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Prediction of Leachate Characteristics via an Analysis of the Solubilized Extract of the Organic Fraction of Domestic Solid Waste from the Municipality of Belém, PA

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Abstract: This work aimed to predict the physical–chemical characteristics of leachate according to the analysis of the solubilized extract from urban household solid waste (UHSW), on a laboratory scale, in the city of Belém/PA, Brazil. The neighborhoods where the waste was collected were sectorized based on geographic and socioeconomic data, with family income as the main parameter. After collection, the material was sent to the segregation area, where a gravimetric analysis of the UHSW was performed and fractions (paper, cardboard, Tetra Pak, rigid plastic, malleable plastic, metals, glass, organic matter, sanitary waste, fabrics and rejects) were segregated. After the gravimetric characterization, it was found that the highest average proportions were 55.57% organic matter, 14.26% sanitary waste and 9.97% malleable plastic. The organic fraction was selected and subjected to drying, crushing, sieving and packaging pretreatment, and then the solubilized extract of this fraction was obtained according to NBR No. 10.006/2004 of the Brazilian Association of Technical Standards. In the analyses of the solubilized extract, values for total nitrogen (201.80 to 359.90 mg·L^{-1}), ammonia nitrogen (161 to 289 mg·L^{-1}), nitrate (10 to 40 mg·L^{-1}) and chemical oxygen demand were obtained (28,701 mg·L^{-1} to 38,608 mg·L^{-1}), indicating the similarity of the waste solubilization conditions to those of leachate from landfills, in addition to being in noncompliance with environmental and health legislation, thus making it necessary to have an efficient waste management system, which avoids the release of waste into the environment that would result in environmental impacts similar to those of leachate contact with the environment.

Keywords: urban solid waste; gravimetric characterization; solubilized extract; leachate extract and organic fraction

1. Introduction

The increase in birth rates, longevity, population rates and industrialization, combined with the culture of consumption and accumulation and the lack of knowledge about the limitation of environmental resources, causes an unbridled production of urban solid waste (MSW), resulting in environmental impacts that directly reflect the quality of life of the population [1–3].

In 2022, approximately 81.8 million tons of urban solid waste was generated in Brazil, corresponding to 224 thousand tons per day, 29.7 million tons was not sent for environmentally appropriate final disposal/destination. Of the units with final disposal, around 64.31% represent environmentally unsuitable alternatives, such as controlled dumps and landfills. In the state of Pará, this value was 90.51% [4,5].

Dumps and landfills cause significant impacts on the environment. Among the impacts, it is possible to detect the depreciation of groundwater, water, soil and air pollution; changes in soil biota, biodiversity and local ecological balance; contamination from collectors; visual pollution; the presence of odors; and the generation of leachate [6,7].

Leachate is a black and/or brown liquid with an unpleasant odor formed during the waste collection process or from its degradation in landfills [8]. Its composition has large amounts of metallic ions, ammonia nitrogen, inorganic salts and organic matter [9]; if released uncontrollably, it can contaminate surface and groundwater and cause changes in drinking water standards [10]. Furthermore, leachate can cause significant changes in soil properties, harming agriculture and natural ecosystems and threatening human health [11].

Obtaining leached and solubilized extracts makes it possible to simulate the impacts of solid waste on the environment, showing the environmental risk that these compounds present to receiving bodies and the soil, which is the case when there is no adequate treatment of these liquid by-products [12,13].

Some studies revealed that physical–chemical analyses of the leachate verified average pH values of 7.74 [14–20], total solids of 4882 $mg \cdot L^{-1}$ [15,16,18,20], ammoniacal nitrogen of 909 $mg \cdot L^{-1}$ [15,16,18–20], nitrite of 12.8 $mg \cdot L^{-1}$ [15–20], nitrate of 23.6 $mg \cdot L^{-1}$ [15,16,18,20], a biochemical oxygen demand (BOD) of 1507.69 $mg \cdot L^{-1}$ [14–20] and a chemical oxygen demand (COD) of 16,524.47 $mg \cdot L^{-1}$. In general, leachate is a liquid that is rich in dissolved organic matter, macronutrients, metals, ammonia and xenobiotic compounds and has high levels of BOD and COD, as well as a dark color [21,22].

The exudates with the solubilized extract were able to prove their ecotoxic effects [23,24], carry out physical–chemical analyses to verify the compounds [23–33] and classify the waste from which these compounds originated according to their dangerousness and solubility [26,28–30].

Therefore, this work aimed to systematically evaluate the physical–chemical characterization of the solubilized extract of the organic fraction of urban solid waste in the city of Belém in PA, predicting the concentrations of pollutants in the leachate resulting from waste degradation.

2. Materials and Methods

2.1. Strategy and Methodology

The process shown in Figure 1 simplifies the processes carried out so that the research objectives are fulfilled. First, information was extracted from the database of the Brazilian Institute of Geography and Statistics (IBGE) as described elsewhere [34] on the nominal income of the inhabitants of the neighborhoods where the collections were carried out. Subsequently, the neighborhoods were grouped into sectors and regions, and a representative statistical sampling was carried out to have knowledge of the amount of solid waste to be collected in each sector.

After the collections, the gravimetric characterization of solid waste was carried out, in which it was classified and separated into *paper, cardboard, Tetra Pak, rigid plastic, malleable plastic, metals, glass, organic matter, sanitary waste, fabrics* and *others wastes*. The proportion of each of these residues was calculated. Subsequently, the organic fraction of the residues was subjected to drying at 105 °C, crushing, sieving through 6-to-9-mesh sieves and freezing at a temperature below 0 °C. Subsequently, the material was thawed at a temperature of 42 °C, and this was also the temperature at which the procedures for obtaining the solubilized extract and the analyses were carried out.

