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From coal mine to sanitary landfill: The rehabilitation of Recreio Mine in Butiá, Brazil

AB Pires *Copelmi Mining, Brazil*
CC Weber *Copelmi Mining, Brazil*

Abstract

The Recreio mine was a coal mine located in the metropolitan region of Porto Alegre (state of Rio Grande do Sul, Brazil – RS/BR) that began operations in the 1970s by Copelmi Mining Ltd. At that time, environmental concerns were minimal in Brazil, and environmental legislation was practically non-existent. Under this context, the mine operated and generated an environmental liability corresponding to a pit of more than 100 hectares of surface disturbance at the end of its life cycle in 1990. In 1988, the new Brazilian Federal Constitution (CFB/88) came into force, explicitly determining that those who exploit mineral resources are now obliged to reclaim the environment degraded by their activity. At that same time, discussions about the prohibition of uncontrolled disposal of municipal solid waste (MSW) in dumps were gaining strength due to the accident that occurred in 1987 with the inadequate disposal of Cesium-137 in a dump, resulting in the contamination of 249 people and 4 deaths. In 1990, the entire metropolitan region of Porto Alegre still deposited its MSW irregularly in dumps and would need to adapt to the norms for the final disposal of its waste. Likewise, Copelmi would need to rehabilitate the Recreio mine under the terms of CFB/88. Considering this statutory scenario, the proximity between the Recreio mine and the municipalities with the highest MSW sanitary generation (90 km), the available volume in the mine final pit (30 million m³), the favourable geological and hydrogeological characteristics of the Recreio mine for controlled disposal of MSW, and, that the construction of a sanitary landfill on previously undisturbed land is an activity that degrades the environment, in 1990, Copelmi (Research and Mineral Mining Company) identified the opportunity to rehabilitate the final pit of the Recreio mine through the construction of a sanitary landfill on the site, named Aterro Sanitário de Minas do Leão (ASML). The sanitary landfill (ASML) received its first environmental permit in 1996. As of 2001, it began to dispose of MSW generated by 35% of the population of the state of RS/BR. Currently, ASML has a daily capacity to receive 120,000 tons of MSW and serves 39% of the population of RS/BR. Since 2007, ASML has been generating carbon credits by destroying gases in a flare and, since 2015, biogas has been fed to six generators that deliver up to eight MWh of electricity to the regulated energy market.

Keywords: *coal mining, municipal urban waste, landfill, asset repurposing, statutory compliance*

1 Introduction

On September 13, 1987, a major accident occurred in Goiânia, the capital of Goiás, Brazil, due to mishandling of an abandoned radioactive source containing Cesium-137 (137Cs), causing direct and indirect damages to hundreds of people. The Goiano Institute of Radiotherapy was the site where a radiotherapy device (teletherapy equipment) was abandoned and later breached for the clandestine sale of its components. The radioactive source contained highly soluble Caesium chloride, which dispersed into the environment and affected animals and plants, causing a series of contaminating events. The radioactive material was sold in scrapyards and even used as gifts due to the blue coloration of certain fragments. The accident resulted in the monitoring of 112,800 individuals, of which 249 were identified with some degree of contamination. In addition to the four direct deaths and severe aftereffects, the 19 grams of exposed Caesium generated over 6,000 metric tons of contaminated waste (Machado, 2017).

This tragic event, along with other factors, led to the National Constitutional Assembly of 1988, which drafted a new Brazilian Federal Constitution with environmental issues gaining constitutional status, recognizing the environment as a fundamental right and establishing the need to protect biological diversity and ecological processes. The New Constitution of 1988 (CFB/88) also provided for the creation of specially protected areas and required prior environmental impact assessments for potentially degrading activities (Varella & Leuzinger, 2008). Although the new constitution did not detail legislation on sanitary landfills then, it granted the states and municipalities the authority to deal with environmental issues, including solid waste management. With a mindset focused on environmental protection and based on appropriate techniques, normative evolution was inevitable over time. Some relevant milestones include Resolution NBR 10.703/1989 and ABNT NBR 8.419/1992, which established the initial criteria and standards for sanitary landfills in the country. Subsequently, standards ABNT NBR 13.896/1997 and NBR 13.895/1997 defined criteria for the implementation, design, and operation of non-hazardous landfills, as well as monitoring well sampling. Law No. 9.605/1998 (Environmental Crimes Law) established sanctions for the improper disposal of solid waste in sanitary landfills. Resolution CONAMA No. 404/2008 established criteria for the environmental licensing of small-scale sanitary landfills, and the National Solid Waste Policy (Law No. 12.305/2010) defined the principles and guidelines for the proper management of solid waste, including waste management hierarchy.

