Soil contamination in a cemetery area: a case study in Nova Hartz City—RS, Brazil

Leandra Morandi[1] , Willian Fernando de Borba[1*] , Clóvis Orlando da Ros[1] , Vanderlei Rodrigues da Silva[1] , Marcos Toebe[1] , Lucindo Somavilla[1] , Pedro Daniel da Cunha Kemerich[2] and Dienifer Stahlhöfer[1]

Abstract

We conducted a study in a cemetery area covering 2608.53 m^2 in the municipality of Nova Hartz, Metropolitan Region of the State of Rio Grande do Sul. Soil samples were collected to determine the physicochemical parameters of the local soil at nine points within the study area and at three different depths (0 cm, 50 cm, and 120 cm). Granulometry and saturated hydraulic conductivity of the soil were assessed, and chemical analyses for Cadmium, Cobalt, Copper, and Chromium were performed using the Atomic Absorption Spectrometry technique.The results revealed that the soil exhibited average values of 78.34% sand, 8.25% silt, and 13.41% clay, classifying it as sandy loam. The saturated hydraulic conductivity was measured at $5.7 \times 10{-4}$ cm s^{-1} across the profile (from 0 to 120 cm). Chemical analyses identified concentrations exceeding the allowed limits for Cadmium (points 1, 4, 5, 6, 7, 8, and 9), Cobalt (points 2, 3, 4, 5, 7, and 8), and Copper (points 4, 5, 6, 7, and 8), with only two values for Chromium (both at point 7). Some points exhibited concentrations above the maximum allowed values at multiple depths. Evaluating vertical distribution, Cadmium did not show depth variations, suggesting a possible natural origin unrelated to cemetery activities. Conversely, Copper, Cobalt, and Chromium displayed increased concentrations with depth. In conclusion, significant changes in concentrations of Cadmium, Cobalt, and Copper were observed, especially between depths of 0 and 120 cm.

Keywords Leaching, Heavy metals, Necrochorume, Necropolis

Introduction

Cemeteries are territorial areas designated for the interment of human bodies. Initially situated away from commercial and residential areas in cities, the advances in urbanization have led to their proximity to these locations [1]. Amadi et al. [2] note that human corpses are considered waste, requiring proper disposal. Improper operation without prior assessment of the physical environment can result in cemeteries posing serious environmental problems.

During the decomposition of a human body, a liquid known as necrochorume is produced. According to Zychowski and Bryndal [3], approximately 0.4 to 0.6 L of necrochorume are generated per kilogram of body mass. This fluid contains pathogenic bacteria and viruses that can reach groundwater, causing contamination. Numerous studies have been conducted to assess the contaminant potential of cemetery areas, both nationally and internationally [4–9]. In these studies, authors consistently describe the contaminant potential of cemetery activities and the associated environmental risks.

Idehen [4] explains that necrochorume can be transported from graves to the soil through cracks and decomposition during the infiltration and water translocation process, posing a risk to groundwater and public health.

*Correspondence:
Willian Fernando de Borba
borbawf@gmail.com
[1] Federal University of Santa Maria, BR 386/158, km 40, Linha 7 de Setembro S/N, Interior, Frederico Westphalen, RS 98400-000, Brazil
[2] Federal University of Santa Maria, Avenida Roraima, 1000, Camobi, Santa Maria, RS 97105-150, Brazil

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This risk is heightened when the body is in direct contact with the soil. Franco et al. [10] assert that traditional burials release ions in the form of organic and heavy metals, bacteria, fungi, and viruses, which permeate the soil profile and reach groundwater. Additionally, Gwenzi [11] notes that the funeral industry may contribute to environmental contamination, particularly through toxic organic contaminants.

Furthermore, soil properties play a crucial role in protecting the underground environment, with saturated hydraulic conductivity indicating the ease of water movement through the soil profile [12]. For cemeteries, geology and hydrogeology are crucial natural factors in safeguarding the underground environment. In this context, our study aims to analyze potential soil contamination in a cemetery area in the municipality of Nova Hartz, located in the metropolitan region of Porto Alegre—RS.

Methodology

Characterization of the study area

The study area is located in the city Nova Hartz (Fig. 1), Metropolitan Region of Porto Alegre, in the State of Rio Grande do Sul (RS). The site covers an area of approximately 2,600 square meters (m^2), and its coordinates are 29º34′59.66 S and 50º 54′07.82″ O. The cemetery is located on Saudade street, downtown Nova Hartz—RS, Brazil. Figure 2 illustrates the aerial image of the cemetery that was the subject of this research.

