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Technical Article

Contamination of groundwater by necro-leachate and the influence of the intervening factors in cemeteries of the municipality of Lages – Brazil

Contaminação das águas subterrâneas por necrochorume e a influência dos fatores intervenientes em cemitérios do município de Lages – Brasil

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ABSTRACT

Cemeteries are potential sources of groundwater contamination and, despite the several studies that evidence this sort of contamination, only a few consider how the aspects and characteristics of the unsaturated zone interfere in this process. This study evaluated the quality of groundwater in the areas of two cemeteries under the same precipitation regime, climate and burial practices, but with pedological differences. During one year, the physicochemical parameters potential hydrogen (pH), electrical conductivity, oxidation-reduction potential, dissolved oxygen, total dissolved solids, chemical oxygen demand, total phenols, total phosphorus and ammonia (NH_3), as well as the heavy metals cadmium (Cd), lead (Pb), copper (Cu), chromium (Cr), nickel ,(Ni) and zinc (Zn), were monitored in the groundwater from two cemeteries located in the urban area of the municipality of Lages, Brazil. Samplings were performed in monitoring wells inside the cemeteries and the local rainfall was registered. The quality of the groundwater from both cemeteries indicates contamination by necro-leachate constituents such as mineral salts, NH_3, total phenols, Cd, Cr and Ni, which, besides being harmful to the environment, pose a risk to public health. The precipitation, which had a direct effect on the height of the water level in the groundwater aquifer, increased the levels of contaminants, while the reduced values of cation-exchange capacity (CEC), considering that a large part of the soil is occupied by Al^{3+} ions, reduced the adsorption potential of the other metals.

Keywords: contaminants; heavy metals; unsaturated zone; water quality.

RESUMO

Os cemitérios são fontes potenciais de contaminação das águas subterrâneas e, apesar dos diversos estudos que evidenciam essa contaminação, poucos são os estudos que consideram como os aspectos e características da zona não saturada intervêm nesse processo. Este estudo avaliou a qualidade das águas subterrâneas nas áreas de dois cemitérios condicionados ao mesmo regime pluviométrico, clima e costumes de sepultamento, porém com diferenças pedológicas. Durante o período de um ano foram monitorados parâmetros físico-químicos: potencial hidrogeniônico (pH), condutividade elétrica (CE), potencial de oxidação/redução (ORP), oxigênio dissolvido (OD), sólidos totais dissolvidos (STD), demanda química de oxigênio (DQO), fenóis totais, fósforo total e amônia (NH_3) e metais pesados: cádmio (Cd), chumbo (Pb), cobre (Cu), cromo (Cr), níquel (Ni) e zinco (Zn), nas águas subterrâneas de dois cemitérios localizados na área urbana do município de Lages, Brasil. As amostragens foram realizadas em poços de monitoramento existentes nas áreas internas dos cemitérios e registrada a pluviometria local. A qualidade das águas subterrâneas de ambos os cemitérios estudados indica que há contaminação por componentes do necrochorume, como sais minerais, NH_3, fenóis totais, Cd, Cr e Ni que, além de serem prejudiciais ao meio ambiente, são um risco potencial à saúde pública. A precipitação, que teve efeito direto sobre a altura do nível da água do aquífero freático, elevou os níveis de contaminantes, enquanto os valores reduzidos de CTC, considerando que grande parte da mesma estar ocupada por íons de Al^{3+}, reduziram o potencial de adsorção dos outros metais.

Palavras-chave: contaminantes; metais pesados; zona não-saturada; qualidade da água.

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INTRODUCTION

The traditional burial activity generates necro-leachate, which poses a potential risk to the environment and public health when not controlled, and is able to cause negative impacts on soils and surface/groundwater. This compound is constituted by many components, which change according to the region, religion and customs of each person, the season of the burial, as well as other variables (BAUM, 2018). However, the potential risk that the environment is exposed to is conditioned by the local pedological, geological and hydrogeological characteristics, as well as by the effect of rainfall on groundwater (SILVA; MALAGUTTI FILHO, 2008; ÜÇISIK; RUSHBROOK, 1998).

In Brazil, the legal system that guides the environmental licensing of cemeteries is quite recent, and is composed of the National Environment Council (CONAMA) Resolutions nos. 335/2003, 368/2006 and 402/2008, valid only for cemeteries opened after 2003 (BRASIL, 2008a, 2006, 2003). Cemeteries which were already in operation before April 2003 must follow the suitability criteria established by state and municipal environmental agencies, that should have been formulated until December 2010 (BRASIL, 2008a); however, many state and municipal agencies do not have specific norms, making several cemeteries all over the country polluting sources (BAUM; BECEGATO, 2018).

Beyond the national scenario, the same problem is identified in several places around the world (NGUYEN; NGUYEN, 2018; TURAJO *et al.*, 2019b), despite the fact that many of them have rules for burials regarding environmental aspects (NCCEH, 2017). According to Cruz *et al.* (2017), the negligence of environmental matters by those responsible for the construction and management of cemeteries, before the establishment of regulatory standards for this service, is one of the main causes of environmental pollution caused by the lixiviate released intermittently during the process of decomposition.

