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Assessment of seasonal variation in physico-chemical characteristics of a lentic waterbody of Bhopal, India

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Abstract
The present study was conducted with an aim to assess the seasonal variation and nutrient status of a lentic water body (Lower lake) of Bhopal, India. Different variables involving water temperature (W.T), Secchi transparency (TRN), pH, total dissolved solids (TDS), conductivity (CON), total alkalinity (T.A), dissolved oxygen (DO), chlorides (CL), total hardness (TH), orthophosphate (PO_4^{-3}) and nitrate (NO_3-N) were examined using the standard methodology of APHA (2005). Significant seasonal variation was observed in Secchi transparency which ranged from 27 cm to 83 cm, chlorides (29 mg/l to 58 mg/l, dissolved oxygen (1.6 mg/l to 9.2 mg/l), phosphate (1.76 mg/l to 2.9 mg/l) and nitrate (0.98 mg/l to 3.57 mg/l). Our results confer that the water body is undergoing nutrient enrichment especially littoral sites due to direct influx of untreated sewage from surrounding urban settlements which has resulted in the deterioration of water quality of the lake. Pearson correlation analysis was employed to determine the relationship among water parameters which revealed both significant positive and negative trends.

Keywords: Lentic water body, seasonal variation, nutrient status

Introduction
Fresh water bodies occupy relatively small portion of the earth surface as compared to marine habitats, but their importance to man is far greater than marine systems due to direct dependence on these habitats. Lakes and reservoirs have been called the ecological barometers of the health of a city as they play a role in the regulation of the microclimate of any urban area (Ateshan and Saxena, 2015) [4]. The quality of water of the surface water bodies have a profound effect on urban ground water recharging network due to existence of direct interaction between surface and groundwater (Jumbe *et al*., 2008; Ravikumar *et al*., 2013) [8, 24]. Lakes provide range of environmental services, such as (a) drinking and irrigation water (b) support livelihoods- provide food and nutrition (c) recharge aquifers (d) recreational services-boating, swimming and fishing (e) rain waters harvesting (f) temporarily store storm water to prevent floods (g) wildlife habitat for fishes and birds and, (h) emergency water supply for fire fighting. Ecologically managed lakes are considered as natural infrastructures to climate change mitigation and adaptation strategy.

Today surface water bodies are most exposed to pollution due to its easy accessibility for disposal of pollutants and wastewaters. During the last decade, widespread deterioration in water quality of aquatic systems has been reported due to extensive use of synthetic fertilizers in agriculture, rapid development of industries and urban sprawl (Olajire and Imeokparia, 2001; Murray *et al*., 2010) [19, 18]. The water quality and the health of the aquatic ecosystem of lakes are very sensitive issues and are essentially determined through its trophic status; based on a classification scale for how productive the lake is. Eutrophication is an ecological process, similar to aging, in which a water body is increasingly enriched. The dynamic nature of the biological productivity and eutrophication due to natural and enhanced anthropogenic activities leaves no single assessment variable as a true measure of the nutrient status of a given aquatic system (Xu *et al*., 2001; Padisak *et al*., 2009) [39, 21]. Lakes particularly in developing countries are unfortunately facing severe problems due to varied human activities and unsustainable use of these resources. Human activities in the surrounding watershed have been accelerating the process of nutrient enrichment thereby affecting the water quality,

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resulting in loss of biodiversity and ecological functions. In India, lakes and reservoirs are experiencing varying degrees of environmental degradation due to encroachments, eutrophication (from domestic and industrial effluents) and siltation. Development has brought many undesirable modifications to environment with increased number of industries and population. There has been a tremendous population increase during the last century without a corresponding expansion of civic facilities, resulting in lakes and reservoirs, especially urban ones, becoming contaminant sinks. Sustainable supply of fresh and clean water to growing population is one of the main issues of populated cities like Bhopal.

