Revista Nacional de
Gerenciamento de Cidades
ISSN eletrônico 2318-8472, volume 11, número 82, 2023

Hazard Assessment of Soil Contamination resulting from Solid Waste Trench Landfill Systems

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ABSTRACT
Contamination due to the inadequate disposal of solid waste can cause irreversible environmental damage and public health risks. In the state of São Paulo (Brazil), legislation allows small municipalities to license landfills adopting the trench model. In most cases, it is not mandatory to carry out environmental protection works such as waterproof lining and the drainage of leachate and gases. The aim of this research was to evaluate soil contamination hazards resulting from Solid Waste Trench Landfill Systems (SWTLS). An consultation with experts was carried out in which a Hazard Level (HL) score was applied that considered factors such as geology, pedology, geomorphology, hydrography, groundwater, environmental protection, land use, composition and gravimetric demographic densities. A resource management unit, UGRHI 16 - Tietê Batalha Hydrographic Basin, was defined as the study area, where hazard level was identified to the trench landfill. It was also found that all the municipalities studied are exempt from installing linings in their landfills, in accordance with Brazilian standards, as water surpluses, analyzed in terms of local rainfall, comply with the limits established by regulation. However, the evaluation carried out as part of the present research considered other important factors, through which the existence of risks at different levels for all the municipalities evaluated in relation to the adoption of small SWTLS was noted. The study concluded that the factors adopted for the research are relevant to decision making in terms of system design and the definition of criteria regarding the need for protective lining.

KEYWORDS: Solid Waste Trench Landfill Systems. Soil Contamination by Waste. Small-sized Sanitary Landfills.

1 INTRODUCTION

Since the onset of urbanization, a constant increase in waste production has created the need for appropriate management to guarantee environmental preservation and quality of life for the communities that waste disposal systems serve. However, solid waste disposal in many Brazilian municipalities is inadequate, generating the potential for environmental liability.

Of the many processes involved in solid waste management, including collection, transportation, processing, recycling and disposal, waste disposal in a suitable solid waste landfill is the most important, as waste dumped in open spaces or inappropriate locations poses a serious threat to the environment and human health. In addition, population growth in urban centers has worsened the problem of solid waste management, especially in less-developed parts of the world, and solid waste management is now recognized as a major global concern (Kumar & Hassan, 2013; Rahman et al., 2008).

Aligning population growth with sustainable development is, therefore, seen as a significant challenge, one reflected in the United Nations' Sustainable Development Goals (SDG 3, Health and well-being; SDG 6, Clean water and sanitation; SDG 11, Sustainable cities and communities), and the National Solid Waste Policy (PNRS), with the latter initially establishing the abolition of landfills for solid waste disposal by 2014, with the deadline extended to 2023. It can be highlighted that the main methods of final disposal of domestic and commercial solid waste adopted by Brazilian municipalities are: sanitary landfills, controlled landfills, or open dumps. Of these three, the sanitary landfill is the only method considered appropriate. However, small municipalities may opt for simplified methods in implementing their landfills.

Nationally, waste disposal is governed by the CONAMA Resolution No. 404, (BRASIL, 2008), which establishes environmental licensing procedures for small-sized solid waste landfills; that is, those with daily waste disposal of up to 20 t (twenty tons) of solid urban waste. However, the limit is more restrictive in the state of São Paulo, where the daily limit is 10 t (ten tons), according to the Roadmap for the Preparation of an Environmental Study for the Implementation of Trench Landfills (with Project Capacity of up to 10 t/day - CETESB, 2018a.). Technical Standard NBR 15849, which was established in 2010, defines guidelines regarding the location, design, implementation, operation and closure of urban solid waste in landfills of this size (ABNT - NBR

15849, 2010). However, these guidelines do not include the mandatory implementation of environmental protection systems such as soil lining (waterproofing), leachate and gas drainage, and soil, surface and underground water monitoring.

When solid waste is disposed of without due consideration for environmental protection, irreversible contamination may occur, leading to ramifications for the municipality responsible in terms of the high costs involved with remedial and maintenance works. Montero and Peixoto (2013) also concluded, in their study on the vulnerability and risk of contamination of aquifers, through a correlation of identified vulnerabilities with potential sources of contamination, that, regardless of location, the disposal of solid waste inherently involves a high risk of contamination. Therefore, evaluating the impacts and remedial costs of environmental damage resulting from inadequate solid waste disposal practices is very important, not least because it highlights the understanding necessary to develop good policies.

