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Determination of metals concentration in sedimentary profiles from lagoons affected by the tailings from the collapse of the Fundão dam

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Astract: The collapse of the Fundão dam in Mariana released more than 59 million m³ of tailings, which flowed almost 700 kilometers along the Doce river, through the states of Minas Gerais and Espírito Santo, reaching the estuary and into the Atlantic Ocean. In view of all the possible impacts that may have been caused by the environmental accident involving the collapse of the Fundão dam, considered the world's largest socio-environmental disaster involving tailings dams, there is a need for studies that address the level of contamination of terrestrial ecosystems, not only because of their capacity to accumulate chemical elements, but also because they are recognized as possible sources of contaminants. In this segment, this study evaluated the concentrations of metals (Zn, Mn, Cr, Cu, Ni, As, Pb, Ba, Al and Fe) in vertical profiles of sediment samples from three lagoons in Espírito Santo State, affected by the collapse of the Fundão dam. A gravity sampler supplied by the Austrian company Uwitec was used to extract the samples. The sediment samples were subjected to acid dissolution and an inductively coupled plasma optical emission spectrometer (ICP-OES) was used to quantify the metals. Maximum concentrations of iron (235,260 mg kg^{-1}) and arsenic (52 mg kg^{-1}) were obtained in the Areal profile; aluminum (30,270 mg kg^{-1}) and manganese (4,590 mg kg^{-1}) in the Areão profile. The concentrations of Cu, Pb and Zn exceeded the guideline values adopted by the CCME, above which the occurrence of negative effects on biota is likely.

Keywords: metals, sediments, lagoons, Espírito Santo, Fundão dam.

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Determinação da concentração de metais em perfis sedimentares de lagoas atingidas pelos rejeitos do rompimento da barragem de Fundão

Resumo: O rompimento da barragem de Fundão, em Mariana, liberou mais de 59 milhões de m³ de rejeitos que alcançou quase 700 quilômetros ao longo do rio Doce, percorrendo os estados de Minas Gerais e Espírito Santo, atingindo o estuário e chegando ao oceano Atlântico. Tendo em vista todos os possíveis impactos que podem ter sido causados pelo acidente ambiental do rompimento da barragem de Fundão, considerado o maior desastre socioambiental do mundo envolvendo barragens de rejeito, ressalta-se a necessidade de estudos que abordem o nível de contaminação dos ecossistemas terrestres, devido não só a sua capacidade em acumular elementos químicos, mas por também serem reconhecidos como possíveis fontes de contaminantes. Neste seguimento, o presente trabalho avaliou as concentrações de metais (Zn, Mn, Cr, Cu, Ni, As, Pb, Ba, Al e Fe), em perfis verticais, de amostras de sedimentos de três lagoas do Estado de Espírito Santo, atingidas após o rompimento da barragem de Fundão. Para a extração dos testemunhos foi utilizado um amostrador gravitacional fornecido pela empresa austríaca Uwitec. As amostras de sedimento foram submetidas a abertura ácida e, para quantificação dos metais, foi utilizado um espectrômetro de emissão ótica em plasma indutivamente acoplado (ICP-OES). Foram obtidas concentrações máximas de ferro (235.260 mg kg^{-1}) e de arsênio (52 mg kg^{-1}) no perfil Areal; de alumínio (30.270 mg kg^{-1}) e manganês (4.590 mg kg^{-1}) no perfil Areão. As concentrações de Cu, Pb e Zn ultrapassaram os valores-guias adotados pelo CCMA, acima dos quais a ocorrência de efeitos negativos à biota é provável.

Palavras-chave: metais, sedimentos, lagoas, Espírito Santo, barragem de Fundão.

1. INTRODUCTION

The collapse of the Fundão dam, one of the three mining tailings containment dams in Mariana (Minas Gerais, Brazil), took place on November 5, 2015 [1]. This accident dumped around 59 million cubic meters of a mixture of solid and liquid tailings into the environment, forming a sludge that covered the entire ecosystems [2]. The impacts generated by this collapse extended from the site of the accident, in the municipality of Mariana, to the Doce River, reaching the state of Espírito Santo [3].

After the accident, various environmental impacts were recorded along the route affected by the mud, such as contamination by heavy metals and chemical compounds of the waters and sediments along the basin, the loss of biological diversity, as well as the deposition of the tailings in the affected areas [3,4]. As the tailings end up being deposited in the sediments, these accumulated sediments contain a historical record of the changes caused by anthropogenic processes. Therefore, using the analysis of overlapping sediment layers is a way of studying the history of a region [5].

The deposition of iron ore tailings from this breach in rivers, lakes, lagoons and estuaries has raised concerns about heavy metal contamination, the effects of which can last for decades. Although essential metals are present in the earth's crust in low concentrations, when in high concentrations they can be integrated into the food chain causing damage to human health and can be toxic to biota [6].

Assessing the concentration of these metals in sedimentary profiles is therefore crucial not only for understanding the extent of the environmental impact, but also for supporting mitigation and recovery measures for aquatic and terrestrial ecosystems [7].