The decomposition of bodies generates, mainly, mineral salts (JONKER; OLIVIER, 2012) and by-products such as carbon dioxide (CO_2), methane (CH_4), ammonium (NH_4^+), nitrate (NO_3^-), as well as biogenic amines such as cadaverine and putrescine (FIEDLER *et al.*, 2012; NECKEL *et al.*, 2017; ŻYCHOWSKI, 2012). The presence of pathogens such as bacteria and viruses is also verified (ŻYCHOWSKI; BRYNDAL, 2015). The decomposition of coffins and their adornments, the fabrics utilized to dress the body and form the coffin bed, generates materials of difficult degradation, such as chemical ligands (WILLIAMS *et al.*, 2009), polyvinyl chloride, creosote or insecticides, as well as varnishes and sealers (JONKER; OLIVIER, 2012). There are also substances introduced into the human body during life (FIEDLER *et al.*, 2012), such as pacemakers and dental amalgam, that have diverse compositions, as well as the substances utilized in the body's preparation for burial, such as phenol, formaldehyde, glycerol and ethyl alcohol (OLIVEIRA *et al.*, 2013; VAN ALLEMANN, OLIVIER; DIPPENAAR, 2018).

The contamination of groundwater by these components depends, mainly, on the soil characteristics and the height of the water table. The unsaturated soil zone works as a filter and an adsorbent (ÜÇISIK; RUSHBROOK, 1998), controlling the attenuation processes and the eventual release of chemicals and microorganisms. According to Aharoni *et al.* (2020), the hydrological characteristics and the geochemical properties of the unsaturated zone can alter the chemical composition of pollutants before they reach groundwater.

For the burial activity, clayish soils with high specific surface area and cation-exchange capacity (CEC) are the most suitable, by maximizing the retention of fluids and metals (ÜÇISIK; RUSHBROOK, 1998). Cutrim and Campos (2010) state that the contamination of aquifers by potentially polluting anthropic activities has become a recurrent issue since, when it comes to the management of water resources, aquifers are considered strategic reservoirs for mankind.

Several studies have evaluated the contamination of groundwater by necro-leachate, from microbiological contamination to that caused by heavy metals, such as those conducted by Fernandes (2017), Paíga and Matos (2016), Silva and Malagutti Filho (2008) and Zychowski (2012). Despite the diversity of studies that evaluate the quality of groundwater under the influence of cemeteries, only a few relate soil and unsaturated zone characteristics in their evaluations, which is fundamental due to their influence in the retention of pollutants.

Given the above, this work evaluated the quality of groundwater under the direct influence of two cemeteries located in the urban area of the municipality of Lages, southern Brazil, with distinct pedological characteristics, but under the same rainfall regime, climate and burial practices. Knowledge of how soil characteristics influence the motion of pollutants in the unsaturated zone can be utilized to formulate public policies to regularize the activity of cemeteries opened before 2003.

METHOD

This work was developed utilizing two cemeteries located in the urban area of Lages, southern Brazil, as study areas. For the evaluation of groundwater, seasonal samplings were performed for one year in the monitoring wells located inside the cemeteries. The evaluation was based on the results obtained from the analyses of physicochemical parameters and heavy metals in groundwater samples, as well as on the characteristics of the unsaturated zone of the cemeteries.

Study areas

The city of Lages, located in southern Brazil, has a population of 156,727 inhabitants, with 98.22% living in the urban area and 1.78% in the rural area (IBGE, 2010). The urban core has two urban public cemeteries: Nossa Senhora da Penha (CNSP) and Cruz das Almas (CCA).

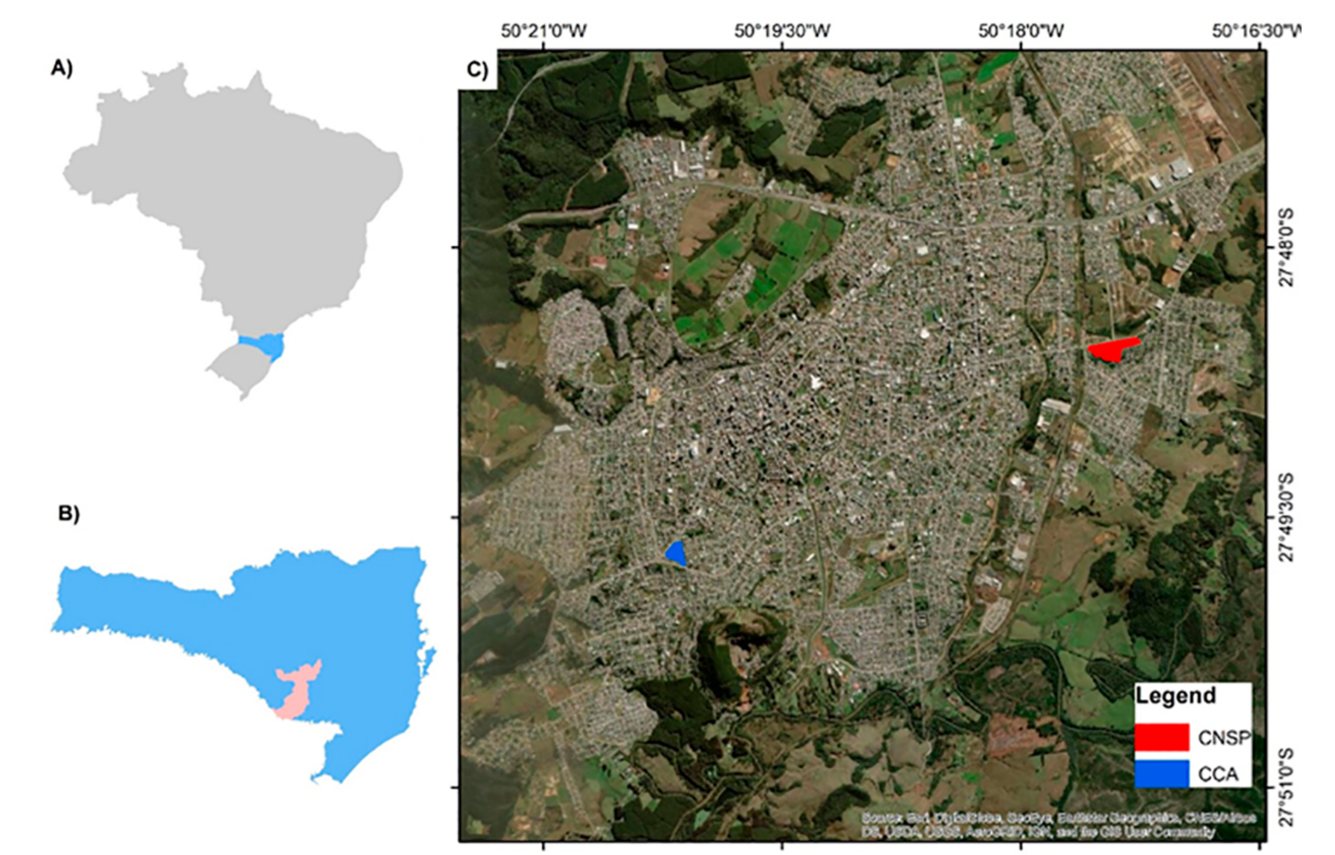
The CNSP has its center located in the geographic coordinates -27.809408° N and -50.290209° E (Figure 1) and has been in operation for approximately 78 years, with an average of 44 burials per month (in 2017). This cemetery covers an area of 60,817 m². Regarding its pedological characteristics, its surroundings have a predominantly clay texture (38% clay and 34% sand), as well as low CEC (12.55 to 22.73 cmolc.dm^{-3}) and high aluminum saturation (Al^{3+}), with an average of 81.24% (BAUM *et al.* 2021).

