Influence of humic substances on the landfill leachate biodegradability with a focus on temporal seasonality

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ABSTRACT

The high resilience to biological treatments from the landfill leachate is generally associated with the presence of humic substances (HS). The brown color characteristic of this effluent is also related to these substances. Landfill leachate with low biodegradability can make biological treatments unfeasible, which can drive up the cost for the treatment of large leachate volumes. In this context, this research aimed to characterize the leachate in different seasonal periods, and verify the influence of HS species on the biodegradability of the effluent to assist in the selection of adequate treatment techniques. The HS quantification was performed using the modified Lowry method and speciation through fractionation according to the molar masses of the HS species. The tropical regions can be the precursor for the rapid stabilization of biodegradable organic matter. The warmer climate contributed to a reduced BOD/COD ratio (0.03) and the predominance of compounds of lower mass (e.g.: fulvic acids). The tests showed an HS concentration of 26.9% of the total COD in the raw leachate in the rainy season, which increased to 37.3% in the dry season. Approximately 70% of HS species refer to fulvic acids, a fraction identified as having the highest biologic treatment resilience.

Key words: biodegradability, humic substances, inert COD, landfill leachate, molar mass distribution

HIGHLIGHTS

- A method for HS determination in the presence of proteins was assessed.
- Leachate is diluted during hydric surplus.
- FA are the main compounds in stabilized leachate among the HS.
- Leachate resilience to biodegradation is mainly derived from FA.
- Hydraulic retention times longer than 20 days are not recommended due to cell lysis.
INTRODUCTION

Leachate is a brown liquid derived from landfill waste biodegradation, added to the waste's natural moisture and rain infiltration. It is estimated that leachate is continuously produced up to 50 years after a landfill's operational activities have ceased (Shafiq & Yusof 2014; Scott et al. 2019). Apart from the high volume, leachate has a complex and variable composition, being strongly affected by the waste disposed of, the dynamics of waste degradation, landfill properties, and climate conditions (Luo et al. 2020).

The environmental conditions are not only linked with quantity but mainly with the leachate quality generated. Lebron et al. (2021) stated that landfill leachate is qualitatively and quantitatively influenced by climatic factors such as rainfall, evapotranspiration, and ambient temperature. Nevertheless, information about the interaction between climate and the composition of landfill leachate are limited. Consequently, researches with this purpose are important in the sense of designing conscious solutions for leachate treatment.

In general, landfills receive a mixture of domestic, commercial, and industrial waste, excluding significant amounts of specific chemical waste. Thus, it is reasonable to presume that leachates are composed of an aqueous solution with four classes of pollutants. The classes are dissolved organic material (volatile fatty acids and recalcitrant organic compounds such as humic substances), inorganic macro components (Ca\(^{2+}\), Mg\(^{2+}\), Na\(^{+}\), K\(^{+}\), NH\(_4\)\(^{+}\), Fe\(^{2+}\), Mn\(^{2+}\), Cl\(^{-}\), SO\(_4\)\(^{2-}\), HCO\(_3\)\(^{-}\)), heavy metals (Cd\(^{2+}\), Cr\(^{3+}\), Cu\(^{2+}\), Pb\(^{2+}\), Ni\(^{2+}\), Zn\(^{2+}\)) and xenobiotic organic compounds originating from domestic waste (aromatic hydrocarbons, phenols, pesticides, etc.) (Ghosh et al. 2017; Costa et al. 2019).

Humic substances (HS) originate from the oxidation and subsequent polymerization of organic matter present in the soil by secondary, biotic and abiotic reactions. HS are also recognized as a series of yellow-brown to black amorphous polymers with a relatively high molar mass. Their classification is purely operational and is based on their solubility properties in aqueous extracting solutions at various pH values. The fractions of humic substances can be divided into humic acids (HA), fulvic acids (FA), and humins (HU). The HA fraction is soluble in an alkaline medium and insoluble in an acidic medium.
(pH < 2). The FA fraction is that which, after solubilization in alkali, remains soluble at any pH value and, lastly, the HU fraction is insoluble in any condition of pH (Lima et al. 2017; Silva et al. 2019).