The local soil is classified as a Haplic Chernosolo [13], and according to FEPAM [14] it presents very low resistance to environmental impacts. The city is inserted in the following geological formations [15]: Serra Geral Formation (Consisting of: flows of basalts, basalt andesites, rhyolites, and rhyolite, of tholeiitic affiliation), Botucatu Formation (Consisting of fine to coarse sandstone, rounded grains, and with high sphericity) and Colluvial-Alluvial Deposit (conglomerate. diamictite, conglomeratic sandstone, sandstone, and mudstone, oui massif with acana stratification). According to the authors, the Gramado Facies are present in the Serra Geral Formation (Fine to medium granular basaltic flows, gray melanocratic, vesicular horizons) and Caxias (effusions of intermediate to acidic composition, rhyodacite and rhyolite, mesocratic, micro
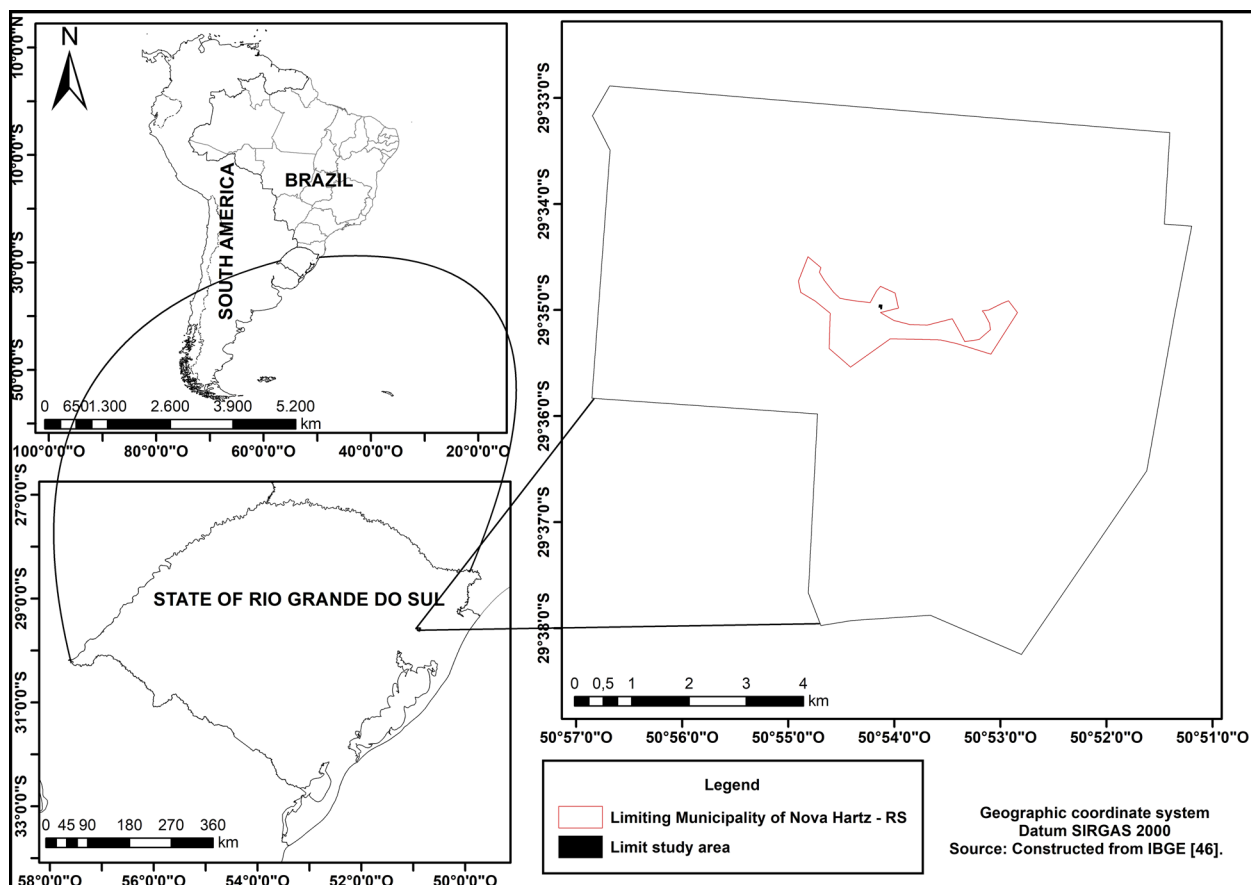

Fig. 1 Location of Nova Hartz/RS—Brazil. Source: Authors

Fig. 2 Aerial Image of the Cemetery Studied in This Research. Source: Authors based on Google Earth Pro (2024)

granular and vitrifies, common spherulitic texture (carijó type).

