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Trophic Status of Lake Phewa and Kulekhani Reservoir, Nepal

Smriti Gurung*, Babi Kumar Kafle[1], Bed Mani Dahal, Milina Sthapit[2], Nani Raut, Chhatra Mani Sharma[2], Kumud Raj Kafle and Sushma Manandhar

Department of Environmental Science and Engineering, Kathmandu University, P.O Box 6250, Nepal
[1]Department of Chemical Science and Engineering, Kathmandu University, P.O Box 6250, Nepal
[2]Central Department of Environmental Science, Tribhuvan University, Nepal
✉ smriti@ku.edu.np

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Abstract: Eutrophication is one of the growing environmental concerns and is affecting and compromising freshwater bodies across the world making the trophic status assessment of water bodies crucial for their restoration and sustainable use. This paper describes the trophic status of Lake Phewa and Kulekhani Reservoir from Nepal. Sampling was conducted during October 2017 (post-monsoon), April 2018 (Pre-monsoon), July 2018 (Monsoon) and February 2019 (Winter). Trophic State Index (TSI) as given by Carlson (1977) and Trophic State Index Deviation given by Carlson (1991) were estimated to assess trophic status and deviations between the Trophic State Indices. One-way analysis of variance showed significant seasonal variation ($p<0.05$) in Secchi depth, total phosphorus (TP), TSI in both the water bodies. Both the water bodies were classified as eutrophic during pre-monsoon and post-monsoon, and hypereutrophic during the monsoon indicating the increased flow of allochthonous inputs from their respective catchments. Non-algal turbidity was found to be the limiting factor for productivity. There is a need for sustainable watershed management in order to reduce the nutrients runoff and accumulation in the water bodies.

Key words: Chlorophyll *a*, eutrophication, Kulekhani Reservoir, Lake Phewa monsoon, nutrient.

Introduction

Eutrophication of water bodies with increased concentrations of nutrients such as phosphorus and nitrogen is a growing environmental concern in many parts of the world (Fink et al., 2018). Eutrophication causes an excessive increase in the phytoplankton growth particularly those of toxic cyanobacteria thereby resulting in algal blooms (González and Roldán, 2019); fish kills, habitat loss, decreased aquatic biodiversity and dissolved oxygen concentrations (Smith and Schindler, 2009). These factors affect the ecological integrity and compromise with the ecosystem functions and services (MEA, 2005) provided by aquatic ecosystems and have serious environmental and socio-economic consequences (Khan and Mohammad, 2014). For instance, algal toxins cause fish mortality (Sanseverino et al., 2016); compromise recreational values (Priskin, 2008). Therefore, eutrophication status assessment of water bodies becomes an integral component of water quality assessments (Karmakar and Musthafa, 2013) for maintaining the ecological integrity as well as effective management of these ecosystems. Eutrophication assessments often involve the determination of the trophic status of aquatic ecosystems (Quevedo-Castro et al., 2019) as trophic status indicates the ecological integrity and water quality (Dodds, 2007) of water bodies' use for various purposes.

*Corresponding Author

A number of freshwater bodies across Nepal are progressively showing nutrient enrichment (Gurung et al., 2019) including those in the remotely located high altitude areas (Ghimire et al., 2013; Gurung et al., 2018). Considering the importance of vital ecosystem services these water bodies provide, there is a need to assess the trophic status of water bodies in the country. Such assessments are crucial to undertake to improve the ecological health of water bodies for their sustainable use.

Lake Phewa in Kaski district and Kulekhani Reservoir in Makwanpur district in Nepal, respectively, represent a freshwater lake and a reservoir serving a number of ecosystem services. Irrigation and cage fishery are the main provisional services provided by Lake Phewa and the lake also has immense recreational importance (Rai, 1998). However, the lake has been facing a number of threats such as sedimentation, eutrophication and lake encroachment (Watson et al., 2019) which could seriously affect the lake's ecosystem services. Kulekhani Reservoir was initially built for the generation of hydroelectricity but cage fishery is also practiced in it, which provides an alternative livelihood for the families displaced by the reservoir impoundment (Gurung et al., 2009). However, sedimentation in the reservoir is considered as one of the major environmental issues (Sthapit, 1995). In recent years, the number of local visitors to reservoir has been rising. Therefore, this study attempts to assess the water quality of Lake Phewa and Kulekhani Reservoir in Nepal especially focussing on their trophic status.