Study area
Lower lake (23°16′0″N and 77°25′0″E) is an urban waterbody located in the heart of Bhopal city of Madhya Pradesh (Fig. 1). The city is famous for its numerous lakes. Lower lake is a part of Bhoj wetland (a Ramsar site) which comprises two man-made basins, the "Upper lake" and the "Lower lake".

The Lower lake has been constructed on the downstream of the dam of Upper lake. The lake receives subsurface seepage from the Upper Lake and drainage from numerous sewage filled nallahs. The waterbody has area of 1.29 km^2 and catchment area of 9.6 km². The average depth of the waterbody appeared to be 3.8 m with maximum depth of 10.7 m. Lower lake is surrounded on all sides by dense urban settlements. The waterbody faces anthropogenic degradation mainly due to human population growth and urbanization.

In the present investigation, 4 sampling sites, 3 littoral sites viz., Site I (Kali Mandir), Site II (Ginnori) and Site III (MVM College) and a central site (Site IV) have been selected to represent catchment characteristics and ecological conditions prevailing in the lake (Fig.). Submerged and floating macrophytes such as *Ceratophyllum demersum, Hydrilla verticillata and Eichornia crassipes* grow in the lake. Among all the sites, Site IV is the deepest site located towards the centre of the lake and is devoid of any macrophytic vegetation.
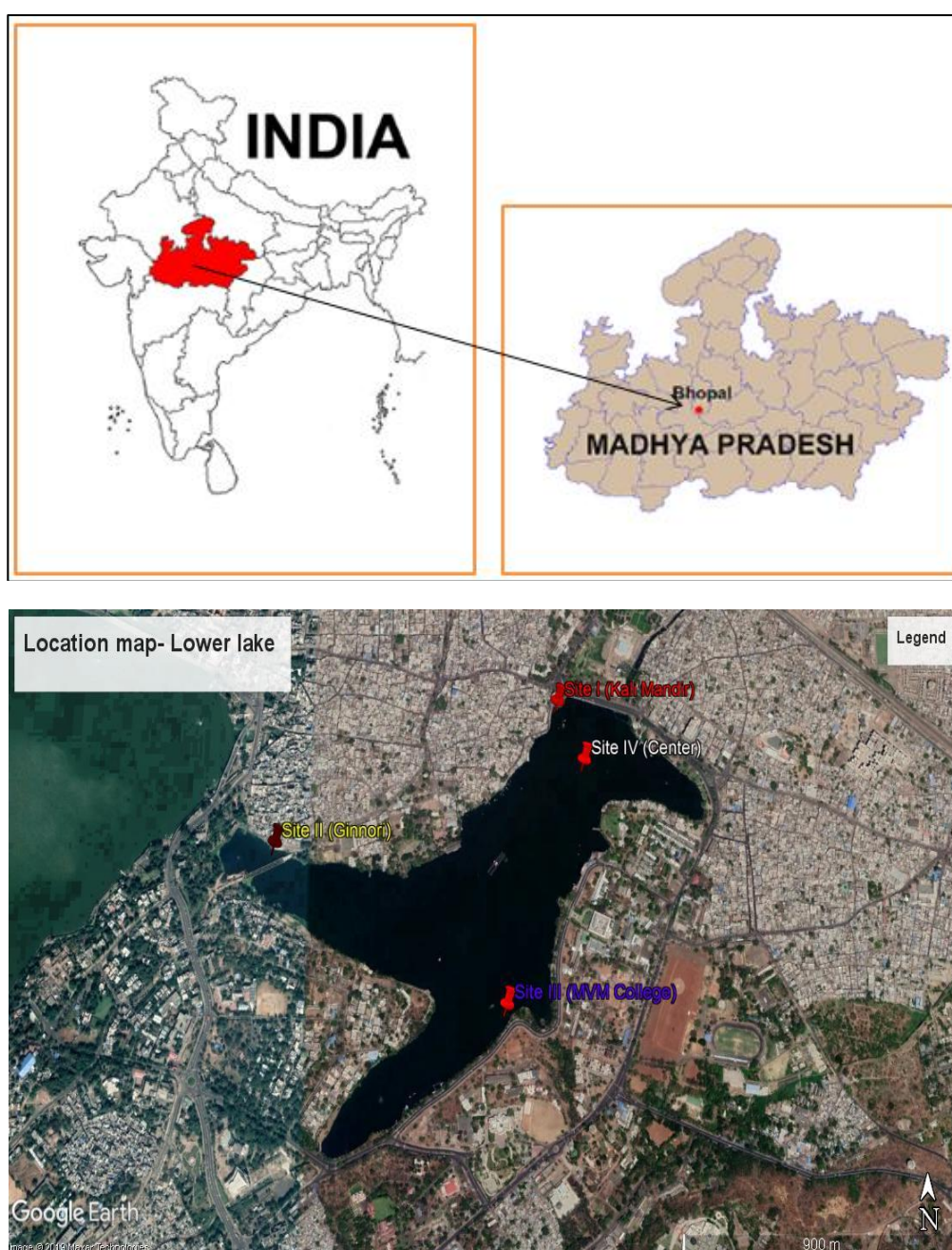