Iwai (2012) considers trench landfills to be an unsustainable solution over time, since there remain questions about the possible creation of environmental liabilities in disposal areas, the need to preserve the quality of water and soil and, additionally, the availability of technological solutions, which are considered cleaner. The author also stresses that while these temporary systems remain in use, there is an imminent risk of recurring contamination, and a requirement, at the very least, to ensure regular monitoring.

Another relevant study is that carried out by Teixeira and Pansani (2002) of the municipal landfill area of Nova Odessa, SP state, and at the laboratory of the Faculty of Civil Engineering, Architecture and Urbanism (FEC/UNICAMP), in order to evaluate the contamination potential of landfills adopting the trench method. The authors point out the real threat of soil (and eventually groundwater) contamination from trench landfill systems, necessitating appropriate measures, such as bottom and (when necessary) sidewall lining.

Chemical contamination is a particular issue. Metals such as chromium, nickel and cadmium come from the disposal of rechargeable batteries, stainless steel, tanned leather, fabrics, and from dysfunctional electrical equipment containing alloys and waste materials, in which chromium and cadmium are used as anti-corrosive agents. Lead can also seep into the ground through paint and petroleum residues. The coating of mechanical parts, especially from oil exploration and maintenance industries, in addition to mechanical parts from vehicles, can also be a source of the nickel present in landfills (CEMPEL et al., 2006).

Although it is not possible to accurately assess whether the presence of metals near solid waste landfill areas is an exclusive function of such activity, or how much it affects the populations which such areas serve, landfills adopting the trench model tend not to be so well controlled. Research carried out in African countries shows that the proximity of housing complexes to waste disposal sites represents a quality-of-life risk factor for their populations.

Odai et al. (2008) reported that cadmium and lead levels in Ghana are much higher than the values recommended by the World Health and Food & Agriculture Organizations. The authors studied vegetables grown in the vicinity of three waste disposal sites located in Kumasi, a municipality in Ghana.

In Nigeria, a study carried out in Uyo assessed the levels of metals and metalloids in soils close to a municipal solid waste disposal site. The study aimed to provide information on the extent of contamination and the environmental and human health risks. The concentrations of metals and metalloids in the study areas were higher than those at a control site, and revealed that soil samples at distances of between 10 and 20 meters from disposal areas were highly polluted with cadmium, the environmental risk assessment carried out showing that cadmium contributed as much as 99% of the total risk. However, no health risks were observed as the hazard indices for other metals and metalloids were less than one, although the study assessed that children were more susceptible to contamination than adults (IHEDIOHA et al. 2017).

According to Samuding (2009), open-air waste dumps are still the main means of disposing of solid waste in the metropolis of Uyo. Waste is dumped indiscriminately, without provision being made for leaching control. Waste streams from various sources are sent to these dumps and, due to the heterogeneity and complexity of the waste, the resulting leachate contains a variety of contaminants, which seep into the groundwater.

As a consequence, soils can be contaminated with metals and metalloids such as lead, cadmium, zinc, iron, nickel, manganese and chromium. The migration of these contaminants from municipal solid waste sites into the soil surrounding them is a complex geochemical process (BOZKURT et al., 2002).

Metals and metalloids are ever-present in the environment and can accumulate to toxic levels. If such toxins are absorbed by plants grown near landfills and ingested by animals through pasture, they can reach the human food chain. Metals and metalloids are xenobiotics and pose a serious health risk. For example, lead and cadmium can cause liver and kidney damage, while zinc, copper and nickel, although essential minerals in small quantities, can be harmful in high concentrations (LUCKEY et al., 1977).

Despite the risks, the adequate management of urban solid waste is not often a priority for municipal public administrations and, therefore, investment is often sporadic. It is common to find locations that are, or have already been, used as dumps: freely-designated waste pockets or landfills which are inadequately cared for and therefore likely sources of contamination.

With these issues in mind, the objective of present study is to investigate the consequences of solid waste disposal in trench landfill systems. It is hoped that the research will stimulate reflection on waste management and facilitate decision-making, in addition to broadening knowledge of the hazard factors. Multi-criteria Decision Analysis (MCDA) will be used to achieve this objective.

