Assessment of Pollution Impact on Three Oligotrophic Lakes in a University and Evaluation of Nature Based Solutions for their Restoration

Arooj Fatima[1], Hira Amjad[2, *], Imran Hashmi[1], Raveen Fatima[3], Asif Mansoor[2]
[1]School of Civil and Environmental Engineering (SCEE), Institute of Environmental Sciences and Engineering (IESE), National University of Sciences and Technology (NUST), Sector H-12 Campus, Islamabad 44000, Pakistan
[2] Pakistan Navy Engineering College, National University of Sciences and Technology (NUST), Habib Rehmatullah Road, Karachi 75350, Pakistan
[3]School of Civil and Environmental Engineering (SCEE), Institute of Geographical Information Systems (IGIS), National University of Sciences and Technology (NUST), Sector H-12 Campus, Islamabad 44000, Pakistan
[*]*Corresponding author*: hamjad@iese.nust.edu.pk
Received: 18-06-2025, Received in Revised form: 28-11-2025, Accepted: 04-12-2025, Published: 31-12-2025

Abstract

Natural and anthropogenic pollution make freshwater lakes uninhabitable for biodiversity and pose a serious threat to humans. Regular monitoring is necessary to detect early signs of pollution for treatment. The present study aims to identify possible waste intrusion sources and evaluate pollutant levels in water, sediment and flora of 3 lakes located in NUST university, Islamabad. Samples were collected from 6 points (Lake 1 inlet (L1I), Lake 1 outlet (L1O), Lake 2 inlet (L2I), Lake 2 outlet (L2O), Lake 3 inlet (L3I) and Lake 3 outlet (L3O)). The average concentrations of physicochemical parameters (total kjeldahl nitrogen (TKN) (26.5-97.6 mg/L), electrical conductivity (EC) (570-1686 µS/cm), turbidity (24.6-90.2 NTU) and phosphate-phosphorus (PO4-P) (0.47-0.75 mg/L)) exceeded the WHO limits. Dissolved oxygen (DO) (1.9-3.2mg/L) levels indicated near hypoxic conditions toxic for lake biota. Average chlorophyll (Chl-a, b and c) concentrations (0.00007-0.0006 mg/L) showed oligotrophic lake conditions while leaf chlorophyll content index (CCI) (3.7-165.3) varied in lake flora with highest average concentration in *Stellaria graminea*. Dominant algae (*Nitzschia sp., Navicula gregaria sp.,* and *Euglena sp.*) were identified under compound microscope. Heavy metal analysis (Lead (Pb), Cadmium (Cd), Chromium (Cr), Zinc (Zn)) of water, sediment and plant samples through atomic absorption spectrophotometer (AAS) showed high Zn concentrations (5.302 mg/kg) as compared to other metals. Seasonal parameters provided a baseline for long term meteorological analysis. Nature Based Solutions (NBS) like phytoremediation were identified to mitigate pollution. Principal component analysis (PCA) and Environmental Systems Research Institute (ESRI) ArcGIS Pro software were used for data analysis and visualization.

Keywords: NUST Lakes, Physicochemical Parameters, Heavy Metals, Eutrophication, Atomic Absorption Spectrophotometer, Dominant Algae.

Introduction

Freshwater lakes are an important water resource for human consumption and they constitute about 0.3% of the total (2.5%) water on earth surface [1]. Pakistan is a developing country and it has shown its commitment towards preserving the freshwater resources under Sustainable Development Goal-6 (SDG-6) i.e., clean water and sanitation for all [2]. In 2017, only 20% of Pakistan's population had access to clean water while 80% of the population was deprived of it. People were relying on water contaminated by pathogens, pesticides and fertilizers [3]. Lake conditions deteriorate due to natural and human activities such as run off, weathering of rocks, construction, transport, agriculture and dumping of waste [4,5]. In order to determine the lake water quality physicochemical parameters, heavy metal concentration and eutrophication levels were measured [6].

Heavy metals are insoluble substances that accumulate in water, sediments and plants. These toxic substances should be continuously monitored and efficient cost-effective methods need to be identified in order to eliminate them [7]. Heavy metals can be essential or non-essential. Zinc (Zn) is an essential heavy metal because it is necessary for the growth of plants [8]. The non-essential heavy metals are cadmium (Cd) and lead (Pb) [9]. They are toxic because of their harmful characteristics [10]. There are mixed reviews on chromium (Cr). According to some studies, trivalent Cr ion, is an essential element but according to some new studies, it is non-essential [11]. Zn and Pb are major pollutants in water and Zn may also significantly impact the sediments.

Heavy metals can also cause deformities in aquatic organisms like fish and negatively impact their reproductive cycle. Moreover, metal accumulation in plants causes alteration in their cellular mechanisms, affect regulatory proteins and plant defense mechanisms. However, some plant species are hyperaccumulators, they can accumulate toxic metals and detoxify the environment. As a result, the environment becomes favorable for native flora and fauna [12,13]. The sources of heavy metals may vary. Pesticides and fertilizers contain Cd, Zn and Pb [14,15] whereas Cr is released from weathering of rocks and anthropogenic activities [16].

Eutrophication is another problem which occurs due to excessive increase in nutrients such as nitrogen (N) and phosphorus (P) in aquatic ecosystems. Eutrophication has become an issue due to increase in anthropogenic activities. One of the main indicators of eutrophication is chlorophyll pigment. Chlorophyll-a (chl-a) is found in all photosynthetic organisms, including plants, algae, and cyanobacteria [17]. Chlorophyll in plants is the ratio of absorbance and reflectance at different wavelengths and it may be represented as Chlorophyll Content Index (CCI). Regular measurements of chlorophyll content in leaves can help in the determination of plant health [18]. Chlorophyll-b (chl-b) is present in green algae and higher plants while chlorophyll-c (chl-c) is commonly found in brown algae, diatoms, and dinoflagellates. Chlorophyll-a (chl-a) concentration measures the density and biomass of algae in lake ecosystems [19]. It depends on the condition of algal cells, water flow, heavy metal concentration, lake depth, and meteorological

http://dx.doi.org/10.24949/njes.v18i2.893

parameters such as light, windspeed, temperature and rainfall [17,20].

If certain algae become too dominant appropriate steps need to be taken to restore balance in aquatic ecosystems such as use of biological methods that reduce the nutrient input into the lakes [21]. However, if chlorophyll concentrations in lakes are low to a point that it becomes difficult to support biodiversity and maintain a healthy lake ecosystem, then the lake trophic status is oligotrophic. Oligotrophication is a comparatively new concept and opposite of eutrophication [22]. Lakes may also be categorized as mesotrophic and hypereutrophic. Mesotrophic lakes are healthy lakes with productivity between oligotrophic (low) and hypereutrophic (extremely high) lakes. Macrophytes compete with lake algae. Higher growth of lake vegetation can absorb nutrients and reduce their availability to algae whereas, in algae dominated turbid water, macrophytes cannot thrive due to imbalance in distribution of nutrients in lakes [24] Shallow lakes must be regularly monitored to prevent their transition to oligotrophic or hypereutrophic lakes [24,25].

The current study aims to highlight heavy metal pollution in 3 lakes at NUST university, Islamabad through Principal Component Analysis (PCA). PCA bi-plot simplifies multi-source pollution data by representing it in simple components [26]. The study also presents data on lake water quality parameters by using Environmental Systems Research Institute (ESRI) ArcGIS Pro software [27]. Limited research has been conducted on NUST lakes. The only published work is a case study [28], highlighting the potential of NUST lake for the generation of renewable energy and deployment of FPVs (Floating Photovoltaic Systems). The lack of detailed study on water, sediments and plants leaves a significant gap in understanding the factors affecting NUST lakes, which is essential for implementing effective lake management strategies.

The current study addresses this gap by analyzing physiochemical parameters of water, concentration of four heavy metals in the water (mg/L), sediments (mg/kg) and flora (mg/kg), chlorophyll (chl-a, b, and c) concentrations in water to measure eutrophication levels, leaf chlorophyll content (chlorophyll content index (CCI)) in lake flora, dominant algae on the basis of their morphology, effect of seasonal parameters on lake ecosystem and providing cost effective Nature Based Solutions (NBS) that could guide the authorities to restore oligotrophic lakes.

Materials and Methods

Study area

The National University of Sciences and Technology (NUST) is located in H-12, Islamabad (capital of Pakistan). Islamabad is situated at the northern edge of Potohar plateau [29]. The study area focuses on the NUST lakes constructed in 2011 to maintain the water table by damming natural streams passing through the university campus. Lake 1 (L1), Lake 2 (L2), and Lake 3 (L3) have an area of 1.5 acres, 2.2 acres, and 2.25 acres respectively. Lake (L3) has the largest volume of 0.74 GL, while lake (L1) and lake (L2) have volumes of 0.17 GL and 0.16 GL respectively. NUST lakes are a habitat of different species such as plants, fish and ducks etc. Figure 1 represents important structures of NUST. The water from L1 and L2 enters L3. Daily activities at the university result in a release of approximately 200,000 US gallons of wastewater per day (Project Management Office (PMO), NUST).

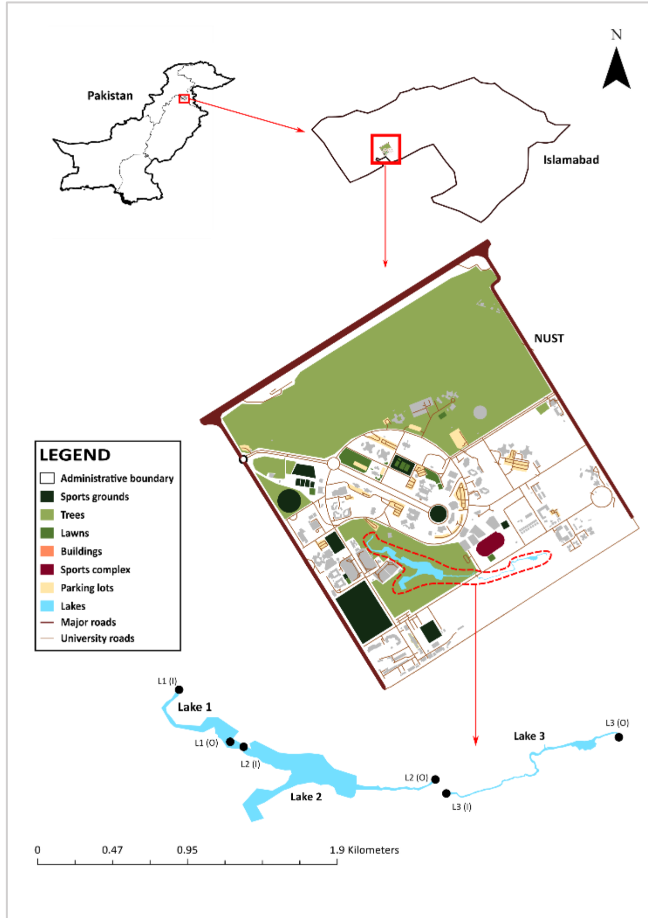

Figure 1. Map showing study area-NUST lakes, Islamabad

Sample Collection and Analysis

Sample Collection

Global Positioning System (GPS) helped in the accurate positioning of water, sediments and plants at the inlets and outlets of 3 lakes for sample collection Figure 1. Sampling of the 3 NUST lakes was performed from (September 2021 - December 2021). Pre-cleaned autoclaved glass bottles were used for the collection of water samples. Plant leaves and shoots were trimmed by stainless steel cutter and kept in paper bags. Surface sediments from lakes (0-15 cm depth) were collected through shovels. The sediment samples were transported to the laboratory in plastic bags for analysis [30,31,32]. Table 1 shows sampling points of the 3 NUST lakes.

