Metals in the soil of urban cemeteries in Carazinho (South Brazil) in view of the increase in deaths from COVID-19: projects for cemeteries to mitigate environmental impacts

Alcindo Neckel1 · Cleiton Korcelski1 · Luis F. O. Silva2 · Henrique Aniceto Kujawa3 · Brian William Bodah1,4 · Adriano Marcos Rodrigues Figueiredo3 · Laércio Stolfo Maculan1 · Affonso Celso Gonçalves Jr.6 · Eliane Thaines Bodah4,7 · Leila Dal Moro1

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Abstract
The increasing mortality of COVID-19 can aggravate soil contamination by metals, harmful to the health of the population, requiring new projects for future cemeteries capable of mitigating these impacts to the environment, justifying the importance of studying the concentrations of metals in the soil of urban cemeteries. The paper analyzed the levels of metals in the soil of urban cemeteries in the City of Carazinho, in the state of Rio Grande do Sul, located in southern Brazil, considering the increase in deaths by COVID-19, for the purpose of future projects for cemeteries aimed at mitigating the impacts generated on the environment. The soils of the three urban cemeteries in Carazinho were sampled, with 5 internal and external points, with 3 repetitions at depths of 0–20 and 20–40 cm, adding 180 samples to measure the concentrations of Fe, Mn, Cu, Zn, Cr and Pb (g kg⁻¹), considering the analytical sequence: (1) analysis in triplicate with mean deviation (RDS); (2) R² of the analytical curve; (3) traceability of the pattern of each metal; (4) quantification limit of each metal (QL), with the performance of nitroperchloric digestion of the samples and the determinations of metals by flame modality atomic absorption spectrometry. Quantitative data on deaths by COVID-19 were analyzed by univariate modeling of time series, in the integrated autoregressive moving averages model. The results of this study were made available to fifteen architects, who attributed future solutions for environmentally sustainable cemeteries. The results showed high levels of copper (Cu) and iron (Fe) in the soil of the cemeteries studied. Considering the increase in deaths and subsequent burials per COVID-19 revealed a prediction for the death toll of 6,082,306 for June 9, 2022, it is assumed that metal contamination can reach even higher levels. To mitigate these levels of contamination by metals, 80% of the architect respondents expressed their preference for a vertical cemetery, with treatment of gases and effluents to mitigate environmental impacts.

Keywords Metal contamination · Pandemic · Population mortality · Environmental analysis · Project solutions

* Alcindo Neckel
alcindo.neckel@imed.edu.br

Extended author information available on the last page of the article
1 Introduction

Metallic soil contamination is widespread globally, with industrial processes responsible for the vast majority (Acosta et al., 2011; Li et al., 2009; Yang et al., 2020). Jonker and Olivier (2012), Neckel et al. (2016), Yang et al. (2020) and Amiel et al. (2021) highlight that excess metal in the soil is due to anthropogenic causes, including human body waste. Similarly, while the decomposition of the human body after death is a natural process, it associated with to release greenhouse gases to the atmosphere and introduce metallic pollutants to the soil of cemeteries (Neckel et al., 2021). The population’s monetary income limited the type of burial in certain areas available (Rae, 2021).

Modern cemeteries utilized in some parts of the world, including Brazil, that allow for the natural decomposition of many bodies in a limited area, can be unhealthy spaces with potentially high concentrations of metallic contaminants in relation to its coverage area (Neckel et al., 2017; Nogueira et al., 2013; Rae, 2021). Metals have been shown to contaminate neighborhoods within a radius of approximately 400–500 m from such locations (Neckel et al., 2021). According to Kemerich et al. (2012) and Neckel et al. (2017), these metals are released by corpses, during the natural process of decomposition, through liquids called necroslurry, thus contributing to physical, in addition to contaminating soil, can also contaminate underground water supplies, further increasing the concern with contamination from cemeteries (Kemerich et al., 2014). Thus, enhancing the need for studies aimed at the environmental impacts generated by cemeteries in cities worldwide is paramount in order to suggest public policies that ensure the protection of the soil and the health of the population, through increased forms of treatment of necroslurry (Neckel et al., 2017; Quinton et al., 2020).

In this context, urban cemeteries have become a global problem, due to the phenomenon of urban expansion that increasingly brings development and urbanization to these locations, surrounding a formerly distant cemetery with dense residential areas, thus leaving this population exposed to contamination by metals, such as zinc (Zn), copper (Cu), manganese (Mn), iron (Fe), chromium (Cr), nickel (Ni), lead (Pb) and cadmium (Cd) (Amuno & Amuno, 2013; Jonker & Olivier, 2012; Kemerich et al., 2014; Natali et al., 2016; Neckel et al., 2016, 2021; Neira et al., 2008; Shafer et al., 2008; Silva et al., 2020; Spongberg & Becks, 2000). The main characteristics of this study in relation to other studies are a scenario unseen for the past century on a global scale. Currently, the COVID-19 pandemic has significantly raised mortality statistics (WHO, 2021); thus, it is assumed that there is a significant increase in the concentration of metals in the soil of cemeteries, due to the high rates of burial and resulting necroslurry production.

