

# A Retrospective Environmental Assessment of the Natural Heritage of Dal Lake for Prospective Implication Scenarios

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**Abstract.** Monitoring at 30 sampling sites of Dal Lake is carried out to assess its spatial-temporal heterogeneity under human pressures. P surpass critical eutrophic index ( $\leq 0.05 \text{ mgL}^{-1}$ ) while nitrate-N persist beneath it ( $\leq 0.5 \text{ mgL}^{-1}$ ). Semi-drainage hydrology recuperates basin volume. Autotrophic assimilation and biocalcification episodes drop conductivity. Anionic prevalence of  $\text{HCO}_3^-$  and Cl exist along  $\text{Ca} > \text{Mg} > \text{Na} > \text{K}$  cationic progression. Autochthonous sediment OM at typical  $< 10 \text{ C/N}$  is the conventional nutrient source. Higher temperature and lower N:P ratio during summer develop P internal loading process. Cr, Ni and Zn exceed the sediment quality guidelines. OM enriched sediments and calcite co-precipitation curtails PTE mobility. Biomass parameters establish similar variations except species turn-over. OM immobilizes nutrients and OC provisions denitrification. Dal Lake exposed to anthro-urban intensification depends on comprehensive management interventions like National Plan for Conservation of Aquatic Ecosystems vital for insitu leniency control and lake-front improvement.

**Keywords:** Bioconcentration, compartmentalization, eutrophication, macrophytes, remediation, sewage.

## 1 Introduction

Water- the elixir of life founds a vital constituent of biota and has foremost expanse ( $> 70\%$ ) over the Blue Planet. Yet, out of the entire estimated global water assets approximately 3% only encompasses the fresh water. This limited stock becomes more indispensable when its major proportion of 99.7% is accounted as unavailable-water locked up in cryosphere or in deep sub-surface water pools while the meager remainder of  $113 \times 10^3 \text{ Km}^3$  exists as accessible surface fresh water [1]. But lakes globally assume the paramount (87%) of the 0.3% surface waters. Lakes feature as prominent standing water bodies over roughly 1.8% of the land area covering 2.5 million  $\text{Km}^2$  and containing about  $2.8 \times 10^5 \text{ Km}^3$  of water [2]. Lakes aren't mere water storages but perform complex dynamic hydrological, biogeochemical, geomorphological, climatic and other ecological functions. These aquatic ecosystems provide crucial services like: (a) Resource provision of water, food, fiber, fuel, fish, medicine, ornaments, and the like; (b) Regulating services of flood cum drought mitigation, self-purification, climate mediation, food-web linkages, aquatic biodiversity, ecotone buffer capacity, navigation routes, etc.; (c) Cultural services of socio-economic, aesthetic, religious, spiritual, recreational, historic and educational values; (d) Supporting services of heat energy budget, geological formation, nutrient cycling, water cycle, habitats and gene pool and primary production [3].

The state of Jammu and Kashmir (J&K) set in the north-west Himalayan biogeographic zone of India exists at an altitude  $\geq 1500 \text{ m a.s.l.}$  The asymmetrical vale of Kashmir measuring about  $15948 \text{ Km}^2$  has the latitudinal expanse of  $33^\circ 20'$  to  $34^\circ 54'$  N while its longitudinal extent is from  $73^\circ 55'$  to  $75^\circ 35'$  E. The temperate climatic valley has about 64% mountainous physiography with the Great Himalayas in its North and Pir Panjal range in its South. Kashmir is proprietary of a collection of natural lacustrine water bodies upholding paramount ecological, cultural, historical and socioeconomic significance. The estimated geographic area occupied by lakes in J&K is 13762 ha that approximates to 3.52% of all its aquatic ecosystems [4]. The lake typology of Kashmir with varying origin, elevational location and biotic composition include: (i) Glacial Lakes situated in snowline vicinity; (ii) Pine- Forest Lakes in the midst of timberline and (iii) Valley Lakes located across 1580 to 1600 m a.s.l. altitude [5]. These lakes harbour diverse gene-pool, act as indispensable source of food, fodder and manure and are sites of invaluable

aesthetic, tourism and recreational value [6]. Lakes are one of the utmost essential natural resources of our State. Apart from being valued natural habitats for a number of flora and fauna, they act as the life line for various communities of our state. No systematic scientific study mechanism for monitoring, planning and management of these lakes is in place as more than 90% of them remain neglected altogether till date. The very existence of the lacustrine water bodies is under continuously intensifying multiple stressors of nutrient loading, siltation, waste disposal, sewerage and agro-chemical residue receivers, expanding floating-garden area, encroachment, blockade and narrowing of drainage channels, hydrological alterations, catchment perturbations and so on [7].

## 2 Study Area and Methods

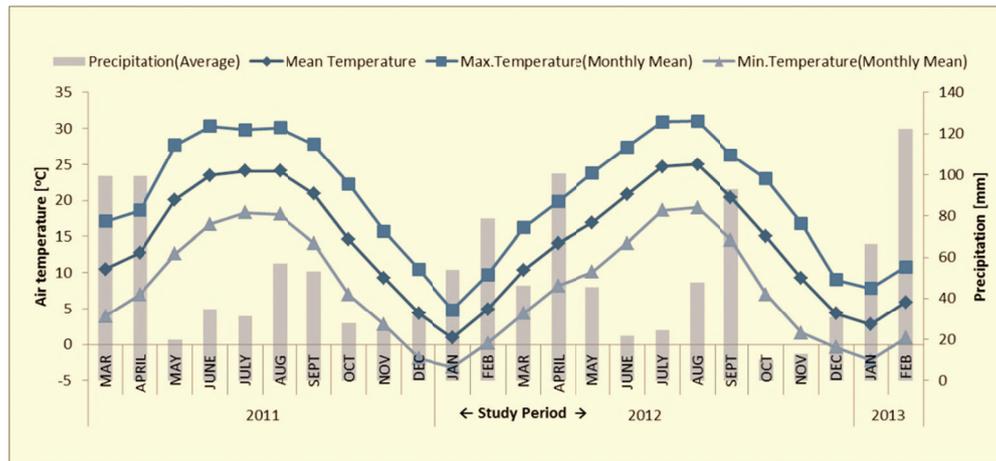


Figure 1. Climate profile of Srinagar 2011 - 2013 (Data source: India Meteorological Department).

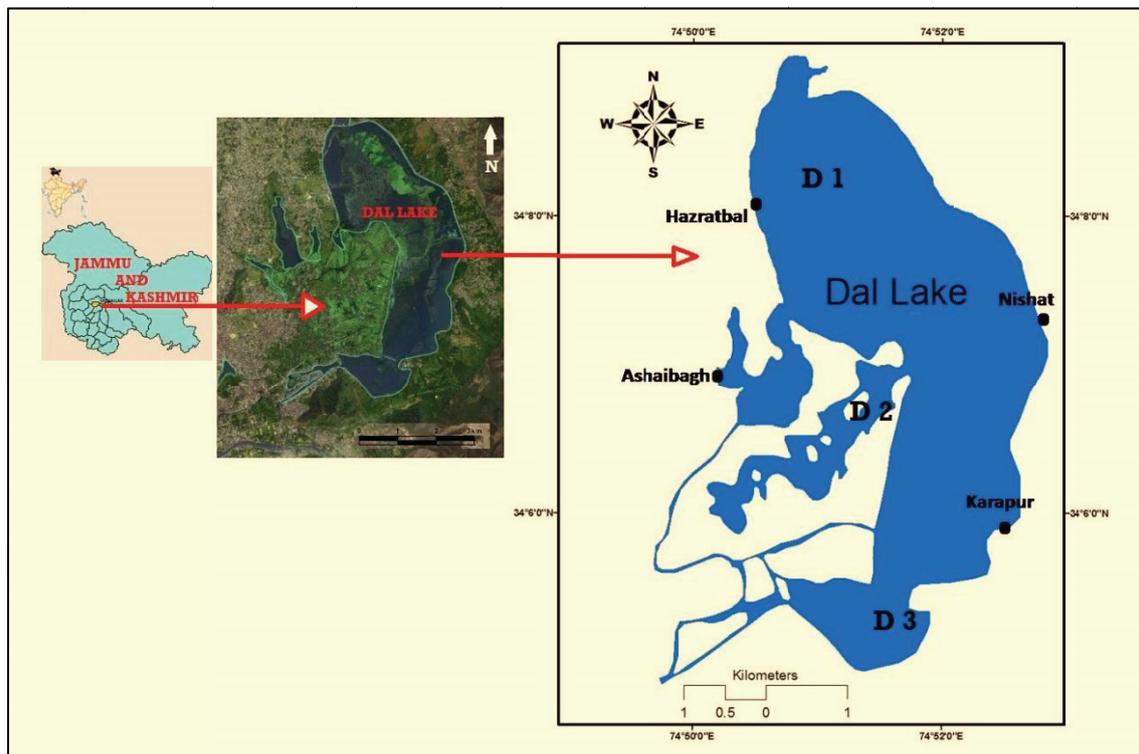
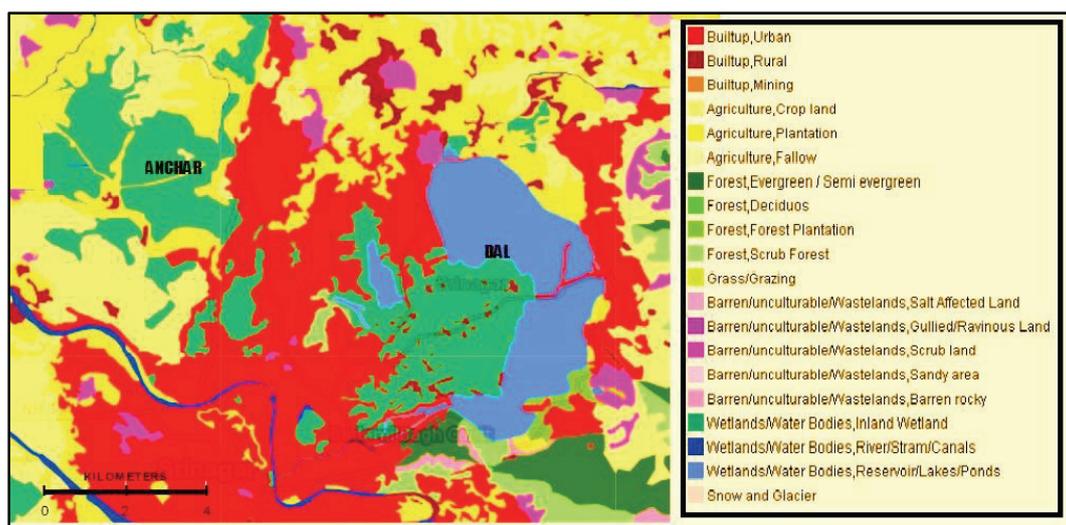


Figure 2. Location of study area (Dal Lake).

