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Concentrations and enrichment of metals in sediment cores: geochemistry and correlations with geoaccumulation index

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ABSTRACT. The Mãe d'Água dam was built in 1962 to supply the Federal University of Rio Grande do Sul's water demanding. Thus, the paper aims to measure Nickel (Ni) and Zinc (Zn) concentrations in many depths of the dam's bottom, sampling cores of sediments silted in it. The samplings were carried out in June, 2014, and it was sampled four sediment cores in pre-defined points of the dam. The methodology for extraction of sediment cores was 'Piston Core'. Sediment particles smaller than 63 μm were separated and used for chemical analysis. EPA 3050 acid digestion methodology is used by the U.S. Environment Protection Agency and it was also used in this study. Analyses were carried out in duplicate and two USGS reference materials were used for quality control: SGR-1b and SCO-1. Zn and Ni concentrations were over than local background values and increasing concentrations of the deepest sendiments to the most recent layers as a result of urbanization activities. Geoaccumulation index was able to characterize decreasing of metal concentrations in depth.

Keywords: sediments, metals, trace elements, geoaccumulation index, Mãe d'Água dam.

Concentrações e enriquecimento de metais em núcleo de sedimentos: geoquímica e correlações com índice de geoacumulação

RESUMO. A barragem Mãe d'Água, foi construída em 1962, a fim de atender à demanda da Universidade Federal do Rio Grande do Sul. Assim, este trabalho tem como objetivo avaliar as concentrações de Zn e Ni em diferentes profundidades amostradas no núcleo de sedimentos produzidos nesta bacia hidrográfica. As coletas das amostras foram realizadas em junho de 2014, sendo amostrados quatro núcleos de sedimentos distribuídos no lago da barragem. Para a extração dos sedimentos de fundo foi utilizado um amostrador core *Piston Core*. Os sedimentos da fração menor que 63 μm foram destinados à análise química para verificação da presença e concentração dos elementos traço: Níquel (Ni) e Zinco (Zn). A metodologia de digestão ácida empregada é a EPA 3050, adotada pela *U.S. Environment Protection Agency*, sendo que as análises foram realizadas em duplicata e, para controle de qualidade, foram utilizados dois materiais de referência da USGS (*U.S. Geological Survey*): SGR-1b e SCO-1. Os resultados obtidos mostraram que as concentrações de Zn e Ni nas amostras apresentaram-se acima do valor de *background* local e com padrões de crescimento, conjuntamente, o índice geoacumulação evidencia a existência de enriquecimento dos sedimentos por estes elementos provavelmente devido às atividades urbanização locais.

Palavras-chave: sedimentos, metais, elementos-traço, índice de geoacumulação, barragem Mãe d´ Água.

Introduction

Urban growth on the banks or in the surrounding aquatic ecosystems causes degradation of water quality, resulting in damages to the aquatic community and public health. Allied to rapid urbanization, the misuse of the soil is currently one of the main causes of degradation of natural resources, causing damage not only due to the hydrological changes, but also because of the load of leached pollutants or pollutants carried along with the sediments, with sedimentation in bodies of water as a final destination.

The drag of sediments process is well-known, because the silting of reservoirs caused by leaching and transport of sediments can lead to a collapse and cause problems such as floods, which can lead to supply problems, or even result in several public health, social and economic problems.

Understanding the dynamics of sediment in a river basin is of a great importance, for example, to comprehend how the use and the land occupation can change some of its aspects as well as to understand urbanization and economic development and the impacts of climate change.

The sediments are found layered in the form of finely divided particles on the bottom of rivers, lakes, reservoirs, bays, estuaries, and oceans. Generally, those consist of various minerals grained, medium and coarse, including clay, silt and sand mixed with organic matter, and its composition (organic and mineral) depends on the local geology and biota, while the particle size or granulometry varies mainly with the conditions of its origin (Manahan, 2000).

According to Alloway (2010), the bottom sediments play an important role in the evaluation of the pollution sources since they reflect the current and/or historical quality of aquatic system, and may be useful to detect the presence of contaminants, especially those which do not remain soluble after its release into bodies of water.

In the urbanized environment, there is a greater likelihood of metals between aggregates pollutants sediment generated naturally and/or anthropogenic. The metals may be associated with contamination, but one must be cautious when analyzing the metal concentration in sediment to make decisions since they are both essential to plants and animals.