In terms of hydrogeology, Machado and Freitas [16] described that the municipality is situated within the following aquifer systems: Serra Geral Aquifer System II (aquifers with medium to low potential for groundwater in rocks with porosity through fractures); Serra Geral Aquifer System III (practically unproductive aquifers in rocks with intergranular porosity or fractures); and Botocatu Pirambóia Aquifer System (aquifers with medium to low potential for groundwater in rocks and sediments with intergranular porosity).

Soil sample collection

For the collection of soil samples for the determination of the chemical parameters, nine sampling points were selected within the study area seeking a homogeneous spatial distribution and respecting the existing constructions. At each sampling point, samples were collected at three depths: first layer (0 to 40 cm), second layer (40 to 80 cm), and third layer (80 to 120 cm). These intervals were adopted due to the burial depth of the bodies (Up to 120 cm). The points were allocated in a way to cover the entire area, in the most uniform way possible.

The samples were collected using a Dutch model auger, which was washed with distilled water after each collection to prevent alterations in the parameters and contamination of subsequent points. For the physical variables, granulometry, and Saturated Hydraulic Conductivity (ksat), samples were collected at a single point, with cylinders measuring 5 cm in height and 5 cm in diameter.

During the soil sample collection, coordinates of the sampling points were recorded, including latitude, longitude, and terrain elevation. Google Earth [17] was utilized for this purpose. Based on the terrain elevation values, it was observed that the terrain is flat, with a gradient of approximately 1 m across the cemetery area. Table 1 presents the coordinates and topographic elevation of each sampling point, while Fig. 3 illustrates the location of the sampling points in conjunction with the local geology.

Analysis methodology

For each collection point, the chemical elements were analyzed: Cadmium (Cd), Cobalt (Co), Copper (Cu) and Chromium (Cr), along with the analysis methodology

Table 1 Geographic coordinates and topographical coordinates

Sampling point	Latitude	Longitude	Ground level (m)
1	29°34′59.25″S	50°54′7.53″O	31.00
2	29°34′58.75″S	50°54′7.07″O	32.00
3	29°34′57.89″S	50°54′7.02″O	32.00
4	29°34′57.25″S	50°54′7.07″O	33.00
5	29°34′57.73″S	50°54′7.54″O	33.00
6	29°34′57.35″S	50°54′7.94″O	32.00
7	29°34′57.40″S	50°54′8.31″O	32.00
8	29°34′58.29″S	50°54′8.16″O	33.00
9	29°34′58.22″S	50°54′7.45″O	32.00

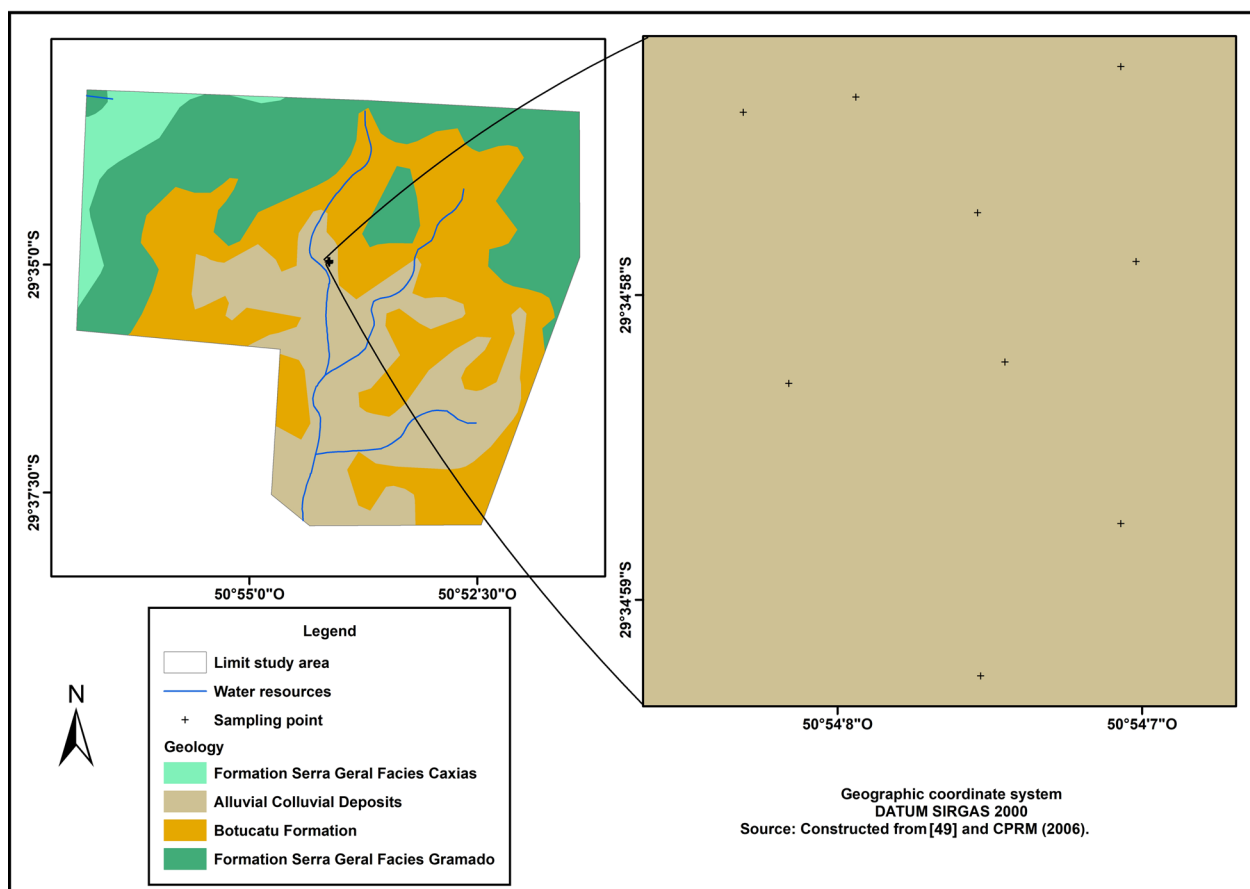Source: Authors based on Google Earth Pro (2024)