Lakes' are conventional natural laboratories to study numerous hydro-geochemical and ecological processes. Eutrophication predominantly impairs surface water quality [8] and [9]. A rational identification of undesirable pollution levels and appropriate desirable remediation targets is possible if assessments involving health risk [10] and ecological impact [11] are practiced. The summer capital (Srinagar) of J&K abides a lake area cover of 2194 ha equivalent to 21.76% of its total wetland area. The city of Srinagar (33°59'14" - 34°12'37" N latitudes and 74°41'06" - 74°57'27" E longitudes) sited on the banks of the Jhelum (Vyeth) spreads across the plains of Kashmir vale. It has a moderate physiography  $\geq 1580$  m a.s.l. representing hill topography. The general climatic conditions resemble the sub-Mediterranean characterized by year-long precipitation events except a few summer and autumn dry periods, besides, both seasonal and diurnal extremes of temperature. During the course of study, the maximum, mean and minimum monthly temperatures ( $^{\circ}\text{C}$ ) and average rainfall (mm) at Srinagar is illustrated in Fig. 1. The emphasis of current limnological research is a relatively managed fluvial urban valley lake namely Dal lake (Fig. 2). The geographical position of Dal lake is north-east of Srinagar city at 1587 m a.s.l. altitude occupying the coordinates of 34° 04' N to 34° 09' N and 74° 49' E to 74° 52' E [4]. It is a tetra-basined ox-bow type lake formed by meandering course of river Jhelum. Its focal feeding source is a perennial Dachigam brook (splitted into 3 rivulets of Telbal, Pishpu and Meerakshah) and several lake-bed springs, however, the main exit discharges via Dalgate into the Jhelum. Indian Institute of Technology (IIT), Roorkee designates an area of 337 km<sup>2</sup> as its catchment while stocking a water volume of  $15 \times 10^6$  m<sup>3</sup>. The 2007 satellite imagery database of Lakes and Waterways Development Authority (LWDA) reveals its total area as 24.6 Km<sup>2</sup> with an open water expanse of 15.41 Km<sup>2</sup> and the remaining occupied by floating gardens, emergent vegetation zone, house boats and human settlement area. A recent assessment intimates the open water spread restricted to just 10.5 Km<sup>2</sup> [12]. The mean depth averages to  $< 3$  m while the maximum depth equals 6 m. Dal is an urban recreational and tourism site having a significant socioeconomic association and reliance. As a consequence of continuous pressure from  $\sim 5$  lac population dwelling in and around the lake, it has degraded to eutrophic state [13]. Some of the problems and threats leading to lakes' deterioration [14] and [15] include nutrient enrichment, unsustainable tourist inflow, peripheral land use, unplanned urbanization, sewage and solid waste recipient, volume reduction by siltation, floating gardens for commercial vegetable production using pesticides and fertilizers, congestion of outflow channels, encroachment, weed proliferation, besides administrative bottle-necks in the form of infrastructural and staff shortage for effective execution of conservation projects. The Dal also receives point sewage effluents from 3 commissioned STP's [16] of 15.2 MLD capacity at Habak (34° 8' 50" N - 74° 50' 36" E), Hazratbal (34° 8' 6" N - 74° 50' 29" E) and Laam (34° 7' 42" N - 74° 52' 36" E).



**Figure 3.** Visualisation of land- cover/use for study site catchment (Source: NRSC/ISRO- Bhuvan).

A primary probe indicates the Dal as impartially managed-lake evident from its physical appearance and open-water surface area. However, the lake is gradually being overwhelmed by urban and agricultural conversions as apparent from the roseate expanses of satellite imagery (Fig. 3). The inter-annual survey, sample collection and hydrobiochemical study of the lake is based on its 3 zones. The three locations (Table 1) labelled as D1, D2 and D3 were further split into 10 sampling stations each (Fig. 2) in order to obtain composite representative samples in triplicate for superior precision. The zone assortment criterion applied here represents the distinct spatial features within the lake. D1 neighborhood is contributed with strategic inlet and sewage treatment plant (STP) discharges; D2 typifies the floating garden area; and D3 adjacent to the outlet is a hotel and house-boat sector. The pictorial glimpses of the select sites are provided in Plate I.

**Table 1.** Coordinates of sampling locations.

SITE	LATITUDE				LONGITUDE			
D1	34°	8'	35''	N	74°	51'	17''	E
D2	34°	7'	56''	N	74°	51'	44''	E
D3	34°	5'	53''	N	74°	51'	18''	E



**Plate I.** Pictorial glimpses of the study site.

The appraisal, sample gathering and limnological analysis of water, sediment and macrophytes from selected sites of the lake were carried out from March, 2011 to February, 2013. For the purpose of contemporary research, water, sediment and macrophytes are collected simultaneously at the same sampling locations. The water samples were analysed for temperature, pH, conductivity, bicarbonates, chloride, calcium, magnesium, sodium, potassium, nitrate nitrogen and total phosphorus on monthly basis while trace elements of Al, As, Cd, Co, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Se, Sn and Zn were measured for spring, summer and winter seasons. The collection, preservation, preparation, storage and estimation of water samples follow standard methods of [17], [18], [19], [20], [21] and [22]. The sediment analysis includes H-ion concentration, electrical conductivity, bicarbonates, organic-C, organic matter, total-N, C/N ratio, elemental composition of Ca, Cl, K, Mg, Na, P, S, Si and the given trace elements for each season. pH and electrical conductivity are determined immediately within 6 hours of sampling and the rest of the parameters are scheduled on oven dried samples following standard recommended methods from [23], [24], [25] and [26]. The biological component (macrophytes) employed in the study is of prominence amongst the lake-community structure and function. The select species (Plate II) chosen from emergent, free-floating, rooted-floating and submerged categories include *Myriophyllum aquaticum*,

*Salvinia natans*, *Nelumbo nucifera* and *Ceratophyllum demersum* respectively. Their selection represents omnipresent abundance at each sampling location besides being high biomass yielding, eutrophication tolerant and hyperaccumulators. The preferred producer species are recognized while referring to standard taxonomic scheme of [27], [28] and [29]. Over again, the macrophytic biomass was analysed for total chlorophyll content, biomass, productivity, specific growth rate, mineral composition (Ca, Cl, K, Mg, N, Na, P, S, Si) and the trace elements during their sprouting (sp.)- (March to May), peak growth (pg.)- (June to October) and senescence (sn.)- (November to February) phases. Due consideration is given to collect and preserve the sub-samples of water, sediment and hydrophytes from the identical spot. For plant and sediment samples various parametric evaluations are performed following [23], [24] and [30]. The multi-elemental quantification of Ca, Cl, K, Mg, Na, P, S and Si in sediments and plant biomass is performed using Wavelength Dispersive X-ray Fluorescence Spectrometer (WD-XRF) at Central Instrumentation Facility (CIF), Pondicherry University. However, the trace elements in all samples were determined at Sophisticated Analytical Instrument Facility (SAIF) IITM, Chennai using ICP-OES (Perkin Elmer Optima 5300 DV) instrument. Further, the descriptive and illustrative statistical analysis is performed using MS-Excel 2010, Origin 8.5, PAST 3 and SPSS 21.

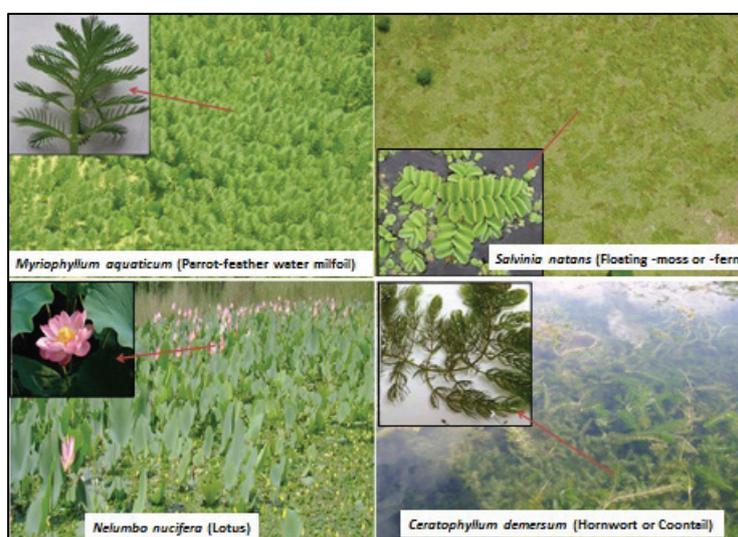


Plate II. Analysed predominant emergent, free-floating, rooted-floating and submerged macrophytes.

