this particular time period, the reservoir was laid in eutrophic category dominance with blue algae in trophic state classification. These empirical results can be proved by the field observations and analysis of plankton community in reservoir as more than 50% of the phytoplankton community has been represented by the Blue green algae (Division-Bascillariophyta) which was mainly dominated by the *Microcystis sp*. Also, this indicates that the reservoir has a tendency of becoming anoxic during the dry season and it may adversely affect for the bottom feeding fish community in the reservoir and ultimately reservoir fishery sector may be badly affected.

However, very little knowledge is available about the relationship between nutrients and chlorophyll in tropical systems or the primary limiting nutrient in tropical and sub-tropical freshwater ecosystems [28]though it is extremely important for the trophic state modelling in aquatic ecosystems.

4. CONCLUSIONS AND RECOMMENDATIONS

The photosynthetic primary production in Muruthawela reservoir, Sri Lanka fall within the boundaries which are already established for tropical fresh water reservoirs with Surface photo inhibition, although it is a relatively deeper reservoir. Site specific variation of primary productivity mainly depends on the watershed characteristics which make profound variations in the nutrient pool in the reservoir. Year round variation in productivity has been mainly coincided with the general rainfall pattern in the study area. The progression of trophic state in Muruthawela reservoir has been occurred from Mesotrophic to Eutrophic state as a gradual process. This conversion from one stage to another has been mainly based on the degree of nutrient inflow which triggers by the seasonal variation of rainfall in the study area and ultimately the primary productivity of the reservoir. As management practices, raising the awareness of local farmers and fisheris community about environmental issues should be seen as an important factor in ensuring the control and prevention of algal bloom. The education for local farmers should focus on how to mange runoff in order to mange input of nutrients from the surrounding agricultural lands. Moreover, Rivers Human activities at the watershed area of the reservoirsuch as cultivation of vegetables along the shore-line and the small islands in the reservoir and live stock farming around the reservoir are increasing with an alarming rate. Therefore, there is an urgent need for appropriate measures to avoid the potential risks. Management and conservation strategies should, therefore, be developed at the earliest possible time with a view to avoid the occurrence of irreversible changes.

5. ACKNOWLEDGEMENT

The authors wish to express their gratitude to Sri Lanka Council for Agricultural Research Policy (CARP) for the financial assistance (CARP/12/URU/FMST/01) to carry out this study.

6. REFERENCES

1. Talling, J.F. and J. Lemoalle, *Ecological dynamics of tropical inland waters*. 1998: Cambridge University Press. 441.
2. Harris, G.P. and G. Baxter, *Interannual variability in phytoplankton biomass and species composition in a subtropical reservoir.* Freshwater biology, 1996. **35**(3): p. 545-560.
3. Silva, E. and R.W. Davies, *Primary productivity and related parameters in three different types of inland waters in Sri Lanka.* Hydrobiologia, 1986. **137**(3): p. 239-249.
4. Reynolds, C., *Temporal scales of variability in pelagic environments and the response of phytoplankton.* Freshwater Biology, 1990. **23**(1): p. 25-53.
5. Rucińiska-Sobkowiak, R., *Oxidative stress in plants exposed to heavy metals.* POSTĘPY BIOCHEMII, 2008. **52**: p. 200.
6. Thornton, K.W., B.L. Kimmel, and F.E. Payne, *Reservoir limnology: ecological perspectives*. 1990: John Wiley & Sons.
7. Fee, E., et al., *Effects of lake size on nutrient availability in the mixed layer during summer stratification.* Canadian Journal of Fisheries and Aquatic Sciences, 1994. **51**(12): p. 2756-2768.
8. Fraterrigo, J.M. and J.A. Downing, *The influence of land use on lake nutrients varies with watershed transport capacity.* Ecosystems, 2008. **11**(7): p. 1021-1034.
9. Calijuri, M., A. Dos Santos, and S. Jati, *Temporal changes in the phytoplankton community structure in a tropical and eutrophic reservoir (Barra Bonita, SP—Brazil).* Journal of Plankton Research, 2002. **24**(7): p. 617-634.
10. Schiemer, F., et al., *Ecosystem structure and dynamics-A management basis for Asian reservoirs and lakes.* ACIAR Proceedings, 2000: p. 215-226.
11. De Silva, S.S., *Reservoirs of Sri Lanka and their fisheries.* FAO Fisheries Technical Paper (FAO), 1988.
12. Amarasinghe, P.B. and J. Vijverberg, *Primary production in a tropical reservoir in Sri Lanka*.* Hydrobiologia, 2002. **487**(1): p. 85-93.
13. Dokulil, M., I. Silva, and K. Bauer, *An assessment of the phytoplankton biomass and primary productivity of Parakrama Samudra, a shallow man-made lake in Sri Lanka*, in *Limnology of Parakrama Samudra—Sri Lanka*. 1983, Springer. p. 49-76.
14. Silva, E., et al., *Some aspects of photosynthetic characteristics in a set of perennial irrigation reservoirs located in five river basins in Sri Lanka.* Hydrobiologia, 2002. **485**(1-3): p. 19-33.
15. Silva, N.D., *Social-Cultural heritage of Hambanthota district*. 2005: Central Cultural fund, Pannipitiya.
16. Mackereth, F.J.H., et al., *Water analysis: some revised methods for limnologists.* 1978.
17. Carlson, R., *A trophic state index for lakes, Contribution N 141, Limnological Research Center.* University of Minnesota, Minneapolis, 17p.[Links], 1977.
18. Carlson, R.E., *More complications in the chlorophyll-Secchi disk relationship.* Limnology and Oceanography, 1980. **25**(2): p. 379-382.
19. Amarasinghe, P.B., J. Vijverberg, and M. Boersma, *Production biology of copepods and cladocerans in three south-east Sri Lankan low-land reservoirs and its comparison to other tropical freshwater bodies.* Hydrobiologia, 1997. **350**(1-3): p. 145-162.
20. Koli, V.K. and M.M. Ranga, *Physicochemical Status and Primary Productivity of Ana Sagar Lake, Ajmer (Rajasthan), India.* Universal Journal of Environmental Research & Technology, 2011. **1**(3).
21. Umavathi, S., K. Longakumar, and Subhashini, *Studies on the nutrient content of Sulur pond in Coimbator, Tamil Nadu.* Journal of ecology and environmental conservation, 2007. **13**(5): p. 501-504.
22. Gunawardhana, H. and A.K.R. Adikari, *Studies om the Quality of Irrigation Waters i1-a Kalawewa Area.* 1982.

23. Banerjea, S., *Water quality and soil condition of fish ponds in some states of India in relation to fish production.* Indian journal of Fisheries, 1967. **14**(1 & 2): p. 115-144.
24. Panabokke, C.R., *Soils and agro-ecological environments of Sri Lanka.* Vol. xvi 220p. 1996, Colombo, Sri Lanka: NARESA.
25. Peckham, S., et al., *Alternate stable states and the shape of the lake trophic distribution.* Hydrobiologia, 2006. **571**(1): p. 401-407.
26. Sifa, L. and X. Senlin, *Culture and capture of fish in Chinese reservoirs*. 1995: Southbound.
27. Thomas, S., et al., *The different primary producers in a small African tropical reservoir during a drought: temporal changes and interactions.* Freshwater Biology, 2000. **45**(1): p. 43-56.
28. Kalff, J., *Limnology: inland water ecosystems*. Vol. 592. 2002: Prentice Hall New Jersey.