The COVID-19 pandemic increased the mortality rate in Latin America’s largest city, the Brazilian city of São Paulo (SP), by 30% throughout 2020. Through monitoring of a single SP urban cemetery, located in the central area of the city, an average of 100 burials per day resulting from COVID-19 deaths were detected (Calmon, 2020). This quantitative problem of burials in cemeteries, responsible for the dispersion of contaminants in the soil, was further aggravated at the end of 2019, all of 2020, an into 2021 with the early burials caused by the COVID-19 epidemic, a consequence of the high human mortality rates due to severe acute respiratory syndrome, triggered by the SARS-CoV-2 virus, commonly known as coronavirus (Alishaq et al., 2021; Berkley, 2020; Fauci et al., 2020). As of July 16, 2021, the official global World Health Association death toll from COVID-19 totaled 4,067,517 individuals (WHO, 2021). Brazil itself has reported 537,394 COVID-19 deaths as of July 16, 2021 (WHO, 2021). This becomes even more worrying if one
considers that each 70 kg cadaver releases approximately 30 L of necroslurry into its surroundings during the process of decomposition (Kemerich et al., 2012; Neckel et al., 2017, 2021; Silva et al., 2020; Silva et al., 2020). Through the process of urban vertical cemeteries, this necroslurry enters the surrounding environment directly; there is no form of treatment or abatement for these liquids. It is assumed that when considering the concentration of 537,394 deaths in Brazil (WHO, 2021), the soil of Brazilian cemeteries received a load of necroslurry greater than 1,128,527,400 m³, can infiltrate with ease for the underground waters. According to CONAMA (2003), Li et al. (2009), Campos (2010), Liu et al. (2017), Röllin and Nogueira (2011), Shirowzhan et al. (2020), Neckel et al. (2021), Lunardi et al. (2021) and O’Hara-Wild et al. (2021b, c), this excess of contaminants in cemeteries can compromise human health and groundwater drinking supplies. This justifies the true contributions of this study; the need to demonstrate the contamination by metals in the soil of urban cemeteries given the high mortality rates and subsequent increase in burials caused by the COVID-19 epidemic. Thus, demonstrating the exacerbation of the concentration of metals in the cemeteries’ soils. The authors combine this with the need for project solutions capable of assigning future measures to mitigate the impacts of contamination by high concentrations of metals in the soil.

The paper analyzed the levels of metals in the soil of urban cemeteries in the City of Carazinho, in the state of Rio Grande do Sul, located in southern Brazil, considering the increase in deaths by COVID-19, for the purpose of future projects for cemeteries aimed at mitigating the impacts generated on the environment. This paper identifies the levels of soil contamination by metals (Fe, Mn, Cu, Zn, Cr and Pb (g kg⁻¹)), the projection of deaths from COVID-19 in global parameters of burials, and the suggestion of future projects for the implementation of environmentally adequate cemeteries, with forms of treatment of effluents and gases. The importance of this study becomes remarkable, in order to implement the methodologies outlined here for future research on a global scale, as the monitoring of contaminants needs to be carried out in cemeteries due to the high rates of burials resulting from COVID-19.

2 Materials and methods

2.1 Study area

The city of Carazinho is located in the south of Brazil, in the State of Rio Grande do Sul (RS) (28°17’ latitude and 52°47’ longitude) (Fig. 1). According to the Brazilian Institute of Geography and Statistics (IBGE, 2021), the territorial area of the city of Carazinho covers a total of 676 km², with an estimated population of 62,265 inhabitants in 2021, comprising a demographic density of 89.19 inhab/km² (IBGE, 2021). This type of cemetery is the one most commonly used in Latin America. In this context, the objects of study were three cemeteries in the city: Cemetery A with 53,160 m², Cemetery B with 11,021 m² and Cemetery C totals 12,526 m². An additional reason for selecting these three cemeteries for this study is that they do not use herbicides, but the practice of manual weeding to control the proliferation of weeds. As herbicides, a high degree of metal in their formulation, the authors did not want this to compromise the results of the soil analysis (Neckel et al., 2021); therefore, the urban cemeteries chosen for the study do not control for weeds by chemical elements.
2.2 Soil collection from urban cemeteries A, B and C

The soils of cemeteries A, B and C were collected, in 5 internal points and in the external area of the cemeteries spaced every 100 m. The soils were sampled at two depths, from 0 to 20 and 20 to 40 cm; with three levels of repetition, totaling 180 samples between the cemeteries A, B and C to evaluate the concentrations of Fe, Mn, Cu, Zn, Cr and Pb (g kg\(^{-1}\)), which were found to be more prevalent in studies involving the soil of cemeteries (Amuno & Amuno, 2013; Jonker & Olivier, 2012; Kemerich et al., 2014; Natali et al., 2016; Neckel et al., 2016, 2021; Neira et al., 2008; Shafer et al., 2008; Silva et al., 2020; Spongberg & Becks, 2000), with the exception of iron, was not analyzed among these studies.

These collections were carried out every 4 months, with the first on August 15, 2017, the second on December 15, 2017 and the third on April 15, 2018, based on the time period for collecting soil samples determined by Neckel et al. (2021) in cemeteries. After each collection, the sampled material was forwarded to the Laboratory of Environmental and Instrumental Chemistry, of the State University of West Paraná—UNIOESTE, located in the state of Paraná/PR (Brazil) to carry out the analysis of the soil material, sampled in cemeteries A, B and C. In the laboratory, the soil samples were compared with the following procedures: (1) analysis in triplicate with mean deviation (RDS); (2) R2 of the analytical curve; (3) traceability of the pattern of each metal; (4) quantification limit of each metal.