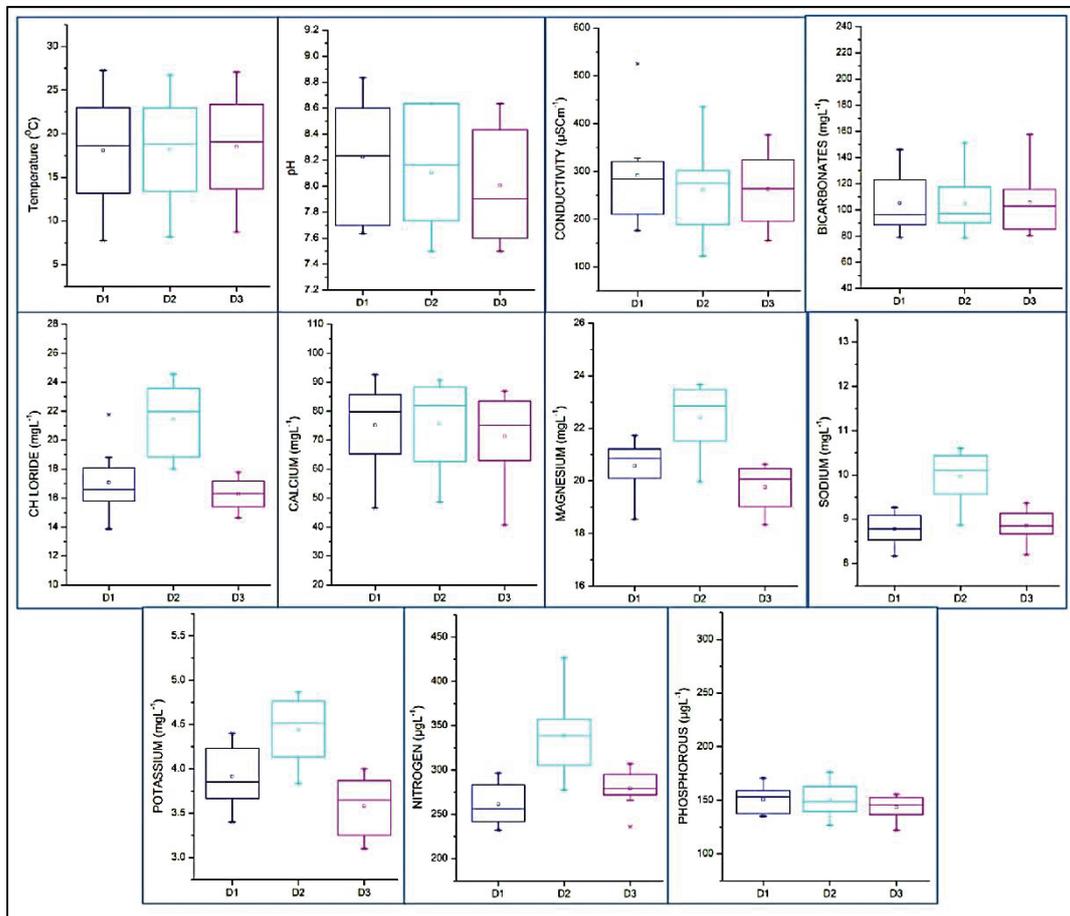
### 3 Results

(a) *Epilimnion*: The spatial (Fig. 4) and temporal (Fig. 5) limnochemical sum up of water variables present a useful depiction of lake circumstance and eutrophic stage. The documented surface water temperature ( $^{\circ}\text{C}$ ) validates the meteorological intervals of the study area. It ranges between 5 to 30  $^{\circ}\text{C}$  time-wise with position averages of  $18.1 \pm 7.4$  at D1,  $18.1 \pm 7.0$  at D2 and  $18.5 \pm 7.0$   $^{\circ}\text{C}$  at D3. The temperature variance between sites ( $F = .013$  and  $p > 0.05$ ) is insignificant, however, seasonal variation is significant ( $F = 1.39$  and  $p < 0.05$ ). The pH findings altered between 7.2 and 8.6 denoting alkaline waters with reasonably higher summer peaks. The site-wise averages are  $8.2 \pm 0.43$ ,  $8.1 \pm 0.43$  and  $8.0 \pm 0.41$ . ANOVA for pH has significance between seasons ( $F = 9.782$  and  $p < 0.05$ ) as well. Conductivity examinations demonstrated a drop towards the spring and summer months apparently due to dilution and ion uptake by vegetation existent in the water-column. The conductivity range witnessed has lowermost value of 100  $\mu\text{Scm}^{-1}$  and maximum of 565  $\mu\text{Scm}^{-1}$  besides having mean site values of  $294.7 \pm 113.83$ ,  $266.8 \pm 100.87$  and  $271.3 \pm 87.60$   $\mu\text{Scm}^{-1}$ . Seasonal ANOVA of conductivity is more substantial ( $F = 7.829$  and  $p < 0.05$ ) than lake contrasts ( $F = 4.526$  and  $p < 0.05$ ). The  $\text{HCO}_3$  concentration ranges from 60 to 218  $\text{mgL}^{-1}$  and at the chosen sites average to  $105.2 \pm 24.93$ ,  $105.0 \pm 25.89$  and  $105.7 \pm 27.95$   $\text{mgL}^{-1}$  respectively. Bicarbonates register noteworthy seasonal variation ( $F = 35.431$  and  $p < 0.05$ ) only. The chloride ( $\text{mgL}^{-1}$ ), calcium ( $\text{mgL}^{-1}$ ), magnesium ( $\text{mgL}^{-1}$ ), sodium ( $\text{mgL}^{-1}$ ), potassium ( $\text{mgL}^{-1}$ ), nitrate nitrogen ( $\mu\text{gL}^{-1}$ ) and total phosphorus ( $\mu\text{gL}^{-1}$ ) although differ in being as major ( $> 5$

mgL<sup>-1</sup>) or minor (0.01 to 10 mgL<sup>-1</sup>) elements but illustrate virtually an undistinguishable prospect of withdrawal through crowning growth periods of macrophytes and again revive in the medium after their senescence. The ANOVA classifies the variables as significantly changeable between the sites ( $p < 0.05$ ) except Ca but insignificantly varying between seasons ( $p > 0.05$ ) except Ca, Mg and K. Their corresponding chronological range and site averages are tabularized in Table 2.

**Table 2.** Range and mean concentration of major and minor nutrients in water at the selected sites.

ELEMENT	RANGE	D1	D2	D3
Cl (mgL <sup>-1</sup> )	11.6 -28.5	17.1±3.06	21.4±3.07	16.3±1.44
Ca (mgL <sup>-1</sup> )	38 -101	75.1±17.34	75.6±17.09	71.4±16.2
Mg (mgL <sup>-1</sup> )	16.8 -25	20.6±1.36	22.4±1.59	19.8±1.05
Na (mgL <sup>-1</sup> )	7.5 -12.7	8.8±0.47	10.0±0.72	8.9±0.52
K (mgL <sup>-1</sup> )	2.6 -5	3.9±0.45	4.4±0.49	3.6±0.42
NO <sub>3</sub> -N (µgL <sup>-1</sup> )	220 -555	261.4±25.1	338.4±57.4	279.3±23.5
P (µgL <sup>-1</sup> )	110 -289	150.67±13.70	150.67±18.46	143.42±12.66



**Figure 4.** Quantitative spatial variation in water quality variables.

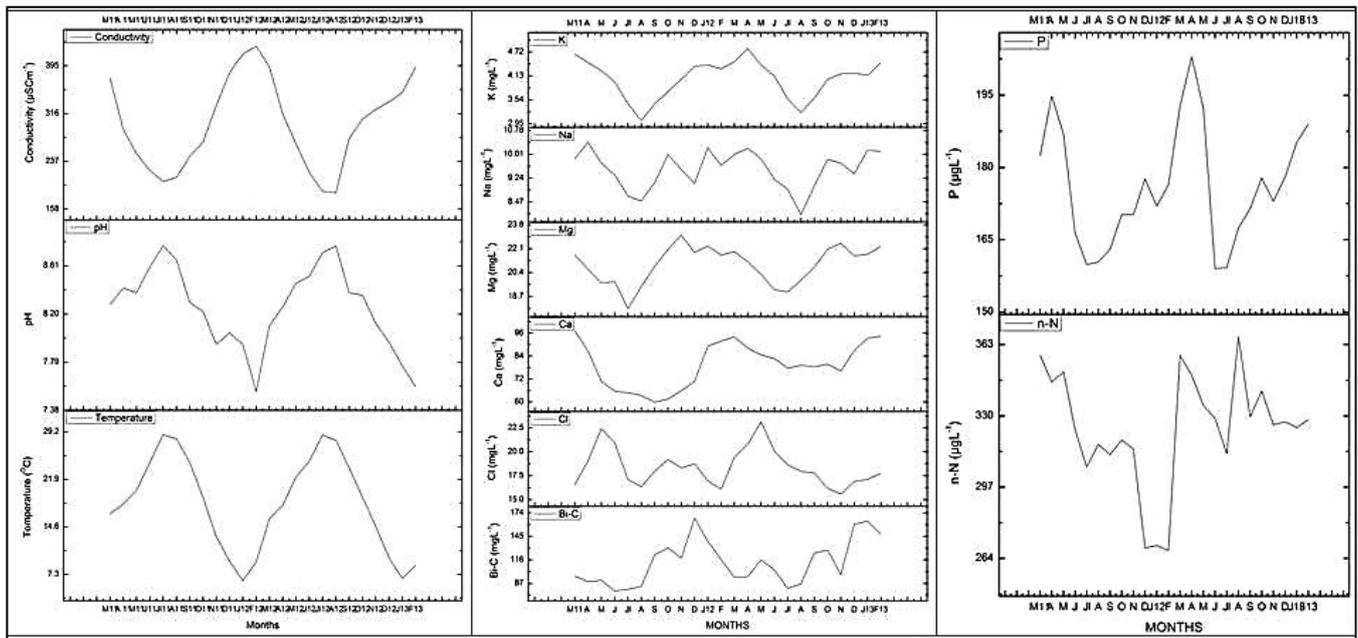


Figure 5. Temporal fluctuations in epilimnion variables.

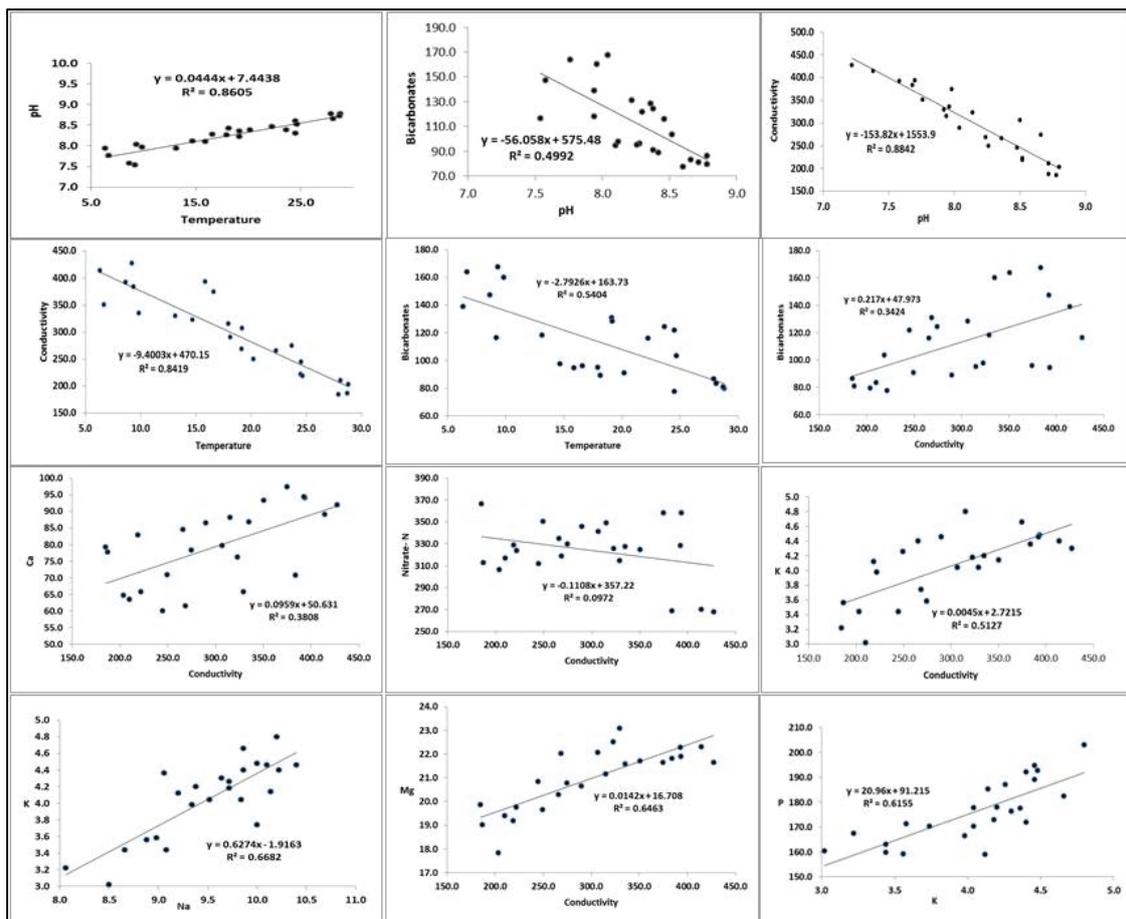


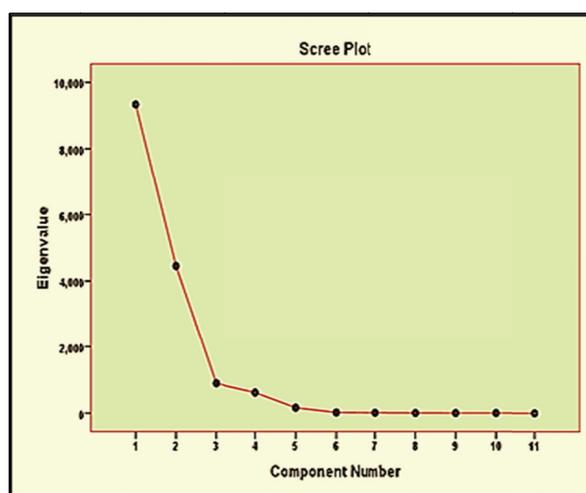
Figure 6. Regression analysis of water variables.