Table 1. Sampling Points of the 3 NUST Lakes

Sampling Points	Location
L1-I	Opposite to NUST Institute of Civil Engineering (NICE) cricket ground
L1-O	Left side of bridge behind Attar hostel
L2-I	Right side of bridge behind Attar hostel
L2-O	Opposite to saddle club, close to cafeteria
L3-I	Opposite to NUST sports complex, near residential apartments
L3-O	Opposite to NUST sports complex near residential apartments

Sample Analysis

Physicochemical Parameters

The analysis of physicochemical parameters was carried out in environmental microbiology laboratory at the Institute of Environmental Sciences and Engineering (IESE). HACH 156 pH meter was used to carry out the analysis of pH and temperature respectively. Electrical conductivity (EC) and dissolved oxygen (DO) were measured by conductivity meter and DO meter (HACH 156) respectively. Nitrate-nitrogen (NO_3-N), nitrite-nitrogen (NO_2-N), phosphate-phosphorus (PO_4-P) were analysed using UV-spectrophotometer (colorimetric method). Total kjeldahl nitrogen (TKN) was determined through kjeldahl assembly, chemical oxygen demand (COD) through HACH reactor digestion method, turbidity was measured using turbidity meter (HACH 2100N), whereas total suspended solids (TSS) and total dissolved solids (TDS) were measured by gravimetric method (HACH) [33,34,35,36,37,38].

Heavy Metals

Atomic Absorption Spectrophotometer (AAS) was used for heavy metal (Cd, Cr, Zn and Pb) analysis of water, sediments and plant samples. The analysis was carried out in Environmental toxicology and Wastewater laboratories, at the Institute of Environmental Sciences and Engineering, NUST. Absorption spectroscopy is an efficient method for the qualitative and quantitative analysis of elements [39]. Water samples were collected through grab sampling method and filtered through 0.45µm pore size filter paper. Afterwards, analytical grade nitric acid (HNO_3) (one part) was added in each sample. The prepared samples were then stored in pre-cleaned glass bottles within refrigerator [40,41]. The sediment samples were dried at 105˚C to remove all the moisture content and were finely powdered using a mortar and pestle. About 0.5 g of dried sediment was digested by adding 12 mL aqua regia (3:1 HCl/HNO_3). After 2 hours of digestion at 80˚C, samples were allowed to cool and they were filtered through Whatman 41 filter papers and diluted up to 50 mL [39]. In case of plants, 1g of powdered leaves and 15 mL of concentrated HNO_3 were added. The plant samples were heated at 90˚C for 45 minutes and then the samples were allowed to boil for 8 hours at 150˚C until 1ml of volume was left. The solution was then filtered with <0.45µm pore size filter paper and diluted till 25ml [42]. Table 2 represents flora at lakes identified with the help of horticulture department at the university.

Table 2. Flora at NUST Lakes and Sampling Locations

Species (Botanical Name)	Common Names	Sampling Locations
Bombax ceiba	Simbal	L1 (I), L1(O), L3 (I)
Sapindus mukorossi	Ritha	L1 (I)
Bischofia javanica	Bishop tree	L1 (O), L2 (I)
Sapium sebiferum	Chinese tallow tree	L3 (I), L1(O)
Stellaria graminea	Common starwort	L1 (O), L2 (I)
Tecoma stans	Tecoma tree	L2 (I)
Salix babylonica	Weeping willow	L2 (I)
Albizia lebbeck	Sirin	L2 (O)
Eucalyptus camaldulensis	Sufaida	L3 (I)
Casia Fistula	Amaltas	L3(O)

Chlorophyll (a,b and c)

Chlorophyll pigments absorb light at different wavelengths. Chlorophyll (chl a, b and c) concentrations in NUST lakes were determined by solvent extraction method (90% acetone) to dissolve chlorophyll, through centrifugation (5000 rpm for 10 minutes) and with the help of UV spectrophotometer at different wavelengths (664, 647 & 630nm) Equations (1, 2, 3 and 4) helped in calculating chlorophyll concentrations [43].

$$\text{Chl a} = 11.85 \times A664 - 1.54 \times A647 - 0.08 \times A630 \quad (1)$$

$$\text{Chl b} = 21.03 \times A647 - 5.43 \times A664 - 2.66 \times A630 \quad (2)$$

$$\text{Chl c} = 24.52 \times A630 - 1.67 \times A664 - 3.56 \times A647 \quad (3)$$

$$A = \text{Absorbance} \quad (4)$$

Leaf Chlorophyll Content-Chlorophyll Content Index (CCI)

Chlorophyll content index (CCI) of vegetation within and around NUST lakes was measured by a chlorophyll meter (ccm-200 plus). Chlorophyll meters help in the determination of plant health by measuring the light passing through plant leaves and light reflected by leaves [44]

Dominant Algae

The fragments of algae were collected from lakes, and the dominant algae were identified on the basis of their structure and shape by using a compound microscope, Leica Microsystem (Germany, Model 1349522X) at 100 magnifications with oil immersion [45].

Seasonal Parameters

Global horizontal index (GHI), wind speed, rainfall and temperature data for the sampling period were obtained from U.S.-Pakistan Center for Advanced Studies in Energy (USPCAS-E), NUST. Seasonal parameters were monitored by Internet of Things (IoT)-based weather stations. These stations have sensors for real time monitoring of parameters.

Pyranometers, rain gauges, thermometers and anemometers measured GHI, rainfall, temperature and wind speed respectively [46,47].

Results and Discussion

Physicochemical Parameters

Walk through survey helped in identifying possible internal waste intrusion sources for the 3 NUST lakes such as, hostels, residential apartments, cafeterias, sports complex, workshops, and the saddle club. Waste intrusion could also have occurred from nearby sectors such as G-13 and H-13, where sediments, dust and other contaminants maybe transported through stormwater runoff. Seasonal variation caused a decrease in water temperature of lakes from 34.7 °C in September to 13.4 °C in December. This decline in temperature can affect the metabolic rates of lake biodiversity and availability of nutrients in lakes [48]. The lake pH (7.4 to 7.8) indicated slightly alkaline conditions. The EC values (570 to 1686 µS/cm > WHO permissible limits) indicated greater concentration of dissolved ionic substances in the water. High TDS (420–905 mg/L) and TSS (25–67.5 mg/L) levels showed the presence of dissolved and particulate matter in the lakes. The TDS and TSS resulted in increased turbidity levels (24.6–90.2 NTU>WHO permissible limits) which may have slowed down photosynthesis due to lower penetration of light in aquatic ecosystems [49]. High COD (187.4–502 mg/L) indicated the presence of significant organic matter undergoing decomposition, which can create stress for aquatic organisms and disrupt microbial activity. The DO ranged from 1.9 to 3.2 mg/L. The <3 mg L^{-1} DO levels in water negatively affect aquatic organisms like fish and create near hypoxic conditions [50]. Nutrients showed varying concentrations with relatively low NO_2-N (0.01-0.8 mg/L) and NO_3-N (0.1-0.35 mg/L) possibly because heavy metals inhibited microbial processes responsible for nutrient cycling. The TKN (26.5 to 97.6 mg/L) and PO_4-P (0.47 to 0.75 mg/L) concentrations were greater than the WHO permissible limits. Elevated TKN and PO_4-P concentrations can lead to nutrient enrichment and result in growth of algae [51,52].

The observed physicochemical conditions may be a result of different anthropogenic activities occurring within and close to the university. Detergents, organic matter, and dissolved salts in wastewater from residential apartments and hostels can contribute to increased TDS, EC, PO_4, and COD concentrations in lakes. Food preparation and waste disposal from cafeterias introduce organic residues and suspended particles into the lake water, thereby increasing turbidity and TSS. Moreover, application of fertilizers in university grounds and sports complex add nitrogen compounds such as TKN, NO_3-N, and NO_2-N into the lakes through surface runoff. Animal feed and waste at saddle club release organic wastes further contributing to the nutrient enrichment. Sediments, pollutants, and particulate matter can be transported through stormwater runoff from nearby sectors (G-13 and H-13) resulting in increased turbidity and suspended solids in lakes [53]. Figures 2 and 3 represent the lake sampling locations and the average concentration of parameters at each location, where larger points represent locations which have greater concentrations and Table 3 represents concentrations of physicochemical parameters and their comparison with national and international standards [54,55].

Heavy Metal Analysis

The internal sources of Cd, Cr, Pb and Zn in the university are 1) detergents, packaging and food waste produced by cafes, hostels and residential apartments, 2) use of pesticides and fertilizers, 3) horse manure at saddle club, 4) welding and metal working at workshop, 5) swimming pool discharge from sports complex, 6) seasonal patterns and weathering of rocks also affect the mobilization of metals and they accumulate in different concentrations in surface sediment, water and plants [56]. Table 4 presents lake sampling points and their possible heavy metal intrusion sources based on their location in NUST University.

Principal Component Analysis (PCA)

The principal directions of variation in Figure 4(a,b) are represented by F1 and F2. F1 captures the most significant variation related to the sources of heavy metals. The water, plants and sediments located near to the heavy metals indicate close association with them while those located far away, show distinct characteristics from other samples. 1) Water and sediments: Based on Figure 4a bi-plot, Zinc in water (Zn (W)) and lead in sediment (Pb (S)) indicate higher contributions to the observed variance because they have long vectors. Cd is located at a distance indicating a different source. L3I, L3O and L2I are far from other points which means they have distinct characteristics in terms of metal accumulation.

2) Lake flora: In PCA bi-plot Figure 4b, Zinc and chromium in plants (Zn (P), Cr (P)), are located in opposite directions indicating different sources. *B. javancia* (L2I), and *B. ceiba* (L1O) are aligned near Cr, *E. camaldulensis* (L3I) and T. stans (L2I) are present near Zn, *B. javancia* (L1O) aligns with Pb and Cd, indicating their presence in polluted environments.