The Quadrilátero Ferrífero is a region that hosts one of the largest iron ore deposits in the world. The main products extracted from this province are iron ore, manganese ore and gold [3]. For this reason, several studies have been carried out to identify whether the presence of metals such as Hg, As, Pb, Zn, Cu, Cd, Co, Cr and Ni in sediments is related to the mineral extraction activities in the region [4,6,8,9].

After the dam collapse, the sediments or mining tailings used as samples showed an increase in their levels of metals, mainly Fe, Mn, Al and As, but also other metals (Ba, Ni, Cr and Pb) [3,4,6,7,8]. Of these chemical elements, the greatest concern is with As, due to its high toxicity and high concentrations in the waters and sediments of the region's rivers [4].

Therefore, the vertical profile of metal concentration in sediments is used as a tool to monitor trace element levels in depositional environments, checking whether there has been accumulation in concentrations that exceed the limits established by sediment quality guidelines [8]. The decrease or increase in the concentration of metals at the surface in relation to deeper sediments may be related to anthropogenic activities [9].

In order to assess the environmental impact of sediment contamination by metals in lagoons affected by iron ore tailings from the Fundão dam collapse, this study analyzed the concentration levels of the elements Zn, Mn, Cr, Cu, Ni, As, Pb, Se, Al and Fe along three sediment profiles collected from three lagoons in Espírito Santo State, which consist of depositional environments, justifying the greater attention given to these points, affected by the collapse of Fundão dam.

2. MATERIALS AND METHODS

2.1. Study place

The mud of iron mining tailings traveled from Mariana, passed through the municipality of Bento Rodrigues and continued downstream, affecting other locations before reaching the Doce river. Some of the tailings were trapped along the way. The tailings, which traveled more than 700 km from the dam site to the Atlantic Ocean, spread a plume of turbidity over a large area [2,3].

The study was carried out in partnership with the Renova Foundation, which is the entity responsible for mobilizing to repair the damage caused by the collapse of the Fundão dam, in Mariana (MG). The Renova Foundation monitors 92 points in rivers, lagoons and coastal regions, with manual or automated operating stations. Laboratory analysis are carried out to monitor the water and sediment along the Doce River.

This work covered three sampling points already used by the foundation itself, in order to determine the concentrations of metals in vertical profiles in depositional environments along the route taken by the tailings slurry after the collapse of the Fundão dam in 2015.

2.2. Sampling

The sediment cores were collected from three different lagoons in the state of Espírito Santo (Figure 1). The first point was collected in Nova lagoon, in an area used for recreation by the community, the second point was collected in the Areal lagoon and the third point was collected in the Areão lagoon. The three lagoons are located in the municipality of Linhares, state of Espírito Santo.

Figure 1: Geographical distribuition of the dam location and the points sampled in the state of Espírito Santo

Source : Google Earth.

The sampling campaign was carried out in April 2023. The cores were sampled and their data was tabulated, including the geographical coordinates of the points and the depths of the water column at each point (Table 1).

Table 1 : Geographic coordinates of the sampling points of the sediments core samples and water column depth

SAMPLING POINT	LONGITUDE	LATITUDE	WATER DEPTH (m)
Nova	40°09'18.83" W	19°24'59.28" S	5.0
Areal	39°50'31.57" W	19°34'29.61" S	2.8
Areão	39°49'39.64" W	19°35'08.00" S	3.1

It was used an Uwitec gravity sampler equipped with a transparent PVC tube 6 cm diameter and 120 cm long, supplied by the Austrian company Uwitec. The lengths of the sediment cores collected varied between 32 and 46 cm and each core were sectioned every 2 cm. At the end, the Nova profile had 20 subsamples, the Areal profile had 23 subsamples and the Areão profile had 16 subsamples.

The samples were then sent to the Radiation Protection Division (DIRAD) at the Institute of Radiation Protection and Dosimetry (IRD/CNEN).

2.3. Particle size analysis

Granulometry was carried out by the Renova Foundation using the ISO 13320:2020 method. The largest particles were sieved and the fractions below the last sieve in the Tyler series were measured by laser diffraction.

The grain size was separated only among silt, clay and sand.

2.4. Sample dissolution and metal determination

The methodology used was adapted from EPA 3050B (1996) for sediment decomposition [10]. This method is not total digestion for most samples. It is a strong acid digestion, which will dissolve almost all the elements that could become environmentally available.

After preparing the samples, 1 g of dry sediment was weighed into Teflon containers and then 10 ml of 65% HNO_3 (Merck) were added and left to stand until the following day.

The samples were then heated in a sand bath for 5 hours at 90 °C. After this process, the supernatant was placed in a 50 ml falcon tube. The precipitate (residual sediment) was washed with 7.5 ml of ultrapure water, homogenized and centrifuged for 5 minutes at 2,500 rpm. At the end of this stage, the supernatant was added to the previously separated extract and topped up with ultrapure water to a volume of 30 ml for subsequent quantification of the metals using ICP-OES (inductively coupled plasma optical emission spectrometer).

The preparation of the samples and the instrumental determinations were accompanied by blank solutions containing all the reagents used in the preparation of these samples, and by the certified reference material Buffalo River Sediment (NIST SRM 2704) to verify the methodology used and to guarantee the quality of the results obtained.

