frontiers | Frontiers in Environmental Science

TYPE Original Research
PUBLISHED 19 September 2022
DOI 10.3389/fenvs.2022.885591

Check for updates

Spatiotemporal distribution of physicochemical parameters and toxic elements in Lake Pomacochas , Amazonas, Peru

Damaris Leiva-Tafur*, Malluri Goñas, Lorenzo Culqui, Carlos Santa Cruz, Jesús Rascón and Manuel Oliva-Cruz

Instituto de Investigación para el Desarrollo Sustentable de Ceja de Selva. Universidad Nacional Toribio Rodríguez de Mendoza de Amazonas, Chachapoyas, Perú

OPEN ACCESS

EDITED BY
Cleber Galvão,
Oswaldo Cruz Foundation (Fiocruz), Brazil

REVIEWED BY
Rachel Ann Hauser-Davis,
Oswaldo Cruz Foundation (Fiocruz), Brazil
Daniele Kasper,
Federal University of Rio de Janeiro, Brazil

*CORRESPONDENCE
Damaris Leiva-Tafur,
damaris.leiva@untrm.edu.pe

SPECIALTY SECTION
This article was submitted to Freshwater Science,
a section of the journal
Frontiers in Environmental Science

RECEIVED 28 February 2022
ACCEPTED 06 September 2022
PUBLISHED 19 September 2022

CITATION
Leiva-Tafur D, Goñas M, Culqui L, Santa Cruz C, Rascón J and Oliva-Cruz M (2022), Spatiotemporal distribution of physicochemical parameters and toxic elements in Lake Pomacochas , Amazonas, Peru. *Front. Environ. Sci.* 10:885591.
doi: 10.3389/fenvs.2022.885591

Lakes are water bodies that play an essential role as water sources for humanity, as they provide a wide range of ecosystem services. Therefore, this study aimed to evaluate Lake Pomacochas, a high Andean lake in the north of Peru. A variety of parameters were studied, including physicochemical parameters such as temperature (T°C), dissolved oxygen (DO), potential hydrogen (pH), electrical conductivity (EC), turbidity, total dissolved solids (TDS), biochemical oxygen demand (BOD), alkalinity, and chlorides hardness; the concentrations of nitrates, nitrites, sulfates, and ammonium; elements such as aluminum (Al), calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), and boron (B); as well as metals and metalloids such as zinc (Zn), cadmium (Cd), copper (Cu), lead (Pb), and arsenic (As). In addition, pH, Zn, and Cu were evaluated at the sediment level. It is important to note that all parameters evaluated in the water matrix showed significant differences in the seasonal period and depth levels. In comparison, the parameters evaluated at the sediment level had no significant differences between the seasonal period and sampling points. As for the seasonal period, the variables that were higher for the dry season were electrical conductivity, total dissolved solids, and lead while that for the wet season were biochemical oxygen demand, zinc, magnesium, turbidity, calcium, dissolved oxygen, temperature, and potential hydrogen. At the depth levels, parameters such as total dissolved solids, lead, and arsenic had similar behavior for the three depths evaluated. According to national standards, latent contamination by cadmium and lead was found in the lake water from the ecological risk assessment. However, by international standards, all sampling stations showed a high level of contamination by cadmium, lead, zinc, copper, and arsenic, which represents a potential risk for the development of socioeconomic activities in the lake. At the same time, the evaluation of sediments did not present any potential risk.

KEYWORDS

metals, metalloids, physicochemical parameters, water, concentration, sediment

Introduction

Lakes account for 50.01% of all terrestrial surface waters worldwide, 49.8% of which are liquid and fresh surface waters (Bhateria and Jain, 2016). These water resources play an essential role as water sources for humanity; in addition, they provide primary beneficial ecosystem services, such as the development of agricultural activities, aquaculture, tourism, recreation, and transportation (Chen H. et al., 2019). Rapid industrial and urban development has compromised the quality and health of these water sources, leaving many pollutants that can be discharged directly into lakes or through runoff, atmospheric deposition, and leaching processes (Stange et al., 2019).

Rapid global industrialization has raised awareness of the presence of metals and metalloids in nature due to their high rate of toxicity and persistence (Niu et al., 2020). These elements are part of organic and inorganic complexes, mainly found in trace concentrations (Utete and Fregene, 2020), whose presence affects aquatic biota and the human population using the water resource (Xu et al., 2017). The sources of metal pollution in lakes can be natural, coming from the original material of the watershed soil or windblown dust. In contrast, anthropogenic pollution comes from agricultural chemicals, such as fertilizers or pesticide, as well as metal-contaminated wastes from mining and smelting (Wang et al., 2021). Thus, high pollution of urban and peri-urban lakes is reported as a consequence of contamination of nearby watersheds (Zerizghi et al., 2020).

High Andean lakes are highly vulnerable to contamination. This vulnerability is due to their particular characteristics, defined by their location, altitude, and prevailing conditions such as geology, topography, soils, climate, diversity, and population settled on their margins (Dodds et al., 2009; López-Martínez et al., 2017; Aranguren-Riaño et al., 2018). Lake Pomacochas is one of the largest high Andean lakes in the Amazon region, located in a developing area of agriculture, fish farming, and tourism, which are the primary sources of local economic income (Barboza-Castillo et al., 2014). However, in recent years, these activities have increased with more intensive use of natural resources and have caused the progressive deterioration of the water body (Matthews-Bird et al., 2017; Marin et al., 2022). Consequently, a moderate trophic state and an advanced state of eutrophy caused by agricultural and livestock waste in the area are reported (Chávez et al., 2016; Rascón et al., 2021). Considering the ecological and economic importance of Lake Pomacochas, this research aims to determine and analyze the presence and concentration of toxicologically relevant elements and the physicochemical parameters of water and sediment. For this purpose, four sampling stations were established during two seasonal periods. The availability and behavior of these elements, concentration indexes, dangers they represent for aquatic life, and development of productive activities were analyzed according to international and national standards.

Materials and methods

Study area

Lake Pomacochas is located in the town of Florida-Pomacochas, in a montane forest zone, on the eastern slope of the Peruvian Andes. It is a lake of tectonic origin at an altitude of 2,233 m. a.s.l., with an approximate surface area of 425.10 ha and an estimated depth of 75.5 m (Wetzel, 2001). It has a humid, warm temperate climate and an average temperature of 15°C. There are two marked seasonal periods with an annual precipitation of 1,104.5 mm (Barboza-Castillo et al., 2014). The wet season from November to April, with the highest precipitation peaks from January to March, and the dry season from May to October with a decrease in precipitation from June to August (Rascón et al., 2021). Precipitation does not present a water deficit throughout the year; on the contrary, there is a surplus of 77.0 and 102.0 mm (Vargas-Rivera). The lake is located in one of the main livestock-raising areas of the Amazon region, where the population settled in the surrounding area is around 7,000 inhabitants (Oliva et al., 2015; INEI, 2018). According to bathymetric studies, precipitation and subway runoff are the main sources of water to the lake (Barboza-Castillo et al., 2014). The main surface effluents are the Fichac and Congona streams, which cross the urban zone, and their effluent (Desaguadero) converges in the Pomacochas River (Figure 1). The main activities in the basin are extensive livestock ranching, vegetable production, aquaculture, and tourism in the western part of the lake (Oliva et al., 2015; ANA, 2016; Chávez et al., 2016).

Collection and preparation of samples

Samples were collected considering seasonal rainfall. One sampling was executed in March (wet season) and another in August (dry season) of 2021. Considering the lake's land use and activities nearby, four sampling points were established in the study area. Sampling point one (P1) was chosen for the direction of the lake discharge zone, sampling point two (P2) for its proximity to the area of population settlement and tourist activity, sampling point three (P3) for its proximity to the livestock production zone, and sampling point four (P4) for its proximity to the tributary inflow zone (ANA, 2016). Water and sediment samples were collected in triplicate at each sampling point. Along the water column, three depths were established using the Secchi disk of 20 cm diameter, which combines white and black quadrants alternatively (Utete and Fregene, 2020). The first depth was considered at the surface level from 0 to 50 cm, the second was about the Secchi disk transparency value, and the third was at 2.5 times the Secchi disk transparency value (Potapov et al., 2019). At each depth, temperature (T°), dissolved oxygen (DO), potential hydrogen (pH), and

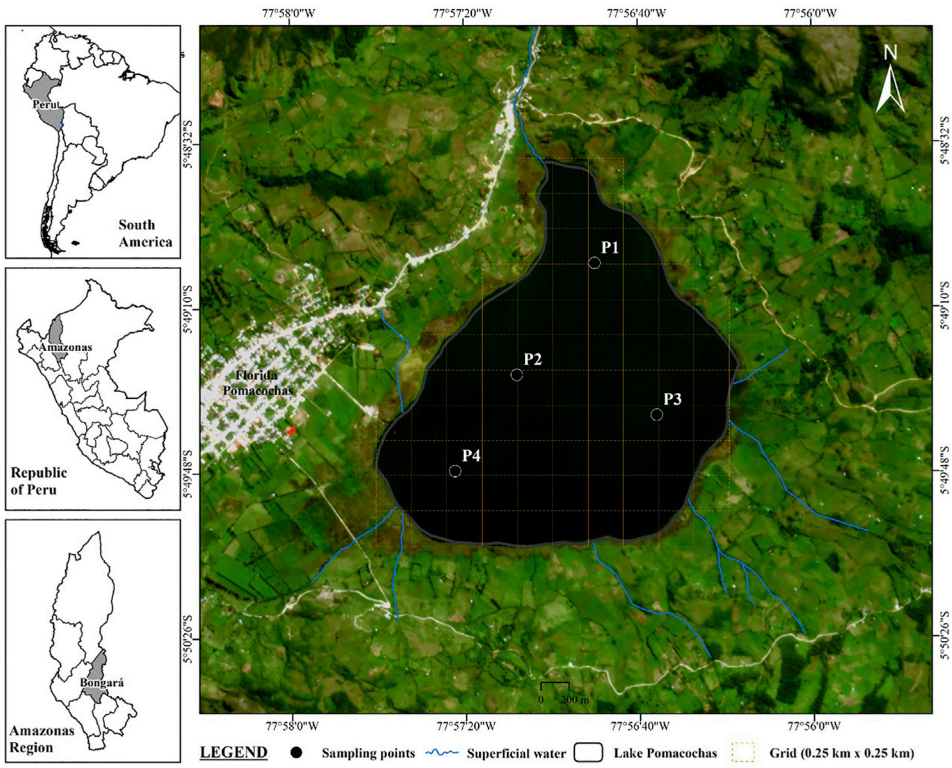

FIGURE 1
Geographic localization of study area.