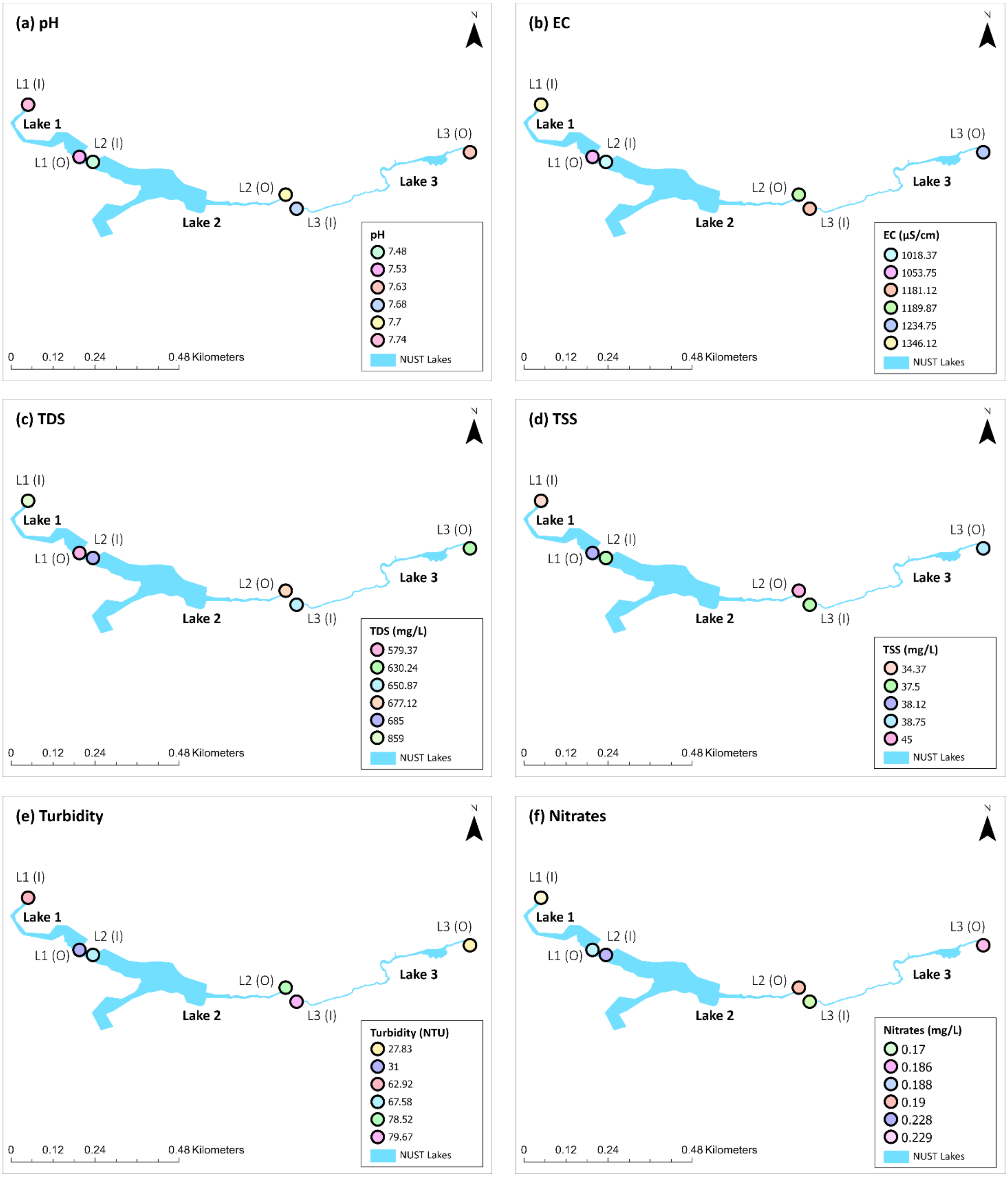

Figure 2. Average profile of (a) pH, (b) EC, (c) TDS, (d) TSS, (e) Turbidity, (f) Nitrates at NUST lakes sampling sites

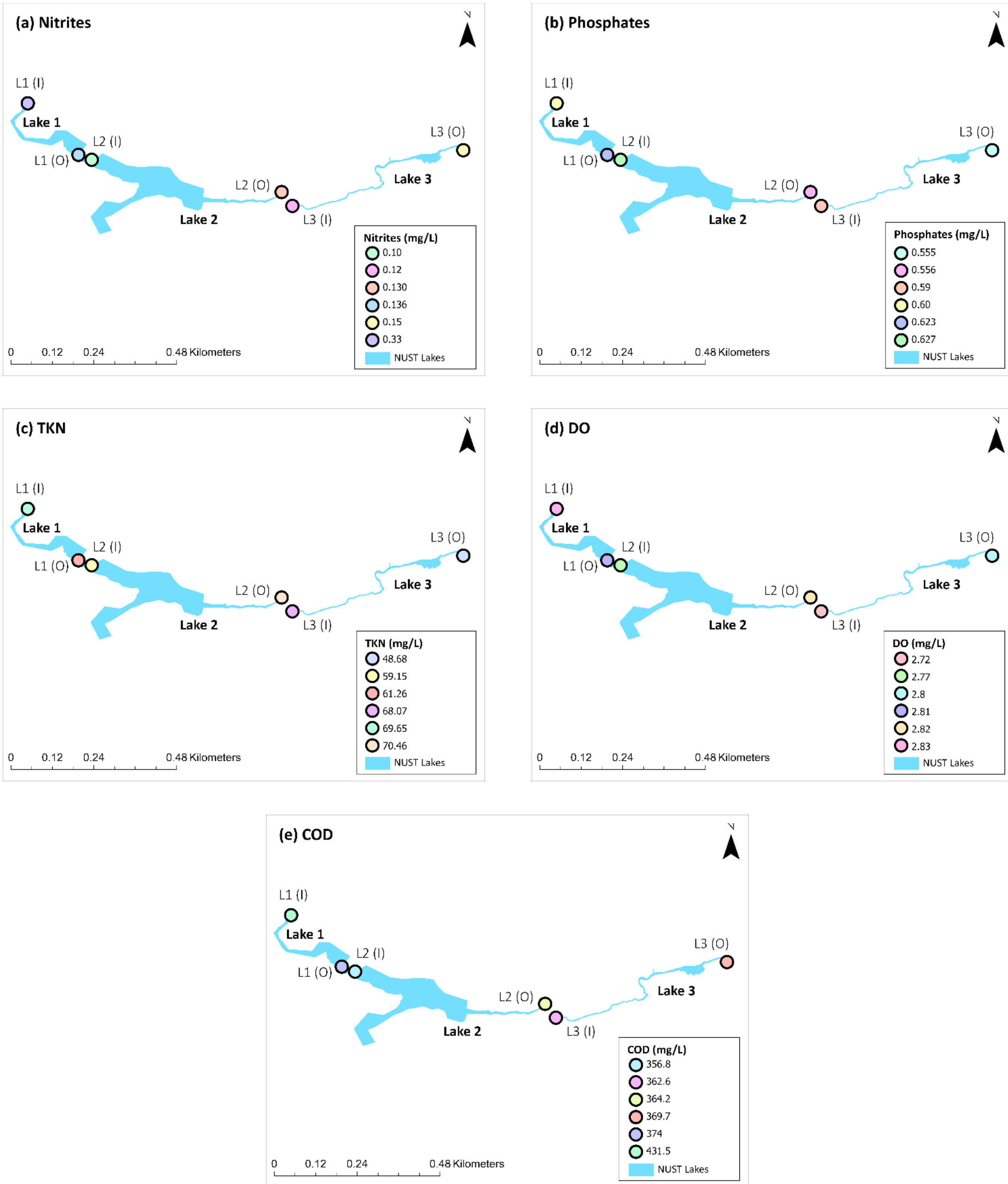

Figure 3. Average profile (a) Nitrite (b) Phosphates (c) TKN (d) DO (e) COD at NUST lakes sampling sites

Table 3. Sampling locations of the NUST lakes and their physicochemical parameters

Parameters	pH				Temperature (ºC)				DO (mg/L)				EC (µS/cm)				TDS (mg/L)				TSS (mg/L)			
WHO/PAK-EPA Limits	**6.5-8.5**				**-**								**1000**				**1000**							
Sampling locations	**Avg**	**Range**	**St Dev**	**Var**	**Avg**	**Range**	**St Dev**	**Var**	**Avg**	**Range**	**St Dev**	**Var**	**Avg**	**Range**	**St Dev**	**Var**	**Avg**	**Range**	**St Dev**	**Var**	**Avg**	**Range**	**St Dev**	**Var**
L1-I	7.74	7.70-7.75	0.02	0.001	23.66	15.20-34.70	8.55	73.18	2.84	2.60-3.05	0.18	0.03	1346.13	1086.50-1497.50	187.52	35164.90	859.00	791.00-905.00	48.24	2327.33	34.38	32.50-35.00	1.25	1.56
L1-O	7.53	7.35-7.75	0.17	0.029	22.23	15.20-29.65	6.68	44.61	2.81	2.35-3.20	0.40	0.16	1053.75	570.00-1477.50	401.98	161585.42	579.38	455.00-725.00	111.14	12351.56	38.13	25.00-55.00	14.24	205.73
L2-I	7.48	7.25-7.75	0.22	0.049	23.20	15.10-33.05	8.15	66.34	2.78	2.95-3.00	0.32	0.10	1018.38	570.00-1481.00	424.82	180472.23	685.00	500.00-820.00	137.72	18966.67	37.50	25.00-45.00	9.57	91.67
L2-O	7.70	7.55-7.85	0.17	0.030	21.49	13.80-28.70	6.82	46.58	2.83	2.90-3.15	0.46	0.21	1189.88	770.00-1686.50	432.87	187372.90	677.12	455.00-835.00	168.96	28548.06	45.00	25.00-67.50	17.44	304.17
L3-I	7.68	7.45-7.85	0.21	0.042	23.19	14.40-35.75	9.45	89.36	2.73	1.90-3.25	0.61	0.37	1181.13	764.50-1630.50	393.47	154820.23	650.87	505.00-836.00	142.68	20358.06	37.50	35.00-45.00	5.00	25.00
L3-O	7.63	7.45-7.75	0.15	0.023	21.14	13.4-29.15	7.35	53.98	2.80	2.25-3.15	0.42	0.18	1234.75	942.50-1609.00	304.23	92554.42	630.25	420.00-838.50	201.68	40676.08	38.75	27.50-35.00	17.85	318.75
Parameters	**NO_2-N (mg/L)**				**PO_4-P (mg/L)**				**COD (mg/L)**				**TKN (mg/L)**				**Turbidity (NTU)**				**NO_3-N (mg/L)**			
WHO/PAK-EPA Limits	**3**				**0.1**								**0.5**				**5**				**50**			
Sampling stations	**Avg**	**Range**	**St Dev**	**Var**	**Avg**	**Range**	**St Dev**	**Var**	**Avg**	**Range**	**St Dev**	**Var**	**Avg**	**Range**	**St Dev**	**Var**	**Avg**	**Range**	**St Dev**	**Var**	**Avg**	**Range**	**St Dev**	**Var**
L1-I	0.33	0.03-0.85	0.36	0.13	0.61	0.45-0.75	0.16	0.03	431.50	390.00-457.50	30.93	956.50	69.65	56.50-97.60	18.92	357.92	62.93	24.30-97.50	30.73	944.43	0.23	0.11-0.35	0.13	0.016
L1-O	0.14	0.02-0.26	0.11	0.01	0.62	0.52-0.74	0.10	0.01	374.00	326.00-435.00	50.41	2540.67	61.26	39.50-75.00	17.00	288.86	31.00	17.00-58.85	19.09	364.37	0.19	0.14-0.21	0.03	0.001
L2-I	0.10	0.02-0.19	0.08	0.01	0.63	0.48-0.73	0.12	0.01	356.80	246.20-445.00	86.88	7547.66	59.15	26.50-92.60	27.47	754.46	67.59	26.50-87.45	28.40	806.32	0.19	0.16-0.21	0.02	0.001
L2-O	0.13	0.02-0.32	0.13	0.02	0.56	0.49-0.63	0.06	0.003	364.28	298.60-430.00	58.39	3409.70	70.46	43.00-87.75	21.57	465.07	78.53	28.00-142.00	55.97	3132.10	0.17	0.10-0.28	0.08	0.006
L3-I	0.12	0.01-0.26	0.11	0.01	0.59	0.49-0.68	0.08	0.01	362.68	187.40-502.50	130.26	16967.14	68.08	38.00-90.75	23.22	539.36	79.68	26.50-143.50	57.35	3289.59	0.23	0.10-0.35	0.10	0.010
L3-O	0.15	0.02-0.39	0.17	0.03	0.56	0.48-0.66	0.07	0.01	369.70	198.80-510.00	128.67	16557.19	48.69	46.00-73.25	17.04	290.31	27.84	5.50-53.75	20.08	403.28	0.19	0.05-0.26	0.05	0.003