The CCA has its center located in the geographic coordinates -27.828271° N and -50.336078° E (Figure 1), and was opened approximately 130 years ago. It has an average of 13 burials per month (in 2017). This cemetery covers an area of 38,824 m². Regarding its pedological characteristics, its surroundings have a predominantly sandy texture (47% sand and 29% clay), low CEC (12.27 to 16.73 cmolc.dm^{-3}) and aluminum saturation (Al^{3+}), with an average of 54.48% (BAUM *et al.* 2021).

The soils inside both cemeteries show concentrations of Cd, Pb, Cr, Ni, Zn and Cu lower than those established as Prevention and Intervention Values by the CONAMA Resolution no. 420/2009 (BRASIL, 2009).

Collection and preparation of water samples

Groundwater samples were collected seasonally in the monitoring wells located inside the studied cemeteries, totaling four campaigns (one sampling campaign in each season of the year). The sampling campaigns were conducted in 2017.



Source: Prepared by the authors, 2022.

Figure 1 – (A) Location of Santa Catarina in Brazil. (B) Location of Lages in Santa Catarina. (C) Location of the Nossa Senhora da Penha (CNSP) and Cruz das Almas (CCA) cemeteries in the urban area of Lages, Santa Catarina.

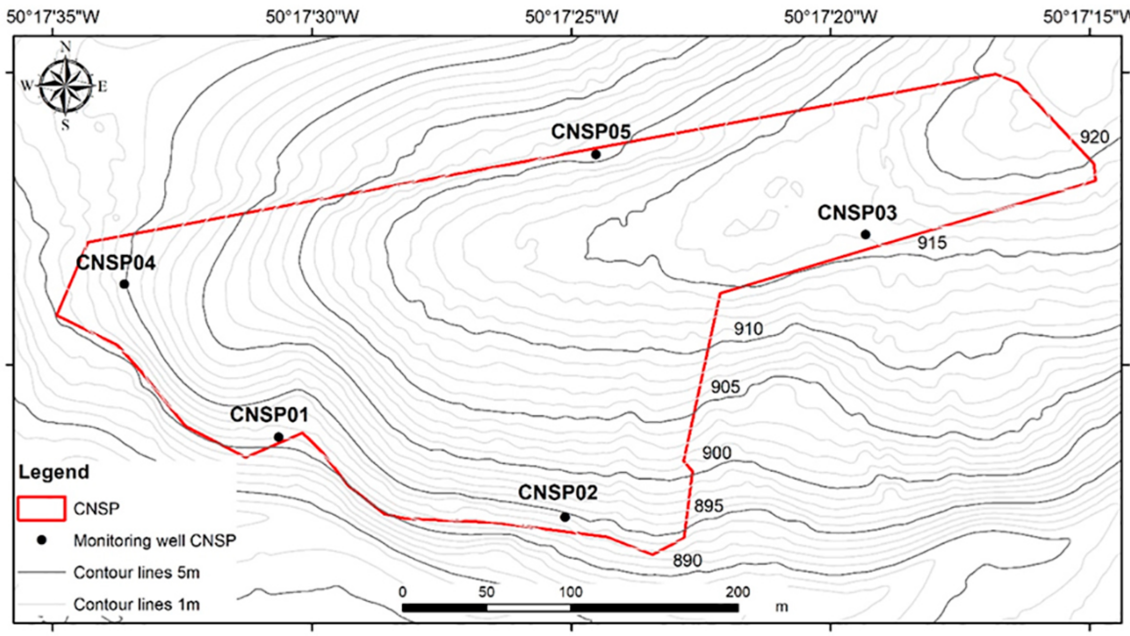
In the CNSP, five wells were monitored (Figure 2), resulting in 16 samples (four in the summer, five in the fall, three in the winter and four in the spring); while in the CCA four wells were monitored (Figure 3), resulting in eight collected samples (one in the summer; four in the fall; one in the winter and two in the spring), totaling 24 samples. In some incursions, the water level made it impossible to collect samples from some wells, since it was below the maximum depth of the wells. Only during the fall was it possible to sample water from all monitoring wells, since the water level was closer to the soil surface.