conductivity (EC) were determined with multiparameter equipment, brand WTW and model 3630 IDS. On the other side, turbidity was determined with a portable turbidity meter, brand HACH and model 2100Q. Triplicate samples were collected from each depth in 1-L polyethylene bottles that were thoroughly cleaned and rinsed with sampling water to determine physicochemical parameters (Popek, 2018). However, for the determination of metals, samples were collected in 100-ml polyethylene bottles treated with a 10% 1M nitric acid solution for 30 min and rinsed with distilled or deionized water (EPA, 1992). Sediment samples were collected in triplicate (a 0.5 cm layer from the lake bottom) using an Ekman Dredge (Cross, 1987). All collected samples were immediately transported to the Soil and Water Research Laboratory (LABISAG) of the Universidad Nacional Toribio Rodríguez de Mendoza de Amazonas, located in Chachapoyas. They were stored at −20°C until processing (Hou et al., 2013). In the laboratory, water samples were filtered using a cellulose filter paper, qualitative grade F1002 CHMLab and thickness 190 µm. The filtered product was acidified with nitric acid (1 + 1) to pH < 2 (EPA, 1994). Sediment samples were dried at 50°C before grinding with an agate mortar and sieving on a 200-mm sieve.

Determination of physicochemical parameters in the water profile

Alkalinity was determined by titration with hydrochloric acid (HCL), hardness by titration with EDTA (ethylenediamine tetraacetic acid), and chlorides by titration with silver nitrate ($AgNO_3$), according to the methodology by APHA, AWWA, and WEF (30). Parameters such as nitrates (NO_3^-) and nitrites (NO_2^-) were determined using the methodology established by HACH (2000). Total dissolved solids (TDS), ammonium (NH_4^+), sulfates (SO_4^{2-}), and chemical oxygen demand (BOD) were determined using the methodology established by APHAAWWA and WEF, 2017).

Determination of the concentration of toxicologically important elements in the water and sediment profile

Pulverized sediment samples were digested with HNO3: H2O2 (EPA, 1996), and elemental concentrations of Cu and Zn were measured (Manoj and Kawsar, 2020). Water samples were determined from the filtrate, acidification, and appropriate digestion in spectroscopy of emission atomic for MP-AES, adapting of methodology for ICP (APHA et al., 2017). The presence and concentration of metals and metalloids in water, such as aluminum (Al), lead (Pb), arsenic (As), boron (B), copper (Cu), cadmium (Cd), zinc (Zn), magnesium (Mg), and calcium (Ca), and the presence and concentration of copper (Cu) and zinc (Zn) in sediment samples were determined.

Microwave plasma atomic emission spectroscopy was performed with an Agilent microwave plasma spectrophotometer, brand Agilent Technologies and model 4100 MP-AES, equipped with a standard torch, Inert OneNeb nebulizer, and dual-pass glass cyclonic spray chamber, brand Agilent Technologies, for all experiments. Nitrogen was obtained from the air using a nitrogen generator, brand Agilent Technologies and model Agilent 4,107. The pump speed was set at 15 rpm. Before reading the samples, 12 s was set for the consumption time, 12 s for the torch stabilization time, and 30 s for the rinsing time. The reading time was 5 s. The spectral intensity was the mean of three repeated readings per sample. The detection wavelength of 193.695, 213.857, 228.802, 249.772, 285.213, 324.754, 393.366, 396.152, 405.781, 588.995, and 766.491 nm was selected for the quantification of As, Zn, Cd, B, Mg, Cu, Ca, Al, Pb, Na, and K, respectively. Before the readings, the equipment was calibrated by using standard solutions of each element in different concentrations, prepared from a 1,000 ppm standard solution (Supplementary Figure S1). The standard solutions used were of Agilent brand, located in the spectrometry area of LABISAG. After each reading, the equipment recovered both concentration and intensity without the need to enrich samples.

Data analysis

All the data obtained were subjected to a normality test applying the Kolmogorov–Smirnov test and homogeneity of a variance test with the application of Bartlett's test to determine which statistical tests to use. For the evaluation of the behavior of the physicochemical parameters and toxicological elements of the water profile in depth and seasonal period, a principal component analysis (PCA) was applied. PCA is a statistical method used to reduce the dimensions of a large data set (Van Der Maaten et al., 2009). At the same time, selecting the most significant variables is a good technique; discard those that are redundant or have a high correlation (Marin and Robert, 2014; Borcard et al., 2018). PCA recognizes the variance within a set of correlated variables to create a smaller group of uncorrelated variables called principal components (PC), which are weighted linear combinations of the novel variables (Thioulouse et al., 2018). In this study, PCA was determined using a correlation matrix. Eigenvalues were calculated to measure the significance of the components. Once the PCA was calculated, the number of components to be used was determined, using the criterion of considering a sufficient number of components able to explain between 70% and 90% of the total variation of the original variables (Rencher, 2012). Finally, a biplot was used to better interpret the first two principal components (Jolliffe, 2002).

To detect spatial, temporal, and depth variations in both water and sediments a non-parametric multivariate analysis of variance (PERMANOVA) based on permutations was used (Anderson and Walsh, 2013). On the other hand, a U Mann–Whitney test was applied to determine the significant differences between the parameters present in water and sediment.

The mean concentration of metals and metalloids present in the water samples was contrasted with the international standards established by the European Union for environmental quality in the field of water policy of European Union (EQS) (EU, 2008), Canadian standard set by the Ministers of the Environment for the protection of aquatic life (CCME) (CCME, 2007), National Primary Drinking Water Regulations (EPA) (EPA, 2009), and National Environmental Water Quality Standards of Peru (ECAs), for the category of conservation of the aquatic environment (C4) and the category of extraction and cultivation of hydrobiological species in lakes or lagoons (C2) (MINAM, 2017). The toxicological elements present in the sediments were contrasted with the Canadian sediment quality standard for the protection of aquatic life in fresh waters (CEQG) (CCME, 2001), considering the previous conversion to the required concentration units and considering the following evaluation parameters: interim freshwater sediment quality guidelines (ISQG) and probable effect level (PEL).

-Sediment concentration < ISQG = No adverse biological effects.
-Sediment concentration > ISQG and < PEL = Occasional biological effects.
-Sediment concentration > PEL = Frequent adverse biological effects.

All statistical analyses were performed at a significance level of $p < 0.05$, using R software version 4.1.0 (R Development Core Team, 2021).

Results

Concentration of physicochemical parameters of the water profile

Table 1 shows the mean values and their standard error for the physicochemical parameters determined in the water.

10.3389/fenvs.2022.885591

TABLE 1 Mean concentration and standard deviation of physicochemical parameters of the water profile.

