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Spatial and Temporal Variations of Nitrogen and Phosphorus in Wular Lake Leading to Eutrophication

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ABSTRACT

Excessive nitrogen (N) and phosphorus (P) are said to be the main driving factors of eutrophication. Eutrophication is a worldwide problem in the aquatic ecosystems. Present study was undertaken to study the spatial and temporal variations of nitrogen and phosphorus in Wular lake (Ramsar Site-A Wetland of International Importance) in Kashmir Himalaya. Higher nitrogen concentrations were registered in winter and lower values were evinced in summer throughout the study. Minimum values of ammonical nitrogen (33.7±10.4 $\mu g\ L^{-1}$) were observed at site III having profuse growth of macrophytes and maximum of 338±43.1 $\mu g\ L^{-1}$ was registered at site VIII (inlet site). Nitrate nitrogen concentration was maintained higher during winter (827.7±35.9 $\mu g\ L^{-1}$), being followed by spring (666.7±67.7 $\mu g\ L^{-1}$) and decreased to lowest (204±9.6 $\mu g\ L^{-1}$) in summer. Contrarily to the above, phosphorus dynamics depicted a different trend, registering higher values in summer and lower values in winter. Higher values of P in summer are attributed to its high internal loading enhanced by warm conditions. The overall nutrient source varied greatly among different catchments depending upon anthropogenic pressures and discharge from the main inlet besides other tributaries. Principal Component Analysis (PCA) revealed that sites I, II, VIII and IX fall in component 1, depicting polluted nature of the sites. Pearson correlation reflect significant positive correlation between ammonical nitrogen and nitrate nitrogen ($r = 0.668$) and negative correlation between total phosphorus and nitrate nitrogen ($r = 0.702$). Bray-Curtis dendrogram showed close similarity (0.98%) between sites V and VI, followed by sites IV and VII.

Key words: Nitrogen, phosphorus, internal loading, eutrophication, shallow lake

INTRODUCTION

Nutrient loading to the aquatic ecosystems is the main cause of eutrophication (Vollenweider, 1968; Hutchinson, 1973; Jeppesen *et al.*, 1997; Sondergaard *et al.*, 2002; Moss *et al.*, 2013). As a result of eutrophication, algal blooms develop rapidly (Smith, 2003). Algal blooms, may directly affect the aquatic ecosystem as well as the humans, impairs water quality and results in change in biological community (Carpenter *et al.*, 1998). Algal blooms limit light penetration in the deeper layers, plummeting growth, causing die-offs of aquatic plants in littoral zone and in addition, they worsens the pray-predation interaction that need light to track and catch prey (Lehtiniemi *et al.*, 2005). During cyanobacterial blooms, small sized zooplankton tends to dominate plankton communities and this has been attributed to anti-herbivore traits (e.g., toxicity, morphology and poor food quality) of cyanobacteria (Porter, 1977). Some algal blooms pose an additional threat by producing noxious toxins (microcystin and anatoxin-a) within freshwater ecosystems (Chorus and Bartram, 1999). In all cases, the linkages between harmful algal blooms and eutrophication are complex and include nutrient enrichment by indirect pathways (Anderson *et al.*, 2002; Gilbert *et al.*, 2005). Eutrophication results in depleting dissolved inorganic carbon and increase in pH due to high rate of photosynthesis by algal blooms. Increasing pH values, in turn, can blind organisms that rely on perception of dissolved chemical cues for their survival by impairing their chemosensory abilities (Turner and Chislock, 2010). Growing anthropogenic activities are responsible for consistent increase in nitrogen and phosphorus export to the aquatic ecosystems causing cultural eutrophication (Schlesinger, 2009). However, the significant anthropogenic nitrogen and phosphorus mobilization through agricultural activities and waste water discharges produces detrimental impacts on the aquatic environment as well as on the human health (Lavelle *et al.*, 2005; Billen *et al.*, 2011; Durand *et al.*, 2011). Further, lakes and wetlands have capability of removing a considerable part of incoming nitrogen and phosphorus load but this capacity is limited and strongly depends on the local ecosystem characteristics (Durand *et al.*, 2011). Consequently, there is a lot of uncertainty on the amount of self-purification by these aquatic ecosystems (Hejzlar *et al.*, 2009). Therefore, the present study highlights the spatial and temporal changes in nutrient concentrations of nitrogen and phosphorus in the lake.

