Carlson's Trophic State Index for the Assessment of Trophic state of Phewa, Begnas and Rupa Lakes in Kaski district, Nepal

Shristi Shrestha[1*], Rabin Malla[1]
[1]Center of Research for Environment, Energy and Water (CREEW), Baluwataar
*Corresponding email: shresthashristi02@gmail.com

Abstract

Eutrophication of wetlands has been considered as a global level environmental problem due to wide range of environmental impacts caused by it. All the lake bodies are subjected to natural eutrophication process but anthropogenic activities like excessive utilization of inorganic fertilizers containing phosphorus and nitrogen in the farmlands which ultimately reach to water bodies through runoff during rainfall further maximizes the eutrophication.The research was conducted to find the trophic state of Lake Phewa, Lake Begnas and Lake Rupa which are three major lakes of Lake Clusters of Pokhara Valley, a Ramsar listed wetland from mid-hills of Nepal.Trophic state of lakes were classified on the basis of Carlson's Trophic State Index. This index was calculated with the measurement of Secchi depth, Chlorophyll-a, and Total Phosphorus using standard methods. Study revealed that all three lakes were mesotrophic in both pre-monsoon and monsoon season. Lake Rupa had the highest Carlson Trophic State Index (CTSI) and Lake Begnas had lowest CTSI in both the season. Development of lake from oligotrophic to eutrophic state is a natural and gradual process and hence these lakes have increased chances of being eutrophic naturally along with natural process being crucially altered by cultural eutrophication which shortens the life expectancy of the affected aquatic body. Suitable conservation measures are needed to reduce organic load from lake to prevent from being further degraded.

Keywords: *Chlorophyll a, Eutrophication, Secchi depth, Total Phosphorus, Trophic State*

Introduction

Lake eutrophication is a natural process as lake ages (Carpenter, 1981) but increased human activities involving excessive utilization of inorganic fertilizers (mainly nitrogen and phosphorus) which ultimately reach to lake water bodies through runoff during precipitation (Ghosh and Mondal, 2012; Schindler, 2012) is maximizing the rate of eutrophication commonly being known as cultural eutrophication. As a result of which globally eutrophication has been recognized as major threat to health of aquatic ecosystems (Carpenter, 2005; Schindler, 2012; Wilkinson, 2017) where lake constitute the major portion of them (Selman and Greenhalgh, 2010). With increase in nutrient and organic load the lake bodies transform from oligotrophic to mesotrophic and finally to eutrophic. Eutrophication excessively increases phytoplankton growth resulting in algal blooms (González and Roldán, 2019), habitat loss, decreased dissolved oxygen concentration (Smith and Schindler, 2009) which further can have serious environmental and socio-economic impacts (Khan and Mohammad, 2014). Hence, assessment of lake water bodies in terms of eutrophication status is essential component in water quality assessment (Karmakar and Musthada, 2013) as well as for its conservation planning and management strategies (Sharma *et al*., 2010; Opiyo *et al*., 2019).

Eutrophication assessment can be easily carried out by determining trophic status of water bodies (Quevedo-Castro *et al*., 2019) which involves determination of concentration of nutrients and classifying the trophiclevel based on their concentration (Bekteshi and Cupi, 2014). Determining trophic state index (TSI) is essential attribute in scientific assessment as it indicates the ecological integrity and water quality (Dodds, 2007) of water bodies' use for various purposes. Furthermore TSI helps to understand biotic and abiotic condition of water body, relation between bio-chemical parameters and condition of the lake in relation to human requirement and usefulness (Carlson and Simpson, 1996; Wetzel, 2001; Matthews *et al*., 2002).

The most common and classical method of determining TSI is Carlson Trophic State Index (CTSI) which was developed by Carlson in1977. CTSI involves use of parameters namely Chlorophyll-a (Chl-a), Total Phosphorus (TP) and Secchi Depth (SD)for determining TSI (Carlson, 1977).

Freshwater bodies across Nepal are reported to show nutrient enrichment (Gurung *et al*., 2019). Lake Phewa, Lake Begnas and Lake Rupa are three major water bodies of Ramsar Site namely Lake Clusters of Pokhara Valley upon which a large portion of population residing in the periphery of these lakes are dependent for their livelihood. These lakes have high biodiversity and recreational value but are under numerous environmental stresses. In addition continuous monitoring of their trophic status is still not considered. Hence, the study seeks to find the eutrophication status of three big lakes of Lake Clusters of Pokhara Valley so that outcome can be strong evidence for formulation of suitable plan, policy or program for sustainable management and conservation of these lake water bodies. Conservation measures needed to adopt for to avoid from lake from being further degraded from eutrophication perspective has also been recommended in the paper