p	D	EE	T °C	DO (mg/L)	pH	EC (µs/cm^2)	Turbidity (UNT)	TDS (mg/L)	BDO (mg/L)	Alkalinity (mg/L)	Chlorides (mg/L)	Hardness (mg/L)	NO_3^- (mg/L)	NO_2^- (mg/L)	SO_4^{2-} (mg/L)	NH_4^+ (mg/L)
P1	D1	Wet	20.1 ± 0.1	7.2 ± 0.0	8.7 ± 0.0	232.7 ± 0.6	4.2 ± 0.1	0.1 ± 0.0	1.1 ± 0.2	178.8 ± 11.9	9.9 ± 0.6	148.7 ± 1.5	8.1 ± 0.2	0.0 ± 0.0	8.0 ± 0.2	0.2 ± 0.0
		Dry	19.0 ± 0.1	6.2 ± 0.0	6.9 ± 0.1	240.3 ± 0.6	3.3 ± 0.2	1.0 ± 0.0	2.3 ± 0.1	119.2 ± 0.0	11.8 ± 2.2	134.2 ± 0.9	5.8 ± 0.0	0.0 ± 0.0	2.2 ± 0.0	0.2 ± 0.0
	D2	Wet	20.5 ± 0.5	7.3 ± 0.0	8.7 ± 0.0	234.0 ± 0.0	4.9 ± 0.3	0.1 ± 0.0	10.1 ± 0.1	119.2 ± 11.9	15.0 ± 0.6	138.7 ± 0.9	7.1 ± 0.2	0.0 ± 0.0	3.8 ± 0.6	0.2 ± 0.0
		Dry	19.5 ± 0.0	6.3 ± 0.4	7.2 ± 0.0	241.3 ± 0.6	2.8 ± 0.1	3.3 ± 3.3	1.7 ± 0.5	119.2 ± 20.6	13.1 ± 0.0	130.7 ± 4.0	8.0 ± 0.6	0.0 ± 0.0	2.4 ± 1.0	0.3 ± 0.1
	D3	Wet	20.0 ± 0.3	6.7 ± 0.0	8.4 ± 0.0	233.7 ± 0.6	4.2 ± 0.2	0.1 ± 0.0	16.7 ± 0.2	135.1 ± 6.9	8.3 ± 0.5	118.2 ± 1.5	6.7 ± 0.0	0.0 ± 0.0	3.3 ± 0.2	0.3 ± 0.0
		Dry	19.2 ± 0.0	6.7 ± 0.0	6.9 ± 0.2	241.3 ± 0.6	3.5 ± 0.3	6.3 ± 1.7	1.9 ± 0.2	170.9 ± 0.0	12.7 ± 0.5	124.2 ± 0.0	7.8 ± 0.2	0.0 ± 0.0	3.2 ± 0.0	0.2 ± 0.0
P2	D1	Wet	20.0 ± 0.1	7.8 ± 0.0	8.8 ± 0.0	229.7 ± 0.6	4.3 ± 0.2	0.1 ± 0.0	0.9 ± 0.3	119.2 ± 6.9	14.0 ± 0.5	155.7 ± 3.8	6.3 ± 0.0	0.0 ± 0.0	4.8 ± 0.1	0.2 ± 0.0
		Dry	19.1 ± 0.0	5.7 ± 0.0	7.5 ± 0.0	242.0 ± 0.0	3.2 ± 0.1	2.7 ± 3.2	2.2 ± 0.4	131.1 ± 0.0	9.6 ± 0.0	118.7 ± 0.0	7.2 ± 0.0	0.0 ± 0.0	2.1 ± 0.0	0.1 ± 0.0
	D2	Wet	19.6 ± 0.0	6.9 ± 0.0	7.6 ± 0.1	250.3 ± 0.6	5.1 ± 0.4	0.0 ± 0.0	7.7 ± 0.1	123.2 ± 0.0	10.8 ± 1.5	120.2 ± 11.4	6.9 ± 0.2	0.0 ± 0.0	2.4 ± 0.3	0.3 ± 0.0
		Dry	19.0 ± 0.0	6.0 ± 0.0	7.1 ± 0.0	240.3 ± 1.2	4.9 ± 0.0	6.2 ± 1.2	2.2 ± 0.3	131.1 ± 0.0	10.8 ± 2.8	117.2 ± 0.0	7.2 ± 0.2	0.0 ± 0.0	1.7 ± 0.1	0.3 ± 0.0
	D3	Wet	19.7 ± 0.0	6.8 ± 0.0	7.3 ± 0.2	230.7 ± 0.6	6.3 ± 0.2	0.1 ± 0.0	12.8 ± 0.3	135.1 ± 6.9	8.3 ± 0.5	119.2 ± 4.0	6.5 ± 0.2	0.0 ± 0.0	1.3 ± 0.1	0.3 ± 0.0
		Dry	19.4 ± 0.0	6.4 ± 0.0	7.3 ± 0.0	242.0 ± 0.0	5.4 ± 0.1	12.8 ± 2.3	2.1 ± 0.3	131.1 ± 0.0	10.2 ± 0.5	123.2 ± 0.0	8.6 ± 0.0	0.0 ± 0.0	1.5 ± 0.0	0.3 ± 0.0
P3	D1	Wet	19.7 ± 0.1	6.9 ± 0.0	7.8 ± 0.0	231.0 ± 0.0	4.6 ± 0.1	0.1 ± 0.0	0.6 ± 0.1	139.1 ± 16.6	10.8 ± 0.6	159.2 ± 0.9	6.5 ± 0.0	0.0 ± 0.0	0.9 ± 0.2	0.3 ± 0.0
		Dry	19.2 ± 0.0	5.6 ± 0.0	7.2 ± 0.0	241.0 ± 0.0	2.8 ± 0.2	18.5 ± 4.3	2.4 ± 0.2	119.2 ± 0.0	10.8 ± 2.2	123.2 ± 2.6	6.7 ± 0.2	0.0 ± 0.0	1.5 ± 0.0	0.2 ± 0.0
	D2	Wet	19.4 ± 0.0	6.9 ± 0.0	8.3 ± 0.0	231.0 ± 0.0	5.0 ± 0.2	0.1 ± 0.0	11.3 ± 0.0	119.1 ± 6.9	8.3 ± 0.6	116.7 ± 1.7	7.2 ± 0.0	0.0 ± 0.0	2.7 ± 0.3	0.4 ± 0.0
		Dry	19.0 ± 0.0	5.8 ± 0.0	7.5 ± 0.0	240.0 ± 0.6	3.1 ± 0.2	12.0 ± 5.5	2.4 ± 0.2	143.0 ± 0.0	13.1 ± 0.0	126.2 ± 0.0	6.2 ± 0.0	0.0 ± 0.0	3.6 ± 0.0	0.3 ± 0.0
	D3	Wet	19.6 ± 0.0	6.8 ± 0.0	7.7 ± 0.0	231.0 ± 0.0	4.8 ± 0.1	0.1 ± 0.0	10.4 ± 0.2	123.2 ± 6.9	12.1 ± 0.6	111.7 ± 0.9	6.1 ± 0.2	0.0 ± 0.0	1.5 ± 0.2	0.2 ± 0.0
		Dry	19.0 ± 0.0	5.9 ± 0.0	7.2 ± 0.0	242.3 ± 0.3	2.8 ± 0.2	0.7 ± 0.3	1.5 ± 0.4	123.2 ± 27.5	14.3 ± 2.2	124.7 ± 1.7	6.8 ± 0.0	0.0 ± 0.0	2.6 ± 0.0	0.3 ± 0.0
P4	D1	Wet	19.7 ± 0.0	6.7 ± 0.0	7.7 ± 0.0	231.0 ± 0.0	4.6 ± 0.1	0.2 ± 0.0	1.2 ± 0.2	127.2 ± 6.9	11.1 ± 0.6	153.7 ± 0.9	5.8 ± 0.0	0.0 ± 0.0	1.5 ± 0.1	0.2 ± 0.0
		Dry	19.4 ± 0.0	6.8 ± 0.0	7.4 ± 0.0	239.3 ± 0.6	3.7 ± 0.0	4.8 ± 0.3	2.5 ± 0.3	143.0 ± 0.0	11.5 ± 0.5	120.2 ± 0.0	6.1 ± 0.0	0.0 ± 0.0	2.8 ± 0.0	0.2 ± 0.0
	D2	Wet	19.7 ± 0.1	6.9 ± 0.0	8.0 ± 0.0	225.0 ± 0.0	5.3 ± 0.2	0.1 ± 0.0	8.4 ± 0.1	135.1 ± 6.9	8.3 ± 0.6	118.2 ± 0.9	6.5 ± 0.0	0.0 ± 0.0	3.4 ± 0.0	0.2 ± 0.0
		Dry	19.2 ± 0.0	6.2 ± 0.0	7.3 ± 0.0	242.0 ± 0.0	3.0 ± 0.2	15.8 ± 0.3	1.7 ± 0.2	143.0 ± 6.9	9.6 ± 0.0	123.2 ± 2.6	8.2 ± 0.0	0.0 ± 0.0	2.3 ± 0.1	0.2 ± 0.0
	D3	Wet	19.5 ± 0.1	7.1 ± 0.0	8.3 ± 0.0	231.0 ± 0.0	4.8 ± 0.2	0.1 ± 0.0	13.3 ± 4.6	127.2 ± 6.9	10.5 ± 1.0	116.7 ± 0.9	6.3 ± 0.2	0.0 ± 0.0	2.4 ± 0.3	0.2 ± 0.0
		Dry	19.0 ± 0.0	6.0 ± 0.0	7.6 ± 0.0	241.7 ± 0.6	2.3 ± 0.1	17.7 ± 4.0	1.5 ± 0.2	143.0 ± 0.0	11.5 ± 0.0	120.2 ± 0.0	4.1 ± 0.2	0.0 ± 0.0	2.1 ± 0.0	0.2 ± 0.0

Sampling point (*p*), depth (D), seasonal epoch (EE), temperature (T °C), dissolved oxygen (DO), hydrogen potential (pH), electrical conductivity (EC), total dissolved solids (TDS), biochemical oxygen demand (BOD), nitrates (NO_3^-), nitrites (NO_2^-), sulfates (SO_4^{2-}), and ammonium (NH_4^+).

10.3389/fenvs.2022.885591

TABLE 2 Concentration of metals and metalloids in the water and sediment.

