

Characterisation of Temperate Urban Lacustrine Surface-Sediments for Minerals and **Metals in Comparison with Geochemical Indices** and Sediment Quality Criteria

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Abstract

The present surface sediment assessment in two temperate lacustrine ecosystems in the region of anthro-urban intensification in less than a century of progressive human history identifies ecosystem responses through space-time monitoring of variable spectrum and their gradients. Sediments have almost no outliers in box-plots across the select sites that suggest their tranquil nature. But temporal fluctuations in pH, bicarbonates, conductivity, OC, OM, TN and C/N can be visualised during Ca-Si dominance. The estimated percentage elemental composition of surface sediments on dry weight basis revealed the order Si > Ca > Mg > K > Na > P > S > Cl. Besides, the micro and trace element quantification represent the descending series of Fe > Al > Zn > Mn > Cu > Cr > Ni > Co > As > Sn > Pb > Cd while Hg and Se remained below detection level (BDL). Sediment pH remained on the basic side but slight acidic nature is noticed during late summer. Significant correlation occurs for conductivity with organic C and organic matter (p < 0.01) as the latter serves an established source for nutrient ions. Similar is the case with sediment organic C, organic matter and total N as being complementary to one another. A general slight gradual decline in nutrient concentration till culmination of active macrophytic growth phase can be associated with active/passive bioaccumulation or anoxic release from sediments. The Enrichment Factor classifies each trace element into "No Enrichment" class to "Very High Enrichment" category. The Geochemical Index (I_{geo}) scale labels "Unpolluted" to "Highly Polluted" element groups in sediments. The construal of Contamination Factor differentiates between "Contaminated" and "Uncontaminated" score of elements. Integrated Pollution Index (IPI) and Pollution Load Index (PLI) also categorize the sites and lakes. Sediment Quality Guidelines (SQG's)

when compared to observed mean values for various elements point to pollution status and associated ecological risks involved.

Keywords

Bicarbonate, Contamination, Fluvial, Monitoring, Trophic Index

1. Introduction

Sediments constitute a vital abiotic component of aquatic ecosystems and a major nutrient pool archiving historical hydroclimatic records [1]. Sediment characterisation regulates nutrient cycling and therefore contributes to overall structure and function of the system. They act as pollutant monitoring indicators of aquatic ecosystems [2] [3]. The various nutrients assimilated by aquatic organisms get incorporated into their biomass and ultimately mineralized either in organic or inorganic form in the sediments. Sediments retain nutrients [4] as well as release contaminants on disturbance [5]. The surface sediments conduct biogeochemical exchange with the overlying water column [6] depending upon the physicochemical and microbiological properties of the duo. [7] proclaimed water quality is modified on account of sediment (source) supplied contaminants facilitated by their collective physicochemical properties in the company of meteorological and hydrologic features of the watershed. The sediment-water interaction at their interface displays both ascendant and descendent exchange of chemical species [8] [9]. Expectedly higher occurrence of dissolved inorganic N ($NO_3^- + NO_2^- + NH_4^+$) in water is duly explicable because of superior accessible C, C/N and S content in sediments ([10] [11]. Instead, the bottom sediments act as a sink (reservoir) of nutrients [12] acquired from superimposing water suspended materials. The efficiency of sediments to act as a sink depends on the nutrient load and their absorbents presence. [13] reported that sedimentation processes are influenced by chemical composition of seston suspended waters and hydrological conditions. Eutrophic lakes and impoundments tend to be the highest depository sites for inorganic and organic C forms [14] for several reasons: 1) allochthonous collection from the watershed [15]; 2) autochthonous productivity and 3) lower decomposition rates of organic matter in anoxic sediments [16]. A significant dynamics of nitrate and dissolved organic N contributions arise out of detritus decomposition [17].

