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Article

Seasonal Variation in Lead in the Water and Sediment of Lake Iripixí: A Study of Possible Sources of Contamination

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ABSTRACT

The study aimed to assess lead concentrations in water and sediments across different seasonal periods in Lake Iripixí, highlighting the significant influence of anthropogenic activities and natural factors. The water and sediment samples were collected at 24 points, divided into 8 in the urban area, 8 in the periurban area, and 8 in the rural area of the lake, following methodologies recommended by ANA, with triplicates for water samples and a single sample for sediment, which were later analyzed using ICP-OES. The Interpolator Inverse Distance Weighted (IDW) method was employed to estimate values at unsampled locations based on nearby observations, giving greater weight to closer points. Results indicated that higher lead concentrations were found in water during the rainy season, with similar trends observed in sediments, particularly near urban areas and at the lake's inlet, suggesting direct impacts from human activities and potential contributions from the Trombetas River. In contrast, lead concentrations in sediments did not exceed limits, indicating that water contamination isn't always correlated with sediment levels due to temporary mobility or chemical conditions. To mitigate these impacts, effective management and remediation strategies are essential, based on comprehensive environmental assessments using tools such as IDW. Understanding these dynamics is crucial for protecting aquatic ecosystems and guiding sustainable resource management practices.
Keywords: toxic metals; seasonality; amazonian lakes; interpolation inverse distance weighted; sediment contamination.

RESUMO

O estudo teve como objetivo avaliar as concentrações de chumbo na água e nos sedimentos em diferentes períodos sazonais no Lago Iripixí, destacando a influência significativa de atividades antropogênicas e fatores naturais. As amostras de água e sedimento foram coletadas em 24 pontos, sendo divididos em 8 na área urbana, 8 em periurbana e 8 em área rural do lago, seguindo metodologias recomendadas pela ANA, de triplicata para amostras de água e única para sedimento, posteriormente sendo analisadas usando ICP-OES. O método Interpolator Inverse Distance Weighted (IDW) foi empregado para estimar valores em locais não amostrados com base em observações próximas, dando maior peso aos pontos mais próximos. Os resultados indicaram que maiores concentrações de chumbo foram encontradas na água durante a estação chuvosa, com tendências semelhantes observadas em sedimentos, particularmente perto de áreas urbanas e na entrada do lago, sugerindo impactos diretos de atividades humanas e potenciais contribuições do Rio Trombetas. Em contraste, as concentrações de chumbo nos sedimentos não excederam os limites, indicando que a contaminação da água nem sempre está correlacionada com os níveis de sedimentos devido à mobilidade temporária ou condições químicas. Para mitigar esses impactos, estratégias eficazes de gerenciamento e remediação são essenciais, com base em avaliações ambientais abrangentes usando ferramentas como IDW. Entender essa dinâmica é crucial para proteger os ecossistemas aquáticos e orientar práticas sustentáveis de gestão de recursos.
Palavras-chave: metais tóxicos; sazonalidade; lagos amazônicos; interpolação ponderada pelo inverso da distância; contaminação de sedimentos.

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Introduction

The conservation of natural resources and the potential harmful consequences associated with soil, sediment, and water contamination are growing global concerns (López-Pacheco et al. 2019). The aquatic ecosystems of the Amazon, which represent unparalleled biodiversity, play a crucial role in regulating the global carbon cycle (Araújo et al. 2022; Correa et al. 2022). However, these systems are not immune to heavy metal contamination, particularly lead (Pb), whose concentrations can vary seasonally and pose serious threats to the environmental health of the region (Jakob & Young 2006).

Consequently, the increase in heavy metal pollution in freshwater eco-systems is becoming a global concern (Mehana et al. 2020; Tan et al, 2016). The presence of these metals in water has been attributed to both natural processes and anthropogenic activities, such as industrial discharge, urbanization, mining, agriculture, and atmospheric deposition (Abende Sayom et al. 2023; Patel et al. 2018). They pose a significant risk to both biota and humans (OSHA, 2012; Salam et al. 2019), primarily due to their high potential for bioaccumulation in the food chain (Alloway, 2012). Heavy metals that infiltrate sediments can contaminate drinking water wells and harm consumers (Zhang et al. 2017; Ajiboye et al. 2021).

In the Amazon, urbanization near water bodies poses a significant challenge, leading to heavy metal contamination (Cruz et al. 2022), Seasonality is a primary factor in this situation. According to Siddiqui et al. (2021), the Amazonian environment is characterized by well-defined rainy and dry seasons that significantly affect the dynamics of aquatic systems. These seasonal changes play a crucial role in the variation of heavy metal concentrations in Amazonian lakes (Jakob & Young 2006).