MATHODOLOGY

Wular Lake, the largest freshwater lake in the Indian subcontinent, is a shallow macrophyte dominated rural valley lake, located 34 km northwest of the city of Srinagar in the high altitude valley of Kashmir (between 340 16'-340 20'N latitude and 740 33'-740 44'E longitude). The lake is mono-basined, elliptical in shape and is of fluviatile origin, formed by the meandering of River Jhelum. It lies at an altitude of 1580 m (a.m.s.l.) and its depth is on average 3.6 m, though it reaches 5.8 m at its deepest point (Shah, 2012; Shah and Pandit, 2013a, b). The major inflows to the Wular Lake are River Jhelum and streams like Gurror, Madhumati and Erin. The lake plays a significant role in the hydrographic system of the Kashmir valley by acting as a huge reservoir, absorbing the high annual flood of River Jhelum (Shah and Pandit, 2012). The largest freshwater shallow lake in 1990 has assumed the status of a Ramsar Site, a Wetland of International Importance.

To study the spatial and temporal variations of nitrogen and phosphorus in the lake water, samples were collected on monthly basis (September 2012 to August 2013) and the results were interpreted on seasonal basis. Standard protocols of APHA (1998) and Wetzel and Likens (2000) were followed. Color intensity was measured using Systronics-116 spectrophotometer model. Nine sites differing in various characteristics like water depth, vegetation and other biotic factors were chosen for the present study (Fig. 1). Sites I and II were chosen near villages Vantage and Laharwalpora, respectively having high anthropogenic pressures from the catchment. Sites III (near Ashtung), IV and V (near Watlab) have well developed macrophytic vegetation with less human interference while, sites VI and VII were located near the outlet of the lake (near Ningli) and the remaining two sites (VIII and IX) were situated near the inlet i.e., River Jhelum (near Makhdoomyari) of Wular lake.

Statistical analysis: Statistical analysis were performed using SPSS (statistical version 11.5 for windows 7, SPSS and Chicago, IL., USA). The relation between various study sites were calculated by another software programme PAST (statistical version 1.93 for windows 7).