Sediments are also a recognized sink for heavy metals that eventually alter water quality ([18]. Organic sediments immobilize the mobile metals and metalloids [19] [20]. [21] documented that metal complexation with organics may mobilize them prospectively. Conversely, calcite rich clayey lacustrine sediments dilute metal enrichment or immobilize via sorption and precipitation [22]. The pH parameter supplemented with anoxic conditions and OM percentage control heavy metal lability in a lake [23]. [24] designated adsorption, retention and release of nutrients and metal to prevailing control factors of pH, temperature, redox state, OM and physicochemical composure of sediments. [25] attempted to delineate the derivation of $CaCO_3$ in lacustrine sediments by declaring a high Ca:Al proportion indicative of endogenic source. [26] concluded *in situ* geochemical weathering (origin) followed by carbonate precipitation within a reservoir at Ca/Al values \geq 10. Accordingly, observed higher content of Al and other metals equated to Ca suggest transported *ex situ* anthropogenic and lithogenic sources. The severity of metal pollution in aquatic ecosystems is effectively comprehended by adapting various sediment quality indices [27].

2. Materials and Methods

The north-west Himalayan biogeographic zone of India embeds the state of Jammu and Kashmir (Figure 1) at an altitude \geq 1500 m a.s.l. 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 characterized by an array of natural lacustrine water bodies upholding paramount ecological, cultural, historical and socio-economic significance. The estimated geographic area occupied by lakes in J & K is 13762 ha that approximates to 3.52% of all its aquatic ecosystems (National Wetland Atlas, 2010). 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 (Vveth) 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 yearlong precipitation episodes except a few summer and autumn dry-periods, besides, both seasonal and diurnal extremes of temperature. During the course of study, the monthly maximum, mean and minimum temperatures (°C) and average rainfall (mm) at Srinagar is illustrated in Figure 2. The lake area cover of Srinagar is 2194 ha equivalent to 21.76% of its total wetland area. The very existence of the urban 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



Figure 1. The summer capital (Srinagar) of Jammu and Kashmir.



Figure 2. Climate profile of Srinagar 2011-2013 (Data source: India Meteorological Department).

perturbations and so on [28] [29]. The focuses of present limnological research remain two fluvial urban valley lakes namely Anchar and Dal situated in the summer capital (Srinagar) of J & K. Anchar is a single basined lake located in the north-west of Srinagar city within the geographical coordinates of $34^{\circ}20'$ - $34^{\circ}26'$ N latitudes and $74^{\circ}82'$ - $74^{\circ}85'$ E longitudes. It has fluvial origin and occupies about 6 km² water surface area at an altitude of 1584 m a.s.l. [30]. Its mean depth is about 1.6 m and has a catchment cover of ~66 km². It has an open drainage feature reflected by a feeding network of streams from river Sindh; Gilsar-Khushalsar lake connections besides natural basin springs while its exit contributes to the Jhelum waters. While as the geographical position of Dal lake is in north-east of Srinagar city at 1587 m a.s.l. altitude occupying the coordinates of $34^{\circ}04'$ N to $34^{\circ}09'$ N and $74^{\circ}49'$ E to $74^{\circ}52'$ E Space Applications Centre, ISRO, Ahmedabad, India, 176. It is a tetra-basined ox-bow type lake formed by meandering course of river Jhelum. Its main feeding source is a perennial Dachigam

creek (splitted into 3 streams of Telbal, Pishpu and Meerakshah) and several lake-bed springs, however, the key exit discharges via Dalgate into the Jhelum. Alternate hydro energy center (AHEC), Roorkee designates an area of 337 km² as its catchment while holding a water volume of 15×10^6 m³. The satellite imagery database of Lakes and Waterways Development Authority (LWDA)-2007 reveals its total area as 24.6 Km² with an open water expanse of 15.41 Km² 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 Km² [31]. The mean depth averages to <3 m while the maximum depth equals 6 m.

The inter-annual survey, sample collection and chemo-sediment study of the two lakes carried out from March, 2011 to February, 2013 is based on their 5 select stations. The five locations (Table 1) designated as A1, A2, D1, D2 and D3 were each further fragmented into ten sampling stations (indicative as red spots in Figure 3) in order to obtain composite representative samples in triplicate for enhanced precision. The site selection criterion implemented here represents the distinct spatial features within the lakes. A1 adjoins the urban locale highly infested with vegetation and diffuse sewage inputs; A2 is situated closer to the lakes' exit and recipient of run-off from paddy fields; D1 vicinity is contributed with key inlet and STP discharges; D2 typifies the floating garden area; and D3 nearby the outlet has hotel and house-boat zone. Surface sediment samples are collected with the help of shovel and Ekman dredge (~0 to 25 cm depth) at the selected sites from both the lakes on seasonal basis for the study period of two years. In order to reduce heterogeneous nature of sediments due to changes in hydrological regime and catchment area geomorphology, composite samples are constituted by mixing at least 5 sub-samples taken from each sampling station. Except pH and electrical conductivity all the parameters are carried out on oven dried samples following standard recommended methods from [32] [33] [34] [35]. 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 trace elements for each season.