The methodology utilized in this study followed the guidelines contained in the Standard Methods for the Examination of Water and Wastewater (APHA, 2012) and the Brazilian Technical Norm (NBR) 9898 (ABNT, 1987). The water samples were collected with a disposable sampler and stored in polyurethane flasks, which were previously rinsed with water from the collecting site before the sampling procedure, then properly labelled and closed after the process. The aliquots were conditioned and transported in a thermal box with ice, in order to preserve their physicochemical standards.

Determination of physicochemical parameters and levels of heavy metals

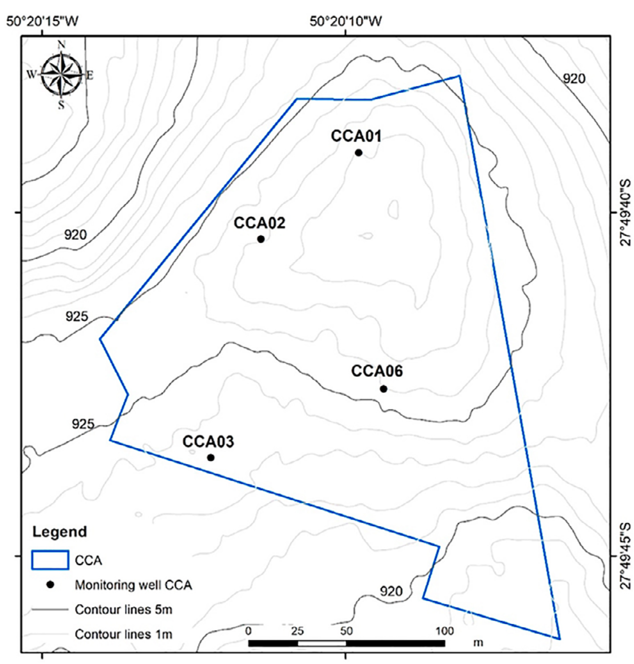
The physicochemical parameters potential hydrogen (pH), electrical conductivity (EC), oxidation-reduction potential (ORP), dissolved oxygen (DO) and total dissolved solids (TDS) were determined in the laboratory right after the sampling procedure, utilizing a Hanna HI 98194 multiparameter portable meter. The parameters chemical oxygen demand (COD), total phenols, total phosphorus and ammonia (NH_3) were determined with an Alphakit AT100P II Multiparameter Photocolorimeter. The concentrations of cadmium (Cd), lead (Pb), copper (Cu), chromium (Cr), nickel (Ni) and zinc (Zn) were determined with an Analytik Jena AG ContrAA 700 High Resolution Continuum Source Atomic Absorption Spectrometer. All determinations were performed in triplicate. The utilized methodologies are described in Chart 1. The characteristics regarding the Flame Atomic Absorption Spectrometry (FAAS) are shown in Chart 2.

The samples were digested according to the 3030 E method (APHA, 2012), which consists in the slow acid digestion of the sample for FAAS, applying the approach for high level analytes (> 0.1 $mg.L^{-1}$). This procedure was conducted utilizing nitric acid (HNO_3), with a Merck analytical standard. For the digestion of the 24 water samples, 100 mL of sample were transferred into an Erlenmeyer flask, followed by 5 mL of Merck HNO_3. The samples were progressively heated on a heating plate until reaching ± 95ºC under reflux, and were reduced to the smallest possible volume (± 15 mL), concluding the digestion process. The aliquots were cooled and diluted to 100 mL with ultrapure water *(*18.3 $M\Omega.cm^{-1}$*)*, and later stored into amber flasks in order to avoid possible alterations caused by the incidence of light. For the calibration of the spectrometer, standard solutions were prepared for each studied metal, according to their respective calibration curves, which were created from reference stock solutions.



Source: Prepared by the authors, 2022.

Figure 2 – Location of the monitoring wells of the Nossa Senhora da Penha Cemetery (CNSP).



Source: Prepared by the authors, 2022.

Figure 3 – Location of the monitoring wells of the Cruz das Almas Cemetery (CCA).

Statistical data analysis

For the analysis, data were firstly subjected to a statistical treatment. Descriptive statistics were employed to check its behavior, followed by a Student's *t* test with a 95% confidence interval, applied to verify if there was a significant difference between the mean values of the parameters analyzed.

Chart 1 – Methodologies utilized in the determination of chemical oxygen demand, total phenols, total phosphorus, ammonia (NH_3), and the metals Cd, Pb, Cu, Cr, Ni and Zn.