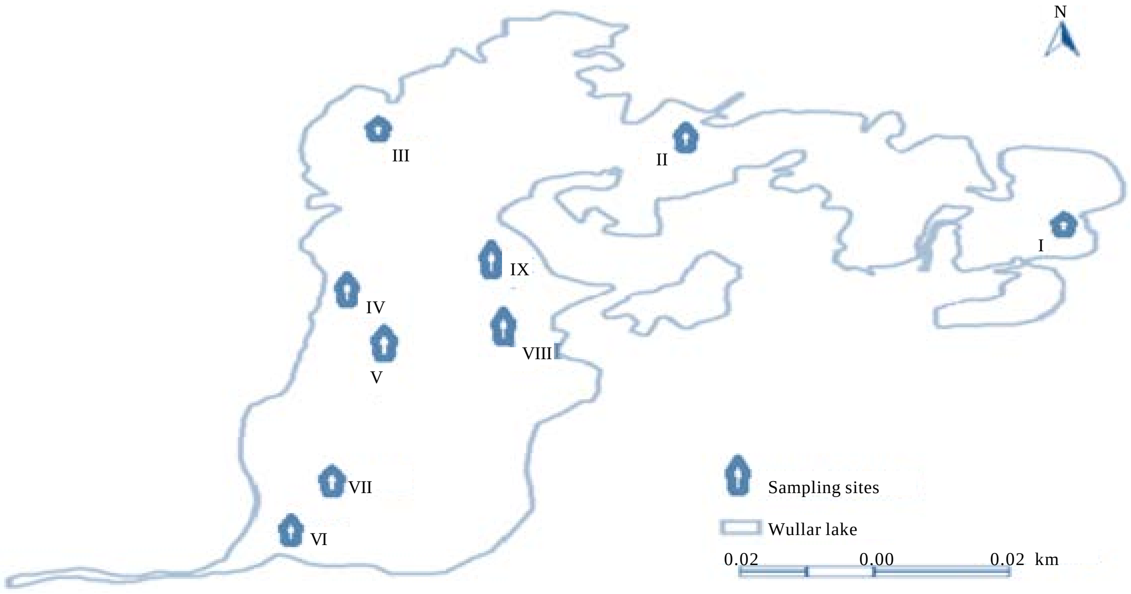

Fig. 1: Wular lake showing study sites

RESULTS AND DISCUSSION

Eutrophication of waterbodies is a world-wide predicament resulting in high phytoplankton production with severe repercussions for both the ecological state and drinking water quality in the water bodies (Smith, 2003; Jin *et al.*, 2005; Schindler, 2006). The reasons being excessive loading of nutrients are from a number of point, non point sources and the internal lake processes especially in shallow ones (Jeppesen *et al.*, 1997, 1999; Gulati and van Donk, 2002; Sondergaard *et al.*, 2002). District spatial and temporal variations were observed among the studied parameters throughout study period. Higher nitrogen concentrations were registered in winter and lower values were evinced in summer. During the entire study period, minimum values of ammonical nitrogen (33.7±10.4 μg L^{-1}) were observed at site III and a maximum (338±43.1 μg L^{-1}) at site VIII (Fig. 2). However, greater levels of nitrate nitrogen were obtained during winter (827.7±35.9 μg L^{-1}) at site VIII and spring (666.7±67.7 μg L^{-1}) at the same site. In contrast, lower values were reported in summer till it touched the lowest ebb of 204±9.6 μg L^{-1} at site V (Fig. 3). Conversely, phosphorus dynamics depicted a slightly different picture with distinct variations, registering higher values of the nutrient in summer against the lower in winter. Distinct spatial variation of Ortho Phosphate Phosphorus (OPP) were also noticed, being greatest at site VIII (180.7±5.1 μg L^{-1}), followed closely by site II (173.7±6 μg L^{-1}) till it touched the lowest of 20.3±6.5 μg L^{-1} at site VII (Fig. 4). Like OPP, Total Phosphate Phosphorus (TPP) was also highest in summer (409.3±15.9 μg L^{-1}) and lowest in winter 91.7±7.6 μg L^{-1} (Fig. 5).

Greater levels of nitrogen in winter can be attributed to lower biological activity by the microorganisms as a result of low temperatures and low diversity of aquatic vegetation. Authors, Kaul *et al.* (1978), Pandit (1980, 1984, 1999) and Laznik *et al.* (1999) ascribed lower nitrogen levels during summer to the consumption of nitrate nitrogen by phytoplankton, macrophytes and denitrification processes in the sediments. Wetlands which are associated with agricultural area (as Wular lake) receive nitrate as a dominant form which later converted into other forms by