<u>Hydrogen ion concentration</u>: pH of fresh sediments is determined within 24 hours of sampling using an Elico (India) make pH meter (model 181E). A suspension (1:2.5 W/V) of 10 g sediment added to 25 mL of distilled water is prepared by constant stirring and allowed to settle down turbidity in order to take

Table 1. Coordinates of sampling locations.

Site	Latitude	Longitude
A1	34°8'24"N	74°47'41"E
A2	34°8'37"N	74°46'52"E
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



Figure 3. Sample collection stations.

replicate pH meter readings. The instrument is calibrated with standard buffer solutions of known pH (4, 7 or 9.2). The electrode is flushed with distilled water before each immersion in the supernatant suspension and the buffer solution.

<u>Electrical Conductivity</u>: A clear filtrate of 1:2 W/V sediment-distilled water suspension (40 g sediment in 80 mL of distilled water) is prepared to determine conductivity. An Elico make and model CM 180 conductivity meter calibrated at 1413 μ S·cm⁻¹ using a standard 0.01 M KCl solution is used to check conductivity at room temperature.

<u>Bicarbonates</u>: For the determination of HCO_3^- anions, a 1:2 sediment-distilled water extract is prepared by mixing 250 g of sediment in 500 mL of distilled water on a shaker for about 20 minutes. 20 mL of the filtered extract is titrated against 0.02 N H₂SO₄ thrice to obtain concordant anion(s) concentration using methyl orange as indicator. The results reported in mg·Kg⁻¹ are calculated using the formula: HCO_3^- (mg·L⁻¹) = (V₁ - V₂) × N × e/V₃ × 1000 where V₁ = volume of titrant used for neutralization of bicarbonates in the sample (mL) for methyl orange end-point; V₂ = volume of titrant used for the blank (mL); V₃ = volume of sample used (50 mL); N = normality of H₂SO₄ standard solution (0.02 N) and e = equivalent weight of HCO_3^- (61 g).

<u>Organic Carbon and Organic matter:</u> 0.5 g of oven dried sediment sample is used for organic C estimation by Walkley and Black wet oxidation method. 10 mL of 1 N K₂Cr₂O₇ solution in presence of 20 mL concentrated H₂SO₄ along with the sample is gently swirled in a flask to mix and then allowed to stand for 30 minutes in order to oxidise organic matter in the sample. The excess $K_2Cr_2O_7$ not reduced by the organic matter is determined by back titrating with 0.5 N ferrous ammonium sulphate using diphenyl amine as indicator to a violet-blue endpoint after adding 200 mL double distilled water, 10 mL of phosphoric acid and a pinch of sodium fluoride to the sample. A reagent blank is run simultaneously. The amount of organic C present in Percentage of Organic Carbon (% C) = $[0.003 \times 10 (B - C) / B \times W \times 100]$ 1.3 where 0.003 g C = 1 mL of 1N $K_2Cr_2O_7$;10 (B - C)/B = volume of 1 N $K_2Cr_2O_7$ used for C oxidation; B = volume of 0.5 N ferrous ammonium sulphate to neutralize 10 mL 1N $K_2Cr_2O_7$ in blanks' titration (mL); C = volume of 0.5 N ferrous ammonium sulphate to react sample and 1.3 is a correction factor for incomplete (77%) oxidation of organic matter. The organic matter content is determined from the above established organic C percentage and is calculated as: Percent Organic Matter (% OM) = % C × 1.724 where 1.724 = Van Bemmelen factor assuming organic matter contains 58% of organic C.