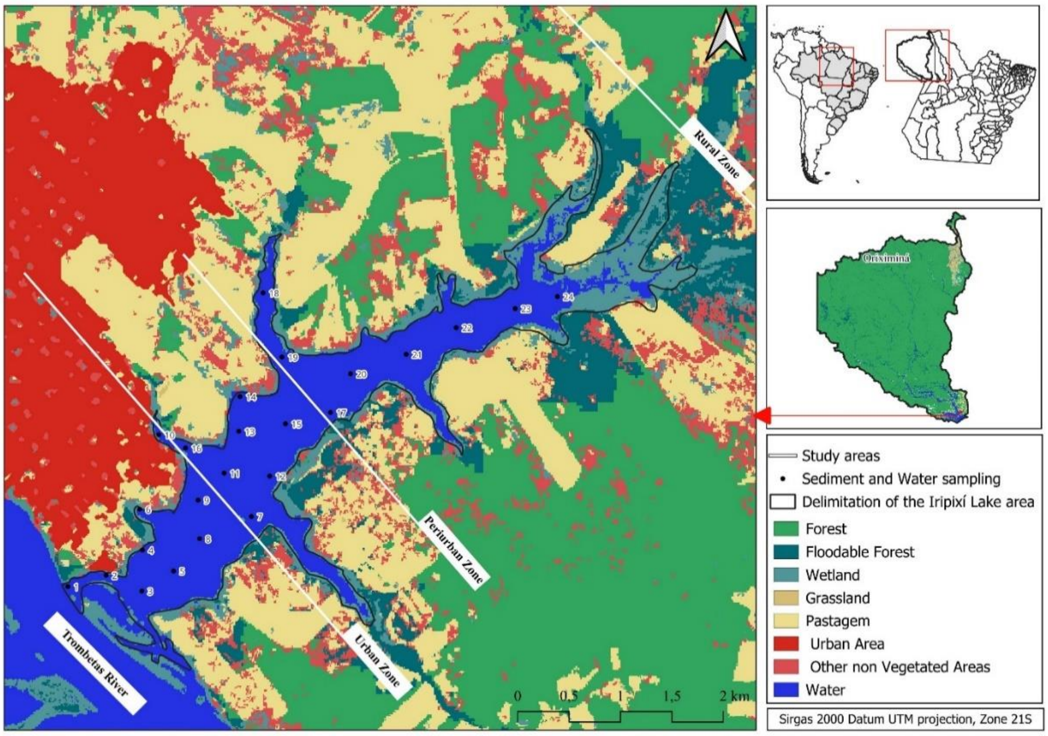
Understanding these seasonal variations is extremely important for the conservation of Amazonian biodiversity and the proper management of water resources. Constant monitoring of heavy metal concentrations is crucial for assessing the risks associated with these contaminants and implementing effective mitigation measures. Given this context, the present study aimed to evaluate the seasonal variation in Pb concentrations in the water and sediments of Lake Iripixí and to identify the main sources contributing to these contaminants.

Materials and Methods

Study Area

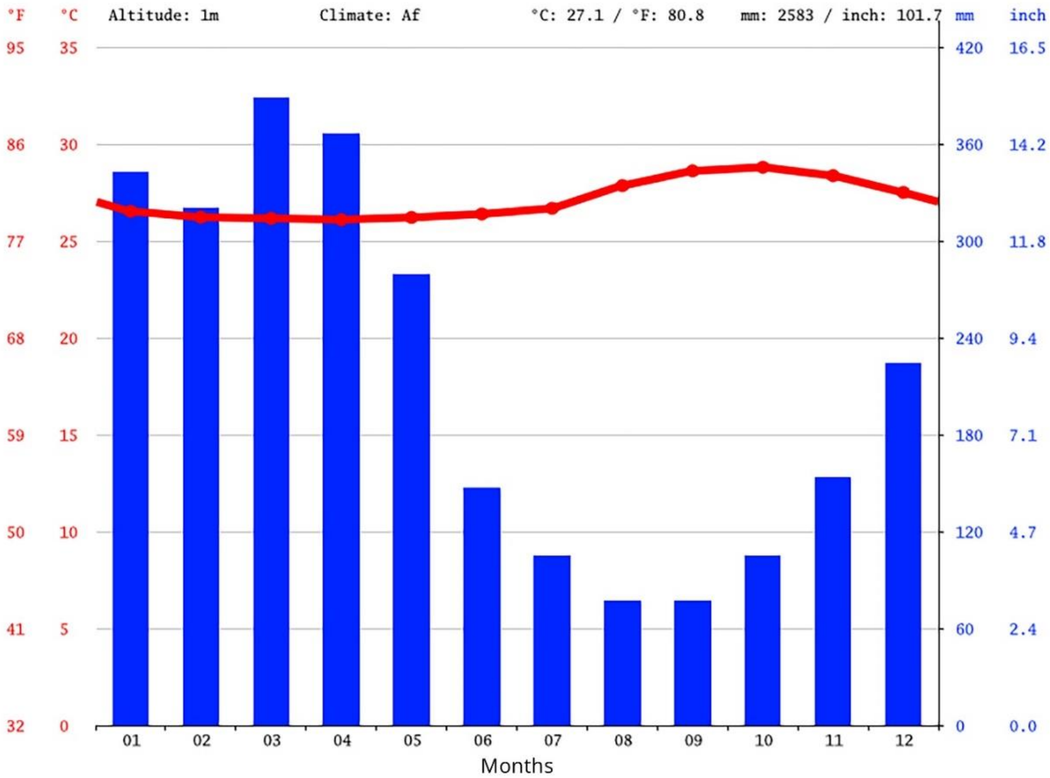
Samples were obtained from Lake Iripixí, located in the municipality of Oriximiná, PA, on the left bank of the Trombetas River. The lake was divided into three sections for the study: urban, peri-urban, and rural areas, as shown in Figure 1. The region where the Iripixí basin is located is characterized by várzea, with igapó and upland forests (Cruz et al. 2022). According to the Köppen and Geiger climate classifications, the region's climate is equatorial, with the rainfall regime and consequent alternation between dry and rainy seasons governed by seasonal winds (monsoons) (Beck et al. 2020).The rainy seasons was defined as occurring from February to May, while the dry season was set from July to December. This classification is based on the observation that the months from January to May exhibit the highest precipitation levels, whereas the months from July to November record the lowest rainfall volumes, as shown in Figure 2.