A spectrometer (Optima 7300 DV, Perkin Elmer, USA), of Labspectro located in PUC-Rio, was used to determine metal concentrations in accordance with the EPA-6010 method. The elements determined were zinc, lead, nickel, manganese, iron, copper, chromium, barium, arsenic and aluminum.

The detection limits (DL) for the metals were calculated using equation 1 and are shown in table 2. In equation (1) below, *s* is the standard deviation of the blank and *a* is the angular coefficient of the analytical curve [10].

$$DL = (3 \: x \: s)/a \qquad (1)$$

Table 2 : Method detection limits

Elements	DL (mg kg^{-1})
Al	3.000
As	6.000
Ba	0.009
Cr	0.030
Cu	0.030

Elements	DL (mg kg⁻¹)
Fe	0.150
Mn	0.003
Ni	0.090
Pb	0.240
Zn	0.030

3. RESULTS AND DISCUSSIONS

3.1. Particle size analysis

The results of the granulometric analysis were made available by the Renova Foundation, showing values at intervals of every two cm up to 10 cm and every ten cm thereafter.

The profiles of the variation in granulometry of the Nova, Areal e Areão samples with depth are shown in figures 2, 3 and 4.

Figure 2: Particle size profile vs. depth at Nova. The yellow and green colors represent the silt and clay fractions of the sediments, respectively

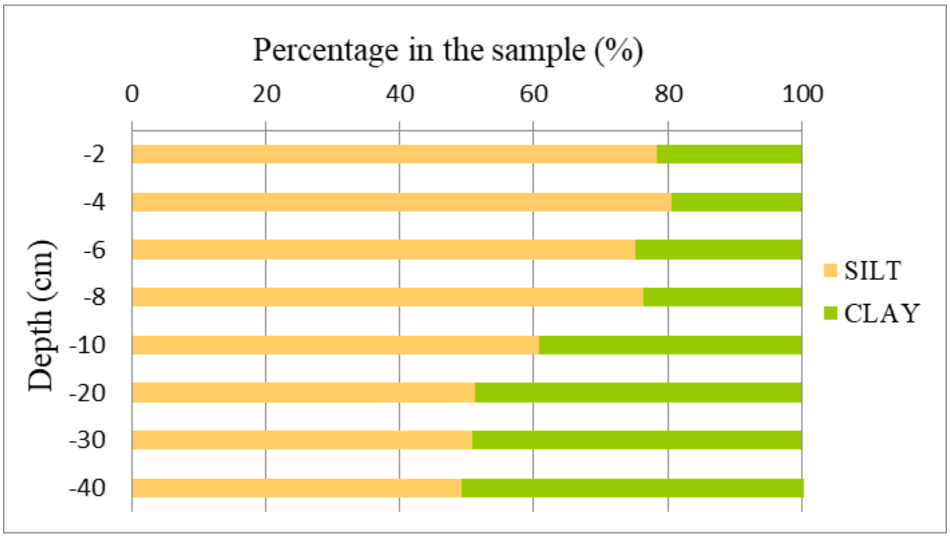


Figure 3: Particle size profile vs. depth at Areal. The yellow and green colors represent the silt and clay fractions of the sediments, respectively

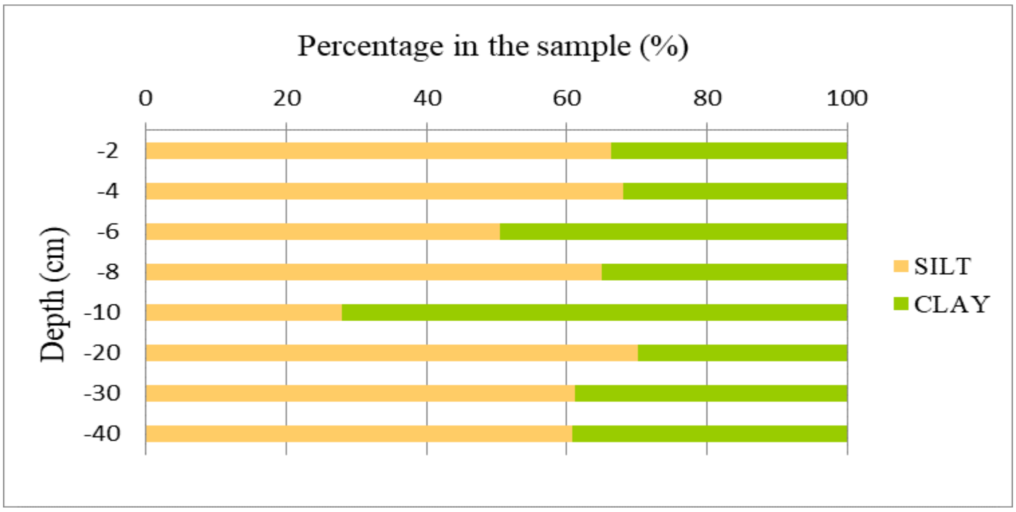
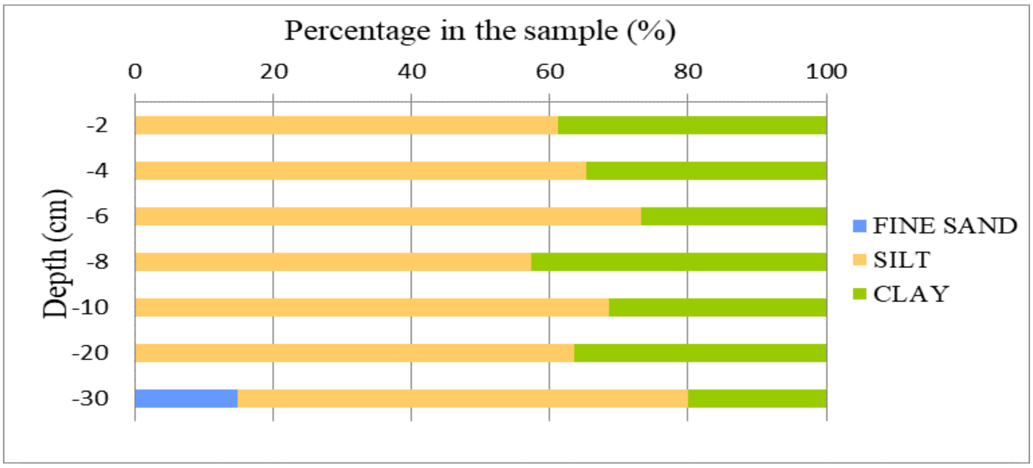