<u>Total Nitrogen</u>: It is estimated by Kjeldahl method using 0.5 g of oven dried and 0.425 mm sieved sediment sample. 20 mL concentrated H_2SO_4 in presence of 1 g K_2SO_4 and 0.5 g $CuSO_4$ is used to digest the sample till it turns torquoise. The volume of digest is raised upto 100 mL with distilled water after cooling. The contents are now distilled along with strong alkali (40% NaOH) and the ammonia liberated is collected in boric acid absorbing solution with the mixed indicator. The resultant greenish ammonium borate in the receiving solution is back titrated with standard 0.02 N HCl till pinkish endpoint. A blank titration is also carried out for calculation of total N as percentage dry weight basis. % Nitrogen in Sediment = $(S - B) \times N \times 1.401/W$ where S = volume of standard HCl titrant used for the sample (mL); B = volume of standard acid used for the blank (mL); N = normality of HCl and W = weight of sample (g).

<u>C/N Ratio</u>: Carbon and nitrogen stoichiometry in sediments is calculated from the results of above given allied methods.

The multi-elemental quantification of Ca, Cl, K, Mg, Na, P, S and Si in sediments is performed using wavelength dispersive X-ray fluorescence spectrometer (WD-XRF) at central instrumentation facility (CIF), Pondicherry University. 1 g of oven dried, finely ground and sieved (0.425 mm/420 micron mesh) sediment sample is used. A homogeneous sample is prepared with 1:4 ratio borate flux [36] for the quantitative analysis on WD-XRF spectrometer of Bruker S4 Pioneer make and model.

However, the trace elements were determined at sophisticated analytical instrument facility (SAIF) IITM, Chennai using ICP-OES (Perkin Elmer Optima 5300 DV) instrument. The simultaneous PTE quantification in lake sediment follow manufacturer's standard operating procedures and conditions. The analyte concentrations in the extract solutions are reported as $mg \cdot Kg^{-1}$ on dry weight basis using the following W/V correction equation: Sample concentration $(mg \cdot Kg^{-1}) = C \times V/W$ where C = concentration in the extract $(mg \cdot L^{-1})$; V = volume of extract (100 mL or 0.1 L) and W = weight of sample (1 g or 0.001 Kg). Further, the descriptive and illustrative statistical analysis is performed using MS-Excel 2010, PAST 3 and SPSS 19. The extrapolation, graphic visualization and interpretation of statistical procedures and scores are based on [37] [38].

3. Results

Sediment characterisation featuring seasonal quantification marks a distinctive outcome. The boxplots of analysed parameters pronounce site wise trend in Figure 4. The observed range of H-ion concentration in surface sediments is 6.16 to 8.35 and the respective mean site values include 7.22 \pm 0.60, 7.30 \pm 0.64, 7.58 ± 0.42 , 7.20 ± 0.58 , 7.49 ± 0.56 . Sediment conductivity ranged between 234 and 498 μ S·cm⁻¹ at 25 °C and the average inter-site comparison is as 395.4 ± 55.7, 312.6 ± 47.2 , 293.3 ± 36.4 , 363.3 ± 50.9 and $323.3 \pm 38.4 \ \mu\text{S} \cdot \text{cm}^{-1}$ respectively. The sediment bicarbonate content has minima of 116 and maxima of 264 mg·Kg⁻¹ and varied between the designated sites as 187.4 ± 25.3 , 193.5 ± 37.2 , 169.8 ± 41.5 , 172.6 ± 41.9 and $189.6 \pm 42.3 \text{ mg} \cdot \text{Kg}^{-1}$ correspondingly. The ranges and average site wise percentage dry-weight variations in sediment organic C (OC), organic matter (OM), total N (TN) and C/N ratio are summarized in Table 2 and visualised in Figure 5. The assessed average percentage elemental composition of surface sediment on DW basis (Figure 6) revealed a slight inter-seasonal variance and follow the dominance order of Si > Ca > Mg > K > Na > P > S > Cl. Besides, the average micro- and trace-element quantification (Figure 7) remained seasonally almost uniform and represent the descending series of Fe > Al > Zn > Mn> Cu > Cr > Ni > Co > As > Sn > Pb > Cd while Hg and Se as BDL.