Figure 1. Study area, Iripixí Lake, with definitions of collection points, land use and area boundaries.



Source: Authors (2024).

Figure 2. The climate chart of the Oriximiná (PA) region, showing the monthly variation of average temperatures (in red) and accumulated precipitation (in blue) throughout the year. The scale on the left indicates temperature in degrees Celsius (°C) and Fahrenheit (°F), while the scale on the right shows precipitation in millimeters (mm) and inches (inch).



Source: Authors (2024).

Collection and Analysis Methods

The collections were carried out from May 29 to 30, 2018. Along Lake Iripixi, 24 collection points were distributed, divided into three zones (urban, peri-urban and rural). In each of the three zones, 8 water and sediment sampling points were allocated. Water samples were collected in triplicate from each point, totaling 72 samples (n=72); and for the sediments, one sample from each point, totaling 24 samples (n=24) (Figure 1). The collections followed the methodology of the National Guide for Sample Collection and Preservation: Water, Sediment, Aquatic Communities, and Liquid Effluents from the National Water Agency (ANA, 2018).

Determination of Pb Contents

The water samples were analyzed at Evandro Chagas Institute Environ-ment Section (IEC/SAMAM). The determination of metals was performed using the USEPA 3015 method (USEPA, 2007). This method is based on the extrac-tion of metals in aqueous solutions using heat emitted by a microwave with the addition of nitric acid (HNO3) or a combination of nitric acid and hydrochloric acid (HCL). The samples were placed in a microwave oven (MDS-2000 CEM®) under the conditions suggested by the EPA 3015 method (USEPA, 2007). After defrosting at room temperature, the samples were distributed in 45 mL Falcon tubes, and 4 mL of nitric acid and 1 mL of hydrochloric acid (ultrapure) were added. The samples were then placed in a microwave oven. Since the microwave oven accommodates only 20 vials, each batch of digested samples included control samples: a blank, a duplicate, and a standard addition. After di-gestion, the samples were analyzed by inductively coupled plasma–optical emission spectrometry (ICP–OES).

Sediment collection was performed according to the ANA (2018) procedure at a depth of 0 to 20 cm using a Van Veen grab made of stainless steel. The sediment was placed in pre-decontaminated zip-lock plastic bags, stored in thermal boxes with ice, and transported to the laboratory. In the laboratory, the samples were stored in a freezer at approximately -20°C. For instrumental processing and analysis, the samples were defrosted at room temperature and dried in an oven at 100°C for 120 minutes. Sediment samples were collected from 0 to 20 cm of the sediment column based on the assumption that contamination is recent and related to the area's usage history (Caeiro et al. 2009)

In the laboratory, the treatment procedures were based on the methodology described by Kazi et al. (2009), where the sediment was dried in an oven at 100°C to constant mass and pulverized using an agate mortar and pestle. Next, the samples were weighed using an analytical balance, and 200 mg of each sample was removed and added to a digestion block. Digestion in the block was performed by adding 200 mg of the sample and 5 mL of aqua regia to a 10 mL digestion tube. The tube was placed in the block at 80°C for 4 hours, after which the solution was transferred to a 50 mL beaker and heated on a hot plate until nearly dry. The solution was filtered using filter paper (QUANTY – white band), the beakers were washed with deionized water, and the volume was adjusted to 20 mL.