Fig. 1 Location of the city of Carazinho, State of Rio Grande do Sul, Brazil. Sources: Adapted from the databases IBGE (2021)
(QL), with the performance of nitroperchloric digestion of the samples and the determinations of metals by flame modality atomic absorption spectrometry (AOAC, 2016).

The results of soil samples collected from the Carazinho cemeteries (A, B and C) were stored in spreadsheets, capable of using linear regression ($y=ax+b$), in order to evaluate the concentrations of the results of internal sampling and exteriors of cemeteries. The Tukey comparison at 5% was applied, with an error of $p<0.05$, ( CETESB, 2005), aimed at understanding the levels of metal concentration in cemeteries A, B and C.

2.3 COVID-19 fatality prediction model

This aspect refers to the prediction analysis of COVID-19 deaths to obtain the world parameters of burials. The incidence of fatal cases of COVID-19 justifies rethinking the structure of cemeteries, so that they can account for the concentration of metals deposited in the soil ( Amuno & Amuno, 2013; Jonker & Olivier, 2012; Kemerich et al., 2014; Natali et al., 2016; Neckel et al., 2016, 2021; Neira et al., 2008; Shafer et al., 2008; Silva et al., 2020; Spongberg & Becks, 2000). A seasonal univariate modeling time series using autoregressive integrated moving average (ARIMA) was applied. For modeling evaluation the packages “fable,” “fabletools” and “feasts” found in the R statistical software v. 4.0 was used as a tool (O’Hara-Wild et al., 2021a, 2021b, 2021c).

The adjustment of the seasonal ARIMA model ($p, d, q)(P,D,Q)[s]$ was performed to better understand and predict the time series. This model reveals already been used in research by He and Tao (2018), where the research and prediction model achieved satisfactory results. Ribeiro et al. (2020) also used the ARIMA model, along with other time series modeling for the short-term prediction of cumulative number of confirmed cases in Brazil. In Italy, ARIMA models were used to predict confirmed and recovered cases of COVID-19, after six days of lockdown, demonstrating that the number of possible cases in the predicted period was confirmed (Chintalapudi et al., 2020). Thus, the ARIMA model ($p, d, q$) is justified, in this research for the prediction of fatal COVID-19 cases in relation to the temporal estimate on a world scale.

The typical ARIMA model states that a series ($y_t$) may be expressed as a function of its own time lagged values ($y_{t-1}, y_{t-2}, \ldots, y_{t-p}$) as well as time lagged innovations ($e_{t-1}, e_{t-2}, \ldots, e_{t-q}$). Lagged values may be represented with the Lag operator (L) so that $L^2 y_t = y_{t-2}, \ldots, L^p y_t = y_{t-p}$. It is said an integrated (I) process if the series ($y_t$) is non-stationary in level but achieves stationarity after using the difference operator ($\Delta y_t = y_t - y_{t-1}$) (and $\Delta y_t$ is stationary—in this case, $I = 1$, say one difference, integrated of order one). We may represent $\Delta^d y_t$ as the $d$th difference of $y_t$.

The seasonal ARIMA model ($p, d, q)(P,D,Q)[s]$ is composed of three parameters in the non-seasonal part: ”$p$” is the autoregressive order in the model; ”$d$” refers to the number of differences applied to the series in order to achieve stationarity, in relation to the number of deaths from COVID-19; and ”$q$” relates to the number of lags in the moving average part (in the innovations) (Chintalapudi et al., 2020; Hyndman & Athanasopoulos, 2021). The seasonal part is represented in capital letters $P, D, Q$, respectively, to the seasonal autoregressive order, to the seasonal difference (to achieve stationarity) and the seasonal moving average. The $[s]$ coefficient relates to the seasonal frequency. All coefficients are best identified and estimated jointly (Enders, 2014: 96). We may have autoregressive and moving average seasonal terms, analogous to the non-seasonal terms.
The seasonal ARIMA model \((p, d, q)(P,D,Q)[s]\) is represented in its generalized model in Eq. (1).

\[
A(L)\Phi(L^s)A^d\Delta^D_s y_t = B(L)\Theta(L^s)e_t,
\]

where \(y_t\) represents the series in time \(t\); \(A\) and \(B\), respectively, represent parameters for the lagged autoregressive and moving average terms so that the polynomials \(\Phi(L^s)\) and \(\Theta(L^s)\) hold to \(L^p\ y_t = y_{t-p}\) and \(A(L) = 1 - \alpha_1 L - \alpha_2 L^2 - \cdots - \alpha_p L^p\) and \(B(L) = 1 - \beta_1 L - \beta_2 L^2 - \cdots - \beta_q L^q\); and \(e_t\) is a white noise process.

To ensure that the final model had valid predicting capacity, it was necessary to consider certain pre-definitions. The first was the series stationarity, through stationarity tests to obtain the results were performed using the Kwiatkowski–Phillips–Schmidt–Shin (KPSS). The KPSS test reveals a null hypothesis that the series is stationary (Hyndman & Athanasopoulos, 2021; Kwiatkowski et al., 1992).

After identifying the series stationarity, the series is modeled optimizing the likelihood function to get the estimated coefficients. The best fit is selected using the Akaike Information Criteria (AIC) and Schwartz Information Criteria (BIC).