Materials and Methods

Study Area

The study was conducted in Lake Phewa and Kulekhani Reservoir in Nepal (Figure 1). Lake Phewa—a Ramsar site (MoFE, 2018)—is a lesser Himalayan sub-tropical mountain lake located in the mid-hills at an altitude of 782 masl (metres above sea level) in Pokhara Valley (Rai et al., 1995). The Kulekhani Reservoir, also known as Indra Sarowar lies about 30 km south-west of Kathmandu in the Makwanpur district. The reservoir was impounded and commissioned by the Nepal ElectricityAuthority in 1982 and it has a storage capacity of about 85.3 million m^3 (Sthapit, 1995). The reservoir is located at an altitude of 1534 masl (Shrestha et al., 2014).

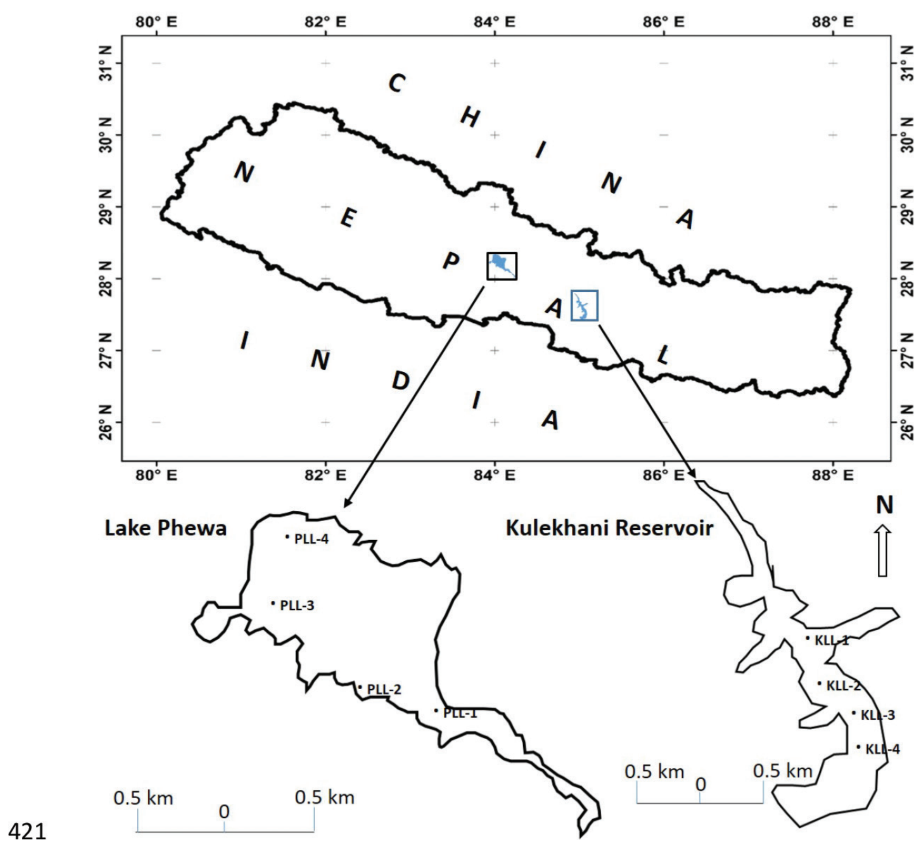

Figure 1: Map of Nepal showing Lake Phewa and Kulekhani Reservoir and the sampling sites.

Sampling was conducted during October 2017 (Post-Monsoon), April 2018 (Pre-monsoon/spring), July 2018 (Monsoon/summer) and February 2019 (Winter). Water samples for total phosphorus (TP) and chlorophyll *a* were collected in high density polyethylene (HDPE) bottles from 0.5 m depth from four sampling sites from each water body (Figure 1). For the TP estimation, 1000 ml of surface water samples were collected and kept in an ice box. For chlorophyll *a* estimation, 1000 ml of surface water samples were collected and immediately filtered through nylon membrane filter paper with a pore size of 0.45 micron. During filtration, the water was pumped maintaining the pressure at 7.5 psi (pounds per square inch). Chlorophyll *a* samples were preserved with Magnesium Carbonate and kept in an ice box for transport and analyses at Kathmandu University. From each lake, 32 water samples were collected (16 for TP and 16 for chlorophyll *a*). The sites were selected on the basis of accessibility and surrounding landuse. Secchi transparency was measured by lowering the Secchi disk slowly into the water body until the black and white quadrants disappeared. This depth was noted and the disk was slowly raised until the black and white quadrants reappeared. The depth at which the quadrants reappeared was also measured and the average of two depths was estimated for Secchi depth transparency.