The above acquired data for sediment metal profile paved way for Pollution Indices and Sediment Quality Criteria adoption.

1) <u>Enrichment Factor (EF)</u> calculations are based on comparison with background levels from global average composition [39]. EF is determined according to [40] definition as the observed Metal/Fe ratio in the sediment sample divided by natural background value of the Metal/Fe ratio. Devoid of any real background or reference values, average crustal composition from [41] are adopted to serve as preindustrial levels. Fe being an immobile element due to vast natural sources and dominant input is used to normalize heavy metal contamination [42]. The calculation of EF in **Table 3** classifies each trace element into "No Enrichment" to "Very High Enrichment" classes of sediment samples collected

Table 2. % (±S.D.) Organic Carbon (OC), Organic Matter (OM), Total Nitrogen (TN) and C/N ratio in select site sediments

Sediment-Variable	RANGE	A2	D1	D2	D3
OC (%)	6.7 to 15.21	9.42 ± 1.58	8.67 ± 0.84	9.83 ± 1.27	7.85 ± 0.77
OM (%)	11.55 to 26.22	16.238 ± 2.726	14.940 ± 1.442	16.939 ± 2.178	13.526 ± 1.327
TN (%)	1.09 to 2.87	1.828 ± 0.322	1.864 ± 0.306	1.900 ± 0.174	2.458 ± 0.322
C/N RATIO	2.55 to 7.53	5.208 ± 0.720	4.789 ± 0.948	5.175 ± 0.554	3.229 ± 0.373



Figure 4. Boxplots of sediment parameters.



Figure 5. Boxplots of organic-C, organic-matter and C/N.



Figure 6. Average percentage elemental composition of surface sediments.





Symbol	EF _[COMBINED]	% EF	EF _[ANCHAR]	%EF	$\mathrm{EF}_{\mathrm{[DAL]}}$	% EF	EF INTERPRETATION
Al	0.2	57.7	0.2	59.0	0.25	57.37	NO ENRICHMENT (<1)
As	22.0	20.9	24.0	23.6	20.43	30.77	VERY HIGH (20 - 40)
Cd	4.5	42.4	3.7	33.3	5.02	48.52	MODERATE (2 - 5)
Co	2.3	41.7	2.3	47.1	2.29	38.72	MODERATE (2 - 5)
Cr	2.6	64.4	2.6	75.7	2.56	55.94	MODERATE (2 - 5)
Cu	10.9	29.5	10.0	24.8	11.53	30.73	SIGNIFICANT (5 - 20)
Fe	1.0	37.6	1.0	37.1	1.00	35.24	MINOR (<3)
Mn	1.4	43.5	1.5	51.0	1.34	38.63	MINOR (<3)
Ni	1.9	40.3	1.9	43.0	1.93	38.07	MINOR (<3)
Pb	1.6	54.5	1.3	47.4	1.79	57.79	MINOR (<3)
Sn	4.5	51.7	5.9	60.0	3.41	27.30	MODERATE (5 - 20)
Zn	26.4	34.7	27.0	32.1	26.03	35.52	VERY HIGH (20 - 40)

Table 3. Elemental enrichment factor (EF) and % EF classification of elements (Han *et al.*,2006).

from the study stations in accordance to [43] interpretation. Besides, Percentage Enrichment Factor (EF %) for each element is calculated as per [44] by applying the equation: % EF = $C - C_{min}/C_{max} - C_{min} \times 100$ where C = mean total concentration of an element; C_{min} = the minimum metal concentration and C_{max} = the maximum metal concentration.

2) <u>Geo-accumulation Index (I_{geo})</u> is a quantitative criterion originally propounded by [45] to measure pollution intensity on a given qualitative scale [46] and [47] as $I_{geo} = \log_2(C_n/1.5B_n)$ where $C_n =$ measured concentration of an examined element (n) in the enriched sediment; $B_n =$ geochemical background concentration of the element (n) and 1.5 is the matrix correction factor to minimize possible lithogenic differences in the control values ([48]. Here the world's crustal surface average composition by [41] is used as the geochemical background. The measures of I_{geo} scale in Table 4 labels "Unpolluted" to "Highly Polluted" element groups in sediments [47].