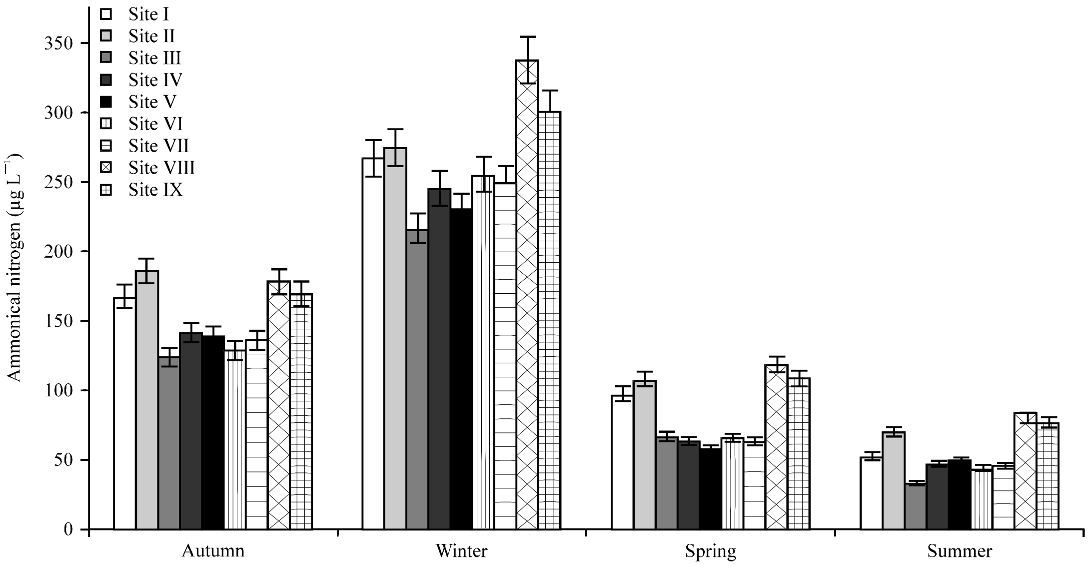

Fig. 2: Seasonal variations of ammonical nitrogen (µg L^{-1}) at nine study sites of Wular lake

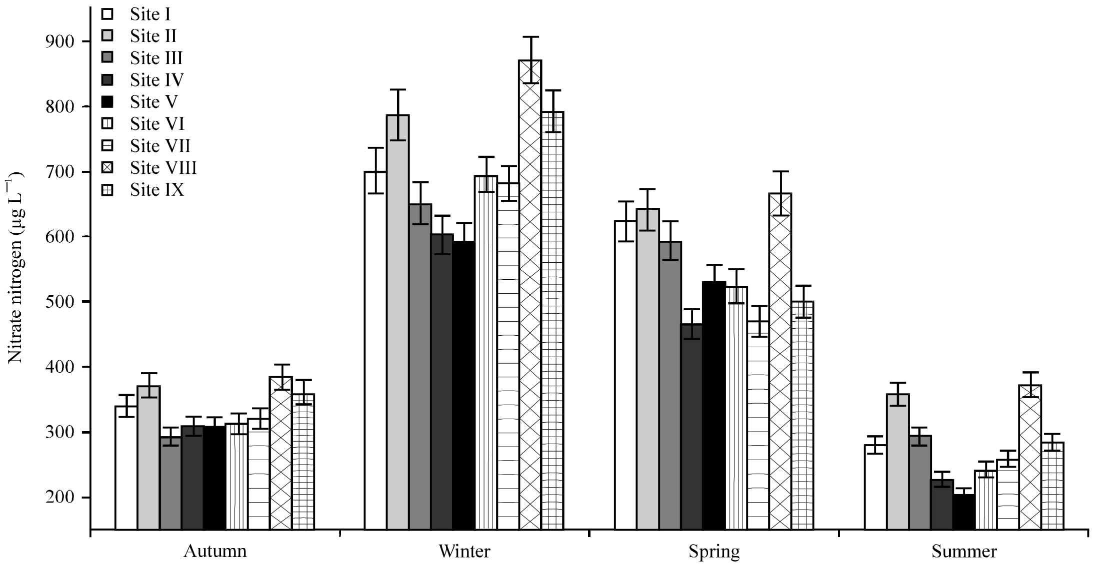

Fig. 3: Seasonal variations of nitrate nitrogen (µg L^{-1}) at nine study sites of Wular lake

denitrification and less by nitrification (Johnston, 1991; Trepel and Palmeri, 2002). Further, wetlands containing macrophytes has a remarkable effect on the dynamics of nitrogen removal during their growth period, as these aquatic plants remove large portion of nitrate as compared to unplanted wetlands (Pandit, 1980; Bastviken and Wittgren, 2001; Moss *et al.*, 2013). However, plants assimilate only a small percentage of the total nitrogen removal when the nitrogen load is high (Tanner *et al.*, 1995).

