ISSN:1984-2295

Revista Brasileira de Geografia Física

Homepage: www.ufpe.br/rbge

Geocological and legal approach to the study of solid waste landfill adequacy on the Pontal do Paranapanema watershed, São Paulo

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Artigo recebido em 28/11/2017 e aceito em 04/04/2018

ABSTRACT

The objective of this study was to apply a geocological approach to evaluate the conditions of the areas occupied by the 22 solid waste landfills located in Water Resources Management Unit (UGRHI) 22, to analyze if these landfills meet current legal restrictions. The method proposed consists of two main stages: creating a thematic map to represent the geocological state of the UGRHI-22 and producing a legal restriction map of the landfills. The geocological map results based on the combination of different natural components of the region, such as geology, geomorphology and pedology, applied with different weights, resulting in five classes of geocological states: homeostatic; moderate-homeostatic; intermediate; moderate-fragile and fragile. For mapping the legal restrictions on landfills, we applied laws and related ordinances such as minimal distances of urban areas, water bodies, airport security, highways and conservation units. Results show 50% of the landfills operating in UGRHI-22 are in areas of lesser or not recommended geocological classes and not in accordance with the required legal standards. We concluded that the geocological approach enables the study of the consequences of the solid waste improper disposal by relating soil geological and geomorphological aspects of the region.

Keywords: thematic map; geocological state; solid waste landfills; environment.

Abordagem geocológica e jurídica para estudo de adequação de aterros de resíduos sólidos na bacia hidrográfica do Pontal do Paranapanema, São Paulo

RESUMO

O objetivo deste trabalho é aplicar uma abordagem geocológica para avaliar as condições das áreas ocupadas pelos 22 aterros de resíduos sólidos na Unidade de Gerenciamento de Recursos Hídricos (UGRHI) 22, assim como analisar se tais aterros atendem às restrições legais vigentes. O trabalho foi subdividido em duas grandes etapas: elaboração de um mapa temático para representar o estado geocológico da UGRHI-22 e produção do mapa de restrição legal dos aterros. Para a elaboração do mapa do estado geocológico adotou-se uma combinação de diferentes componentes naturais da região, tais como a geologia, geomorfologia e pedologia, aos quais foram aplicados diferentes pesos, resultando em cinco classes de estado geocológico: homeostático; moderado-homeostático; intermediário; moderado-fragilizado e fragilizado. Para o mapeamento das restrições legais dos aterros, foram aplicadas leis e portarias relacionadas, como distâncias mínimas de áreas urbanas, corpos hídricos, da segurança aeroportuária, das rodovias e das unidades de conservação. Os resultados apontam que, atualmente, 40% dos aterros em operação na UGRHI-22 encontram-se em áreas de classes geocológicas pouco ou não recomendadas, bem como não estão de acordo com os parâmetros legais exigidos. Conclui-se que a abordagem da geocologia viabiliza o estudo das consequências da disposição incorreta dos resíduos sólidos, por relacionar, dentre outros, aspectos pedológicos, geológicos e geomorfológicos da região.

Palavras-chave: mapa temático; estado geocológico; aterros de resíduos sólidos; meio ambiente; geocologia.

Introduction

Inadequate disposal of solid waste is among the anthropogenic activities with highest potential for negatively impacting the environment. Areas where solid wastes are deposited require specific geotechnical conditions that meet minimum standards, both physical and operational (Boskov, 2008). Thus, the characterization of the physical environment is essential to evaluate the capacity of these areas to withstand the impacts from these deposits. In the process of characterizing the environment, a relevant step is mapping its natural components, as this helps improve landfill site selection as well as the monitoring of these areas (Moraes et al., 2010).