Laboratory Analysis

Laboratory analysis followed standard procedures. Total phosphate was analysed using the persulphate digestion method (APHA, 2012). Chlorophyll *a* estimation was performed by following the acetone extraction method (Lorenzen, 1967) and Chlorophyll *a* was estimated using the following formula:

$$\text{Chlorophyll } a\ (\text{mg m}^{-3}) = \frac{[26.7 * (663b - 665a) * V1]}{V2 * L}$$

where, $V1$ = Volume of extract, L

$V2$ = Volume of sample, m^3

L = Light path in cm

$663b$ = Corrected optical density of 90% acetone extract before acidification

$665a$ = Corrected optical density of 90% acetone extract after acidification

Carlson's Trophic State Index (TSI) (Carlson, 1977) was estimated to assess the trophic status of both the water bodies using the following formula:

$$TSI_{TP} = 14.42 * \text{LN (TP)} + 4.15 \text{ (in µg L}^{-1})$$

$$TSI_{CHL\ a} = 30.6 + 9.1 \text{ Ln (Chl } a) \text{ (in µg L}^{-1})$$

$$TSI_{SD} = 60 - 14.41 * \text{Ln (SD) (in metres)}$$

$$\text{Average TSI} = \frac{[\text{TSI (TP)} + \text{TSI (Chl } a) + \text{TSI (SD)}]}{3}$$

Where TP is total phosphorus; Chl *a* is chlorophyll *a* and SD is Secchi depth.

The TSI values range from a scale of 0-100 and based on the values obtained, water bodies can be categorised into oligotrophic, mesotrophic, eutrophic and hyper-eutrophic (Carlson and Simpson, 1996) (Table 1).

Table 1: TSI values and corresponding Carlson Trophic State

TSI values	*Trophic state*
<30-40	Oligotrophic
40-50	Mesotrophic
50-60	Eutrophic
>70	Hyper-eutrophic

Source: Adapted from Carlson and Simpson, 1996

Deviations between the TSIs were estimated by subtracting the mean of TSI_{TP} and TSI_{SD} from TSI_{CHL} following Carlson (1991). It is a graphical method to identify non-nutrient limiting factors and involves simultaneous plotting of $TSI_{CHL} - TSI_{TP}$ and $TSI_{CHL} - TSI_{SD}$ in a single graph. Deviations of TSI_{CHL} from the TSI_{TP} indicate degrees of phosphorus limitation, while deviations of TSI_{CHL} from TSI_{SD} indicate the degree of light penetration in proportion to the number and size of particles. The points lying to the right of the Y-axis in the first and fourth phases (first and fourth quadrants) indicate the presence of large particles such as zooplankton grazing and the dominance of blue green algae. In contrast, points to the left of the Y-axis in the second and third phases (second and third quadrants) are attributed to high concentrations of dissolved organic matter and colour thereby resulting in non-algal turbidity (Carlson,1991).

Statistical Analysis

Descriptive statistical analyses were performed to estimate the mean values of different parameters. One-way analysis of variance (ANOVA) was performed to assess the significant variation in Secchi transparency, chlorophyll *a* concentration, total phosphorus concentration, and TSIs. Tukey's multiple comparison test was conducted to assess significant variation in these parameters between different seasons.

Results and Discussion

The annual mean, maximum and minimum values and seasonal mean values of Secchi depth transparency, TP, chlorophyll *a,* TSIs and trophic categorisation of Lake Phewa and Kulekhani Reservoir are presented in Tables 2 and 3, respectively.

The Secchi values in both the water bodies were the lowest during the monsoon whereas the TSI values were the highest during this season (Figures 2a and 2b). Higher Secchi values were associated with the lowest TSI values and observed during the winter. Low Secchi transparencies in both the water bodies indicate water turbidity. Water transparency is affected by the plankton density, total suspended solids (TSS) and the total dissolved substances (TDS) (Lenard et al., 2019; Wetzel, 2001). The TSS and TDS are measurements for the non- algal turbidity (Dzialowski et al., 2011), and along with plankton biomass, these factors reduce water transparency. In general, eutrophic water bodies tend to have low Secchi values (Stephens et al., 2015) attributed to dense phytoplankton biomass. However, some oligotrophic lakes located at glaciated basins may also have low Secchi values (Tartari et al., 1998) primarily attributed to the presence of glacial flour.