Ammonical nitrogen is generated by heterotrophic bacteria as the primary end product of decomposition of organic matter and is readily assimilated by plants (Wetzel, 2001). Quiros (2003) is of the opinion that lower nitrogen forms in summer can be attributed to impounding by

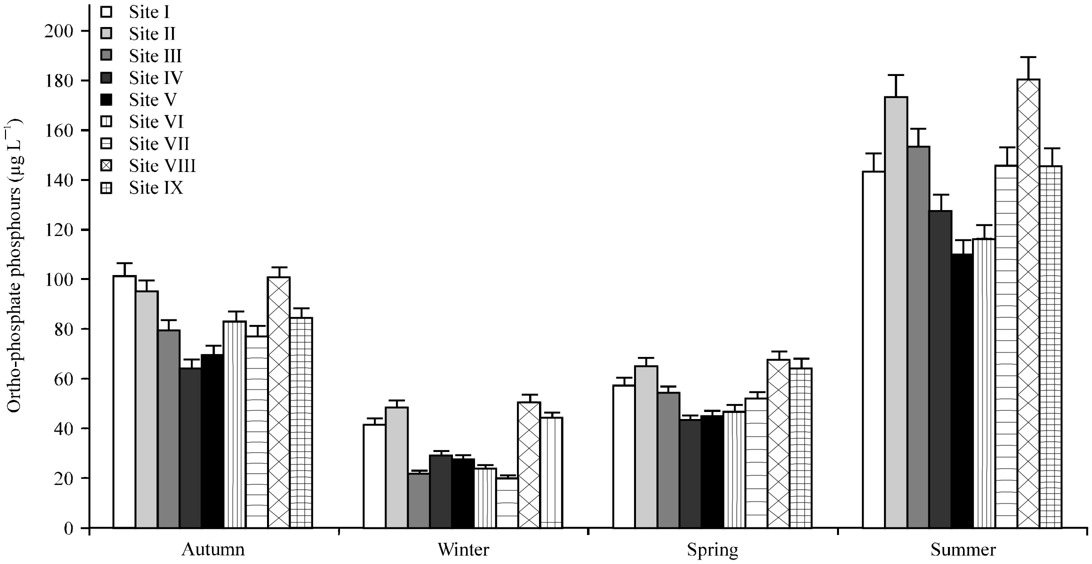

Fig. 4: Seasonal variations of ortho-phosphate phosphorus (µg L^{-1}) at nine study sites of Wular lake

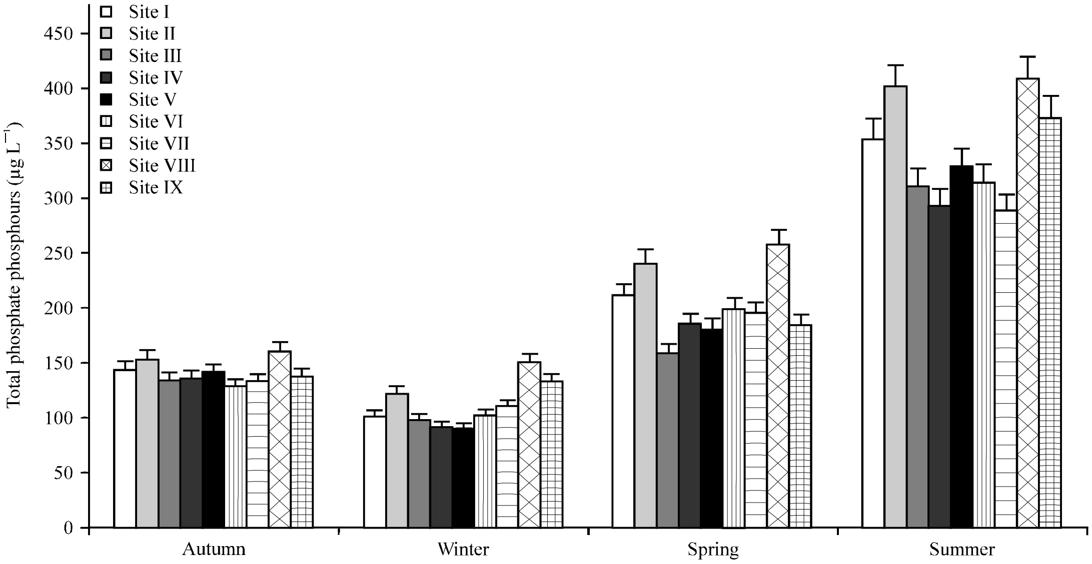

Fig. 5: Seasonal variations of total phosphate phosphorus (µg L^{-1}) at nine study sites of Wular lake