Analyses	Methodologies
Total phenols	Adapted from: Analisis Del Água. E. Merck. Darmstadt. Germany. p. 96. Nitroaniline Method.
Total phosphorus	Adapted from: APHA (2012). 4500 B. Sample digestion. APHA (2012). 4500 E. Ascorbic Acid Method. Santos Filho (1976), p. 206. Molybdenum Blue Colorimetric Method.
Ammonia (NH_3)	APHA (2012). 4500 F. Indophenol Method ABNT (1988).
COD	APHA (2012). 5220 D. Colorimetric Method ABNT (1989).
Metals	APHA (2012). 3030 E. Slow acid digestion for high-level analytes. APHA (2012). 3111 B. Determination — Direct Air-Acetylene Flame Method.

COD: chemical oxygen demand.
Source: Prepared by the authors, 2022.

RESULTS AND DISCUSSION

Groundwater physicochemical parameters

In Brazil, the CONAMA Resolution no. 396/2008 sets the maximum permissible value (MPV) of many parameters in groundwater (BRASIL, 2008). Among the parameters analyzed, DO, pH, ORP, EC, COD and total phosphorus do not have standard values for human consumption, according to the aforementioned regulation. The parameter TDS had its mean value below the MPV (1000 $mg.L^{-1}$) in all measurements, while the mean value for total phenols stayed above the legally established value.

Chart 2 – Characteristics of the standard solutions for the determination of metals by Flame Atomic Absorption Spectrometry.

Element	Reagent	Brand	Minimum Detection Limit ($mg.L^{-1}$)	Wavelength (nm)	Slit Width (nm)
Cadmium	1,000 $mg.L^{-1}$ Cadmium	Fluka	0.0004	228.0004	0.5
Lead	1,000 $mg.L^{-1}$ Lead	Specsol	0.005	217.005	1.0
Copper	1,000 $mg.L^{-1}$ Copper	Specsol	0.001	324.001	0.5
Chromium	1,000 $mg.L^{-1}$ Chromium	Specsol	0.005	357.005	0.2
Nickel	1,000 $mg.L^{-1}$ Nickel	Specsol	0.012	232.012	0.2
Zinc	1,000 $mg.L^{-1}$ Zinc	Specsol	0.001	213.001	1.0

Source: Prepared by the authors, 2022.

Tables 1 and 2 show the mean values of each parameter obtained in the four incursions, as well as their respective standard deviations.

Total phenols in groundwater intended for human consumption, according to the CONAMA Resolution no. 396/2008, have their concentration limited to 0.003 $mg.L^{-1}$ (BRASIL, 2008b). All samples analyzed showed high levels of phenols in both cemeteries, with a mean minimum concentration of 0.03 $mg.L^{-1}$ (CCA 06), and a mean maximum concentration of 1.468 $mg.L^{-1}$ (CNSP 01). Phenols are not commonly utilized in the evaluation of contamination of groundwater by cemetery activities; however, alongside formaldehyde, glycerin and ethyl alcohol, it is one of the most used products for the preservation of bodies (OLIVEIRA *et al.*, 2013) in techniques such as thanatopraxy.

Ammonia also showed high concentrations, however there is no VMP established by the CONAMA Resolution no. 396/2008 (BRASIL, 2008b). According to Zychowski (2012), it is considered the main product generated after decomposition, with a considerably quicker flow when compared to those of chloride, sulfate and sodium ions.

Heavy metals

Among the studied metals, Cu and Pb showed, in all samples, concentrations lower than the limit of detection (LOD) of the spectrometer. Ni and Zn showed levels above the LOD in the sample collected during the summer at the CNSP04 monitoring well. Cd and Cr had concentrations above the LOD in all samples. The total concentrations of the studied metals are shown in Table 3 below.

Zn had a concentration of 0.655 $mg.L^{-1}$, below the MPV for human consumption (5 $mg.L^{-1}$), established by the CONAMA Resolution no. 396/2008 (BRASIL, 2008b). On the other hand, Ni had a concentration of 0.899 $mg.L^{-1}$, above the MPV of 0.02 $mg.L^{-1}$ for human consumption, established by the same CONAMA Resolution. According to Gonzalez (2016), Ni is a stable and persistent element in the environment, since it cannot be biologically or chemically degraded or destroyed.

Cd showed concentrations above the MPV for human consumption, of 0.005 $mg.L^{-1}$ according to the CONAMA Resolution no. 396/2008 (BRASIL, 2008b) (Table 3). The lower concentrations were registered during the spring, in both cemeteries. Cr also showed values above the MPV for human consumption (0.05 $mg.L^{-1}$), according to the aforementioned legislation (BRASIL, 2008b) (Table 3). Cd had levels above the MPV in 83.34% of the samples, with mean concentrations of 0.025 $mg.L^{-1}$ in the CNSP and 0.026 $mg.L^{-1}$ in the CCA (Table 4). Cr showed concentrations above the MPV in all samples, with mean values reaching 0.502 $mg.L^{-1}$ in the CNSP and 0.577 $mg.L^{-1}$ in the CCA (Table 4).

The CNSP04 well, during the summer, had the highest concentrations of Cd (0.034 $mg.L^{-1}$) and Cr (0.848 $mg.L^{-1}$), as well as registering a mean concentration of Ni (0.899 $mg.L^{-1}$) above the MPV. This situation may be owed to the accumulation of contaminants in lower topographic elevations.