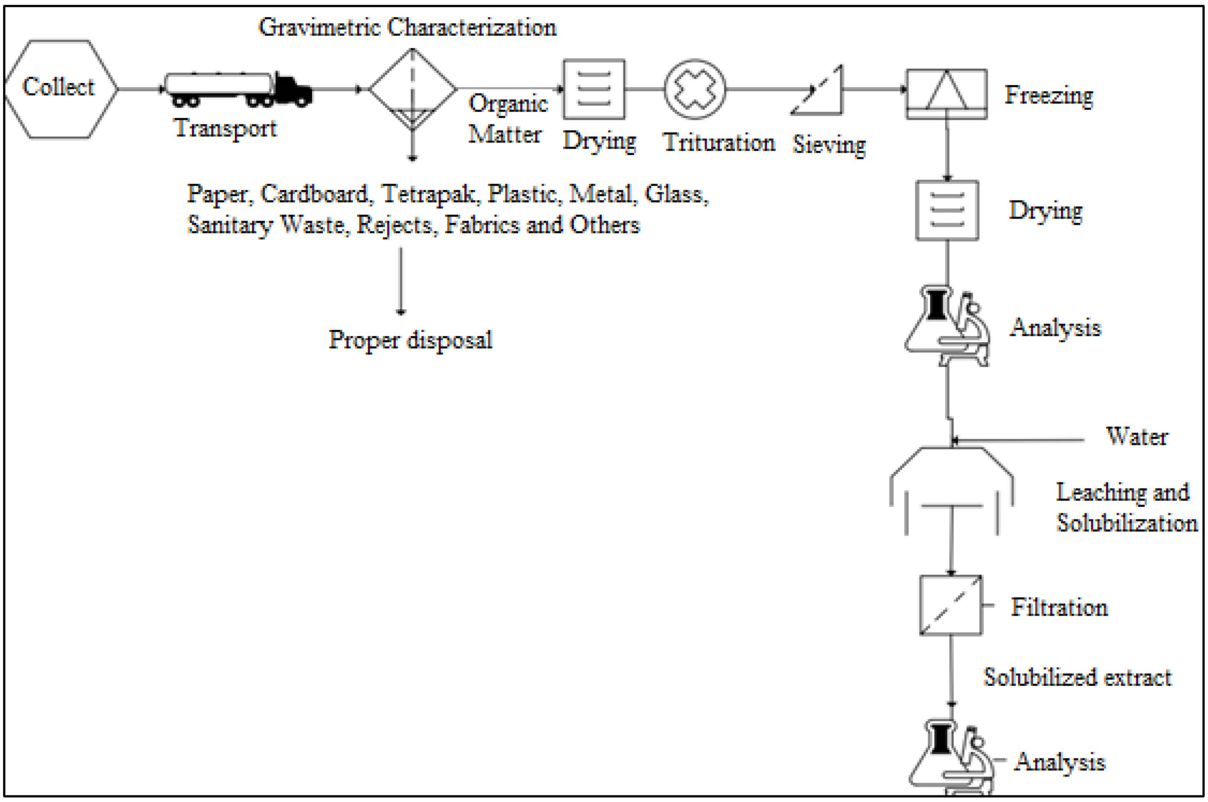

Figure 1. Process flowsheet of collection, classification/segregation and pretreatment of the organic fraction of MSW and obtainment of the solubilized extract.

2.2. Conceptual Design

The plan of action applied to systematically study the effect of the solubilization of solid waste in the environment, when released, in addition to proposing technologies that prevent the proliferation of these materials was designed conceptually as a logic sequence of ideas, concepts and methods, including the *determination and characterization of the study area, statistical sampling of the mass of waste to be collected, collection door-by-door of solid waste in the neighborhoods, gravimetric characterization according to the class of materials (paper, cardboard, Tetra Pak, rigid plastic, malleable plastic, metals, glass, organic matter, sanitary waste, fabrics and others wastes), pretreatment of the organic fraction of solid waste, obtainment of the solubilized extract and analysis of the solubilized extract*.

2.2.1. Determination on the Study Area

The gravimetric collections and characterizations of this research, in addition to the logistics in the collection of materials, were financed with resources from the CNPq Project (Edital 12/2020 MAI/DAI UFPA-Terraplena), Development and Application of Technology for the Sustainability of the Provision of the Collection Service and Urban Solid Waste Transport, coordinated by Prof. Dr. José Almir Rodrigues Pereira (FAESA/ITEC/UFPA) (see Figure 2).

For a better distribution of the neighborhoods and for the formation of representative samples for carrying out the collection procedures, the neighborhoods were grouped into sectors and regions, in which the average nominal income was considered as the main factor for this type of organization. The grouping resulted in nine sectors and three regions, originating from twenty-one neighborhoods and thirty-seven waste collection routes. To carry out the groupings, the neighborhoods were divided by average nominal income, according to the methodology recommended by Assunção et al. [34], who stated that the Brazilian population is divided into five social classes: A, B, C, D and E. Social classes are defined based on the total income of a family group (Tables 1 and 2).

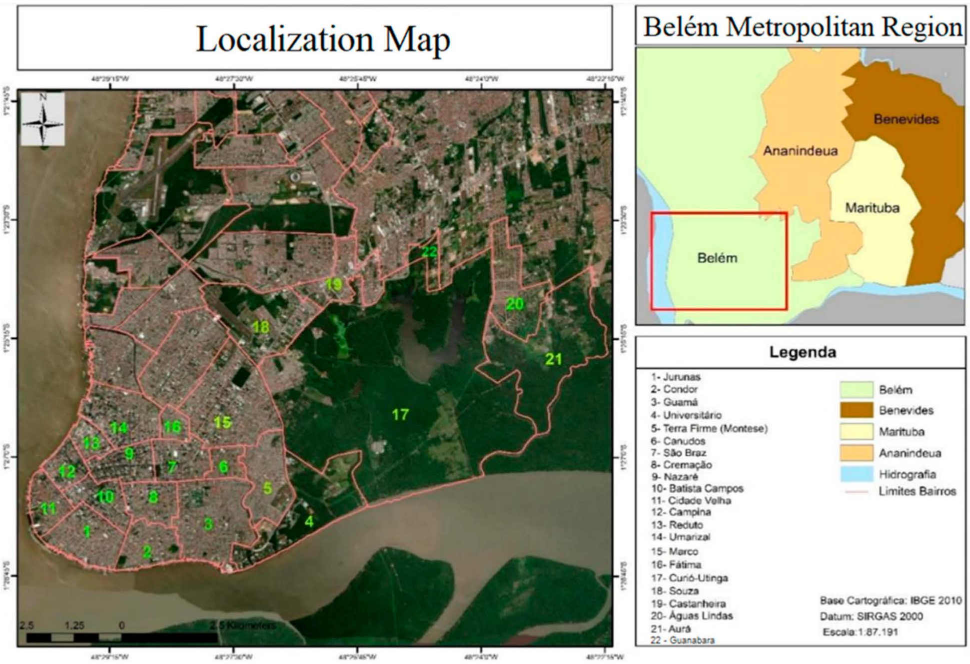

Figure 2. Neighborhoods served by Terraplena in Belém.