phytoplankton. Further, uptake of ammonical nitrogen is favoured by phytoplankton as compared to nitrate due to the higher energy requirements for nitrate uptake (Galan *et al.*, 2004). Nitrate concentrations were significantly higher during the winter and spring and then fell in summer which is in consonance with the findings of Phillips *et al.* (1997). The relatively higher levels of nitrate nitrogen in spring is also ascribed to the application of nitrogen fertilizers in the immediate catchment being comprised of agricultural land and their subsequent leaching into the waterbody along with the high water discharge (along with run-off) during this season.

Moss *et al.* (2013) opined that the trophic status and water quality of lakes are mostly determined by P concentration, as it predictably limit productivity in fresh waters. In shallow lakes, the main reason for water quality degradation is high P content (Sondergaard *et al.*, 2003; Kangur and Mols, 2008). The concentration of P in the shallow lakes is slightly controlled by external P loading, however, internal lake process plays a major impact on the functioning of shallow lakes (Moore *et al.*, 1998; Egemose *et al.*, 2011; Erisman *et al.*, 2011). Filbrun *et al.* (2013) proposed a few criteria for the lakes having high internal P loading which include: (1) Lake morphometry (shallow depth, large surface area and long fetch), (2) Flat and intensely agricultural surrounding lands and (3) Increase of summer temperature (that co-vary with elevated pH and decreased light penetration). All these criteria befitting Wular lake, therefore, justify its high internal phosphorus loading.

Higher values of both the forms of phosphorus (OPP and TPP) were observed in summer against the lower values in winter which is in consonance with the earlier findings (Ahlgren, 1989; Phillips *et al.*, 1994; Barbiero and Kann, 1994; Boros *et al.*, 2009; Spears *et al.*, 2012). A perusal of the data showed that during summer and early autumn, 2-3 fold increase in P concentration was noticed as compared to winter which corroborates with the earlier studies of Sondergaard *et al.* (1999) who opined that in most eutrophic lakes, summer concentrations typically exceed winter concentrations by 200-300% from June until October. Kozerski *et al.* (1999) found that in summer, high P release rates were related to low nitrate input to Lake Müggelsee. Further, increases in temperatures strengthen microbial processes and diffusion from the sediments resulting in elevated P concentration in the overlying water column (Bostrom *et al.*, 1982; Maassen *et al.*, 2005). Internal loading may also be intensified by active transport of nutrients from the bottom to the water column by algae (Kangura *et al.*, 2013). The organic matter in the sediment of the lake originates mainly from plankton which is settled during winter. Decomposition of this material and release of P may constitute an important source of P to the overlying water column during the growing season (Kangura *et al.*, 2013). According to Sondergaard *et al.* (2003), increasing biological activity in spring in most lakes triggered the release of some of the P retained during winter. Due to increase in temperature, sediments in a shallow lake become warmer and bacterial activity also intensifies, releasing P which tends to increase while N may decrease owing to denitrification as the water warms (Andersen, 1982; Bostrom *et al.*, 1982; Jensen *et al.*, 2006). Especially in eutrophicated shallow lakes, there will be a substantial increase of P in the overlying water during summer (Sondergaard *et al.*, 2003), leading to a summer depletion of N (Hameed *et al.*, 1999; Jensen *et al.*, 2006).

Principal Component Analysis (PCA) was performed to ascertain the nature of the study sites. PCA revealed that in general, sites IX, I, II and VIII fall in component 1, reflecting high PCA score and experiencing high anthropogenic pressures within their catchment as a result of human settlements and agricultural practices. Among these polluted sites, site IX experienced severe pollution due to the sewage outfalls brought to the lake through River Jhelum itself. In contrast, component 2 revealed differential behaviour of other sites (III, IV, V and VI) which are infested by profuse growth of macrophytes, locking up nutrients in the growing season and reducing nutrient (N and P) levels (Fig. 6 and Table 1). Pearson correlation was carried out within these parameters which reflected significant positive correlation between ammonical nitrogen and nitrate nitrogen ($p<0.01$, $r = 0.668$) and negative correlation between total phosphorus and nitrate nitrogen ($p<0.01$, $r = 0.702$) (Table 2). Application of Bray-curtis dendrogram was meant to distribute the sites in two categories: (1) Four sites (I, II, VIII and IX) and