Figure 4: Particle size profile vs. depth at Areão. The yellow, green and blue colors represent the silt, clay and fine sand fractions of the sediments, respectively



Although all the samples can be classified as silt-clay, the presence of sand is only noticeable in the Areão profile. In general, metals are associated with the fine fractions of sediments [10].

3.2. Determination of metals

Tables 3, 4 and 5 shows the descriptive statistics by position (mean and median) and amplitude (minimum and maximum values, absolute and standard deviation), in mg kg^{-1}, for the three sediment cores.

Table 3 : Descriptive statistics of the results of metals determination in the Nova profile (values in mg kg^{-1})

Elements	Mean	Median	SD	Minimum	Maximum
Al	16,973	15,228	7,091	7,839	33,600
As	8	9	1	7	9
Ba	274	279	36.8	210	322
Cr	90.8	86.5	22.9	53	140
Cu	32.8	33	8.8	18	50
Fe	33,948	33,090	7,756	21,459	49,050
Mn	1,441	1,179	647	813	3,120
Ni	27.4	27	7.8	15	44
Pb	40	44	7.6	25	51
Zn	100	100	23	62	152

Table 4 : Descriptive statistics of the results of metals determination in the Areal profile (values in mg kg^{-1})

Elements	Mean	Median	SD	Minimum	Maximum
Al	8,292	7,653	4,042	2,566	17,136
As	26	16	17	8	59
Ba	53.9	52.5	18.5	22	93
Cr	98.5	102	42.1	23	168
Cu	11	12	2	4	16
Fe	125,232	118,815	57,023	35,280	235,260
Mn	532	525	216	169	952
Ni	4	3	2	1	12
Pb	21.5	21.5	14.8	11	32
Zn	39.1	38.5	12.6	21	65

Table 5 : Descriptive statistics of the results of metals determination in the Areão profile (values in mg kg^{-1})

Elements	Mean	Median	SD	Minimum	Maximum
Al	15,818	15,195	7,917	1,626	30,270
As	9	8	1	8	10
Ba	248	299	104	35	329
Cr	81	89.5	28	15	111

Elements	Mean	Median	SD	Minimum	Maximum
Cu	30.3	32	8.44	10	39
Fe	35,237	36,345	11,593	5,001	46,020
Mn	1,924	1,515	1,188	281	4,590
Ni	24.3	25	6.2	13	34
Pb	34.4	39	10.5	11	43
Zn	81	91.5	28.4	15	107

Considering the metals iron, aluminum and arsenic, all related to mining activities, it was possible to observe that iron concentrations ranged from 21,459 to 49,050 mg kg^{-1} in the Nova profile, from 35,280 to 235,260 mg kg^{-1} in the Areal profile and in the Areão profile, the iron concentrations ranged from 5,001 to 46,020 mg kg^{-1}. While the Areão profile had the lowest concentration of iron, the Areal profile had the highest concentration of this element.