p	Matrix	D	EE	Mg (mg/L)	Al (mg/L)	Ca (mg/L)	Na (mg/L)	K (mg/L)	Zn (mg/L)	Cd (mg/L)	Cu (mg/L)	Pb (mg/L)	B (mg/L)	As (mg/L)
P1	Water	D1	Wet	3.70 ± 0.0	0.40 ± 0.0	43.43 ± 0.2	3.75 ± 0.0	4.24 ± 0.0	0.01 ± 0.0	0.00 ± 0.0	0.01 ± 0.0	0.03 ± 0.0	0.06 ± 0.0	0.12 ± 0.1
			Dry	3.68 ± 0.0	0.31 ± 0.0	25.98 ± 0.2	3.94 ± 0.0	4.61 ± 0.0	0.00 ± 0.0	0.00 ± 0.0	0.01 ± 0.0	0.12 ± 0.0	0.06 ± 0.0	0.14 ± 0.1
		D2	Wet	3.92 ± 0.0	0.14 ± 0.0	43.47 ± 0.4	4.06 ± 0.0	4.35 ± 0.0	0.01 ± 0.0	0.00 ± 0.0	0.01 ± 0.0	0.02 ± 0.0	0.07 ± 0.0	0.03 ± 0.0
			Dry	3.74 ± 0.0	0.18 ± 0.0	26.79 ± 0.7	5.79 ± 2.5	4.46 ± 0.0	0.00 ± 0.0	0.07 ± 0.0	0.01 ± 0.0	0.05 ± 0.0	0.11 ± 0.0	0.13 ± 0.0
		D3	Wet	3.99 ± 0.0	0.18 ± 0.0	44.38 ± 0.0	3.76 ± 0.0	4.31 ± 0.0	0.02 ± 0.0	0.00 ± 0.0	0.01 ± 0.0	0.02 ± 0.0	0.05 ± 0.0	0.03 ± 0.0
			Dry	3.71 ± 0.0	0.16 ± 0.0	26.19 ± 0.0	3.67 ± 0.0	4.52 ± 0.0	0.01 ± 0.0	0.00 ± 0.0	0.01 ± 0.0	0.05 ± 0.0	0.04 ± 0.0	0.06 ± 0.0
	Sediment	-	Wet	–	–	–	–	–	3.13 ± 0.1	0.00 ± 0.0	5.12 ± 0.0	0.00 ± 0.0	–	–
			Dry	–	–	–	–	–	1.85 ± 0.2	0.00 ± 0.0	3.44 ± 0.0	0.00 ± 0.0	–	–
P2	Water	D1	Wet	3.94 ± 0.0	0.03 ± 0.0	43.98 ± 0.2	3.74 ± 0.0	4.28 ± 0.0	0.01 ± 0.0	0.00 ± 0.0	0.01 ± 0.0	0.03 ± 0.0	0.01 ± 0.0	0.08 ± 0.1
			Dry	3.69 ± 0.0	0.19 ± 0.0	25.61 ± 0.4	3.80 ± 0.0	4.51 ± 0.0	0.00 ± 0.0	0.00 ± 0.0	0.01 ± 0.0	0.06 ± 0.0	0.06 ± 0.0	0.13 ± 0.0
		D2	Wet	3.98 ± 0.0	0.06 ± 0.0	44.32 ± 0.2	4.74 ± 0.0	5.07 ± 0.0	0.05 ± 0.0	0.00 ± 0.0	0.01 ± 0.0	0.03 ± 0.0	0.05 ± 0.0	0.08 ± 0.0
			Dry	3.71 ± 0.0	0.19 ± 0.0	25.93 ± 0.1	3.56 ± 0.0	4.40 ± 0.0	0.00 ± 0.0	0.01 ± 0.0	0.01 ± 0.0	0.04 ± 0.0	0.01 ± 0.0	0.06 ± 0.0
		D3	Wet	3.95 ± 0.0	0.01 ± 0.0	44.34 ± 0.0	4.45 ± 0.0	4.65 ± 0.1	0.02 ± 0.0	0.09 ± 0.0	0.01 ± 0.0	0.02 ± 0.0	0.05 ± 0.0	0.05 ± 0.1
			Dry	3.79 ± 0.0	0.19 ± 0.0	26.69 ± 0.1	4.35 ± 0.0	4.62 ± 0.0	0.03 ± 0.0	0.0 0 ± 0.0	0.01 ± 0.0	0.04 ± 0.0	0.09 ± 0.0	0.11 ± 0.0
	Sediment	-	Wet	–	–	–	–	–	3.30 ± 0.1	0.00 ± 0.0	5.62 ± 0.0	0.00 ± 0.0	–	–
			Dry	–	–	–	–	–	5.42 ± 0.0	0.00 ± 0.0	4.03 ± 0.0	0.00 ± 0.0	–	–
P3	Water	D1	Wet	3.98 ± 0.1	0.05 ± 0.0	44.47 ± 0.4	4.40 ± 0.0	4.64 ± 0.0	0.02 ± 0.0	0.09 ± 0.0	0.01 ± 0.0	0.02 ± 0.0	0.07 ± 0.0	0.10 ± 0.0
			Dry	3.73 ± 0.1	0.18 ± 0.0	6.28 ± 0.1	5.26 ± 0.0	4.47 ± 0.0	0.00 ± 0.0	0.00 ± 0.0	0.01 ± 0.0	0.06 ± 0.0	0.02 ± 0.0	0.10 ± 0.0
		D2	Wet	3.90 ± 0.1	0.01 ± 0.0	44.50 ± 0.1	4.05 ± 0.0	4.60 ± 0.0	0.01 ± 0.0	0.29 ± 0.0	0.01 ± 0.0	0.03 ± 0.0	0.06 ± 0.0	0.11 ± 0.0
			Dry	3.73 ± 0.1	0.17 ± 0.0	25.90 ± 0.1	3.98 ± 0.0	4.48 ± 0.0	0.00 ± 0.0	0.00 ± 0.0	0.01 ± 0.0	0.05 ± 0.0	0.04 ± 0.0	0.08 ± 0.0
		D3	Wet	3.97 ± 0.1	0.00 ± 0.0	43.94 ± 0.0	4.12 ± 0.0	4.46 ± 0.1	0.02 ± 0.0	0.00 ± 0.0	0.01 ± 0.0	0.03 ± 0.0	0.05 ± 0.0	0.11 ± 0.0
			Dry	3.74 ± 0.1	0.19 ± 0.0	27.61 ± 0.1	8.73 ± 0.0	4.66 ± 0.0	0.02 ± 0.0	0.00 ± 0.0	0.01 ± 0.0	0.06 ± 0.0	0.11 ± 0.0	0.09 ± 0.1
	Sediment	D1	Wet	–	–	–	–	–	4.41 ± 0.1	0.00 ± 0.0	5.66 ± 0.1	0.00 ± 0.0	–	–
			Dry	–	–	–	–	–	0.98 ± 0.1	0.00 ± 0.0	4.05 ± 0.0	0.00 ± 0.0	–	–
P4	Water	D1	Wet	3.98 ± 0.1	0.01 ± 0.0	44.64 ± 0.3	3.98 ± 0.0	4.54 ± 0.0	0.03 ± 0.0	0.06 ± 0.0	0.01 ± 0.0	0.02 ± 0.0	0.06 ± 0.0	0.04 ± 0.0
			Dry	3.72 ± 0.1	0.16 ± 0.0	26.19 ± 0.1	3.91 ± 0.0	4.40 ± 0.0	0.00 ± 0.0	0.01 ± 0.0	0.01 ± 0.0	0.13 ± 0.0	0.05 ± 0.0	0.19 ± 0.1
		D2	Wet	3.91 ± 0.1	0.07 ± 0.0	43.69 ± 0.2	3.98 ± 0.0	4.45 ± 0.0	0.02 ± 0.0	0.00 ± 0.0	0.01 ± 0.0	0.02 ± 0.0	0.06 ± 0.0	0.04 ± 0.0
			Dry	3.70 ± 0.1	0.19 ± 0.0	26.36 ± 0.1	4.18 ± 0.0	4.51 ± 0.0	0.00 ± 0.0	0.00 ± 0.0	0.01 ± 0.0	0.04 ± 0.0	0.11 ± 0.0	0.05 ± 0.0
		D3	Wet	3.90 ± 0.1	0.09 ± 0.0	46.01 ± 0.2	4.20 ± 0.0	4.24 ± 0.0	0.01 ± 0.0	0.00 ± 0.0	0.01 ± 0.0	0.06 ± 0.0	0.07 ± 0.0	0.04 ± 0.1

(Continued on following page)

TABLE 2 (*Continued*) Concentration of metals and metalloids in the water and sediment.

p	Matrix	D	EE	Mg (mg/L)	Al (mg/L)	Ca (mg/L)	Na (mg/L)	K (mg/L)	Zn (mg/L)	Cd (mg/L)	Cu (mg/L)	Pb (mg/L)	B (mg/L)	As (mg/L)
			Dry	3.75 ± 0.1	0.20 ± 0.0	26.41 ± 0.2	3.87 ± 0.0	4.48 ± 0.0	0.01 ± 0.0	0.00 ± 0.0	0.01 ± 0.0	0.04 ± 0.0	0.10 ± 0.0	0.12 ± 0.1
	Sediment	-	Wet	–	–	–	–	–	2.86 ± 0.1	0.00 ± 0.0	5.65 ± 0.0	–	–	–
			Dry	–	–	–	–	–	9.5 ± 0.2	0.00 ± 0.0	6.05 ± 0.0	–	–	–

Sampling point (*p*), depth (D), magnesium (Mg), aluminum (Al), calcium (Ca), sodium (Na), potassium (K), zinc (Zn), cadmium (Cd), copper (Cu), lead (Pb), boron (B), and arsenic (As).

TABLE 3 Results of the principal component analysis of all parameters evaluated in the Lake Pomacochas.

	PC1	PC2	PC3	PC4	PC5	PC6	PC7
Standard deviation	2.68	1.85	1.53	1.36	1.27	1.05	1.01
Proportion of variance	0.29	0.14	0.09	0.07	0.06	0.04	0.04
Accumulated proportion	0.29	0.42	0.52	0.59	0.66	0.70	0.74
Loads	T° (−0.74), DO (−0.80), pH (−0.70), EC (0.74), turbidity (−0.78), BOD (−0.62), Mg (−0.85), Al (0.66), Ca (−0.94), Zn (−0.51), and Pb (0.66)	pH (0.57), BOD (−0.57), hardness (0.76), Al (0.53), and K (−0.73)	Chlorides (−0.57), Na (−0.57), and Zn (−0.54)	Chlorides (−0.53)	NO_3^- (−0.75) and NH_4^+ (−0.51)	As (0.56)	Cu (0.66)

Temperature (T °C), dissolved oxygen (DO), hydrogen potential (pH), electrical conductivity (EC), biochemical oxygen demand (BDO), nitrates (NO_3^-), nitrites (NO_2^-), total dissolved solids (TDS), ammonium (NH_4^+), sulfates (SO_4^{2-}), chemical oxygen demand (BOD), magnesium (Mg), aluminum (Al), calcium (Ca), sodium (Na), potassium (K), zinc (Zn), cadmium (Cd), copper (Cu), lead (Pb), boron (B), and arsenic (As).

The water's hydrogen potential (pH) values at the three depths ranged from 6.89 to 8.76, with a mean of 7.68, indicating a near neutral pH environment. The lowest dissolved oxygen (DO) values, which occurred in the dry season (S), ranged from 5.59 mg/L to 5.96 mg/L. Turbidity values are influenced by the wet season (H), with the highest values occurring at the sampling points and depths. TDS generally did not show significant variations, nor did conductivity whose mean value was 236.87 µs/cm^2. Biochemical oxygen demand (BOD) values ranged from 1.11 mg/L to 13.25 mg/L, with a mean of 4.95 mg/L.

Concentration of metals and metalloids in the water and sediment profile

The concentrations of metals and metalloids in the water and sediment profile are shown in Table 2. At the water profile, the highest concentration of aluminum (Al) was found at point 1 (P1) at depth 1 (D1), as well as lead (Pb) and zinc (Zn), and arsenic (As) at depth 2 (D2). Cadmium (Cd) presented the highest concentration value at point 4 (P4), depth 2 (D2), lead (Pb) presented the highest values at points 1 and 2 (P1, P2), and boron (B) presented its highest value at point P2 depth 1 (D1). In the sediments, zinc (Zn) was reported with its highest concentration value at point 4 (P4) in the dry season, as well as copper (Cu).

Behavior of physicochemical parameters and toxicological elements of the water profile at depth and seasonal period

From the evaluating parameters in the water for both seasonal periods and each depth, seven main components (PC) were selected that explain 42.3% of the total variance. The value of each parameter by component was evaluated, considering a moderate correlation ($p \geq \pm$ 0.50), from which it is reported that T°, DO, pH, EC, turbidity, BOD, Mg, Al, Ca, Zn, and Pb are the parameters with more significant weight for CP1 are shown; for CP2, pH, BOD, hardness, Al, and K; for CP3, chlorides, Na, and Zn; for CP4, chlorides; for PC5, nitrates, and ammonium; for PC6 and As; and for PC7 and Cu (Table 3).