* WHO= World Health Organization, Pak-EPA= Pakistan Environmental Protection Agency (Standards) [54,55]

Table 4. Lake Sampling Points and their Possible Heavy Metal Intrusion Sources

Internal Sources	Possible Metals Released	Pollution	References
Residential apartments	Zn, Pb Cd	Detergents, household waste, plumbing corrosion, batteries, discharge of domestic wastewater.	[57,58,59,60,61]
Hostels	Zn, Pb, Cd	Detergents, plumbing corrosion, discharge of domestic wastewater.	
Cafeterias	Zn, Pb	Food waste, galvanized equipment in kitchen, plumbing corrosion, use of cleaning agents.	
University workshop	Cr, Zn, Pb	Processing of metals, use of batteries, paints, lubricants, repairing of machinery and equipment.	
Sports complex	Zn, Pb, Cd, Cr	Swimming pool pipes and plumbing corrosion, pool chemicals, corrosion of metal structures and gym equipment, pollution from parking area and vehicular emissions near complex, polluted soil	
Saddle club	Zn, Pb	Animal manure, animal feed, contamination of soil.	
Vehicular emissions	Zn, Pb, Cd	Traffic emissions, tire wear, road dust	
External sources (G-13, H-13)	Zn, Pb, Cd, Cr	Anthropogenic activities such as, industrial and construction activities, runoff from roads, stormwater drainage.	[57,59]

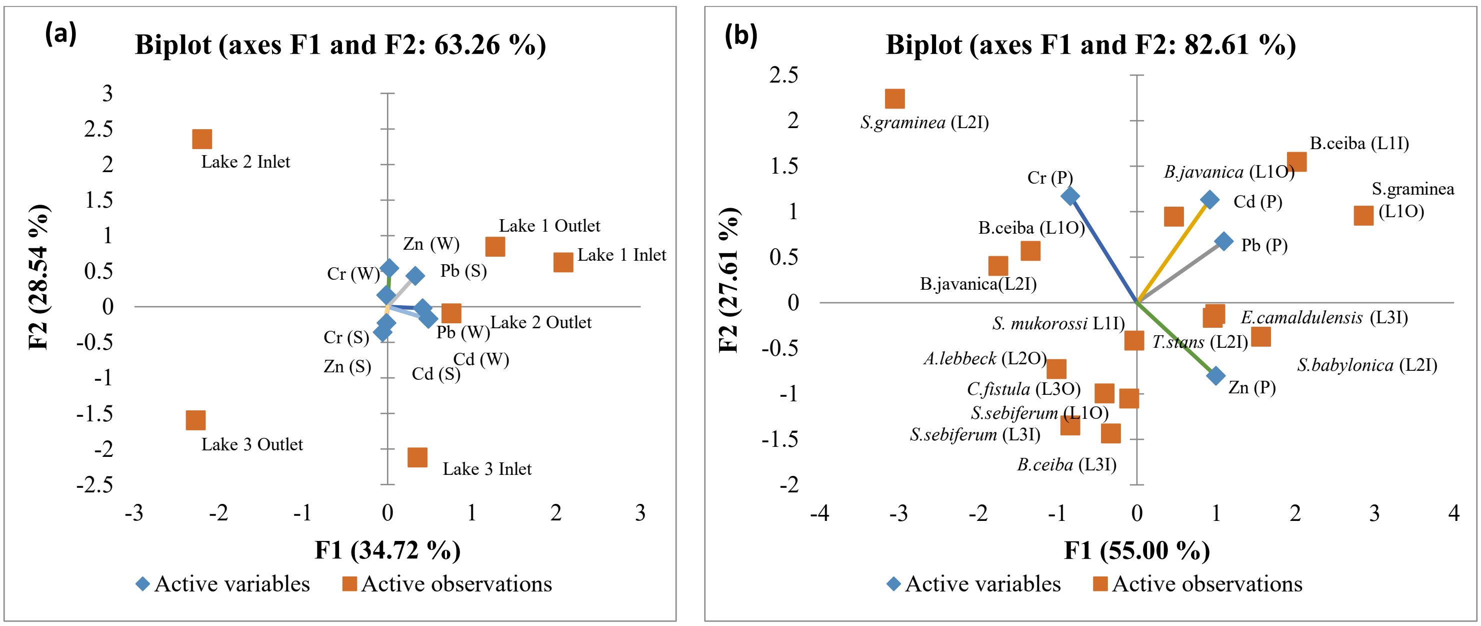

Figure 4. Principal component analysis (PCA) (a) heavy metals in water and surface sediment of NUST lakes (b) heavy metals in flora of NUST lakes

Spectrophotometer analysis shows that in *lake water and sediment*, 1) average Zn concentration was highest in L3O sediment (4.021 mg/kg) and L2I water samples (3.974 mg/L), 2) significant Cr concentration was detected in L3I sediment (0.043 mg/kg), and L2I water (0.096 mg/L), 3) detectable Cd levels (0.185mg/kg) were found in L3O water while in other water and sediment samples, Cd was below the detection limit. 4) Pb was below detection limit in both sediment and water. In *lake plants*, 1) *B.ceiba* at L1I accumulated highest Pb concentration (0.202 mg/kg), 2) *S.sebiferum* at L1O had highest Cd concentration (0.047 mg/kg), 3) *B.javanica* at L1O had significant Cr levels (0.013 mg/kg) and 4) highest Zn concentrations (5.302 mg/kg) were detected in *S.sebiferum* at L1O. The highest metal concentrations at different lake points indicate that the Zn, Pb, Cd and Cr concentrations are likely to exceed the permissible limits of WHO in some of the investigated samples. However, PCA bi-plot presents overall trends and correlation patterns instead of individual readings. In order to determine the spatial variation, long term monitoring of metal intrusion sources and measurement of their concentrations is required [62,63,64,65]. Table 5 presents the metals that can be accumulated by plants at the inlets and outlets of NUST lakes.

Table 5. Metal accumulation by flora at NUST lakes

Plant species	**Metal best accumulated**	**References**
Bombax ceiba	Cr, Pb	[66,67]
Sapindus mukorossi	Cd, Cr, Zn, Pb	[68,69]
Bischofia javanica	Cd, Zn	[70]
Sapium sebiferum	Cd, Zn, Pb	[71]
Stellaria graminea	Cd, Cr, Zn, Pb	[72]
Tecoma stans	Cd, Zn, Pb	[73]
Salix babylonica	Cd, Cr, Zn, Pb	[74,75]
Albizia lebbeck	Cd, Cr, Zn, Pb	[76]
Eucalyptus camaldulensis	Cd, Cr, Zn, Pb	[77,78]
Casia Fistula	Cd, Cr, Zn, Pb	[79]

Chlorophyll Concentration (Chl a, b, c)

The average chlorophyll concentration ranged from 0.00007-0.0006 mg/L Figure 5. NUST lakes are oligotrophic due to lower chlorophyll content i.e., < 0.001 mg/L [80]. Detergents, food residues and human waste released from hostels, cafeteria and residential apartments contain nitrates and phosphates that can enter the lakes through runoff during rainfall. Application of fertilizers on university green areas and stormwater runoff from G-13 and H-13 may also transport sediments carrying nutrients and organic matter into the university lakes. Chemical analyses revealed elevated levels of TKN and phosphates, typically associated with eutrophic conditions, however, the lake exhibited characteristics of an oligotrophic system containing low chl-a concentrations. This disturbed state maybe due to ecological disturbance in the lake ecosystem. One possible reason is heavy metal toxicity. Elevated concentrations of metals such as Zn affect phytoplankton growth, photosynthetic activity and algal biomass despite nutrient availability. Additionally, extensive aquatic vegetation may act as a nutrient sink by absorbing nutrients from the water column and sediments. Consequently, nutrient enrichment in the lake may not translate into increased algal biomass, resulting in the observed low chl-a levels [52,81,82,83].

Leaf Chlorophyll Content-Chlorophyll Content Index (CCI)

The average values of leaf chlorophyll ranged from 3.7-165.3. The highest leaf chlorophyll values were detected in *Stellaria graminea* at L2I. Nitrate-N (NO_3-N) concentrations and seasonal parameters could have affected the plant's photosynthetic process and chlorophyll content [18]. Figure 6 represents the map of plant species with significant chlorophyll content index (CCI) and their respective locations at NUST lakes.

Dominant Algae

Three dominant algal species (*Nitzschia sp., Navicula gregaria sp., and Euglena sp.*) were identified (Figure 7) on the basis of their morphology under the compound microscope and compared with relevant literature [84].

Seasonal Parameters

Maximum GHI (211 W/m^2) was observed in september and maximum ambient temperature was (27˚C), while wind speed remained constant with insignificant variation throughout the sampling period (1.3 to 0.9 m/s). September had maximum rainfall (21.4 mm) whereas, December had minimum rainfall (4.5 mm). In shallow lakes, short term seasonal changes give information about temporary variability in lake parameters such as algal biomass and nutrients whereas monitoring long-term seasonal variations capture a bigger picture and give reliable results. The short term seasonal variability in university lakes provides a baseline for future studies (Figure 8) [85].