According to Alloway (2010), several studies of heavy metals in ecosystems indicated that large areas near urban complex, metallurgical and highways have high concentrations of those elements. Accumulated metals in the soil slowly deplete due to absorption processes by plants, leaching, or erosion (Kabata - Pendias & Pensias, 2001).

According to Baird (2002), trace elements have a high density compared to other materials and they are often characterized for causing risks to human health and they also aggregate particles of sediment or soil in its final deposition. Most of those trace elements tend to focus on more fine grained sediments, mainly in the silt and clay fractions (fraction less than 63 μm).

In the sediment accumulation process in aquatic environments, the ratio of anthropogenic effects on the natural occurrence of deposition of those sediments can be identified by determining the Geoaccumulation Index sediment which has great importance to comprehend the geochemical processes that have been occurring over the years.

The Geoaccumulation Index is a measure of the amount of pollution produced by metals in aquatic sediments. That index establishes the relationship between the levels of metals found in the studied area and a reference value equivalent to the world average for metals associated with clays (Soares, Mizusaki, Guerra, & Vignol, 2004).

This study aims to determine the concentrations of the metals Zinc and Nickel by sampling sediment profiles (Core Sampling), deposited over the years on Mãe d'Água dam and apply the methodology for calculating the Geoaccumulation Index, aiming to infer the correlation between enrichment by metals present in sediments and the intensity of the contamination, in accordance with I_{geo} classes, together with the reference values (Background).

Material and methods

The site chosen for the study is located in the Rio Grande do Sul state, in the metropolitan region of Porto Alegre, more precisely in Viamão city. Mãe d`Água dam is a tributary of the Arroio Flood, an important watercourse that extends to the city of Porto Alegre, cutting the East-West direction.

Mãe d`Água dam is related to four streams corresponding to an area of 353 ha and is located in the Valley Campus of the Federal University of Rio Grande do Sul. Figure 1 shows the size of the dam, featuring its location and the study area.

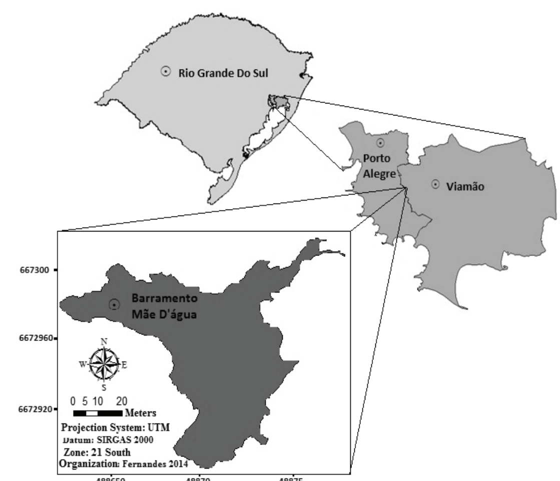

Figure 1. Location and representation of the study dam in the Metropolitan Area of Porto Alegre- RS.

Collection of urban sediments

The sample collection was carried out on 09/06/2014. The points of collection were planned, seeking to obtain a better spatial distribution in the lake and respecting the hydrodynamics of the site.

The material were sampled and the their data were tabulated such as the geographical coordinates points, water depth and the length of the sedimentary profile according to Table 1.

The technique used was the core sampler (Core Sampling) which is a set of detachable parts, consisting of the introduction of a rigid cylindrical tube of PVC with 75 mm in diameter, to sample the bottom sediment. At the time of collection, it was used a boat, which provided security to the development of the activity, ensuring the stability of the crew and withdrawal of the samples.

Table 1. Information of the collected sediment cores.

Sample(Core Sampling)	UTM coordinates (m) (Ellipsoid WGS-84) X	Y	Water line (m)	Core sampling length (m)
T1	488716.34	6672912.68	0.40	0.52
T4	488729.65	6672984.72	0.40	0.52
T6	488681.47	6672977.90	0.40	0.52
T8	488633.55	6672976.31	0.40	0.52

Determination of metals in sediments

They were sent to the Soil Laboratory of UFRGS School of Agronomy about 5 g of each sample to evaluate the total concentration of Zinc and Nickel metals. The digestions were performed in duplicate plus 'White 1' (white sample is carried out using the same reagents and procedures but without addition of the sample sediment) for quality control analyzes (Poleto & Gonçalves, 2006). Additionally, two reference materials were used, whose concentrations are known, purchased from USGS (U.S. Geological Survey): SGR-1b and SCO-1.

