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Technical Article

Numerical Modeling Applied to Leachate Generation using Hydrus – Case Study: Seropédica, Rio de Janeiro, Brazil

Modelagem numérica aplicada à geração de lixiviado usando Hydrus – Estudo de Caso: Seropédica, Rio de Janeiro, Brasil

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ABSTRACT

Improper design and management of the cover layer of a sanitary landfill has been proven to produce harmful environmental impacts on the environment. One alternative at hand is to develop scenarios based on simulation of physical and computational models to represent the expected field water balance of a landfill coverage layer. This paper investigates the design of a sanitary landfill final cover in the municipality of Seropédica, which is located at the state of Rio de Janeiro - Brazil. More specifically, the compact soil coverage, which is widely used for landfill final cover of municipal solid waste, is evaluated in contrast to vegetation cover by grass, vegetation cover by brachiaria and capillary barrier. To accomplish such task, hydrometeorological forcing conditions, namely daily rainfall and temperature, were retrieved from the Anchieta weather station, which is situated nearby the study area. The Hydrus 1D and 2/3 D computational codes were employed to develop a set of scenarios to follow the contamination plume evolution within the landfill along the time frame of 20 years with some degree of reliability. It should be noted that the performed evaluation indicates the possibility to control the leachate release and consequently to avoid contaminating the environment, notably to prevent soil and water resources pollution. Vegetation cover by grass and brachiaria showed important control mechanisms with respect to the movement of the contaminant plume. In addition, it should be noticed that the best results for the landfill final cover were achieved for the capillary barrier, while poor performance results were obtained for the commonly employed compact soil.

Keywords: landfill; urban solid waste; leachate; storage cell; landfill final cover; soil contamination; numerical modeling; Hydrus 1D and 2D/3D.

RESUMO

O projeto e a gestão inadequados da camada de cobertura de um aterro sanitário produzem impactos ambientais prejudiciais ao meio ambiente. Uma alternativa disponível é desenvolver cenários baseados na simulação de modelos físicos e computacionais para representar o balanço hídrico que se espera que ocorra em uma camada de cobertura do aterro por meio de um experimento de campo. O presente trabalho investiga o projeto de cobertura final de um aterro sanitário no município de Seropédica, localizado no estado do Rio de Janeiro - Brasil. Mais especificamente, a cobertura compacta do solo, que é amplamente utilizada para a cobertura final de aterro de resíduos sólidos urbanos, é avaliada em contraste com a cobertura vegetal por gramíneas, cobertura vegetal por braquiária e barreira capilar. Para realização dessa tarefa, forçantes hidrometeorológicas, nomeadamente precipitação e temperatura na escala diária, foram obtidas da estação meteorológica de Anchieta, situada nas proximidades da área de estudo. Os códigos computacionais Hydrus 1D e 2/3 D foram empregados para desenvolver um conjunto de cenários para acompanhar a evolução da pluma de contaminação no interior do aterro ao longo do período de 20 anos com algum grau de confiabilidade. Ressalta-se que a avaliação realizada indica a possibilidade de controlar a liberação de chorume e, consequentemente, de evitar a contaminação do meio ambiente, notadamente para prevenir a poluição do solo e dos recursos hídricos. A cobertura vegetal por gramíneas e braquiárias apresentou importantes mecanismos de controle com relação ao movimento da pluma contaminante. Além disso, deve-se notar que os melhores resultados para a cobertura final do aterro foram alcançados para a barreira capilar, enquanto que os resultados de baixo desempenho foram obtidos para o solo compacto comumente empregado.

Palavras-chaves: aterro sanitário; resíduos sólidos urbanos; lixiviado ou chorume; célula de armazenamento; cobertura final de aterro; contaminação de solo; modelagem numérica; Hydrus 1D e 2D/3D.

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INTRODUCTION

This paper addresses the behavior of the landfill coverage layer based on computational and numerical modeling. In particular, the landfill final cover can be used as a barrier to avoid or reduce the amount of water infiltration into the landfill as previously shown in the literature (*e.g.*, DOUSSAN; PAGES; VERCAMBRE, 1998; SABBAS *et al*., 2003; HILTEN; LAWRENCE; TOLLNER, 2008; ABRAMSON, ADAR; LAZAROVITCH, 2014; ABRAMSON *et al*., 2014; DAWOOD; AUBERTIN, 2014; LI; BABCOCK JR., 2014; MORRISSEY; JOHNSTON; GILL, 2015; BRUNETTI; SIMUNEK; PIRO, 2016; BRUNETTI *et al*., 2017).

Computational advances in numerical modeling fostered the design of more physically-adherent models to simulate water and solute migration transfer processes in variably-saturated porous media. The Richards equation (RICHARDS, 1931) and the convection-dispersion equation are proposed to describe the water flow and solutes transport processes in the vadose zone. Those types of models are also used to explain existing preferential water flows observed in laboratory and field experiments (JOHNSON *et al*., 1998; ROSQVIST; DESTOUNI, 2000; ROSQVIST; DOLLAR; FOURIE, 2005; SIMUNEK; VAN GENUCHTEN; SEJNA, 2005; 2008, 2012; SIMUNEK *et al*., 2008; SIMUNEK; SEJNA; VAN GENUCHTEN, 2018).

It should be noted that the leachate migration could be described by means of a physical conceptual model that considers a system composed of two subdomains with macropores in a fracture network and micropores in the soil matrix (HAN; SCICCHITANO; IMHOFF, 2011). Johnson, Schaap and Abbaspour (2001) showed that such dual-permeability description was necessary to explain the water drainage from a municipal landfill of incinerated solid waste. The authors also concluded that using a single domain model leads to unsatisfactory results. As a support from the more specialized literature on this subject, previous studies showed that landfill functionality varies according to the type of coverage adopted (BENSON *et al*., 2001; ALBRIGHT *et al*., 2004; SKAGGS *et al*., 2004; YOUNG *et al*., 2006).

On the other hand, vegetation and corresponding plant roots in the landfill final cover adapt according to the climatic conditions of the region. To be more specific, roots are located mainly in the 0-20 cm deep soil layer with a corresponding three-dimensional network structure (WAN *et al*., 2016). The type of vegetation to be chosen for a landfill final cover should feature high heating storage capacity and high resistance and resilience, along with a well-developed rooting system to face short and long drought and flooding periods.