In accordance with Farias (2002) and the Solid Waste Landfill Quality Index (IQR) used by the Environmental Sanitation Technology Company (CETESB), Loureiro (2005) presents suitability parameters for solid waste deposits and emphasizes the need to improve the infrastructure and operational aspects of these sites. Among these parameters, Loureiro highlights the need to install gas drainage, slurry and rainwater systems, landfill area monitoring by means of surveillance to control fires and the presence of animals and illegal garbage collectors, the daily covering of the solid waste, waterproofing of the trenches and slurry treatment. Regarding the geotechnical aspects, the criteria of Moreira et al. (2008) consist of a minimum depth for the excavated cell of at least three meters above the rocky substrate and four and a half meters from any underground water, as well as describing the complications associated with different slopes on the terrain.

It is worth noting the legal parameters for waste landfill areas. For example, CETESB requires a minimum distance of 200 meters (m) from water bodies and highways. There is also a minimum distance of 500 m from any population center, restrictions near airport facilities, which must have a radius of 20 km for routes that operate with IFR (Instrument Flight Rules), as well as 13 kilometer restriction for other airdrome (CONAMA 04/1995), and a restriction of 10 kilometers from conservation units (CONAMA 13/1990).

The objective of this work was to evaluate the conditions of the areas occupied by solid waste deposits located in Water Resources Management Unit (UGRHI) 22, known as the Pontal do Paranapanema basin, based on a geoecological and

legal approach. For the purpose of the present work, we use the term “solid waste deposits” to describe all the municipal landfills, whether they are sanitary, controlled or even dumpsites. Our hypothesis was that a map of geoecological state assists in the identification of areas of greater or lesser support capacity for the final destination of solid waste. Another important contribution of this work was the verification of the destination of the residues, not only with the physical environment but also within the legal parameters imposed on this part of São Paulo state.

Materials and Methods

Study Area

The study area was the UGRHI-22, with 22 solid waste landfills in use (**Figure 1**). According to the 2010 census, conducted by the Brazilian Institute of Geography and Statistics (IBGE), there are 300,203 inhabitants in the 22 corresponding municipalities.

Geologically, the UGRHI-22 represents the Caiuá, Santo Anastácio and Adamantina (K_{aI} , K_{aIV} and K_{aV}) formations of the Bauru Group, and the Serra Geral Formation, belonging to the São Bento Group (Almeida et al., 1981). According to the classification of Ross and Moroz (1996), UGRHI-22 has Colinas Amplas (D_c), Colinas Baixas (D_t) and Planícies and Terraços Aluviais.

With regard to the soils, the region is predominated by podzolic soils, such as Argissolo Vermelho and Vermelho-Amarelo, latosols, as Latossolo Vermelho and Vermelho-Amarelo, Nitossolo Vermelho, Neossolo Litólico and Gleissolo Háplico (EMBRAPA, 1999).

The climate is subdivided according to Boin's classification (2000), in climatic units in the regions of Iepê ($BIII_m$), Presidente Prudente ($BIV_{m\alpha}$) and Pontal do Paranapanema ($BIV_{m\beta}$). In the UGRHI-22 the frontological mechanisms created by the participation of the Maritime Polar air mass are confronted with the Maritime Tropical air mass, promoting rainfall precipitation in this sector and, thus, its subtropical climate.

Finally, the vegetation is divided between native species of Atlantic Forest (Semideciduous Seasonal Forest), Cerrado and Transitional Forests between both biomes (IBGE, 2012).

Figure 1 - Limits of UGRHI-22 and locations of solid waste deposits.

Producing the Geocological Map

In order to relate the characteristics of the physical environment to the geotechnical conditions where solid waste landfills are located, it is necessary to identify the potentialities and fragilities of the natural environment. The determination and understanding of these properties can be obtained by mapping the geocological conditioners of the area, thus synthesizing information from the natural environment. In order to map the elements of the physical environment, the geocological approach was applied through the use of the map algebra technique (Longley et al., 2013), which makes it possible to determine the potentialities or environmental fragilities of a region.