In 1990, despite CFB/88 and recent technical standards, the entire metropolitan region of Porto Alegre, the capital of the state of Rio Grande do Sul (RS), still disposed of its MSW in open dumps without following proper standards; this called for corrective measures in line with the new environmental values. In 2013, although this situation had significantly improved, there were still eight municipalities in the state of Rio Grande do Sul that disposed of MSW in open dumps, namely Ijuí, Ipiranga do Sul, Novo Machado, Santa Margarida do Sul, São Gabriel, Tupanciretã, Uruguaiana, and Viamão (Reif, 2013). Currently, this situation is still not regularized, and the deadlines for the definitive closure of open dumps have been systematically extended through frequent editions of the National Solid Waste Plan. In its latest edition published in 2022, the new deadline for the closure of open dumps was set for 2024 (MMA, 2022).

Parallel to the normative efforts undertaken since 1988 to prevent environmentally inadequate disposal of MSW in open dumps, there were also efforts to establish stricter environmental regulations in the mining industry. For example, Article 225 of the CFB/88 stipulated that "those who exploit mineral resources are obligated to restore the degraded environment in accordance with a technical solution required by the competent public authority, as provided by law." The subsequent directive No. 97.632/1989 defined that environmental impact assessments (EIAs) used in environmental licensing, when applied to mining, should include a plan to restore the degraded area. Over time, Brazilian legislation and regulations issued by the mining regulatory agency have progressively improved to make environmental restoration an integral part of mining project planning, integrating restoration and mine closure plans.

In this context of increasing environmental value, where mining activities were being conditioned by better environmental standards, COPELMI, a coal mining company that has been operating in Rio Grande do Sul since 1883, had to adapt previously mined areas to these new standards of environmental restoration and mine closure. Under the new legislation, these COPELMI's mining-impacted areas became environmental liabilities. The most significant of these areas was called the Mina do Recreio Oeste (RM), which consisted of an open pit covering over 200 hectares, with depths of up to 40 meters.

While there was a need to environmentally restore the RM area operated by COPELMI, it was also necessary to address the environmental problem of MSW disposal in open dumps in Rio Grande do Sul. Therefore, the convergence of ideas between the need for environmental restoration of the RM area and the implementation of sanitary landfills for MSW resulted in the conversion of the former coal mining pit at RM into the largest sanitary landfill in the state of Rio Grande do Sul, receiving over 35% of the state's domestic solid waste.

This article aims to demonstrate that addressing the environmental liabilities of coal mining activities, when analysed from the perspective of mine closure with a focus on the "future use" of the area, can contribute to solving one of the growing problems of consumer society: the environmental management of MSW disposal and its respective value creation.

2 The Recreio's mine (RM) of Copelmi Mining

Copelmi is the largest private coal mining company in Brazil, with a long history of coal extraction dating back to 1883 when the first underground mining shaft was established in the city of Arroio dos Ratos, Rio Grande do Sul, Brazil. The company has undergone several name changes over the years and adopted its current name, COPELMI, in 1941. Its headquarters are located 80 km from Porto Alegre, the capital of the state of Rio Grande do Sul, Brazil (Figure 1).

Figure 1 Copelmi's mine operations base location

The company previously conducted coal mining through underground methods, with extraction carried out through rudimentary galleries and shafts. In the 1940s, the mining method evolved to room and pillar mining and later to strip mining using heavy machinery.

Although strip mining is known for its high ore production, it also causes a significant environmental impact on the surface. After removing and stockpiling the organic soil, the overburden stripping operation begins, which involves removing the overlying waste materials, such as clays, sands, gravels, and siltstones, found above the coal seams to be mined. The extracted coal is stored in stockpiles and sent to the beneficiation plant, where parameters such as ash content and calorific value are adjusted according to market quality standards.

During the strip-mining process, an ascending waste dump is constructed in the mined area, forming successive benches (Figure 2). This construction provides better geotechnical conditions, allowing for proper compaction of the sterile material through equipment traffic. The deposition can be done directly, with the inversion of waste layers, or in a more appropriate manner, trying to return the excavated area to its original geological configuration after the mining operations have been completed.