According to Roy (1997), MCDA is a technique that is concerned with structuring and solving multi-criteria decision and planning problems, through the concepts of action and communication applied through the decision process. The purpose of MCDA is to support decision-makers in forming a conviction rather than determining an ideal. The application of MCDA in environmental studies has seen significant growth in the last decade (HUANG et al. 2011 and GUARNIERI, 2015).

Nascimento et al. (2017) used the MCDA method to develop a model for assessing susceptibility to environmental impacts at solid waste disposal locations. Their study methodology considered, among other issues, the selection of environmental decision factors and sub-factors. Nascimento (2012), who studied the development of a proposal for indications of areas for the implementation of a sanitary landfill in the Municipality of Bauru (SP), adopted geology, pedology, geomorphology, water resources and climate as relevant factors, with associated subfactors.

2 METHODOLOGY

2.1 Area of Study

The area chosen for the present study was the water resources management unit UGRHI-16, which covers the Tietê-Batalha Hydrographic Basin, located in the state of Sao Paulo, Brazil. The region is composed of, for the most part, municipalities profiled as of small size; that is, more than 50% of the municipalities in the area generate up to 10 t (ten tons) of household waste per day.

The Tietê-Batalha Hydrographic Basin comprises 36 municipalities, among which 27 are classified as small because they generate up to 10 tons of solid waste daily. However, 10 municipalities transship waste to private landfills and 17 have adopted the trench system for the final disposal of solid waste. For the latter group, anthropic and environmental factors or processes were profiled, in order to understand the fragility of each in terms of the workings of a solid waste trench landfill system (SWTLS).

2.2 Soil Contamination Hazard Assessment based on the Solid Waste Trench Landfill System

Having defined the overall study area, the Tietê-Batalha Hydrographic Basin, small-sized Solid Waste Trench Landfill Systems (SWTLS) were identified using geographic coordinates obtained following consultation with the Landfill Quality Indexes (LQI) of each municipality (CETESB, 2018b) and the UGRHI 16 map (IGC, 2011), on which the municipal boundaries are delineated. Then, using GIS QGIS 2.18.14, a map of the basin was produced with details of the 17 municipalities with SWTLS.

To carry out the hazard assessment for the present study on soil contamination resulting from SWTLS, it was decided to use Multicriteria Analysis (MCDA). The adoption of MCDA was two-pronged: to facilitate the decision-making process of the present study, and to create a proposal that could be utilized for other assessments and locations. It should be clarified that the specific methodology presented in Fonseca et al. (2008) was adopted, since their analysis considered both qualitative and quantitative aspects.

Fonseca et al (2018) carried out a Structured Multicriteria Assessment to understand expert opinion regarding the quality of cycleways in Brazil, based on the Structured Pairwise Comparison (SPC) method used by Sharifi et al. (2006) and Taleai et al. (2007) as an alternative to the Pairwise Comparison procedure usually adopted for the AHP (Analytic Hierarchy Process) method. In the case of Fonseca et al (2018), the method involved a literature review and the application of questionnaires sent to experts, which referred aspects relating to quality of cycling infrastructure. The experts were asked to rank them by importance, by which means investment priorities for the implementation of future cycling infrastructure could be identified.

For the present study on waste disposal, a consultation form was initially sent to sixteen experts. Eight responded to the questions posed. From these responses an assessment of pre-determined factors could be made, quantifying and ordering them according to their level of hazard and relevance. The specialists included undergraduate and graduate students from the areas of environmental geotechnics, hydraulics, hydrology, basic sanitation, geology, environmental and sanitary engineering, soil mechanics, agronomy (irrigation and drainage), as well as activities associated with the theme of sanitary landfills. One of the respondents claimed specialization in environmental analysis for earth sciences.

The factors were defined based on the literature review carried out, which considered the environmental impacts of similar systems, transport of pollutants, legislation, standards, resolutions and applicable guidelines, being: F1 (Geology), as geological characteristics can influence water infiltration, if rock formations are porous or have flaws; F2 (Pedology), being a characteristic that determines high or low terrain permeability; F3 (Geomorphology), since terrain shape influences runoff and flat areas are prone to infiltration and leaching; F4 (Hydrography), as it is a standard criterion that landfills are located at a minimum distance (> 200 m) from watercourses; F5 (Groundwater), considering standard criteria according to the depth of the water table; F6 (Environmental Protection Areas), due to the importance of respecting protected areas; F7 (Land Use), as it can result in the spread of contamination; F8 (Gravimetric Composition), knowing the percentage of organic matter in waste is considered relevant in relation to the generation of leachate; and F9 (Urban and Rural Densities), a factor that enables a better understanding of the distribution of the human population across the area studied and its influence on waste generation.