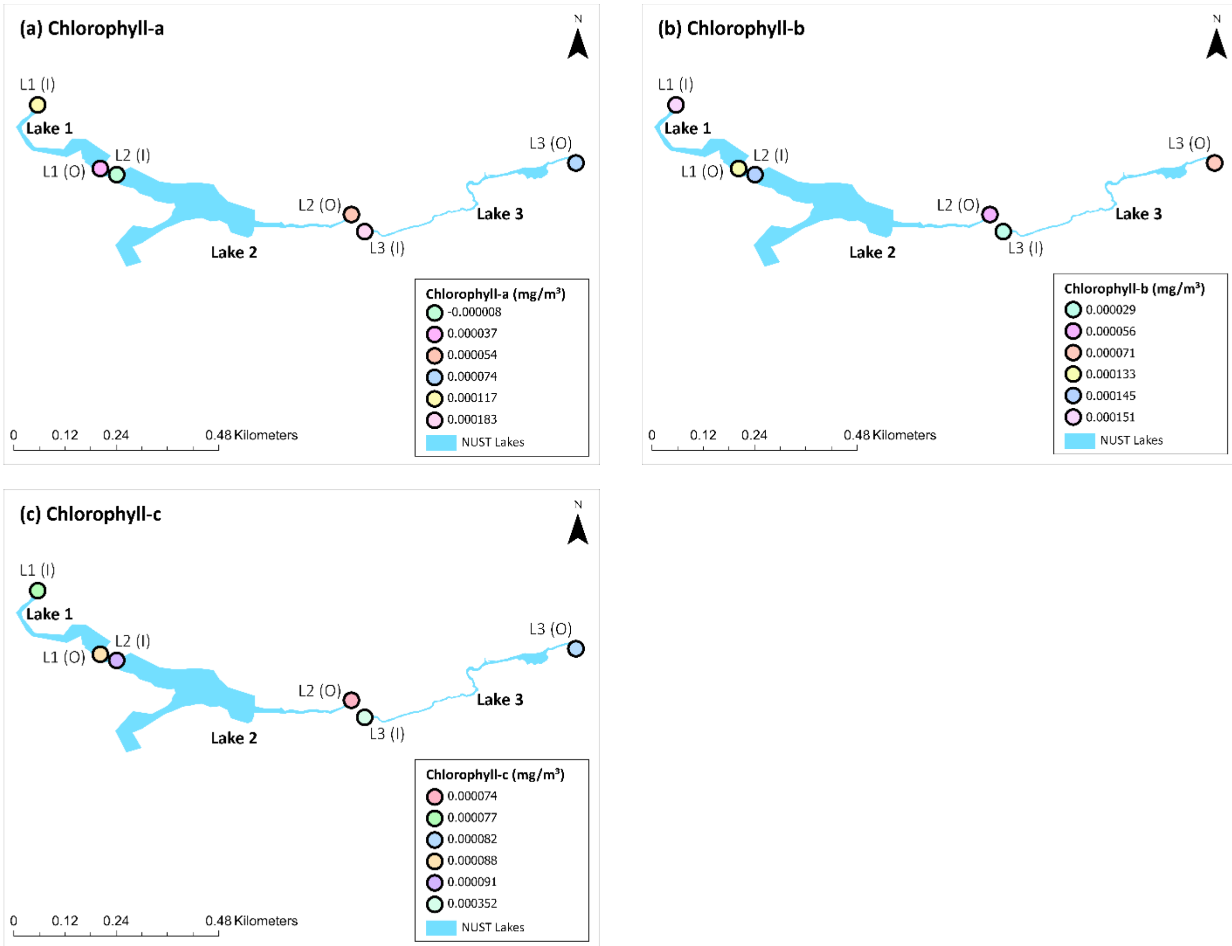

Figure 5. Map showing average (a) Chlorophyll-a (b) Chlorophyll-b (c) Chlorophyll-c concentration at NUST lakes sampling points.

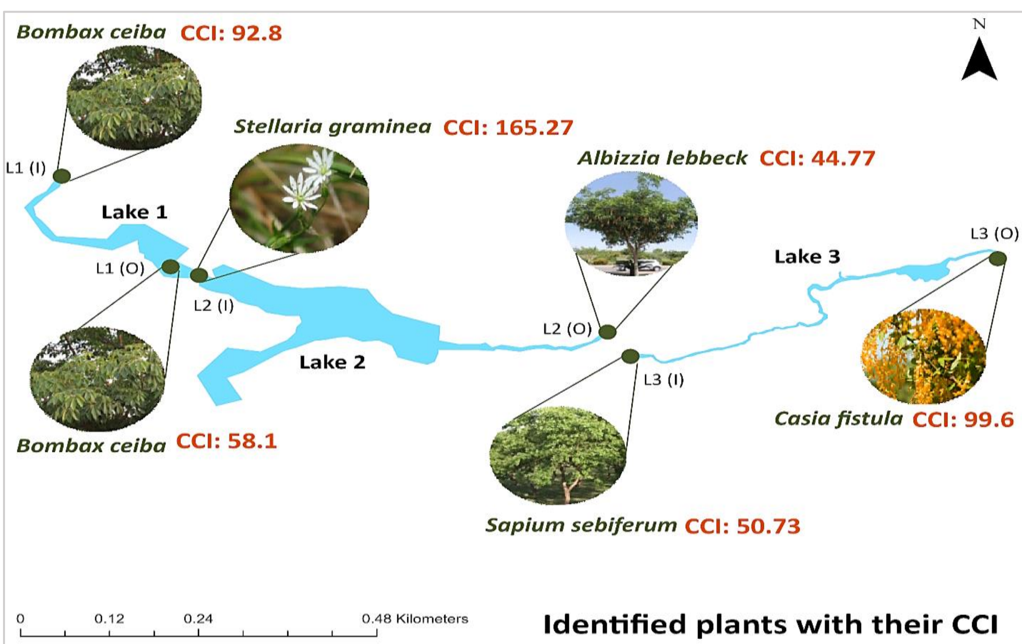

Figure 6. Plant species with significant chlorophyll content index (CCI) values found at different sampling locations of the NUST lakes.

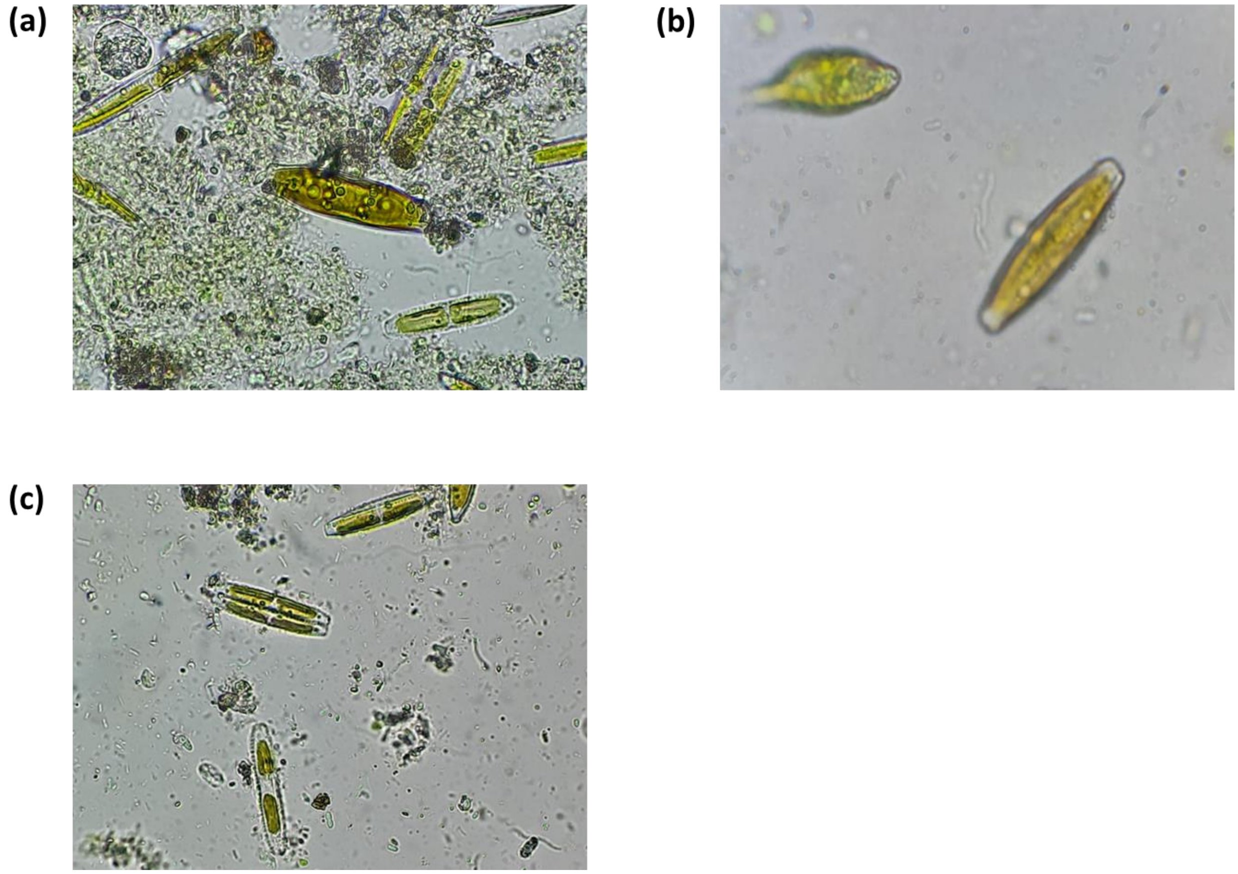

Figure 7. Microscopic images of dominant algae at NUST lakes (a) *Nitzschia sp.* (b) *Navicula gregaria sp*. (c) *Euglena sp*.

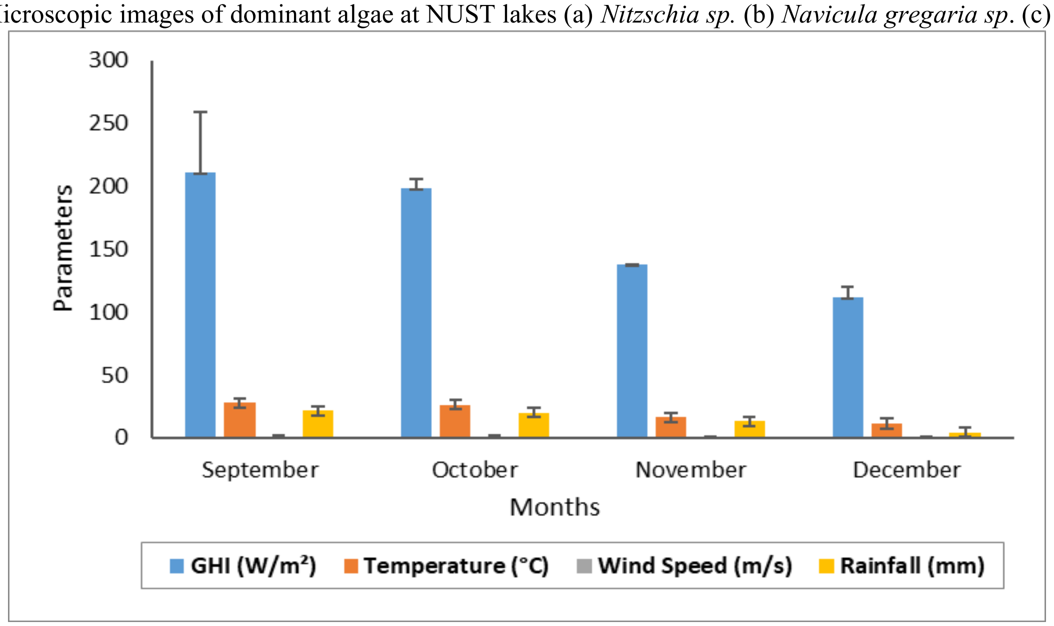

Figure 8. Seasonal data obtained from USPCAS-E, NUST

Discussion

The results showed a significant impact of pollution on NUST lakes, most likely due to human activities within and outside the residential university. Nature Based Solutions (NBS) were identified as the most efficient and cost-effective methods to mitigate the impacts of natural and anthropogenic pollution. The heavy metal analysis of lake plants and relevant literature showed their potential for phytoremediation. Further studies need to be conducted to determine their effectiveness in mitigating pollution. Phytoremediation can be a sustainable solution for lake management if surface aquatic plants and woody trees are managed carefully using different mechanical methods. The surface vegetation in shallow lakes can be removed by using large-scale mechanical harvesting, specialized boats or machinery which can physically cut and extract the plants from surface. This helps in managing vegetation overgrowth and assessing the ecological effects such as their effects on water quality parameters and nutrient levels. Periodic harvesting of metal containing biomass of woody trees along lakes must be done to prevent the re-release of contaminants into water or soil during natural decay. Trees can be cut or forested on a defined rotation. This rotation helps in removal of stems, leaves and branches containing accumulated metals. Safe processing of biomass must be ensured after harvesting which can be achieved through composting in controlled conditions with leachate stabilization, thermochemical treatments like pyrolysis, gasification, hydrothermal carbonization, and safe disposal in landfill sites to control the mobilization of metals. The conversion of biomass into hydrochar through hydrothermal carbonization stabilizes heavy metals and produces biofuel which mitigates pollution and ensures safe usage of toxic biomass. These post-harvest management strategies should be explored and applied according to the feasibility to protect the environment from recirculation of metals [86,87,88,89]. Campus vegetation health status should also be regularly monitored by measuring leaf chlorophyll content. Local flora management is necessary for even nutrient distribution in the environment. The trophic status of NUST lakes should be mesotrophic instead of oligotrophic or hypereutrophic. Buffer zones could be created in future to minimize nutrient runoff to prevent oligotrophic status of NUST lakes from changing to hypereutrophic [23,24]. Dominant algae can be characterized through polymerase chain reaction (PCR). Regular sampling for prolonged seasons is required to detect any non-native or toxin inducing algae in lakes and to identify how native algae can be controlled to prevent algal boom [90]. Furthermore, lake fish should be tested for any accumulation of heavy metals. Toxic fish should be removed through nets (biomanipulation) to cleanse the lake water [23,12].