The trophic status of the studied water bodies showed seasonal variation with lower TP concentrations and TSI_{TP} values during the pre-monsoon but higher during the monsoon and post-monsoon. Based on the Carlson Trophic Index (Carlson, 1977) both the water bodies were classified as hypereutrophic during monsoon and eutrophic during post-monsoon and pre-monsoon. However, the trophic status of Lake Phewa during winter was found to be mesotrophic whereas, Kulekhani Reservoir was observed to be eutrophic (Table 3). As per reports, precipitation induces increased concentrations of nutrients and chlorophyll *a* in the water bodies in Asia (eg., Jung et al., 2016; Mamun and An, 2017) and elsewhere (Silvano and Barbosa, 2015; Sahoo et al., 2016). Elevated levels of nutrients in lentic systems in South East Asia during the monsoon are resulted from catchment erosion and agricultural runoff (Jones et al., 2003). Thus, higher TP concentrations in both water bodies during monsoon indicate an increase in the allochthonous inputs. The runoff from the Kulekhani catchment during the monsoon has been reported to

Table 2: Annual mean, minimum and maximum values of Secchi depth, TP, Chlorophyll *a* concentration and TSI in Lake Phewa and Kulekhani Reservoir

Parameters	*Lake Phewa*			*Kulekhani Reservoir*		
	Max	*Min*	*Average*	*Max*	*Min*	*Average*
Secchi depth (m)	3.40	0.34	1.57±0.93	3.48	0.58	1.85±1.03
TP (mgL^{-1})	1.53	0.01	0.63±0.62	3.60	0.02	0.89±0.98
Chl ‘*a*’ (μgL^{-1})	18.34	1.82	4.55±4.11	65.25	0.88	11.26±16.23
TSI	92.38	41.17	63.11±12.93	79.31	48.16	63.64±8.43

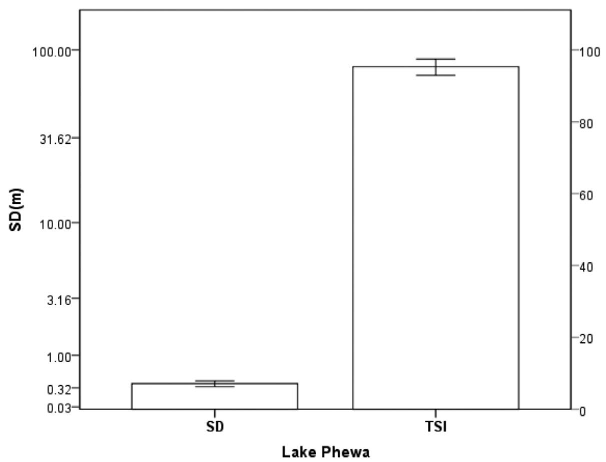

Figure 2a: Secchi and TSI values of Lake Phewa during monsoon.

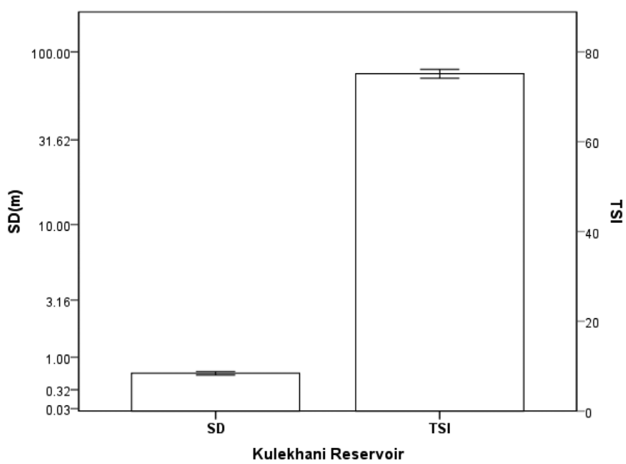

Figure 2b: Secchi and TSI values of Kulekhani during monsoon.

Table 3: Seasonal variation in Secchi depth, TP, Chlorophyll *a*, TSI_{SD}, TSI_{TP}, TSI_{CHL}, TSI and Trophic status of Lake Phewa and Kulekhani Reservoir