The environmental concern about the selection of a reliable type of landfill final cover are definitely related to the disposal of waste, especially when taking into account pollution vulnerability of groundwater and surface water resources, potential damage to vegetation and soil, prevention of the movement of the leachate beyond landfill site and health risk assessment for population (JOHANNESSEN, 1999; POPOV, 2005).

In Europe, some studies (*e.g.* STEGMANN; EHRIG, 1989) showed that 15 and 60% of the amount of leachate generated from municipal solid waste (MSW) landfills, whose top layer remains uncovered or partially covered with vegetation, are due to annual rainfall volume. It is also worthwhile referring to the research work conducted by Sabbas *et al.* (2003), in which water balances were carried out for landfills in Austria. Sabbas *et al.* (2003) showed that the leachate movement is the result of the interaction with a diversity of chemical and physical factors. The authors concluded that increased leachate production over time is directly correlated to climate and to the type of vegetation used in the landfill final cover.

An additional short comment should be made in this introductory section with respect to the application of the capillary barrier effect, which is considered to be an alternative method for the hydraulic waterproofing of the grounded residues (SMESRUD; SELKER, 2001). The operation of a capillary barrier is based on the contrast of the unsaturated hydraulic conductivity of overlapping soil layers as long as both materials are in the unsaturated condition. In order for the capillary barrier to work properly, there should be a hydraulic discontinuity between the landfill itself and its final cover. The efficiency of a capillary barrier can be verified when maintaining a minimum suction profile necessary to decrease the flow of water and oxygen uptake rate that will reach the residue. Such related functionality is based on the soil water retention curve and corresponding soil unsaturated hydraulic conductivity.

In summary, the landfill final cover retains rainwater, according to the water absorption capacity by the plant's rooting system, removing it by means of evaporation and transpiration. Therefore the water balance modeling performed at the surface soil layer covered by native grass involves controlling the precipitation that infiltrates into the soil by means of two basic mechanisms: soil water storage; and evapotranspiration from the soil water reservoir.

Given the broad scope of the subject, this paper constrains itself mainly to describing in details the influence of the sanitary landfill final cover using HYDRUS, version 3 (2D/3D), as a supporting computational tool (SIMUNEK; SEJNA; VAN GENUCHTEN, 2018). First, it should be noted that the HYDRUS model (1D/2D/3D) is a well-known and worldwide tested computational program developed using the finite element method (FEM) and able to handle a variety of boundary conditions in order to solve partial differential equations used to describe water, heat, and solute transport in porous media (SIMUNEK; VAN GENUCHTEN; SEJNA, 2005; 2008; 2012; SIMUNEK *et al*., 2008; SIMUNEK; SEJNA; VAN GENUCHTEN, 2018).

Under the provided framework, the manuscript contributes to the discussion about the functionality of a sanitary landfill final cover based on the evaluation of the water balance and water recharge rates for the designed landfill. Snapshots are taken to reveal the spatiotemporal evolution of the degree of contamination due to the plume movement monitored over what we called the near future encompassing the time period of 5 to 20 years.

In particular, it is worth noting that the HYDRUS computational program was used to develop modeling simulation scenarios to evaluate the performance of landfill final cover commonly used for MSW storage cells, which is here-in simply called compact soil. This type of final cover is contrasted with an arrangement forming a capillary barrier and two distinct arrangements with vegetation cover by grass and brachiaria, respectively. The paper is organized as follows: Section 2 illustrates the study area; Section 3 describes the mathematical model used; Section 4 presents the results; and Section 5 summarizes and presents the concluding remarks of the research work.

CASE STUDY

The land cover of the landfill located at the Santa Rosa in the state of Rio de Janeiro, in the municipality of Seropédica (22°47'44.53"S and 43°45'38.01"W), as depicted in Figure 1A, was investigated. Seropédica neighborhood includes the municipalities of Rio de Janeiro, Nova Iguaçu, Japeri, Queimados, Itaguaí, and Paracambi.

Complementarily, Figure 1B shows relief variations for Seropédica based on retrieved datasets from the Advanced Spaceborne Thermal Emission and