The consultation with experts was carried out using the Survey Monkey virtual platform. An invitation was sent by email to the short-listed experts, with a hyperlink giving access to a form with 10 questions. Respondents were asked to give hazard level (HL) scores, referring to the aspects identified in the study area for each factor evaluated, and to also classify the relevance of each factor.

In order to facilitate the assessment, the HL scores were applied using a range of 0 to 5, in which the lowest value related to situations of lesser hazard and the highest value to situations of greater hazard, defined as 0 to 1 "Very Low"; 1.1 to 2 "Low"; 2.1 to 3 "Medium"; 3.1 to 4 "High"; 4.1 to 5 "Very High".

Element prioritization was affected by attributing weights to each factor and each theme (aspect), obtained in consultation with the experts. Thus, using the SPC method as a reference, the degree of importance was analyzed by adding together the weights given by the respondents for each topic in respect of each factor evaluated. This sum was normalized so that its sum totaled 1 (one), as shown in Table 1. The normalized sum of the theme was then calculated using equation (01):

$$SNt = \frac{ST}{\sum ST} \tag{01}$$

In which: SNt is the normalized sum of the theme; ST is the sum of the scores applicable to a determined theme; $\sum ST$ is the sum total of all the themes.

Table 1 – Example of a Degree of Theme Importance, by Factor

Pedology topics	R1	R2	R3	R4	R5	R6	R7	R8	ST	SNt
Argisol	1	2	2	2	2	2	2	4	17	0.38
Oxisol clayey texture	4	4	3	3	5	3	3	2	27	0.61
Sum total									**44**	**1**

Note: R = respondent (8 specialists responded to the questionnaire)

To assign the weights of the factors, the data answered in consultation with the experts were initially added together. Then, a normalization formula (eq. 02) was applied to the sums obtained, which related to the relevance of the factors. To calculate the factor weights, it was necessary to perform the inversion by dividing 1 by the sum value, as the order of relevance was applied in such a way that score 1 was assigned to the most relevant factor, while score 9 was assigned to the least relevant factor; this is because the questionnaire required the experts to organize the 9 factors proposed in order of relevance. Equation (02) shows how the weights of the factors were calculated and normalized, after their inversion.

$$PF = \frac{1/SF}{\Sigma(\frac{1}{SF})} \quad (02)$$

In which: PF is the normalization of the factor; that is, the weight of the factor; SF is the sum of the factor; $\sum(\frac{1}{SF})$ is the sum total of all the factors.

The weights of the themes and factors were determined by a statistical balance applied to the scores given by the experts, with this data organized, as shown in Table 1, separately for each factor with its respective themes. These weights were later applied to the themes (aspects) identified in the municipalities studied. Thus, the Municipality Rating (MR) was calculated by multiplying the Hazard Level Rating (HLR) of the theme identified in the studied area by the Factor Weight (FW), according to equation (03).

$$MR = HLR \times FW \quad (03)$$

In which: MR is the municipal score; HLR is the Hazard Level Rating of the themes identified in the area studied; FW is the factor weight.

Once the municipality scores had been calculated for each topic, they were added and normalized by applying equations (04) and (05). It should be noted that for municipalities that do not have data for factor 8 (gravimetry), the sum of the weighting was derived from the sum of the Municipality Scores (MS) for the other factors, except F8, that is:

$$\sum MS *= MS \times F1 + MS \times F2 + MS \times F3 + MS \times F4 + MS \times F5 + MS \times F6 + MS \times F7 + MS \times F9 \quad (04)$$

In which: $\sum MS *$ is the sum total of the 8 municipal scores; $MS \times F\text{m}$ is the municipal score for each Fm factor.

The gravimetric factor appears to be irrelevant in this study, considering that the target group comprised small-sized municipalities with very similar gravimetric waste compositions. However, the methodology adopted proposes that this aspect be analyzed, due to its possible application in other areas of study with different characteristics. Furthermore, the percentage of organic matter is generated from data used in calculating the water surplus of a given landfill area.