3) Contamination Factor (CF) connotes to a fraction of mean content of an element (C_i) as antecedent and its pre-industrial level (C_n) as consequent, viz, CF = C_i/C_n . The construal of CF differentiates between "Contaminated" and "Uncontaminated" score of elements in **Table 5** as per [49].

4) <u>Integrated Pollution Index (IPI)</u> is the mean value of single factor pollution index (PI) for each element which in turn denotes the fraction of C_n (observed metal concentration) and B_n (baseline metal concentration) [50]. Again, Pollution Load Index (PLI) provides an integrated and site-wise comparative assessment of cumulative heavy metal pollution [51]. It is given as the nth root of the product of n contamination factor values, viz, PLI = $(CF_1 \times CF_2 \times CF_3 \times \cdots \times CF_n)^{1/n}$ where CF is the contamination factor and n designates the number of metals examined. IPI and PLI in **Table 6** categorize the lakes on their respective scales in accordance to [50] [52] respectively.

Element	Igeo [COMBINED]	I _{geo [ANCHAR]}	I _{geo [DAL]}	Interpretation	
Al	-3.59	-3.58	-3.59	Unpolluted (≤ 0)	
As	2.93	3.14	2.76	Moderately to highly polluted (≤3 but an char lake highly polluted(≤4)	
Cd	0.61	0.44	0.74	Unpolluted to moderately polluted (\leq 1)	
Со	-0.34	-0.25	-0.39	Unpolluted (≤0)	
Cr	-0.17	-0.06	-0.23	Unpolluted (≤0)	
Cu	1.91	1.88	1.94	Moderately polluted (\leq 2)	
Fe	-1.51	-1.45	-1.59	Unpolluted (≤0)	
Mn	-1.06	-0.89	-1.16	Unpolluted (≤0)	
Ni	-0.58	-0.5	-0.64	Unpolluted (≤0)	
Рb	-0.86	-1.03	-0.75	Unpolluted (≤0)	
Sn	0.62	1.1	0.18	Unpolluted to moderately polluted (≤1) But anchar lake moderately polluted (≤2)	
Zn	3.19	3.31	3.11	Highly polluted (\leq 4)	

Table 4. Geochemical index (I_{geo}) measure of elements (Macias *et al.*, 2006).

Table 5. Contamination factor (CF) of elements (Raj and Jayaprakash, 2007).

ELEMENT	CF _[COMBINED]	CF _[ANCHAR LAKE]	CF _[DAL LAKE]	Interpretation
Al	0.12	0.13	0.12	Uncontaminated < 1
As	11.41	13.23	10.19	Contaminated > 1
Cd	2.35	2.04	2.51	Contaminated > 1
Со	1.20	1.26	1.14	Contaminated > 1
Cr	1.34	1.44	1.28	Contaminated > 1
Cu	5.66	5.52	5.75	Contaminated > 1
Fe	0.52	0.55	0.50	Uncontaminated < 1
Mn	0.72	0.81	0.67	Uncontaminated < 1
Ni	1.00	1.06	0.96	Uncontaminated < 1
РЬ	0.83	0.73	0.89	Uncontaminated < 1
Sn	2.31	3.23	1.70	Contaminated > 1
Zn	13.73	14.86	12.99	Contaminated > 1

Table 6. Integrated pollution index (IPI) and pollution load index (PLI) categorization of the lakes (Wei and Yang, 2010; Zhang *et al.*, 2011).

Index	Combined	Anchar lake	Dal lake	Interpretation
IPI	3.43	3.74	3.22	high level of pollution (2 to \leq 5)
PLI	1.23	1.26	1.21	unpolluted to moderately polluted (1 to \leq 2)

5) Sediment Quality Guidelines (SQG's) including Threshold Effect Level (TEL), Effects Range Low (ERL), Lowest Effect Level (LEL), Probable Effect Concentrations (PEC) and Threshold Effect Concentrations (TEC) benchmark connotations include the final corollaries. SQG's include chemical specific numerical criterion or standard or guideline or value or indicator or alert/action/threshold range levels above which site contamination or ecological effect occurrence are expected. Such a quantitative index or characteristic concentration when evaluated demonstrates the current state, quality or ecological trend of a system for its strategic regulatory management practices. Adverse effects are rarely observed due to elements < TEL or < ERL and no potential ecological risks are associated below PEC or TEC while acceptable effects occur at < LEL. These SQG's are compared with the observed mean values for various elements in Table 7 in order to ascertain their pollution status and associated ecological risks [53] [54].