After the analysis, the results were compared with the CONAMA 357/2005 data for water and 454/2012 CONAMA for sediment, we have the following Pb limits that classify the waters and sediments for the values obtained from the samples collected in Lake Iripixí (Table 1).

Table 1: Water and Sediment Quality Standards According to CONAMA Resolutions 357/2005 and 454/2012

Resolution 357/2005 (Water):	Resolution 454/2012 (Sediment):
Class I: ≤ 0.010 mg/L Class II: * Class III: > 0.033 mg/L	Class I: ≤ 35 mg/Kg Class II: ≥ 91 mg/Kg

* Only classified for brackish Waters. Source: Brasil (2005, 2012)

Interpolator Inverse Distance Weighted (IDW)

The method is a predictive technique that estimates a value at an unsampled location based on nearby observations. According to Jakob and Young (2006), the Inverse Distance Weighting (IDW) is an interpolation technique that calculates the estimated value at an unknown point based on the weighted average of known values, where the weights are determined by the inverse of the distances raised to a power *p*. The closer a known observation point is to the point of interest, the greater its contribution to the interpolated value.

For the application of the IDW method, some interpolation parameters must be entered. The lower and upper limits of neighbors in the interpolation correspond to the minimum and maximum number of points influencing the value estimates, respectively. A range of at least 2 neighbors and a maximum of 5 neighbors was defined. The exponent value (*p*) allows controlling the influence of known points on the interpolated values based on the distance from the output point. A value of 2, as indicated by Landim (2000), was defined as the standard. The IDW estimator is given by Equation 1.

$$Z(x_0, y_0) = \frac{\sum_i^n 1 \frac{z(x_i, y_i)}{d(x_0, y_0, x_i, y_{i,})p}}{\sum_i^n 1 \frac{1}{d(x_0, y_0, x_i, y_{i,})p}} \quad (1)$$

Z (X_0, Y_0) is the estimated value at the point of interest (X_0, Y_0).

Z (x_i,y_i) are the known values at the observation points (x_i,y_i)(x_i,y_i).

d (x_0, y_0, x_i, y_i) is the Euclidean distance between the point of interest (x_0, y_0) and the observation point (x_i,y_i).

n is the number of known observation points.

p is a parameter that controls the degree of distance influence. A common value for *p* is 2, which makes the IDW similar to an inverse distance squared weighted average.

To choose different values of "*p*" that affect the interpolation:

p = 0**:** When p equals zero, all sampling points have the same weight regardless of distance. This means that the interpolation will be based only on the average values of the nearest sampling points. It is a very smooth interpolation.

$p = 1$**:** When p equals one, the weights are inversely proportional to the distance, following a linear relationship. Closer sampling points will have more influence on the estimate but will still consider more distant points.

$p > 1$: Higher values of p cause the influence of distance to decrease rapidly. This means that the interpolation will be highly influenced by the nearest sampling points, making the estimate sensitive to small data variations.

$p < 1$: Lower values of p smooth the influence of distance, making the interpolation more dependent on distant sampling points. This results in smoother estimates and less sensitivity to local data variations.

Data Analysis

Data analysis was performed using different software tools. The maps were created in QGIS 3.28.3, while tabular data were processed in Excel 365. For statistical analysis, a one-way ANOVA ($p > 0.05$) was employed in IBM SPSS Statistics 29.0 to verify differences in contaminant concentrations between seasonal periods. Finally, the data were compared with the maximum allowable limits of Pb in freshwater established by CONAMA Resolution 357/2005 (Brasil, 2005), which provides guidelines on water body classification and environmental standards for their classification. For sediment, a comparison was made with the maximum allowable limits for Pb as described in CONAMA Resolution 454/2012 (Brasil, 2012), which establishes general guidelines and reference procedures for managing dredged material in waters under national jurisdiction.

Results and Discussion

The assessment of heavy metals in freshwater environments is a field that requires deep knowledge, as the concentrations of these metals can vary significantly seasonally (Huang et al. 2012; Lenoble et al. 2013). These seasonal variations are crucial because the desorption properties of metals can differ from season to season. Therefore, understanding these fluctuations is essential for an accurate and comprehensive assessment.

Heavy metals in aquatic systems can be quickly deposited in sediment, becoming a potential source of environmental pollution. However, changes in environmental conditions such as alterations in pH or redox potential (Eh) can trigger the rapid release of these metals from sediments (Tan et al. 2016; Singh et al. 2017). Thus, continuous evaluation of heavy metal concentrations in freshwater is necessary, considering seasonal variations and the influence of changes in environmental conditions.

One of the analytical methods used is IDW (inverse distance weighting), which is based on the premise that values at unknown locations can be estimated based on the proximity of known observations. The closer an unknown point is to a known observation point, the greater the influence of that point on the estimated value. Consequently, as the distance between the unknown point and the observation point increases, the influence decreases. This results in a weighted estimate where the closest points have a greater weight in the value interpolation.