In terms of structural aspects, HS fractions differ in their functional groups and order of molar mass. FAs have the lowest molar mass, less carbon and nitrogen, and have the highest content of oxygen-containing functional groups (CO₂H, OH, C = O) per unit weight compared with HA and HU. HU resembles HA in its chemical structure, and the HU insolubility may be due to its adsorption to inorganic constituents present in the soil. That appears to be a possible explanation for the resistance of HS to biodegradation since, in general, they form stable metallic and/or clay-organic complexes (Zhang et al. 2013; Moradian et al. 2020).

Previous studies reported that 50–60% of the COD content in a leachate sample collected after landfill stabilization was constituted by HS (Lima et al. 2017; Gu et al. 2019). Considering the recalcitrance of HS, it is to be expected that landfill leachate has high resilience to biological treatments (Costa et al. 2019). The contribution of seasonal variation to leachate recalcitrance was estimated in a previous review paper, although not empirically assessed (Lebron et al. 2021).

The most papers do not empirically assess the seasonal variation effect onto the leachate and its various properties such as biodegradability, HS speciation and recalcitrance. Considering this fact, this research verified the effects of rain on the physicochemical characteristics of the leachate and the influence of HS on the biodegradability of the effluent. By that, it is expected that the lack of knowledge related to the seasonal variation and landfill leachate composition is covered, proving the necessity for more appropriate techniques for leachate treatment. Furthermore, alongside other papers (Kumar et al. 2021) this work can build on the knowledge on the degradation of other types of recalcitrant compounds.

Finally, future research may provide more information on the local climate and precipitation levels in landfills. Other adverse characteristics of the leachate can also be studied, such as the influence of toxicity on the biodegradability of the effluent. The influence of the frequency of effluent collection on the data can also be evaluated.

**MATERIALS AND METHODS**

**Leachate sampling and physicochemical characterization**

Landfill leachate was collected in a solid waste sanitary landfill located in Belo Horizonte/MG – Brazil. The landfill occupies an area of 133 hectares, has landfill cells with different ages and characteristics. The mean operating load was 4,200 ton/day and during the sampling period, the leachate generation was 300 m³/day. The leachate sampling period during hydric surplus corresponded to the months of January and February. The period of hydric deficit corresponded to the months of May and June.

Raw leachate was characterized by the following physical-chemical parameters: apparent and real color (2120 C), chemical oxygen demand (COD) (5220 B), biological oxygen demand (BOD) (5210 B), pH (4500 B), alkalinity (2320 B), solids (2540 C), total nitrogen (4500 C), phosphorus (4500 BE) and metals (3111 B). All the analyzes followed the recommendations of the Standard Methods for the Examination of Water and Wastewater (APHA 2017).

Lipid analyzes were performed using the sulfophosphovanillin method (Postma & Stroes 1968). The method consists of adding concentrated sulfuric acid, concentrated phosphoric acid and vanillin solution, which in the presence of lipids result in a pink color. Absorbance is read at 537 nm. The concentration of lipids present in the samples was determined using a standard curve previously constructed with soybean oil.

Carbohydrate analyzes were performed using the phenol and sulfuric acid method based on the methodology described by Dubois et al. (1956). The addition of reagents (phenol and sulfuric acid) to samples containing carbohydrate results in an orange color. Absorbance is read at 488 nm. The concentration of carbohydrates present in the samples was determined through a standard curve previously constructed with glucose.

**Humic substances quantification**

Frolund et al. (1995) proposed a modified Lowry’s method (Lowry et al. 1951) for HS quantification in leachate samples. It is considered that the leachate composition could be grouped into two large groups. The first, generically called non-humic substances (NHS) and mainly consists of protein, and the second associated with HS (Stevenson 1994). Based on that, a procedure was developed for HS quantification under the presence of proteins.

In summary, the method relies on colorimetric principles and external calibration curves (r² > 0.99; λ: 750 nm) for protein quantification (Lowry et al. 1951), with and without the addition of copper sulfate (CuSO₄), using bovine serum albumin (BSA) and HS standards (both provided by Sigma-Aldrich, St. Louis – MO). The interference in absorbance values measured
Humic substances speciation and molar mass distribution

The raw leachate was fractionated into aliquots with molar masses between 5, 10, and 100 kDa aiming at HS speciation. As proposed by McBride (1994), FA would have a molar mass <5 kDa, HA between 10–100 kDa, and HU > 100 kDa). The samples were submitted to molar mass distribution in an Amicon ultrafiltration cell (model 8200). Ultrafiltration was carried out in series using membranes with a cut-off molar mass (MWCO) of 5, 10, and 100 kDa. The membranes were initially washed by permeating 150 mL of deionized water and subsequently fed with a leachate sample (180 mL) previously filtered in an AP40 filter (47 mm – Millipore, Merck). After ultrafiltration, another 100 mL of deionized water was added, and the ultrafiltration continued until the remaining volume was lower than 20 mL. The depressurized cell was then left under stirring for about 10 minutes to recover compounds eventually adsorbed to the membrane. The retained fractions were analyzed for the concentration of carbohydrates, lipids, proteins, HS, and COD.