Fig. 3 Location of sampling points together with local geological formation and hidrology. Source: built from Fepam [49]

and the Limit of Detection (LOD) of the technique (Table 2). These elements were selected due to their relationship with funerary practices, in addition to being present in funeral accessories. The analyses were carried out in the Soil Analysis Laboratory of the Federal University of Santa Maria (UFSM), Frederico Westphalen campus, RS, through nitroperchloric extraction and quantification by Atomic Absorption Spectroscopy (AAS), as proposed by USEPA [18] with the SW 846—3050B method as described by Silva [19]. According to this method,

the sample was digested using nitric acid on a heating plate and then analyzed using Flame Atomic Absorption Spectrometry (F-AAS) with equipment from Shimadzu, model AA-6200.

For the determination of ksat, a constant load permeameter was used [21] and for the granulometry, the proposed by NBR 7.181 [22] was followed. After the analyses, the results were compared with the current legislation, according to Ordinance No. 85/2014 of the State Foundation for Environmental Protection Henrique

Table 2 Chemical elements, methodology used, detection and quantification limits

Chemical element	Methodology	*LOD (mg kg^{-1})	**QRV (mg kg^{-1})
Cadmium (Cd)	USEPA [18] modified Silva [19]	0.01	0.42
Cobalt (Co)		0.06	7.00
Copper (Cu)		0.04	11.00
Chromium (Cr)		0.12	21.00

Source: Self-authored (2021)

*Detection limit

**QRV: Quality Reference Value for the region of sandstone sedimentary rocks of the Plateau, the South Shield—Grandense and the Peripheral Depression [20]

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Luiz Roessler, for the region of sandstone sedimentary rocks of the Plateau, the South Shield—Grandense and the Peripheral Depression [20]. For granulometry, three deformed samples were collected, while for ksat form, undeformed samples were collected.

Contamination factor

The Contamination Factor (CF) is defined as the ratio of the Mean Concentration (MC) of a chemical element analyzed to the Background Concentration of the soil matrix (Cbackground), as expressed in Eq. 1 [23]. In this study, the FEPAM Quality Reference Value (QRV) was used as the reference background concentration (Cbackground) for comparison. The QRV for Region 4—Sandstone sedimentary rocks of the Plateau, the South Shield—Riograndense, and the Peripheral Depression was employed due to the absence of a nearby area for collecting a white point (an area without contamination or in its natural condition).

The Contamination Levels (CN) of the soil, determined by the respective Contamination Factor (CF), are presented in Table 3.

$$CF = \left(CM/C_{Background}\right) \tag{1}$$

Equation 1—Formula for determining the Contamination Factor. Source: Adapted from Poleto [24].

Where:

CF—Contamination factor

CM—Average concentration of the metal species quantified in the sample; and Cbackground—Background concentration of the matrix.