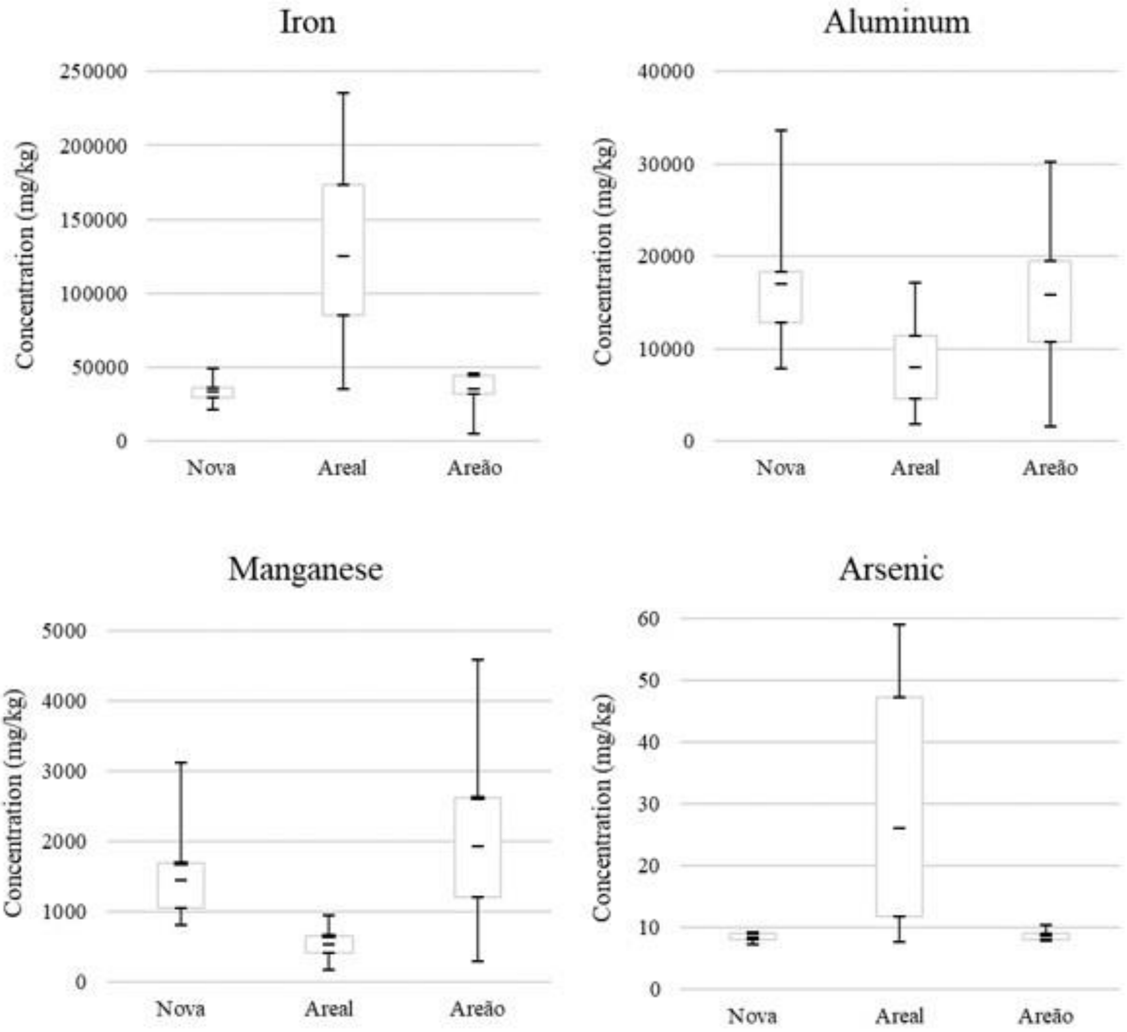
Aluminum concentrations ranged from 7,839 to 33,600 mg kg^{-1}, from 2,566 to 17,136 mg kg^{-1} and from 1,626 to 30,270 mg kg^{-1} at the points Nova, Areal and Areão, respectively. The Areão profile showed the lowest and highest concentration of this metal compared to the other points. The highest concentrations of arsenic were 9.1 mg kg^{-1}, 52 mg kg^{-1} and 10 mg kg^{-1} in the Nova, Areal and Areão profiles, respectively. The Areal profile had a concentration five times higher than the other profiles.

It was observed that the manganese concentration ranges were from 813 to 3,120 mg kg^{-1} in the Nova profile, from 169 to 952 mg kg^{-1} in the Areal profile and from 281 to 4,590 mg kg^{-1} in the Areão profile. Comparing the three profiles, Areal had the lowest concentration and Areão had the highest.

This characteristic is also observed for Cr. The three cores had very close means and medians. The element Zn showed very similar descriptive statistics for the Nova and Areão samples.

For a better view, figure 5 shows the distribution of the elements Fe, Al, Mn and As in the three profiles. The graphs show that Areal was the lagoon most affected by the tailings from the Fundão dam.

Figure 5: Boxplot comparative: concentration vs. the three profiles



The following tables (6, 7 and 8) show the correlation matrices (Pearson) of the elements profile by profile. Correlation analysis is useful for identifying the main relationships between the variables studied.