The acid digestion used was the EPA 3050 method, which is directed to analyzing the concentration of inorganic elements in sediments, sludges and soils. It was developed and adopted by U.S. Environment Protection Agency [EPA] (1996).

'Background' values

The background values used in this study were based on Poleto's work (2008). The author obtained a representative average concentration of natural concentrations of metals analyzed in the study area through three composite samples (each sample was the result of three other sub-samples of the topsoil). Samples were collected at the head region of the Mãe D'Água Lake on the top of Santana Morro in forest areas that had no anthropogenic changes. The values obtained for Zinc and Nickel metals are shown in Table 2.

Table 2. Base values of metal-trace analyzed.

Metal-trace	Values background (mg kg^{-1})
Zinc	47.4
Nickel	4.9

Quality Control of Metal Samples (Zn and Ni)

The determination of metal levels in two standard reference materials (MRP) of USGS soil laboratory was performed in order to ensure the quality control of the analyzes (Table 3). The results for the two reference materials analyzed Green River Shale (SGR -1b) and Cody Shale (OCS -1) were satisfactory with good representative data analysis, demonstrating that the methodology showed good development in the digestion of the metals and provided reliable results.

Table 3. Concentrations of Zn and Ni in the reference materials, Green River Shale (SGR-1b) and Cody Shale (SCo-1), of the USGS[a].

Element	Certified sample	Determined in this study by ICP-OES
	Mean ± SD	Mean
	Green River Shale (SGR-1b)	
Ni (mg kg^{-1})	29 ± 5	27
Zn (mg kg^{-1})	74 ± 9	77
	Cody Shale (SCo-1)	
Ni (mg kg^{-1})	27 ± 4	24
Zn (mg kg^{-1})	103 ± 8	110

[a]United States Geological Survey; SD = Standard Deviation.

Geoaccumulation Index – I_{geo}

For the evaluation of sediment contamination intensity, it can be used GeoAccumulation Index (I_{geo}) proposed by Müller (1977). That index establishes the relationship between the levels of metals found in the study area and a reference value equivalent to the world average for metals associated with clays. The value obtained allows classifying the levels of enrichment of metal with progressive contamination intensities.

The enrichment levels are classified into seven distinct classes, ranging from 0 to 6 and they are associated with increasing levels of contamination (Table 4). The highest value corresponds to an enrichment of approximately 100 times over when it is compared to the reference level.

Table 4. Classification I_{geo}.

Classification	Classes I_{geo}	IGEO
Extremely Polluted	6	> 5
Heavily to Extremely Polluted	5	> 4 to 5
Heavily Polluted	4	> 3 to 4
Moderately to Heavily Polluted	3	> 2 to 3
Moderately Polluted	2	> 1 to 2
Pollution-free to Moderately Polluted	1	> 0 to1
Virtually Pollution-free	0	< 0

Source: Müller, Grimmer, & Böhnke (1977).

The I_{geo} calculation is performed and is related to the concentrations measured in the silt fraction / clay (< 0,062 mm). Therefore, Ca is the concentration of the element in the silt fraction more clay sediment. This procedure allows the best representation of the lithological contributions of the study areas.

The Geoaccumulation Index is calculated by Equation 1:

$$I_{geo} = log_2 \; x \; \frac{Ca}{1.5 \; x \; Cp} \quad (1)$$

where:

Ca represents the concentration of the element in the clay fraction of the sediment (mg kg^{-1});

Cp represents the concentration of the element in the reference standard in mg kg- 1 (average shale or crust);

1.5 is a correction factor for possible variations in the benchmark caused by lithological differences.

Results and discussion

Concentrations in sediment cores (Zn and Ni)

The total levels of metals include all forms of elements in the sediment, in the form of ions bound to the crystal structure of primary and secondary minerals; adsorbed on the surface of secondary minerals such as clay, oxides and carbonates; complexed by solid state of the organic matter; or in the form of free ions on the water column (Alloway, 2010).