Humic substances versus inert COD/biodegradability

Inert COD tests were performed as proposed by Germirli et al. (1991). The method considers the use of two batch aerobic reactors (2 L each), one fed with a sample of known COD concentration and the other with a glucose solution of equivalent concentration. The inoculum used was sludge from activated sludge systems (volatile suspended solids (VSS) 100 mg L⁻¹). In the reactors, 2 mL of a solution of each nutrient used in the BOD assay (5210 B – Standard Methods for the Examination of Water and Wastewater) were also added and they were kept continuously aerated. The COD in the reactors was monitored until the end of biological activity was observed.

Biodegradability was assessed through the method proposed by Zahn-Wellens (OECD 302 B, 1992). 2 L reactors were used, fed with leachate, 2 mL of a solution of each nutrient used in the BOD assay (5210 B – Standard Methods for the Examination of Water and Wastewater) and inoculum at a concentration of 100 mg L⁻¹ of VSS. The reactors were subjected to aeration using electric compressors. The substrate depletion was monitored by means of soluble (filtered) COD analysis for 30 days, with a periodicity of approximately 2 days. It is noteworthy that for this assessment, tests were carried out with leachate collected in the rainy season, whose characterization has already been presented previously. The reactors evaluated for each extract were fed with the same COD concentration (550 mg L⁻¹) and subjected to similar operating conditions.

RESULTS AND DISCUSSION

Raw leachate physicochemical characterization

The raw leachate characterization was carried out taking into account seasonality effects in the most critical monitoring periods through a year, totaling 20 samples, 5 in each period. The period of hydric surplus corresponded to January and February, while the period of hydric deficit corresponded to May and June. An average monthly accumulated precipitation of 270 mm was observed in the period of water surplus against 30 mm in the period of water deficit. Table 1 presents the parameters evaluated in the characterization of the raw leachate.

The low standard deviation values demonstrate the stability in the leachate characteristics despite the different seasonal periods. The fact that the leachate was collected in the landfill cell drain also contributed to the low deviation values found. The effluent dilution was relevant during the period of water surplus. The average value of color in the period of water surplus
was 66% lower when compared to the period of water deficit. However, the leachate polluting potential remained high. The presence of dissolved substances as HS can be confirmed by the proximity of the real and apparent color values.

A high concentration of organic matter can be seen during both seasonal periods (COD $> 2,000$ mg L$^{-1}$). The low BOD/COD ratio indicates a low biodegradability of the leachate and confirms its stage of advanced stabilization. The results suggested that the leachate has a high oxidation condition; that is, the microbiological reactions of BOD degradation are limited. The value of 0.64 for $\text{BOD}_2/\text{BOD}_{20}$ indicates the presence, for the most part, of organic compounds that are resilient to biochemical stabilization processes. This condition may be related to the fact that the maximum BOD is found close to the 20th day of incubation. The results for $\text{BOD}_5/\text{BOD}_{20}$ concur with what was recently summarized by Lebron et al. (2021).

According to the authors, the warmer climate in tropical regions can be the precursor for changes in the microbiome and enhances microbiological activity. The ultimate result is a rapid stabilization of biodegradable organic matter which reduces the BOD/COD ratio.

The pH was higher than conventionally reported in the literature [3–7.5; (Costa et al. 2019)]. The result should be associated with the alkalinity derived from the large amount of civil construction waste that was disposed of in this landfill. According to data from the landfill, approximately 40% of landfilled waste corresponds to waste from civil construction.

The BOD/NTK ratio represents the amount of organic matter in relation to the amount of the macronutrient nitrogen, similar to the C/N ratio. The values found for this ratio are very low (1/16). This low rate indicates an excess of nitrogen that is mainly in the form of ammonia, generated by the degradation of proteins (the largest fraction of the biodegradable organic matter in the leachate). Since the BOD/COD ratio is very low (0.03), aerobic microbiological degradation in the landfill cell may be limited due to the lack of easily biodegradable organic matter or the presence of toxic compounds present in the effluent. There is also no limitation in the concentration of phosphorus when compared to the ratio indicated as favorable to the development of microorganisms (C:P = 5:1).