For the classification of scores, the range of values was used in accordance with Hakanson [25]; Zarah et al. [26]; Hortellani et al. [27] apud Silva et al. [23].

Statistical analysis of the analyzed variables

Descriptive statistics, encompassing measures of central tendency and variability, were computed for each variable (Cd, Co, Cu, and Cr) at each collection layer (0–40; 40–80; 80–120) based on the nine sampled points. To assess differences in variable values among the three layers, a t-test for dependent (related) samples

Table 3 Contamination Level according to the respective contamination factor

Contamination Factor	Contamination level
<1	Low contamination
1<CF<3	Moderately contaminated
3<CF<6	Significantly contaminated
CF>6	Highly contaminated

Source: Constructed from Poleto [24]

was conducted at a 5% probability of error. Additionally, confidence intervals for the population mean were constructed for each variable at a 95% confidence level. The statistical analyses were carried out using Microsoft Office Excel and BioEstat 5.0 software [28].

Results and discussion

Chemical and physical soil parameters

Regarding the analyzed parameters, the soil exhibited 78.30% sand, 8.30% silt, and 13.40% clay, classifying it as sandy loam [29]. The average saturated hydraulic conductivity (ksat) for the site was $5.7 \times 10{-4}$ cm s^{-1}. In a study conducted at the Parque Cachoeira Municipal Cemetery in Betim, MG, Marques [21] found a low ksat $(8.0 \times 10{-5}$ cm s$^{-1})$ in soil with 54.5% sand. This underscores the significance of grain size, especially the sand fraction, in influencing water and solute movement in the soil. In the Nova Hartz cemetery area, where the sand content was 78.34%, the necrochorume can move more rapidly, potentially mixing with groundwater and increasing the risk of waterborne diseases if used for public supply [30]. Additionally, according to information from the Groundwater Information System [31], the water level in the study area is at a depth of less than 7 m, indicating a higher susceptibility to groundwater contamination given the permeability of the medium and the depth of the groundwater.

According to Matos and Pacheco [32], soils of fine texture, more clayish and lower hydraulic conductivity establish ideal physicochemical conditions for the occurrence of the saponification phenomenon in corpses, unabling the actions of bacteria and delaying the decomposition of the corpse. In sandy soils, like the one in this area, Magalhães [33] affirms that the presence of oxygen might work as a sanitizer agent, forming biological filters and diminishing environment contamination. However, the high permeability of sandy soil allows contaminants to move more easily into the vadose zone.

In the statistical analysis of the variables (Table 4), the element Cd did not show significant differences among depths. The element Co exhibited higher concentrations at a depth of 50 cm. The elements Cu and Cr did not differ statistically, although numerically higher values were identified in deeper layers. Notably, the highest standard deviation was observed in the concentrations of elements Cu and Cr in the deepest layers (between 50 and 120 cm).

It is noteworthy that the high values of coefficient of variation (VC) are associated with concentration variations across points in the entire area (Table 4). This is primarily attributed to the topography of the location and variations in concentrations at the same depth. The highest VC occurred at depths 0 and 120 cm, except for the element Cr.

Table 4 Descriptive statistics for the four elements evaluated in three depths of soil collected in a cemetery

Element	Layers (cm)	Average[1] ± EP[2]	Median	Standard deviation	VC[3]	IC$_{95\%}$
Cd	0	0.52^a ± 0.19	0.19	0.57	109.97	0.08 ≤ μ ≤ 0.96
	50	0.36^a ± 0.08	0.33	0.24	67.96	0.17 ≤ μ ≤ 0.55
	120	0.41^a ± 0.12	0.35	0.35	85.79	0.14 ≤ μ ≤ 0.68
Co	0	2.08^b ± 0.7	1.26	2.10	100.70	0.47 ≤ μ ≤ 3.69
	50	8.18^a ± 1.37	7.26	4.10	50.18	5.02 ≤ μ ≤ 11.33
	120	5.23^{ab} ± 1.36	5.64	4.07	77.84	2.10 ≤ μ ≤ 8.36
Cu	0	10.63^a ± 2.34	8.03	7.01	65.95	5.24 ≤ μ ≤ 16.01
	50	12.82^a ± 2.12	10.72	6.36	49.57	7.94 ≤ μ ≤ 17.71
	120	14.61^a ± 2.7	15.56	8.11	55.52	8.37 ≤ μ ≤ 20.84
Cr	0	9.23^a ± 1.48	9.53	4.43	47.97	5.83 ≤ μ ≤ 12.64
	50	9.96^a ± 2.02	8.54	6.05	60.72	5.31 ≤ μ ≤ 14.61
	120	11.75^a ± 2.19	10.73	6.58	56.03	6.69 ≤ μ ≤ 16.81

Source: Self-authored (2020)

[1] Average followed by the same lower case letter in the column do not differ statistically by the t-test for dependent samples at 5% error probability

[2] Standard error

[3] Variation coefficient

Considering all collection points, each with three depths, the four parameters studied obtained some values above the QRV (Table 5). Ten concentrations above the allowed values were found for Cd (Points 1, 4, 5, 6, 7, 8 and 9); eight for Co (Points 2, 3, 4, 5, 7 and 8); ten for Cu (Points 4, 5, 6, 7 and 8) and two for Cr (Point 7).