Table 1. Socioeconomic classification in the municipality of Belém in Pará, Brazil, based on minimum salary [34].

Socioeconomic Classification	
Classes	**Family Income (Minimum/Basic Salary)**
A	Over 20 salaries
B	From 10 to 20 salaries
C	From 4 to 10 salaries
D	From 2 to 4 salaries
E	Up to 02 salaries

Table 2. Socioeconomic classification, population, average family income in reais (BRL) and grouping into sectors of all the neighborhoods in the municipality of Belém in Pará, Brazil [34].

Region	**Sectors**	**Neighborhoods**	**Average Family Income (BRL)**	**Population (Inhabitants)**	**Socioeconomic Classification**
Region 1	Sector 1	Aura	354.51	1.827	E
		Águas Lindas	344.47	17.520	E
	Sector 2	Curió-Utinga	708.53	16.642	E
		Guanabara	381.58	1.588	E
		Castanheira	748.87	24.424	E
	Sector 3	Souza	1291.02	13.190	D
		Marco	1326.37	65.844	D

Table 2. *Cont.*

Region	Sectors	Neighborhoods	Average Family Income (BRL)	Population (Inhabitants)	Socioeconomic Classification
Region 2	Sector 4	Canudos	821.81	13.804	E
		Terra Firme	414.65	61.439	E
		Guamá	525.80	94.610	E
	Sector 5	Condor	483.06	42.758	E
		Jurunas	633.08	64.478	E
	Sector 6	Fátima	656.14	12.385	E
Region 3	Sector 7	Umarizal	1991.17	30.090	D
		São Brás	1971.37	19.936	D
		Cremação	1093.94	31.264	D
	Sector 8	Batista Campos	2537.63	19.136	C
		Nazaré	3036.30	20.504	C
		Reduto	2964.30	6.373	C
	Sector 9	Campina	2035.60	6.156	D
		Cidade Velha	1235.27	12.128	D
		Total population	-	*576.096*	-

The strategy applied for the selection of collecting routes in the municipality of Belém in Pará, Brazil, is described synthetically as follows. The grouping into sectors and regions facilitated the planning of the collections, the gravimetric composition and all the packaging and transformation processes carried out in the waste, considering the objectives of the research carried out.

2.2.2. Simulation of Sample Mass of MHSR

In order to compute the statistically representative sample volume of MHSW, a simulation was performed with the aid of the software StatDisk 13.0. The simulation was based on the volume collected by route, using a collector truck of 15 m^3, assuming that the average density of MHSW was that of liquid water. The significance and confidence levels were set equal to 5% and 95%, respectively, with a margin of error of 10%, *resulting in a sample of mass* ≈ 100 kg [35].

2.2.3. Collections and Gravimetric Characterization of Solid Waste

The door-to-door collection methodology was chosen because, in this way, the waste is collected in conditions similar to those of its generation and there is no compression in the material, not altering the degree of humidity.

After the collections were carried out using the door-to-door method, the residues were sent to a suitable space for carrying out the gravimetric characterization, at the Federal University of Pará. Immediately after the arrival of the material, the gravimetric characterization of the collected solid waste began. In the collections carried out at night, the gravimetric characterization was carried out in the morning of the following day.

The gravimetric characterization was carried out by separating the solid waste into types: *paper, cardboard, Tetra Pak, rigid plastic, malleable plastic, glass, metal, organic matter, fabrics, sanitary waste and others*. Before carrying out the gravimetric characterization, the total mass of waste was measured to guide the gravimetry process, using the correct proportion of characterized waste. The characterization was carried out in an outdoor location, in a hygienized space suitable for carrying out the procedures. The volunteers involved in the characterization process used personal protective equipment (PPE) to mitigate physical, chemical and biological risks.

2.3. Materials

Pretreatment of the Organic Matter

The organic matter, a mixture of *carbohydrates, lipids, proteins and fibers*, selected from municipal household solid waste (MHSW) was submitted to pretreatment (drying, crushing and sieving) and conditionate in a freezer to avoid physicochemical and microbiologic degradation. The material was dried using a thermal oven with air recirculation and analogous temperature control. Gravimetric characterization was carried out at the Sludge Treatability Laboratory, and pretreatment was carried out at the Chemical Engineering Laboratory, both located at the Federal University of Pará.

After drying, the material underwent the crushing process, aiming to increase the surface area and reduce dimensions. Grinding is important for the next processes to be carried out with the residues since, in the case of laboratory-scale processes, a small amount of material, of low granulometry, is required. In order to further reduce the size of the particles, to facilitate laboratory processes, the residue was subjected to the sieving process. Sifting was carried out immediately after comminution in order to proceed with subsequent packaging. The sieves used had a 6-and-9-mesh opening.

2.4. Experimental Procedures

2.4.1. Obtaining the Solubilized Extract of Organic Solid Waste

The preparation of the solubilized extract was carried out as recommended by NBR 10.006/04 [36], as shown in Figure 3. Sample preparation was carried out at the Laboratory of Pilot Installations for Water and Sludge Treatability (FUPA). Sufficient samples were prepared for all the analyses foreseen in this work. The complete collection of material carried out in all sectors was homogenized, considering the grouping of sectors into regions.