In Table 5 is showed the tabulated data regarding the changes of the concentration values of Zn and Ni, which was showed graphically by vertical profiles (Figures 2 and 3).

Table 5. Concentration of Zn and Ni (mg kg^{-1}) in the sediments accumulated in the Mãe d'Água dam.

Zn and Ni (mg kg^{-1})									
Zn (mg kg^{-1})					Ni (mg kg^{-1})				
Depth (cm)	Sampling				Depth (cm)	Sampling			
	T1	T4	T6	T8		T1	T4	T6	T8
2	597	103	300	417	2	17	5	13	14
10	317	157	231	418	10	13	7	13	14
18	198	243	214	287	18	11	11	13	11
26	184	251	293	307	26	11	11	13	13
34	174	203	230	225	34	12	9	11	13
42	162	215	202	230	42	8	11	10	12
50	149	205	193	219	50	9	12	11	12
58	118	225	176	186	58	8	12	9	10
66			154	179	66			8	11
74			180	175	74			9	11
82			153	171	82			10	11
90			176	133	90			10	9
98			109	133	98			8	9
106			124	113	106			10	9
114			124		114			9	
122			97		122			9	
130			39		130			3	
138			34		138			3	
146			25		146			2	
Average	237	200	161	228		11	10	9	11
Standard deviation	157	49	79	97		3	3	3	2
Minimum	118	103	25	113		8	5	2	9
Maximum	597	251	300	418		17	12	13	14

Total zinc concentrations in sediment cores

In urban areas, the dust particles arranged in the traffic lanes come into contact with the waste wear and vehicle emissions, which is one of the most important sources of trace metals (Sezgin, Ozcan, Demir, Nemlioglu, & Bayat, 2003), especially Zn^{2+}.

Figure 2 shows the vertical distribution of Zinc contents (in mg kg^{-1}) in the different samples (T1, T4, T6 and T8, respectively) from bottom sediment deposited in the Mãe D'Água Lake. All of the samples showed above local background values (47.4 mg kg^{-1}), and the human activities within the watershed explain the increase in the concentration of Zn. Except for the T4, that had reduced values, all profiles showed an enrichment of Zn along the sediment deposition process. According to Alloway (2010), Zn is a quite remarkable element to be present in relatively large amount when compared to other metals, such as Copper (Cu), Lead (Pb) and Nickel (Ni).

Table 5 shows the data tabulated regarding the variations of the values of Zn concentrations, which was presented graphically through the vertical profiles. Sample 1, in the first layer near the surface, appeared as the most polluted, with 597 mg kg^{-1}. On the other hand, the sample 6 had the lowest concentration in the extract in its base (25 mg kg^{-1}). On the average data analysis, T6 also appears as the point of deposition where the sediments exhibit lower association with the Zn metal trace and T8, the greater. The results presented in T1 show the concentration data on its surface which lead to an increased average due to those extreme values.

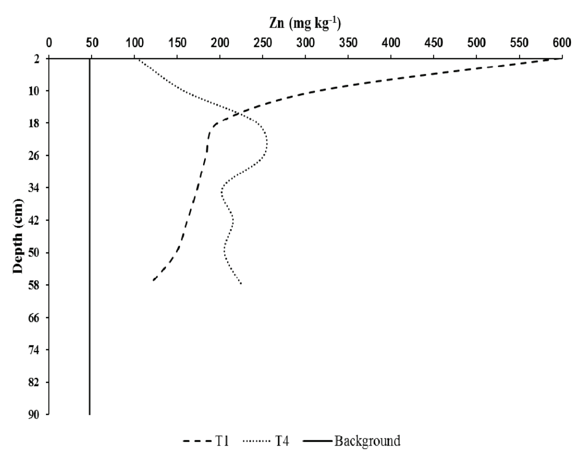

Figure 2. Distribution of zinc content in depth, in sediment cores in Mãe d'Água dam.

The T1 Zn concentration on the surface (2 cm) was 597 mg kg^{-1}. That point is located in the south portion of the lake and near the edge, and its concentration is equivalent to five times more than those determined on the basis of that profile. According to Alloway (2010), the surface enrichment of Zn in soil and sediments is mainly through atmospheric deposition of particles, fertilization and dump sewage sludge originated from human activity. The average values of Zn T1 were 237 mg kg^{-1}. The minimum value determined was 118 mg kg^{-1} Zn in the profile of the base, close to the rock, showing that factors such as erosion and input of metals by human activities are primarily responsible for the enrichment of that metal. According to Alloway (2010), Zinc is the 24th most abundant element on Earth and it is present in igneous rocks such as basalt, on average concentrations of 110 mg kg^{-1}.