**Table 3.** Average seasonal total trace elements in lake waters ( $\text{mgL}^{-1}$ ).

SITE	SEASON	Al	As	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Se	Sn	Zn
D1	SPRING	1.2	BDL	BDL	BDL	0.041	0.012	2.96	BDL	1.33	0.05	BDL	BDL	0.29	26.2
	SUMMER	0.9093	0.013	0.003	0.005	0.035	0.052	9.133	BDL	0.343	0.025	0.074	0.005	0.239	7.385
	WINTER	1.16	BDL	BDL	BDL	0.011	0.01	1.97	BDL	0.5	BDL	0.03	0.004	BDL	21.6
D2	SPRING	BDL	BDL	BDL	BDL	0.019	BDL	2.43	BDL	0.31	BDL	BDL	BDL	BDL	13.3
	SUMMER	0.9735	0.009	0.003	0.002	0.038	0.042	3.328	BDL	0.218	0.024	0.083	0.014	0.171	15.51
	WINTER	0.2	BDL	BDL	BDL	BDL	BDL	6.1	BDL	1.25	BDL	BDL	BDL	0.11	10
D3	SPRING	0.82	BDL	BDL	BDL	0.027	0.051	4.76	BDL	0.14	BDL	BDL	0.01	BDL	17.6
	SUMMER	1.361	0.011	0.003	0.004	0.038	0.097	10.15	BDL	0.381	0.025	0.085	0.016	0.236	22.22
	WINTER	1.41	0.005	0.003	0.002	0.026	0.08	9.97	BDL	0.27	0.019	0.12	BDL	0.21	30.4
AVERAGE		1.678	0.012	0.003	0.010	0.040	0.133	5.602	BDL	0.610	0.034	0.090	0.010	0.191	18.520
STANDARD DEVIATION		1.322	0.003	0.001	0.007	0.023	0.108	2.741	BDL	0.438	0.018	0.028	0.005	0.053	7.118
MINIMUM		0.2	0.005	0.002	0.002	0.01	0.01	1.97	BDL	0.1	0.016	0.03	0.003	0.1	7.385
MAXIMUM		4.516	0.015	0.004	0.02	0.09	0.33	10.15	BDL	1.512	0.071	0.12	0.016	0.29	30.4

**Table 4.** Factor loading and variance of PC1, PC2 and PC3.

COMPONENT NUMBER	PARAMETER	PC1	PC2	PC3
1	CONDUCTIVITY	0.38	-0.19	0.21
2	K	0.38	0.11	-0.29
3	Na	0.37	0.21	-0.17
4	Mg	0.34	-0.04	-0.32
5	Ca	0.29	0.08	0.40
6	P	0.29	0.34	0.38
7	$\text{HCO}_3$	0.27	-0.22	0.24
8	$\text{NO}_3$ -N	0.20	0.48	0.15
9	Cl	0.12	0.37	-0.54
10	pH	-0.23	0.47	0.26
11	T	-0.35	0.38	-0.02
Eigen value		9341.34	4452.90	896.66
% variance		60.27	28.73	5.79

**Figure 7.** Scree plot for the water parameters.

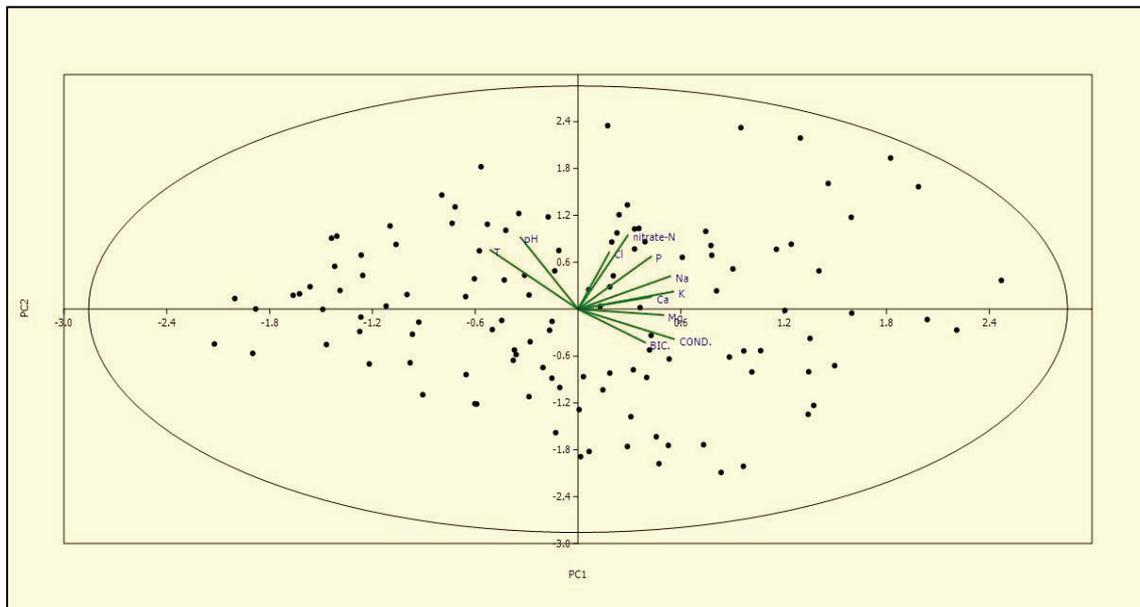


Figure 8. Biplots of PC1, PC2 and PC3 of the water variables (magnitude and sign).

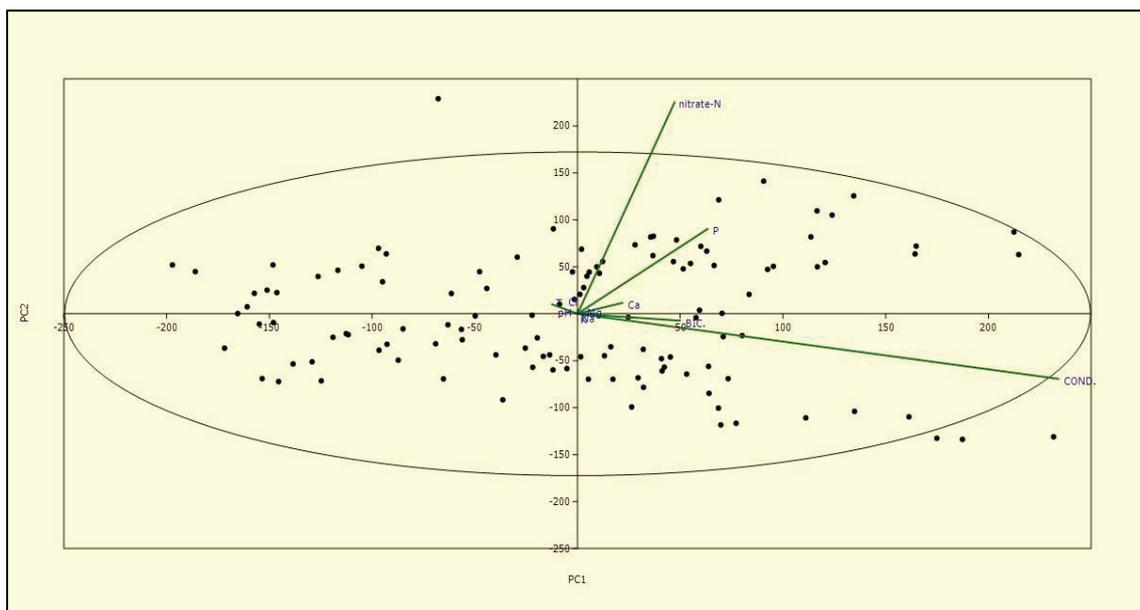
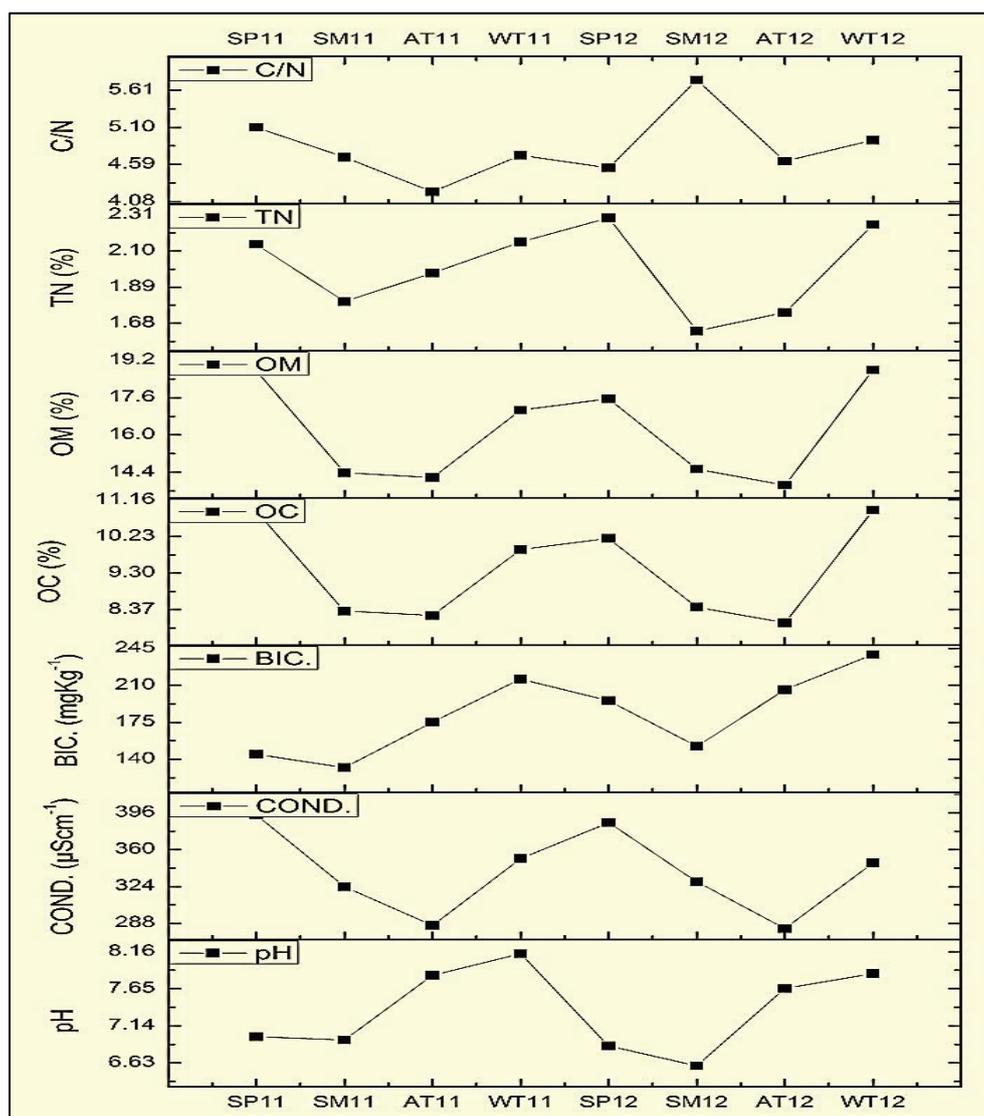


Figure 9. Biplots of PC1, PC2 and PC3 of the water variables (interactions).