### Table 1 | Raw leachate characterization in different seasonal periods

| Parameter                        | Max. | Min. | Mean       | Max. | Min. | Mean       |
|----------------------------------|------|------|------------|------|------|------------|
| **Hydric surplus**               |      |      |            |      |      |            |
| Real color (uH)                  | 568  | 420  | 467 ± 60   | 1,579| 1,229| 1,374 ± 155|
| Apparent color (uH)              | 748  | 519  | 590 ± 94   | 1,845| 1,536| 1,711 ± 154|
| COD (mg L$^{-1}$)                | 2,428| 2,220| 2,354 ± 94 | 3,156| 2,886| 2,990 ± 130|
| $\text{BOD}_2$ (mg L$^{-1}$)     | 85   | 50   | 68 ± 15    | 130  | 70   | 99 ± 28    |
| $\text{BOD}_{20}$ (mg L$^{-1}$)  | 130  | 75   | 105 ± 23   | 195  | 100  | 154 ± 44   |
| BOD/COD                          | 0.04 | 0.02 | 0.05 ± 01  | 0.04 | 0.02 | 0.03 ± 01  |
| pH                               | 8.44 | 8.10 | 8.26 ± 0.15| 8.55 | 8.07 | 8.30 ± 0.22|
| Kjeldahl nitrogen (NTK) (mg L$^{-1}$) | 1,172| 1,036| 1,105 ± 57 | 1,731| 1,054| 1,429 ± 308|
| Alkalinity (mg L$^{-1}$)         | 6,041| 4,791| 5,263 ± 557| 8,089| 7,137| 7,576 ± 430|
| Phosphorous (mg L$^{-1}$)        | 20   | 11   | 15 ± 4     | 94   | 43   | 66 ± 24    |
| Total solids (TS) (g L$^{-1}$)   | 9.4  | 8.1  | 8.8 ± 0.6  | 13.1 | 9.3  | 11.3 ± 1.9 |
| Total fixed solids (TFS) (g L$^{-1}$) | 6.0 | 5.1  | 5.6 ± 0.4  | 7.7  | 5.6  | 6.7 ± 1.0  |
| Total volatile solids (TVS) (g L$^{-1}$) | 3.7 | 2.5  | 3.2 ± 0.6  | 5.4  | 3.7  | 4.5 ± 0.9  |
| Total suspended solids (TSS) (mg L$^{-1}$) | 26.5| 17.0 | 22.4 ± 4.1 | 43.0 | 24.5 | 34.0 ± 8.4 |
| Fixed suspended solids (FSS) (mg L$^{-1}$) | 4.5 | 1.5  | 3.1 ± 1.4  | 13.0 | 1.8  | 7.7 ± 7.7  |
| Volatile suspended solids (VSS) (mg L$^{-1}$) | 22.0| 15.5 | 19.3 ± 2.8 | 30.0 | 22.7 | 26.3 ± 3.3 |
| Cadmium (mg L$^{-1}$)            | 0.524| <0.005| 0.466 ± 0.264| 0.605| <0.005| 0.366 ± 0.111|
| Lead (mg L$^{-1}$)               | <0.02| <0.02 | <0.02      | <0.02| <0.02| <0.02      |
| Chromium (mg L$^{-1}$)           | 0.49 | <0.05 | 0.23 ± 0.23| 0.56 | 0.07 | 0.29 ± 0.23|
| Iron (mg L$^{-1}$)               | 10.35| 2.20  | 5.68 ± 3.60| 11.36| 3.56 | 7.54 ± 3.49|
| Zinc (mg L$^{-1}$)               | 0.14 | 0.07  | 0.10 ± 0.03| 0.21 | 0.07 | 0.13 ± 0.07|

Note: Figures in bold are the most impactful physical-chemical properties of the effluent.
Regarding alkalinity, a slight decrease in the rainy season can be noticed. Despite greater salt leaching due to the increase in the moisture content in the waste mass, the leachate dilution is also greater due to the infiltration of water.