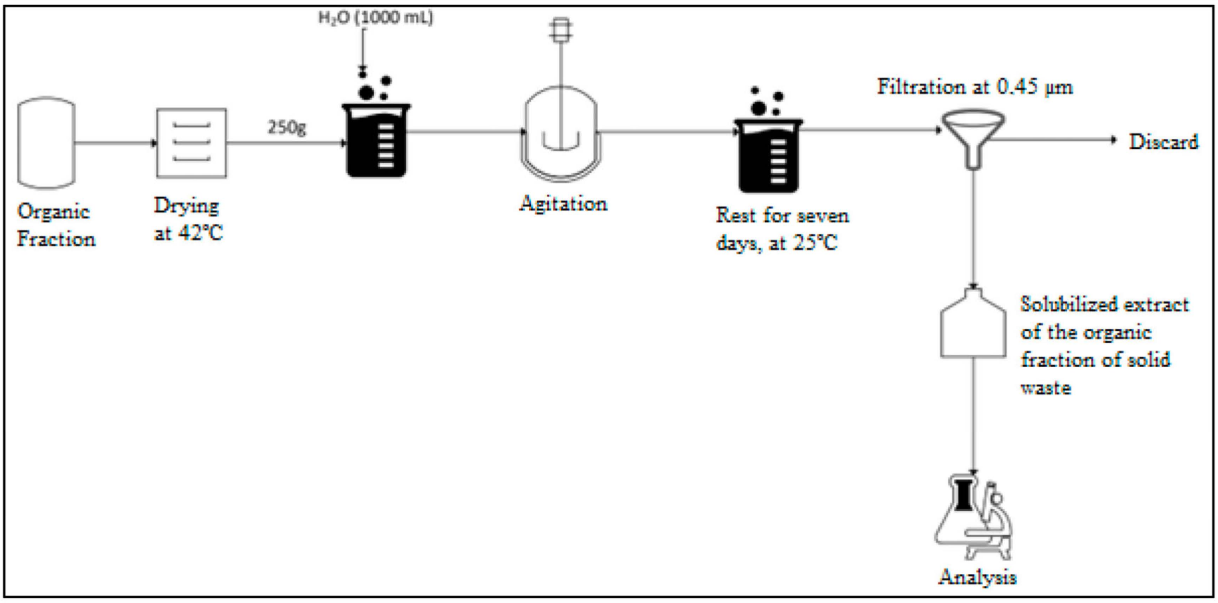

Figure 3. Procedure for obtaining the solubilized extract.

2.4.2. Physicochemical Analysis

After the sample preparation procedures for extracting the solubilized extract, determined according to NBR 10.006/04 [36], were used, the extract was analyzed according to the methodologies described in the Standard Methods for the Examination of Water and Wastewater (SMWW) [37] and the parameters of the current potability standards, in the case of Brazil, Ordinance GM/MS No. 888/2021 [38]. In addition to the potability ordinance, CONAMA Resolution No. 357/2005 [39] was also considered, which classifies water bodies and provides guidelines for the classification of water bodies. The analyses were carried out at the facilities of the Federal University of Pará (Table 3).

Table 3. Physical–chemical parameters analyzed in the solubilized extract.

Parameter	Method	Parameter	Method
Hydrogenionic potential	SMWW-4500H^+	Organic nitrogen	SMWW-4500-N_{org}
Turbidity	SMWW-2130	Ammoniacal nitrogen	SMWW-4500-NH_3
Apparent color	SMWW-2120 B	Nitrite	SMWW-4500-NO_2
True color	SMWW-2120 B	Nitrate	SMWW-4500-NO_3
Electric conductivity	SMWW-2510	Total phosphorus	SMWW-4500-P
Total dissolved solids	SMWW-2540 C	Reactive phosphorus	SMWW-4500-P
Total alkalinity	SMWW-2320	Hydrolyzable phosphorus	SMWW-4500-P
Free CO_2	SMWW-CO_2	Condensable phosphorus	SMWW-4500-P
Chloride	SMWW-4500-Cl^-	Organic phosphorus	SMWW-4500-P
Cyanide	SMWW-4500-CN^-	Total hardness	SMWW-2340
Fluoride	SMWW-4500-F^-	Magnesium hardness	SMWW-2340
Sulfide	SMWW-4500-S^{2-}	Calcium hardness	SMWW-2340
Sulfate	SMWW-4500-${SO_4}^{2-}$	Total COD	SMWW-5520
Total nitrogen	SMWW-4500-N	COD filtered	SMWW-5520
Total Kjeldahl N	SMWW-4500-N	-	-

For the treatment of data, comparisons were made with bibliographic research carried out. The data are presented in the tables, with relevant information presented in graphs and other tools that allow for a better understanding of the information raised throughout the research carried out.

3. Results

3.1. Gravimetric Characterization of MHSW

Table 4 shows the results of the gravimetric analysis of MSHW in the municipality of Belém in the period from 4 November 2021 to 13 May 2022, according to ABNT NBR 10.007/2004 [40]. In addition, Table 5 shows the mean and median results, in comparison to the standard deviation of the analyzed values. In both tables, it is possible to see the proportions of materials as percentages of MHSW fractions (*paper, cardboard, Tetra Pak, rigid plastic, malleable plastic, metals, glass, organic matter, sanitary waste, fabrics* and *others wastes*). By performing an analysis of Table 5, it is possible to verify the heterogeneity between the MHSW fractions in different sectors and, consequently, in different regions. When analyzing the values, in percentages, of the mass of residues, it is noticed that the percentage values of the fraction of organic matter are higher in relation to the other proportions, as verified by the gravimetric characterizations previously carried out in the city of Juiz de Fora [41]; the values of organic matter mass (%) vary between 49.45% and 61.12%, with mean values of 55.57%, a median of 54.55% and a standard deviation of 3.62% between the values collected in the sectors. Still, between the maximum and minimum values, it is possible to observe a variance of 13.09%.

Table 4. Results of the gravimetric characterization for the nine sectors in relation to the percentage of the collected mass of waste, collected in the municipalities of Belém and Ananindeua, state of Pará, between 4 November 2021 to 13 May 2022.