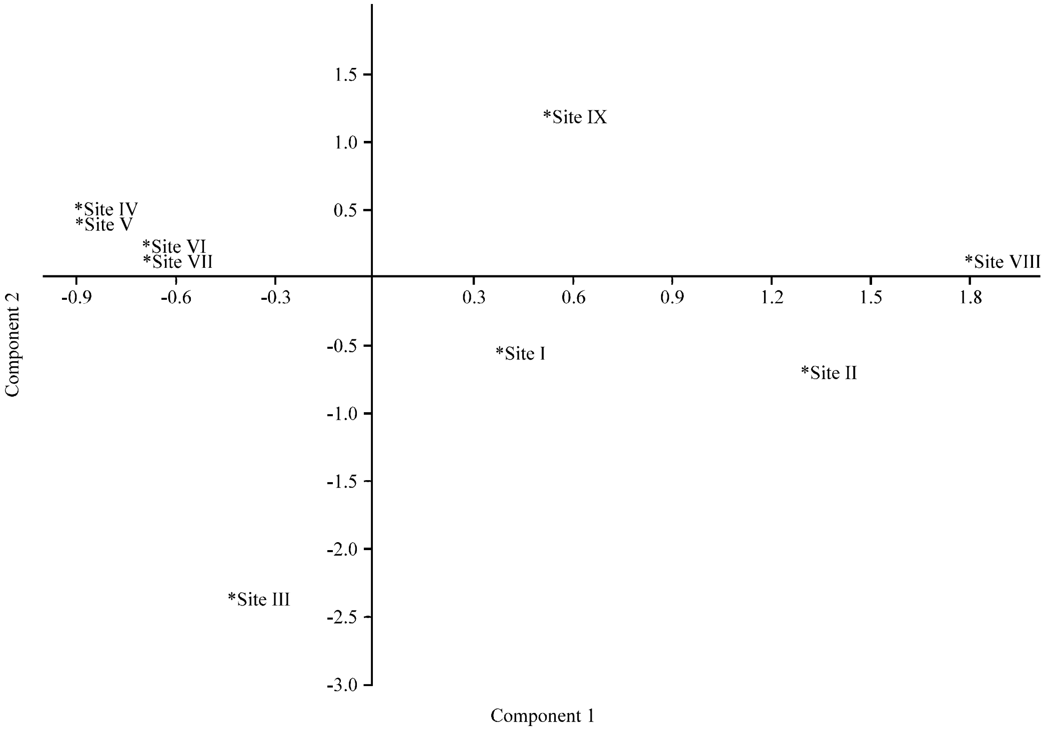

Fig. 6: Principal component analysis within study sites of Wular lake

Table 1: Principal Component Analysis (PCA) score of different study sites of Wular lake

	PCA scores			
Sites	1	2	3	4
I	0.36474	-0.41137	**0.68745**	0.477880
II	**1.21050**	-0.61906	-0.54651	-0.601420
III	-0.60385	-2.21940	0.35044	0.663680
IV	-0.90498	0.60973	0.22187	0.816750
V	-0.89624	0.56090	-1.68250	0.064697
VI	-0.72402	0.35823	-0.83307	0.023090
VII	-0.71756	0.22915	1.10790	-2.270500
VIII	**1.76660**	0.22542	-0.66845	-0.220140
IX	0.50480	**1.26640**	**1.36290**	**1.046**

Bold values represent high loading

Table 2: Pearson correlation coefficient within parameters

Parameters	NH_4N	NO_3N	OPP	TPP
NH_4N	1			
NO_3N	0.668(**)	1		
OPP	-0.592(**)	-0.700(**)	1	
TPP	-0.702(**)	-0.493(**)	0.854(**)	1

NH_4N: Ammonical nitrogen, NO_3N: Nitrate nitrogen, OPP: Ortho-phosphate phosphorus, TPP: Total-phosphate phosphorus, **Correlation at 0.01 (2-tailed)