While producing the geocological map, the concepts of Tricart (1977), Amaral and Ross (2006) and Rodrigues et al. (2013), as well as the technique described by Crepani et al. (2001) were applied. The map of the geocological state

consists of a thematic map (Martinelli, 2014), which one can use to evaluate whether the areas of the 22 landfills in the Pontal do Paranapanema basin are appropriate for receiving the negative impacts caused by such anthropogenic action.

The thematic maps used in the synthesis of the geocological state map correspond to those that represent the main natural aspects of the studied region, such as geology, pedology, geomorphology, vegetation, declivity and erosion susceptibility (**Table 1**). All thematic maps are at the 1:250,000 scales and made available by the Cooperative of Services and Technological and Industrial Researches (CPTI), in 1999.

A total of five classes were defined to represent the geocological state of UGRHI-22, being: **Homeostatic** state; **Moderate-Homeostatic** state; **Intermediate** state; **Moderate-Fragile** states; and **Fragile** state. These classes are the result of map algebra performed with the above-mentioned thematic maps, where weights were applied from one to five, as shown in

Table 1. The denomination of each geoeological state is based on the work of Mateo-Rodrigues et al. (2013) and the weight values are an adaptation of Crepani et al. (2001), considering the particularities of the study area and observing the potential environmental risks of having a solid waste deposit for the region. The weights, ranging from 1 to 5, were defined according to subjective criteria, linked to the experience of professionals related to the area, previously consulted during the

research of this work, and also based on the description of the literature indicated previously. Classes of lower fragility correspond to those where it is favorable to pedogenesis, while the classes of greater fragility were defined according to their tendencies to favor morphogenesis, as well as to present greater vulnerability in relation to water resources, superficial and underground.

Table 1 – Values used in each class for the geoeological synthesis map of UGRHI-22

Component	Classification and weight referring to fragility (1 to 5)
Geology	Serra Geral Formation (1); Caiuá Formation (2); Santo Anastácio Formation (4); Formation Adamantina Ka ₁ (3), Ka _{IV} (5) and Ka _V (5).
Geomorphology	Colinas Amplas (1); Colinas Baixas (3); Planícies and Terraços Alúviais (5).
Pedology	Latossolo Vermelho (1); Nitossolo Vermelho (2); Argissolo Vermelho and Vermelho-Amarelo (3); Gleissolo (4); Neossolo (5).
Erodibility	Low (5); Middle-Low (1); Average (2); Middle High (3); High (4).
Declivity	Below 15% (1); Above 15% (5).
Vegetation	Atlantic Forest (1); Cerrado (1); Grassland (3); Alluvial Forest (4).

Table 2 - Classification of the geoeological state for UGRHI-22

Class	Description
Homeostatic	Balanced natural conditions, favoring the development of deep soils. Relief is essentially flat, with a slightly uneven topography and low degrees of dissection. The susceptibility to erosion in these areas is low, presenting low drainage density with interfluvies more distant from each other. There is a strong presence of arboreal vegetation, corresponding to fragments of great expression.
Moderate-Homeostatic	Presents greater predominance of the pedogenetic processes, which favors the development of deep soils. Topography is not very rugged, with low degrees of dissection and low slope indices. The relief is flattened and related to a low or medium density of drainage, with greater distance between the interfluvies of the water channels carved in the valley bottoms. Fragments of arboreal vegetation are common in this state.
Intermediate	Characterized as a means of balancing between pedogenesis (soil formation) and morphogenesis (land formation). In these environments, the topography is not highly rugged and the degree of relief dissection is medium, with a greater distance between its interfluvies and medium drainage density than the previous categories. Soils are shallow, but more developed compared to those found in rough reliefs.
Moderate-Fragile	In this class the erosive processes are intense, but not as aggressive as the 'Fragile' state. The areas present rugged topography, with high classes of declivity. The high drainage density is associated with regional hydrogeological characteristics. The soils are shallow, covered by fragments of arboreal vegetation of lesser expression than other areas.
Fragile	Corresponds to sectors susceptible to erosive processes as a means of intensive morphogenic action. Topography is rugged and marked by high slope classes. Soil is normally shallow and the relief breaks abrupt, with slopes equivalent to 15% or more, eventually exposing rocks. The relief is strongly undulated, dissected and with a greater branching of the hydrographic system. This results in moist areas, such as groundwater exposed on the half-slope and by the upper sides of the watercourses, as well as in alluvial plains and terraces and floodplain areas of the region's largest rivers. In turn, the presence of arboreal vegetation, is small or even null.