The principal component analysis shows the distribution of the physicochemical parameters and toxicological elements determined in the water by seasonal period. This shows a grouping of those variables that are representative of the wet season, such as BOD, Zn, Mg, turbidity, Ca, DO, T, and pH, whereas for the dry season Pb, EC, and TDS. The analysis of the water profile at the three depths shows an overlap that demonstrates that Pb and TDS behaved similarly at the three depths, whereas other variables differed or were not influenced by depth (Figure 2).

The PERMANOVA analysis of the concentration of physicochemical parameters and toxicological elements

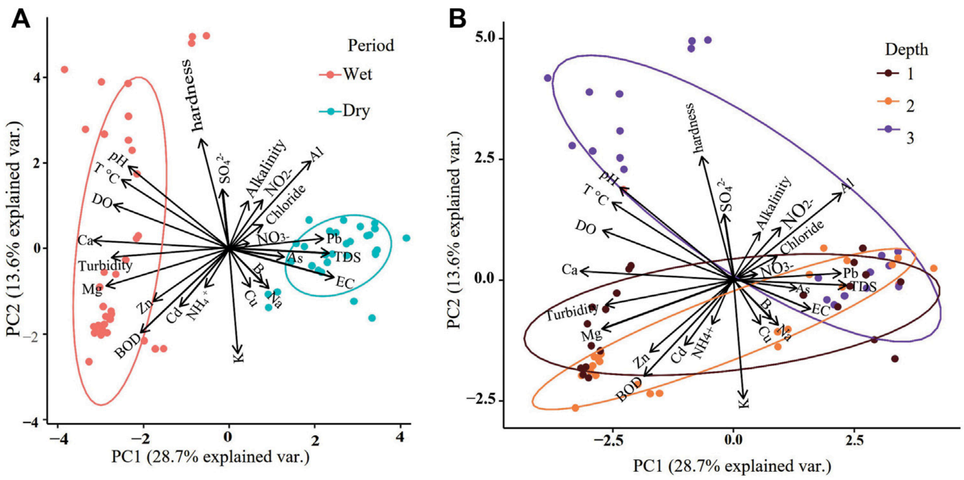

FIGURE 2
Principal component analysis describing the concentration of physicochemical parameters and toxicologically important elements by seasonal period **(A)** and depth level **(B)** in Lake Pomacochas. Temperature (T°C), dissolved oxygen (DO), hydrogen potential (pH), electrical conductivity (EC), biochemical oxygen demand (BDO), nitrates (NO_3^-), nitrites (NO_2^-), total dissolved solids (TDS), ammonium (NH_4^+), sulfates (SO_4^{2-}), chemical oxygen demand (BOD), magnesium (Mg), aluminum (Al), calcium (Ca), sodium (Na), potassium (K), zinc (Zn), cadmium (Cd), copper (Cu), lead (Pb), boron (B), and arsenic (As).

present in the water indicates no significant differences by the sampling point (F = 1.694, p = 0.099), whereas at the depth and seasonal level, there are significant differences (F = 6.129, p = 0.001; F = 15.024, p = 0.001). Regarding the concentration of toxicological elements evaluated in the sediment, the PERMANOVA analysis indicates a significant difference in the concentrations by the sampling point (F = 2.701, p = 0.043), whereas at the seasonal period level, there is no significant difference (F = 2.186, p = 0.97).

Differences between parameters present in water and sediment

About the parameters present in water and sediment, only pH, Cu, and Zn were selected as they are the only parameters whose values are available for both matrices. It was found that there are no significant differences between the matrices for pH (W = −1.168, p = 0.245). However, it is observed that there are significant differences between the concentrations of Cu (W = −9.474, p = 0.000) and Zn (W = −7.442, p = 0.000), with values higher in the sediment.

Comparison of parameters against international and national standards

The concentration of the elements presents at each sampling point, at each depth level, and by seasonal period was contrasted with the concentration of the elements established by CCME standards. Overall, collected concentrations from this study are mainly above the established limit concentrations. Concerning the EQS and EPA standards, the concentrations of elements such as Cu, Pb, and As exceed the established limit values. About the national environmental quality standards for water (ECAs) in conservation of the aquatic environment (C4) and extraction and cultivation of hydrobiological species in lakes or lagoons (C2), the concentration of elements such as As and Pb present the highest risk by exceeding the limit concentrations (Figure 3).

After comparing the concentrations of heavy metals found in the sediments with the CEQG standard, it was found that both Cu and Zn values do not exceed the values established by the standard, for both the ISQG limit and the PEL limit (Figure 4).

Discussion

Physicochemical parameters of the water profile

The biochemical oxygen demand in the water profile of Lake Pomacochas presents lower values of 2 mg/L, more severe at points P1 and P3, at depth 1 in the wet season. These values per sampling point may be due to various external causes, such as land use and agricultural practices that enrich the lake with nutrients (Kemp et al., 2005). For example, P1 is influenced by urban effluent discharges and P3 by tourist activity (Rascón et al., 2021). Small BOD values at depth may be due to nocturnal

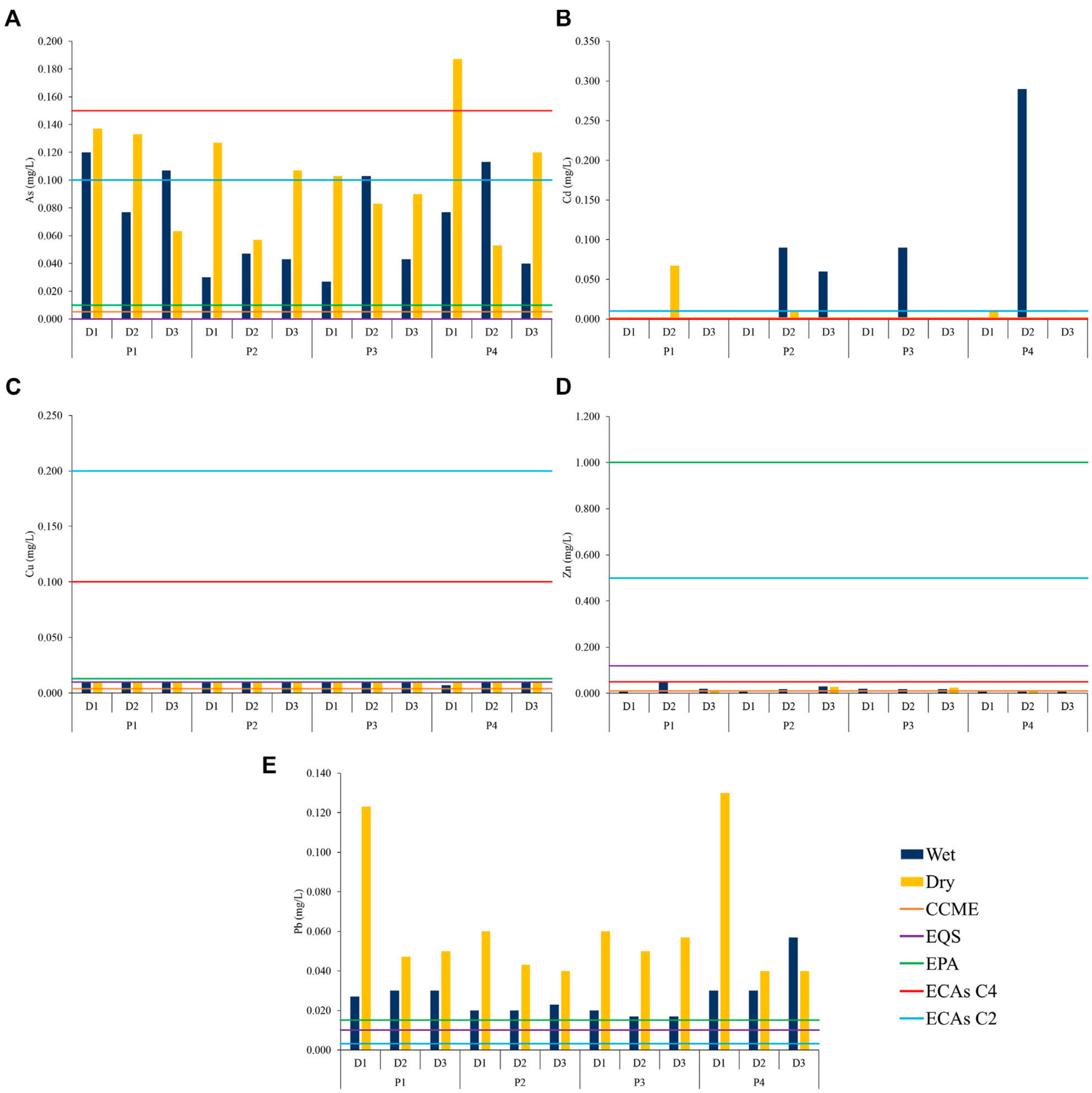

FIGURE 3
Concentration of metals and metalloids in the water and its contrast with international standards and the Peruvian standard. Arsenic **(A)**, cadmium **(B)**, copper **(C)**, zinc **(D)**, and lead **(E)**. (CCME: Canadian standard set by the ministers of the environment for the protection of aquatic life (CCME, 2007); EQS: international standards established by the European Union for environmental quality in the field of water policy (EU, 2008); USEPA: National Primary Drinking Water Regulations (EPA, 2009); ECAs C2 and C4: National Environmental Water Quality Standards of Peru, for the category of conservation of the aquatic environment and the category of extraction and cultivation of hydrobiological species in lakes or lagoons (MINAM, 2017)).

oxygen depletion by plant respiration (Caraco and Cole, 2002), stratification events (Özkundakci et al., 2010), and wind-generated turbulence, leading to deoxygenation of the water column (Townsend and Edwards, 2003). With all these factors, water quality worsens in the wet season (Jia et al., 2021). Dissolved oxygen values do not present multiple variations possibly because the lake remains in continuous movement. This implies that the water column is frequently oxygenated, and the *in situ* parameter sampling shows relatively homogeneous values (Wang et al., 2022). Behavior was