For the other municipalities, the sum of the weighting was determined through the sum total of all the Municipality Scores (MS), that is:

$$\sum MS = MS \times F1 + MS \times F2 + MS \times F3 + MS \times F4 + MS \times F5 + MS \times F6 + MS \times F7 + MS \times F8 + MS \times F9 \quad (05)$$

In which: $\sum MS*$ is the sum total of the municipal scores; $MS \times F\mathrm{n}$ is the Municipal score for each $F\mathrm{n}$ factor.

These calculations were normalized separately for municipalities with and without gravimetry data, applying the equation (06):

$$\sum normalized = \frac{Maximum\ \text{-}\ Value}{Minimum\ \text{-}\ Value} \quad (06)$$

In which: $\sum normalized$ is the sum total of the normalized municipal scores; Value is the sum of the municipal scores ($\sum MS$); Maximum is the sum of MS in the most hazardous situation; Minimum is the sum of MS in the least hazardous situation.

The values obtained were classified into HL ranges, being 0 to 0.19 “very low”, 0.2 to 0.39 “low”, 0.4 to 0.59 “medium”, 0.6 to 0. 79 “high” and 0.8 to 1 “very high”.

3 RESULTS AND DISCUSSIONS

3.1 Profile of the area

The Geological Map of the State of São Paulo (IPT, 1981) was used to identify the geology of the areas studied, which are located on the Adamantina Formation. According to Mendonça and Gutierre (2000), these formations have predominantly sandy characteristics. Therefore, it could be concluded that all municipalities lie on rocks composed of sandstone, a material that has a high level of infiltration.

After spatialization on the Pedological Map for the state of São Paulo (IF, 2018; IDE, 2018), the predominant soil types in the landfill areas of the municipalities studied were identified according to Chart 1.

Chart 1- Pedology of Municipalities with Solid Waste Trenched Landfills, UGRHI 16

Municipalities	Pedology, Texture Order
Adolfo, Irapuã, P. Alves, Reginópolis, Sales	Oxisols (LV21), Medium
Guarantã	Oxisols (LV22), Clayey or Medium
Balbinos, Borborema, S. Ernestina, Cafelândia, Ibirá, Dobrada, Elisiário, Potirendaba	Argisols (PVA1), Sandy/Medium
Guaiçara, Marapoama and Sabino	Argisols (PVA4), Sandy/Medium or Medium/Clayey

Source: IF, 2018.

According to the Basin Plan (CBH TB, 2008), UGRHI 16 is located in the Geomorphological Province known as the Western Plateau. The Western Plateau Province is characterized by the presence of slightly undulating relief forms with long, low-formed slopes, principally represented by broad and medium hills with flattened tops. Using the geomorphological map of the Basin Plan (CBH TB, 2008), the relief characteristics of the SWTLS of the 17 municipalities studied were examined. Chart 2 presents this information, with the descriptions of each municipality evaluated. As can be seen, only the municipality of Balbinos, whose drainage is of medium to high density, is located within elongated hills and peaks.

Chart 2- Geomorphology of the UGRHI 16 municipalities with SWTLS

Municipalities	Geomorphology
Adolfo, Borborema, Guaiçara, Guarantã, Irapuã, Presidente Alves, Sabino and Sales	Broad Hills
Santa Ernestina, Dobrada, Elisiário, Marapoama, Ibirá, Cafelândia, Reginópolis and Potirendaba	Medium Hills
Balbinos	Elongated Hills and Peaks

Source: Tietê-Batalha River Basin Committee (CBH-TB), 2016.

The spatial distribution of the SWTLS across the drainage network of the State of São Paulo means that analyzing the distances of water bodies in relation to each landfill was possible. The analysis found that none of the SWTLS studied reached the minimum distance established by standards (> 200 m). However, the SWTLS within the municipalities of Sabino and Balbinos are very close to the limit. This is note-worthy, for when future installations are planned.

According to the LQI of the SWTLS in each of the municipalities studied (evaluated during a technical visit by CETESB), the permeability coefficients (P) of the soils were classified as either lower or higher than 10^{-6} cm/s. Values above 10^{-6} cam/s are considered inadequate. Municipalities whose landfills are at a depth range of 1 to 3 meters from the groundwater were identified. Values of less than 1 meter are considered inadequate (CETESB, 2018b). From the data evaluated, it could be concluded that the SWTLS in the municipalities studied are in compliance with the Brazilian technical standard ABNT - NBR 15849 (2010), as shown in Chart 3.