Production of the Legal Restriction Map

Environmental agencies and legislation establish guidelines for the legal ordering of solid

waste landfill activities. Among the main guidelines, we highlight the minimum distances of landfills in relation to any water bodies, urban areas, airdromes, highways and conservation units. We considered 200 m lengths for the water bodies, corresponding to the main water courses (rivers, streams and streams) of the region (MINTER Ordinance 124/1980); (CETESB, 2015); 13 km and 20 km for airdromes (CONAMA 04/1995) and 10 km for the conservation units (CONAMA 13/1990). In the study case, the airports of Presidente Prudente (SP) and Presidente Epitácio (SP), which operate according to the IFR, received the minimum length of 20 km, while the airdromes received 13 km.

With regard to the urban areas, road system and airdromes, we used products made available by the Brazilian Institute of Geography and Statistics (IBGE) database. For the water collections, we used data from the São Paulo State Environment Department (SMA), in the 1: 50,000 scale, were

used, and the conservation units were acquired through the Geobank of the Mineral Resources Research Company (CPRM). After the data were organized, the required buffer was applied to each of these vectors, creating separate polygons. We chose to assemble and represent these polygons on a map of legal restrictions for the adequacy of solid waste landfills in the region, adopting methodology similar to Calijuri et al. (2002) and by Moreira et al. (2010). This map of restrictions was then subdivided (map A and map B) to facilitate its visualization.

Results and Discussion

Figure 2 shows the map of the geoecological state of the 22 solid waste landfills in the UGRHI-22. **Figures 3** and **4** show the map of legal restrictions on the installation and operation of these 22 municipal solid waste landfills in the same region.

Figure 2 - Map of geoeological states and solid waste landfills in UGHRI-22 (SP).

Figure 3 - Map (A) of legal restrictions on the installation and operation of solid waste landfills in UGRHI-22 (SP).

Figure 4 - Map (B) of legal restrictions on the installation and operation of solid waste landfills in UGRHI-22 (SP).

The geoeological state class of the type **Fragile** shall not contain landfills or any other forms of final disposal of solid waste. The reason for this restriction is due to the low capacity to support this type of activity, because of the shallow soil depths shallow soils (**Figure 4**), as well as the alluvial deposits adjacent to the fluvial channel.

Three of the 22 solid waste landfills are located in areas of greater fragility: the Anhumas, Regente Feijó and Taciba landfills (**Figure 2**). The

municipal landfill of Anhumas is located on atop a hill, which guarantees a more privileged position compared to the others, with a safer distance from the nearest water resource. Nevertheless, the risk of the Anhumas landfill contaminating the water body is high, since the area presents high slope values (>15% and 20%). The other two landfills, from Taciba (**Figure 5**) and from Regente Feijó, lie near water courses, with low depth soils and rugged topography.

Figure 5 - Soil depth in Presidente Prudente (left) and solid waste disposal in the Taciba landfill (right).

The **Moderate-Fragilized** class is characterized by shallow soils, young soils (**Figure 6**) and rugged topography. Therefore, these areas are at risk of contamination by solid waste landfills. Thus, any landfills installed in this category should receive constant monitoring. The UGRHI-22 landfills identified in this geoeological class are located in the municipalities of Indiana, Marabá Paulista, Martinópolis, Pirapozinho, Presidente Bernardes, Venceslau and Santo Anastácio (**Figure 2**). Among these, the landfills of Indiana and

Marabá Paulista are in better natural conditions, with more flattened relief.