Fig 1: Lower lake of Bhopal

Material and Methods
Water samples were collected in triplicates from selected sites during winter, 2016 to monsoon, 2016 and the results were expressed as average values. Collected water samples were preserved and transported to laboratory and analysed within 24 hour as per the standard procedures recommended by APHA (2005) [2] and CSIR (1974). Water temperature and pH were measured on the spot by means of a mercury thermometer and digital pH meter. Dissolved oxygen (DO) was analysed by modified Winkler method (APHA 1998). The other selected water quality parameters include total alkalinity, chlorides, total hardness, nitrate-nitrogen and orthophosphorus (PO_4^{3-}). Careful calibration and blank measurements were performed to acquire accurate values (APHA 2005; CSIR 1974) [2]. Statistical analysis was carried out using OPSTAT (Sheoran *et al*., 1998) [29].

Result and Discussion
Lower lake is located within the tropical conditions, atmospheric temperature ranged between 20.4 °C in winter and 39 °C in summer (Fig. 2a). Water temperature is regarded as vital, as it controls distribution of aquatic biota (Wetzel, 1983) [36], influences limnological phenomenon such as solubility of gases, pH, conductivity and biological production (Singh, 1990; Lewis, 2000) [12]. In the present study, the water temperature showed significant seasonal variation (ranged from 16.7 °C to 29 °C) in winter and summer respectively (Fig. 2b). The Secchi transparency fluctuated between 27 cm to 83 cm as depicted in Fig. 2c. Lowest transparency in summer season is a consequence of suspended matter and maximum population of phytoplankton (*Microcystis aeruginosa, Scenedesmus* sp. and *Planktothrix aghardhii*) in the epilimnetic water which significantly reduce the penetration of light into the lake. In contrast, maximum water transparency during winter may be attributed to low phytoplankton population, low suspended load due to absence of rains and run-off. This fact is in agreement with the studies of Mahar, (2003) [15] and Singh *et al*., (2017) [33]. pH is an important hydrological variable as it influences many biological and chemical processes within a water body (Shah and Pandit, 2013; Yaseen et. al., 2015) [26]. The pH of the lake water fluctuated between 6.8 units during winter to 8.9 units in summer (Fig. 2d). Near neutral pH has also been observed by Wanganeo and Ishaq, (2011) [34] and Ahmad and Wanganeo, (2015) [6] in Bhoj wetland of Bhopal. Furthermore, alkaline nature of the water reveals productive nature of the waterbody. Whitemore, (1989) [37] and Whitemore *et al*., (2006) [38] described alkaline pH to be a characteristic feature of eutrophic and mesotrophic waters. The concentration of TDS varied between 286 ppm at Site IV in winter to 460 ppm at Site II during monsoon implying that TDS concentration in the lake is also controlled by rainfall during which urban run-off loaded with silt and clay in combination with influx of household sewage result in the increasing concentration of dissolved solids. Salahuddin *et al*., (2013) [25] also related high TDS load to entry of urban wash off and sewage into the Narsinh Mehta Lake of Gujrat during rainy season. Similarly, conductivity which gives an indication about the total ionic strength of the solution varied from 372 μS cm⁻¹ (at Site IV) to 537 μS cm⁻¹ at Site II in summer and monsoon season respectively (Fig. 2f). Higher values of conductivity during monsoon season reflects the influx of sewage from surrounding human habitations and subsequent mineralization of organic matter thereby causing an increase in the conductivity of water as also opined by