According to Rieuwerts *et al.* (2006), pH has a strong influence on the dynamics of metal cations, which are less mobile under low pH conditions. Generally, acidic conditions favor the increase of the leaching potential of the soluble forms of metallic compounds (FERNANDEZ *et al.*, 2007). Under higher pH values, metals tend to precipitate (LANGE, 2012). The pH of the groundwater under the influence of the studied cemeteries ranged from 5.26 (fall) to 6.98 (spring). Despite the fact that the groundwater normally have a reduced mobility, the low pH of the studied waters favors the mobility of the metals. The fact that the levels of Cd and Cr do not show a high variability between the studied monitoring wells, in the same season, regardless of the area being of recent or older burials, indicates that the metals are carried by groundwater, what can affect neighbor areas and even underlying aquifers.

Despite most parameters not having values established by the Brazilian legislation, they allow signs of groundwater contamination to be identified. The higher values of EC and TDS were detected in places next to recent burials, corroborating what was stated by Dent and Knight (1998), who verified an increase in EC and levels of mineral salts in groundwater near more recent graves. NH_3, another indicator of recent pollution, showed values above the maximum limits in some places, and due to its fast mobility in groundwater, this parameter does not need to be identified in areas of recent burials. This feature — areas with older and more recent burials —, associated with the differences between water level heights, as well as differences in rainfall, can explain the high variability between the seasons for almost all parameters (Table 5).

The lowest mean concentrations of total phenols were registered in the fall. This may be owed to the fact that the sampling was conducted during a rainy period, which has the potential of rising the water level of the phreatic aquifer. According to Branco *et al.* (2013), the phenol molecule shows high solubility in water due to the presence of hydroxyl groups; thus, with more water available in the phreatic aquifer, the solubilization capacity of the phenol in the environment becomes higher.

Precipitation is the main non-continuous source of natural recharge of aquifers, directly influencing the height of the water level in the phreatic aquifer and the mobility of pollutants in the unsaturated zone. During the groundwater monitoring period, between November 2016 and October 2017, 1,158.2 mm of rainfall were registered (Figure 4) — a value below the historic average of 1,509.2 mm for one water-year (SOCCOL, CARDOSO and MIQUELLUTI,

Table 1 – Mean concentrations, by monitoring well, of the physicochemical parameters of groundwater under the influence of the Nossa Senhora da Penha Cemetery.

Parameters	CNSP01	CNSP02	CNSP03	CNSP04	CNSP05	MPV
DO (mg.L-1)	5.705 ± 3.19	---	4.673 ± 5.60	4.985 ± 5.82	3.297 ± 3.58	NE
pH	5.763 ± 0.56	5.920 ± 0.00	5.777 ± 0.50	5.357 ± 0.07	6.084 ±0.32	NE
ORP (mV)	17.608 ± 23.93	50.533 ± 0.00	15.167 ± 25.56	17.589 ± 22.52	11.800 ± 29.11	NE
EC (μS.cm-1)	147.833 ± 19.59	113.000 ± 0.00	178.500 ± 78.45	21.222 ± 5.98	406.000 ± 168.90	NE
TDS (mg.L-1)	73.417 ± 10.47	71.667 ± 0.00	95.250 ± 36.03	10.556 ± 3.02	213.500 ± 92.32	1,000.00 (1)
COD (mg.L-1)	5.490 ± 7.41	0.000 ± 0.00	6.145 ± 7.77	2.124 ± 3.67	3.877 ± 7.75	NE
Total phenols (mg.L-1)	1.468 ± 1.00	0.040 ± 0.00	0.654 ± 1.01	0.521 ± 0.50	0.360 ± 0.56	0.003 (1)
NH_3 (mg.L-1)	17.950 ± 34.90	1.843 ± 0.00	6.645 ± 12.71	1.742 ± 2.93	0.118 ± 0.10	NE
Total Phosphorus (mg.L-1)	0.010 ± 0.02	0.000 ± 0.00	0.000 ± 0.00	0.000 ± 0.00	0.100 ± 0.21	NE

MPV: maximum permissible value; DO: dissolved oxygen; pH: potential hydrogen; ORP: oxidation-reduction potential; EC: electrical conductivity; TDS: total dissolved solids; COD: chemical oxygen demand.
OBS.: For well CNSP02, the standard deviation for all parameters was zero, since only one sampling was carried out along the monitoring period (maximum depth of the wells above water level); NE: nonexistent; (1) MPV: National Environment Council Resolution no. 396/2008.
Source: Prepared by the authors, 2022.

Table 2 – Mean concentrations, by monitoring well, of the physicochemical parameters of groundwater under the influence of the Cruz das Almas Cemetery.

Parameters	CCA01	CCA02	CCA03	CCA06	MPV
DO (mg.L-1)	8.633 ± 0.0	---	3.638 ± 4.19	---	NE
pH	6.182 ± 0.29	5.697 ± 0.00	6.819 ±0.31	6,117 ± 0.00	NE
ORP (mV)	2.983 ± 32.26	28.333 ± 0.00	14.300 ±	26.633 ± 0.00	NE
EC (μS.cm-1)	35.500 ± 1.17	53.333 ± 0.00	210.583 ± 62.65	165.000 ± 0.00	NE
TDS (mg.L-1)	17.500 ± 0.70	26.667 ± 0.00	104.833 ± 31.63	82.667 ± 0.00	1,000.00 (1)
COD (mg.L-1)	0.343 ± 0.04	1.103 ± 0.00	0.639 ± 1.22	0.000 ± 0.00	NE
Total phenols (mg.L-1)	0.435 ± 0.56	0.087 ± 0.00	1.005 ± 1.14	0.033 ± 0.00	0.003 (1)
NH_3 (mg.L-1)	0.280 ± 0.04	0.103 ± 0.00	0.288 ± 0.38	0.623 ± 0.00	1.2 (2)
Total phosphorus (mg.L-1)	0.000 ± 0.00	0.000 ± 0.00	0.050 ± 0.10	0.000 ± 0.00	NE

MPV: maximum permissible value; DO: dissolved oxygen; pH: potential hydrogen; ORP: oxidation-reduction potential; EC: electrical conductivity; TDS: total dissolved solids; COD: chemical oxygen demand.
OBS.: For wells CCA02 and CCA06, the standard deviation for all parameters was zero, since only one sampling was carried out along the monitoring period (maximum depth of the wells above water level); NE: nonexistent; (1) MPV.
Source: Prepared by the authors, 2022.