The municipal landfill of Martinópolis, in spite of the soil being deeper than the others, is next to some drainage areas. In Pirapozinho and Presidente Bernardes, solid wastes are deposited on a spring of the local water table (**Figure 6**). In Santo Anastácio, the soil depth is low in the landfill, since blocks were excavated in most of the ditches during field visits in 2014, rock, which indicates the presence of the low depth of its soils.

Figure 6 - Corrugated relief with soil exposure in Pirapozinho (left) and excavated area with groundwater in the Presidente Bernardes landfill (right).

As for the **Intermediate** class, we verified that it comprises a great territorial portion of the basin of the UGRHI-22 (**Figure 2**.) This geoecological state presents characteristics favorable to the installation and operation of solid waste landfills, since the soils found in this type of class are more developed when compared to the **Fragile** and **Moderate-Fragile** classes. Moreover, the declivity and its topography characterize some flat reliefs at its higher portions (**Figure 7**). These physical conditions of the environment allow greater control and safety to the installation of

landfills, which assists in getting solid waste to the correct destination.

The UGRHI-22 solid waste landfills in the **Intermediate** geoecology class belong to the municipalities of Caiuá, Estrela do Norte, Mirante do Paranapanema and Tarabai (**Figure 7**). These landfills share similar geotechnical conditions, such as a flat relief, relatively deep soils and excavated ditches about three to four meters deep, with good permeability and reduced infiltration capacity.

Figure 7 - Top of convex relief with small fragments of vegetation in Mirante do Paranapanema (left) and burned waste in landfill of Tarabai (right).

The **Moderate-Homeostatic** state has well developed soils, with deeper rocky substrate than the geoecological classes already mentioned, as well as flat reliefs, which contributes to the geoecological picture of these areas (**Figure 8**). It

is also contains vegetation fragments, which contribute to the stabilization of the natural landscape. Thus, the presence of a solid waste landfill in these areas, even if adequate, should be

restricted, and it cannot cause conflicts with other areas of greater fragility.

Figure 2 shows that the landfills located in areas classified in the **Moderate-Homeostatic** geocological class belong to the municipalities of Euclides da Cunha Paulista, Iepê, Nantes, Narandiba, Presidente Epitácio, Rosana, Sandovalina and Teodoro Sampaio. These landfills were installed in areas with favorable geotechnical conditions. The solid waste landfill of Iepê stands out due to its soil being more clayey, of the

Nitossolo Vermelho type (EMBRAPA, 1999), which offers greater support for solid waste disposal.

Another exception is the landfill of Presidente Epitácio (**Figure 8**), because this area is close to alluvial terraces, i.e., extremely vulnerable water collections. Nevertheless, this place is isolated and, like the other municipalities, offers a soil of good depth on a flatter relief than the other municipalities in this category.

Figure 8 – Flat relief with fragments of vegetation in Presidente Bernardes municipality (left) and solid waste landfill of Presidente Epitácio (right).

The class containing the so-called **Homeostatic** geocological state is characterized by a higher concentration of fragments of natural vegetation and characteristics of greater geocological stability (flat relief and deep soil) when compared to other geocological classes of the territory covered by UGRHI-22. An example of these fragments of natural vegetation is the Morro do Diabo Ecological State Park (**Figure 9**), in the municipality of Teodoro Sampaio. This park represents the last large Atlantic Forest reserve in

the interior of the state of São Paulo, known as Semidecidual Seasonal Forest (IBGE, 2012).

There are also other fragments of vegetation found in this **Homeostatic** class, which corresponds to protected reserves. In these areas of this geocological state, protection is recommended since they are stabilized in relation to their natural properties. None of the 22 solid waste landfills of UGRHI-22 were found on this geocological class (**Figure 2**).