Lake Phewa					*Kulekhani Reservoir*			
Parameters	*Season*				*Season*			
	Pre-monsoon	*Monsoon*	*Post-monsoon*	*Winter*	*Pre-monsoon*	*Monsoon*	*Post-monsoon*	*Winter*
Secchi depth(m)	1.41±0.08[a]	0.39±0.05[b]	1.68±0.2[a]	2.79±0.7[c]	1.26±0.09[a]	0.63±0.04[b]	3.19±0.34[c]	2.34±0.2[d]
TP(μgL^{-1})	162.5±17.08[a]	1437.50±40.31[b]	869.25±443.13[c]	34.25±22.07[a]	155.00±17.32[a]	1622.50±64.5[b]	1700.25±1270.8[c]	76.25±51.3[a]
Chl *a*($\mu g\ L^{-1}$)	4±2.18[a]	8.04±9[a]	3.62±2.3[a]	3.40±0.08[a]	2.88±2[a]	11.25±11[a]	3.33±1.53[a]	27.56±25.7[a]
TSI_{SD}	55.09±0.80[a]	73.67±1.89[b]	52.62±1.48[a]	45.51±3.31[c]	56.70±1.04[a]	66.77±0.90[b]	43.37±1.63[c]	47.79±1.21[d]
TSI_{TP}	77.5±1.55[a]	108.99±0.41[b]	100.60±6.25[b]	52.52±10.37[c]	76.81±1.55[a]	110.73±0.58[b]	109.00±8.99[b]	63.16±12.66[a]
TSI_{CHL}	43.34±4.48 [a]	45.62±0.92[a]	41.80±5.99[a]	42.6±0.22[a]	39.04±7.63[a]	48.52±13.60[a,c]	41.55±4.83[a,c]	60.18±8.66[b,c]
TSI values	58.64±0.87[a,d,e]	76.09±2.56[b]	65.00±1.57[c,e]	46.88±3.81[d]	57.52±2.31[a]	75.34±4.40[b]	64.64±1.64[a]	57.04±5.99[a]
Trophic status	Eutrophic	Hypereutrophic	Eutrophic	Mesotrophic	Eutrophic	Hypereutrophic	Eutrophic	Eutrophic

Note: Values followed by different letters within rows are significantly different (p<0.05).

be almost three times higher (Shrestha et al., 2014) bringing increased concentrations of nutrients. In contrast, the sources of nutrients from the catchment of Lake Phewa are attributed to agricultural runoff and landslides; untreated sewage and rapid urbanisation in lake surroundings (Rai, 2000). Increased nutrient loading from the watershed during the monsoon probably explains the hypereutrophic nature of Lake Phewa and Kulekhani Reservoir during the monsoon.

Nakanishi et al. (1988) reported the trophic status shift of Lake Phewa from oligotrophic to mesotrophic.

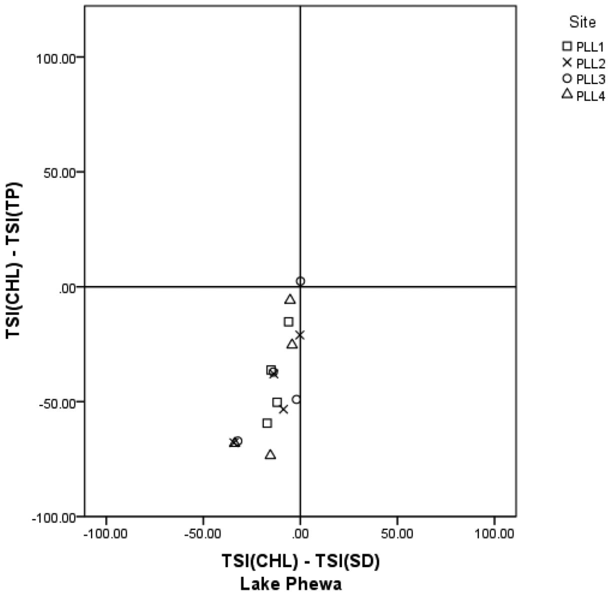

Figure 3a: Trophic state deviation of Lake Phewa.

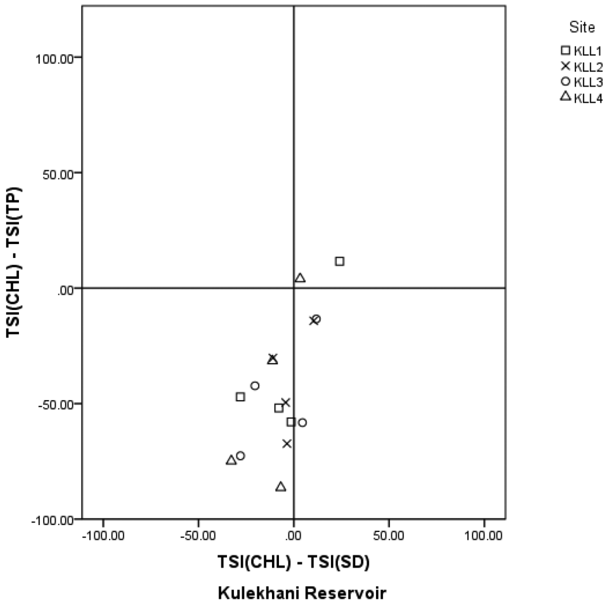

Figure 3b: Trophic state deviation of Kulekhani Reservoir.