The model selection was carried out by predicting the time series one year ahead (365 days), to demonstrate the expected behavior for the series until July 2022. For the analysis, daily worldwide data on accumulated fatal cases of COVID-19 were obtained from the COVID-19 Data Repository by the Center for Systems Science and Engineering (CSSE) at Johns Hopkins University, (https://github.com/CSSEGISandData/COVID-19/tree/master/csvse_covid_19_data/csvse_covid_19_time_series), from January 22, 2020, until July 06, 2021, on a worldwide scale (Dong et al., 2020). So, the database has 279 regions/countries and 536 days. The data are then summed up over regions/countries to achieve the worldwide total.

2.4 Architectural parameters by BIM modeling for future cemetery improvements

The architectural parameters for future cemetery projects capable of involving sustainability were assigned by the fifteen \([15]\) selected architects, as established by Neckel et al. (2017), for their experience in the development of projects and research in the area of cemeteries. In order to improve the clarity of the interviewees regarding the study, the results of the soil analyzes of cemeteries \(A\), \(B\) and \(C\) and of the quantitative variations in mortality caused by the COVID-19 epidemic were made available.

In this sense, respondents were asked to assign improvements to be allocated to projects for the construction of future cemeteries and were able to mitigate these environmental impacts of soil contamination by metals of cemeteries (Giannetti et al., 2020). The seven response most attributed by the interviewees were modeled in BIM (Building Information Modeling), for the construction of architectural design parameters, in the sense of elaborating 3D formats from this response attributed by the interviewees, elaborated in the following stages of the research (Won & Lee, 2016): BIM objective, use of BIM, Key Performance Indicators (PID) and Unit Verification.

Considering that, the interviewees attributed the following improvements to be implemented in future cemeteries: vertical cemetery (1), cremation (2), liquid treatment (3); gas treatment (4); universal accessibility (5), ventilation systems (6) and the isolation between interment niches (7). Through these answers, the parameters of the BIM objective were constructed, corresponds to the modulation of a vertical cemetery with a crematorium, to hold parameters 3, 4, 5, 6 and 7 assigned by the interviewees. Because, the use of BIM
considered the project procedures, with the architectural guidelines, built from the assigned items (1, 2, 3, 4, 5, 6 and 7). The PID considered the respondents’ responses and the identification of the parameters built in the BIM, with the modeling of items 1 and 2, with the parameterizations of items 3, 4, 5, 6 and 7. The unit verification occurred through 3D modeling in the BIM system, representing the items assigned by the interviewees (Fig. 2).

3 Results and discussion

3.1 Proportions of metals present in the internal and external soil of cemeteries A, B and C

Results were obtained from soil samples collected in the inner area of cemeteries A, B and C, involving the average depth pattern from 0 to 20 cm and 20 to 40 cm, respectively. The analysis of manganese and lead showed an increase in concentration, based on the first and second layers of soil analyzed (Fig. 3). For Neckel et al. (2016), exposure to excess manganese in the environment has been shown to cause Parkinson’s disease in humans. Furthermore, Capitani (2009), Morillas et al. (2019), Kortei et al. (2020), Neckel et al. (2021) and Oliveira et al. (2021a, b) have shown that lead, when absorbed by the human body, becomes a potent neurotoxin, causing negative consequences to the central and peripheral nervous system, hematopoietic, cardiovascular, neuromuscular and reproductive system impairment, and lead contamination, presents indexes with the cause of kidney failure and

![Diagram](image_url)

Fig. 2 Answers from the 15 interviewed architects, represented in a BIM model
spontaneous abortions. The levels of these metals found in the top layers of the cemeteries’ soil are quite concerning.

Figure 3 shows the concentrations of copper, zinc, iron and chromium in the inner area of cemeteries A, B and C that revealed a quadratic movement in the behavior curve, determining greater complexity in its analysis; it may reveal another important factor that come to change its behavior in the soil layers analyzed, but showed high concentrations of metals.

Table 1 shows that lead (Pb) presented high concentrations of 88.2 (g kg\(^{-1}\)) in cemetery A and 86.6 (g kg\(^{-1}\)) in cemetery B at a depth of 0 to 20 cm. At depth 20 to 40 cm, the soil of cemetery A presented levels of 82.7 (g kg\(^{-1}\)) and cemetery B was identified 80.3 (g kg\(^{-1}\)) of Pb (Table 1), demonstrates contaminations above the recommended parameters by CETESB (2005), is 72 (g kg\(^{-1}\)) of tolerated levels of Pb. Thus, it becomes possible to alert to the richness of Pb contamination in the internal area of the cemeteries, assuming that it can spread to the groundwater reservoirs beneath the cemeteries. The local region
utilizes artesian wells for both public and private water supplies. This study also warns of the high proportions of Fe in the internal area of cemeteries, considering that currently there is no standard in Brazil on a tolerated concentration standard, but according to Morillas et al. (2019), the element iron can stimulate cardiac arrhythmias, cirrhosis of the liver, cancer and Alzheimer’s when ingested in elevated amounts.

Sample points also existed in the area outside cemeteries A, B and C at a distance of 100 m (Figs. 4, 5 and 6), by points, consists of an analysis radius of 500 m from each cemetery analyzed. In cemeteries A, B and C, where the concentration of the chemical elements copper, zinc, lead and chromium tended to decrease with increasing distance from the cemetery, assuming that the dangerous elements are found with a high concentration in the internal area of analyzed cemeteries. When analyzing the limits of concentration in the soil from the distance intervals of 100 m, predetermined by legislation through studies (Neckel et al., 2017), it is clear that copper is the main element that exceeded these limits (60 g kg\(^{-1}\)) up to a distance of approximately 200, 400 and 500 m, respectively, from cemeteries A (Fig. 4), B (Fig. 5) and C (Fig. 6), exceeding the Prevention Value (PV), determined by Brazilian CETESB standards (2005) (Table 1). This indicates that this chemical element is a potential problem in the surroundings of these analyzed cemeteries. Zinc, lead and chrome did not exceed their respective limits imposed by legislation in any analyzed cemetery.