Figure 9 - Forest cover in the Morro do Diabo reserve, seen from a distance (left) and with a view of the top (right), in Teodoro Sampaio municipality.

Table 3 shows the classifications of the 22 solid waste landfills, in relation to four of the five geoecological classes defined by the geoecological map (**Figure 2**). Analyzing the geographical

location of landfills (**Figure 1**), in relation to the legal restriction map (**Figures 3 and 4**) shows which municipalities do not meet the legal requirements.

Table 3 - Distribution of solid waste landfills according to their geoecological state and legal restrictions violated at the UGRHI-22

Geoecological State	Landfills	Legal Restriction	Landfills
Homeostatic	00	Water bodies	03
Moderate-Homeostatic	08	Urban areas	04
Intermediate	03	Aerodrome	15
Moderate-Fragile	07	Road system	13
Fragile	04	Conservation units	03

In 2015, CETESB evaluated these 22 landfills through the IQR (**Table 4**). In most of the 22 municipalities, the daily production of residues is proportional to the number of inhabitants. The IQR of these landfills in 2015 demonstrates that

most of the municipal deposits (with the exception of Pirapozinho and Presidente Epitácio) are in adequate condition, i.e., within the minimum required standards for water body distance, slope, etc.

Table 4 - Evaluation by CETESB of UGRHI-22 waste landfills

City	IQR	City	IQR	City	IQR
Anhumas	8.4	Mirante do Paranapanema	7.2	Rosana	7.4
Caiuá	7.5	Nantes	9.5	Sandovalina	7.2
Estrela do Norte	7.4	Narandiba	7.4	Santo Anastácio	7.2
Euclides da Cunha Paulista	7.1	Pirapozinho	3.6	Taciba	7.1
Iepê	7.9	Presidente Bernardes	7.2	Tarabai	9.0
Indiana	8.6	Presidente Epitácio	6.1	Teodoro Sampaio	7.8
Marabá Paulista	7.3	Presidente Venceslau	9.4		
Martinópolis	7.1	Regente Feijó	7.3		

Source: CETESB (2015).

It is possible to make comparisons with the constraints found in the geoecological state map. As shown in **Table 3**, results show that, of the 22 landfills, at least 15 are in illegal conditions for violating CONAMA 04/1995, while three landfills are violating the MINTER Decree (124/1980), four landfills are less than 500 meters from the urban perimeter (CETESB, 2015) and 13 are less than 500 m from the road system (CONAMA 04/1995), as well as 3 landfills are within 10 km of conservation units (CONAMA 13/1990). This shows that many of the landfills infringe on more than one of the minimum distances, raising a counterpoint to the positive IQR assessment. Of the total landfills, 11 are located in inappropriate natural areas, corresponding to 50% of the solid waste deposits in the Pontal do Paranapanema region.

As shown, the geoecological characterization of the area allows for a better understanding of the regional fragility or potentiality. The parameters determined for the landfills, together with the conditions of the physical environment, are an important tool for evaluating solid waste landfills. Particularly in relation to the geoecological aspects, in the case studied, 11 of the 22 landfills are in inappropriate means (**Fragile and Moderate-Fragile** geoecological state). Solid waste landfills may offer a lower risk to the natural environment in middle and moderate-homeostatic classes, because of the natural conditions of these areas.

The areas classified as **Fragile** and **Moderate-Fragilized** offer few conditions for installing and maintaining a landfill. These areas have poorly developed soils, which runs contrary to the minimum criteria required not only by the environmental organization (the CETESB), but also other studies focused on the issue. Boscov (2008) argues that a solid waste landfill requires a stable geotechnical environment, where geology, soil, relief and other physical factors do not impair the operation of the site; as well as, in the case of landfills, minimum resistance to possible contamination.