However, this study has revealed that the lake is hypereutrophic during monsoon indicating a progressive increase in the concentrations of nutrients over the years particularly during the monsoon period. A similar result was obtained for Kulekhani Reservoir too with the reservoir showing hypereutrophic condition during the monsoon. These findings suggest that the monsoon runoff has a significant impact on the nutrient concentrations and trophic states of both the water bodies.

Most of the values of TSI_{CHL}-TSI_{SD} for both the water bodies lied in the third phase with negative mean and median values of TSI_{CHL}-TSI_{SD} and TSI_{CHL}-TSI_{TP} (Table 4). This indicates that algal productivity is being generally limited by non-algal turbidity. Many lentic systems in Nepal are phosphorus limited including Lake Phewa (Gurung et al., 2019; Rai, 2000). However, phosphorus is not the only limiting factor for aquatic primary productivity. Non-algal turbidity has long been established as a limiting factor controlling algal productivity and a similar case has been shown in this study. A recent study on Khacheopalri – a sub-tropical Himalayan lake in India has also reported its trophic state to be limited by non-algal turbidity (Nayek et al., 2018).

Table 4: Descriptive statistics of TSI deviation in Lake Phewa and Kulekhani Reservoir

TSI deviation	*Mean*	*Median*	*SD*	*Min*	*Max*
Lake Phewa					
TSI_{CHL}-TSI_{SD}	-13.39	-12.82	11.36	-34.21	0.04
TSI_{CHL}-TSI_{TP}	-41.56	-43.50	23.54	-73.45	2.42
Kulekhani Reservoir					
TSI_{CHL}-TSI_{SD}	-6.34	-5.56	15.64	-32.81	24.06
TSI_{CHL}-TSI_{TP}	-42.61	-48.30	28.46	-86.35	11.62

Different factors affecting the trophic status of water bodies include nutrients from allochthonous and autochthonous sources, lake morphometric features, catchment size and landuse, seasons (Lee et al., 2019; Soranno et al., 2015; Wetzel, 2001), watershed geological attributes (Watson et al., 2019). For instance, lake depth can affect water mixing (Wetzel, 2001), light availability (Liu et al., 2011), hydraulic residence time (An and Park, 2002; Laspidou et al., 2017) and dissolved oxygen availability, particularly at the lake bottom (Hou et al., 2013). Pollutants, minerals and nutrients have good sustainability with longer residence time. Hypolimnetic anoxic conditions can induce phosphate release from sediments via microbial activity (Wetzel, 2001), thereby increasing the nutrient concentration and planktonic growth. Seasons can induce variation in the algal productivity (Kasprzak et al., 2008) due to differences in the amount of allochthonous inputs from the catchments (Jain et al., 1999), atmospheric depositions (Zheng et al., 2019) and microbial processes (Shah et al., 2014). Catchments with agricultural land use practices tend to act as an important source of allochthonous materials in the water bodies (Silvano and Barbosa, 2015). Allochthonous inputs have been identified as one of the major pathways for nutrient inputs in a large number of reservoirs in Asia (Hwang et al., 2003) and include not only agricultural runoff but sewage discharge as well (Yadav and Pandey, 2017). The watersheds of both the waterbodies are prone to erosion (Shrestha et al., 2014; Watson et al., 2019). Landslides and increased agricultural runoff from their watersheds during the monsoon seem to be the major allochthonous sources of sediments and nutrients in Lake Phewa and Kulekhani Reservoir.

Conclusion

Based on Carlson TSI, Kulekhani Reservoir was classified as eutrophic to hypereutrophic and Lake Phewa was classified as mesotrophic to eutrophic to hypereutrophic showing seasonal variation. Non-algal turbidity limited the algal productivity in both the water bodies. The presence of hypereutrophic conditions in both the water bodies during the monsoon indicate increased allochthonous inputs from their respective catchments, giving a clear indication of anthropogenic impacts and watershed geological attributes. This implies the need for sustainable watershed management such as soil and nutrient management that has less potential for nutrient accumulation through runoff from the watershed. The findings of this study would be useful for future lake and reservoir management.

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