4. Discussion

The sediment characterisation and comparison provide an insight into its influences on the hydro-geomorphological setting of a lentic system. The abiotic quiescent zone of sediments is a suitable long-term indicator of lake environmental conditions [55] and [56]. Sediment nutrient constitution corresponds to catchment land use [57]. 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 [58]. Sediments reflect weaker source but stronger sink behaviour and capacity [26] depicted via transformations of adsorption/desorption, mineralization/demineralization, bioassimilation and burial phenomenon. Alkaline pH records of the sediment in general determine the catchment calcite predominance [59] whereas slight summer diminution is temperature improved OM decomposition effect. [60] labelled sediment pH as

Table 7. Sediment quality guidelines (MacDonald *et al.*, 2000; Maanan *et al.*, 2015): threshold effect level (TEL); effects range low (ERL); lowest effect level (LEL); probable effect concentrations (PEC); threshold effect concentrations (TEC).

Sediment Quality Guidelines [mg·Kg ⁻¹ or ppm or μg·g ⁻¹]						
ELEMENT	TEL	ERL	LEL	PEC	TEC	OBSERVED MEAN
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).

the principal factor enacting nutrient accessibility and movement. The seasonal organic C changes in sediments aptly describe [60] pattern of temperature induced decrement during summers fulfilling the mineralization promotion. The analysis of superficial sediment chemical characters reveals connections with trophic index [61] [62]. Besides, [63] and [64] evidenced eutrophication influence on C flow in lakes to the effect of 0.6 Pg·Y⁻¹ global OC burial estimate by [65]. The typical < 10 C/N implies autochthonous OM [16], besides low decomposition rates controlled by N budgeting and speciation via biochemical (enzyme and pH) fluctuations [66] under alkaline conditions. Its possible reason could be NH_4^+ microbial preference instead of NO_3^- stimulating decomposition [67] despite eutrophied state. NO_{2}^{-} exacerbations also shift decomposer community structure from fungal to bacterial causing OM decomposition decline [68]. Hence, eutrophied shallow lakes favour C sequestration. Surface sediments harbouring maximum OM profoundly determine biogeochemical cycling of major, minor and trace elements [16]. 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 [69], however, N-limited lakes suffer greater eutrophication catastrophes [70]. 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 [71]. Nonetheless, higher Al, Ca and Fe proportions in sediments inactivate P mobilization [72]. Curbing the external N and P loads is effective in remediation but the sediment internal loading supplement compensates the loss [73]. Meanwhile sediment dredging is beneficial for internal nutrient deloading only after the external inputs are checked [74]. Trace metals bound to OM or Fe/Mn-oxides [75] separate on their decomposition and reductive dissolution respectively near hypolimnion-sediment overlap [71]. A comparative of sediment: water compartmentalization for different elements exhibit more retention potential for the sediment component conforming their sink-selves. Assuming the immensity and multifaceted networking in in situ 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 [76].

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 [77]. The EF differentiated very high anthropogenic contamination of As, significant in case of Cu and none for Al [77]. I_{geo} measure indicates Zn as highly polluting contaminant, As as moderate to highly polluting pollutant and Cu polluting moderately [44]. In the context of IPI and PLI, the

selected sites and lakes exhibit moderate metal contamination [79]. CF calculations scale contamination with respect to As, Cd, Co, Cr, Cu, Sn and Zn [80]. Furthermore, the observed mean concentration of Cr, Ni and Zn exceed the given sediment quality guidelines posing particular potential ecological risks [81]. However, Cd and Pb don't transcend them. Again As is below ERL and Cu lags in PEC [54] [82]. 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 [83] [84]. The lower Ca: Al values also suggest *ex situ* human cause for PTE transport to the designated lacustrine sites [26]. Nonetheless, the mobility of PTE's is effectively curtailed by OM enriched sediments and calcite co-precipitation [85].

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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