Materials and Methods

Study Area

The study was conducted in three major lakes of Lake Clusters of Pokhara Valley namely Lake Phewa, Lake Begnas and Lake Rupa which lies in Gandaki province (Figure 1.). The detailed information regarding geographical location, catchment area, water body areas etc. of individual lakes are presented in Table1.LCPV has humid subtropical climate with summer temperature between 25°C and 35°C and winter temperature from -2°C to 15°C. The lakes are highly important from environmental, social and economic viewpoint as Lake Phewa and Lake Begnas are the most famous touristic destination in Pokhara valley. Individual lakes play important regional hydrological role in contributing to groundwater recharge, flood control, sediment trapping etc. (DNPWC & IUCN, 2016). The lake area is reported to be habitat to globally threatened and endangered endemic flora and fauna like *Alstonia scholaris; Apostasia wallichii*, *Michelia champaca*, *Bulbophyllum plyrhiza*, *Cymbidium iridioides*, *Dendrobium densiflorum*, *D. fimbiatum*, *Cyathea spinosa*, *Dioscorea deltoidea; Oberonia nepalensis; O. iridifolia; Oroxylum indicum*, *Papilionantheteres sp.*, *Oryza rufipogon* , *Tinospora sinensis* , *Ceratophyllum demersum*, *Trapa natans*, *Typha angustifolia*. The lakes host several globally threatened migratory birds and several mammals like Spiny Babbler (*Turdoides nepalensis*), Nepal Wren Babbler (*Pnoepyga immaculate*), Comb duck (*Sarkidiornis melanotos*), Baer's Pochard (*Aythya baeri*), Ferruginous Duck (*Aythya nyroca*), common otter (*Lutra lutra*) etc. (MoFE, 2018).

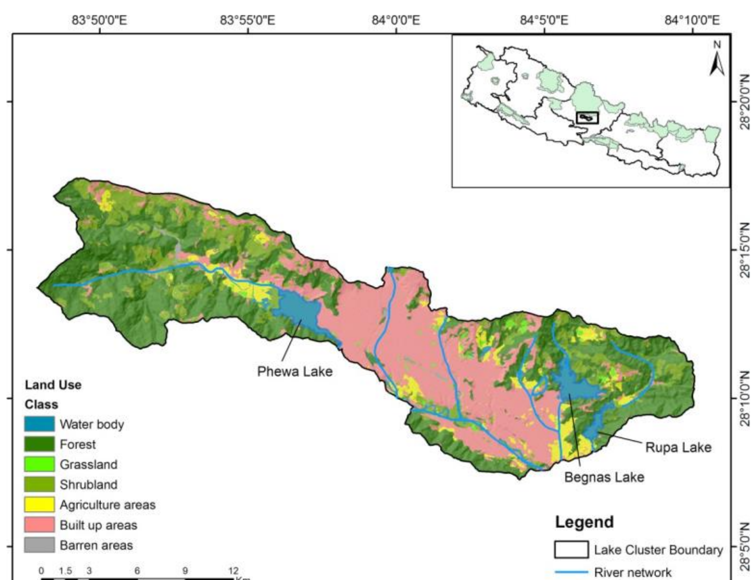

Figure 1: Map showing Lake Phewa, Lake Begnas and Lake Rupa

Table1. Detailed information on Lake Phewa, Lake Begnas and Lake Rupa

S.N.	Lake	Metropolitan City/Rural Municipality	Geographical coordinates	Altitude (m)	Catchment area (km^2)	Water body area (km^2)	% of area covered by water body
1	Phewa	Pokhara Lekhnath Metropolitan City Annapurna Rural Municipality	28.1943-28.2902 83.8004-83.9898	762 – 2,482	119.39	4.33	3.6
2	Begnas	Pokhara Lekhnath Metropolitan	28.1621-28.2167 84.0814-84.1332	647-1447	18.40	3.13	16.8
3	Rupa	Pokhara Lekhnath Metropolitan City Rupa Rural Municipality	28.139-28.2061 84.1004-84.1699	580-1420	27.60	1.11	4.3

Methodology

Sample collection and transportation

Sampling was done during September 2019. A total 10 lake water sample was collected from each lake so that the sample would be representative for whole lake. Secchi depth was measured directly on site and from the point where Secchi depth was measured water samples for analysis of Total Phosphorus and Chlorophyll a was collected in polyethylene bottles. The water samples were preserved in ice box at the sampling site, refrigerated at 4°C during field sampling days and immediately transferred to laboratory within 2 days.

Water sample analysis

Secchi depth was determined by Secchi disk method before water sample collection. A Secchi disc of size 20centimeter in diameter was used for Secchi depth determination. The disc was slowly lowered into the water body until it disappeared and the depth was noted. The disk was lowered a few more centimeters and then was slowly raised again until it reappeared and the second reading of depth was also noted. The average of these two readings was taken as the final Secchi disc visibility depth (APHA, 1995).