### 3.2 COVID-19 fatal case prediction (world scale)

In this research, only globally reported fatal cases of COVID-19 were considered for the forecast ARIMA methodology. In this process, it was possible to understand the behavior of the time series, mainly, if the series is stationary or if it has a unit root. The series was plotted (Fig. 7) and did not show the stationary behavior necessary for ARIMA modeling.

The lack of stationary behavior for the series is certainly due to the robust disease transmission of COVID-19. In accordance with standard procedure, KPSS (Kwiatkowski et al., 1992) unit root test was performed. The results of series from the KPSS test confirmed the non-stationarity of the analyzed results of the temporal series (test statistic equal to 7.45 with \(p\) value 0.01). As the series has the presence of a unit root, the number of differences necessary to achieve stationarity was explored using the unitroot\_ndiffs function of

| Cemetery | Cu     | Zn     | Fe     | Mn     | Pb     | Cr     |
|----------|--------|--------|--------|--------|--------|--------|
|          | (g kg\(^{-1}\)) |        |        |        |        |        |
|          | CV (%) |        |        |        |        |        |
| PV       | 60     | 300    | –      | –      | 72     | 75     |
| 0–20 cm  |        |        |        |        |        |        |
| A        | 114.3  | 142.1  | 1825.2 | 369    | 88.2   | 28.9   |
| B        | 114.8  | 140.4  | 1802.2 | 413.3  | 86.6   | 22.6   |
| C        | 105.6  | 110.9  | 1670.2 | 400.7  | 69.5   | 22.2   |
| CV (%)   | 10.5   | 41.2   | 7.6    | 21.1   | 13.9   | 18.5   |
| 20–40 cm |        |        |        |        |        |        |
| A        | 105.4  | 119.4  | 1623.3 | 364.8  | 82.7   | 23.2   |
| B        | 105.8  | 117.1  | 1667.9 | 448.3  | 80.3   | 23.2   |
| C        | 108.2  | 115.5  | 1802.3 | 374.4  | 67.7   | 23.1   |
| CV (%)   | 13.4   | 28.2   | 6.6    | 36.1   | 18.1   | 21.9   |

PV prevention value CETESB (2005), CV coefficient of variation
Fig. 4 Concentration of metallic elements in the soil outside the cemetery A. *Prevention value: the prevention value is the maximum permissible concentration of the element in the soil by Brazilian federal regulations. When exceeded, monitoring of the resulting impacts should be required (CETESB 2005)
Fig. 5  Concentration of metallic elements in the soil outside the cemetery B. *Prevention value: the prevention value is the maximum permissible concentration of the element in the soil by Brazilian federal regulations. When exceeded, monitoring of the resulting impacts should be required (CETESB 2005)
Fig. 6 Concentration of metallic elements in the soil outside the cemetery C. *Prevention value: the prevention value is the maximum permissible concentration of the element in the soil by Brazilian federal regulations. When exceeded, monitoring of the resulting impacts should be required (CETESB 2005)
the feasts R package. Two differences were then applied to the original series (unitroot_ndiffs = 2). Another test searched the presence of seasonality and found a weekly seasonality in the daily data, using the unitroot_nsdiffs function of the feasts package (one seasonality of 7 days length). We decided to train the data with 95% of the whole data: from Jan 22, 2020, until Jun 9, 2021, with 505 days (regular data with no missing gaps). Then, the test data will have the remaining 27 observations until Jul 6th, 2021.

The algorithm in the fable package fits the series according to the best (the lowest) information criteria (Corrected Akaike Information Criterion = AICc) and following the usual maximum likelihood estimation. The best fit model was identified as an ARIMA(2,1,3)(0,1,1)[7]. Specific modeling data are shown in Table 2. The main accuracy measures in the test set were as follows: RMSSE = 0.21490; MPE = 0.32463; MAPE = 0.32463; MASE = 0.24106. According to Hyndman and Athanasopoulos (2020), “MASE or RMSSE are often preferable scale-free measures for point forecast

Fig. 7 Number of worldwide accumulated fatal cases caused by COVID-19 from January 22, 2020, until July 06, 2021. Source: Raw data from the COVID-19 Data Repository by the Center for Systems Science and Engineering (CSSE) at Johns Hopkins University

| Parameters | Estimates | SE  | Statistic | P values |
|------------|-----------|-----|-----------|----------|
| ar1        | 0.092     | 0.066 | 1.402     | 0.162    |
| ar2        | 0.859     | 0.063 | 13.642    | 0.000    |
| ma1        | 0.360     | 0.075 | 4.780     | 0.000    |
| ma2        | −0.512    | 0.058 | −8.890    | 0.000    |
| ma3        | −0.164    | 0.045 | −3.637    | 0.000    |
| sma1       | −0.605    | 0.045 | −13.339   | 0.000    |

*Notes: sigma2 = 763,089, log_lik = −4070, AIC = 8154, AICc = 8154, BIC = 8184
accuracy.” The accuracy values were very low, giving us confidence in the analysis. We tested the null hypothesis for absence of residuals autocorrelation using the Ljung–Box Test with the statistic of 0.0225 and $p$ value $= 0.8808$ do not allow the rejection of the null (say, we do not have any remaining residual autocorrelation).