The Pearson’s correlation coefficients from correlation matrix of water quality variables provide statistically significant relations in case of temperature, pH, bicarbonates and conductivity but nitrate-N relates to bicarbonates only. Besides, their regression analysis (Fig. 6) gives regression coefficients that depict the intense intra-aqueous interdependence by relating the line of best-fit ( $R^2$ ). Table 3 enlists average seasonal total trace element concentration ( $\text{mgL}^{-1}$ ) in lake waters at the given sites. The trace elements do not follow any definite seasonal variability ( $p > 0.05$ ). But ANOVA between sites confirm significance for Al ( $F= 49.14$  and  $p < 0.05$ ), Cr ( $F= 3.854$  and  $p < 0.05$ ), Cu ( $F= 28.64$  and  $p < 0.05$ ) and Ni ( $F= 7.05$  and  $p < 0.05$ ). Besides, positively significant Pearson correlation grouping at  $p < 0.01^{(**)}$  or  $p < 0.05^{(*)}$  occurs for Al with Co $^{(**)}$ , Cr $^{(*)}$ , Cu $^{(**)}$  and Ni $^{(*)}$  while As associates with Cd $^{(**)}$  and Ni $^{(**)}$ , Cd with Pb $^{(**)}$ , Co with Cu $^{(**)}$  and Ni $^{(*)}$ , Cr with Cu $^{(**)}$ , Cu with Ni $^{(*)}$  and Pb with Zn $^{(*)}$ . PCA prompted

biplot of the water variables at all select sites collectively visualizes the systematic interaction and variance pattern (between columns and rows, between columns and between rows) of coefficient matrix of PC1, PC2 and PC3 (Table 4). Scree plot description in Fig. 7 defines Eigen value allocation of the components. The magnitude and sign of each variable's contribution to first 2 PC's is visualized in Fig. 8 while their interactions can be extrapolated from Fig. 9. A similarity index of the sites in the form of a dendrogram derived from Hierarchical Cluster Analysis (HCA) of water variables suggests a site specific peculiarity dependence on micro local conditions and perturbation types existing in the lakes. The site cluster arrangement reflects trophic ranking of D2 > D3 > D1. Similarly, the month-wise clustering of the bi-annual observations of the water quality confides seasonal contiguities.



**Figure 10.** Seasonal fluxes in sediments [SP, SM, AT and WT correspond to 4 seasons of years 2011 & 2012].

(b) *Surface Sediments*: Sediment report presenting seasonal quantification marks a distinctive outcome. The detected range of H-ion concentration in surface sediments is 6.1 to 8.3 and the respective mean site values include  $7.58 \pm 0.42$ ,  $7.20 \pm 0.58$  and  $7.49 \pm 0.56$ . Sediment conductivity fluctuated between 234 and 498  $\mu\text{Scm}^{-1}$  at 25 °C and the average inter-site contrast is as  $293.3 \pm 36.4$ ,  $363.3 \pm 50.9$  and  $323.3 \pm 38.4$   $\mu\text{Scm}^{-1}$  respectively. The sediment bicarbonate content has minima of 116 and maxima of 264  $\text{mgKg}^{-1}$  and varied between the designated sites as  $169.8 \pm 41.5$ ,  $172.6 \pm 41.9$  and  $189.6 \pm 42.3$   $\text{mgKg}^{-1}$  congruently. The ranges and average site wise percentage dry-weight variations in sediment organic carbon (OC),

organic matter (OM), total nitrogen (TN) and C/N ratio are abridged in Table 5. Similarly, the percentage (%) seasonal sediment composition on dry weight (DW) basis of Ca, Cl, K, Mg, Na, P, S and Si along with their averages, standard deviations and ranges at the specified sites are given in Table 6. Pearson correlation matrix of select sediment parameters establish significant relationship between pH and bicarbonates ( $p < 0.05$ ), conductivity and OC or else OM ( $p < 0.01$ ), OC and OM or also TN ( $p < 0.01$ ), and OM and TN ( $p < 0.01$ ). A temporal trend of the aforementioned sediment characteristics for contiguous eight seasons of two year study can be visualised in Fig. 10. The assessed average percentage elemental composition of surface sediment on DW basis (Fig. 11) presented a minor inter-seasonal difference and follow the dominance order of  $Si > Ca > Mg > K > Na > P > S > Cl$ . Besides, the average micro- and trace- element quantification (Fig. 12) persisted seasonally almost uniform and denote the descending series of  $Fe > Al > Zn > Mn > Cu > Cr > Ni > Co > As > Sn > Pb > Cd$  while Hg and Se as BDL. The calculation of Enrichment Factor (EF) in Table 7 organises each trace element into ‘No Enrichment’ to ‘Very High Enrichment’ classes in accordance to [31] interpretation. The measures of Geochemical Index ( $I_{geo}$ ) scale in Table 7 labels ‘Unpolluted’ to ‘Highly Polluted’ element sets in sediments [32]. Integrated Pollution Index (IPI) score of 3.22 corresponds to ‘High Level of Pollution’ and Pollution Load Index (PLI) tally of 1.21 categorizes the lake as ‘Unpolluted to Moderately Polluted’ on the scales of [33] and [34] respectively. The construal of Contamination Factor (CF) differentiates between ‘Contaminated’ and ‘Uncontaminated’ score of elements in Table 7 as per [35]. The various Sediment Quality Guidelines’ (SQG) like Threshold Effect Level (TEL), Effects Range Low (ERL), Lowest Effect Level (LEL), Probable Effect Concentrations (PEC) and Threshold Effect Concentrations (TEC) are matched to the identified mean values for various elements in Table 8 in order to establish their pollution status and concomitant ecological risks [36] and [37].

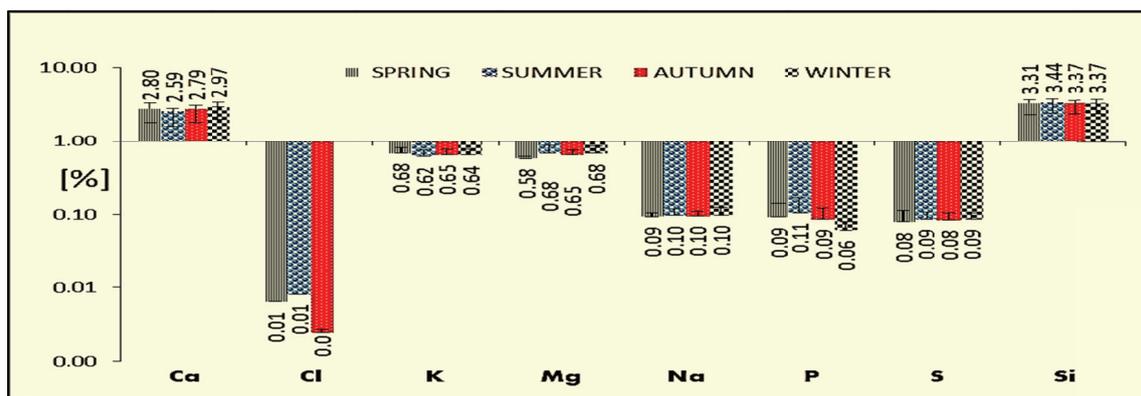


Figure 11. Average percentage elemental composition of surface sediments.

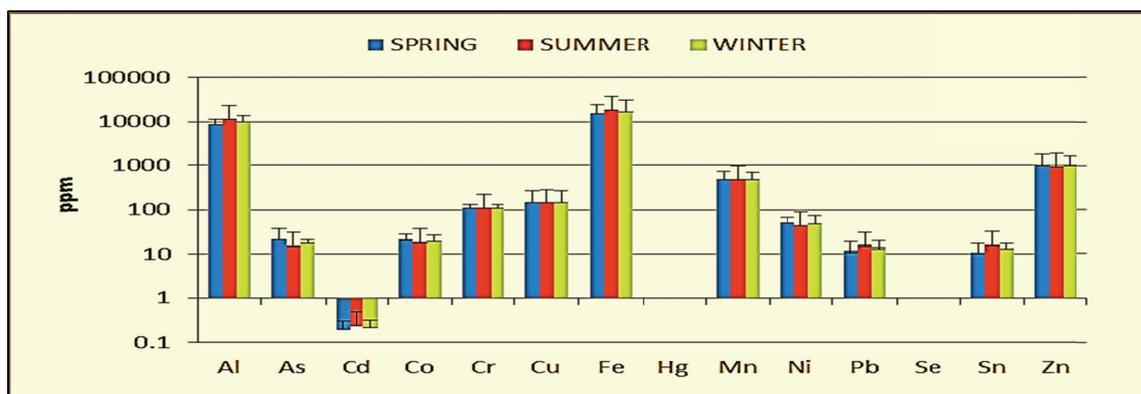


Figure 12. Mean micro- and trace- element quantification.