In conclusion, assessing heavy metal concentrations in freshwater environments is a complex challenge requiring a deep understanding of seasonal variations and the behavior of these metals. Using tools such as IDW is fundamental for providing accurate estimates at unsampled locations. By combining solid scientific knowledge and robust evaluation methods, we can ensure a comprehensive understanding of the impact of heavy metals on aquatic ecosystems and take effective measures to protect these precious natural resources.

Seasonal Variations in Lead in Water and Sediment

For the analysis of Pb concentrations in sediments, a single sample was collected per point. In contrast, for the evaluation of Pb concentrations in water during the dry and flood periods, samples were collected in triplicate. The data used to generate maps correspond to the obtained averages, as presented in Table 2. Identical values at points 18 to 24 for water and sediment were observed in the rural area. In this region, the triplicate values were very low, showing differences only in the fourth or fifth decimal place. When rounded to three decimal places, the values became similar.

Table 2. Pb average concentrations in water and sediment during the rainy season and dry season periods.

	Water (mg L^{-1})		Sediment mg kg^{-1}	
Sample	**Rainy**	**Dry**	**Rainy**	**Dry**
1	0.037	0.024	0.165	0.124
2	0.012	0.034	0.195	0.105
3	0.017	0.023	0.192	0.121
4	0.060	0.015	0.003	0.091
5	0.064	0.024	0.009	0.104
6	0.006	0.036	0.117	0.112
7	0.197	0.023	0.011	0.129
8	0.098	0.031	0.001	0.104
9	0.030	0.020	0.093	0.069
10	0.094	0.011	0.102	0.180
11	0.076	0.013	0.114	0.060
12	0.006	0.066	0.132	0.014
13	0.079	0.077	0.040	0.010
14	0.055	0.032	0.033	0.008
15	0.028	0.023	0.059	0.042
16	0.092	0.018	0.036	0.061
17	0.008	0.008	0.050	0.050
18	0.017	0.017	0.057	0.057
19	0.013	0.013	0.050	0.050
20	0.065	0.065	0.013	0.013
21	0.077	0.077	0.009	0.009
22	0.031	0.031	0.004	0.004
23	0.022	0.022	0.037	0.037
24	0.018	0.018	0.037	0.037

Source: Authors (2024).

The results indicate that during the wet period, 15 out of the 24 analyzed points exceeded the Class I limit, with points 1, 4, 5, 7, 8, 9, 10, 11, 13, 14, 16, 20, and 21 showing higher levels of Pb. It is evident that during the wet period, there is a greater propensity for Pb contamination, possibly due to increased surface runoff and leaching of contaminants from urban or industrial zones into water bodies, or potentially from mining activities, as suggested by Calvo and Oliveira (2020).

During the dry period, 6 out of the 24 points exceeded the Class I limit, with 3 of these also exceeding the Class III limit. Specifically, points 2, 6, 12, 13, 20, and 21 exceeded the Class I limit, and points 13, 20, and 21 also exceeded the Class III limit. In contrast, the analysis of Pb concentration in the sediment showed no points exceeding the Class I limit during either period. This suggests that while water concentrations are alarming at several points, sediment contamination appears to be relatively less significant.

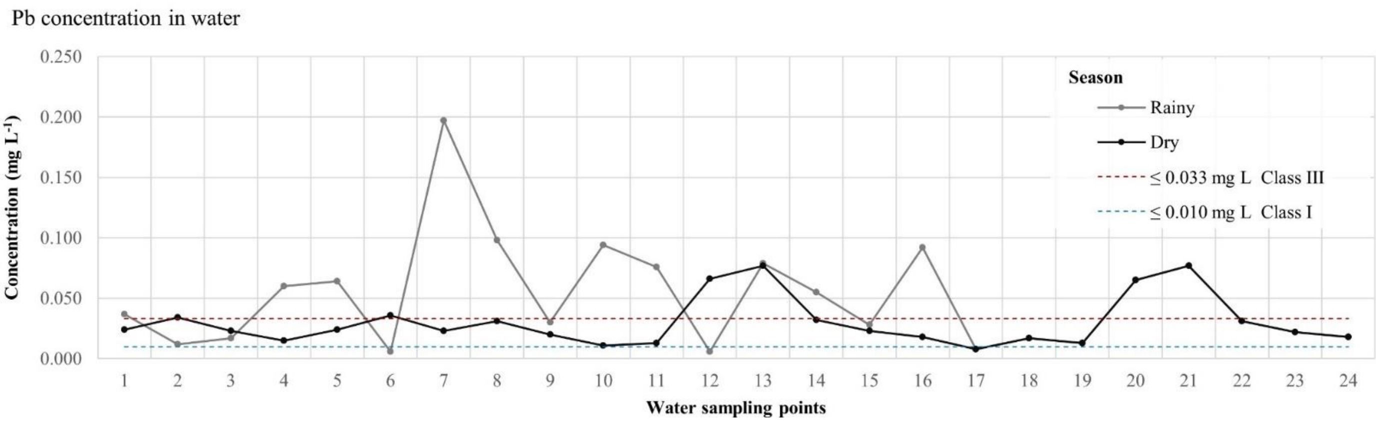
The finding of high concentrations of Pb in water but not in sediment might seem counterintuitive, as many heavy metals, including Pb, typically bind to solid particles and accumulate in sediment (Cristol et al. 2008; Martins et al. 2018; Lages et al. 2022). However, several reasons could explain this observation.