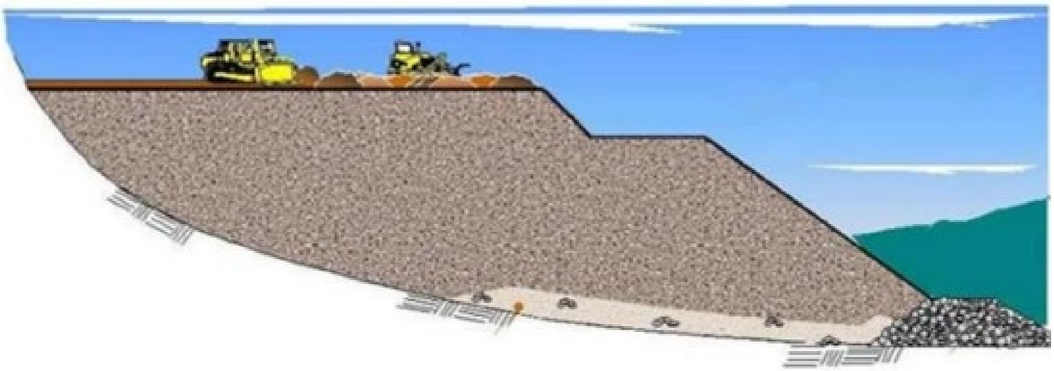


Figure 2 Waste pile deposition method (Aragão,2008)

Another characteristic of this method is the construction of a waste material pile outside the mining area (Figure 3), which results in an ample void space at the end of mining. This space is typically filled with water from peripheral drainage, creating artificial water reservoirs that can be used for agricultural activities, livestock farming, fish farming, or even for supplying the population with water.

Figure 3 Recreio's mine (RM) in 1990, waste pile on the left side

The RM was operated as an open-pit mine; however, the deposition of waste materials mainly occurred outside the mining area. As a result, the pit's dimensions were larger than those currently used in COPELMI's strip mining processes. Therefore, at the end of its operation in 1990, the RM consisted of a pit with an area of 200 hectares, a depth of 40 meters, and steep lateral slopes. This configuration limited future use options, including the formation of an artificial water reservoir.

In the 1990s, while the mining of one of the RM pits was being completed, the new environmental regulations regarding the management of MSW had just been defined. Aware of this, the mine planning engineering team and environmental consultants at Copelmi identified the opportunity to use the final pit of the RM for the establishment of the largest sanitary landfill for MSW in the state of Rio Grande do Sul. In other words, there was an opportunity to utilize a degraded area from mining for an environmentally degrading activity, which is the final disposal of MSW.

3 Analysis of the landfill project area

The design of the sanitary landfill (ASML) at RM required the adaptation of the mine planning to meet specific needs, taking advantage of the geological and hydrogeological conditions of the region. The pit excavation occurred from east to west, within the boundaries of the hatched area shown in orange in Figure 4.