The material present in the study area, due to the existing geological formation, is characterized by a permeable medium, as evidenced by granulometry (80% sand). This characteristic facilitates water percolation through the soil profile, carrying potential contaminants into the underground environment. In a similar context, Silva and Souza [34] analyzed the geochemistry of an alluvial deposit in the State of Paraíba, Brazil, where they described that materials in sedimentary environments may contain chemical elements exceeding those in the water column.

Moreover, the average precipitation in the Municipality of Nova Hartz, RS, is 1611 mm [35]. Combined with cemetery activities and the soil/geology type, these precipitation rates may enhance the percolation of constituents through the soil profile to the aquifer. Regarding the types of contaminants present, Necroleach can vary widely, depending on the treatment processes the individual received, for example. Carneiro [36] states that Necrochorume has a greater density than water, facilitating its infiltration through the soil to the aquifer. However, the author notes that sandy soils (like the one present in the study area) lack the capacity to retain water or contaminants in their interstices.

For the element Cd, most samples (16 readings) indicated low contamination in the layers between 0 and

120 cm, while 10 showed moderate contamination in the same layers, and only one was classified as considerable contamination at 0 cm. The low Contamination Levels (CNs) are observed at all three depths, suggesting that Cd content likely remains consistent with depth. It can be inferred that Cd levels in the study area range from low to considerable, indicating potential contamination of the area. Co concentrations in most samples (19 readings) indicated low contamination (At depths between 0 and 120 cm), eight showed moderate contamination (at depths of 50 and 120 cm), and no sample was classified as considerable contamination. The low NC are located at all three depths, while the moderate CN is found only at depths of 50 and 120 cm, demonstrating, in the study, that Co content probably increases with depth. Thus, it is possible to infer that the levels of Co, within the study area, present NC from low to moderate, indicating possible contamination of the area.

For the element Cu, most samples (18 readings) indicated low contamination at depths between 0 and 120 cm, while nine showed moderate contamination at the same depths, with no sample classified as having considerable contamination. Both low and moderate Contamination Levels (CNs) were observed at all three depths, suggesting that the Cu content likely remains relatively constant with depth. From these data, it can be inferred that Cu levels within the study area present CN from low to moderate, indicating potential contamination.

Concerning Cr, the majority of samples (25 readings) indicated low contamination at depths between 0 and 120 cm, with only two showing moderate contamination at depths of 50 and 120 cm. It's noteworthy that the two

Table 5 Elements concentrations at the points and depths analyzed in the cemetery area