Given the estimate of the model for the COVID-19 series of deaths, the prediction was made out for a year ahead (365 days), but we exhibited only the 30 days-ahead results. The increase in the number of total worldwide number of deaths is illustrated in Fig. 8, or specifically a prediction of 6,082,306 for June 09, 2022, with 95% confidence intervals as low as 1,082,481 or as high as 11,082,131. The more distant the values, the greater the dispersion of the predicted average values. This dispersion was clearly presented from the general number of deaths from COVID-19 in Table 3 and Fig. 8.

The results presented in Table 3 endorse that the adequacy for environmental sustainability consists in the construction of vertical cemeteries, both to decrease soil contamination and to adapt physical structures to meet the greater demand for burials in the periods following the pandemic. This is because the number of worldwide COVID-19 deaths predicted for July 9, 2021, alone would be 4,004,983 in the mean (lower $= 3,926,398$; upper $= 4,083,567$ for 95% confidence). It is understood that our recommendations cannot be adapted in such a rapid fashion as to provide an immediate interment solution but rather to provide guidelines for construction and design of urban cemeteries to be adequately prepared to absorb a rapid increase in deaths while not compromising environmental quality, enabling sustainable development (Oliveira Neto et al., 2018), and without compromising the population’s health.
3.3 Research products: cemetery design guidelines

The fifteen [15] architects were consulted in order to facilitate a design for a truly sustainable vertical cemetery, aimed at mitigating all foreseeable environmental impacts. Thus, design guidelines were assigned that can be applied in the construction of future cemeteries, with the purpose of cleaner production and sustainability, with the possibility of treating liquids and gases, released during the process of decomposition of the corpses, after burial. The increase in burials generated by COVID-19 is noteworthy, tends to lead to greater soil contamination by excess metals, because if measures were not taken by the government, the referent, according to Neckel et al. (2021) the construction of future cemeteries, environmentally adequate to environmental standards.

In this context, 80% of the interviewed architects first recommend the construction of a vertical cemetery (1), due to the ease of treating contaminants released by corpses during

| Date year-month-day | Forecast value | Confidence interval 95% Lower | Confidence interval 95% Upper |
|---------------------|----------------|--------------------------------|------------------------------|
| 2021-06-10          | 3,767,201      | 3,765,489                      | 3,768,913                    |
| 2021-06-11          | 3,777,235      | 3,774,216                      | 3,780,254                    |
| 2021-06-12          | 3,785,604      | 3,781,239                      | 3,789,969                    |
| 2021-06-13          | 3,791,958      | 3,786,301                      | 3,797,615                    |
| 2021-06-14          | 3,798,855      | 3,791,802                      | 3,805,907                    |
| 2021-06-15          | 3,809,760      | 3,801,312                      | 3,818,208                    |
| 2021-06-16          | 3,819,668      | 3,809,738                      | 3,829,597                    |
| 2021-06-17          | 3,828,979      | 3,817,207                      | 3,840,752                    |
| 2021-06-18          | 3,838,361      | 3,824,583                      | 3,852,138                    |
| 2021-06-19          | 3,846,372      | 3,830,521                      | 3,862,223                    |
| 2021-06-20          | 3,852,134      | 3,834,145                      | 3,870,122                    |
| 2021-06-21          | 3,858,668      | 3,838,485                      | 3,878,851                    |
| 2021-06-22          | 3,869,031      | 3,846,601                      | 3,891,460                    |
| 2021-06-23          | 3,878,577      | 3,853,854                      | 3,903,300                    |
| 2021-06-24          | 3,887,389      | 3,860,048                      | 3,914,730                    |
| 2021-06-25          | 3,896,415      | 3,866,325                      | 3,926,504                    |
| 2021-06-26          | 3,903,964      | 3,871,027                      | 3,936,901                    |
| 2021-06-27          | 3,909,377      | 3,873,539                      | 3,945,214                    |
| 2021-06-28          | 3,915,482      | 3,876,668                      | 3,954,297                    |
| 2021-06-29          | 3,925,506      | 3,883,672                      | 3,967,340                    |
| 2021-06-30          | 3,934,653      | 3,889,740                      | 3,979,566                    |
| 2021-07-01          | 3,943,136      | 3,894,866                      | 3,991,406                    |
| 2021-07-02          | 3,951,788      | 3,900,027                      | 4,003,549                    |
| 2021-07-03          | 3,959,021      | 3,903,678                      | 4,014,365                    |
| 2021-07-04          | 3,964,084      | 3,905,094                      | 4,023,074                    |
| 2021-07-05          | 3,969,885      | 3,907,178                      | 4,032,593                    |
| 2021-07-06          | 3,979,580      | 3,913,105                      | 4,046,055                    |
| 2021-07-07          | 3,988,435      | 3,918,137                      | 4,058,733                    |
| 2021-07-08          | 3,996,610      | 3,922,231                      | 4,070,988                    |
| 2021-07-09          | 4,004,983      | 3,926,398                      | 4,083,567                    |
the natural process of decomposition. According to Hariyono (2015), the construction of a vertical cemetery represents an innovative investment project in favor of environmental preservation, as it is a controlled environment capable of adequately treating the generated waste (gases and liquids). However, the other 13.33% of the interviewees emphasize that treatment systems should be placed in horizontal cemeteries, and another 6.67% prefer to continue with direct burials in the ground, thus following the natural form of traditional burials. Consequently, 66.60% of respondents prefer the provision of cremation services (2), 53.33% attributed the need to implement an effluent treatment system (3), and gases (odors) (4) in the design of vertical cemeteries. Considering that the built structure attributed by 40% of respondents to be geared toward universal accessibility (5), 33.33% suggest the implementation of a ventilation system (6) and 26.66% of respondents see the need for sealing interment niches completely to contain all gas and liquid production (7) by the interviewed architects (Fig. 9).