Total phosphorus was analyzed by digestion method. The water sample was digested with Nitric acid and Sulphuric acid followed by determining the phosphorus content by stannous chloride method. The absorbance of blue color complex was formed which was measured at 690nm using spectrophotometer (6715 UV/Vis Spectrophotometer

JENWAY). Finally, the concentration of phosphorus was determined from the standard curve (APHA, 1989) prepared.

Chlorophyll a was estimated by Trichromatic method and using spectrophotometric procedure (APHA, 1989) (Table 2.)

Table 2. Parameters and methods followed for field and laboratory analysis

S.N.	Parameters	Method involved	Materials involved	Reference
1	Secchi depth	Secchi disk method	Secchi disk	APHA, 1995
2	Total Phosphorus	Digestion with nitric acid and sulphuric acid followed by stannous chloride method	Spectrophotometer (6715 UV/Vis Spectrophotometer JENWAY)	APHA, 1989
3	Chlorophyll a	Trichromatic method and using spectrophotometric procedure	Spectrophotometer (6715 UV/Vis Spectrophotometer JENWAY)	APHA, 1989

Assessment of CTSI

Trophic status of lake was determined by using CTSI. Trophic state determines how green the lake is and is measured by algae biomass amount in the water. Oligotrophic, mesotrophic and eutrophic are three trophic state categories as they grow progressively greener. Among the various methods identified for determining TSI of lake, CTSI is one of the popular and mostly used methods that takes into account measurement of variables namely total phosphorus, chlorophyll a and Secchi depth. The following equations are used to determine CTSI:

$TSI\ (P) = 14.42 \ln TP\ (\mu g/l) + 4.15$................................(i)

$TSI\ (Chl) = 9.81 \ln Chl\text{-}a\ (\mu g/l) + 30.6$................................ (ii)

$TSI\ (SD) = 60 - 14.41 \ln SD\ (meters)$ ....(iii)

$Average\ TSI = [TSI\ (P) + TSI\ (Chl) + TSI\ (SD)]\ /3$................................ (iv)

Where, TP = Total phosphorus

Chl-a = Chlorophyll a

SD = Secchi Depth

In = natural log

Based on the obtained values of CTSI, lakes are classified as oligotrophic (low productive), mesotrophic (moderately productive) and eutrophic (highly productive). The range of CTSI values and classification of lakes are presented in the Table 3.

Data Analysis and Interpretation

Data analysis was done in Statistical Package for the Social Sciences (SPSS) and the results are presented in tabular and radar diagram.

Table 3: TSI Values and Corresponding Carlson Trophic State

TSI Value	Trophic Status	Attributes
<30	Oligotrophic	Clear water, oxygen throughout the year in the hypolimnion
30-40	Oligotrophic	A lake will still exhibit oligotrophy, but some shallower lakes will become anoxic during the summer
40-50	Mesotrophic	Water moderately clear, but increasing probability of anoxia during the summer
50-60	Eutrophic	Lower boundary of classical eutrophy: Decreased transparency, warm-water fisheries only
60-70	Eutrophic	Dominance of blue-green algae, algal scum probable, extensive macrophyte problems
70-80	Hyper eutrophic	Heavy algal blooms possible throughout the summer, often hypereutrophic
>80	Hyper eutrophic	Algal scum, summer fish kills, few macrophytes

Source: Carlson and Simpson, 1996

Results and Discussion

Analysis of CTSI of three big lakes namely Phewa, Begnas and Rupa revealed that all the three lakes were mesotrophic in both pre-monsoon and monsoon season. Among three lakes Lake Rupa had highest CTSI value of 43.53 and 42.82 in pre-monsoon and monsoon season respectively while Lake Begnas had lowest CTSI value of 42.16 and 41.46 in pre-monsoon and monsoon season respectively (Table 4). According to CTSI value and corresponding trophic state of the lake it is revealed that water of the lakes are moderately clear but there are increasing chances of anoxia during summer (Table 3 and 4). Monsoon TSI is comparatively lower than pre-monsoon TSI which might be due to more amount of rainfall in monsoon season than in pre-monsoon season which might have diluted the chemical concentration in lake water bodies. Also, Pokhara valley receives highest amount of rainfall in the country with reference record of 5244mm average annual precipitation in Lumle (Luitel *et al*., 2020).

Our result which reported mesotrophic characteristics of the lakes didn't clash with other results as Nakanishi *et al*. (1982) reported that the Fewa Lake is oligomesotrophic and Begnas and Rupa Lake are eutrophic based on the total phosphorus concentration. Rai (2000) classified these three lakes as oligoeutrophic based on the chlorophyll a content. This might be due to the reason that trophic state of lake depends mostly on precipitation and use of water by farmers for irrigation (Rai, 2000)

Waters from these lakes has been largely used for drinking purpose especially from Begnas (MOFE, 2018) also evidenced by the lowest CTSI value of Lake Begnas. In the past the lakes mainly Phewa resulted in high algal bloom and mass fish kills but during research period Phewa had very few algal blooms and also the water was mesotrophic. This might be due to various local conservation initiatives carried out by local people for lake conservation. As Lake Rupa has highest CTSI among the three which might be due to frequent human activities like cleaning and washing dishes, clothes, bathing in the lake which was evidenced in the field days.