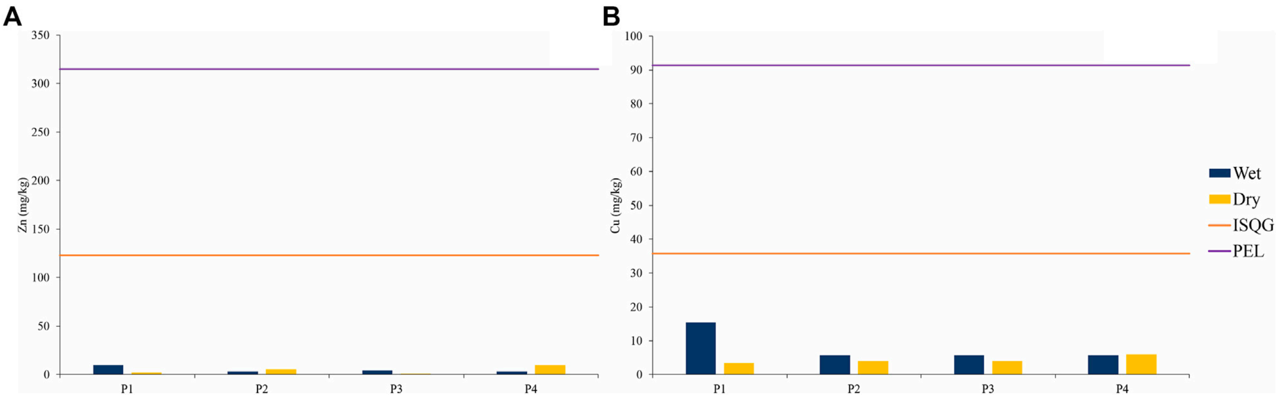

FIGURE 4
Concentration of zinc **(A)** and copper **(B)** in sediments and their contrast to the international standard: (CEQG: Canadian sediment quality standard for the protection of aquatic life in fresh waters (CCME, 2001), ISQG: interim freshwater sediment quality guidelines; PEL: probable effect level).

completely different with biochemical oxygen demand, whose digestion procedure allows for more concise data on the amount of organic matter present (Abd El-Mageed et al., 2022). There are similar studies where biochemical oxygen demand values are near 1 mg/L, as in the case of Lake Veeranam, where it is presumed that these values are the result of organic pollutants, which cause an oxygen demand that causes the death of aquatic life (Ramya et al., 2021). Since 2015, in Lake Pomacochas, values of biochemical oxygen demand between 7.2 and 8.1 mg/L have been reported. Research where microbiological parameters and physicochemical parameters, together with the trophic pollution index (ICOTRO), reported moderate pollution in the lake (Chávez et al., 2016). For 2016 and 2017, monitoring was developed in Lake Pomacochas. In this monitoring, Carlson's trophic state index, Aizaki's modified trophic state index, Toledo's modified trophic state index, and Vollenweider's trophic state index were calculated. These indices reported that Lake Pomacochas is in a very advanced eutrophic state due to the waste generated by livestock and agriculture carried out in the area. The highest levels of trophism were observed in the wet period, so the trophic state depends on the rainfall regime (Rascón et al., 2021). These results are similar to the data obtained since they show an increase in multiple parameters in the wet season. Special mention should be made of the pH, which increases in the wet season. This increase is mainly due to the geology of the High Andean basins, given that it is composed chiefly of calcium carbonate (limestone and calcite) (Benito et al., 2018; Schmidt et al., 2019). These characteristics suggest that Lake Pomacochas, having these high pH values, has a high buffering capacity in terms of acid contaminations related to agriculture and livestock (Ogato et al., 2015). The sulfate concentrations also showed an increase during the wet season, possibly due to diffuse pollution sources that carry pollutants from urban and agricultural areas. This would also justify the increase in chloride, nitrite, and nitrate values at some points and depths during the wet season (Ahmed et al., 2018; Wei et al., 2019).

Physicochemical parameters and toxicological elements of the water profile at depth and seasonal points

The temporal variation of the parameters shows BOD, Zn, Mg, turbidity, Ca, DO, T, and pH values higher in the wet season. This variation is because the main source of organic matter enters the aquatic ecosystem as an allochthone input due to rainfall and runoff during the wet season (Derrien et al., 2019). The lake has two-point surface sources of inflow, the Congona and Fichac streams feed the lake after crossing the locality, and multiple other temporary inflows (Chávez et al., 2016). The dry season's parameters are EC, TDS, and Pb, which are higher at this season. These characteristics are due to the metals being weakly bound to the suspended particulate fraction (Kamala-Kannan et al., 2008). Also, variation in parameters evaluated can modify the solubility, mobility, and availability of the element (Kannan and Krishnamoorthy, 2006). Seasonal variation in Lake Pomacochas, which can also be considered a peri-urban lake due to its proximity to the town of Florida-Pomacochas, suggests that municipal wastewater is the major contributor pollutant in the dry season. The main concentration variation source in parameters in the wet season is due to surface runoff and soil leaching processes (Rahman et al., 2021). The analysis of water parameters at depth shows significant differences because the elements that enter the lake tend to adsorb, mobilize, and settle to the bottom (Tang et al., 2016). The presence of macrophytes is also directly related to sediment resuspended due to their ability to contain wind and waves (Miranda et al., 2021). This suggests an increase in parameter concentrations as depth increases (Kong et al., 2021).

Toxicologically important elements of the water and sediment profile

Zn, Ca, and Mg concentrations are partly due to wastewater discharges, agricultural fertilizer leachates, and natural geological processes such as weathering and rock and soil erosion, which are accentuated during the rainy season (Kang et al., 2019). The slope of the Lake Pomacochas's micro basin (Barboza-Castillo et al., 2014) and the geological formation of the basin, whose geological structure is limestone and calcareous siltstone, must also be taken into consideration (Castro-Medina, 2007). The presence of Cu evaluated in the water column is controlled by the Cu in the sediment. In some cases, concentrations below 40 μg/L to 3 μg/L can be toxic for certain fish species such as trout (*Oncorhynchus mykiss*) (Lynch et al., 2016; Ramrakhiani et al., 2017).

The variation of sediment parameters in the sampling points shows that the highest concentration is located in P1, corresponding to the surface drainage area or drainage channel. It is presumed that the high values are due to the transport processes and sediment loading regime, considering that this is the outflow area (Potemkina and Potemkin, 2021). Variation of physicochemical parameters such as turbidity, T, pH, and DO affect the distribution of heavy metals in lakes (Jiang et al., 2018). Regarding pH, it is known that an increase in pH can facilitate the release of suspended metals in the sediment (Kang et al., 2019). On another side, an increase in alkalinity enhances the adsorption and precipitation of heavy metals such as Cu, Pb, and Zn (Wang et al., 2018). The presence of Cu and Zn, the elements with the highest concentrations in the lake sediments, primarily reflects the impact of human activities on the aquatic system, such as livestock and pasture production around Lake Pomacochas (Oliva et al., 2015). These activities, through runoff processes, insert pollutants into the water body. It is known that Cu is a common component in many pesticides and herbicides (Jančula and MarŠálek, 2011). Cu represents a risk for biotic beings because it hurries through the food chain and accumulates in organisms (Derrien et al., 2019).

This study does not report significant differences in the water and sediment matrix seasonal period. However, as mentioned before, the heavy metals' distribution and concentration, such as Cu and Zn in sediments, are related to complex physicochemical processes. Any change in environmental conditions, such as temperature, pH, organic matter, and redox potential, markedly influence the compartment of Cu and Zn in sediments (Pourabadehei and Mulligan, 2016; Kadhum et al., 2017). At acidic pH, lower than 4, the adsorption of metals decreases, whereas at more alkaline pH, the adsorption of metals increases (Kouassi et al., 2019).

On the other hand, the presence of zinc (Zn) in the lake sediment is considered typical because it can be found in phosphate fertilizers, galvanizing, industrial and landfill leachates, poultry wastewater, and compost, which makes it more easy to contaminate natural water supplies (Ramrakhiani et al., 2017). The presence of Zn in the water column is mainly due to two factors: the complexation of the element with organic matter and the development and zones dominated by algae and macrophytes (Chen M. et al., 2019). These organisms are Zn's primary transporters and collectors through their absorption processes and lacustrine systems (Bonanno et al., 2018).

Toxicological elements and their relation to the limit values established by international and national standards for water quality

After contrasting the concentrations of heavy metals in water, such as Zn, Cd, Cu, Pb, and As with the international standards implemented by the European Union, Canada, and the United States, it indicates the risk of contamination by these metals in Lake Pomacochas. On the other hand, the Peruvian standards show the latent risk of Cd and Pb contamination, both for conserving the aquatic environment and for extracting and cultivating hydrobiological species in lakes. Furthermore, the risk of contamination by Zn, Cu, and As is accentuated in some sampling stations, the most representative of the risk at point P4 at depths one and 2. Regarding the concentration of heavy metals in sediments in contrast with the international standard of Canada, it is verified that there are no adverse biological effects due to the presence of metals.

Conclusion

The concentration of physicochemical parameters in the water profile, accentuated in the wet season, indicates a degree of contamination and an increase in the inflow load of the various tributaries that bring material dragged from the highlands. The concentrations of toxicological elements such as Ca, Mg, Zn, Pb, Cd, Cr, Pb, and As in the water profile, show the impact of the surrounding land use on the lake, whose compounds are transferred by runoff and leaching during the wet season. The predominant toxicological elements in the sediments are Cu and Zn and are localized in point P1 due to drainage and entrainment from the lake. The contrast of the element concentrations in the water profile with the international standards established by the European Union, Canada, and the United States shows the imminent risk of contamination by Zn, Cu, Cd, Pb, and As, whereas the national standard shows the risk to hydrobiological species, especially Cd and Pb. On the other hand, the concentration of Zn and Cu in the sediments, in comparison to the Canadian international standard, does not report biological risk for the moment.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material; further inquiries can be directed to the corresponding author.

Author contributions

DT contributed to conceptualization; LC and CSC helped with data; JR, DT, MG, and MO collaborated in the formal analysis; MO obtained funding; DL and JR elaborated the methodology; DT and JR participated in project management; DT and JR helped with software; MG and MO validated the study; LO contributed to visualization; DT wrote the original draft; and DT, JR and MG reviewed and edited the manuscript. All authors have read and accepted the published version of the manuscript.