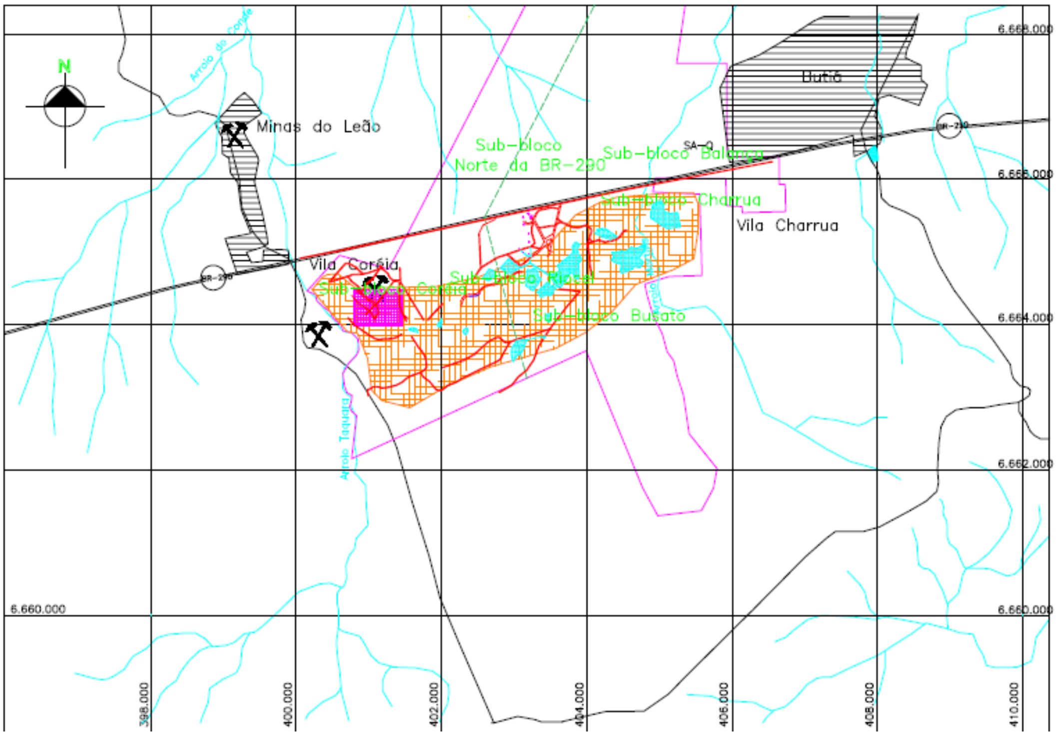
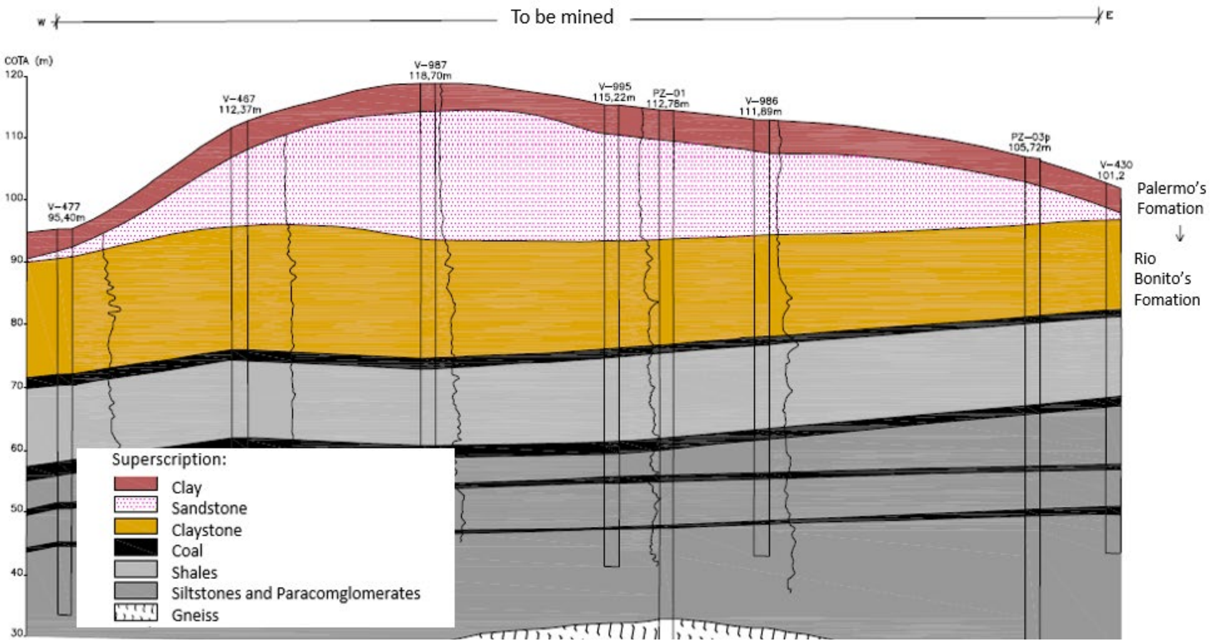
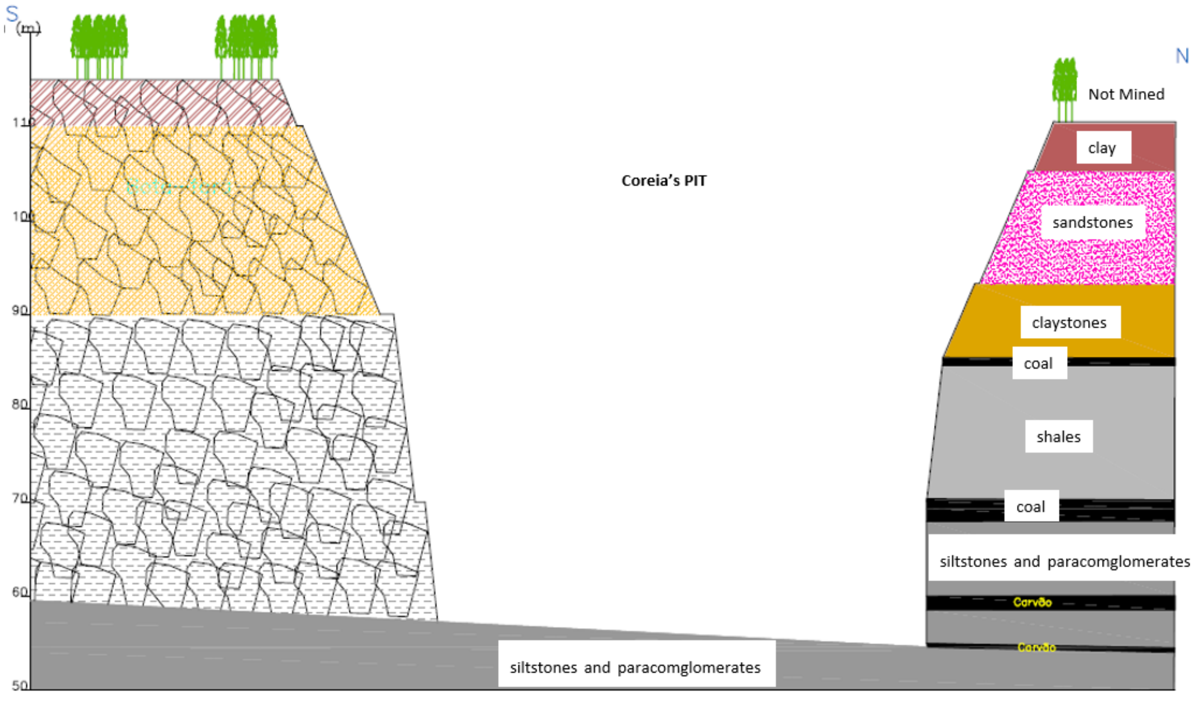