Point	Depth[1]	Cd (mg kg^{-1})	CF[2]	Classf.	Co (mg kg^{-1})	CF	Classf.	Cu (mg kg^{-1})	CF	Classf.	Cr (mg kg^{-1})	CF	Classf.
P1	0	0.02	0.05	LC[3]	0.02	0.00	LC	4.26	0.39	LC	8.22	0.39	LC
	50	**0.58***	1.38	MC[5]	2.80	0.40	LC	10.72	0.97	LC	4.20	0.20	LC
	120	0.35	0.83	LC	0.02	0.00	LC	7.24	0.66	LC	2.42	0.12	LC
P2	0	0.19	0.45	LC	1.26	0.18	LC	9.41	0.86	LC	2.60	0.12	LC
	50	0.34	0.81	LC	4.35	0.62	LC	6.23	0.57	LC	3.71	0.18	LC
	120	0.01	0.02	LC	**7.46***	1.07	MC	5.04	0.46	LC	6.59	0.31	LC
P3	0	0.02	0.05	LC	1.15	0.16	LC	6.77	0.62	LC	9.96	0.47	LC
	50	0.02	0.05	LC	**7.26***	1.04	MC	7.21	0.66	LC	8.54	0.41	LC
	120	0.22	0.52	LC	6.09	0.87	LC	8.46	0.77	LC	10.73	0.51	LC
P4	0	0.01	0.02	LC	3.60	0.51	LC	8.03	0.73	LC	10.00	0.48	LC
	50	0.30	0.71	LC	**11.71***	1.67	MC	8.62	0.78	LC	6.89	0.33	LC
	120	**0.49***	1.17	MC	0.02	0.00	LC	**15.56***	1.41	MC	10.24	0.49	LC
P5	0	0.08	0.19	LC	5.20	0.74	LC	10.59	0.96	LC	9.53	0.45	LC
	50	**0.59***	1.40	MC	**13.04***	1.86	MC	10.58	0.96	LC	10.07	0.48	LC
	120	**0.87***	2.07	MC	5.64	0.81	LC	**16.96***	1.54	MC	15.10	0.72	LC
P6	0	**0.71***	1.69	MC	2.45	0.35	LC	7.81	0.71	LC	5.03	0.24	LC
	50	0.02	0.05	LC	5.14	0.73	LC	**16.03***	1.46	MC	8.65	0.41	LC
	120	0.54	1.29	MC	3.75	0.54	LC	**18.63***	1.69	MC	19.06	0.91	LC
P7	0	**1.10***	2.62	MC	0.02	0.00	LC	**15.39***	1.40	LC	13.03	0.62	LC
	50	**0.73***	1.74	MC	**11.50***	1.64	MC	**25.51***	2.32	MC	**22.62***	1.08	MC
	120	0.02	0.05	LC	**10.74***	1.53	MC	**31.13***	2.83	MC	**22.31***	1.06	MC
P8	0	**1.12***	2.67	MC	5.02	0.72	LC	**27.30***	2.48	MC	17.80	0.85	LC
	50	0.33	0.79	LC	**12.94***	1.85	MC	**19.62***	1.78	MC	16.61	0.79	LC
	120	0.19	0.45	LC	**10.90***	1.56	MC	**19.06***	1.73	MC	14.39	0.69	LC
P9	0	**1.42***	3.38	CC[4]	0.01	0.00	LC	6.08	0.55	LC	6.94	0.33	LC
	50	0.32	0.76	LC	4.84	0.69	LC	10.90	0.99	LC	8.34	0.40	LC
	120	**1.01***	2.40	MC	2.45	0.35	LC	9.39	0.85	LC	4.92	0.23	LC
QRV[6]		**0.42**			**7.00**			**11.00**			**21.00**		

[1] Depth

[2] Contamination factor

[3] Low contamination

[4] Considerable contamination

[5] Medium contamination

[6] Quality Reference Value for the region of sandstone sedimentary rocks of the Plateau, the South Shield—Grandense and the Peripheral Depression [20]

Source: Self-authored (2020)

*Highlighted values above the QRV, 90th percentile, for region 4 (Sandstone sedimentary rocks of the Plateau, the South Shield and the Peripheral Depression)

samples with moderate contamination occurred at P7, at depths of 50 and 120 cm. Low CNs were observed at all three depths, while moderate CNs were found only at depths of 50 and 120 cm, suggesting that Cr content is likely consistent with depth in the study. The data suggest that Cr levels within the study area present CN from low to moderate, indicating potential contamination, with most points showing low contamination, making it the element with the lowest contamination index at the site.

According to Neckel et al. [37], in a study conducted in three cemeteries (A, B and C) in the municipality of Carazinho—RS, the element Cu had an average concentration of 113.64 mg kg^{-1} reaching maximum values of 183.00 mg kg^{-1} in cemetery A, 144.00 mg kg^{-1} in cemetery B and 139.00 mg kg^{-1} in cemetery C. These concentrations are higher than those found in this study. As for the Cr element, the authors found average values of 26.93 mg kg^{-1}, which were higher than those found in this research. Baum [38], in Lages—SC, found that the average concentration obtained for Cr was 0.73 mg kg^{-1} and for Cd 0.07 mg kg^{-1}. Thus, when compared to the present study, the values were lower for Cr and similar for Cd. The author also describes that Cd presented characteristics for the possibility of leaching,

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considering that it obtained higher concentrations at lower topographic levels.

It is considered a phytotoxic element, because it is more toxic to plants than to animals [39]. Although Cu is found in the soil with a concentration between 2 and 100 mg kg^{-1}, when compared to the results presented in Table 4, and analyzing the 90th percentile QRV of Ordinance No. 85/2014, the values obtained were above the allowed.