According to Silva (2020), this might be a case of temporary mobility, where there may have been a recent release of Pb in the area, leading to high concentrations in the water column, but the Pb has not had enough time to settle and accumulate. Alternatively, specific chemical conditions in water, such as pH and the presence of dissolved organic matter, could influence the solubility and mobility of Pb (Lages et al. 2022).

Under certain conditions, Pb may remain more soluble and less likely to bind to particles and settle (Coles et al. 2000; Li et al. 2013). Another possible explanation could be high erosion or activities that disturb the sediment (such as navigation, construction, or fishing activities), which can reintroduce Pb accumulated in the sediment back into the water column through sediment movement (Rumuri et al. 2023).

Graphical analysis of the seasonal variation in Pb concentrations in water (Figure 3) revealed significant variations between points, with a peak concentration during the wet period at point 7 (0.197 mg L^{-1}) and the lowest at point 12 (0.006 mg L^{-1}), with an amplitude of 0.191 mg L^{-1}. During the dry period, this variation was smaller, with an amplitude of approximately 0.069 mg L^{-1}. According to Lages et al. (2022), the relationship between Pb concentration and water pH is crucial for understanding the observed variations during different seasonal periods.

Figure 3. Variation of Pb concentration in water during the rainy season and dry season periods in Lake Iripixi.



Source: Authors (2024).

Table 3 confirms this variation, indicating significant differences in the values found in each period. The presence of Pb in water is a serious public health concern. Pb is a toxic substance that can have significant adverse health effects even at relatively low concentrations. The main health impacts associated with Pb exposure in water include neurotoxicity and cardiovascular, renal, and reproductive problems.

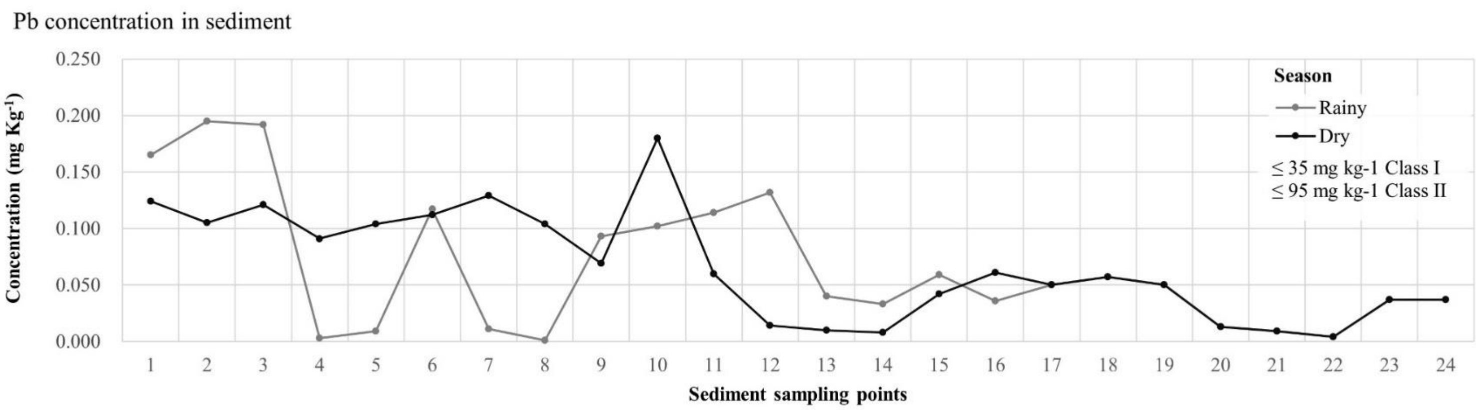
Table 3. One-Factor ANOVA for Pb in water during the rainy and dry season periods.

Group	**Count**		**Sum**	**Mean**		**Variance**
Pb in water - rainy	24		1.202	0.05008		0.00192
Pb in water - dry	24		0.721	0.03004		0.00041
Source of variation	SQ	gl	MQ	F	p-value	Critical F
Between groups	0.00482	1	0.00482	4.1259	0.04803	4.05174
Within groups	0.05373	46	0.00116			
Total	0.05855	47				

Source: Authors (2024).