Chart 3- Water Table Depths (P) and Permeability Coefficients (k)

Cities	(P), (k)
Adolfo, Dobrada, Cafelândia, Elisiário, Guarantã, Guaiçara and Marapoama	P> 3 m, $k < 10^{-6}$ cm/s
Balbinos, Borborema, Ibirá, Irapuã, P. Alves, Reginópolis, S. Ernestina, Sabino, Sales and Potirendaba	1<= P <= 3 m, $k < 10^{-6}$ cm/s

Source: CETESB, 2018.

The spatialization of SWTLS operating within the Tietê Batalha river basin of the MMA Map of Conservation Units (CU) (2018) revealed that there are three SWTLS within the area of the APA Rio Batalha, created in 2001 and managed by the Secretariat of the Environment for the State of São Paulo. The municipalities are Balbinos, Reginópolis and Presidente Alves.

Additionally, through a spatialization of the SWTLS according to the CBH TB Watershed Land Use and Occupation Map (2008), the types of land use, within a radius of approximately 500 meters of each SWTLS, could be identified. It was also found that the basin area is predominantly occupied by sugarcane fields and pasture land. Chart 4 shows the uses and occupations of land in the regions of the SWTLS of UGRHI 16.

To profile the composition of solid waste generated, the municipalities that had carried out a gravimetric study (a process which involves an analysis of a sample of waste) presented their gravimetric data. This is given in Table 2. The other municipalities either do not have or did not provide data. The compositional data verified that the percentage of organic waste is consistently higher than the percentages for waste containing other components.

Chart 4- Use and Occupation of Land

Municipalities	Use and Occupation
Adolfo	Pasture and Crops
Balbinos, Cafelândia, Guaiçara, Sabino, Guarantã, Reginópolis	Pasture
Borborema, Irapuã	Sugarcane, Pasture and Perennial Crops
Dobrada and Santa Ernestina	Sugarcane
Elisiário, Ibirá, Marapoama, Potirendaba	Sugarcane and Pasture
Presidente Alves	Pasture, Reforestation and Wood
Sales	Pasture, Wood and Sugarcane

Source: Tietê-Batalha Hydrographic Basin Committee (CBH-TB), 2016.

Table 2 – Gravimetric Composition

(%)	Guaiçara	Marapoama	P.Alves	Reginópolis	Sales	Borborema	Elisiário	Guarantã
Plastic	20.0	14.0	20.0	18.0	14.0	10.0	15.0	10.8
Paper	12.0	9.0	14.0	10.0	5.0	4.5	7.0	19
Metal	9.0	1.0	2.0	4.0	3.0	1.5	1.0	2.3
Glass	2.0	9.0	1.0	1.0	6.0	0.0	1.0	2.7
Organic	46.0	59.0	51.0	60.0	47.0	77.0	60.0	45.7
Other	11.0	8.0	12.0	8.0	25.0	7.0	16.0	19.5

Source: Rodrigues, 2019.

3.2 Soil Contamination Hazard Levels in terms of Solid Waste Trench Landfill Systems (SWTLS)

The consultation with experts enabled the order and degree of relevance of the aspects identified and the factors studied to be estimated, so that the appropriate weights could be applied when calculating the hazard levels arising from each SWTLS.

The factors were ranked according to the responses from experts, using a progressive rating scale from 1 to 9, in order of relevance. Table 3 shows the weights of the factors obtained through the normalized sums of the 9 factors studied and Table 4 gives the order of relevance of the 9 factors studied, which were obtained through the weights of the factors, after normalization.

Table 3 – Weights of the factors

FACT.	REL.	R1	R2	R3	R4	R5	R6	R7	R8	SF	1/SF	PF
F1	4	9	3	5	1	6	5	2	7	38	0.026	0.100
F2	2	8	1	2	6	5	2	1	1	26	0.038	0.146
F3	8	7	8	9	7	7	6	6	2	52	0.019	0.073
F4	3	1	5	6	5	3	4	4	6	34	0.029	0.111
F5	1	2	2	1	2	1	1	3	3	15	0.067	0.252
F6	5	6	6	4	3	2	9	5	4	39	0.026	0.097
F7	7	5	9	3	9	4	7	7	5	49	0.020	0.077
F8	6	3	4	8	4	8	3	8	8	46	0.022	0.082
F9	9	4	7	7	8	9	8	9	9	61	0.016	0.062
Sum total											**0.264**	**1.000**

Note: *FACT. = Factor; REL. = Relevance

Table 4 – Order of relevance of the factors

Relevance	1st	2nd	3rd	4th	5th	6th	7th	8th	9th
Factor	F5	F2	F4	F1	F6	F8	F7	F3	F9

Revista Nacional de
Gerenciamento de Cidades
ISSN eletrônico 2318-8472, volume 11, número 82, 2023

The result of the order of relevance classification of the factors analyzed showed the greater relevance of factors F5 (Groundwater), F2 (Pedology) and F4 (Hydrography) for determining the hazard levels at the SWTLS studied.