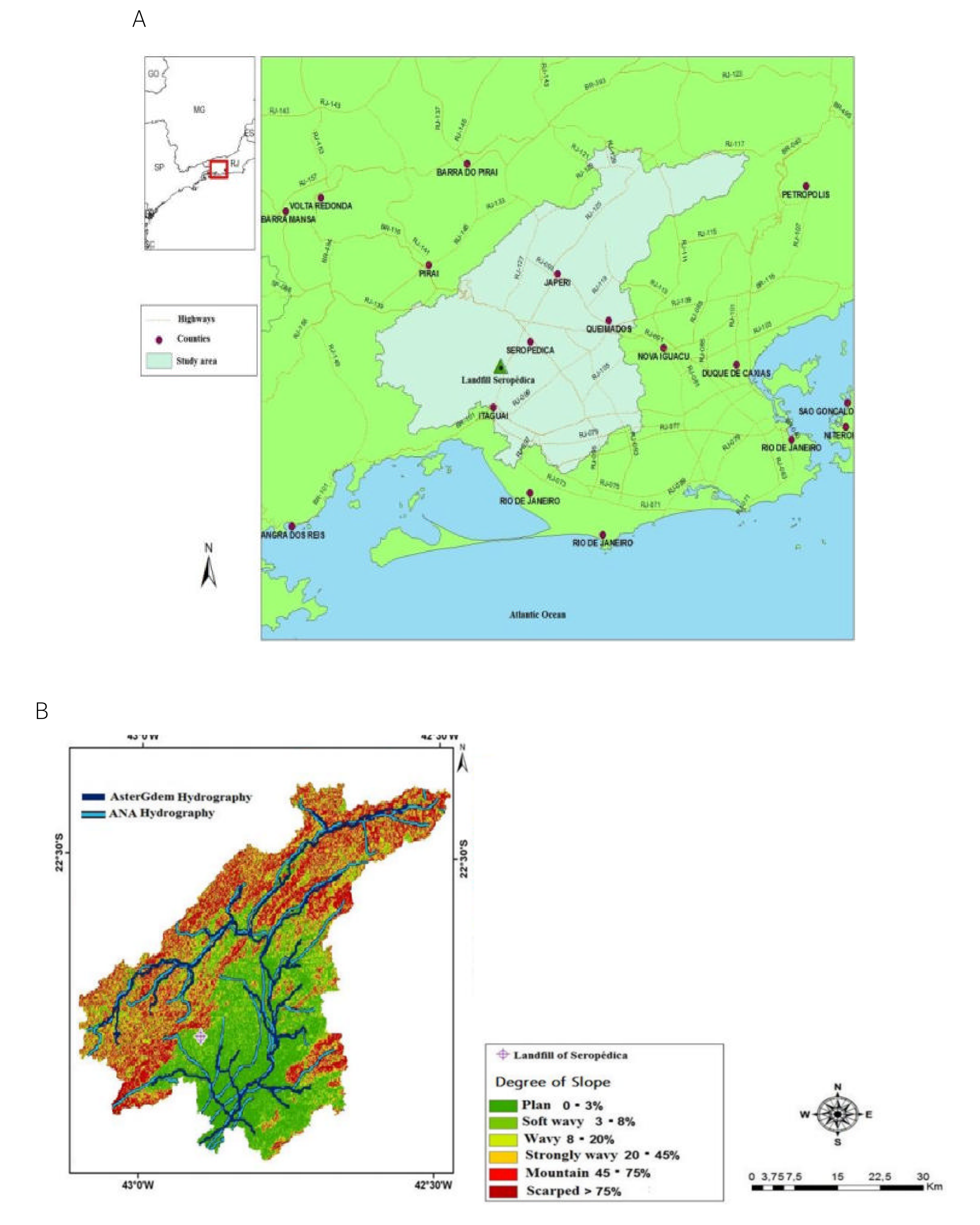

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Figure 1 – (A) Map of the municipality of Seropédica (on the upper part); (B) Mapping of degree of slope and river network delimited with AsterGdem data, where both maps were superimposed on the hydrographic map at 1:200,000 scale of the region provided by Brazilian National Water Agency (ANA); the mapping of the degree of slope was produced based on the digital elevation model (DEM) prepared for the region (on the lower part).

Reflection Radiometer (ASTER) and the Global Digital Elevation Model (GDEM). The landfill is located on the edge of the Serra do Mar, close to a region which is characterized by high altitudes that can be noticed in the mapping of the corresponding degree of slope (Figure 1B). The presence of several rivers, streams, and channels in the Guandu river basin which encompasses the location area of the landfill site are shown according to the computationally delimited hydrographic network (Figure 1B). Such river network was validated in contrast to the hydrographical map of the area at the scale 1:200,000, which was made available by the Brazilian National Water Agency (*Agência Nacional de Águas* – ANA).

MATHEMATICAL MODEL DEVELOPMENT

Fluid flow equation

The initial part of the simulation corresponds to the use of the HYDRUS 1D model. The mathematical model used is based on the Richards equation (1931), which represents the water flow in the unsaturated porous medium given by Equation 1:

$$\frac{\partial\theta(h)}{\partial t} = \frac{\partial}{\partial z}\left[\mathrm{k}(h)\frac{\partial h}{\partial z} - \mathrm{k}(h)\right] - s(h) \tag{1}$$

where:

$\theta\,[L^3.L^{-3}]$ – volumetric water content [residual (θ_r) and saturated water content (θ_s)];

$h[L]$ – hydraulic potential of water;

t $[T]$ – time;

z$[L]$ – spatial coordinate;

k$(h)[L.T^{-1}]$ – unsaturated hydraulic conductivity.

The sink term $s(h)$ in Equation 1 varies with root water uptake efficiency. If there is vegetation in the landfill final cover, $s(h)$ is non-zero.

This study considers the equation proposed by Feddes, Kowalik and Zaradny (1978) in which the root uptake is calculated according to specific characteristics of each type of vegetation by means of Equation 2:

$$s(h) = \lambda(\theta)a_r(z)T_p \tag{2}$$

where:

$\lambda(\theta)$ – root efficiency function;

T_p – potential transpiration used as surrogate for atmospheric demand;

ar(z) – plant root density function (FEDDES; KOWALIK; ZARADNY, 1978).

In this study, the van Genuchten model (VAN GENUCHTEN, 1980), jointly with the statistical pore-size distribution of Mualem model developed to obtain a predictive equation for unsaturated hydraulic function in terms of soil water retention parameters, was used to describe characteristics of water movement as follows in Equations 3, 4, and 5:

$$k(h) = k_s s_e^l\left[1 - (1 - s_e^{l/m})^m\right]^2 \tag{3}$$

$$\theta(h) = \begin{cases}\theta_r + \dfrac{\theta_s - \theta_r}{(1 + |\alpha h|^n)^m} & h < 0\\ \theta_s & h \geq 0\end{cases} \tag{4}$$

$$s_e^l = \frac{\theta - \theta_r}{\theta_s - \theta_r} \tag{5}$$

where:

K_s – saturated hydraulic conductivity $[LT^{-1}]$;

s_e^l – effective water content;

α, n, m and l - relative empirical parameters, where m = 1−1/n; and the parameter l was defined as 0.5, as suggested by Mualem. Calibrated hydraulic parameters are shown in Table 1.

The procedure used in the HYDRUS 1D model is to solve the numerical simulation of the water flow with the objective to determine the recharge rate. These values will be used as boundary conditions to model the transport of contaminants in the landfill based on the HYDRUS 2D/3D computational code.

Contaminant leaching

The leachate produced by the landfill percolates through the unsaturated zone, generating soil pollution and groundwater contamination with the corresponding

Table 1 – Soil hydraulic parameters used in the van Genuchten model (Souza, 2011).

	Thickness[L] [cm]	$\Theta_s\,[L^3.L^{-3}]$ $[cm^3.cm^{-3}]$	$\Theta_r\,[L^3.L^{-3}]$ $[cm^3.cm^{-3}]$	α [L⁻¹] $[cm^{-1}]$	n[-] [-]	K_s[L.T⁻¹] [cm.s⁻¹]
Organic Layer						
C1	0-10	0.0680	0.38	0.0080	1.0900	106.1
C2	10-60	0.0746	0.4004	0.0240	1.3000	50.0
C3	60-90	0.0450	0.43	0.1450	2.6800	1000.0
C4	90-150	0.0746	0.4004	0.0200	1.3000	2.33
C5	150-2100	0.2500	0.53	0.2000	1.9800	233.28
Capillary Barrier						
C1	0-30	0.0030	0.6190	0.0195	1.5900	0.0864
C2	30-60	0.0496	0.3790	0.0353	3.6420	865.45
C3	60-90	0.0450	0.4300	0.1450	2.6800	8640
C4	90-150	0.0746	0.4000	0.0240	1.3000	2.33
C5	150-650	0.2500	0.5300	0.2000	1.9800	233.28

Source: elaborated by the authors.

exposure to organic and inorganic compounds. The model of leachate generation hinges on understanding the mechanisms of mass release from the solid to the liquid phase.