Prasannakumari *et al*., (2000) [23], Khatri and Dhankar, (2003) [10] and Sharma and Tiwari, (2018). The low conductivity values recorded during summer season may be due to maximum uptake of nutrients by the autotrophs (Lu *et al*., 2010; Bhat and Pandit, 2014) [5]. Wanganeo and Pani, (1998) [35] have reported low average conductivity values for Lower lake (255.71 μS cm⁻¹) as compared to our studies indicating that the waterbody has considerably accumulated nutrients during the course of time. According to Kadam, (1990) [9], waterbodies having high electrical conductivity indicate higher pollution status. Alkalinity is a quantitative capacity of water to neutralize acids. The lake water was found to be alkaline (126 mg/l in summer to 174 mg/l in winter) throughout the monitoring period (Fig. 2g). Similar trend has been obtained by Bhat *et al*., (2015) [6] in Bhoj wetland of Bhopal. The concentration of chloride in Lower lake was quite high and fluctuated between 29 mg/l in winter and 58 mg/l in summer (Fig. 2h). Lower lake receives organic waste and untreated sewage continuously from adjacent housing colonies which is responsible for the rise in chloride levels as reported by Pathak and Pathak, (2012) [22] in Sagar Lake. Dissolved oxygen (DO) is one of the most important parameter, helps in determining the water quality criteria of a water body. Its concentration is essential to support the biodiversity of aquatic ecosystems (Parna and Burrows, 2005; Matta *et al*., 2015). Minimum dissolved oxygen (1.6 mg/l) at Site III and maximum dissolved oxygen (9.2 mg/l) at Site IV was recorded during monsoon and summer season respectively (Fig. 2i). The high concentration of DO in lake water during summers is a consequence of high planktonic production due to which more oxygen is released as a result of photosynthetic activity. Authors like Singhal *et al*., (1986) and Sharma, (2014) also reported high DO concentration during summer months in different waterbodies of India. Total hardness values varied between 120 mg/l to 162 mg/l with high concentration in monsoon and low in winter season (Fig. 2j). The runoff loaded with high concentration of Ca and Mg cations in addition to sulphates and nitrate during monsoon rains may be the reason for higher hardness in lake during monsoon season. Besides this, Lower lake is situated in the heart of the densely populated city, so there is continuous influx of sewage into the lake, thereby altering the water quality of the lake. High hardness values during monsoon season have been reported by Angadi *et al*., (2005) [3] in Papnash pond of Karnataka. Phosphorus (P) is a key biological nutrient required for all living organisms. Biological organisms commonly take orthophosphate (PO_4^{3-}) which is a soluble form of phosphorus. The concentration of this critical nutrient ranged from 1.76 mg/l in summer to 2.9 mg/l in monsoon season (Fig. 2k). Lower value during summer indicates its incorporation in algal biomass which has also been confirmed by Komárková and Hejzlar, (1996) in Rimov reservoir of Czech. However, high concentration of orthophosphate during monsoon may be related to the contribution of runoff from surrounding areas due to which substantial amount of phosphate is washed down into the lake. Ling *et al*., (2017) [13] also confirmed rise in phosphate concentration in a tropical reservoir of Malaysia during rainy season. Furthermore, the values of orthophosphate obtained in our study were extremely high in comparison to previous records of Valecha *et al*., (1991) who recorded PO_4^{3-} in the range of 0.095 mg/l to 0.42 mg/l indicating that the waterbody is undergoing tremendous nutrient enrichment resulting in increased algal biomass and deterioration of water quality of the lake. The concentration of NO_3-N in the waterbody