T1 results are similar to those determined by Cardoso & Poleto (2013) in a very close geographical coordinate point. According to Cardoso & Poleto (2013), the initial concentration found at the base of the sample varied from 88 to 133 mg kg^{-1}, which shows the constant enrichment of Zinc in the sample space.

Sediment cores 4 (T4) had the lowest levels of Zn on the surface from the sampled profiles , ranging between 103 and 157 mg kg^{-1} in the depths of 0 and 10 cm, respectively. Smaller values for the T4 surface indicate that the enrichment process does not occur , and they are related to the granulometry which describes the large amount of course materials of that sample, since the determination of metal contents is performed only in its fine fraction (< 63 μm). Another factor that can influence the amounts of Zn in T4 is the high rate and water flow at that point of the dam.

Sample 6 had average levels of 161 mg kg^{-1} of Zn, with the maximum level determined on the surface (300 mg kg^{-1}). Because of the depth of that profile, possibly the lowest value of Zn determined near the rock (25 mg kg^{-1}) reflect the true bottom value of the dam also known as background. Cardoso & Poleto (2013) found similar results in the base of the profile named T2, located in another sample region on the same dam, but the similarity is in the depths of the samples, and both have the same enrichment characteristics, showing that collection point covers certainly a significant period of deposition history.

The sediments core 8 is located near the spillway. It has a uniform behavior of increasing Zn concentration profile from the base to the top or surface. Mean values at this point was 228 mg kg^{-1}, with a minimum of 113 and maximum of 418 mg kg^{-1}. The enrichment of Zn in sediments present in that region is evidenced by the steady accumulation of sediments with fine granulometry predominance (silt and clay). It is strongly associated with the concentration of the metal sediment which, due to the presence of spillway structure water, leads to the reduction of the flow stream velocity, thereby providing its sedimentation.

Rubio, Rae, & Rey (2001) describe in their study the occurrence of fluctuations in Zn sorption process and attaches it to a migration of Zinc for the higher sediments strata during the degradation of organic matter. Thus, as seen in the sediments cores T1, T6 and T8, there is a relationship with the metal dynamics between the water column and sediment particles and the growth of its concentration. The data obtained for Zinc concentrations, associated with carried sediments of the lake, allowed to infer the growth of pollution of the area of study, arising mainly from diffuse sources from urbanization, which have been intensified in the basin in recent decades.

Total nickel concentrations in sediment cores

The element Nickel (Ni) is naturally found in all types of rocks and is present throughout the pedosphere ranging from trace amounts up to relatively high concentrations when compared to other trace elements (Alloway, 2010).

The levels of Nickel (Ni) in the bottom sediment depth of Mãe D'Água dam are shown in Figure 3. All of them have above local background values (4.9 mg kg^{-1}). Such behavior is due to the urbanization of the area owing to the anthropogenic processes such as the construction of housing developments, industrialization and waste releases (liquid, solid and gaseous) which caused the gradual growth of concentrations from the bottom to the surface, which is the latest deposition. The exception occurred on the basis of sample 6, whose Ni concentrations were below the local reference value, and the same low result was obtained for Zn element.

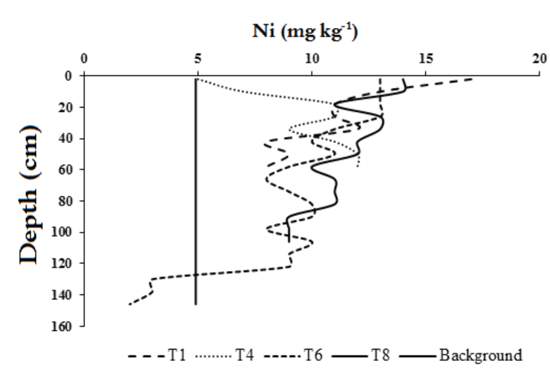

Figure 3. Distribution of nickel content (mg kg^{-1}) in depth, in sediment cores in Mãe d'Água dam.