Table 3 – Total concentrations (mg.L-1) of Cr and Cd in the groundwater of the Nossa Senhora da Penha and Cruz das Almas cemeteries.

Monitoring Wells	Summer		Fall		Winter		Spring	
	Cd	Cr	Cd	Cr	Cd	Cr	Cd	Cr
	----------------mg.L-1----------------							
CNSP01	0.032	0.5241	0.033	0.374	0.033	0.461	0.003	0.2366
CNSP02	NE	NE	0.031	0.502	NE	NE	NE	NE
CNSP03	0.033	0.4985	0.033	0.500	0.030	0.497	0.003	0.6146
CNSP04	0.034	0.8484	0.033	0.488	NE	NE	0.006	0.5007
CNSP05	0.033	0.4527	0.032	0.569	0.033	0.549	0.003	0.4104
CCA01	NE	NE	0.034	0.619	NE	NE	0.004	0.3958
CCA02	NE	NE	0.032	0.553	NE	NE	NE	NE
CCA03	0.032	0.5973	0.034	0.663	0.034	0.582	0.003	0.5729
CCA06	NE	NE	0.033	0.630	NE	NE	NE	NE

NE: Nonexistent, since the water level was below the maximum depth of the monitoring well.
Source: Prepared by the authors, 2022.

2010). The highest rainfall before a sampling campaign was registered during the fall, in June (51.6 mm).

The parameters DO and COD showed the highest concentrations in the spring, which had a precipitation volume of 44.6 mm in the ten days before the sampling campaign. The lowest values for these parameters were registered during the summer campaign, when there was a precipitation volume of 11.2 mm in the ten days before the sampling. Despite the fact that the flow velocity of pollutants is generally low in groundwater (when compared to surface water), when there is a rise in water level, there is a naturally higher dispersion of these compounds, such as is the case with mineral salts. However, it stands out that the water that supplies the phreatic aquifer may leach new soil pollutants, such as phenols, whose concentrations, as found in this study, were higher under rainier conditions prior to the sampling campaigns.

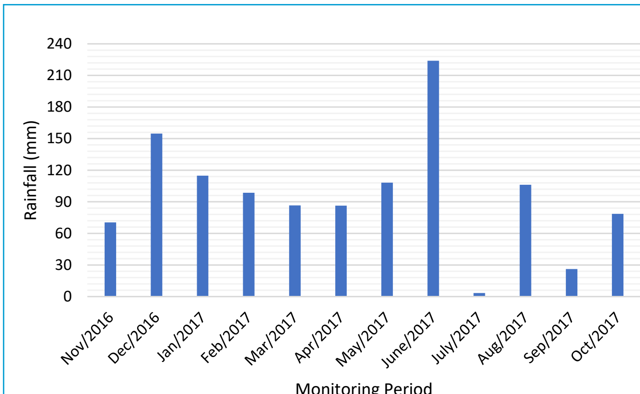
The thickness of the unsaturated soil layer is one of the factors that are directly related to the polluting potential of cemeteries on groundwater, since the unsaturated zone does not act like a barrier to block contaminants. The CONAMA Resolution no. 368/2006 establishes that the lower level of the graves must be at a minimum distance of 150 cm above the highest phreatic level, measured at the end of the rainy season. During the period of the study, it was observed that the level of the phreatic aquifer varied between 1.45 and 2.55 m in relation to the soil surface. In the CNSP, it ranged between 1.75 and 3.75 m. Considering that burials normally occur at deeper layers of the soils (1.5 to 1.8 m) (BARROS *et al.*, 2008), the distance between the lower level of the graves and the highest level of the phreatic aquifer in the areas of the graveyards is inadequate for burials in these places, and possibly contributes to the elevated concentrations of some of the parameters evaluated, such as total phenols and NH_3.

Regarding the potential for influencing soil texture, the soil of the CNSP has a predominantly clayish texture, while the soil of the CCA is characterized as predominantly sandy (BAUM *et al.* 2021). According to Üçisik and Rushbrook (1998), soils constituted by a clay-sand mixture of high porosity and high specific area, such as those found at the CNSP, maximize the retention of degradation products. According to Silva (1995, *apud* SILVA and MALAGUTTI FILHO, 2008), soils with a texture considered suitable for burial activities must contain 20 to 40% of clay, in order to favor the processes of aerobic decomposition, as well as the drainage of necro-leachate. However, it is not possible to affirm that the differences in soil texture influenced in the percolation of some contaminants, since in summer and

Table 4 – Statistical results of water samples from the Nossa Senhora da Penha and Cruz das Almas cemeteries for Cr and Cd.