The low concentration of suspended solids explains the small difference between the apparent and real color of the effluent (low turbidity). The VSS/FSS represents the ratio between the amount of volatile solids (organic fraction) and fixed suspended solids (inorganic fraction). In addition to the low concentration of solids, there is a VSS/FSS ratio varying between the range of 3 and 6 in periods of high and low rainfall respectively. The low VSS/FSS ratio indicates microbiological maturity, as VSS can be directly associated with the existing biomass concentration in the effluent.

The concentration of heavy metals found was low, but most probably enough to impact the soils surrounding the landfill. Hussein et al. (2021), which quantified even lower concentrations for cadmium and chromium compared with the current study, confirmed an advanced decline of soil quality by leachate contamination. The authors still mentioned that the existence of heavy metals represented a potential threat to the local flora, groundwater, and surface water in the landfill vicinities.

The higher iron concentration than other metals can be attributed to the natural geomorphological characteristics of the soil in which the landfill is located.

**Humic substances**

**Validation of the modified Lowry method**

Experimentally, an average absorbance reduction factor \((F)\) equal to 0.32 was obtained when the absorbance values with and without \(\text{CuSO}_4\) were compared (Equation (3)). Thus, Equations (1) and (2) can be re-written as Equations (4) and (5), the latter adjusted for the effluent under study. Equations (4) and (5) were rearranged to Equations (6) and (7) and were further used to estimate the theoretical absorbance values, comparing with experimental values in Figure 1.

\[
\begin{align*}
A_{\text{prot}}/\text{CuSO}_4 & = A_{\text{proteins}} + A_{\text{HS}} \\
A_{\text{prot}}/\text{CuSO}_4 & = 0.32 \cdot A_{\text{proteins}} + A_{\text{HS}} \\
A_{\text{proteins}} & = 1.47 \cdot (A_{\text{prot}}/\text{CuSO}_4 - A_{\text{prot}}/\text{CuSO}_4) \\
A_{\text{HS}} & = 1.47 \cdot A_{\text{prot}}/\text{CuSO}_4 - 0.47 \cdot A_{\text{prot}}/\text{CuSO}_4
\end{align*}
\]

The theoretical absorbances values related to proteins concentration (Figure 2 – ‘Protein (T)’) and those obtained empirically (‘Protein (E)’) coincided for all HS concentrations (0–102 mg L\(^{-1}\)), which suggests a coherent fit. Another observation is the increase in experimental absorbance values when the concentration of proteins + HS increased, an expected and desired response (Figure 1). That allowed us to properly correlate the theoretical and experimental absorbance values relative to the HS concentration. Figure 2(a) shows the theoretical absorbances relative to the standard HS concentration as a function of the BSA protein concentration. Figure 2(b) shows the correlation between the absorbance and the concentration of HS. The overall results summarized in Figures 1 and 2 reassure the method’s capability to HS measurements in the presence of proteins.

**Quantification and speciation**

**Figure 3** shows the quantitative and qualitative results for HS present in the leachate under study.

The results showed that the amount of HS is equivalent to 26.9% of the total COD in the raw leachate in the rainy season. This percentage increased to 37.3% of COD in the dry season (Figure 3(a)). Considering seasonality, it was concluded that in the dry season more humic substances and organic material remained concentrated in the leachate. For the rainy season, the concentration of these substances decreases due to dilution. The values obtained were lower than those verified by Kang et al. (2002). However, this author worked with landfills in the operational phase, differently from the scenario of this study.

The raw leachate showed FA predominance compared with other HS fractions. The presence of FA was equivalent to approximately 70% of the HS, followed by HA and HU in minor proportions (Figure 3(b)).
Figure 1 | Experimental (E) and theoretical (T) absorbances obtained for BSA standard solutions with different concentrations of humic substances standard. (a) BSA$^+0\text{ mg L}^{-1}$ HS, (b) BSA$^+17\text{ mg L}^{-1}$ HS, (c) BSA$^+51\text{ mg L}^{-1}$ HS and (d) BSA$^+102\text{ mg L}^{-1}$ HS. 'T' refers to theoretical absorbance values obtained with Equations (6) and (7) and 'E' to experimental absorbance values.

Figure 2 | (a) Theoretical absorbances relative to the concentration of the HS standard as a function of the BSA protein concentration; (b) correlation curve between absorbances and the concentration of HS.
Humic substances versus inert COD/biodegradability

To confirm the hypothesis commonly found in the literature that the leachate recalcitrance is associated with HS (Costa et al. 2019; Lebron et al. 2021), the inert COD and biodegradability parameters were evaluated by the molar mass distribution range of HS species (Figure 4).