Class of MHSW	Sectors								
	S1 (%)	S2 (%)	S3 (%)	S4 (%)	S5 (%)	S6 (%)	S7 (%)	S8 (%)	S9 (%)
Paper	1.24	2.30	6.38	6.13	5.01	1.67	4.70	6.45	11.95
Cardboard	2.26	3.11	1.87	2.63	4.82	2.66	5.39	3.17	2.90
Tetra Pak	0.31	0.68	0.48	0.34	0.63	0.99	0.92	0.87	3.25
Hard plastic	3.72	3.29	3.98	2.25	4.10	3.25	4.53	3.37	3.70
Soft plastic	7.96	11.69	9.50	10.15	8.44	8.17	10.66	15.25	7.90
Metal	2.03	2.39	1.39	1.68	3.09	2.35	2.58	1.20	1.25
Organic matter	61.12	54.15	60.43	49.45	53.71	57.61	54.33	54.79	54.55
Glass	2.87	4.29	0.53	0.00	0.43	2.93	0.63	1.39	3.65
Sanitary waste	16.67	13.00	15.44	20.34	12.78	18.78	12.72	10.34	8.25
Fabrics	1.81	5.10	-	1.87	6.17	1.58	3.55	3.17	2.60
Waste	-	-	-	5.17	0.82	-	-	-	-
Total	100	100	100	100	100	100	100	100	100

Table 5. Mean, standard deviation, median, variance, maximum and minimum values of percentages of waste fractions collected in collection campaigns and gravimetric characterization results.

Class of MHSW	Mean ± SD	Median	Variance	Maximum	Minimum
Paper	4.85 ± 3.28	5.01	10.76	11.95	1.24
Cardboard	2.96 ± 1.16	2.90	1.35	5.39	1.87
Tetra Pak	0.70 ± 0.90	0.68	0.81	3.25	0.31
Hard plastic	3.33 ± 0.65	3.70	0.42	4.53	2.25
Soft plastic	9.72 ± 2.38	9.50	5.68	15.25	7.90
Metal	1.75 ± 0.66	2.03	0.43	3.09	1.20
Organic matter	55.33 ± 3.62	54.55	13.09	61.12	49.45
Glass	1.61 ± 1.59	1.39	2.53	4.29	0.00
Sanitary waste	14.01 ± 3.91	13.00	15.29	20.34	8.25
Fabrics	2.99 ± 1.66	2.89	2.75	6.17	1.58
Waste	2.75 ± 3.08	3.00	9.46	5.17	0.82

After raising the values, it is possible see that the values of organic matter represent more than 50% of the total values of the fraction of solid waste, followed by the fraction of sanitary waste (14.30%) and malleable plastic (10%). These first three represent almost 80% of the total mass of collected waste (Figure 4).

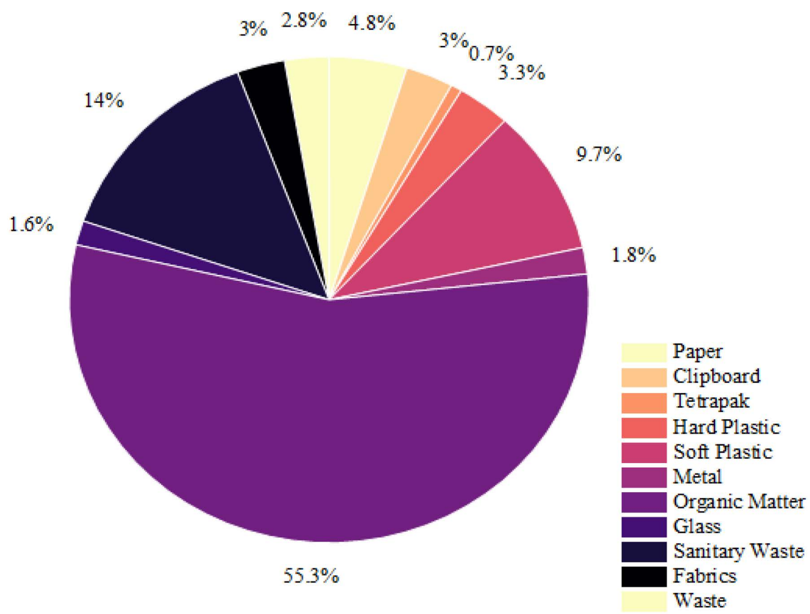

Figure 4. Proportions of waste fractions collected in the municipality of Belém.

3.2. Analysis of the Solubilized Extraction of the Organic Fraction of MHSW

3.2.1. Analysis of Physical–Chemical Parameters

After the period of conditioning the residues and the generation of the solubilized extract of the organic fraction of the solid residues, these were submitted to physicochemical analyses, in which pH values between 3.69 and 4.77 were verified, making it possible to verify an acidic character of the residues and obtained values, in addition to high values of total dissolved solids and alkalinity (except for the values of Region 1). The cyanide and fluoride values found were below what could be measured with the equipment used. Sulfide values between 420 and 100 μg·L^{-1} and sulfate with maximum values of 24 mg·L^{-1} were verified (Table 6).

Table 6. Hydrogenionic potential (pH), electric conductivity (EC), total dissolved solids (TDS), total alkalinity (TA), carbon dioxide (CO_2), chloride, cyanide, fluoride, sulfite and sulfate. QL represents values below the limit of quantification.

Region	pH	EC (mS·cm^{-1})	TDS (mg·L^{-1})	TA (mg·L^{-1})	CO_2 (mg·L^{-1})	Chloride (mg·L^{-1})	Cyanide (mg·L^{-1})	Fluoride (mg·L^{-1})	Sulfite (μg·L^{-1})	Sulfate (mg·L^{-1})
R1	3.69	10.13	5330	>QL	18.70	223.00	<0.005	<0.005	110	25
R2	4.77	15.67	8040	2900	10.20	349.30	<0.005	<0.005	130	<2
R3	4.92	15.99	8030	3650	12.80	230.40	<0.005	<0.005	420	<2

3.2.2. Turbidity, Color and Hardness Analysis

Turbidity, color and hardness values were analyzed based on the instructions in the Standard Methods for the Examination of Water and Wastewater [37], and it was possible to find turbidity values between 791 and 1733 TU (turbidity unit), in addition to values of apparent color between 8500 and 12,500 CU (color unit) and from 1400 to 6000 CU. Additionally, the hardness values were also considered, and the results were verified in the order of 234 to 371 mg·L^{-1} for total hardness, maximum values of 207 mg·L^{-1} for calcium hardness and values between 164 and 235 mg·L^{-1} for magnesian hardness. The analyzed values can be seen in Table 7.

Table 7. Turbidity, apparent color, true color, total hardness, calcium hardness and magnesium hardness values obtained in laboratory analyses.