fluctuated between 0.98 mg/l in summer and 3.57 mg/l in winter (Fig. l). The contribution of nitrate in urban water bodies is mainly due to discharge of nitrogenous wastes. Decrease in nitrate level in summer may be due to three processes which include its uptake by phytoplankton as a source of nutrient, its reduction to ammonical form and incorporation in biomass (Maier, 2015). Gosh and Salla, (2014) reported enhancement in nitrate concentration to the extent of 2.81 mg/l in Lower lake and concluded that the main contribution of this nutrient is household sewage and organic matter.

Pearson Correlation analysis was employed to determine the relationship among the physico-chemical variables (Table 1). pH showed significant positive correlation with water temperature (r= 0.967*, $p<0.05$), whereas significant negative correlation existed between total alkalinity and water temperature (r= -0.994*, $p<0.05$). Chlorides depicted significant negative correlation with transparency (r= -0.999*, $p<0.05$) and total alkalinity (r= -0.998*, $p<0.05$). PO_4^{3-} revealed significant negative correlation with pH (r= -0.994*, $p<0.05$). Significant negative correlation was observed between NO_3-N and water temperature (r= -0.993*, $p<0.05$).

Table 1: Pearson correlation between physico-chemical parameters

	W.T	TRN	pH	TDS	CON	T. A	CL	DO	TH	PO_4^{3-}
TRN	-0.977									
pH	0.967*	-0.892								
TDS	0.761	-0.881	0.572							
CON	-0.461	0.263	-0.67	0.225						
T. A	-0.994*	0.994	-0.935	-0.826	0.363					
CL	0.987	-0.999*	0.913	0.857	-0.309	-0.998*				
DO	0.736	-0.576	0.883	0.121	-0.94	-0.659	0.615			
TH	-0.23	0.02	-0.469	0.456	0.97	0.125	-0.068	-0.828		
PO_4^{3-}	-0.932	0.835	-0.994*	-0.475	0.751	0.888	-0.861	-0.931	0.567	
NO_3-N	-0.993*	0.972	-0.973	-0.745	0.482	0.991	-0.982	-0.752	0.254	0.941