**Table 5.** Organic carbon (OC), organic matter (OM), total nitrogen (TN) and C/N ratio in sediments.

SEDIMENT-VARIABLE	RANGE	D1	D2	D3
OC (%)	6.7 to 15.21	8.67±0.84	9.83±1.27	7.85±0.77
OM (%)	11.55 to 26.22	14.940±1.442	16.939±2.178	13.526±1.327
TN (%)	1.09 to 2.87	1.864±0.306	1.900±0.174	2.458±0.322
C/N RATIO	2.55 to 7.53	4.789±0.948	5.175±0.554	3.229±0.373

**Table 6.** Elemental composition (%) of surface sediments on dry weight basis.

ELEMENT	SEASON	D1	D2	D3	AVERAGE	MINIMUM	MAXIMUM
Ca	SPRING	3.67	3.32	2.11	2.798±0.596	2.11	3.67
	SUMMER	2.76	2.50	2.91	2.592±0.208	2.36	2.91
	AUTUMN	3.11	3.13	2.74	2.788±0.305	2.31	3.13
	WINTER	2.89	3.56	3.20	2.973±0.444	2.21	3.56
	AVERAGE	3.107±0.349	3.127±0.394	2.739±0.400	Range = 2.11 to 3.67		
Cl	SPRING	BDL	BDL	BDL	0.006	0.006	0.006
	SUMMER	BDL	BDL	BDL	0.008	0.008	0.008
	AUTUMN	BDL	BDL	BDL	0.002	0.002	0.003
	WINTER	BDL	BDL	BDL	BDL	BDL	BDL
	AVERAGE	BDL	BDL	BDL	Range = 0.002 to 0.008		
K	SPRING	0.70	0.92	0.66	0.682±0.133	0.56	0.92
	SUMMER	0.62	0.87	0.54	0.623±0.129	0.53	0.87
	AUTUMN	0.71	0.85	0.56	0.649±0.118	0.53	0.85
	WINTER	0.81	0.76	0.48	0.643±0.135	0.48	0.81
	AVERAGE	0.711±0.067	0.851±0.061	0.561±0.067	Range = 0.48 to 0.92		
Mg	SPRING	0.61	0.59	0.53	0.577±0.040	0.53	0.62
	SUMMER	0.47	0.52	0.63	0.685±0.186	0.47	0.91
	AUTUMN	0.55	0.53	0.58	0.646±0.115	0.53	0.80
	WINTER	0.57	0.47	0.60	0.677±0.165	0.47	0.88
	AVERAGE	0.549±0.053	0.529±0.043	0.584±0.036	Range = 0.47 to 0.91		
Na	SPRING	0.11	0.09	0.08	0.094±0.011	0.08	0.11
	SUMMER	0.13	0.10	0.06	0.096±0.023	0.06	0.13
	AUTUMN	0.11	0.09	0.07	0.096±0.015	0.07	0.11
	WINTER	0.09	0.09	0.08	0.097±0.027	0.08	0.15
	AVERAGE	0.111±0.015	0.092±0.003	0.072±0.007	Range = 0.06 to 0.15		
P	SPRING	0.09	0.18	0.07	0.092±0.050	0.03	0.18
	SUMMER	0.09	0.23	0.08	0.105±0.064	0.05	0.23
	AUTUMN	0.08	0.15	0.08	0.086±0.034	0.04	0.15
	WINTER	0.06	0.03	0.09	0.061±0.018	0.03	0.09
	AVERAGE	0.082±0.011	0.148±0.072	0.078±0.007	Range = 0.03 to 0.23		
S	SPRING	0.04	0.07	0.08	0.079±0.034	0.04	0.14
	SUMMER	0.08	0.06	0.08	0.086±0.022	0.06	0.13
	AUTUMN	0.07	0.06	0.09	0.084±0.022	0.06	0.13
	WINTER	0.10	0.06	0.10	0.086±0.020	0.06	0.11
	AVERAGE	0.069±0.021	0.063±0.005	0.087±0.007	Range = 0.04 to 0.14		
Si	SPRING	2.79	3.17	3.13	3.313±0.375	2.79	3.77
	SUMMER	3.34	2.90	3.24	3.439±0.375	2.90	3.91
	AUTUMN	3.23	3.17	3.12	3.373±0.271	3.12	3.84
	WINTER	3.56	3.44	2.99	3.367±0.333	2.99	3.85
	AVERAGE	3.230±0.281	3.167±0.192	3.119±0.089	Range = 2.79 to 3.91		

**Table 7.** Elemental enrichment factor (EF), geochemical index ( $I_{geo}$ ) and contamination factor (CF).

Element	EF	$I_{geo}$	CF
Al	no enrichment (< 1)	unpolluted ( $\leq 0$ )	uncontaminated < 1
As	very high (20-40)	moderately to highly polluted ( $\leq 3$ )	contaminated >1
Cd	moderate (2-5)	unpolluted to moderately polluted ( $\leq 1$ )	contaminated >1
Co	moderate (2-5)	unpolluted ( $\leq 0$ )	contaminated >1
Cr	moderate (2-5)	unpolluted ( $\leq 0$ )	contaminated >1
Cu	significant (5-20)	moderately polluted ( $\leq 2$ )	contaminated >1
Fe	minor (< 3)	unpolluted ( $\leq 0$ )	uncontaminated < 1
Mn	minor (< 3)	unpolluted ( $\leq 0$ )	uncontaminated < 1
Ni	minor (< 3)	unpolluted ( $\leq 0$ )	uncontaminated < 1
Pb	minor (< 3)	unpolluted ( $\leq 0$ )	uncontaminated < 1
Sn	moderate (2-5)	unpolluted to moderately polluted ( $\leq 1$ )	contaminated >1
Zn	very high (20-40)	highly polluted ( $\leq 4$ )	contaminated >1

**Table 8.** A comparative of sediment quality guidelines [TEL; ERL; LEL; PEC and TEC] with observed mean element concentrations.

ELEMENT	Sediment Quality Guidelines [mgKg <sup>-1</sup> or ppm or $\mu$ gg <sup>-1</sup> ]					OBSERVED MEAN
	TEL	ERL	LEL	PEC	TEC	
As	5.9	33	6	*	*	17.1
Cd	0.6	5	0.6	5	1	0.2
Cr	37.3	80	26	110	43	114.1
Cu	35.7	70	16	150	32	141.5
Pb	35	35	31	130	36	13.3
Hg	0.17	0.15	0.2	*	*	*
Ni	18	30	16	49	23	50.0
Zn	123	120	120	460	120	975.2

(\* indicates unknown value)

(c) *Macrophyte analysis*: The biochemical assays of select macrophytes for appropriate parameters carried out in tandem with water and sediment associates unveil their organised and inter-reliant interacting. The highest total chlorophyll concentration is noted in *Ceratophyllum demersum* (0.92 mgg<sup>-1</sup>) during its peak growth at site D3 while a minimum 0.02 mgg<sup>-1</sup> is recorded both in case of *Myriophyllum aquaticum* at site D2 and *Salvinia natans* at site D3 throughout senescence. The individual ranges of chlorophyll content (mgg<sup>-1</sup>) for *M. aquaticum*, *N. nucifera*, *C. demersum* and *S. natans* include 0.02 to 0.37, 0.05 to 0.72, 0.10 to 0.92 and 0.02 to 0.87 respectively. The productive capability of the explored macrophytes calculated on the basis of dry weight mean biomass (gm<sup>-2</sup>) for each experimental species in the three major growth phases is presented in Fig. 13. The biomass calculations reflect subsequent ranges for each species: *M. aquaticum* (107 to 960 gm<sup>-2</sup>), *N. nucifera* (66 to 750 gm<sup>-2</sup>), *C. demersum* (39 to 231 gm<sup>-2</sup>) and *S. natans* (01 to 55 gm<sup>-2</sup>). In terms of mean peak dry weight biomass values *M. aquaticum* (880.2 gm<sup>-2</sup>) dominated *N. nucifera* (678.4 gm<sup>-2</sup>), *C. demersum* (182.4 gm<sup>-2</sup>) and *S. natans* (45 gm<sup>-2</sup>). A similar fashion low occurred in dry weight (gm<sup>-2</sup>) during their senescence period ranking by way of 152.4 > 75.4 > 49 > 4.2 respectively. The percentage contribution of various life form classes among the studied macrophytes towards production (dry weight biomass, gm<sup>-2</sup>) as well as specific per cent relative difference during sprouting, peak growth and senescence phases is described in pie-chart illustrations accessible in Fig. 14. Other biomass parameters like Productivity (g m<sup>-2</sup> day<sup>-1</sup>), Net Primary Productivity (NPP, gm<sup>-2</sup>) and Specific Growth Rate (day<sup>-1</sup>) establish uniform variations in the experimental species of the order: emergent *M. aquaticum* > rooted floating *N. nucifera* > submerged *C. demersum* > free floating *S. natans* but Species Turnover is highest in case of *S. natans* and lowest for *C. demersum*.

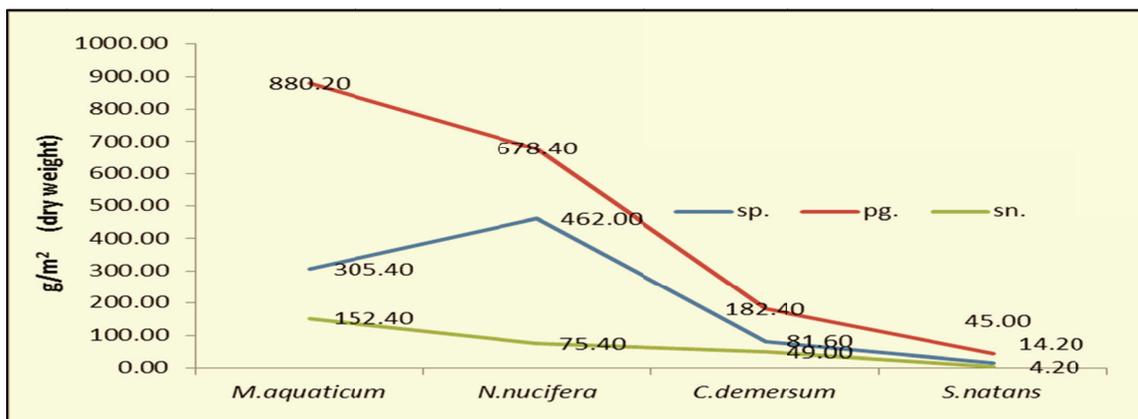


Figure 13. Average biomass values ( $\text{gm}^{-2}$  dry weight).