Figure 4 Landfill project location (purple square) (Bastiani, 2007)

- The local landscape of the RM area is characterized by gentle hills and watercourses. The topography varies in elevation, ranging from 50 to 130 meters, with slopes between 4% and 7%. Sandstones, which are more resistant lithologies, contribute to the formation of higher reliefs, especially in the western part of the mine. However, due to open-pit coal mining and subsequent reclamation of the areas, there have been modifications in the geomorphology, generally reducing the original slopes.
- In addition to changes in slope, mining has also led to an increase in the volume of material in the spoil piles due to the bulking of the removed material. However, it is essential to highlight that the final slope of the spoil piles has an average inclination of 10%. This practice is commonly employed during mine pit reclamation to ensure the area's safety and foster the creation of a more organic and sustainable environment following the cessation of mining activities. It facilitates ecological restoration, mitigates erosion, and enables the establishment of a stable and functional ecosystem in the reclaimed area. The objective was to restore conditions close to the original and rehabilitate the mined areas, aiming to achieve a final elevation of the reclaimed areas as close as possible to the original elevation.
- To understand the geology, hydrology, and hydrogeology of the region, as well as the characteristics of the overburden material and coal seams, it is essential to consider the main stratigraphic unit present in the area: the Rio Bonito Formation. This formation is composed of a variety of lithologies, with economically mineable coal seams and overburden material, mainly dark gray siltstones and paraconglomerates. The cover of the coal seams consists predominantly of siltstones, shales, and clays, figure 5.



(a)



(b)

Figure 5 Geological section of the area after coal mining, demonstrating the unmined area (a), the dump deposits and the remaining pit (b) (Bastiani, 2007)

The hydrographic characteristics of the region are determined by two low-flow watercourses: Arroio Martins and Arroio Taquara. The former borders the operating area to the east, while the latter is closer to the Recreio's mine. These watercourses receive sanitary and industrial sewage and act as surface drainage for the surrounding areas of the enterprise. Understanding and properly managing these hydrographic characteristics is essential in the management of the RM, as both watercourses contribute to the Arroio do Conde, a significant tributary of the Rio Jacuí, the largest river in the state of Rio Grande do Sul.

The RM area presents different types of aquifers, with a predominance of type II aquifers. These aquifers are found in the sedimentary rocks of the Rio Bonito Formation and are capped by the sandstones at the base of the Palermo Formation. The pre-Cambrian aquifer system consists of metamorphic rocks and granitoids of the crystalline basement, functioning as a fractured aquifer. The Rio Bonito aquifer system consists of three lithofacies and can behave as an aquifer or aquiclude, depending on the interconnections through fractures. The Palermo aquifer system consists of porous sandstones at the base of the Palermo Formation. Additionally, the areas modified by mining, known as spoil piles, have different hydrogeological

conditions. The water table level in these deposits is established at the contact between the deposit and the bedrock substrate of the original pit.