In the present study, the rate of mass transfer from the solid to the liquid phase is calculated by Equation 6:

$$\frac{\partial(\theta_{i,j}C_{i,j})}{\partial t}+\frac{\partial(\rho_{i,j}S_{i,j})}{\partial t}=\frac{\partial}{\partial x_{i,j}}\left(\theta_{i,j}D_{i,j}\frac{\partial C_{i,j}}{\partial x_{i,j}}\right)-\frac{\partial(q_{i,j}C_{i,j})}{\partial x_{i,j}} \quad (i,j=1,2) \tag{6}$$

where:

$C_{i,j}$ – matrix of solution concentration $[ML^{-3}]$;

$S_{i,j}$ – matrix adsorbed concentration $[MM^{-1}]$;

$\rho_{i,j}$ – matrix of soil bulk density $[ML^{-3}]$;

$D_{i,j}$ – matrix dispersion coefficient $[L^2T^{-1}]$;

$q_{i,j}$ – volumetric flux $[LT^{-1}]$.

The dispersion tensor D_{ij} in Equation 5 is given according to Bear (1972) as Equation 7:

$$D_{ij}=D_0\tau+\frac{1}{\theta}\left[(D_l-D_t)\frac{q_iq_j}{|q|}+D_tq\right] \tag{7}$$

where:

D_{ij}– ionic or molecular diffusion $[L^2T^{-1}]$;

D_o – coefficient in free water $[L^2T^{-1}]$;

τ – tortuosity factor [-] (e.g., Millington and Quirk, 1961);

D_L and D_T – values of longitudinal and transversal dispersivity [L].

Generally, leachate has high concentrations of heavy metals, suspended solids, and organic compounds originated from the degradation of substances that are metabolized from the urban soil residue. The heavy metals commonly found are cadmium (Cd), lead (Pb), copper (Cu), chromium (Cr), manganese (Mn), mercury (Hg), and zinc (Zn), among others. Estimated values of chemical concentrations of these metals were based on the references by Celere *et al.* (2007) and Kuajara *et al.* (1997). In this paper, the following parameters were considered with respect to the solute transport equation (Equation 6) (KUAJARA *et al.*, 1997): ρ= 1.4 $kg.cm^{-3}$, D_l = 2 cm, D_t = 1 cm e D_o = 0.

RESULTS AND DISCUSSION

Initially, it should be noted that the soil properties presented in Table 1 were used as input data to generate simulations with the HYDRUS 1D model for different landfill final covers. The three models for the cover layer (Figure 2) have been conceived with typical vegetation of the region, which are able to withstand and adapt to the local climatic conditions. In the present study, grass (20 cm of root and 5 cm of crown height) and brachiaria (70 cm of root and 30 cm of height of the canopies) are used. The water uptake parameter was adopted based on the root for grassland-type vegetation (WESSELING *et al.*, 1991).

First, the proposed scheme for modeling the cover layer consists of a final layer of 10-cm thickness of organic compost (C1), superimposed on a layer with a thickness of 50 cm (C2), including another 30 cm layer (C3), 60 cm of material with compact local soil (C4), and 500 cm of urban soil residue (C5), according to the parameters identified in Table 1 (Figure 2A).

Second, it is assumed that the landfill final cover is formed by soils with varied particle sizes used to prevent the entrance of water into the innermost layers of the landfill. This type of configuration is called the capillary barrier (Table 1 and Figure 2B). It has a layer made up of fine particle size, being arranged over a layer built up of thicker particle size (sand or gravel). A 30-cm layer of thin soil (C1) is used, followed by a 30-cm layer of intermediate soil material (C2), a further 30-cm thick unsaturated soil (C3), plus 60-cm more compact soil material (C4), then ending with 500-cm urban soil residue (C5).

Third, the last model examined is widely used as a final coverage of waste storage cells, once it is based on a conventional system of cover layer built up with a 60-cm thickness layer of clay disposed directly over the waste. It should be noted that, in all the cases above, a 500-cm layer of urban soil residues is used, and finally a 40-cm thick layer of crushed stone is employed (Figure 2C).

The HYDRUS 1D model uses the input data for local precipitation as an initial condition. The daily precipitation data was obtained by means of an automatic meteorological station at the Anchieta site, for the period from January 2003 to December 2010, based on the retrieval of the dataset used in Souza (2011). To conduct the 20-year evaluation, the HYDRUS computational code received as input the referred precipitation dataset replicated for performing the simulation within the proposed time frame.

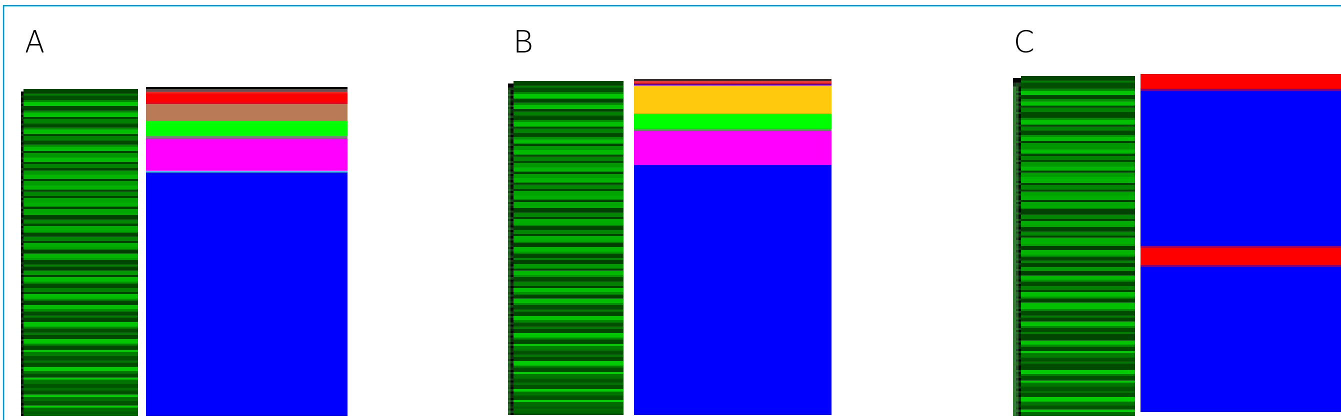

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Figure 2 – Profiles 1D: (A) vegetation cover (grass or brachiaria); (B) capillary barrier; (C) compact soil.