Funding

This work was funded by the SNIP project Nor. 352650 "Creation of the Forestry and Agrosilvopasture Research Center of the Universidad Nacional Toribio Rodríguez de Mendoza, Región Amazonas"—CEINFOR, which was financed by the Peruvian Economy and Finance Ministry's (MEF's) National System of Public Investment (SNIP).

Acknowledgments

The authors would like to express their gratitude to District Municipality of Florida for the permits granted to evaluate and assess Lake Pomacochas.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors, and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2022.885591/full#supplementary-material

References

Abd El-Mageed, A. M. G., Enany, T. A., Goher, M. E., and Hassouna, M. E. M. (2022). Forecasting water quality parameters in Wadi El Rayan Upper Lake, Fayoum, Egypt using adaptive neuro-fuzzy inference system. *Egypt. J. Aquatic Res.* 48, 13–19. doi:10.1016/j.ejar.2021.10.001

Ahmed, W., Payyappat, S., Cassidy, M., Besley, C., and Power, K. (2018). Novel crAssphage marker genes ascertain sewage pollution in a recreational lake receiving urban stormwater runoff. *Water Res.* 145, 769–778. doi:10.1016/j.watres.2018.08.049

ANA (Autoridad Nacional del Agua) (2016). *Protocolo Nacional para el Monitoreo de la Calidad de los Recursos Hídricos Superficiales*. Lima: Autoridad Nacional del Agua.

Anderson, M. J., and Walsh, D. C. I. (2013). PERMANOVA, ANOSIM, and the Mantel test in the face of heterogeneous dispersions: What null hypothesis are you testing? *Ecol. Monogr.* 83, 557–574. doi:10.1890/12-2010.1

APHA, AWWAWEF (2017). *Standard methods for the examination of water and wastewater*. Washington DC: American Public Health Association/American Water Works Association/Water Environment Federation.

Aranguren-Riaño, N. J., Shurin, J. B., Pedroza-Ramos, A., Muñoz-López, C. L., López, R., and Cely, O. (2018). Sources of nutrients behind recent eutrophication of Lago de Tota, a high mountain Andean lake. *Aquat. Sci.* 80, 39. doi:10.1007/s00027-018-0588-x

Barboza-Castillo, E., Maicelo, J. L., Vigo-Mestanza, C., Castro-Silupú, J., and Oliva, M. (2014). Análisis morfométrico y batimétrico del lago Pomacochas (Perú). *INDES Rev. Investig. el Desarro. Sustentable* 2, 90–97. doi:10.25127/indes.201402.009

Benito, X., Fritz, S. C., Steinitz-Kannan, M., Tapia, P. M., Kelly, M. A., and Lowell, T. V. (2018). Geo-climatic factors drive diatom community distribution in tropical South American freshwaters. *J. Ecol.* 106, 1660–1672. doi:10.1111/1365-2745.12934

Bhateria, R., and Jain, D. (2016). Water quality assessment of Lake water: A review. *Sustain. Water Resour. Manag.* 2, 161–173. doi:10.1007/s40899-015-0014-7

Bonanno, G., Vymazal, J., and Cirelli, G. L. (2018). Translocation, accumulation and bioindication of trace elements in wetland plants. *Sci. Total Environ.* 631–632, 252–261. doi:10.1016/j.scitotenv.2018.03.039

Borcard, D., Gillet, F., and Legendre, P. (2018). *Numerical ecology with R.* Dordrecht: Springer Science+Business Media. doi:10.18637/jss.v067.b03

Caraco, N. F., and Cole, J. J. (2002). Contrasting impacts of a native and alien macrophyte on dissolved oxygen in a large river. *Ecol. Appl.* 12, 1496–1509. doi:10.1890/1051-0761(2002)012[1496:CIOANA]2.0.CO;2

Castro-Medina, W. F. (2007). *Geología. Zonificación ecológica y economica del departamento de amazonas*. Iquitos: Instituto de Investigaciones de la Amazonía Peruana.

CCME (Canadian Council of Ministers of the Environment) (2001). *Canadian sediment quality guidelines for the protection of aquatic life*. Ottawa: Canadian Council of Ministers of the Environment.

CCME (Canadian Council of Ministers of the Environment) (2007). *Protocol for the derivation of water quality guidelines for the protection of aquatic life*. Ottawa: Canadian Council of Ministers of the Environment.

Chávez, J., Leiva, D., Rascón, J., Hoyos, I., and Corroto, F. (2016). Estado trófico del lago Pomacochas a través de parámetros fisicoquímicos y bacteriológicos. *INDES Rev. Investig. el Desarro. Sustentable* 2, 98–107. doi:10.25127/indes.20140

Chen, H., Jing, L., Yao, Z., Meng, F., and Teng, Y. (2019a). Prevalence, source and risk of antibiotic resistance genes in the sediments of Lake tai (China) deciphered by metagenomic assembly: A comparison with other global lakes. *Environ. Int.* 127, 267–275. doi:10.1016/j.envint.2019.03.048

Chen, M., Wang, D., Ding, S., Fan, X., Jin, Z., Wu, Y., et al. (2019b). Zinc pollution in zones dominated by algae and submerged macrophytes in Lake Taihu. *Sci. Total Environ.* 670, 361–368. doi:10.1016/j.scitotenv.2019.03.167

Cross, T. K., and Summerfelt, R. C. (1987). Oxygen demand of lakes: Sediment and water column bod. *Lake Reserv. Manag.* 3, 109–116. doi:10.1080/07438148709354766

Derrien, M., Brogi, S. R., and Gonçalves-Araujo, R. (2019). Characterization of aquatic organic matter: Assessment, perspectives and research priorities. *Water Res.* 163, 114908. doi:10.1016/j.watres.2019.114908

Dodds, W. K., Bouska, W. W., Eitzmann, J. L., Pilger, T. J., Pitts, L., Riley, A. J., et al. (2009). Eutrophication of U.S. Freshwaters: Analysis of potential economic damages. *Environ. Sci. Technol.* 43, 12–19. doi:10.1021/es801217q

EPA (Environmental Protection Agency) (1994). *Method 200.7 - determination of elements and trace elements in water and wastes by inductively coupled plasma-atomic emmission spectropemtry*. Washington DC: United States Environmental Protection Agency.

EPA (Environmental Protection Agency) (1992). *Method 3005A - acid digestion of waters for total recoverable or dissolved metals for analysis by FLAA or ICP spectroscopy*. Washington DC: United States Environmental Protection Agency.

EPA (Environmental Protection Agency) (1996). *Method 3050B - acid digestion of sediments, sludges, and soils*. Washington DC: United States Environmental Protection Agency.

EPA (Environmental Protection Agency) (2009). *National primary drinking water guidelines*. Washington DC: United States Environmental Protection Agency.

EU (European Union) (2008). *Directive 2008/105/EC : Water environmental quality standards*. Estrasburg: European Parliamen.

HACH (2000). *Manual de análisis de agua*. Loveland: HACH COMPANY.

Hou, D., He, J., Lü, C., Ren, L., Fan, Q., Wang, J., et al. (2013). Distribution characteristics and potential ecological risk assessment of heavy metals (Cu, Pb, Zn, Cd) in water and sediments from Lake Dalinouer, China. *Ecotoxicol. Environ. Saf.* 93, 135–144. doi:10.1016/j.ecoenv.2013.03.012

INEI (Instituto Nacinal de Estadistica e Informatica) (2018). *Resultados definitivos censo Región amazonas*. Lima: Instituto Nacinal de Estadistica e Informatica.

Jančula, D., and MarŠálek, B. (2011). Critical review of actually available chemical compounds for prevention and management of cyanobacterial blooms. *Chemosphere* 85, 1415–1422. doi:10.1016/j.chemosphere.2011.08.036

Jia, Z., Chang, X., Duan, T., Wang, X., Wei, T., and Li, Y. (2021). Water quality responses to rainfall and surrounding land uses in urban lakes. *J. Environ. Manage.* 298, 113514. doi:10.1016/j.jenvman.2021.113514

Jiang, Z., Xu, N., Liu, B., Zhou, L., Wang, J., Wang, C., et al. (2018). Metal concentrations and risk assessment in water, sediment and economic fish species with various habitat preferences and trophic guilds from Lake Caizi, Southeast China. *Ecotoxicol. Environ. Saf.* 157, 1–8. doi:10.1016/j.ecoenv.2018.03.078

Jolliffe, I. T. (2002). *Principal components analysis*. New York, USA: Springe-Verlagr.

Kadhum, S. A., Ishak, M. Y., Zulkifli, S. Z., and Hashim, R. B. (2017). Investigating geochemical factors affecting heavy metal bioaccessibility in surface sediment from Bernam River, Malaysia. *Environ. Sci. Pollut. Res.* 24, 12991–13003. doi:10.1007/s11356-017-8833-8

Kamala-Kannan, S., Prabhu Dass Batvari, B., Lee, K. J., Kannan, N., Krishnamoorthy, R., Shanthi, K., et al. (2008). Assessment of heavy metals (Cd, Cr and Pb) in water, sediment and seaweed (Ulva lactuca) in the Pulicat Lake, South East India. *Chemosphere* 71, 1233–1240. doi:10.1016/j.chemosphere.2007.12.004

Kang, M., Tian, Y., Peng, S., and Wang, M. (2019). Effect of dissolved oxygen and nutrient levels on heavy metal contents and fractions in river surface sediments. *Sci. Total Environ.* 648, 861–870. doi:10.1016/j.scitotenv.2018.08.201

Kannan, S. K., and Krishnamoorthy, R. (2006). Isolation of mercury resistant bacteria and influence of abiotic factors on bioavailability of mercury - a case study in Pulicat Lake North of Chennai, South East India. *Sci. Total Environ.* 367, 341–353. doi:10.1016/j.scitotenv.2005.12.003

Kemp, W. M., Boynton, W. R., Adolf, J. E., Boesch, D. F., Boicourt, W. C., Brush, G., et al. (2005). Eutrophication of chesapeake bay: Historical trends and ecological interactions. *Mar. Ecol. Prog. Ser.* 303, 1–29. doi:10.3354/meps303001