Research [27] was conducted on techno economic perspective of Floating Solar Photovoltaic Systems (FPVs) deployment over NUST lake. The study focused more on the economic perspective rather than highlighting environmental issues associated with the lakes. Application of any technology with insufficient information about the study area may lead to additional costs for repair due to environmental factors affecting its efficiency. This study highlights the urgent need of Nature Based Solutions (NBS) to improve water quality in urban lakes and provides a baseline data for future ecological assessments. It serves as a guideline for the authorities to help them prevent waste intrusion into the lakes from internal sources (hostels, cafeteria, workshop, saddle club, sports complex and residential apartments), treat the water pollution from external sources (G-13 and H-13 sectors of Islamabad), ensure that contaminated lake water is not being consumed by the university residents, staff and visitors, raise awareness, ensure strict implementation of mitigation measures to make NUST lakes healthy again and make necessary changes in the policies. The study duration was limited to one season; therefore, the effect of meteorological parameters could not be studied in detail. Future work could explore seasonal changes and their effects on physicochemical parameters, nutrients and heavy metal concentrations more comprehensively. Results might vary if full annual cycle is monitored including the summer and monsoon season.

Statistical Analysis

To perform a statistical analysis, XLSTAT for Principal Component Analysis (PCA-Biplot) was used. Arc-GIS Pro 3.3.0 was used to visualize the physicochemical parameters. In addition to this, a bar graph for seasonal baseline was created using (Microsoft Excel) MS-Excel.

Conclusions

Monitoring pollutant levels in NUST lakes aligns with SDG6 developed by UN in 2015 i.e., clean water and sanitation for all. Results of the parameters showed that pH, TDS, NO_3-N and NO_2-N concentrations were within the WHO permissible limits while TKN, EC, turbidity and PO_4-P, exceeded the limits. The DO concentrations indicated toxic conditions for aquatic organisms like fish. Zinc (Zn) had highest concentration in water, sediment and plants as compared to other metals. The dominant algae in lake water were determined on the basis of morphology. Identification and characterization of dominant algal species through PCR may be conducted in future for long term eutrophication analysis. In addition to this, average CCI was highest in *Stellaria graminea*. Potential hyperaccumulators could be selected for the mitigation of heavy metal pollution. The seasonal parameters showed insignificant impact on water quality parameters due to the oligotrophic status of lakes. Impact of weather and seasonal patterns needs to be monitored regularly for timely and efficient monitoring of pollution status. These steps will help in carrying out different sports activities and fulfill the recreational purpose of NUST lakes in future. NUST lakes were a habitat of diverse flora and fauna. Ducks and fish species were observed initially in walk through surveys. Contaminated lake water will not only affect the biodiversity but also deteriorate health of students, faculty, staff and visitors. Therefore, its restoration must be ensured by applying Nature Based Solutions (NBS) methods. The current research will have pragmatic applications in areas including amelioration of water quality, enhancement of public health status, and implementation of policy measures indispensable to meet the said goals.

Acknowledgments
The authors are grateful to postgraduate program of the National University of Sciences and Technology (NUST), Islamabad, Pakistan. Suggestions from horticulture department, NUST, U.S.- Pakistan Center for Advanced Studies in Energy (USPCAS-E), NUST, Project Management Office (PMO), NUST, colleagues from the Environmental toxicology research group, Environmental microbiology research group, Institute of Environmental Sciences and Engineering, SCEE (IESE), NUST and Institute of Geographical Information Systems, SCEE (IGIS), NUST are also appreciated.

Competing Interests
None.

Authors' Contribution
Conceptualization and methodology, A.F., H.A. and I.H.; formal analysis, investigation, resources, data curation, A.F., H.A. and I.H.; software, R.F.; visualization, A.F. and R.F.; writing—original draft preparation, A.F., H.A. and I.H.; writing—review and editing, A.F., H.A, I.H, R.F. and A.M.; supervision, H.A. and I.H. All authors have read and agreed to the published version of the manuscript.

References

1. Vasistha. P and Ganguly. R, "Water quality assessment of natural lakes and its importance: An overview", *Materials Today: Proceedings*, Vol. *32*, 2020, pp. 544-552. https://doi.org/10.1016/j.matpr.2020.02.092
2. Zeewaqar. M, "Sustainable development goals in pakistan: A comprehensive analysis of progress, challenges, and recommendations", *Preprints*, 2024. http://dx.doi.org/10.20944/preprints202409.1670.v1
3. Nabi. G, Ali. M, Khan. S and Kumar. S, "The crisis of water shortage and pollution in Pakistan: Risk to public health, biodiversity, and ecosystem", *Environmental Science and Pollution Research*, Vol. 26, 2019, pp. 10443-10445. https://doi.org/10.1007/s11356-019-04483-w
4. Xu. Y, Wu. Y, Han. J and Li. P, "The current status of heavy metal in lake sediments from China: Pollution and ecological risk assessment", *Ecology and evolution*, Vol. 7, No. 14, 2017, pp. 5454-5466. https://doi.org/10.1002/ece3.3124
5. Zhou. Q, Yang. N, Li. Y, Ren. B, Ding. X, Bian. H and Yao, X, "Total concentrations and sources of heavy metal pollution in global river and lake water bodies from 1972 to 2017", *Global Ecology and Conservation*, Vol. 22, 2020, pp. e00925 https://doi.org/10.1016/j.gecco.2020.e00925
6. Oyege. I, Katwesigye. R, Kiwanuka. M, Mutanda. H. E, Niyomukiza. J. B, Kataraihya. D. J and Egor. M, "Temporal trends of water quality parameters, heavy metals, microplastics, and emerging organic pollutants in Lake Victoria and its basin: Knowns, gaps, and future direction", *Environmental Nanotechnology, Monitoring & Management*, Vol. 22, 2024, pp. 100962. https://doi.org/10.1016/j.enmm.2024.100962
7. Piwowarska. D, Kiedrzyńska. E and Jaszczyszyn. K, "A global perspective on the nature and fate of heavy metals polluting water ecosystems, and their impact and remediation", *Critical Reviews in Environmental Science and Technology*, Vol. 54*,* No. 19, 2024, pp. 1436-1458. https://doi.org/10.1080/10643389.2024.2317112
8. Vardhan. K. H, Kumar. P. S and Panda. R. C, "A review on heavy metal pollution, toxicity and remedial measures: Current trends and future perspectives", *Journal of Molecular Liquids*, Vol. 290, 2019, pp. 111197. https://doi.org/10.1016/j.molliq.2019.111197
9. Edelstein. M and Ben-Hur. M, "Heavy metals and metalloids: Sources, risks and strategies to reduce their accumulation in horticultural crops", *Scientia Horticulturae*, Vol. 234, 2018, pp. 431-444. https://doi.org/10.1016/j.scienta.2017.12.039
10. Pambudiono. A, Suarsini. E and Amin. M, "The potential of indigenous bacteria for removing cadmium from industrial wastewater in lawang, east java", *Journal of Tropical Life Science*, Vol. *8*, No.1, 2018, pp. 62-67. https://doi.org/10.11594/jtls.08.01.11
11. Vincent. J. B, "New evidence against chromium as an essential trace element", *The Journal of Nutrition*, Vol. 147*,* No.12, 2017 pp. 2212-2219. https://doi.org/10.3945/jn.117.255901
12. Fatima. S, Muzammal. M, Rehman. A, Rustam. S. A, Shehzadi. Z, Mehmood.A and Waqar, M, "Water pollution on heavy metals and its effects on fishes", *International Journal of Fisheries and Aquatic Studies*, Vol. 8*,* No.3, 2020, pp. 6-14.
13. Singh. S, Yadav. V, Arif. N, Singh. V. P, Dubey. N. K, Ramawat. N and Chauhan, D. K, "Heavy metal stress and plant life: uptake mechanisms, toxicity, and alleviation", *Plant life under changing environment*, 2020, pp. 271-287. Academic Press. https://doi.org/10.1016/B978-0-12-818204-8.00001-1
14. Yu. Z, Liu. E, Lin. Q, Zhang. E, Yang. F, Wei. C and Shen. J, "Comprehensive assessment of heavy metal pollution and ecological risk in lake sediment by combining total concentration and chemical partitioning", *Environmental Pollution*, Vol. 269, 2021, pp. 116212. https://doi.org/10.1016/j.envpol.2020.116212
15. Liu. P, Wu. Q, Wang. X, Hu. W, Liu. X, Tian. K and Khim. J. S, "Spatiotemporal variation and sources of soil heavy metals along the lower reaches of Yangtze River, China", *Chemosphere*, Vol. 291, 2022, pp. 132768. https://doi.org/10.1016/j.chemosphere.2021.132768
16. Sun. C, Zhang. Z, Cao. H, Xu. M and Xu. L, "Concentrations, speciation, and ecological risk of heavy metals in the sediment of the Songhua River in an urban area with petrochemical industries", *Chemosphere*, Vol. 219, 2019, pp. 538-545. https://doi.org/10.1016/j.chemosphere.2018.12.040