In the HYDRUS 1D model, free drainage was assumed as a boundary condition at the bottom of the storage cell and infiltration flow as a boundary condition in deeper layers of the soil column. Cumulative infiltration rate curves for the models of coverage layers are shown in Figure 3, while cumulative evaporation rate curves are illustrated in Figure 4.

The change in cumulative bottom flux is calculated through HYDRUS 1D (Figure 5). The last value of the accumulative bottom flux, which corresponds to the simulated time period of twenty years, is used for the calculation of the recharge rate. Those values for the time period of 20 years can be obtained by HYDRUS 1D, being calculated by the option "long-term slope" of HYDRUS, which is based on the water balance performed along the time frame of the study. The value calculated for the brachiaria vegetative cover layer was 1.38×10^{-5} *cm.s*$^{-1}$, while the value of 6.25×10^{-5} *cm.s*$^{-1}$ was achieved for grass cover. Complementarily, the value of the recharge rate was 7.52×10^{-5} *cm.s*$^{-1}$ for compacted soil, while the value of 1.27×10^{-5} *cm.s*$^{-1}$ was found for the soil cover layer composed of a capillary barrier. Those recharge rates were used as boundary conditions for modeling conducted using the HYDRUS 2D/3D computational code.

Figure 6A illustrates the geometric configuration scheme adopted for the use of compact soil cover in the proposed numerical simulations. The null flux is assumed as the boundary condition on both sides and for the lower part of the model. In the central region of the landfill base, a circular region (40-cm diameter) is considered, allowing the slurry to flow, representing the cell drain. To solve the systems of partial differential equations (Equations 1 and 6), the HYDRUS computational code is used. The domain was discretized into 6,856 triangular elements. The mesh is constructed in such a way to reproduce the

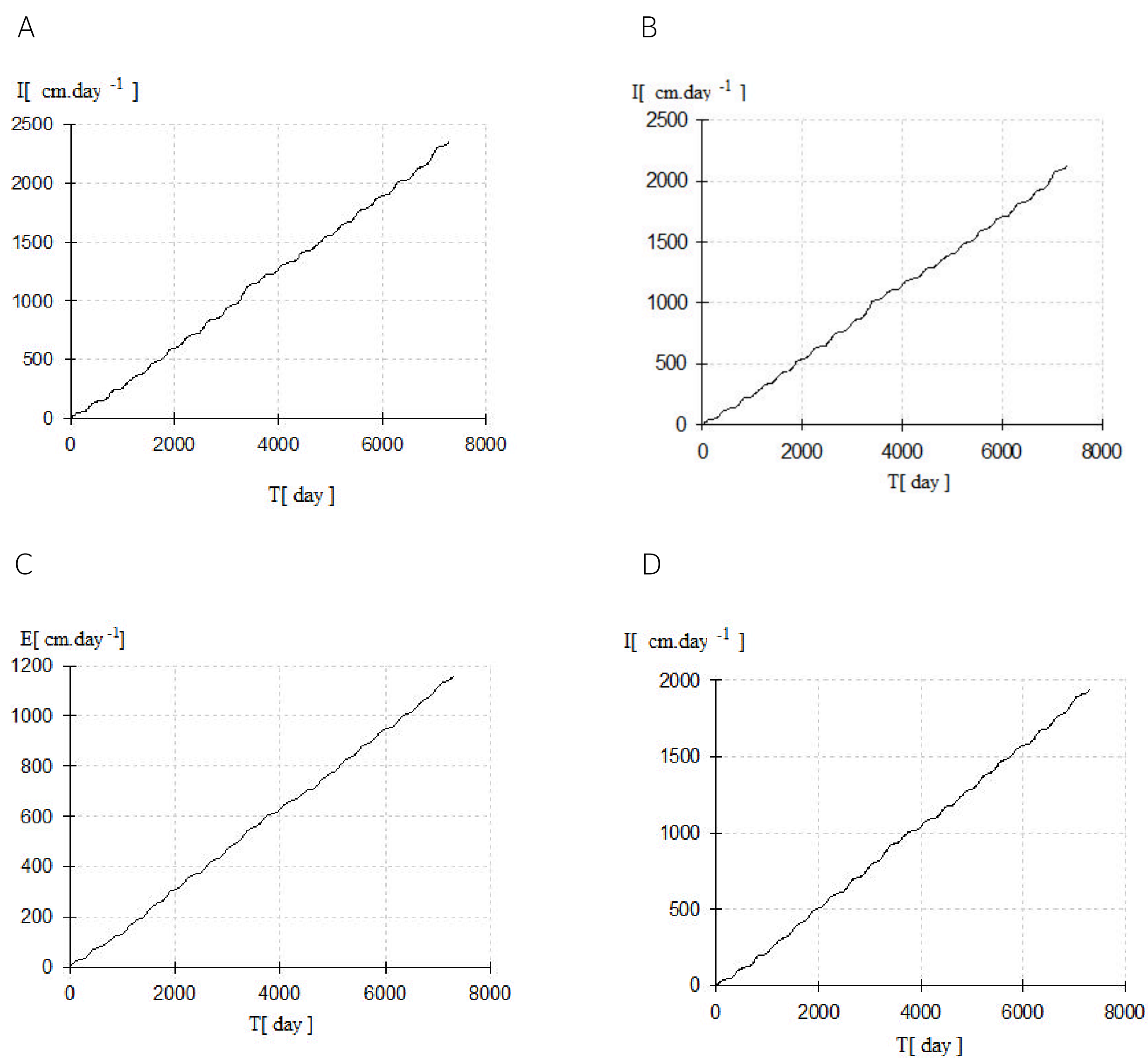

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Figure 3 – Cumulative infiltration rate for the four coverage layers of the landfill: (A) vegetation cover by grass; (B) vegetation cover by brachiaria; (C) compact soil coverage; (D) capillary barrier coverage.