Region	Turbidity (TU)	Apparent Color (CU)	True Color (CU)	Total Hardness ($mg \cdot L^{-1}$)	Calcium Hardness ($mg \cdot L^{-1}$)	Magnesium Hardness ($mg \cdot L^{-1}$)
R1	1072.00	8500.00	6000.00	371.00	207.00	164.00
R2	791.00	12,500.00	9000.00	234.00	<0.05	234.00
R3	1733.00	12,000.00	1400.00	255.00	<0.05	235.00

It is possible to verify that the fraction of organic residues from Region 2 presents the lowest values of turbidity, while in the values of the solubilized extract of residues collected in Region 3, the highest values of color and turbidity are verified, indicating greater concentrations of total solids and dissolved solids (Figure 5).

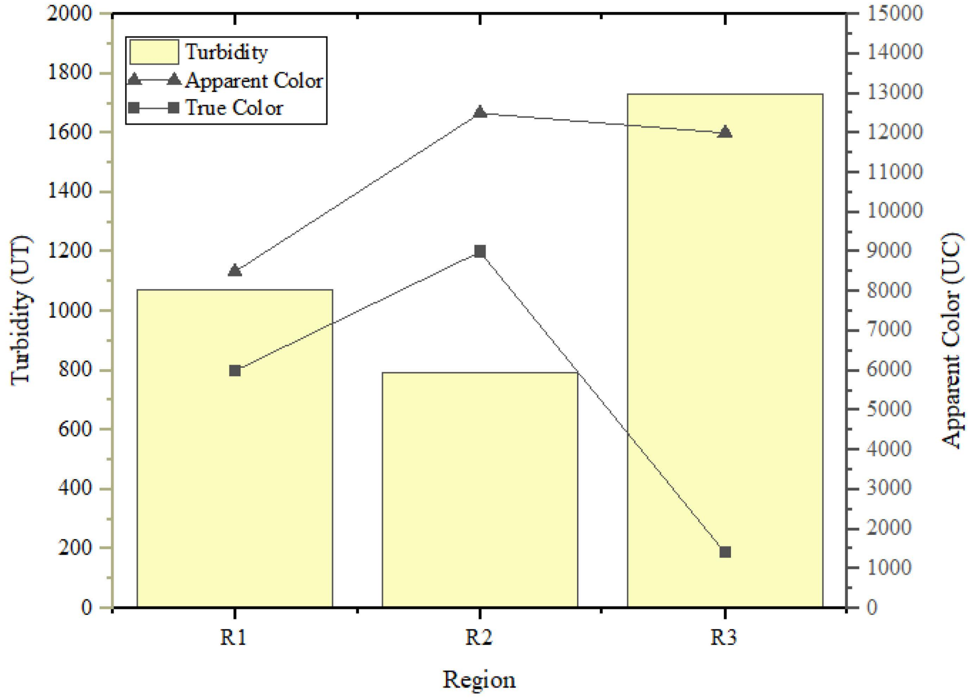

Figure 5. Comparison between the color and turbidity values of the solubilized extract obtained in relation to the regions delimited in the methodology.

3.2.3. Nitrogen Series Analysis

The values of the nitrogen series were verified using the instructions in the Standard Methods for the Examination of Water and Wastewater [37], in which it was possible to verify total nitrogen values in the range between 201.80 and 359.90 $mg \cdot L^{-1}$ and of total Kjeldahl nitrogen in the range between 191 and 319 $mg \cdot L^{-1}$. Still, it was possible to analyze values in the order between 30 and 40 $mg \cdot L^{-1}$ for organic nitrogen and between 161 and 289 $mg \cdot L^{-1}$ for ammoniacal nitrogen. Among nitrogenous ions, values between 0.30 and 0.90 $mg \cdot L^{-1}$ were found for nitrite and between 10 and 40 $mg \cdot L^{-1}$ for nitrate (Table 8).

Table 8. Total nitrogen, total Kjeldahl nitrogen, organic nitrogen, ammoniacal nitrogen, nitrite and nitrate values obtained in laboratory analyses.

Region	Total Nitrogen ($mg{\cdot}L^{-1}$)	Total Kjeldahl Nitrogen ($mg{\cdot}L^{-1}$)	Organic Nitrogen ($mg{\cdot}L^{-1}$)	Ammoniacal Nitrogen ($mg{\cdot}L^{-1}$)	Nitrite ($mg{\cdot}L^{-1}$)	Nitrate ($mg{\cdot}L^{-1}$)
R1	201.80	191.00	30.00	161.00	0.80	10.00
R2	310.30	270.00	40.00	230.00	0.30	40.00
R3	359.90	319.00	30.00	289.00	0.90	40.00

It is possible to verify higher values of total nitrogen, total Kjeldahl nitrogen and ammoniacal nitrogen in the solubilized extract obtained for solid organic waste generated in Region 3. The values of organic nitrogen were higher in the analysis of the solubilized extract generated in Region 2. The values of nitrite and nitrate were close for all regions, indicating that a large portion of total nitrogen originates from organic and ammoniacal compounds (Figure 6).