The tabulated data on variations of Ni concentrations are shown in Table 5. The sample 1 in the first layer near the surface appeared as the most polluted, with 17 mg kg^{-1}, however the sample

4 had the lowest concentration in the extract in its base (12 mg kg^{-1}). When it comes to the average data analysis, T6 also appears as the point of deposition where the sediments have a lower association with metal trace Ni while the data obtained from other sediments cores such as T1, T4 and T8 presented the largest.

Comparing the distribution lines of Ni concentrations with Zn (Figure 2), it is clear that there is the same behavior in all sediments cores. Thus, just like with Zn, sediments cores T1, T6 and T8 have an enriched Ni level. Anthropogenic sources have resulted in a significant increase in Ni levels in soils and sediments (Utermann, Duwel, & Nagel, 2006). Much of the Ni sources occur through industrial emissions and particulate coming from the coal plants and oil combustion. The application of phosphate fertilizer and manure can also be an important cause of Ni in soils (Alloway, 2010).

The most recent sediments are those of the upper layers (represented by the sample of 2 cm), closest to the water column and with the highest levels of concentration. The sample 1, which is 2 cm from the most recent sediment surface, has the highest concentration of Ni (17 mg kg^{-1}). In T4, there is a decrease in concentration as the surface is approached. The sediment core T6 has a significant peak increase in the depth of 66 cm, from 8 to 13 mg kg^{-1} and remained stable until the surface. T8 showed a similar behavior in 122-130 cm depth to T6 testimony, reaching the maximum concentration of 14 mg kg^{-1}.

In general, analyses of the mean concentration of Ni in the four sediments cores were 11, 10, 9, and 11 mg kg^{-1} for T1, T4, T6 and T8, respectively. It is noticed that the concentration of that metal are low in the whole dam, ranging from 2 mg kg^{-1} in the base near the T6 source rock (this value is presented below background concentrations since it is under natural conditions with no effect anthropogenic) and 17 mg kg^{-1} on the surface of T1. Cardoso & Poleto (2013) found lower concentrations determined in the present study which can be explained by the occurrence of the freshest sedimentation in recent years, a result of the urbanization process. According Alloway (2010), the contents of Nickel are widely variable in pedosphere (0.2 to 450 mg kg^{-1}) with an overall average of 22 mg kg^{-1}. Utermann et al. (2006) in their research determined the Ni background concentrations ranging from 3 to 48 mg kg^{-1}, with lower values in soils formed of sandy materials and higher levels in soils derived from volcanic rocks.

Furthermore, based on the assessment of the background area value, there is an increased presence of that contaminant, arising from carried materials into the basin from human activities. The data collected here demonstrate the existence of interaction between the sediments of the area and the Nickel compounds, but it also exposes a possible weakness of that interaction, because of the oscillating patterns of association between metal sediment along the sedimentary column. The solubilization of Nickel compounds is clearly correlated to carcinogens, with a possible environmental hazard that needs to be evaluated.

When evaluating diffuse sources of pollution, it is essential to observe characteristics of residential and industrial urban areas because they provide a wide range of pollutants to the environment. Among them, stand out the trace metals, presented in the study (Zn and Ni). The lack of sewage treatment and the improper disposal of that waste provide a great deal of organic matter, key player in controlling the sorption and desorption processes of metals to the sediments.

Geoaccumulation rate

The Geoaccumulation Index (I_{geo}) was used as an analysis tool to compare the local enrichment of metals in the various sampling point.

The Figures 4 and 5 graphically represent the classification of Geoaccumulation for the Zinc and Nickel content varying according to the depth. It can be noticed a clear and objective way that the values are within the classificatory ranges established according to Müller (1981), which relates the concentration of metals with depth and its correlation with contamination and enrichment of sediments. The study occurred in the portions near the surface showing consistency between the established results.

From the results obtained, the only concern ratings was for the Zinc metal close to the surfaces, in the sediments cores 1, in 2 cm depth and from 2 to 10 cm depth to sediment core 8. In those depths, the I_{geo} classified them as moderately to highly pollute in T1 whose percentage was 2% of the total sampled points. Also, I_{geo} classified T8 as moderately polluted with percentage of 4 % of all samples. Thus, there is the likelihood of contamination caused by this metal at those points (T1 and T8 surface) than the others , which were classified as unpolluted to moderately polluted ($0 < I_{geo} < 1$).