Statistical parameters	CNSP		CCA	
	Cr	Cd	Cr	Cd
	----------------$mg.L^{-1}$----------------			
Count	16	16	8	8
Mean	0.502	0.025	0.577	0.026
Median	0.499	0.032	0.590	0.033
Minimum	0.237	0.003	0.396	0.003
Maximum	0.848	0.034	0.663	0.034
Standard Deviation	0.126	0.013	0.052	0.011
Variation Coefficient (%)	0.252	0.514	0.090	0.434

CNSP: Nossa Senhora da Penha; CCA: Cruz das Almas.
Source: Prepared by the authors, 2022.



Source: Adapted from Instituto Nacional de Meteorologia, 2017.

Figure 4 – Mean rainfall during the studied period.

Table 5 – Comparison between the mean concentrations of each parameter by season.

Parameters	CCA				CNSP			
	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring
DO ($mg.L^{-1}$)	0.677 a	---	---	7.617 b	1.44 a	---	---	7.89 b
pH	6.77 a	6.23 b	6.40 ab	6.68 ab	6.06 a	5.72 ab	5.83 ab	5.54 b
ORP (mV)	56.07 a	24.08 b	12.23 c	-23.25 d	33.76 a	37.10 a	-10.70 b	-1.67 b
EC ($\mu S.cm^{-1}$)	281.33 a	96.58 b	198.67 c	132.67 bc	153.08 a	172.06 a	251.44 a	216.75 a
TDS ($mg.L^{-1}$)	140.67 a	48.17 b	98.00 c	66.17 bc	77.91 a	91.80 a	143.22 a	107.92 a
COD ($mg.L^{-1}$)	0.00 a	0.20 a	0.37 a	2.47 b	0.72 ab	0.00 b	3.46 a	13.80 c
Total phenols ($mg.L^{-1}$)	2.72 a	0.16 b	0.41 c	0.63 d	1.43 a	0.08 b	0.71 ab	0.82 ab
NH_3 ($mg.L^{-1}$)	0.04 ac	0.47 b	0.006 a	0.26 bc	0.61 a	20.64 b	0.02 a	0.05 a
Total phosphorus ($mg.L^{-1}$)	0.00 a	0.00 a	0.00 a	0.61 b	0.03 a	0.00 a	0.00 a	0.31 a

CCA: Cruz das Almas; CNSP: Nossa Senhora da Penha; DO: dissolved oxygen; pH: potential hydrogen; ORP: oxidation-reduction potential; EC: electrical conductivity; TDS: total dissolved solids; COD: chemical oxygen demand.
OBS.: Means followed by the same letter are not statistically different from each other according to Student's *t* test ($p > 0.05$).
Source: Prepared by the authors, 2022.

fall the concentrations of total phenols, for example, were higher in the CCA. In the CNSP, on the other hand, the highest levels were found in spring and fall.

Despite the soil texture being adequate, the values of CEC from both cemeteries are low, due to the fact that a great part of it is occupied by Al^{3+} ions (BAUM *et al.* 2021), preventing other cations, such as heavy metals, being adsorbed in the edges of clay minerals. Under these conditions, and considering that the soils of the surroundings of the cemeteries, as well as their inner areas, do not show levels of heavy metals above the MPVs, the metals originated from the process of degradation of burial materials may be leaching into groundwater, where concentrations above the MPVs were found for Cd, Cr and Ni. According to He *et al.* (2004), the availability and mobility of heavy metals are controlled by chemical and biochemical processes, such as precipitation-dissolution, adsorption-desorption, complexation-dissociation and oxidation-reduction.

After comparing the results between both cemeteries and considering the characteristics of the soils, it was possible to observe that, even with the CNSP having more suitable percentages of clay to retain pollutants, this cemetery registered the highest levels of NH_3 and heavy metals. This situation shows that, despite the characteristics of the soil being one of the main factors to consider in order to evaluate the contamination of groundwater in areas influenced by cemeteries, other factors should also be considered.

CONCLUSION

Water quality in both cemeteries showed signs of contamination by necroleachate compounds, such as mineral salts, NH_3, total phenols and metals such as Cd, Cr and Ni. These metals, as well as being harmful to the environment, become a public health issue, since groundwater — phreatic aquifers — is not static, and is captured and utilized for various purposes.

Although the pedological characteristics are fundamental for the construction of cemeteries, knowing the maximum height of the phreatic aquifer and the hydrogeological behavior of these areas is essential to understand the dynamics of pollutants in the unsaturated zone. In this study, rainfall, which had a direct effect on the water level of the phreatic aquifer, also impacted results directly. In Brazil it is necessary to establish regional regulations that consider pedology and hydrogeology. Due to the pedologic and hydrogeologic amplitude of the Brazilian territory, the federal legislation does not make clear essential particularities for the construction and operation of cemeteries.

Undertakings operating under inadequate conditions must have their impacts on the environment investigated and be made to cease their activities in case contamination spots are detected. In addition, recovery plans that consider the peculiarities of each region must be proposed. It is also recommended to carry out a long-term continuous monitoring of the cemeteries that have ceased their operations, in order to check if there are changes in groundwater quality.

AUTHORS' CONTRIBUTIONS

Baum, C.A.: Conceptualization, Data curation, Investigation, Methodology, Project administration, Writing – original draft, Writing – review & editing. Becegato, V.A.: Conceptualization, Investigation, Methodology, Resources, Writing – review & editing. Vilela, P.B.: Data curation, Investigation, Methodology. Lavnitcki, L.: Data curation, Investigation, Methodology. Becegato, V.R.: Investigation, Methodology, Writing – review & editing. Paulino, A.T.: Resources, Methodology.

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