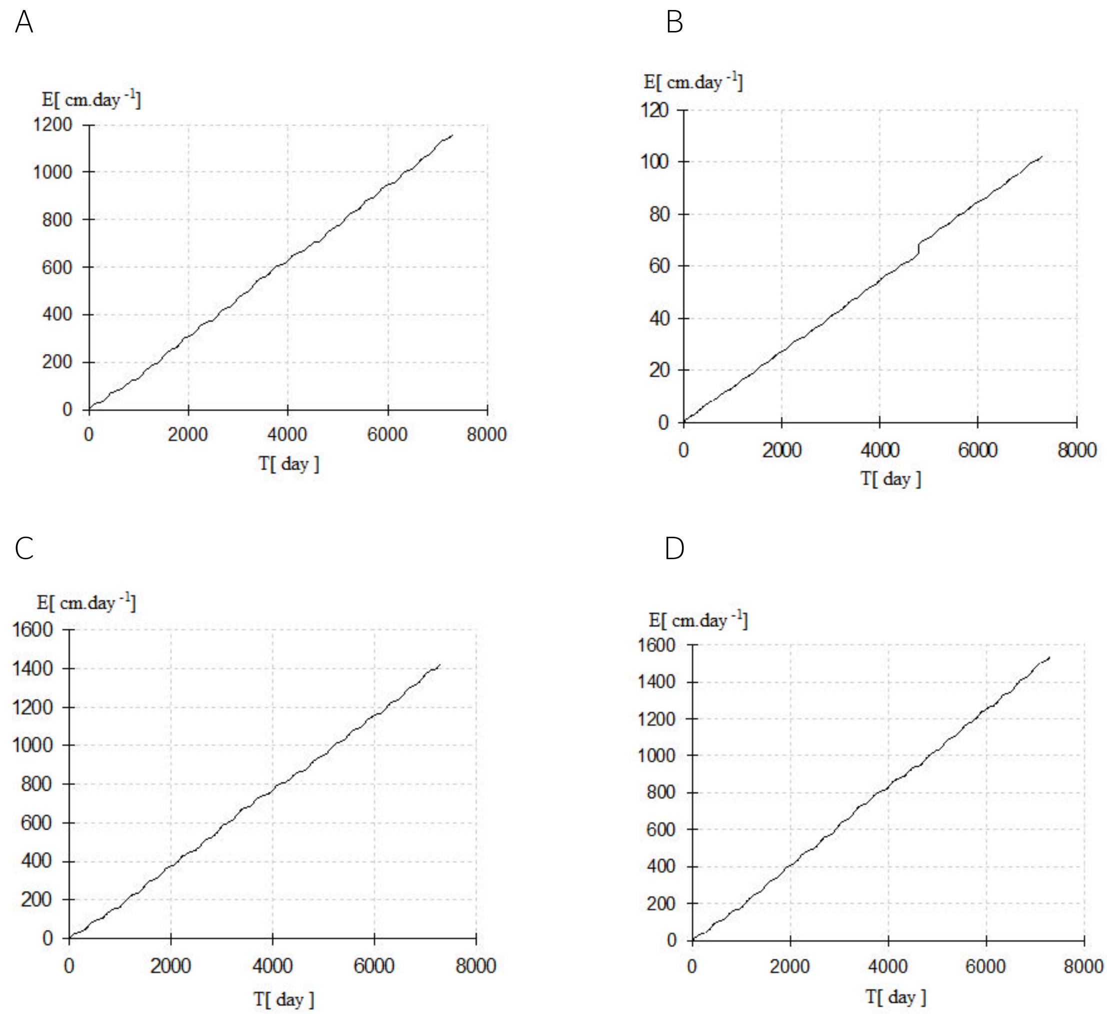

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Figure 4 – Cumulative evaporation rate for the four coverage layers of the landfill: (A) vegetation cover by grass; (B) vegetation cover by brachiaria; (C) capillary barrier

geometry of the storage cell, as shown in Figure 6B. In the HYDRUS 2D/3D model, namely in the last layer, a drain is used to withdraw the fluid. The permanent regime state is used in the simulation of leachate transport.

The results show that the average recharge rate was lower for the model made up with capillary barrier. This fact is due to the adopted configuration of a granular soil layer under a thin soil layer, causing a reduction of the volumetric moisture content. Therefore, the downward flow of water from the thin soil layer is limited.

Vegetation covers such as grass and brachiaria present a difference between the values of recharge rates, as water is eliminated through evaporation and transpiration of these plant species. The accumulated infiltration rate is reduced when a vegetation type with a deeper root is used, as is the case of the brachiaria vegetation, which has about 70 cm of root length.

The surface evaporation rate achieved with the soil covered by the brachiaria vegetation was about 10 times higher when compared to that covered by grass, since the soil is more protected against the solar incidence and, thus, absorbs less heat in the former case. Therefore, the brachiaria retains more water than the grass.

Another way to verify the influence of the coverage layer is related to the contaminant generation in the 2D computational modeling of the storage cell. According to the type of cover of the final layer, as shown in the snapshots depicted in Figure 7, it is possible to verify that there is a reduction in the mobility of the contaminants in agreement with the scheme of cover layer used for the coverage of the landfill.

Once the temporal evolution of the contamination plume is examined over a simulation time period ranging between five and twenty years, the cover type having an arrangement that is configured as a capillary barrier, as shown in Figure 7D, shows efficiency against the water flow as it limits the movement of downward flow of water as it comes from the thin soil layer.

This situation is due to the configuration of granular soil layer under a thin soil layer, where water is trapped by capillary forces, notably involving the