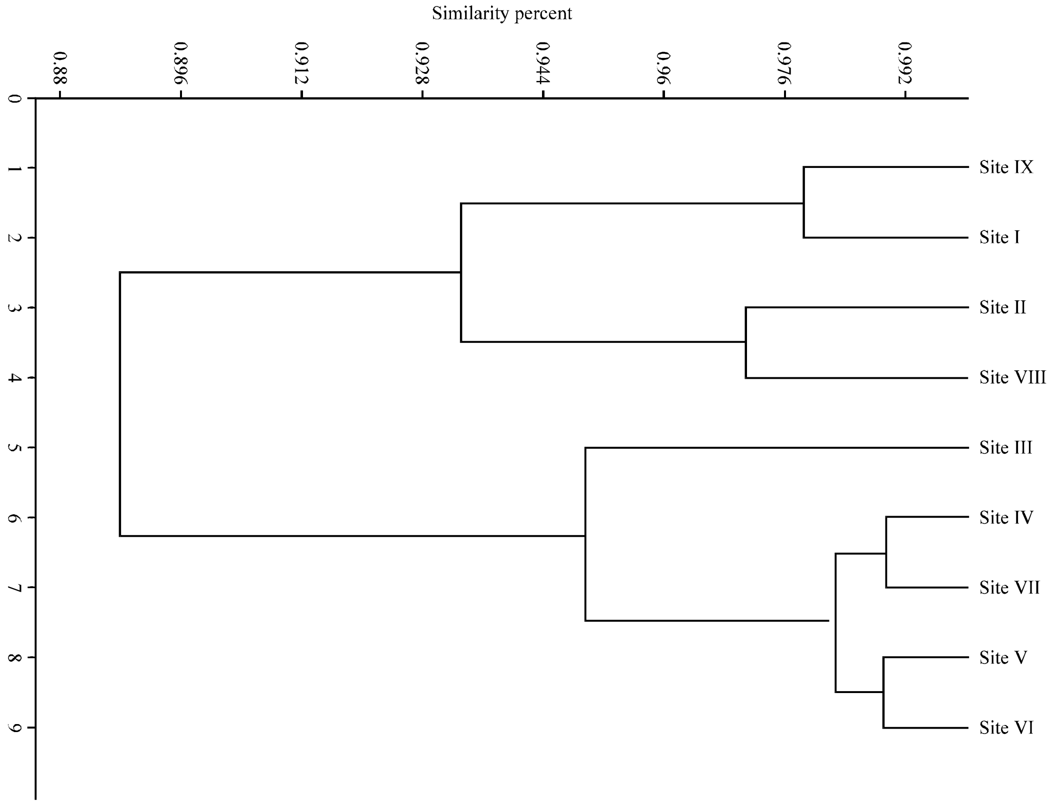

Fig. 7: Bray-Curtis analysis between various study sites

(2) Five sites (III, IV, V, VI and VI). The dendrogram depicted close similarity (0.98%) between sites V and VI (being in close proximity) followed closely by sites IV and VII having abundant macrophytic growth (Fig. 7).

CONCLUSION

Nutrient dynamics, particularly N and P, in the Wular lake showed distinct temporal and spatial variations in their concentrations. Highest phosphorus concentrations were observed in summer due to high internal loading as the lake under study is of shallow type. However, nitrogen concentrations were highest in winter, being followed by spring which is attributable to lower biological activity during this season. While as, moderate levels of the latter plant nutrient in spring are attributable to the high run-off from the catchment due to melting of snow and subsequent rainfall.

In order to control nutrient loading and restoring water quality of the lake, it is necessary to minimize and if possible, restrict the entry of nutrients especially N and P. In order to control, some necessary steps are taken, such as (1) Reduction of soil erosion, (2) Establishment of sewage treatment plants and (3) Overall reduction of point and diffuse sources of pollution to the lake. Further, constructions of settling basins around the lake especially along its tributaries will help in settling the major sediment load which, otherwise, will make the lake shallow and enhance eutrophication.

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