The scores obtained for each aspect identified in the study area were applied, and multiplied by the weight calculated for their respective factors. The scores calculated for each municipality (MR) referring to each factor were normalized, and then added and later normalized, as described in the methodology.

It should be noted that it was necessary to carry out the calculations separately for municipalities with and without solid waste gravimetry data, so that the absence of this data would not interfere with the results for municipalities that had supplied this information.

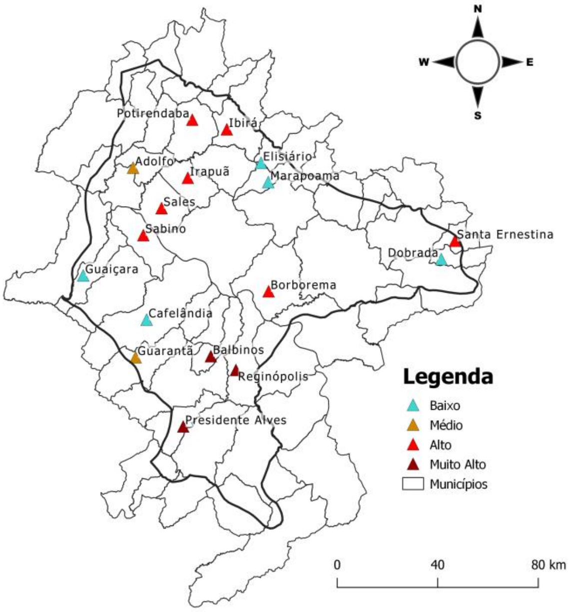
Chart 5 and Figure 1 show the hazard levels of each municipality studied, identified in the Hazard Assessment developed by the study.

Chart 5- Summary of the Hazard Levels

Municipalities	Hazard Level
Cafelândia, Dobrada, Elisiário, Guaiçara and Marapoama	Low
Adolfo and Guarantã	Medium
Borborema, Ibirá, Irapuã, Potirendaba, Sabino, Sales and S. Ernestina	High
Balbinos, Presidente Alves and Reginópolis	Very High

Source: Rodrigues et. al, 2014.

Figure 1 - Hazard Map for the UGRHI 16 area SWTLS studied



1.2.1 Discussion considering the water surplus

The ABNT - NBR 15849 (2010) defines criteria for exempting waterproof lining, and includes variables such as permeability, water surplus, the organic fraction of waste and the depth of the water table.

The Water Surplus (WS) analysis parameter is obtained, based on a series of average annual rainfall, temperatures and surface runoff coefficients; that is, taking into account the weather patterns for the region studied. This value was determined through the National Institute of Meteorology (INMET, 2018) portal, by inputting the geographic coordinates of each location, considering that INMET provides official data based on the weather stations closest to the coordinates entered.

Table 5 shows the WS limits established, depending on the organic fraction of waste, the permeability coefficient of the local soil and the water surpluses obtained. To establish WS values, the geographic coordinates of the landfill areas and the types of soil were identified, considering sandy soil for the oxisols and clayey soil for the argisols, and the soil permeability coefficients verified in the LQI forms as <10-6cm/s. The organic fraction of the waste was considered according to the gravimetric compositions identified, which amounted to more than 30% organic composition across the landfills studied.