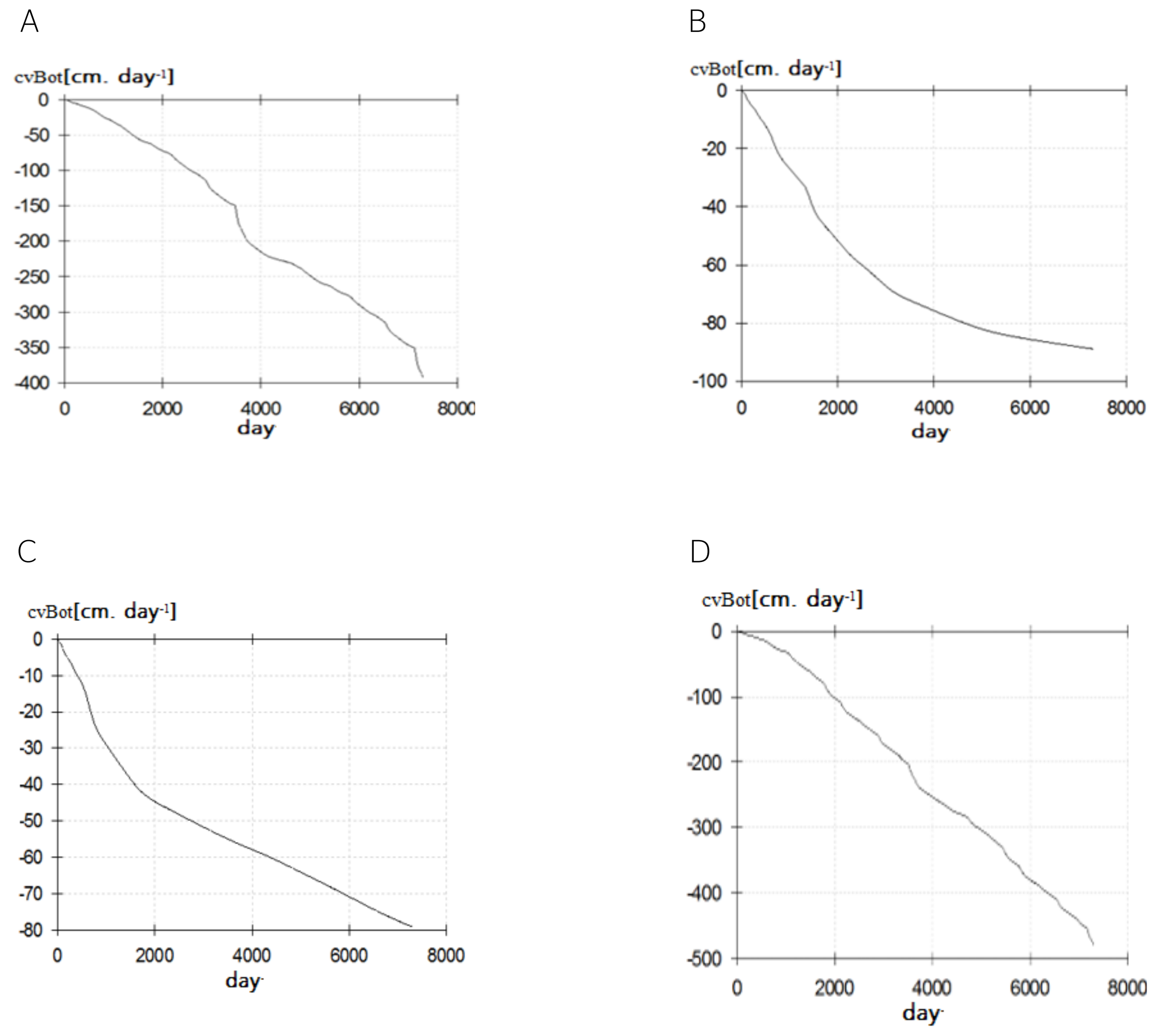

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Figure 5 – Graphical representation of the accumulated bottom flux for the four coverage layers of the landfill: (A) vegetation cover by grass; (B) vegetation cover by brachiaria; (C) capillary barrier coverage; (D) compact soil coverage.

high degree of saturation of this layer of fine material. It presents, therefore, low volumetric moisture content and, consequently, low unsaturated hydraulic conductivity, which allows for a hydraulic discontinuity to occur between the layers of waste and a higher retention of water.

The movement of water from the upper to the lower layers produces the exorbitant hydraulic gradient, hindering the downward flow of water against the more negative surface gradient of the layers below. Due to this phenomenon, the amount of water drained from the simulations using the capillary barrier was smaller in contrast to the use of the compact soil.

On the other hand, the vegetation cover models of Figures 3B and 4B, in addition to Figure 7B, have the role of controlling the rate of infiltration by natural processes. Water is eliminated by evaporation and transpiration of the plant species. This method is often used to slow the movement of contaminated groundwater. In this way, migration to groundwater or even to the air can be prevented by reducing bioavailability for possible introduction of the contaminant into the food chain, processes in which contaminant concentrations can be minimized to an acceptable level through the direct action of plants.

The worst result is the use of compact soil as a cover layer, with behavior observed in Figure 7C for the 20-year period. The use of this cover layer reveals that there is a larger increase of the displacement of the plume of contamination and potentially entails in possible contamination in the surroundings of the soil or, in the worst cases, of the water table in the region of insertion of the landfill.

However, the use of mathematical models necessarily depends on a detailed study of their operation and verification tests to choose the functions and values of the parameters in the condition of interest based on the measured data. In this sense, this work presented the results of the 2D time evolution of the infiltration rate, relating it to the presence of the urban solid residues in the storage cell. In order to predict the behavior of the most usual coverage layers under

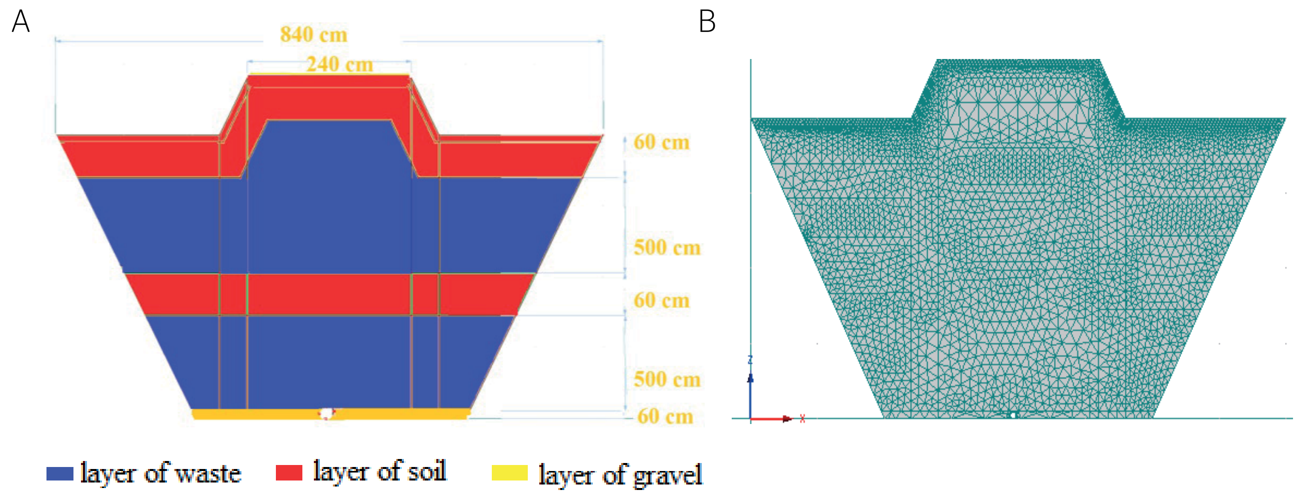

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Figure 6 – Mathematical simulation scheme: (A) geometric representation of the HYDRUS 2D numerical simulation; (B) triangular mesh used in numerical simulation.