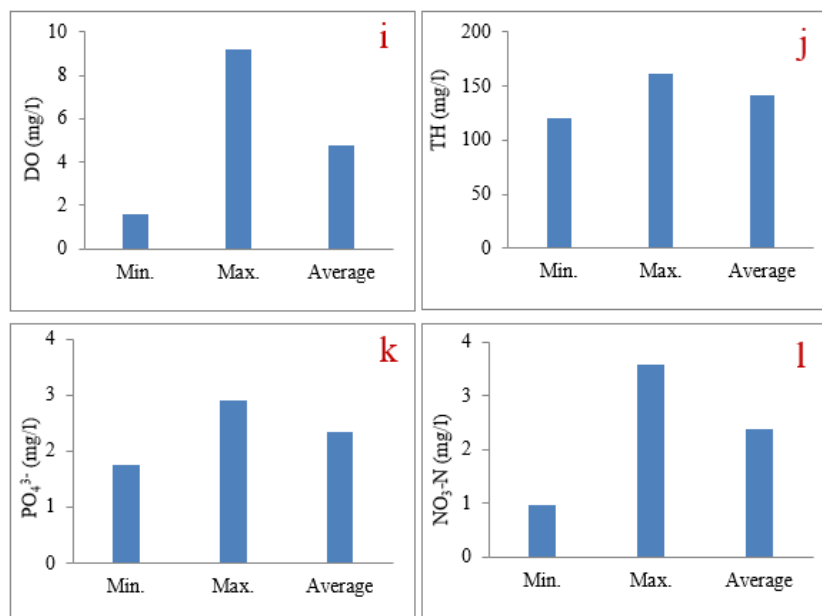* Correlation is significant at the 0.05 level
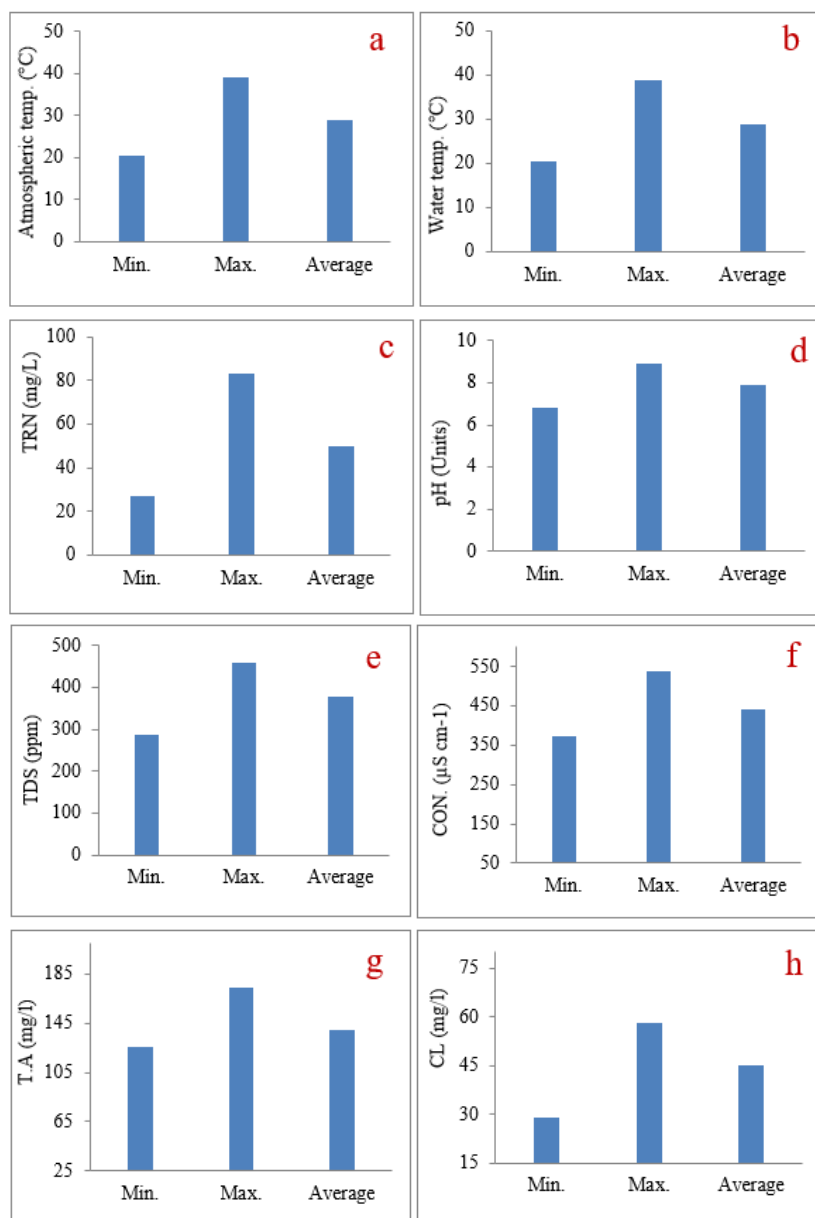
Fig (2a- l): Variation in various limnological variables of Lower lake

Conclusion
The present study revealed that Lower lake is experiencing increasing disturbances from anthropogenic activities occurring in the vicinity like input of untreated domestic sewage and storm water runoff mainly responsible for the nutrient enrichment in the lake. High values of orthophosphate, nitrate and low Secchi transparency reflect high nutrient status of the waterbody. Sewage treatment management and solid waste management are suggested to prevent the waterbody from deterioration and destruction.

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