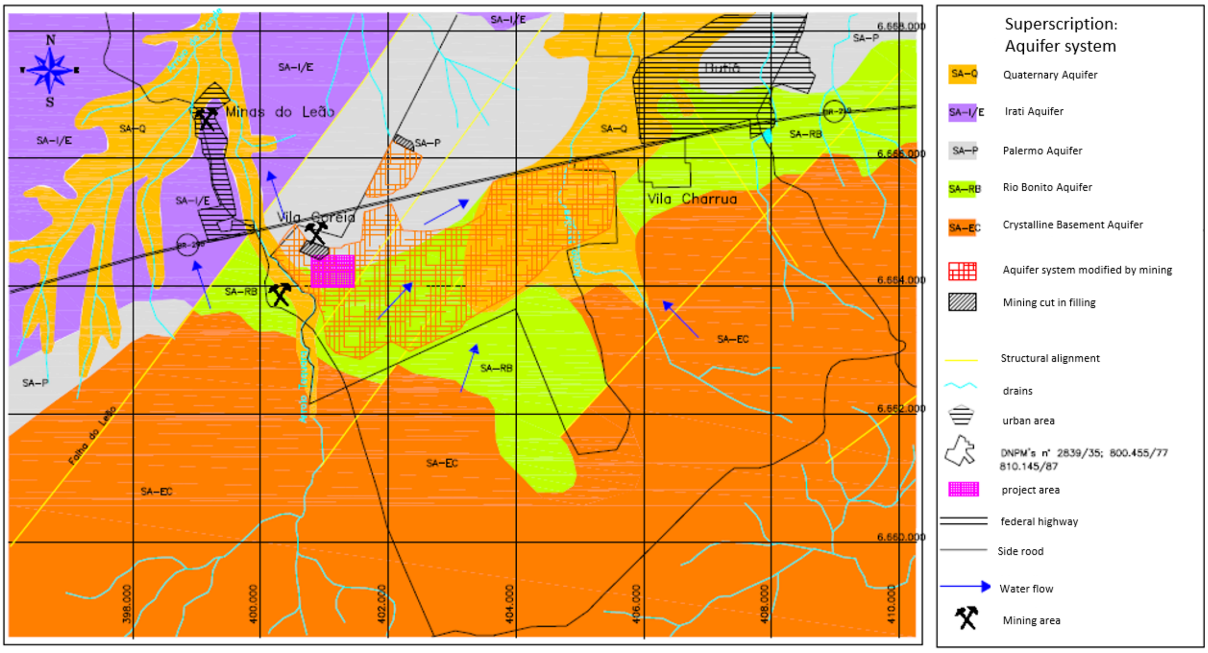


Figure 6 Aquifer systems in the region (Bastiani, 2007)

The operation of a MSW landfill poses operational and environmental risks that need to be properly planned and managed in order to control them. Some of these risks are as follows:

- Soil pollution: Decomposing waste that has been leached can infiltrate the soil and contaminate groundwater.
- Water contamination: Uncontrolled or untreated leachate liquids can contaminate nearby water resources, causing damage to the aquatic ecosystem and threatening human health.
- Emission of toxic gases: Anaerobic decomposition (methane and hydrogen sulfide) releases foul-smelling gases that can be flammable or toxic in high concentrations.
- Fires: Heat generated by waste decomposition can lead to fires, potentially harming the environment and the surrounding population.
- Disease vector attraction: Poorly treated waste can attract flies, rats, and other animals that may transmit diseases to nearby communities.
- Visual impacts: Improper waste disposal can negatively impact the landscape
- Geotechnical instability: If the landfill is not properly designed and constructed, it can experience soil instability and landslides, causing structural damage and compromising the landfill's safety.

To avoid or mitigate these risks, it is essential to implement good management practices, continuous environmental monitoring, adoption of appropriate technologies for leachate and gas treatment, proper training for workers, and careful planning for the former mined pit and waste disposal. Slope instability and contamination of the surface and subsurface areas by leachate released from the landfill are two points of particular attention. Regarding geotechnical stability, the studies conducted for the MSW landfill focused on analyzing the geomechanical characteristics of the materials that were extracted as waste during mining operations. Therefore, sandy clay with reddish and red coloration, yellow clay, grayish-green shale, and dark-gray siltstone were subjected to various tests to determine their properties and bearing capacity. These low-permeability materials, such as siltstones, were utilized to line the base and sides of the sanitary landfill, aiding in the containment of contaminated water and preventing the migration of contaminants to the substrate. Additionally, they contribute to odor reduction and inhibition of insect proliferation. Monitoring wells and piezometers have been installed to continuously analyze the groundwater samples. And, the feasibility of using the waste materials removed from above the coal horizons has led to reduced operational costs for the solid waste landfill, thereby enhancing its economic viability.