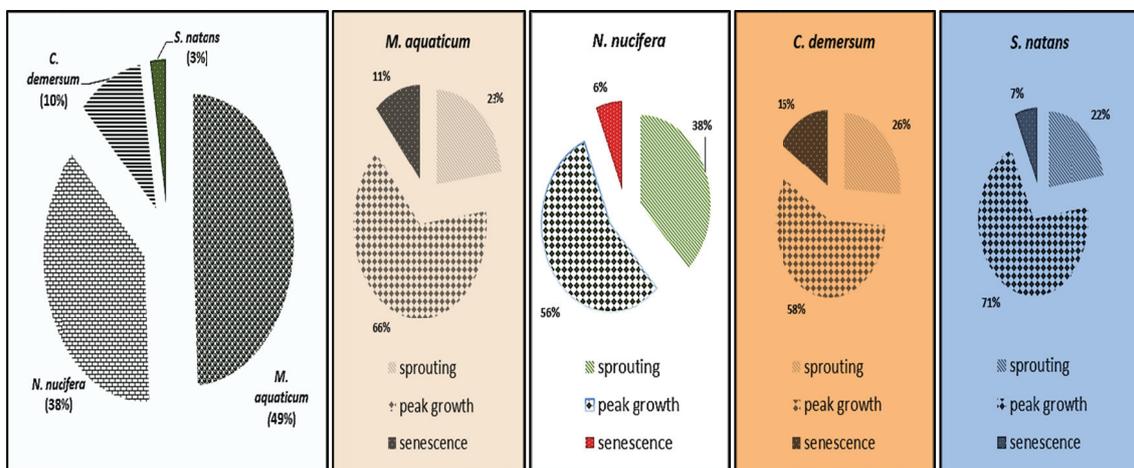


Figure 14. A comparative of percent dry weight biomass ( $\text{gm}^{-2}$ ) across growth-phases and species.

The average tissue concentration of analysed elements fluctuated not only between the select species but also depicted growth-phase variations within the same species. However, no significant site contrasts were noticed. The ANOVA test conducted between the species for the mineral composition of macrophytes convey significance for Cu ( $p < 0.05$ ), K ( $p < 0.001$ ), Na ( $p < 0.05$ ), Se ( $p < 0.01$ ) and Si ( $p < 0.01$ ) only. Whereas ANOVA for their growth-phases reflect significance in case of Al ( $p < 0.05$ ), As ( $p < 0.001$ ), Ca ( $p < 0.05$ ), Co ( $p < 0.05$ ), Cr ( $p < 0.05$ ), Fe ( $p < 0.05$ ), Mg ( $p < 0.05$ ), Mn ( $p < 0.001$ ), Ni ( $p < 0.01$ ), Pb ( $p < 0.01$ ) and Zn ( $p < 0.001$ ). The Bioconcentration Factor (BCF) criterion adopted indicates hyperaccumulation phenomenon for most of the micro- and trace-elements in *C. demersum* and *S. natans* except for Pb, Sn and Zn. And *M. aquaticum* hyperaccumulates Cd and Mn while *N. nucifera* Mn only. The Removal Potential of the macrophytes clearly stipulates species specific variation ensuing a generalized arrangement of emergent *M. aquaticum* > rooted floating *N. nucifera* > submerged *C. demersum* > free floating *S. natans*.

## 4 Discussion

The deliberation is compliant to inter-annual insitu compartmentalization and phytofiltration of major, minor and trace elements within the principal structural integrals of the lacustrine ecosystem. At the inception general condition of the bulk lake-ecosystem component of water on a spatio-temporal basis pronounce its hydro-geomorphological setting. Next, the sediment characterisation and comparison provides an insight into its influences on the system. Later, the biotic features of macrophytes are

considered in terms of their function and interrelationships with other compartments. Water quality [38], sediment characteristics [39], biological indicators [40] and even key ecological processes like primary production [41] are crucial to assess the integrity and health of the ecosystem. The temporal variation in ionic composition of natural waters along with its spatial distribution in a region aids significantly to distinguish the source [42].

The limnochemical statistics that developed during the study retro expound unambiguous and unavoidable evolving physico-biochemical configuration of the lake under multiple anthropogenic stress [43]. The chemical composition of water closely related to dual factors of connected catchment and human intervention thereof [44]. The trophic range oscillated within the eutrophic limits. But for the semi-drainage type hydrology flushing via fixed drainage channels and improved by ephemeral and sub-aqueous inputs vitalized the self-reclaimed homeostasis by way of keeping together the basin holding-time of water low ( $2^{1/2}$  months). The statistical insignificance in recorded epilimnion temperature variance as well as significant temporal inconsistency discloses similar geo-climatic setting of the lakes. Even if the entire recorded pH profile ( $> 7$ ) reflects buffered waters but has prominent variance both site- and time-wise suggesting position and period specific photosynthetic activity that removes  $\text{HCO}_3^-$  thereby enriching diurnal pH [45]. Contrarily, poorer pH during winter apparently on account of excess carbonic acid generation is due to higher [Respiration : Photosynthesis] proportion. The ionic strength (conductivity) measures vindicate superior eutrophy (solute richness) besides autotrophic assimilation and biocalcification contributing towards its summer falls [46]. Cationic progression is as  $\text{Ca} > \text{Mg} > \text{Na} > \text{K}$  [5], along with anionic predominance of  $\text{HCO}_3^-$  and  $\text{Cl}^-$  [47]. The lime grade catchment characteristic [48] contributed to Ca dominance phenomenon and hard water type classification [49]. K features base association with agricultural runoff and Cl to faunal organic pollution [50]. Although a range of human actions (agriculture, farming, sewage, factories, etc.) result in N species inflow [51], the spring fed basin of the lake and preferential reduced  $\text{NH}_4^+$  autotrophic assimilation instead of oxidised  $\text{NO}_3^-$  also better concentration of nitrate – N in water [1]. Additionally, [48] ascribed isolated geogenic N pockets as evaporative deposits in phyllite, schist and carbonate bed rocks in Kashmir. Forest surface runoff also contain  $\leq 20 \text{ mgL}^{-1}$  nitrate as a natural source to lakes [52]. Summer decreases of the least abundant macronutrient (P) limits bio-productivity owing to its utilization and carbonate coprecipitation [53]. The overall total P limit surpassed critical eutrophic index ( $\leq 0.05 \text{ mgL}^{-1}$ ) but nitrate N persisted underneath it ( $\leq 0.5 \text{ mgL}^{-1}$ ) mostly [54].

The correlation matrix verily suggests temperature increments elevating pH but diminishing conductivity,  $\text{HCO}_3^-$ , Ca, Mg, Na, K and P significantly [55]. However, Cl and  $\text{NO}_3\text{-N}$  remain unaffected due to temperature and pH ordeal. The influence of pH improvements correlate negatively with conductivity as well. Subsequently, the factors of temperature and pH clearly state that improved growth environment for biological uptake and calcite co-precipitation of ions reduce their epilimnion concentrations in peak growth summer cycle. Such a systematics attributed to photosynthetically induced precipitation and utilization by autotrophs is concomitant to the studies of [56]. The only negative association of  $\text{NO}_3^-$  – N with  $\text{HCO}_3^-$  shows eutrophication navigates on C assimilation for it serves as the main inorganic N source [57]. The close covariance of P with Ca, Mg, Na and K depict their analogous limited absorbance constraint by the biota. A supportive understanding of water variable interaction offers significant coefficient of determination ( $R^2$ ) alongside simple least square regression lines [58] for pH versus temperature (0.8), conductivity versus pH (0.9), conductivity versus temperature (0.8) and BIC versus temperature (0.5). An equation with the world average stream content ( $\text{mgL}^{-1}$ ) of recorded Ca ( $> 15$ ), Mg ( $> 4$ ), K ( $> 2.3$ ) and Na ( $> 6.3$ ) acclaim noticeable human inputs from common uses like fertilizers, plaster, pigments, lime, alloys, pharmaceuticals, batteries, food additives, glass, baking powder, soft drinks, electroplating, caustic soda, water treatment chemicals, etc. [17]. ANOVA discloses significant seasonal variance in temperature, pH, conductivity and BIC compared to significant site contrasts for Cl, Mg, Na, K,  $\text{NO}_3^-$  – N and P [59] and [60]. The BIC, Cl, Ca, Mg, Na, K, nitrate N and total P display virtually a matching situation of withdrawal throughout highest growth periods of macrophytes and once more pickup in post senescence period [2] and [61]. Anthropogenic effluents are recognized prime sources of traces in surface waters [62]. While paralleling the observed average epilimnion trace element concentration ( $\mu\text{gL}^{-1}$ ) with the average global abundance [17] in absence of any baseline data, an intense skewed ascent for As ( $\sim 10 > 2$ ), Cd ( $\sim 3 > 1$ ), Cr ( $\sim 40 > 1$ ), Co ( $\sim 10 > 0.2$ ), Cu ( $\sim 130 > 10$ ), Fe ( $\sim 5600 > 700$ ), Pb ( $\sim 90 > 3$ ), Mn ( $\sim 600 > 7$ ), Ni ( $\sim 30 > 1$ ), Se ( $\sim 9 > 0.2$ ), Sn ( $\sim 190 > 0.1$ ) and Zn ( $\sim 18520 > 20$ ) proclaim their anthropogenic origins [63].

Pertinently, such proportions exceed maximum permissible limits for drinking water but are suitable as irrigation liquid ordinarily [9] and [64]. The exceptions of Fe ( $>5 \text{ mgL}^{-1}$ ) and Zn ( $>2 \text{ mgL}^{-1}$ ) enhance the maximal concentrations in irrigation recommendations [65]. Still, Zn has lesser toxicity in organic soils at  $\text{pH} >6$  and Fe contributes towards acidification and reduced P availability. Al, a non-priority pollutant at  $\text{pH} 6.5$  to  $9$  is well below the freshwater Criterion Continuous Concentration (CCC) chronic exposure limit of  $\geq 87 \text{ } \mu\text{gL}^{-1}$ . Fe exceeds CCC at  $>1000 \text{ } \mu\text{gL}^{-1}$  too. But all the priority pollutants of As, Cd, Cr, Cu, Pb, Ni and Se remained below chronic level of CCC except Zn [9]. The complexing phenomena of heavy metals with carbonate and BIC limit their direct or indirect outcomes [66].

PCA biplot reveal the water variables contributed 89% with the most important being conductivity, K, Na, Mg, Ca, P,  $\text{HCO}_3^-$ ,  $\text{NO}_3^-$ -N and Cl for the first axis (60.27%) whereas in the second axis (28.73%) temperature and pH predominated. Both temperature and pH show inverse relationship whereas conductivity is strongly associated with rest of the ions [67]. Again temperature and pH increments compared to all ions imply their decrements due to absorption. Conductivity subtends an obtuse angle (cosines of the angles) ( $\cos \theta$ ) with respect to temperature and pH, so, the projection showcases a high negative correlation. But a high positive correlation appears for conductivity and other ions due to acute  $\cos \theta$  represented in the biplot in approximately same orientation. BIC, conductivity, nitrate – N and TP as the more important variables (high contributors) to interpret corresponding to their higher regression coefficients due to longer vectors closer to the unit circle [68].