In this relationship, items 1, 2, 3, 4, 5, 6 and 7 pointed out in greater expression by the interviewees were modeled in BIM (Fig. 9), according to (Oraee et al., 2019; Shirowzhan et al., 2020) facilitates greater visualization of the design sketch formed from design concepts. A vertical cemetery consists of a building intended for burial, cremation and funeral acts (Hariyono, 2015). However, the crematorium design needs to understand environmental parameters, with the allocation of gas filters generated during combustion of the body, preventing these environmentally harmful gases from being released into the atmosphere (González-cardoso et al., 2018). This could generate gases with ultra-fine particles, dispersing these dangerous elements into the atmosphere, and could cause harmful risks to human health (Oliveira et al., 2021a, 2021b). Therefore, the need to think of cleaner production as a way to reduce the emission of gases into the atmosphere, through the use of biological filters, considering the low carbon and sustainability measures aimed at environmental protection and preservation (Barbusinski et al., 2017; Wu et al., 2019) (Table 4).

The item 3 (Fig. 9) enhances the need for the treatment of biological fluids (necroslurry) generated by the decomposition of cadavers (Rajan et al., 2019). These generated effluents tend to increase due to the increasing number of deaths from COVID-19 that began at the end of 2019 (Alishaq et al., 2021; Berkley, 2020; Fauci et al., 2020). According to Haque (2020) and Kleywegt et al. (2019), an adequate effluent treatment system needs to comply with the environmental legislation of the country in which they will be installed. Emphasizing that the effluent treatment system in vertical cemeteries needs to be able to remove metals originating from the necroslurry, with pH correction (hydrogenionic potential) (Fernandes et al., 2018; Kleywegt et al., 2019).

As for the treatment of gases (4) released by the decomposition of corpses, according to Barbusinski et al. (2017), Oliveira Neto et al. (2018) and Ryals et al. (2019) have the need to carry out self-sustainable treatments, aimed at treating odors, harmful gases and biological organisms (viruses, bacteria, and fungi) harmful to human health. In addition to improving the quality of the environment, through the use of a biological filter aimed at reducing greenhouse gas emissions, thus raising environmental sustainability indices, through Table 4, shows that it is possible to visualize a preposition of vertical cemetery projects, which aimed at future indicators of Cleaner Production and environmental sustainability.

The public’s access through the vertical cemetery and to the crematorium depends on adequate levels of accessibility (5) allocated to the project. This is materialized, according to Neckel et al. (2021) for the use of accesses and ramps with widths and slopes that allow the movement of people through wide spaces. While it is hopeful that the lifespan of these structures will exceed the COVID-19 pandemic, it is unknown when another pandemic will
come (Munasinghe, 2020). Designing in the present for adequate future social distancing is encouraged whether current and future pathogens are easily transmissible or not (Tay et al., 2020).

Regarding the ventilation system (6), a vertical cemetery to be allocated in the project, according to the interviewees (Fig. 9), according to Neckel et al. (2017), Chen et al. (2020), Parhizkar et al. (2020) and Neckel et al. (2021), is intended for the control of the internal air of the detoxification, being characterized as a natural or mechanical system, with the ability to direct all possible odors to the exhaust system, thus avoiding the accumulation...
Table 4  Proposal for an ideal cemetery, utilizing the concepts of Cleaner Production and sustainability. \textit{Sources}: Indicators for cleaner production and sustainability in cemeteries based on the following studies: Hariyono (2015), Achawangkul et al. (2016), Yong et al. (2016), Barbusinski et al. (2017), Neckel et al. (2017), Morelli et al. (2018), Oliveira Neto et al. (2018), Giannetti et al. (2020), Azzara et al. (2021) and Neckel et al. (2021)

| Architects’ opinion         | Cleaner production                                                                 | Sustainability indicators                                                                 |
|-----------------------------|-----------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------|
| Vertical cemetery           | The physical structure itself needs to allow for the adequate treatment of contaminants generated in the natural process of decomposition of those entombed | Reduction of greenhouse gas emissions                                                      |
| Crematorium                 | The use of filters reduces atmospheric contamination                              | Reduction of greenhouse gas emissions                                                      |
| Effluent treatment system   | Adequate treatment of liquid effluent released by the decomposing bodies, protecting the environment from metal contamination | Pollutant reduction with effluent treatment system                                          |
| Gas treatment system (odors)| Through the use of biological filters, greenhouse gas emissions and the release of decomposition odors generated in the vertical cemetery and crematorium are reduced | Reduction of greenhouse gas emissions and odors                                           |
| Universal public accessibility | Large rooms with accessible aisles, emergency exits, elevators, access ramps with tactile floors and user guidance signs | Increased accessibility                                                                    |
| Ventilation system          | The ventilation system allows for efficient use of resources and energy, with the use of natural ventilation, reducing the monthly electricity costs of the building | Electricity sourced from renewable sources                                                 |
| Sealing of the interment niche | The sealing of the interment niche prohibits the release of contaminants to the communal area in the form of liquid effluents or gases | The visiting public is not exposed to potential pathogens and greenhouse gas emissions are reduced |
of fungi, viruses and bacteria to the living who are visiting and/or mourning the deceased. For Parhizkar et al. (2020) and Neckel et al. (2021), the use of natural ventilation needs to be considered in projects of vertical cemeteries, as it enhances the reduction of electricity costs, with the reduction in the use of mechanical ventilation. Consequently, the use of a ventilation system becomes a protection against possible leaks in the interment niches. However, the sealing of the front face of the interment niches (7) is extremely necessary to prevent the transmission of possible contaminants through the air (Neckel et al., 2017; Parhizkar et al., 2020). According to the National Council for the Environment of Brazil, described in resolution 335/2003, a project for vertical cemeteries needs to waterproof the niches in the deceased that are placed, thus ensuring their sealing (Brasil, 2003).