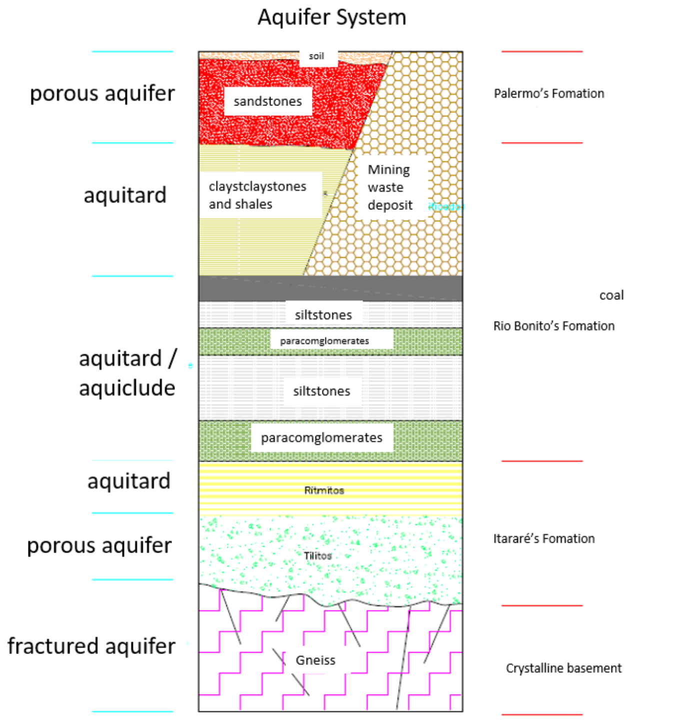


Figure 7 Geological profile with aquifer systems in the region (Bastiani, 2007)

It would be unacceptable for leachate to reach the groundwater, so characterization and diagnostic studies of the aquifers in the vicinity of the landfill project were conducted. A groundwater monitoring plan was established to characterize the media involved in the landfill site and establish a monitoring network for groundwater and surface water. The groundwater monitoring network followed technical standards, with piezometers positioned upstream and downstream of the groundwater flow. Infiltration tests were performed, and monitoring wells were constructed in the rock formations to track the behavior of groundwater levels and quality. The results of these studies were used to assess the condition of the physical environment and its capacity to support the implementation of the MSW landfill in compliance with existing regulations.

The study conducted by MSc. Geologist Gustavo Antônio Bastiani in 2007 was based on various geological, hydrogeological, and geotechnical characteristics and provided a comprehensive diagnosis of the RM area, which was essential for properly implementing the sanitary landfill.

In the following image, the proportion of the pit that was preserved for use as the MSW landfill is presented. With an area of 123 hectares, of which 84 acres are designated for waste disposal, its total capacity is 23,000,000 tons, with an estimated operation for an additional 23 years from 2023.

(a)

(b)

Figure 8 Surpac's final pit file (a), **landfill aerial picture – 2022 (b)**

Based on the data presented in the geological and hydrogeological study of the area, the evaluation of these data regarding the project area and its surroundings indicated that the rock package involved is homogeneous, with an excellent correlation between the strata. There are no abrupt changes that could allow fluid percolation. The faults present in the area are small-scale, except for the regional Leão fault, which does not directly affect the project area. These minor faults are stabilized and do not generate open zones due to the plasticity of the sedimentary materials.

These facts were based on extensive geological research in the area, including sampling of boreholes with geophysical logging and the mining history. In summary, the rocks present at the landfill site are mainly gray siltstones and claystones, with interbedded coal layers, and at the base, there are pelitic matrix paraconglomerates. The waste dump deposits are mainly composed of weathered siltstones and paraconglomerates, with high material compaction.

The area's hydrogeology is dominated by pelitic rocks, which act as aquicludes and aquitards, resulting in predominant surface runoff. Infiltration tests conducted during the project execution demonstrated permeabilities between 10-6 and 10-7 cm/s in the constructed piezometers. Permeability tests performed in rotary drillings at the bottom of the mining pit indicated values around 10-8 cm/s, which means that these rocks have a natural water retention capacity of approximately 300 years per meter of rock column.