For Pb in the sediment, even greater variations were observed (Figure 4). This variation is mainly explained by the differences between the collection areas, which have varying degrees of anthropogenic impact. According to Rauret et al. (1999), physical disturbances at collection points can release metals faster than biological disturbances, which could explain the observed variation between points. The maximum Pb concentration in the sediment was 0.195 mg/L, approximately 0.001 mg/L lower than the water concentration during the same seasonal period. The amplitude of variation was 0.194 mg/L during the rainy period and 0.176 mg/L during the dry period.

Figure 4. Variation of Pb concentration in sediment during the rainy and dry periods in Iripixi Lake.



Source: Authors (2024).

Table 4. One-Factor ANOVA for Pb in sediment during the rainy and dry season periods.

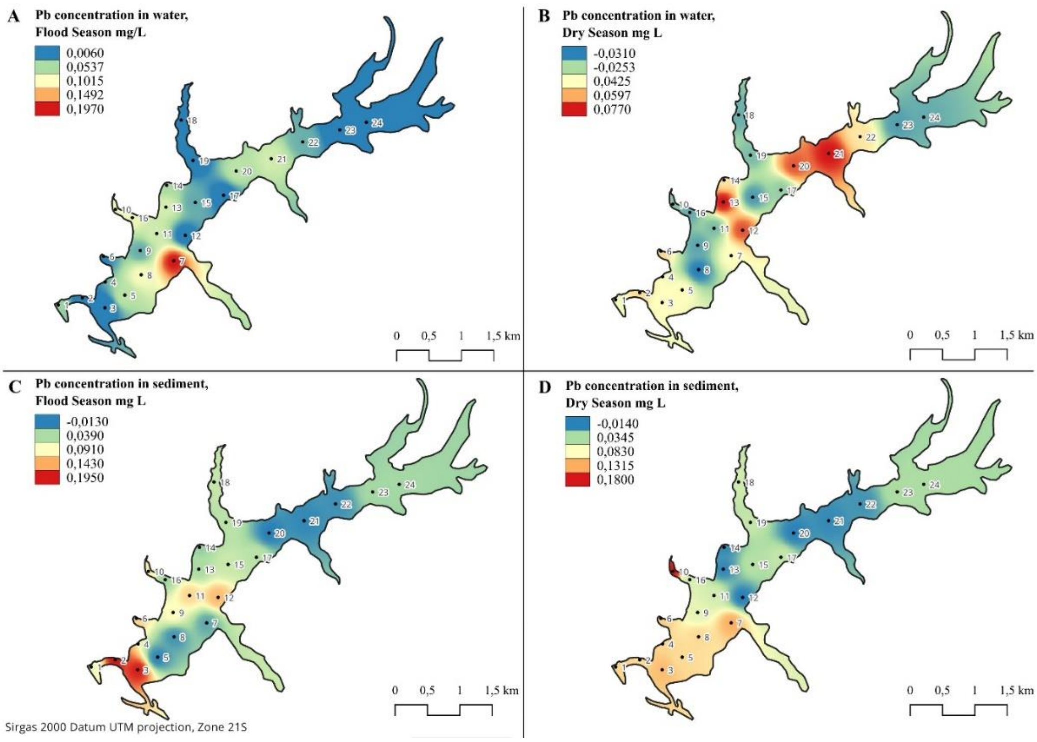
Group	Count		Sum	Mean		Variance
Pb in sediment - rainy	24		1.559	0.06495		0.00360
Pb in sediment - dry	24		1.591	0.06629		0.00228
Source of variation	SQ	gl	MQ	F	p-value	Critical F
Between groups	0.000021	1	2.13333	0.00724	0.93254	4.05174
Within groups	0.135466	46	0.00294			
Total	0.13548	47				

Source: Authors (2024).

IDW Interpolation for Pb Concentrations in Lake Iripixí

Figure 5 shows the Pb concentrations in both seasonal periods for water and sediment. Figure 5A, which represents the rainy period and the Pb concentration in the water, highlights the point at which the highest concentration occurred: point 7, at approximately 0.197 mg L^{-1}. By applying IDW analysis, these concentrations were estimated for the entire lake. The highest water values are near urban and peri-urban areas. This contrasts with the average values found in rural areas, which, under lower anthropogenic influence, have concentrations approximately three times lower (0.053 mg L^{-1}).

Figure 5. IDW interpolation results for lead in water and sediment the rainy season (left panel) and dry season (right panel) in Lake Iripixí.



Source: Authors (2024).

According to Pandey and Singh (2017), urbanization directly influences water quality. Activities such as atmospheric pollution by vehicle fleet, deforestation, and drainage are primary causes. In the urban area, fluctuations in concentrations suggest a recent introduction of Pb, likely from city sewage combined with mining residues from the Trombetas River.