Items 1, 2, 3, 4, 5, 6 and 7 (Fig. 9), pointed out by respondents as a suggestion for future sustainable projects in the form of a vertical cemetery, being necessary not only for the city of Carazinho (southern Brazil), but for the development of other studies, or for the creation of public policies aimed at adapting cemeteries on a global scale. This study warns of contamination by metals in the soil and spreads from these traditionally built horizontal cemeteries to their neighboring areas, and the tendency is for this contamination to increase due to the high incidence of deaths caused by the epidemic of COVID-9 and motivates even more thinking about the construction of future vertical cemeteries (Fig. 9), which aimed at environmental sustainability (Abad-Segura et al., 2019).

### 4 Conclusions

This paper highlights the soilborne chromium pollution present in three urban cemeteries in a southern Brazilian city and highlights the presence of Cu, Fe, Mn, Pb and Zn, warning of a possible excess of these metals in larger cemeteries. Pandemics increasing rates of human mortality, such as COVID-19, create the need for hastily constructed burials as urban cemeteries are overwhelmed. Such increased rates significantly worsen soil contamination in cemeteries, compromising the quality of life of the surrounding population (Kemerich et al., 2012; Neckel et al., 2017; Silva et al., 2020). Pandemics are a regular part of human civilization, and COVID-19 will someday be followed by another pandemic. It is worth noting that the biggest limitation for carrying out this study is that the population still does not understand the cemetery as a factor of pollution, but rather its cultural importance.

This paper offers guidelines to public managers on the construction of new public burial policies. The interviewed architects described the characteristics of an ideal cemetery (1, 2, 3, 4, 5, 6 and 7). These seven variables in the BIM platform (El-Diraby et al., 2017; Liu et al., 2017; Neckel et al., 2021; Oraee et al., 2019; Wang et al., 2020) were efficient for modeling the design of vertical cemeteries.

This paper highlights the importance of incorporating CP principles when constructing new urban cemeteries (Table 4) to achieve a level of sustainability in this necessary facet of human civilization.

In vertical cemeteries, the implementation of effluent treatment systems, gas (odor) treatment, and sealing of the interment niche makes it possible to utilize Cleaner Production in urban cemetery design. To this end, the incorporation of natural ventilation systems as opposed to systems must be powered utilizing non-renewable resources, ensures sustainability.
The world is currently experiencing unprecedented number of hastily conducted burials caused by the high mortality rates of COVID-19 victims, between the years 2019, 2020 and 2021. This has the potential of significantly increasing the burden of soil metal contamination in cemeteries worldwide. Consistent monitoring in current cemeteries is suggested to ensure soil pollutants remain within allowable levels. When constructing new cemeteries, the paper suggests the use of CP principles in conjunction with a vertical design that allows for adequate treatment of gaseous and liquid effluent to prevent the release of pollutants to the surrounding environment. This study can be used as a methodology for other research aimed at environmental sustainability related to the construction of future cemeteries, given the current scenario of soil contamination of traditional cemeteries by metals and the high number of deaths caused by the COVID-19 epidemic on a global scale.

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**Authors and Affiliations**

**Alcindo Neckel**¹, **Cleiton Korcelski**¹ · **Luis F. O. Silva**² · **Henrique Aniceto Kujawa**³ · **Brian William Bodah**¹,⁴ · **Adriano Marcos Rodrigues Figueiredo**⁵ · **Laércio Stolfo Maculan**¹ · **Affonso Celso Gonçalves Jr.**⁶ · **Eliane Thaines Bodah**⁴,⁷ · **Leila Dal Moro**¹

¹ Faculdade Meridional (IMED), Rua Senador Pinheiro 304, Passo Fundo, RS 99070-220, Brazil
² Department of Civil and Environmental Engineering, University of La Costa, CUC, Calle 58 # 55–66, Barranquilla, Atlántico, Colombia
³ University of Perugia, Piazza Università, 1, 06123 Perugia, Italy
⁴ Thaines and Bodah Center for Education and Development, 840 South Meadowlark Lane, Othello, WA 99344, USA
⁵ Federal University of Mato Grosso Do Sul - UFMS, Cidade Universitária, Av. Costa E Silva, Pioneiros, MS 79070-900, Brazil
Center of Agrarian Sciences, State University of Western Paraná - UNIOESTE, Rua Pernambuco, 1777, Centro, Marechal Cândido Rondon, PR 85960-000, Brazil

State University of New York, Onondaga Community College, 4585 West Seneca Turnpike, Syracuse, NY 13215, USA