There is no risk of environmental contamination because the thickness from the base package to the granitoids of the basement, which could conduct contaminants, is approximately 30 meters measured from the bottom of the pit. The permeabilities of the surrounding waste dump deposits are low, between 10-5 and 10-6 cm/s, due to the predominance of pelitic materials and high compaction, which prevents groundwater flow through these materials. Groundwater is confined within the waste dump deposits, where a slow saturation occurs.

Surface drainage systems, such as the Arroio Martins and the Arroio Taquara, are far from the project site, eliminating the possibility of contamination. The stability of the slopes at the sides of the landfill was established, considering the operational inclinations of coal mining, which were verified throughout the mining process.

Conclusions

This article provides a brief overview of the study conducted on the feasibility of using a coal mining pit at RM, located in Minas do Leão, RS, as a site for the final disposal of urban solid waste (the final stage of the waste management process, in which waste that can no longer be recycled, reused, or recovered is appropriately disposed of to prevent negative environmental and public health impacts) in compliance with environmental legislation. This approach, which involves utilizing previously mined areas for waste landfill implementation, proves to be an economically viable and environmentally favorable alternative, thereby avoiding the degradation of new areas and providing revenue for companies and municipalities, generating benefits for society as a whole. It is worth noting that the taxes generated from this landfill represent 18% of the municipal revenue of Minas do Leão and that the initiative contributes to the creation of 130 jobs for the local residents, as reported in "A cidade subterrânea do lixo: conheça o aterro para onde vão quase 40% dos resíduos produzidos no RS" by GaúchaZH.

However, it is essential to highlight that the construction of this landfill cannot be indiscriminately applied to all coal mining pits in the state of Rio Grande do Sul, as its feasibility is conditioned by the specific geological and hydrogeological characteristics of each location. Additional precautions must be taken in deposits which have permeable rocks to prevent damage to fractured aquifers and potential contamination.

In addition to providing a suitable location for solid waste disposal, this project also contributes to the generation of carbon credits through the destruction of gases in a flare. Since 2015, the project has been supplying six generators with biogas, providing up to 8 MWh of electricity to the regulated energy market, and there are plans to increase this supply to 14.5 MWh. Additionally, the creation of a biogas-fueled fuel station is being planned, further expanding the environmental and economic benefits of this initiative.

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References

BASTIANI, A. Gustavo. (2007). Diagnóstico geológico, hidrogeológico e geotécnico de área de mineração de carvão para implantação de um aterro sanitário.

MACHADO, A. da S. Patrícia. (2017). *Césio 137 – 30 anos: Fotorreportagem do acidente radioativo em Goiânia. Goiânia: Governo do Estado de Goiás; Secretaria de Estado da Saúde: Superintendência de Controle, Avaliação e Gerenciamento das Unidades de Saúde*; https://www.saude.go.gov.br/files/CARAfotorreportagem_cesiofotorreportagemcesio.pdf

REIF, Karina (2013, October 13). *Oito municípios gaúchos mantêm lixões a céu aberto. Correio do Povo*.

VARELLA, Marcelo Dias; LEUZINGER, Márcia Dieguez. (2008). *O meio ambiente na Constituição de 1988: sobrevoo por alguns temas vinte anos depois*. Revista de Informação Legislativa, Brasília, v. 45, n. 179, p. 397-402.

MMA, Ministério do Meio Ambiente. (2022). *PLANO NACIONAL DE RESÍDUOS SÓLIDOS*". https://www.gov.br/mma/pt-br/acesso-a-informacao/acoes-e-programas/agendaambientalurbana/lixao-zero/plano_nacional_de_residuos_solidos-1.pdf. Disponível em 18/06/2023.

GaúchaZH (2019). *A cidade subterrânea do lixo: conheça o aterro para onde vão quase 40% dos resíduos produzidos no RS*. https://gauchazh.clicrbs.com.br/ambiente/noticia/2019/06/a-cidade-subterranea-do-lixo-conheca-o-aterro-para-onde-vao-quase-40-dos-residuos-produzidos-no-rs-cjx54tuj401eu01mv7c1ol1a7.html#:~:text=Mas%20o%20aterro%20sanit%C3%A1rio%20de,um%20lix%C3%A3o%20como%20o%20conhecemos&text=Um%20munic%C3%ADpio%20de%208%20mil,o%20Rio%20Grande%20do%20Sul.

ARAGÃO, G. A. S. (2008). *Classificação de pilhas de estéril na mineração de ferro* [Masterdegree dissertation, Universidade Federal de Ouro Preto].