17. Spaulding. S. A, Platt. L. R, Murphy. J. C, Covert. A and Harvey. J. W, "Chlorophyll a in lakes and streams of the United States (2005–2022)", *Scientific Data*, Vol. 11, No.1, 2024, pp. 611. https://doi.org/10.1038/s41597-024-03453-3
18. Liu. C, Liu. Y, Lu. Y, Liao. Y, Nie. J, Yuan. X and Chen. F, "Use of a leaf chlorophyll content index to improve the prediction of above-ground biomass and productivity", *PeerJ*, Vol. 6, 2019, pp. e6240 https://doi.org/10.7717/peerj.6240
19. Doddavarapu. B, Crasta. G. L and Shankar. M, "Comparative studies on chlorophyll concentration in some important plant families", *Journal of Pharmacognosy and Phytochemistry*, Vol. 10, No .3, 2021, pp. 214-220. https://doi.org/10.22271/phyto.2021.v10.i3c.14074
20. Li. Z, Zhang. Z, Xiong. S, Zhang. W and Li. R, "Lake surface temperature predictions under different climate scenarios with machine learning methods: a case study of Qinghai lake and Hulun lake, China", *Remote Sensing*, Vol. 16, No.17, 2024, 3220. https://doi.org/10.3390/rs16173220
21. Alhamarna. M. Z and Tandyrak. R, "Lakes restoration approaches", *Limnological Review*, Vol. 21, No. 2, 2021, pp. 105-118. http://dx.doi.org/10.2478/limre-2021-0010
22. Kornijów. R, "Eutrophication and derivative concepts. origins, compatibility and unresolved issues", *Ecohydrology & Hydrobiology*, Vol. 24, No. 2, 2024, pp. 289-298. https://doi.org/10.1016/j.ecohyd.2023.07.001
23. Pereira. A. C and Mulligan. C. N, "Practices for eutrophic shallow lake water remediation and restoration: A critical literature review", *Water*, Vol. 15, No. 12, 2023, pp. 2270. https://doi.org/10.3390/w15122270
24. Liu. C, Du. Y, Zhong. J, Zhang. L, Huang. W, Han. C and Gu. X, " From macrophyte to algae: Differentiated dominant processes for internal phosphorus release induced by suspended particulate matter deposition", *Water Research*, Vol. 224, 2022, pp. 119067. https://doi.org/10.1016/j.watres.2022.119067
25. Tigli. M, Bak. M. P, Janse. J. H, Strokal. M and Janssen. A. B, "The future of algal blooms in lakes globally is in our hands", *Water Research*, Vol. 268, 2025, pp. 122533. https://doi.org/10.1016/j.watres.2024.122533
26. Khan. M, Omer. T, Ellahi. A, Ur Rahman. Z, Niaz. R and Ahmad Lone. S, "Monitoring and assessment of heavy metal contamination in surface water of selected rivers", *Geocarto International*, Vol. 38, No.1, 2023, 2256313. https://doi.org/10.1080/10106049.2023.2256313
27. Oseke. F. I, Anornu. G. K, Adjei. K. A and Eduvie. M. O, "Assessment of water quality using GIS techniques and water quality index in reservoirs affected by water diversion," *Water-Energy Nexus*, Vol. 4, 2021, pp. 25-34. https://doi.org/10.1016/j.wen.2020.12.002
28. Hafeez. H, Janjua. A. K, Nisar. H, Shakir. S, Shahzad. N and Waqas. A, "Techno-economic perspective of a floating solar PV deployment over urban lakes: a case study of NUST lake Islamabad," *Solar Energy*, Vol. 231, 2022, pp. 355-364. https://doi.org/10.1016/j.solener.2021.11.071
29. Latif. A, Yu. T and Mangi. Y, "Climate change and urban vulnerabilities: analyzing flood and drought resilience of Islamabad", 2023. https://dx.doi.org/10.2139/ssrn.4653784
30. Que. W, Yi. L, Wu. Y and Li. Q, "Analysis of heavy metals in sediments with different particle sizes and influencing factors in a mining area in Hunan Province", *Scientific Reports*, Vol. 14, No. 1, 2024, pp. 20318. https://doi.org/10.1038/s41598-024-71502-3
31. Acharya. S. M, "Collection and preparation of soil, water and plant samples for analysis," *International Journal of Chemical Studies*, Vol. 6, No. 2, 2018, pp. 3298-3303.
32. Moursy. A. R, Hassan. M. N and Elhefny. T. M, "Sampling and analysis of soil and water: A review", *International Journal of Geography, Geology and Environment*, Vol. 4, 2022, pp. 34-41.
33. HACH, "2100Q Portable Turbidimeter EPA, 0–1000 NTU" https://www.hach.com/p-2100q-portable-turbidimeter-epa-01000ntu/2100Q01?promo=promosuper15 February 9, 2025.
34. HACH, "Nitrogen, Total Kjeldahl" https://www.bing.com/ck/a?!&&p=d976ebc8bbb1f32f0deb148ec95532a481675a5a3cfd68d14aeeb7746cf96e3bJmldHM9MTczNDk5ODQwMA&ptn=3&ver=2&hsh=4&fclid=19e4d62f-e7f4-62a8-3aed-c2bbe68b6394&psq=KJELDAHL+TKN+APPARATUS+HACH&u=a1aHR0cHM6Ly9pbWFnZXMuaGFjaC5jb20vYXNzZXQtZ2V0LmRvd25sb2FkLmpzYT9pZD03NjM5OTgzODA5&ntb=1 February 9, 2025.
35. HACH, "*Sension+ MM156 Portable Multi-Parameter Meter Field Kit with Multi-sensor for pH, Conductivity, Salinity, and Dissolved Oxygen (DO)*", https://my.hach.com/sension-mm156-portable-multi-parameter-meter-field-kit-with-multi-sensor-for-ph-conductivity-salinity-and-dissolved-oxygen-do/product-details?id=%2059428397002 February 9, 2025.
36. HACH, "VIS and UV-VIS Spectrophotometers", https://www.hach.com/products/instrument-type/spectrophotometer (accessed on February 9, 2025.
37. HACH, "Solids Sensors, Standards and Equipment", https://www.hach.com/parameters/solids#:~:text=Gravimetric%20Method%3A%20The%20most%20common%20technique%20for%20measuring,and%20determ%20ing%20the%20dry%20weight%20of%20these%20solids February 9, 2025.
38. HACH, *"COD Digestion Vials, High Range, pk/150"*, https://www.hach.com/p-cod-digestion-vials-high-

range-pk%20150/2125915 February 9, 2025.

39. Aquisman. A. E, Assim. Z. B, Wahi. R. B, Kwabena. D. E and Festus. W, "Validation of the atomic absorption spectroscopy (AAS) for heavy metal analysis and geochemical exploration of sediment samples from the Sebangan River", *Advances in Analytical Chemistry*, Vol. 9, 2019, pp. 23-33. 10.5923/j.aac.20190902.01
40. Kannan. L, Gokulprasath. M, Gurusamy. R, Selvam. R and Palaniswamy. R, "Analysis of heavy metals contamination in water: A review", *International Journal of Research and Analytical Reviews*, Vol. *8, No.* 4, 2021, pp. 201-213.
41. US Environmental Protection Agency, "Method 1669: Sampling Ambient Water for Trace Metals at EPA Water Quality Criteria Levels", 1996. https://www.epa.gov/sites/default/files/2015-10/documents/method_1669_1996.pdf February 9, 2025.
42. Hseu. Z. Y, Chen. Z. S, Tsai. C. C, Tsui. C. C, Cheng. S. F, Liu. C. L and Lin. H. T, "Digestion methods for total heavy metals in sediments and soils", *Water, Air, and Soil Pollution*, Vol. 141, 2002, pp. 189-205. https://doi.org/10.1023/A:1021302405128
43. CSIRO, ANACC Methods and Materials, "Chlorophyll Spectrophotometric Analysis 2002", https://research.csiro.au/anaccmethods/phycological-techniques/biomass-estimation/chlorophyll-spectrophotometric-analysis/ February 9, 2025.
44. Kamarianakis. Z and Panagiotakis. S, "Design and implementation of a low-cost chlorophyll content meter", *Sensors*, Vol. 23, No. 5, 2023. . https://doi.org/10.3390/s23052699
45. Qian. P, Zhao. Z, Liu. H, Wang. Y, Peng. Y, Hu. S and Zeng, Z, "Multi-target deep learning for algal detection and classification", Proceedings of the 2020 42nd Annual International Conference of the IEEE Engineering in Medicine and Biology Society, Montreal, QC, Canada, July 20-24, 2020. doi.org/10.1109/EMBC44109.2020.9176204
46. Narayana. T. L., Venkatesh. C, Kiran. A, Kumar. A, Khan. S. B, Almusharraf. A and Quasim. M. T, "Advances in real time smart monitoring of environmental parameters using IoT and sensors", *Heliyon*, Vol. 10, No. 7, 2024, pp. e28195. https://doi.org/10.1016/j.heliyon.2024.e28195
47. Oyelami. S, Azeez. N. A, Adedigba. S. A, Akinola. O. J and Ajayi. R. M, "A pyranometer for solar radiation measurement-review", *Adeleke University Journal of Engineering and Technology*, Vol. 3, No. 1, 2020, pp. 61-68.
48. Dory. F, Nava. V, Spreafico. M, Orlandi. V, Soler. V and Leoni. B, "Interaction between temperature and nutrients: How does the phytoplankton community cope with climate change?", *Science of the Total Environment*, Vol. 906, 2024, 167566. https://doi.org/10.1016/j.scitotenv.2023.167566
49. Kassa. Y and Tibebe. D, "Analyses of potential heavy metals and physico-chemical water quality parameters on Lake Tana, Ethiopia", *Journal of Academia and Industrial Research* (JAIR), Vol. 8, No. 7, 2019, pp. 130-138.
50. Pilla. R. M., Williamson, C. E., Overholt, E. P., Rose, K. C., Berger, S. A., Couture, R. M., and Yao, "Deepwater dissolved oxygen shows little ecological memory between lake phenological seasons", *Inland Waters*, Vol. *13, No.* 3, 2023, pp. 327-338. https://doi.org/10.1080/20442041.2023.2265802
51. Rahman. A, Jahanara. I and Jolly. Y. N, "Assessment of physicochemical properties of water and their seasonal variation in an urban river in Bangladesh", *Water Science and Engineering*, Vol. 14, No. 2, 2021, pp. 139-148. https://doi.org/10.1016/j.wse.2021.06.006
52. Nkwalale. L, Schwefel. R, Yaghouti. M and Rinke. K, "A simple model for predicting oxygen depletion in lakes under climate change", *Inland Waters*, Vol. 13, No. 4, 2023, pp. 576-595. https://doi.org/10.1080/20442041.2024.2306113
53. Rahman. K, Barua. S, and Imran. H. M, "Assessment of water quality and apportionment of pollution sources of an urban lake using multivariate statistical analysis", *Cleaner Engineering and Technology*, Vol. *5*, pp. 100309. https://doi.org/10.1016/j.clet.2021.100309
54. World Health Organization, "*Guidelines for drinking-water quality* (4th ed.)", Geneva, 2017. https://www.who.int/publications/i/item/9789241549950
55. Pakistan Environmental Protection Agency, "*National Standards for Drinking Water Quality (NSDWQ)",* Ministry of Environment, Government of Pakistan, Islamabad, 2008. https://environment.gov.pk/Detail/MDUzMDI1OGItYWYzZC00NzQ0LTlhZWItZjYzY2RkOTkyZGVh
56. Angon. P. B, Islam. M. S, Kc. S, Das. A, Anjum. N, Poudel. A and Suchi. S. A, "Sources, effects and present perspectives of heavy metals contamination: Soil, plants and human food chain", *Heliyon*, 2024. https://doi.org/10.1016/j.heliyon.2024.e28357
57. Chiutula. C, Mtewa. A. G, Abraham. A, Mvula. R. L. S, Maluwa. A, Eregno. F. E, and Njalam'mano. J, "Assessment of Heavy Metal Accumulation in Wastewater–Receiving Soil–Exotic and Indigenous Vegetable Systems and Its Potential Health Risks: A Case Study from Blantyre", Malawi. *International Journal of Environmental Research and Public Health*, Vol. 22, No. 11, 2025, pp. 1614. https://doi.org/10.3390/ijerph22111614
58. Ariyibi. E. A, "Assessment of potentially toxic elements concentration and distribution in soils at automobile mechanic workshops across different geological environments: a review", *NRIAG Journal of Astronomy and Geophysics*, Vol. 14, No. 1, 2025, pp. 1-24.
59. Iwegbue. C. M, Nnanna. C. A, Ogwu. I. F, Odali. E. W,

and Martincigh. B. S, "Concentrations, sources and exposure to metals in dust from automobile mechanic workshops in Nigeria", *Journal of Trace Elements and Minerals*, Vol. 10, 2024, pp. 100186. https://doi.org/10.1016/j.jtemin.2024.100186