All the three lakes are currently in the early mesotrophic state as per CTSI but the developmental process of lake being eutrophic from oligotrophic is very natural process but often accelerated by various anthropogenic induced factors (Steffanson *et al*., 2001; Sharma *et al*., 2010). Various environmental stresses that would degrade the lake quality were seen in the field days. The similar environmental stress like pollutants runoff from agricultural chemicals, sewages, waste disposal (solid and liquid) etc. has been reported by various other researches too (MOFE, 2018). Various other researches also reported environmental pressures like encroachment, sedimentation, alien species invasion, land use change and other driving forces like weak wetland governance, policy overlapping etc. in the lakes (DNPWC & IUCN, 2016; Husen & Dhakal, 2009; MOFE, 2018; Pant *et al*., 2019). Such trend finally leading to cultural eutrophication significantly alters natural process and shortens life expectancy of lake water bodies.

Table 4: CTSI of Lake Phewa, Begnas and Rupa in pre-monsoon and monsoon season

S.N.	Lake cluster name		SD (m)	TP (µg/l)	Chl-a (µg/l)	TSI (SD)	TSI (TP)	TSI (Chl-a)	TSI	Trophic Status	Specific attributes of the trophic status of the lakes as per CTSI
Pre-monsoon analysis											
1	Phewa	Mean ± S.E	1.68 ± 0.05	2.90 ± 0.22	4.35 ± 0.34	52.83	19.15	55.89	42.62	Mesotrophic	Water moderately clear, but increasing probability of anoxia during the summer
2	Begnas	Mean ± S.E	1.58± 0.01	2.78 ± 0.16	4.17 ± 0.25	53.39	18.68	54.40	**42.16**	Mesotrophic	Water moderately clear, but increasing probability of anoxia during the summer
3	Rupa	Mean ± S.E	0.96± 0.04	4.43 ± 0.43	6.65 ± 0.64	60.63	24.98	44.90	**43.53**	Mesotrophic	Water moderately clear, but increasing probability of anoxia during the summer
Monsoon analysis											
1	Phewa	Mean ± S.E	1.37 ± 0.01	2.36 ± 0.14	3.55 ± 0.21	55.44	16.30	54.94	42.24	Mesotrophic	Water moderately clear, but increasing probability of anoxia during the summer
2	Begnas	Mean ± S.E	1.70± 0.01	2.61 ± 0.18	3.91 ± 0.27	52.29	17.67	54.09	**41.46**	Mesotrophic	Water moderately clear, but increasing probability of anoxia during the summer
3	Rupa	Mean ± S.E	0.94± 0.01	2.40 ± 0.20	3.61 ± 0.30	60.92	16.33	51.20	**42.82**	Mesotrophic	Water moderately clear, but increasing probability of anoxia during the summer

Conclusion and Recommendations

Trophic state monitoring is crucial part in assessing and managing lake ecosystems. CTSI values recorded for Lake Phewa, Begnas and Rupa were in between 40 – 45. Based on Carlson TSI, Lake Phewa, Begnas and Rupa were classified as mesotrophic in both pre-monsoon and monsoon season. But the lake can show the increased tendency becoming anoxia in the summer.

Development of lake from oligotrophy to eutrophic state is a natural and gradual process which is based on the changes in the degree of nutrient flow and productivity in the lake. This natural process is crucially altered by cultural eutrophication which shortens the life expectancy of the affected aquatic body. All three lakes were mesotrophic during the research period. As mentioned earlier these lakes have increased chances of being eutrophic naturally along with various anthropogenic factors being involved in it suitable conservation measures is needed to be adopted for to avoid from lake being degraded.

- Regular manual or automatic cleaning of macrophytes and algal biomass should be done to prevent these lake water bodies from being degraded
- Involve citizen scientists, volunteers for water conservation programs to educate common man regarding threats to water body and conservation strategies that can be adopted
- Control of pollution at source through removal and control of point sources, diversion of nutrients
- In lake treatment method through treatment and control measures like dredging, nutrient inactivation/ precipitation, chemical and biological control of nuisance organisms etc.
- Formulation of legal framework, specific laws regarding non-point sources
- Integrated Lake Basin Management (ILBM) approach to attain sustainable management through spatially and thematically holistic integrated approach

Acknowledgements

The authors would like to thank Center of Research for Environment, Energy and Water (CREEW) for funding first author for the research work.

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