Kemerich et al. [40, 41] in a study conducted in the city of Seberi—RS, found that Cu concentrations for surface samples ranged from 120 to 520 mg kg^{-1}, for 50 cm, the values were between 410 and 590 mg kg^{-1}, and for 100 cm, between 126 and 179 mg kg^{-1}. Therefore, all these concentrations were above the values found in this research, a fact that can be explained by the difference in soil in the study region. As for the Cr element, the authors verified that for the superficial samples (0 cm), the values varied from 65 to 125 mg kg^{-1}, for 50 cm, the values were between 65 and 125 mg kg^{-1}, and for 100 cm, between 126 and 174 mg kg^{-1}. Therefore, all these concentrations were above the values found in this research, a fact that can be explained by the difference in soil in the region under study.

Point P7 obtained the highest number of concentrations above the Quality Reference Value (QRV), primarily due to its location at a lower topographic elevation (32 m) compared to other collection points. An analysis of the land's topography reveals that the direction of both surface and subsurface flow tends toward P7, which may explain the elevated concentrations observed at this site. The elevation of the site and the depth of the graves directly impact the soil's contamination levels, as bodies are buried, leading to more intense contamination in their proximity.

Despite point P1 being situated at a lower elevation (31 m), only one sampling point had a value above the allowable limit, specifically for the element Cd at a depth of 50 cm. Table 6 presents additional research that investigated soils in cemetery areas.

According to Marinho [45], anthropogenic processes capable of causing pollution or groundwater contamination originate at the soil surface. The behavior of contaminants in the soil and subsoil is determined by geochemical, physical, and biological processes, including the decomposition of organic matter, bacterial activity, and bioaccumulation. This may explain why some points exhibit higher concentrations at the surface compared to other depths. Examples include P1 for Cr, P2 for Cu, P6 for Cd, P7 for Cd, P8 for Cd and Cr, and P9 for Cd.

Cu is one of the main metals present in the human body, participating in protein activities such as tyrosinase, cytochrome oxidase, and ceruloplasmin, requiring 2 to 5 mg of copper per day, according to Azevedo et al. [46]. Thus, the presence of this metal in cemetery soil can be explained by its vital function in the human body. Cr is a naturally occurring metal found in rocks, soil, dust, volcanic mists, water, animals, and plants, and its most abundant form is chromite, as stated by Ferreira [47].

The concentrations of metals such as Zn, Cu, Fe, Mn, Cr, Ag, and Al occur due to the release of materials used during the destruction of coffins, such as paints, varnishes, and trims, according to Campos [48]. Therefore, the use of coffins with easily decomposable wood and devoid of metal parts, paints, varnishes, and plastic materials is crucial to reduce the concentration of these metals.

Conclusion

The obtained results revealed alterations in the natural soil quality for the analyzed elements. Cadmium and Copper exhibited concentrations exceeding allowable levels at depths between 0 and 120 cm in ten samples. Cobalt, in turn, surpassed the established limit in eight samples, specifically at depths of 50 and 120 cm. Chromium showed elevated values at two sampling points, at depths of 50 and 120 cm. These findings suggest a potential modification of chemical element levels in accordance with the current legislation for the studied region. Statistically, Cadmium did not exhibit significant differences in depth, suggesting the possibility that this element may not be directly related to the observed activity.

Table 6 National and international research analyzing cemetery soils

Authors	Element (Concentration mg kg^{-1})			
	Cd	Co	Cu	Cr
Baun et al. [42]	0.06–0.07	Not analyzed	0.09–1.31	0.11–1.47
	0.06–0.07	Not analyzed	0.43–0.79	0.09–4.89
Itodo et al. [43]	0.167	Not analyzed	Not detected	0.032
Greinert and Kostecki [44]	0.14–0.64	Not analyzed	6.4–63.4	Not analyzed

Source: Authors

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Conversely, the other elements (Copper, Cobalt, and Chromium) demonstrated an increase in concentration with depth.

As per the study's assessment, the site poses a potential contamination risk, with certain sampling points exceeding the allowable limits set by legislation. However, with proper implementation and management, the pollution potential of the site can be controlled.

Based on the obtained results, it is recommended that further studies be conducted to assess contamination levels by other chemical elements. Additionally, the installation of piezometers for analyzing and monitoring underground water quality, determining hydraulic conductivity at deeper levels, and characterizing the site's granulometry—particularly identifying clay minerals and cation exchange capacity (CTC)—is essential for effective environmental control of the area.

Author contributions
LM—Preparation, editing and review. WFB—Guidance, review and editing. COR, VRS and MT—Review and editing. LS—Statistical analysis. PDCK and DS—Sample preparation and analysis.

Availability of data and materials
Not applicable.

Code availability
Not applicable.

Declarations

Competing interests
The authors declare that there is no competing interests.

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