Therefore, the results obtained in the geoecological and legal restriction maps show differences when compared to the table presented by the IQR of the environmental agency, since many of these landfills that are considered to be under adequate conditions are in fact at risk. The geoecological map is only intended to assist in the detection of potentialities and weaknesses

however, and for this condition field confirmation is necessary. One example is the landfill of Presidente Bernardes, which is located on a spring region and was approved by the IQR. Farias (2012) and Loureiro (2005) point out problems with performing the IQR, not only the need to reevaluate it, but also to make use of other evaluation tools.

Another issue that deserves to be highlighted is the presence of solid waste landfills within the minimum radius of 13 kilometers established by airport security (CONAMA 04/1995). This restriction refers to the presence of animals, specifically birds that fly over the landfill area. As a safety measure, it is advisable to avoid their presence so as not to interfere with aircraft routes, which within the imposed limit are at lower altitudes. Thus, the condition described shows only that the municipalities did not make use of this data when they chose the current areas for their deposits. Similarly, the IQR makes no mention of this distance. Nevertheless, the research of Moreira et al. (2010) and Oliveira (2015) show that this parameter, as well as many others, must be taken into account when choosing a suitable area.

Finally, the lack of sanitary landfills at UGRHI-22 should be highlighted. One exception is the landfill of Presidente Venceslau, which is classified as a sanitary landfill. On-site visits revealed flaws in its management, as required by Law (BRASIL, 2010). For this reason, even if this landfill meets the minimum requirements established by the CETESB, these solid waste deposits do not yet meet the criteria required to become environmentally adequate. This stems from the inability of a single index to encompass all possible variables. For that, it takes an effort and the cooperation of different visions to actually diagnose the problem. Thus, it is necessary to combine information obtained with the field surveys and the construction of the mapping database. Thus, the cartographic information produced can complement the information obtained in field surveys, reducing errors in the evaluation and adequacy of the areas with the solid waste landfills.

Conclusions

This work proposes the evaluation of areas occupied by solid waste landfills in the region of the Pontal do Paranapanema (UGRHI-22), based on a geoecological approach in accordance with the legal parameters imposed to this region. With this,

we pointed out areas of greater or smaller capacity for the final destination of the solid waste produced in this region.

We concluded that half of the solid waste landfills are located in areas of low suitability or not recommended geocological states, and an even larger portion of landfills end up infringing the minimum distances recommended by law. Through site visits, we verified these landfills are not properly monitored, compromising the physical characteristics of the area. Although analyses of soil contamination and water resources around the landfills are necessary for further evaluation, the map of the geocological state allows a preliminary diagnosis of the landfill area conditions.

We also concluded that the geocological approach, by gathering and synthesizing physical components of the regional landscape, promotes the interrelationship between pedological, geological, geomorphological, hydrological and biological aspects and thus better explains the problems arising from anthropic activities of solid waste disposal. In areas classified as **Moderate-Fragile** and **Fragile** state, it is not recommended to install or operate a landfill, because of the difficulty imposed by the physical environment in which they are located. In areas with an **Intermediate** and **Moderate-Homeostatic** geocological state, the implementation of solid waste landfills produces less negative impacts on the region. The **Homeostatic** state class, since they consist of areas that maintain biodiversity and require protection, is not recommended as destination areas for the solid waste.

Along with the geocological properties of the region, it is recommended that sanitary landfills be installed in areas that obey the existing laws. In areas where conditions are incompatible with the legal parameters, such as the violation of soil depth, proximity to the water resource or high declivity of the land, we recommend closing the landfill and beginning appropriate environmental recovery techniques.

We recommend further studies in each one of the solid waste landfills of the studied region, checking their compatibility with the local geotechnical parameters, as well as evaluating the environmental conditions. This diagnosis should allow the UGRHI-22 municipalities to better identify the characteristics of their landfills, which will benefit the practices adopted for area closures and the relocation of sanitary landfills.

Acknowledgments

The authors thank the Coordination for the Improvement of Higher Education Personnel (CAPES) for the Master's degree scholarship of the main author.

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