Table 6 : Correlation matriz for the metals in the Nova profile

	Fe	**Al**	**As**	**Mn**	**Ba**	**Cu**	**Pb**	**Zn**	**Ni**	**Cr**
Fe	-									
Al	**0.972**	-								
As	**0.685**	**0.798**	-							
Mn	0.453	0.353	**0.124**	-						
Ba	0.675	0.657	**0.402**	0.410	-					
Cu	0.875	0.865	**0.609**	0.627	**0.858**	-				
Pb	0.738	0.713	**0.442**	0.624	**0.868**	0.948	-			
Zn	0.662	0.661	**0.419**	0.264	**0.822**	0.770	0.754	-		
Ni	0.896	0.893	**0.631**	0.549	**0.872**	0.989	0.912	0.797	-	
Cr	0.965	0.956	**0.680**	0.485	**0.798**	0.951	0.837	0.745	0.974	-

Table 7 : Correlation matriz for the metals in the Areal profile

	Fe	**Al**	**As**	**Mn**	**Ba**	**Cu**	**Pb**	**Zn**	**Ni**	**Cr**
Fe	-									
Al	0.982	-								
As	**0.821**	**0.872**	-							
Mn	0.737	0.633	0.411	-						
Ba	0.687	0.600	0.280	**0.917**	-					
Cu	0.906	0.882	0.637	0.702	0.736	-				
Pb	**0.215**	**0.105**	- 0.067	**0.585**	**0.579**	**0.249**	-			
Zn	0.791	0.718	0.484	**0.944**	0.927	0.718	0.583	-		
Ni	**0.196**	**0.170**	0.123	**0.286**	**0.333**	**0.131**	**0.580**	**0.377**	-	
Cr	0.923	0.942	0.781	0.480	0.478	0.910	- 0.002	0.533	0.079	-

Table 8 : Correlation matriz for the metals in the Areão profile

	Fe	Al	As	Mn	Ba	Cu	Pb	Zn	Ni	Cr
Fe	-									
Al	**0.803**	-								
As	**0.489**	**0.536**	-							
Mn	0.506	0.169	**0.132**	-						
Ba	0.841	0.766	**0.347**	0.508	-					
Cu	0.862	0.900	**0.444**	0.353	**0.948**	-				
Pb	0.873	0.788	**0.403**	0.537	**0.984**	0.963	-			
Zn	0.907	0.864	**0.416**	0.381	**0.963**	0.986	0.972	-		
Ni	0.912	0.935	**0.508**	0.306	**0.876**	0.959	0.903	0.962	-	
Cr	0.939	0.927	**0.526**	0.339	**0.900**	0.970	0.927	0.975	0.982	-

It is observed a similar trend in the Areão and Nova profiles with a high correlation between the trace elements like Ba, Cr, Cu, Ni, Pb and Zn and also between the elements and Al and Fe, which is an indicative to their relationship to the silt-clay fraction. On the other hand, As presented a weaker correlation with these trace elements and, also, a weaker correlation to Al and Fe. A different behaviour is verified in the Areal profile where As presented a stronger correlation to Al and Fe, may be due to the influence of the mine tailing. Also related to the Areal profile, Pb and Ni did not present a correlation with the others trace metals and also not to Al and Fe. Manganese has a trend different from the other elements and is poorly correlated with all the determined elements in Areão and Nova profiles but presented higher correlation coefficients in the Areal profile, in particular, with Ba and Zn.

Table 9 shows a comparation between the results obtained in the present work and the results obtained by other authors for sediments affected by the Fundão dam tailings. It can be observed that the Areal lagoon was much more affected by the tailings than the Areão and Nova lagoons and presented Fe concentration similar to other affected areas. Arsenic concentration seems also to be affected by the Fundão tailings. On the other hand, the tailings seem to have a contrary effect on elements such as Al, Ba, Cu, Mn, Ni, Pb and Zn, lowering the concentration and Cr seems to be not affected by it.

Table 9 : Comparison of the average concentrations of the elements obtained in this work versus the literature (values in mg kg^{-1})

Elements	Nova	Areal	Areão	(3)	(4)	(7)	(9)
Al	16,973	8,292	15,818	-	-	-	5,546
As	8	26	9	164	301.9	-	11.3
Ba	274	53.9	248	-	-	22.2	148.5
Cr	90.8	98.5	81	-	214.2	79	32.6
Cu	32.8	11	30.3	-	47	4.8	8.4
Fe	33,948	125,232	35,237	-	-	128,000	216,780
Mn	1,441	532	1,924	2,298	-	600	1,733
Ni	27.4	4	24.3	-	64.8	9.3	11.7
Pb	40	21.5	34.4	-	58.6	-	8.1
Zn	100	39.1	81	-	78.4	17.3	17.7