60. Zgłobicki. W, Telecka. M, and Skupiński. S, "Heavy metals in playgrounds in Lublin (E Poland): sources, pollution levels and health risk", *Environmental Science and Pollution Research*, Vol. 28*, No.* 15, 2021, pp. 18328-18341. https://doi.org/10.1007/s11356-020-09375-y
61. Nnabugwu. A. E, and Uchenna. A. P, "Swimming pools quality risk assessment for heavy metal deposition and intake via oral and dermal exposure. *Environmental Analysis, Health and Toxicology*", Vol. 34, No. 3, 2019, pp. e2019008. https://doi.org/10.5620/eaht.e2019008
62. Olayinka-Olagunju. J. O, Dosumu. A. A and Olatunji-Ojo. A. M, "Bioaccumulation of heavy metals in pelagic and benthic fishes of Ogbese River, Ondo State, South-Western Nigeria", *Water, Air and Soil Pollution*, Vol. 232, No. 2, 2021, pp. 44. https://doi.org/10.1007/s11270-021-04987-7
63. Gulab. H, Mahmood. M, Ali. S and Jan. F. A, "Assessment of heavy metals in various parts of plants, soil and air of some selected areas of district Charsadda, Pakistan", *Carpathian Journal Earth and Environmental Sciences*, Vol. 10, 2015, pp. 219-224.
64. Atta. M. I, Zehra. S. S, Dai. D. Q, Ali. H, Naveed. K, Ali. I and Ali. I, "Amassing of heavy metals in soils, vegetables and crop plants irrigated with wastewater: Health risk assessment of heavy metals in Dera Ghazi Khan, Punjab, Pakistan", *Frontiers in Plant Science*, Vol. 13*,* 2023, pp. 1080635. https://doi.org/10.3389/fpls.2022.1080635
65. Osmani. M, Bani. A and Hoxha. B, "Heavy metals and Ni phytoextractionin in the metallurgical area soils in Elbasan", *Albanian Journal of Agricultural Sciences*, Vol. 14, No. 4, 2015, pp. 414.
66. Sabir. M. A, Guo. W, Nawaz. M. F, Yasin. G, Yousaf. M. T. B, Gul. S, and Rahman. S. U, "Assessing the effects of limestone dust and lead pollution on the ecophysiology of some selected urban tree species", *Frontiers in Plant Science*, Vol. 14, 2023, pp. 1144145. https://doi.org/10.3389/fpls.2023.1144145
67. Alrabie. A, ALSaeedy. M, Al-Adhreai. A, Al-Qadsy. I, Al-Odayni. A. B, Saeed, W. S., and Farooqui, M, "Unraveling the therapeutic potential of *Bombax ceiba* roots: a comprehensive study of chemical composition, heavy metal content, antibacterial activity, and in silico analysis", *Open Chemistry*, Vol. 21, No. 1, 2023, pp. 20230179. 10.1515/chem-2023-0179
68. Ugwu. E, Gupta. B. S, Adeloye. A. J, and Martínez-Villegas. N, "Removal of Cu, cd, Pb and Zn from contaminated soil by using plant-based surfactants, *Sapindus mukorossi L* (Soapnut) and *Acacia concinna* (Shikakai)", *International Journal of Environmental Science and Development*, Vol. 10, No. 6, 2019, pp. 183-187. https://doi.org/10.18178/ijesd.2019.10.6.1169
69. Mondal. M. H, Malik. S, Garain. A, Mandal, S, and Saha. B, "Extraction of natural surfactant saponin from soapnut (*Sapindus mukorossi*) and its utilization in the remediation of hexavalent chromium from contaminated water", *Tenside Surfactants Detergents*, Vol. 54, No. 6, 2017, pp. 519-529. https://doi.org/10.3139/113.110523
70. Lai. M. L, Dong. X. Q, Xie. S. Y, Feng. J. Y, Xing. H. Y, Zeng. S. C, and Wu. D. M, "Plant adaptability and heavy metals accumulation of different landscape plants in soil applied with sewage sludge", Vol. 43, No. 4, 2022. http://dx.doi.org/10.7671/j.issn.1001-411X.202108021
71. Zhou. H, Yang. G, Jiang. X, Zhao. W, Hou. Y, Wu. P, and Zeng. J, "Naturally growing plants accumulate heavy metals differently in phosphate waste rocks and phosphorus chemical industrial zones in Southwest China", *Journal of Environmental Sciences*, Vol. 164, 2025. https://doi.org/10.1016/j.jes.2025.12.016
72. Murtić. S, Čivić. H, Sijahović. E, Zahirović. Ć, Šahinović. E, and Podrug. A, "Phytoremediation of soils polluted with heavy metals in the vicinity of the Zenica steel mill in Bosnia and Herzegovina: Potential for using native flora", *European Journal of Environmental Sciences*, Vol. 11, No.1, 2021, pp. 31-37. https://doi.org/10.14712/23361964.2021.4
73. Santos-Jallath. J, Castro-Rodríguez. A, Huezo-Casillas. J, and Torres-Bustillos. L, "Arsenic and heavy metals in native plants at tailings impoundments in Queretaro, Mexico", *Physics and Chemistry of the Earth, Parts A/B/C*, Vol. 37, 2012, pp. 10-17. https://doi.org/10.1016/j.pce.2011.12.02
74. Jia. M, Zhou. D, Lu. S, and Yu. J, "Assessment of foliar dust particle retention and toxic metal accumulation ability of fifteen roadside tree species: Relationship and mechanism", *Atmospheric Pollution Research*, Vol. 12, No. 1, 2021, pp. 36-45. https://doi.org/10.1016/j.apr.2020.08.003
75. Ouyang. J, Li. B, Li. C, Shang. X, and Zou. J, "Cadmium effects on mineral accumulation and selected physiological and biochemical characters of *Salix babylonica* L", *Polish Journal of Environmental Studies*, Vol. 26, No. 6, 2017, pp. 2667-2676. https://doi.org/10.15244/pjoes/71554
76. Ishaq. M, Rehman. A, Adnan. M, Ullah. N, Ahmad. I, and Aamir. M, "Comparative study of heavy metals in *Albizia lebbeck*, collected from different environmental sites", *International Journal of Pharmaceutical Sciences Review and Research*, Vol. 20, No. 2, 2013, pp. 5-9.
77. Rahman. S. U, Yasin. G, Nawaz. M. F, Cheng. H, Azhar. M. F, Riaz. L, and Lu. Y, "Evaluation of heavy metal phytoremediation potential of six tree species of Faisalabad city of Pakistan during summer and winter seasons", *Journal of environmental management*, Vol. 320, 2022, pp. 115801. https://doi.org/10.1016/j.jenvman.2022.115801
78. Gebretsadik. H, Gebrekidan. A, and Demlie. L,

"Removal of heavy metals from aqueous solutions using *Eucalyptus Camaldulensis*: an alternate low cost adsorbent", *Cogent Chemistry*, Vol. *6, No.* 1, 2020, pp. 1720892. https://doi.org/10.1080/23312009.2020.1720892

79. Karak. T, "Influence of Metals In Soil on The Comparative Phyto chemical Characterization and Antioxidant Study of Indian Golden Shower (*Cassia Fistula*)", Vol. 50, No. 3, 2016.
80. Sterner. R. W, Reinl. K. L, Lafrancois. B. M, Brovold. S and Miller. T. R, "A first assessment of cyanobacterial blooms in oligotrophic Lake Superior", *Limnology and Oceanography*, Vol. 65, No. 12, 2020, pp. 2984-2998. https://doi.org/10.1002/lno.11569
81. El-Agawany. N. I, and Kaamoush. M. I, "Role of zinc as an essential microelement for algal growth and concerns about its potential environmental risks", *Environmental Science and Pollution Research*, Vol. 30, No. 28, 2023, pp. 71900-71911. https://doi.org/10.1007/s11356-022-20536-z
82. Yu. W, Wang. L, Ma. X, Li. J, Li. Z, Wang. H, and Yu. D, "Restoration of submerged vegetation modulates microbial communities to decrease nitrogen and phosphorus loads in sediment-water systems", *Water Research*, Vol. 269, 2025, pp. 122835. https://doi.org/10.1016/j.watres.2024.122835
83. He. Y, Zhang. H, Chen. Q, and Zhang. X, "Spatio-Temporal Variation in Water Quality in Urban Lakes and Land Use Driving Impact: A Case Study of Wuhan", *Water*, Vol.18, No. 2, 2026, pp. 153. https://doi.org/10.3390/w18020153
84. Khalil. S, Mahnashi. M. H, Hussain. M, Zafar. N, Khan. F. S, Afzal. U and Irfan. M, "Exploration and determination of algal role as bioindicator to evaluate water quality–Probing fresh water algae", *Saudi Journal of Biological Sciences*, Vol. 28, No. 10, 2021, pp. 5728-5737. https://doi.org/10.1016/j.sjbs.2021.06.004
85. Graeber. D, McCarthy. M. J, Shatwell. T, Borchardt. D, Jeppesen. E, Søndergaard. M, and Davidson. T. A, "Consistent stoichiometric long-term relationships between nutrients and chlorophyll-a across shallow lakes", *Nature Communications*, Vol. 15, No. 1, 2024, pp. 809. https://doi.org/10.1038/s41467-024-45115-3
86. Zhao. B, Li. H, Yang. X, Xiao. J, and Chen, G, "Hydrochar derived from willow using in phytoremediation: hydrochar properties, metals behavior and potential applications", *Separation and Purification Technology*, Vol. 339, 2024, pp. 126697. https://doi.org/10.1016/j.seppur.2024.126697
87. Liu. Z, and Tran. K. Q, "A review on disposal and utilization of phytoremediation plants containing heavy metals", *Ecotoxicology and environmental safety*, Vol. 226, 2021, pp. 112821. https://doi.org/10.1016/j.ecoenv.2021.112821
88. Pang. Y. L, Quek, Y. Y, Lim. S, and Shuit. S. H, "Review on phytoremediation potential of floating aquatic plants for heavy metals: a promising approach", *Sustainability*, Vol. 15, No. 2, 2023, pp. 1290. https://doi.org/10.3390/su15021290
89. Zhu. J, Peng. Z, Liu. X, Deng. J, Zhang. Y, and Hu. W, "Response of aquatic plants and water quality to large-scale Nymphoides peltata harvest in a shallow lake", *Water*, 11, No. 1, 2019, pp. 77. https://doi.org/10.3390/w11010077
90. Li. J, Xiao. X, Xian. X, Li. S, Yu. X and Zhang. X, " Green algae outcompete cyanobacteria in a shallow lake, Longhu Lake", *Water Supply*, Vol. 23, No. 7, 2023, pp. 2649-2661. https://doi.org/10.2166/ws.2023.1