The mean values of Zinc and Nickel found by Martínez & Poleto (2014) during a case study in urban sediments collected in Porto Alegre, showed values in ascending order of Zn (3.04) < Ni (3.14), ranking them as heavily polluted. Being sediments of urban origin, it is possible that those metals can be carried away to the nearest water body, causing enrichment of sediment and contamination of the lake ecosystem.

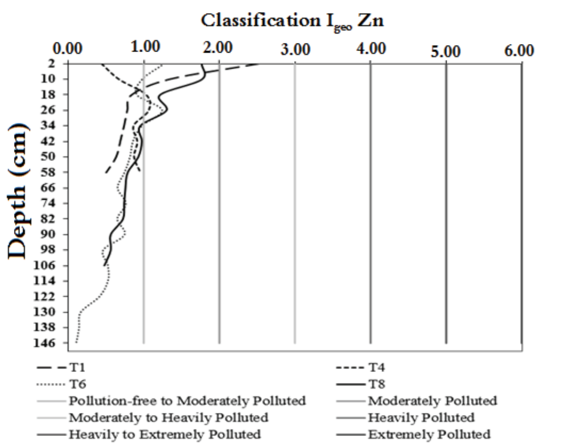

Figure 4. Classification of I_{geo} values for Zn in depth in sediment cores in Mãe d'Água dam.

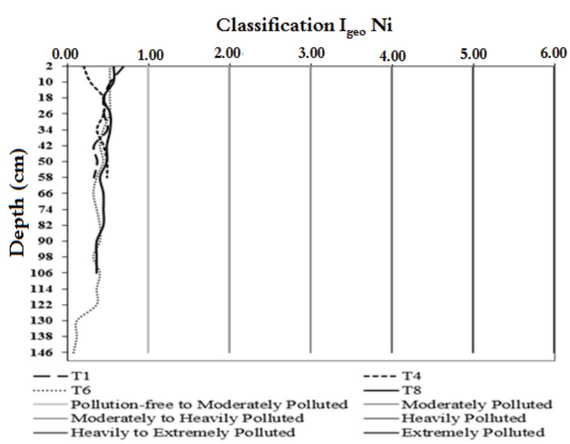

Figure 5. Classification of I_{geo} values for Ni in depth in sediment cores in Mãe d'Água dam.

Shi et al., (2010) found, in a metropolitan region of China, the following I_{geo} values represented in ascending order, Ni (0.37) < Zn (2.44). Comparing those values with those obtained by Martínez & Poleto (2014), it is clear that the production of contaminated sediments in Porto Alegre is alarming, because the levels are high and the transport of those sediments can lead to a possible contamination of water resources and its ecosystem due to the misuse of the environmental resources in urban centers.

Based on the results of Geoaccumulation Index of this study, it can be noted that the enrichment of metals in the surface layers can be justified by the high production and transportation of those contaminated sediments to water resources. The basin which is in the lake Mãe D'Água dam is being highly urbanized in recent decades, which ends up reflecting negatively on the water bodies presented there.

Conclusion

The steps involved in this research, as well the results, are presented satisfactory and characterize the importance of environmental research.

Zn and Ni metals showed high concentrations in recent fractions of sedimentation. Thus, on the surface of the sediments cores T1, T6 and T8 there are the highest concentrations of those metals, being evidenced the existence of the enrichment of sediments by those elements. Furthermore, all strata of sedimentary column analyzed showed concentrations above the background value. That behavior is due to the urbanization of the area, an anthropogenic process that leads to the gradual growth of concentrations until the surface which is the latest deposition.

On the other hand, the Geoaccumulation index shows that most of the metal concentrations in depth are not polluted. Although, it is eminent the enrichment on the surface, where the sorting through the I_{geo} ranged from moderately to heavily polluted, confirming that the anthropogenic changes that have occurred in recent decades in the basin may involve several environmental liabilities such as contamination of the lake ecosystem. This type of study should be accompanied by temporal and spatial variability analysis of metals concentrations in sediment samples, as was held, to allow suggest useful new alternatives in the management of sediments in order to reduce the risks that those contaminants can represent to the health of the population and the ecosystem in the river basin.

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