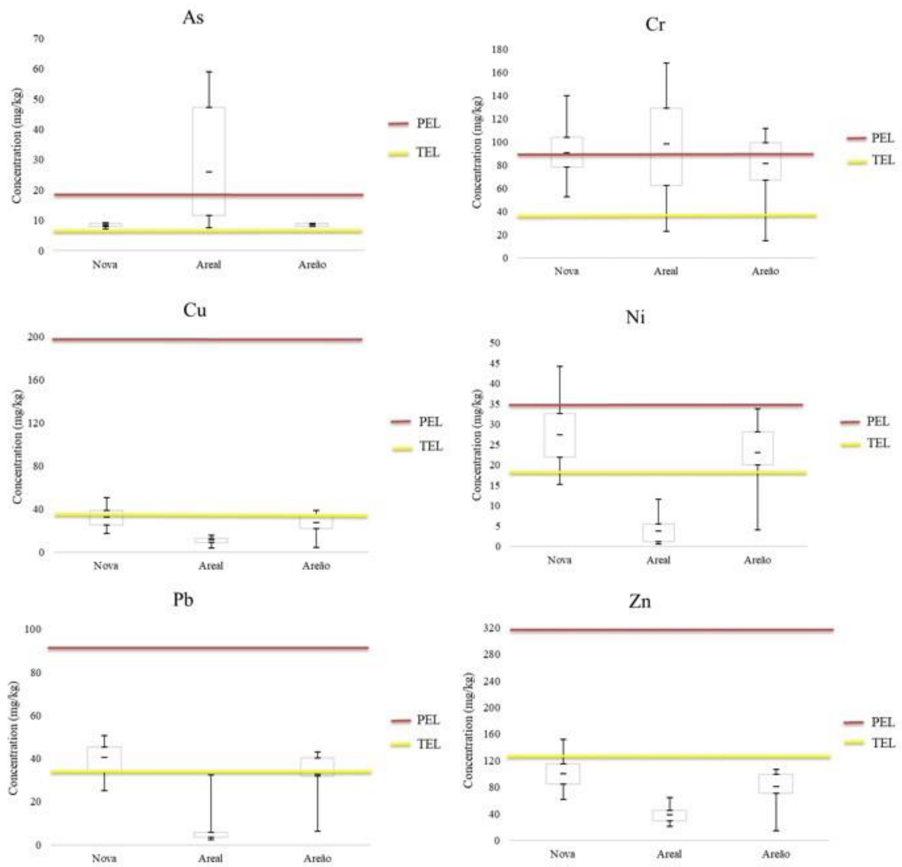
3.3. Sediment quality analysis

As there is still no specific criterion in legislation for classifying the quality of sediments in relation to the concentration of metals in Brazil, the National Environment Council (through CONAMA Resolution nº. 454 (2012)) uses the values provided by the *Canadian Council of Ministers of the Environment* [11]. This Canadian protocol establishes two values for the elements As, Pb, Cr, Cu, Ni and Zn for assessing sediment quality, based on specific concentration values: TEL ("*threshold effect level*" means that concentrations below this value are rarely associated with adverse biological effects) and PEL ("*probable effect level*" means that concentrations above this value are associated with adverse biological effects) [12]. Table 10 shows the established PEL and TEL limits for the six elements mentioned above, and the medians and maximum values of the elements analyzed in this present work. For a better view, figure 6 shows the results obtained for the concentration profiles of the elements in relation to the TEL and PEL values in the three cores.

Table 10 : Concentration values for freshwater sediment quality elements established by the *Canadian Council of Ministers of the Environment* (CCME, 1999), medians and maximum values in the three profiles (values in mg kg^{-1})

Elements	TEL	PEL	Nova		Areal		Areão	
			Median	Maximum	Median	Maximum	Median	Maximum
Al	-	-	15,228	33,600	7,653	17,136	15,195	30,270
As	5.9	17	9	9	16	59	8	10
Ba	-	-	279	322	52.5	93	299	329
Cr	37.3	90	86.5	140	102	168	89.5	111
Cu	35.7	197	33	50	12	16	32	39
Fe	-	-	33,090	49,050	118,815	235,260	36,345	46,020
Mn	-	-	1,179	3,120	525	952	1,515	4,590
Ni	18	35.9	27	44	3	12	25	34
Pb	35	91.3	44	51	21.5	32	39	43
Zn	123	315	100	152	38.5	65	91.5	107

Figure 6: As, Cr, Cu, Ni, Pb and Zn concentration profiles vs. depth in the Nova, Areal and Areão samples. The yellow and red lines indicate, respectively, the TEL and PEL values for each element analyzed



The ranges of the values obtained in this work for the elements As, Cr, Cu, Ni, Pb and Zn at the Nova point were compared with the TEL and PEL values, in accordance with the guidelines of the *Canadian Council* [12]. Of the elements studied, the concentrations of Cu, Pb and Zn were below the TEL and PEL values, so no likely deleterious biological effects are expected. Chromium, on the other hand, showed concentrations above the TEL and PEL values, while Ni showed concentrations above the PEL, indicating that adverse effects may occasionally occur. These values may indicate a degradation of the lake environment due to various impacts, one of which may be the presence of tailings after the collapse of the Fundão dam.

Of the elements studied at the Areal point, Cu, Ni, Pb and Zn found concentrations below the PEL and TEL values, so no likely deleterious biological effects are expected. On the other hand, As and Cr showed concentrations above the PEL value, indicating that it is possible that the local biota is being impacted by these two metals.