Table 5 – Water Surplus Values obtained and the Exemption Limit for lining (waterproofing)

Title	Soil type	Waterproofing coefficient of the local soil k (cm/s)	Depth of Water Table (m)	Organic Waste percentage (%)	Water Surplus - WS (mm/aa)	Maximum WS for Lining Exemption ABNT - NBR 15849 (2010)
Adolfo	sandy	$k \leq 1x10^{-6}$	P> 3	>30%	118	188
Balbinos	clayey	$k \leq 1x10^{-6}$	1 <= P <= 3	>30%	21.68	188
Borborema	clayey	$k \leq 1x10^{-6}$	1 <= P <= 3	>30%	18.23	188
Cafelândia	clayey	$k \leq 1x10^{-6}$	P> 3	>30%	24.24	188
Dobrada	clayey	$k \leq 1x10^{-6}$	P> 3	>30%	54.98	188
Elisiário	clayey	$k \leq 1x10^{-6}$	P> 3	>30%	23.42	188
Guaiçara	clayey	$k \leq 1x10^{-6}$	P> 3	>30%	30.7	188
Guarantã	sandy	$k \leq 1x10^{-6}$	P> 3	>30%	109.86	188
Ibirá	clayey	$k \leq 1x10^{-6}$	1 <= P <= 3	>30%	31.39	188
Irapuã	sandy	$k \leq 1x10^{-6}$	1 <= P <= 3	>30%	114.51	188
Marapoama	clayey	$k \leq 1x10^{-6}$	P> 3	>30%	21.5	188
Potirendaba	clayey	$k \leq 1x10^{-6}$	P> 3	>30%	26,42	188
P. Alves	sandy	$k \leq 1x10^{-6}$	1 <= P <= 3	>30%	109.71	188
Reginópolis	sandy	$k \leq 1x10^{-6}$	1 <= P <= 3	>30%	103.17	188
Sabino	clayey	$k \leq 1x10^{-6}$	P> 3	>30%	24.7	188
Sales	sandy	$k \leq 1x10^{-6}$	P> 3	>30%	114.16	188
S.Ernestina	clayey	$k \leq 1x10^{-6}$	1 <= P <= 3	>30%	58.68	188

The criteria for lining (waterproofing) system exemption were analyzed, as established by ABNT - NBR 15849 (2010), a comparison being made between the WS results obtained for the areas studied and the maximum WS necessary for lining exemption, according to the profiles of the locations - assuming a WS of 188 mm/aa for all the SWTLS sites evaluated (Table 5).

By this means it could be verified that the WS of the areas studied do not exceed the limit established by the standard, and are therefore considered exempt from mandatory lining. However, based on the assessment carried out for the municipalities of UGRHI 16, which considered other factors relevant to the issue for analysis, it was found that hazards prevailed at different levels across all municipalities profiled in relation to the adoption of SWTLS.

Although the results of the research show that the municipalities studied are exempt from the need for lining, some of the SWTLS were profiled as having high or very high levels in the hazard assessment: Balbinos, Presidente Alves and Reginópolis being “Very High” and Borborema, Ibirá, Irapuã , Potirendaba, Sabino, Sales and Santa Ernestina being “High”.

Therefore, the analysis of environmental and anthropic factors or processes adopted in this research are considered relevant for decision-making in other systems designed for the disposal of solid waste in landfill, as well as for defining lining (waterproofing) exemption criteria.

3 CONCLUSIONS

The results indicate that SWTLS hazard levels, depending on local characteristics, have a greater or lesser likelihood of causing contamination of the soil, surface and underground water in the vicinity. In a general analysis of the seventeen municipalities analyzed, three were identified as having a “very high” level of contamination hazard, namely: Balbinos, Presidente Alves and Reginópolis. Notably, the SWTLS at Presidente Alves and Regionópolis are situated in areas where the soil is highly permeable. The three “very high” level risk SWTLS have low groundwater depth and are within an Environmental Protection area (APA).

The SWTLS classified as “high” hazard level included the municipalities of Borborema, Ibirá, Irapuã, Potirendaba, Sabino, Sales and Santa Ernestina. The low permeability of the soil in these regions, however, is offset by the fact of low water table levels.

The SWTLS in the municipalities of Adolfo and Guarantã were classified as of “medium” hazard level, and in the SWTLS of the municipalities of Dobrada, Elisiário, Marapoama, Cafelândia and Guaiçara the hazard levels were classified as “low”. No municipality was classified as being of a “very low” hazard level.

In conclusion, this assessment of environmental and anthropic processes identified factors through which Sold Waste Trench Landfill Systems (SWTLS) can be profiled. The study acts as a guide for the ordering and planning processes of Solid Waste Management in the Hydrographic Basin and in the municipalities covered.

Furthermore, the methodology developed for this Hazard Assessment of soil contamination in SWTLS could be applied to assess other locations, be it a specific area, municipality or region.

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