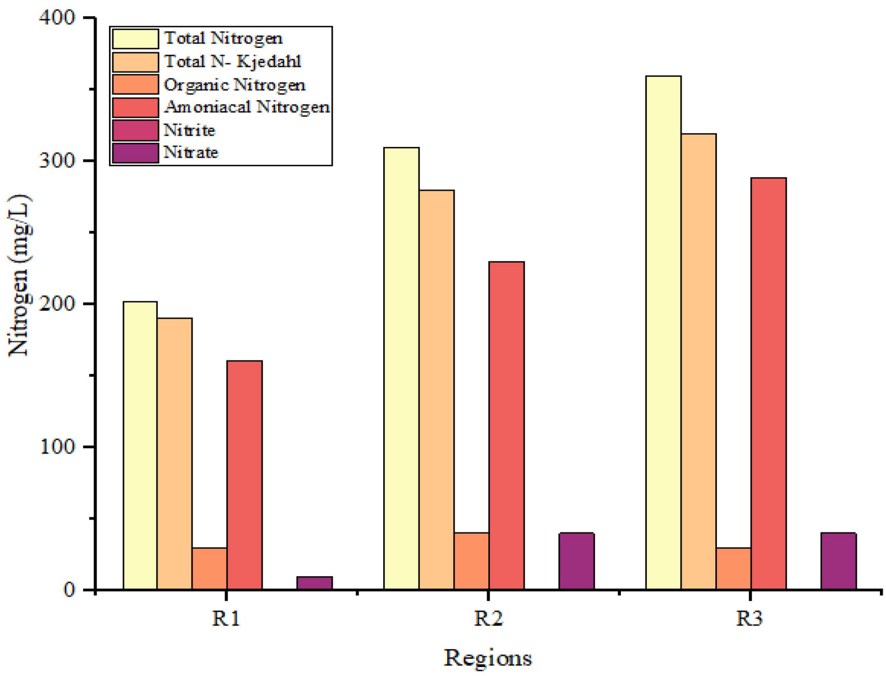

Figure 6. Concentration of the analyzed nitrogen series parameters for the delimited regions, according to the research methodology.

3.2.4. Phosphorus Series Analysis

Phosphorus values were analyzed through total phosphorus concentrations and as a function of phosphate ion. For the phosphorus series, values between 52.30 and 166.80 $mg{\cdot}L^{-1}$ of total phosphorus and 160.80 to 510.40 $mg{\cdot}L^{-1}$ of total phosphate were found. As for reactive phosphorus values, values between 100 and 456 $mg{\cdot}L^{-1}$ were verified, and for hydrolyzed phosphate values, values were found in the range between 96 and 404 $mg{\cdot}L^{-1}$. As for the condensable and organic phosphate fractions, values were found in the range of 4 to 52 $mg{\cdot}L^{-1}$ and 34 and 106.40 $mg{\cdot}L^{-1}$, respectively (Table 9).

Table 9. Total phosphorous, total phosphate, reactive phosphate, hydrolyzed phosphate, condensable phosphate and organic phosphate values obtained in laboratory analyses.

Region	Total Phosphorous (mg·L^{-1})	Total Phosphate (mg·L^{-1})	Reactive Phosphate (mg·L^{-1})	Hydrolyzed Phosphate (mg·L^{-1})	Condensable Phosphate (mg·L^{-1})	Organic Phosphate (mg·L^{-1})
R1	52.30	160.80	138.00	126.00	12.00	34.00
R2	55.30	169.36	100.00	96.00	4.00	73.36
R3	166.80	510.40	456.00	404.00	52.00	106.40

In the analysis of phosphorus and phosphate concentrations, higher values are found for all compounds in the solubilized extract analyzed in Region 3, where values are up to three times higher than those in other regions. For Regions 1 and 2, the concentrations of total phosphorus, total phosphate, reactive phosphate and hydrolyzed phosphate present similar values (Figure 7).

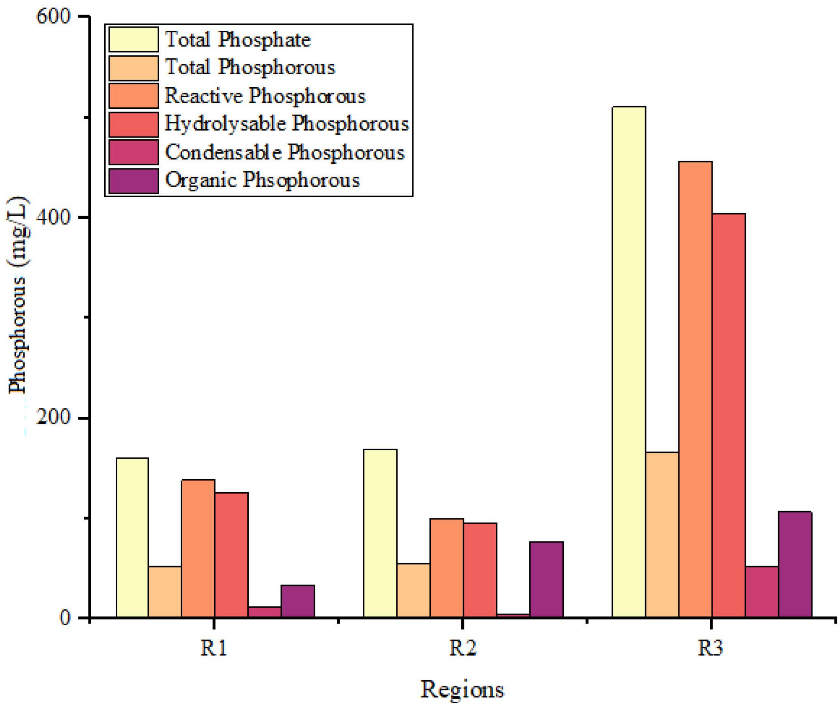

Figure 7. Concentration of the analyzed phosphorous series parameters for the delimited regions, according to the research methodology.

3.2.5. Organic Matter Analysis

To carry out the analyses of organic matter, the parameter of chemical oxygen demand was used since, due to the material conditioning process, it was not possible to carry out the analysis of biochemical oxygen demand according to the standards defined by ABNT NBR 10.007/2004 [40]. After the physical–chemical analyses carried out in the laboratory, values in the order of 28,701 mg·L^{-1} to 38,608 mg·L^{-1} of total chemical oxygen demand and 24,469 to 30,078 mg·L^{-1} for filtered chemical oxygen demand were determined, as shown in Table 10.

Table 10. Total chemical oxygen demand and filtered chemical oxygen demand values obtained in laboratory analyses.

Region	Total Chemical Oxygen Demand ($mg \cdot L^{-1}$)	Filtered Chemical Oxygen Demand ($mg \cdot L^{-1}$)
R1	28,701.00	24,469.00
R2	38,608.00	29,260.00
R3	34,428.00	30,078.00

After the results of the analyses, high values of chemical oxygen demand were verified in the solubilized extracts from all regions; since the residue comes from organic matter, high values of related parameters are expected. Both for the total chemical oxygen demand and for filtered chemical oxygen demand, the highest values are presented in the solubilized extract of Region 2 (Figure 8).