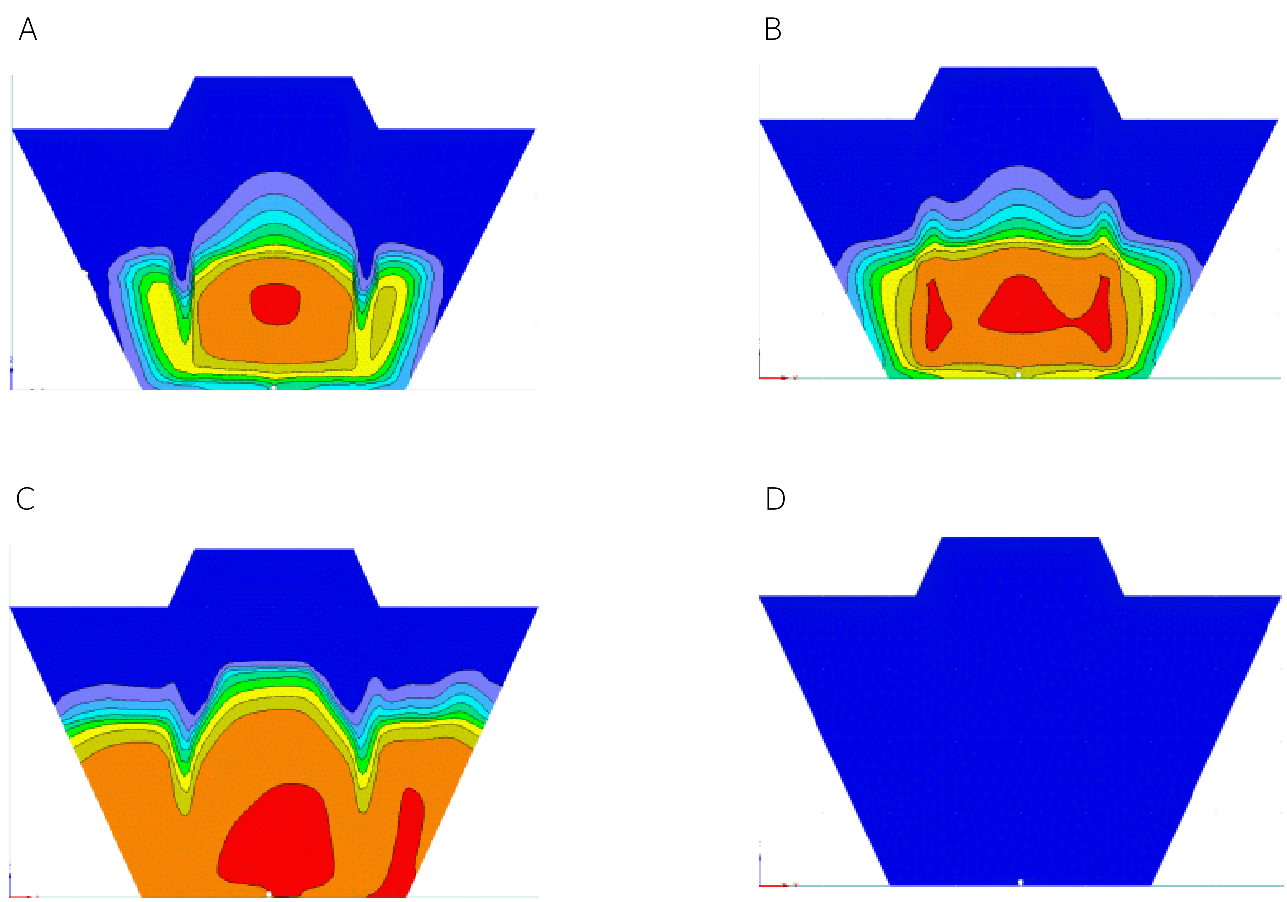

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Figure 7 – Contaminant behavior over the time frame of 20 years by means of instant photographs for the four coverage layers of the landfill: (A) vegetation cover by grass; (B) vegetation cover by brachiaria; (C) capillary barrier coverage; (D) compact soil coverage.

different scenarios for the landfill of Seropédica, ground-based measurements of daily rainfall and daily temperature were taken into account. It is noteworthy to say that the HYDRUS computational code was proven to be an interesting tool to be used in order to choose the best alternative of landfill coverage aiming to increase its functionality.

CONCLUSION

The performance of a landfill is directly linked to the type of coverage. In this work, we investigated the behavior of the landfill final cover proposed for Seropédica-RJ, taking into account the hydrometeorological conditions obtained in the automatic weather station of Anchieta located close to the landfill site. Four types of landfill final cover were examined: vegetation cover by grass; vegetation cover by brachiaria; compact soil coverage; and capillary barrier coverage.

It should be recalled that compact soil is the usual approach taken for the landfill final cover with respect to municipal solid waste. In this sense, this work highlights the performance of the other arrangements proposed for the landfill final cover in comparison to the employment of compact soil for that purpose. It was found a relationship between the coverage layer and the water infiltration rate. It was also observed that the downward flow of water into the innermost layers was much more pronounced in the case of compact soil coverage when compared to the other coverage layers.

In addition, the analysis of the layers with the type of capillary barrier coverage configuration provided the best results in terms of retaining or retarding percolation of the solute and consequently the movement of the contaminant plume. This finding is predominantly due to soil particle size distribution, which resulted in a lower value of unsaturated hydraulic conductivity, thus reducing the downward flow of water derived from the upper thin layer of the soil.

Soils with vegetative cover also play an interesting role in minimizing the infiltration of rainwater as was depicted in the evaluated cases of grass and brachiaria. In fact, the snapshots showed that vegetation coverings contained the spread of polluting residues. The plant root system increases soil aeration, promoting evaporation and transpiration. The differences in the results for grass and brachiaria were due to the differences regarding the depth of their roots and height of their crowns.

As a final word, we would like to emphasize that the importance of the use of HYDRUS for performing the computational simulations and analysis in the case of exploring the behavior of different coverages of a landfill is confirmed in the sense that it allows to control and monitor the evolution of the contaminant plume minimizing or avoiding, as much as possible, the need to apply an invasive method for collecting or performing *in situ* measurements.

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