In the peri-urban area, which includes eight distinct points, the soil is predominantly used for grazing. The maintenance of vessels can alter Pb concentrations. The scenario changes in the dry period, as represented in Figure 5B. Higher concentrations begin to occur at greater distances from urban areas, suggesting a reduced impact from urban leachate and the river on the lake. The average concentrations were also lower than those in the rainy period, further supporting the idea that urban leachate and rivers contributed to the lake.

Considering the characteristics of Amazonian lakes, factors such as humic substances can alter Pb mobility and bioavailability. The lower concentrations in rural areas, for example, can be attributed to the significant presence of macrophytes, which, according to Nabi (2021) and Junk and Furk (1980), absorb heavy metals.

In urban areas, Pb concentrations vary greatly between points, indicating that Pb concentrations are recent and are believed to mainly originate from city sewage and likely from mining residues from the Trombetas River. The contamination level of the lake depends on the rate and volume of water flowing between the river and the lake and the capacity of the Iripixí lake to dilute or process contaminants.

Figure 5C shows that during the rainy season, the Pb concentrations are diluted due to increased rainfall. In Lake Iripixí, the highest Pb concentrations in sediment are in the most urbanized area, similar to observations by Bancon-Montigny et al. (2019). Additionally, sediment transport during this season can bury contaminants, reducing their availability in the water column.

Amazonian lakes may have unique characteristics, such as humic substances that can interact with Pb and influence its mobility and bioavailability (Junk & Furch 1980). These lower concentrations in rural areas are due to the high presence of macrophytes. According to Nabi (2021) and Junk and Furk(1980), aquatic macrophytes can absorb large amounts of heavy metals, and after their death, these residues can be incorporated into limnic sediment. Moreover, factors such as the seasonality of rainfall and variations in water level can also influence Pb dynamics in sediments (Silva et al. 2021).

In Lake Iripixí, the Pb concentrations in the sediment were highest in the most urbanized area and in the closest connection between the river and the lake, similar to the findings of Bancon-Montigny et al. (2019), where the Pb concentrations in the sediment were higher in the lake channel, which has a direct connection to the sea.

Although the Pb concentrations in the sediment were greater during the wet period in the urban area, the rest of the lake exhibited less variation in the interpolation. However, the dry season presents a different scenario. With reduced water volume, the Pb concentration increases. This occurs due to the concentration of contaminants in the remaining waters, making them more visible and impactful. However, in Lake Iripixí, these concentrations showed a slight reduction and greater homogeneity within the urban area, with no concentration peaks at any point. In peri-urban and rural areas, concentrations remained low as in the wet period, and in rural areas, concentrations were lower in both periods.

According to Li et al. (2013), the pH of sediment or water can influence Pb mobility. Generally, at low pH (acidic), Pb tends to be more soluble and therefore more mobile. This means that in acidic environments, Pb can be more easily released from sediments into the water column, explaining the higher water values of this element. Lages et al. (2022) and Martins et al. (2018) reported that Pb can form complexes with different substances present in water or sediment. The formation of these complexes can be influenced by pH, and in some cases, complex formation can decrease the amount of Pb adsorbed in sediment.

The influence of seasonal variations in heavy metal concentrations affects not only water but also aquatic biota (Gao et al. 2022). Organisms that depend on these lakes as habitats face challenges during the dry season, when exposure to elevated levels of heavy metals such as Pb can have adverse health and reproductive impacts (Moiseenko & Gashkina 2020).

In summary, a combination of physical, chemical, and biological factors can result in high Pb concentrations in the water column, while sediment levels remain relatively low and stable. It is important to conduct thorough investigations considering potential contamination sources, hydrological and geochemical characteristics of the area, and aquatic ecosystem dynamics to fully understand the observed discrepancy.

While data analysis reveals general trends, it is crucial to understand the geographical and anthropogenic context. The high variability between points suggests that local factors such as industrial discharge, agricultural practices, or natural sources may influence Pb concentrations. It is vital to expand the monitoring network to include other parameters, such as pH, organic matter, and conductivity, that influence Pb mobility. A deeper understanding of Pb sources and hydrological pathways in the studied area is also necessary.

Conclusion

In conclusion, the seasonal variation in the concentrations of heavy metals such as Pb in Amazonian Lake water is a complex phenomenon influenced by multiple factors. As observed, values are still within the permitted limits of the legislation, but they indicate that human activities around the lake are impacting water quality and consequently the biota. Therefore, to mitigate these impacts, sustainable management of these aquatic systems, involving a deep understanding of these seasonal dynamics and a collaborative approach involving governments, scientists, and local communities, is necessary. Only through these joint efforts can we preserve the rich biodiversity of the Amazon and protect its valuable water resources for future generations.

Ethical Approval

Not applicable

Conflict of Interest Statement

The authors declare that they have no competing interests in this work.

Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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