The abiotic quiescent zone of sediments is suitable long-term indicator of lake environmental conditions [69] and [70]. Sediment nutrient constitution corresponds to catchment land use [71]. They provide settling space for water carried elements, both acquired and innate, in the form of ions, organic/inorganic- complexes and dissolved/suspended- matter associations [72]. Sediments reflect weaker source but stronger sink behaviour and capacity depicted via transformations of adsorption/desorption, mineralization/demineralization, bioassimilation and burial phenomenon [73]. Alkaline pH records of the sediment in general determine the catchment calcite predominance [48] whereas slight summer diminution is temperature improved OM decomposition effect. [74] labelled sediment pH as the principal factor enacting nutrient accessibility and movement. The seasonal organic – C changes in sediments aptly describe a pattern of temperature induced decrement during summers fulfilling the mineralization promotion [75]. The analysis of superficial sediment chemical characters reveals connections with trophic index [76]. Besides, eutrophication is evidenced to influence C flow in lakes to the effect of  $0.6 \text{ PgY}^{-1}$  global OC burial [77] and [78]. The typical  $< 10 \text{ C/N}$  implies autochthonous OM [2], besides low decomposition rates controlled by N budgeting and speciation via biochemical (enzyme and pH) fluctuations under alkaline conditions [79]. Its possible reason could be  $\text{NH}_4^+$  microbial preference instead of  $\text{NO}_3^-$  stimulating decomposition despite eutrophied state [80].  $\text{NO}_3^-$  exacerbations also shift decomposer community structure from fungal to bacterial causing OM decomposition decline [81]. Hence, eutrophied shallow lakes favour C sequestration. Surface sediments harbouring maximum OM profoundly determine biogeochemical cycling of major, minor and trace elements [2]. Significant correlation occurred for conductivity with OC and OM as the latter serves an established source for nutrient ions. Similar is the case with sediment OC, OM and TN as being complementary to one another.

Improved N:P ratios parallel chronic nitrogen influx in P-limited lakes [82], however, N-limited lakes suffer greater eutrophication catastrophes [83]. Higher temperature and lower N:P ratio during summer develop the P internal loading process. This P recycling mediates via degradation (oxic), denitrification and sulphate reduction [84]. Nonetheless, higher Al, Ca and Fe proportions in sediments inactivate P mobilization [85]. Curbing the external N and P loads is effective in remediation but the sediment internal loading supplement compensates the loss [86]. Meanwhile sediment dredging is beneficial for internal nutrient deloading only after the external inputs are checked [87]. Trace metals bound to OM or Fe/Mn- oxides separate on their decomposition [88] and reductive dissolution respectively near hypolimnion-sediment overlap [85]. A comparative of sediment-water compartmentalization for different elements exhibit more retention potential for the sediment component conform their sink-selves. Assuming the immensity and multifaceted networking in insitu conditions only a slight inconsistent inter-seasonal variance of Ca, Cl, K, Mg, Na, P and Si were observed. But BIC, conductivity, pH, OM, TN and C/N fluxed more on account of additional compartmental exchange quanta. A general gradual decline in nutrient concentration till culmination of active macrophytic growth phase can be associated with active/passive bioaccumulation or anoxic release from sediments [89].

Devoid of any universal sediment pollution indicator or guideline, multiple approaches were applied on the recorded holistic seasonal and site contents of micro and trace elements [90]. The EF differentiated very high anthropogenic contamination of As, significant in case of Cu and none for Al [91].  $I_{geo}$  measure indicates Zn as highly polluting contaminant, As as moderate to highly polluting pollutant and Cu polluting moderately [92]. In the context of IPI and PLI, the selected lake exhibit moderate metal contamination [93]. CF calculations scale contamination with respect to As, Cd, Co, Cr, Cu, Sn and Zn [94]. Furthermore, the observed mean concentration of Cr, Ni and Zn exceed the given sediment quality guidelines posing particular potential ecological risks [95]. However, Cd and Pb don't transcend them. Again As is below ERL and Cu lags in PEC [37] and [96]. A generalization of the above indices elucidates the source of contaminants to be chiefly anthropogenic, degrading the sediment profile with hazardous consequences for the dependent biota in the offing [97]. The lower [Ca : Al] values also suggest exsitu human cause for PTE transport to the designated lacustrine sites [73]. Nonetheless, the mobility of PTE's is effectively curtailed by OM enriched sediments and calcite co-precipitation [98].

The selected biomonitors among the macrophyte community manifested both contribution (command) and subservience to its abiotic allies. Macrophytes dominate mineral regulation between sediment and water [99]. They are capable to remove nutrients even at low loading rates [100]. Their adaptive advantage to lock up minerals from nutrient pool is helpful to check degradation primarily and restore mineral loading later on [101]. N and P are intimately related to biological productivity of aquatic ecosystems [1]. The productivity also lies in consonance with developmental stage, ambient nutrient medium and physiognomy of a species [102]. Higher temperature favour bio-production and elevate carbonate driven pH significantly [103]. Among the evaluated species *M. aquaticum* accumulated 49% of the dry weight biomass annually, whereas *S. natans* contributed only 3% but it outdid in species turnover comparison. Biomass parameters like dry weight, productivity, NPP and specific growth rate establish similar variations in the experimental species but species turn-over is highest in case of *S. natans* and lowest for *C. demersum*. Substantial OM productions by macrophytes contribute towards nutrient immobilization and provide OC requirement for denitrification while decaying [104]. The upgraded biomass configuration property establishes an additional nutrient and trace element interception feature of hyperaccumulation from the growth medium [105]. Even if temperate lakes during winter have uniform density nutrient enriched water devoid of thermal stratification, still, productivity is inhibited due to deficient light and temperature levels [106].

The gaining momentum for comprehending phyto-nutrient dynamics and their implications for water quality management or eco-restoration is a subject of site specific (habitat) application of a suitable phytoremediator [107]. The peak nutrient uptake and bioconcentration coincided with peak biomass in summer and autumn. The diminishing conductivity at improved temperature conditions suggest higher bioaccumulation rate of nutrients [108]. The removal potential pattern of the emergent accrued more Si, the rooted floating retained greater K, while the rootless submersed and free floating ones amassed Ca. Although the quantum of removal potential for different elements in the analysed species is divergent but the pattern is related which suggests unselective absorption [109]. The elemental turn-over rates in select macrophytes closer to the reference value of 1 has significance. The vascular aquatic plants possess higher productivity (C:N and C:P ratios) with organic polymer body capacitating their slowed decomposition that improves nutrient and C capture potential and as a result net autotrophy [110]. The concurrence of peak bioaccumulation and biomass production empowers the concept of high yield harvesting [111]. The harvesting of macrophyte biomass suitably during peak growth phase is perfect to avoid nutrient and metal remobilization from belowground vegetative parts or during senescence leaching on ultimate OM mineralization [112]. Similarly, a mono annual harvesting practice improves height; shoot density and biomass of macrophytes, although leading to nominal increment for mass TN and TP removal rates [113]. The ANOVA comparing the species shows uptake preference mode for Cu, K, Na, Se and Si indicating specific role in the unlike macrophytes [114]. Contrarily, the growth-phase variance for Al, As, Ca, Co, Cr, Fe, Mg, Mn, Ni, Pb and Zn possibly implies their short-term raised presence or bioavailability during the annual developmental cycle [46]. BCF criterion indicates hyperaccumulation for most of the metals in case of *C. demersum* and *S. natans*. The BCF apportionment clearly summarize *M. aquaticum* and *N. nucifera* to dissipate the PTE in their rhizosphere zone but the rootless *C. demersum* and *S. natans* concentrate them in their foliage parts [115].

The tissue concentration of nutrients and trace elements differ species wise but well correlate with ambient water and sediment media [116]. The biological sinks scavenge the deleterious proportions of nutrient supply from lakes preventing them from being overtaken by blooms. Even if slight phyto-extraction of inorganics would have occurred physically compared to large scale quanta of the insitu media, still the biogenic calcification evidenced in the summers is capable of lowering them mediated via temperature, pH,  $\text{HCO}_3^-$  and Ca changes [45]. Hence, a selective and scaled dewatering practice can thereby work wonders in lake management and restoration programmes [117].

## 5 Conclusion and Recommendations

A progressive urban expansion and associated activities have introduced substantial problems in the lake. Besides, the Dal is a shallow (1 m mean depth) urban recreational and tourist spot with crucial socio-economic reliance supporting ~5 lac population within >10 catchment to lake ratio. Since cultural eutrophication coincides with human pressures inside the inland surface waters, along the drainage basins and surrounding catchments as well, their evolution to dystrophy is certain yet manageable. The deteriorating water quality; ecological changes; eutrophication; reduced morphometric dimensions and volume holding; devaluing aesthetic, economic and recreational values; increased organic production and pollution are a cumulative product of denuded catchment leading to erosion and leaching; encroachment; diffuse garbage, sewage and city sewerage dumping; animal, human, agricultural and urban waste; silt loading and blockade of outflow channels; floating gardening and decomposition of biotic debris; unregulated tourism stress and roadway runoff. Another aspect of eutrophication process finds a complex interrelationship of contributing factors of climate, precipitation, basin morphology, hydrogeography of natural drainage and cultural factors. Monitoring the prevalent trophic status and other ecological conditions of an aquatic ecosystem is imperative for formulating conservation policies and action plan vital for its future sustenance, management and restoration. The study reveals the importance of effective monitoring program and appropriate management mechanism to attain and/or conform to desired water quality guidelines. The management of water resources aims at their sustainable use by protecting and improving both the quality and quantity while maintaining socioeconomic development.

In spite of multiple anthropogenic stresses and catchment intervention, the low basin holding period due to semi-drainage type hydrology ensures a self-reclaimed homeostasis in nutrient and pollutant dissipation. Calcite co-precipitation and biological uptake reduce epilimnion ion concentrations considerably. Primary source of traces have anthropogenic origin but the priority pollutants remain below USEPA chronic CCC levels. The sediment zone corresponds to catchment character and land-use while its element profile conform their sink-selves. Sediment dredging is beneficial for insitu nutrient deloading only when exsitu inputs are delimited. Since macrophytes scavenge nutrients unselectively even at low loading rates to limit water quality degradation, their biomass harvesting post peak-growth phase will avoid nutrient and metal remobilisation. The present research assessment signifies the lake as a region of anthro-urban intensification in less than a century of progressive human history. The financial assistance provided under National Plan for Conservation of Aquatic Ecosystems (NPCA) is essential for imminent prevention of pollution, insitu leniency control and cleaning, catchment area treatment and lake-front improvement. Comprehensive management interventions employed to limit degradation and to revive its condition include sewage treatment and solid waste management, house boat sanitation, regulated catchment area and shoreline development, controlled dredging, selective and scaled manual-cum-mechanical dewatering, unblocking of clogged channels, construction of settling basin on Telbal nallah, law enforcement to remove and prevent encroachment, relocation of lake populace, etc. in order to improve the hydrology and ecology of the lake. Further portions of the study sanction eco-management of stressor human practices to avoid extreme eutrophication (hypertrophism) when N and P exceed 30 and 3  $\text{mgL}^{-1}$  respectively. Conclusively, the main lacustrine components contemporarily reflect 'euoecism' as a cooperative defensive mechanism for sustaining integral structure and function of the system. But once the hypertrophic limits are surpassed due to mismanagement or negligence detrimental 'dysoecism' shall prevail.

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