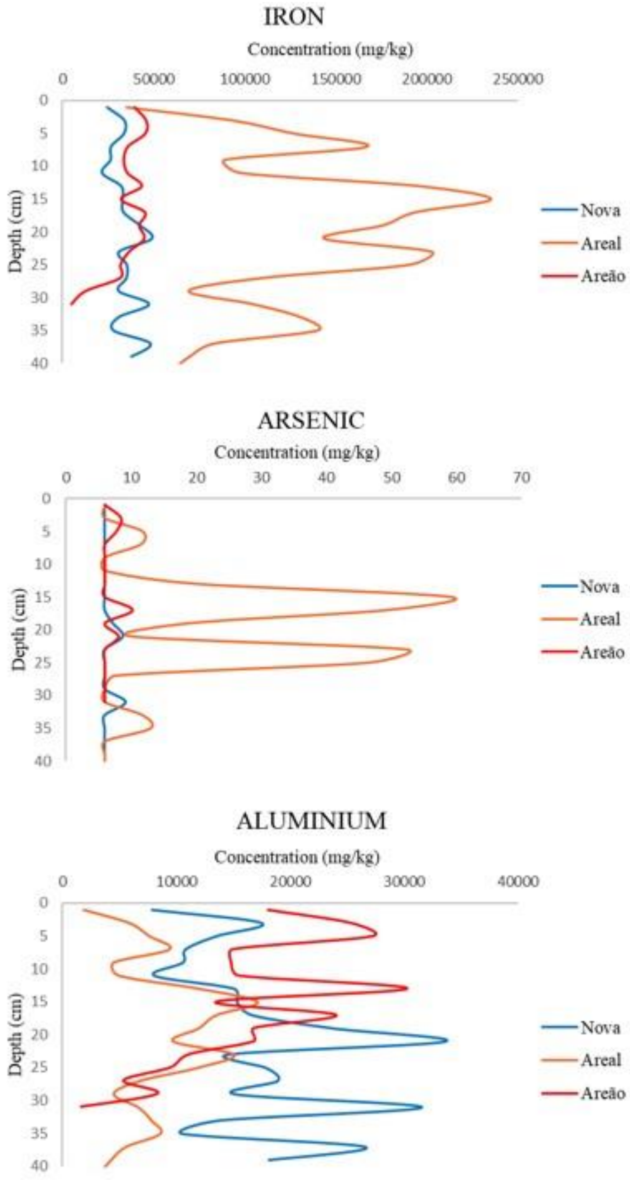
In the Areão profile, the concentrations of Cu, Ni, Pb and Zn were below the PEL and TEL values, so no likely deleterious biological effects are expected. As at the Areal point, the metal Cr showed concentrations higher than the PEL value and lower than the TEL value, and may be causing some adverse effect on the flora and fauna of the two lagoons.

3.4. Profile analysis

The effect of the Fundão tailings on the As and Fe concentrations can clearly be observed on the depth profile presented in figure 7, and enhance the fact that the Areal lagoon was much more affected by it than the other two others. The observed As and Fe peaks, in the Areal lagoon, may be related to flowding events that carry contaminated sediments into the Areal lagoon. Aluminum presents a quite different profile relative to Fe and seems to corroborate the idea that the taylings had a contrary effect on its concentration lowering instead of increasing.

The results obtained for the concentration profiles of the three elements characteristic of the iron ore analyzed in this work, at different depths associated with the three cores, are shown in figure 7.

Figure 7: Fe, As and Al concentration profiles vs. depth in the Nova, Areal and Areão cores



Although the three lagoons received tailings sludge from the dam collapse, it can be seen that the behavior of the elements studied was different in the three profiles.

In the first graph, it can be seen that iron concentrations were very high in the Areal profile and these values decreased over time, identified by depth. The Areão profile behaved in the same way up to a depth of 21 cm and, from then on, the concentration of iron decreased considerably due to the granulometry of this lagoon. Iron is characteristic of clay and as there was a change in granulometry, the concentration of this element changed. In the Nova profile, iron concentrations remained the same from the beginning to the end of the testimonial.

In the second graph, the Areal profile showed the highest concentrations of arsenic compared to the Nova and Areão profiles. One of the characteristics of iron ore is the coexistence of the metal arsenic and this can be justified from the arsenic graph, where the highest concentrations of this element in the Areal profile were at the same depths as the highest concentrations of iron in this profile.

The third graph shows that the aluminum concentrations in the three profiles were irregular. The Nova profile showed higher concentrations of aluminum from depth 21 onwards, while the Areal profile showed the lowest concentrations of this element. The Areão profile showed high concentrations of aluminum in the initial layers and a significant decrease from the 21 cm depth onwards. Both iron and aluminum are characteristic of clay. The change in the granulometry of the sediment in this lagoon altered the concentration of both elements, due to the fact that they have a larger surface area with more binding sites, thus increasing the transport of metals. Remember that the clay and silt fractions are known to promote greater adsorption of metals on particles [10].

4. CONCLUSIONS

This study determined the concentrations of metals in three lagoons (Nova, Areal and Areão) affected by mining tailings from the ruptured Fundão dam, in Mariana, municipality in the Brazilian state of Minas Gerais.

From the granulometric analysis, it was observed that the samples from the three lagoons can be classified as silty-clayey, although fine sand was found in the Areão profile.

The Areal profile was the most impacted by the dam tailings, as it had much higher iron concentrations than the Nova and Areão profiles. Still in relation to the concentrations of metals present in the sediments, it was possible to observe that Cu, Pb and Zn are between the TEL and PEL limit values in the three lagoons. However, the As values found in the Areal lagoon were higher than the PEL value, which may be related to the collapse of the Fundão dam; the Ni values were above the PEL only in the Nova lagoon and Cr in all three lagoons.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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