**Figure 3** | Humic substances in the leachate at different seasonal periods. (a) concentration and (b) speciation.

**Humic substances versus inert COD/biodegradability**

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**Figure 4** | Soluble COD profiles of crude leachate and glucose with corresponding concentration to extracts with molar mass less than 5 kDa (<5), between 5 and 10 kDa (5 < x < 10), between 10 and 100 kDa (10 < x < 100), and greater than 100 kDa (>100). Abbreviations: FA – Fulvic acids; HA – Humic acids; and HU – Humins.
A lower decay rate of soluble COD can be observed in the reactor fed with extracts with molar masses smaller than 5 kDa (C/C₀ = 0.85), followed by the fraction between 10 and 100 kDa (C/C₀ = 0.80) and >100 kDa (C/C₀ = 0.63). The phenomenon of cell lysis in reactors occurred close to the 20th day of incubation. The phenomenon of cell lysis can be denoted by the slight increase in COD, suggesting the maximum hydraulic detention time for optimal operating conditions in aerobic reactors. The reactor with extract with molar masses between 5 and 10 kDa reached a minimum value of COD on the 25th day of incubation. This fact suggests greater availability of compounds susceptible to biodegradation in this molecular weight range.

The results of molar mass distribution and inert COD/biodegradability versus HS for all extracts were summarized in Figure 5(a) and 5(b), respectively. Data shown in Figure 5(a) corresponds to extracts collected prior to cell lysis (20th day). Figure 5(b) shows the extract data collected when the higher COD degradation was achieved (18th day for the fraction <5 kDa, 20th day for the fractions 10–100 and >100 kDa and 25th day for the fraction 5–10 kDa).

It can be seen in Figure 5(a) that, in the raw leachate, most of the organic matter is presented as low molar mass compounds (FA), portraying the advanced stage of degradation of this effluent. Quantitatively, ∼72% of COD has a molar mass less than 5 kDa. Regarding HS, its presence was detected in the molar mass ranges less than 5 kDa, between 10 and 100 kDa and greater than 100 kDa. The fact that these substances were not detected in the range between 5 and 10 kDa reinforces the characterization of the species of HS in relation to the molar mass, as reported by McBride (1994).

It can be seen in Figure 5(b) that the leachate extract with a molar mass less than 5 kDa presented higher inert COD (74.9%) and lower biodegradability (22.6%) when compared to the results obtained for the raw leachate (unfractionated; inert COD: 44.0% and biodegradability: 46.6% of the total COD). This fact corroborates what is stated in the literature since, in this fraction, a high concentration of FA was found.

![Figure 5](http://iwaponline.com/wst/article-pdf/84/12/3780/979794/wst084123780.pdf)

**Figure 5** | (a) Molar mass distribution and (b) inert COD and biodegradability of leachate extracts with different molar masses. Inert COD was calculated considering the lowest COD point. Biodegradability was calculated considering the 18 – 20th day after incubation, prior to cell lysis. Abbreviations: FA – Fulvic acids; HA – Humic acids; and HU – Humins.
High values of inert COD (67.5%) and biodegradability (30.0%) were also found in the leachate extract with molar mass between 10 and 100 kDa. This fact is probably related to the presence of HA. Despite their lower concentration compared to FA, HA have greater molar mass and complexity in their structures, consequently making these species highly recalcitrant.

In the leachate extract with a molar mass greater than 100 kDa, recalcitrance can be mainly related to the presence of HU, in addition to other compounds with high molar mass. The inert COD value close to 50% corroborates this condition. This further reinforces the relationship of this fraction of HS with the resilience to biochemical degradation of the leachate.

CONCLUSION

The raw leachate characterization in both seasonal periods agree with leachate from stabilized landfills, mainly due to the high NTK concentration and low BOD/COD ratio. The tests showed that 26.9% of total COD corresponded to HS in the rainy season, compared with 37.3% for the dry season. It was concluded that in the dry season more HS and organic material remained concentrated in the leachate while in the rainy season, the concentration of these substances decreased due to dilution. Among the HS, a greater presence of FA in the leachate was observed. Its presence is equivalent to approximately 69–75% of the HS present in this wastewater, followed by HA (18–27%) and a small HU (4–7%).

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DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

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