Kong, M., Zhu, Y., Han, T., Zhang, S., Li, J., Xu, X., et al. (2021). Interactions of heavy metal elements across sediment-water interface in Lake Jiaogang. *Environ. Pollut.* 286, 117578. doi:10.1016/j.envpol.2021.117578

Kouassi, N. L. B., Yao, K. M., Sangare, N., Trokourey, A., and Metongo, B. S. (2019). The mobility of the trace metals copper, zinc, lead, cobalt, and nickel in tropical estuarine sediments, Ebrie Lagoon, Côte d'Ivoire. *J. Soils Sediments* 19, 929–944. doi:10.1007/s11368-018-2062-8

López-Martínez, M. L., Jurado-Rosero, G. A., Páez-Montero, I. D., Madroñero-Palacios, S. M., Mariana, U., et al. (2017). Estructura térmica del lago Guamués, un lago tropical de Alta montaña. *Luna Azul*, 94–119. doi:10.17151/luaz.2017.44.7

Lynch, N. R., Hoang, T. C., and O'Brien, T. E. (2016). Acute toxicity of binary-metal mixtures of copper, zinc, and nickel to *Pimephales promelas*: Evidence of more-than-additive effect. *Environ. Toxicol. Chem.* 35, 446–457. doi:10.1002/etc.3204

Manoj, M. C., and Kawsar, M. (2020). Metal contamination assessment in a sediment core from vagamon lake, southwest India: Natural/anthropogenic impact. *Environ. Nanotechnol. Monit. Manag.* 14, 100362. doi:10.1016/j.enmm.2020.100362

Marin, J.-M., and Robert, C. (2014). *Bayesian essentials with R*. New York, EEUU: Springer Science+Business Media.

Marin, N. A., Barboza, E., López, R. S., Vásquez, H. V., Fernández, D. G., Murga, R. E. T., et al. (2022). Spatiotemporal dynamics of grasslands using landsat data in livestock micro-watersheds in Amazonas (NW Peru). *Land* 11, 674–718. doi:10.3390/land11050674

Matthews-Bird, F., Valencia, B. G., Church, W., Peterson, L. C., and Bush, M. (2017). A 2000-year history of disturbance and recovery at a sacred site in Peru's northeastern cloud forest. *Holocene* 27, 1707–1719. doi:10.1177/0959683617702232

MINAM (Ministerio del Ambiente) (2017). D.S. N° 004-2017-MINAM. Aprueban Estándares de Calidad Ambiental (ECA) para Agua y establecen Disposiciones Complementarias. Available at: http://www.minam.gob.pe/wp-content/uploads/2017/06/DS-004-2017-MINAM.pdf.

Miranda, L. S., Ayoko, G. A., Egodawatta, P., Hu, W. P., Ghidan, O., and Goonetilleke, A. (2021). Physico-chemical properties of sediments governing the bioavailability of heavy metals in urban waterways. *Sci. Total Environ.* 763, 142984. doi:10.1016/j.scitotenv.2020.142984

Niu, Y., Jiang, X., Wang, K., Xia, J., Jiao, W., Niu, Y., et al. (2020). Meta analysis of heavy metal pollution and sources in surface sediments of Lake Taihu, China. *Sci. Total Environ.* 700, 134509. doi:10.1016/j.scitotenv.2019.134509

Ogato, T., Kifle, D., and Lemma, B. (2015). Underwater light climate, thermal and chemical characteristics of the tropical soda lake Chitu, Ethiopia: Spatio-temporal variations. *Limnologica* 52, 1–10. doi:10.1016/j.limno.2015.02.003

Oliva, M., Oliva, C., Rojas, D., Oliva, M., and Morales, A. (2015). Botanical identification of native species most important of dairy basins Molinopampa, Pomacochas and Leymebamba, Amazonas, Peru. *Sci. Agropecu.* 6, 125–129. doi:10.17268/sci.agropecu.2015.02.05

Özkundakci, D., Hamilton, D. P., and Scholes, P. (2010). Effect of intensive catchment and in-lake restoration procedures on phosphorus concentrations in a eutrophic lake. *Ecol. Eng.* 36, 396–405. doi:10.1016/j.ecoleng.2009.11.006

Popek, E. P. (2018). *Sampling and analysis of environmental chemical pollutants: A complete guide*. Cambridge: Elservier.

Potapov, S. A., Tikhonova, I. V., Krasnopeev, A. Y., Kabilov, M. R., Tupikin, A. E., Chebunina, N. S., et al. (2019). Metagenomic analysis of virioplankton from the pelagic zone of lake baikal. *Viruses* 11, 991. doi:10.3390/v11110991

Potemkina, T., and Potemkin, V. (2021). Quantifying the actual sediment load flux into lake baikal: A case study of the main tributary – the selenga river (Russia). *Int. J. Sediment Res.* 37, 238–247. doi:10.1016/j.ijsrc.2021.08.004

Pourabadehei, M., and Mulligan, C. N. (2016). Resuspension of sediment, a new approach for remediation of contaminated sediment. *Environ. Pollut.* 213, 63–75. doi:10.1016/j.envpol.2016.01.082

R Development Core Team (2021). R: A language and environment for statistical computing. Available at: http://www.r-project.org.

Rahman, K., Barua, S., and Imran, H. M. (2021). Assessment of water quality and apportionment of pollution sources of an urban lake using multivariate statistical analysis. *Clean. Eng. Technol.* 5, 100309. doi:10.1016/j.clet.2021.100309

Ramrakhiani, L., Halder, A., Majumder, A., Mandal, A. K., Majumdar, S., and Ghosh, S. (2017). Industrial waste derived biosorbent for toxic metal remediation: Mechanism studies and spent biosorbent management. *Chem. Eng. J.* 308, 1048–1064. doi:10.1016/j.cej.2016.09.145

Ramya, M., Elumalai, S., and Umamaheswari, A. (2021). Study of physicochemical and statistical analysis of water quality parameters in Veeranam Lake, Cuddalore district, Tamil Nadu, India. *Mater. Today Proc.* 49, 2934–2942. doi:10.1016/j.matpr.2021.11.354

Rascón, J., Corroto, F., Leiva-Tafur, D., and Gamarra Torres, O. A. (2021). Variaciones limnológicas espaciotemporales de un lago altoandino tropical al norte de Perú. *Ecol. Austral* 31, 343–356. doi:10.25260/ea.21.31.2.0.1200

Rencher, A. C. (2012). *Methods of multivariate analysis*. Hoboken: John Wiley & Sons.

Schmidt, S. R., Lischeid, G., Hintze, T., and Adrian, R. (2019). Disentangling limnological processes in the time-frequency domain. *Limnol. Oceanogr.* 64, 423–440. doi:10.1002/lno.11049

Stange, C., Yin, D., Xu, T., Guo, X., Schäfer, C., and Tiehm, A. (2019). Distribution of clinically relevant antibiotic resistance genes in Lake Tai, China. *Sci. Total Environ.* 655, 337–346. doi:10.1016/j.scitotenv.2018.11.211

Tang, W., Duan, S., Shan, B., Zhang, H., Zhang, W., Zhao, Y., et al. (2016). Concentrations, diffusive fluxes and toxicity of heavy metals in pore water of the Fuyang River, Haihe Basin. *Ecotoxicol. Environ. Saf.* 127, 80–86. doi:10.1016/j.ecoenv.2016.01.013

Thioulouse, J., Dufour, A. B., Jombart, T., Dray, S., Siberchicot, A., and Pavoine, S. (2018). *Multivariate analysis of ecological data with ade4*. New York: Springer Science+Business Media.

Townsend, S. A., and Edwards, C. A. (2003). A fish kill event, hypoxia and other limnological impacts associated with early wet season flow into a lake on the Mary River floodplain, tropical northern Australia. *Lakes &amp. Reserv.* 8, 169–176. doi:10.1111/j.1440-1770.2003.00222.x

Utete, B., and Fregene, B. T. (2020). Assessing the spatial and temporal variability and related environmental risks of toxic metals in Lake Asejire, south-western Nigeria. *Sci. Afr.* 7, e00259. doi:10.1016/j.sciaf.2019.e00259

Van Der Maaten, L. J. P., Postma, E. O., and Van Den Herik, H. J. (2009). Dimensionality reduction: A comparative review. *J. Mach. Learn. Res.* 10, 1–41. doi:10.1080/13506280444000102

Vargas-Rivera *J. Clima. Zonificación Ecológica y Económica del departamento de Amazonas*. Iquitos. Instituto de Investigaciones de la Amazonía Peruana.

Wang, M., Bao, K., Heathcote, A. J., Zhu, Q., Cheng, G., Li, S., et al. (2021). Spatio-temporal pattern of metal contamination in Chinese lakes since 1850. *Catena* 196, 104918. doi:10.1016/j.catena.2020.104918

Wang, X., Zhang, L., Zhao, Z., and Cai, Y. (2018). Heavy metal pollution in reservoirs in the hilly area of southern China: Distribution, source apportionment and health risk assessment. *Sci. Total Environ.* 634, 158–169. doi:10.1016/j.scitotenv.2018.03.340

Wang, Z., Wang, C., Jiang, H., and Liu, H. (2022). Higher dissolved oxygen levels promote downward migration of phosphorus in the sediment profile: Implications for lake restoration. *Chemosphere* 301, 134705. doi:10.1016/j.chemosphere.2022.134705

Wei, T., Wijesiri, B., Jia, Z., Li, Y., and Goonetilleke, A. (2019). Re-thinking classical mechanistic model for pollutant build-up on urban impervious surfaces. *Sci. Total Environ.* 651, 114–121. doi:10.1016/j.scitotenv.2018.09.013

Wetzel, R. G. (2001). *Limnology: Lake and river ecosystems*. San Diego: Academic Press Elservier.

Xu, Y., Wu, Y., Han, J., and Li, P. (2017). The current status of heavy metal in lake sediments from China: Pollution and ecological risk assessment. *Ecol. Evol.* 7, 5454–5466. doi:10.1002/ece3.3124

Zerizghi, T., Yang, Y., Wang, W., Zhou, Y., Zhang, J., and Yi, Y. (2020). Ecological risk assessment of heavy metal concentrations in sediment and fish of a shallow lake: A case study of baiyangdian lake, north China. *Environ. Monit. Assess.* 192, 154. doi:10.1007/s10661-020-8078-8