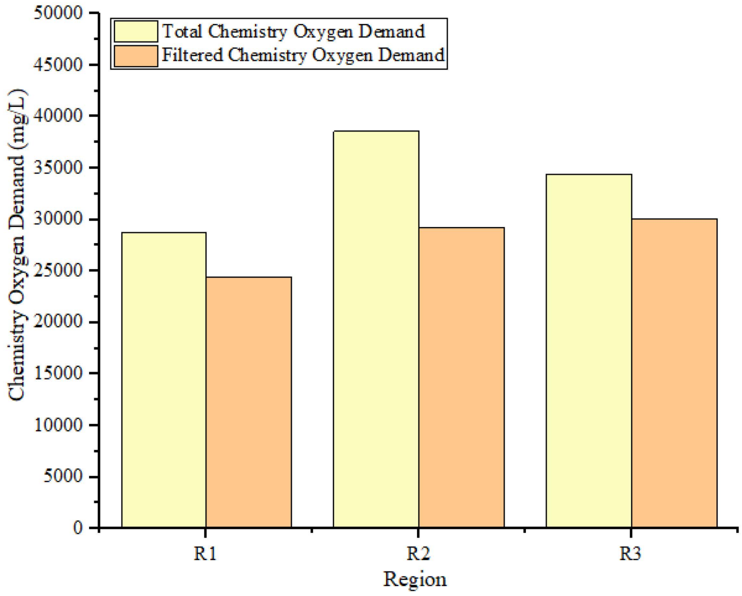

Figure 8. Concentration of the analyzed organic matter parameters for the delimited regions, according to the research methodology.

3.3. Verification of Compliance with the Limit Values of Ordinance MS/GM No. 888/2021 and Resolution of the National Council for the Environment No. 357/2005

ABNT NBR 10.004/2004 [42] mentions that the results of physical–chemical analyses of solubilized extracts of solid waste must be compared with reference values present in potability ordinances, mainly, and other environmental norms. Such a verification was carried out, together with Resolution No. 357/2005 [39] of the Brazilian National Council for the Environment for freshwater bodies of class II.

After the analyses, verifications of compliance with Brazilian health and environmental legislation confirmed that the parameters hydrogenionic potential, turbidity, true color, apparent color, total dissolved solids, sulfide, total nitrogen, ammoniacal nitrogen and total phosphorus were not in accordance with the legislation for the solubilized extract of solid organic waste grouped in Region 1. It is possible to observe in Table 11 the verification of conformity, where "no" means that it does not comply with the values and "yes" means that it is according to the limit values in the legislation. There are some parameters that are not mentioned in the legislation, such as electrical conductivity, total alkalinity, free carbon dioxide, total Kjeldahl nitrogen, organic nitrogen, phosphorus series (exception of total phosphorus) and chemical demand of oxygen.

Table 11. Verification of compliance of the analyzed parameters of the solubilized extract of Region 1 according to the Brazilian environmental and public health agencies.

Parameter	MS/GM 888/2021	CONAMA 357/2005	Parameter	MS/GM 888/2021	CONAMA 357/2005
Hydrogenionic potential	No	No	Sulfide	No	No
Turbidity	No	No	Sulfate	Yes	Yes
Apparent color	No	-	Total nitrogen	-	No
True color	-	No	Ammoniacal nitrogen	-	No
Total dissolved solids	No	No	Nitrite	Yes	Yes
Chloride	Yes	Yes	Nitrate	Yes	Yes
Cyanide	-	Yes	Total phosphorus	-	No
Fluoride	Yes	Yes			

For the solubilized extract of waste from Region 2, noncompliance with legal standards was verified for the parameters of hydrogenionic potential, turbidity, apparent color, true color, total dissolved solids, chloride, sulfide, total nitrogen, ammonia nitrogen, nitrate and total hardness. For parameters such as apparent color, true color and total dissolved solids, there was a relevant discrepancy with the legal standard values. You can view the verification performed in Table 12.

Table 12. Verification of compliance of the analyzed parameters of the solubilized extract of Region 2 according to the Brazilian environmental and public health agencies.

Parameter	MS/GM 888/2021	CONAMA 357/2005	Parameter	MS/GM 888/2021	CONAMA 357/2005
Hydrogenionic potential	No	No	Sulfide	No	No
Turbidity	No	No	Sulfate	Yes	Yes
Apparent color	No	-	Total nitrogen	-	No
True color	-	No	Ammoniacal nitrogen	-	No
Total dissolved solids	No	No	Nitrite	Yes	Yes
Chloride	No	No	Nitrate	No	No
Cyanide	-	Yes	Total phosphorus	-	No
Fluoride	Yes	Yes	Total hardness	No	-
Cyanide	-	Yes			

In the analysis of the solubilized extract of organic residues from Region 3, it was possible to verify the noncompliance in regard to the parameters of hydrogenionic potential, turbidity, apparent color, true color, total dissolved solids, sulfide, total nitrogen, ammoniacal nitrogen, nitrate, total phosphorus and hardness. It is possible to visualize the verification of each parameter for this case in Table 13.

Table 13. Verification of compliance of the analyzed parameters of the solubilized extract of Region 3 according to the Brazilian environmental and public health agencies.

Parameter	MS/GM 888/2021	CONAMA 357/2005	Parameter	MS/GM 888/2021	CONAMA 357/2005
Hydrogenionic potential	No	No	Sulfide	No	No
Turbidity	No	No	Sulfate	Yes	Yes
Apparent color	No	-	Total nitrogen	-	No
True color	-	No	Ammoniacal nitrogen	-	No
Total dissolved solids	No	No	Nitrite	Yes	Yes
Chloride	Yes	Yes	Nitrate	No	No
Cyanide	-	Yes	Total phosphorus	-	No
Fluoride	Yes	Yes	Total hardness	No	-

3.4. Comparison of Concentration Values Obtained with Literature Values for Solubilized and Leached Compounds

3.4.1. Hydrogenionic Potential

For the pH values, the results below those of most of the consulted authors were verified, making it possible to verify proximity with the results of [16]. However, it is possible to notice differences between the pH values raised by the authors [14,15,17–20], in which in these experiments the pH, for the most part, demonstrated basic characteristics. The pH of the solubilized extract is considered acidic (below 7), thus presenting acidic characteristics. Figure 9 offers a comparison between the values of pH determined in this research and the values of the authors of the studies that we consulted.

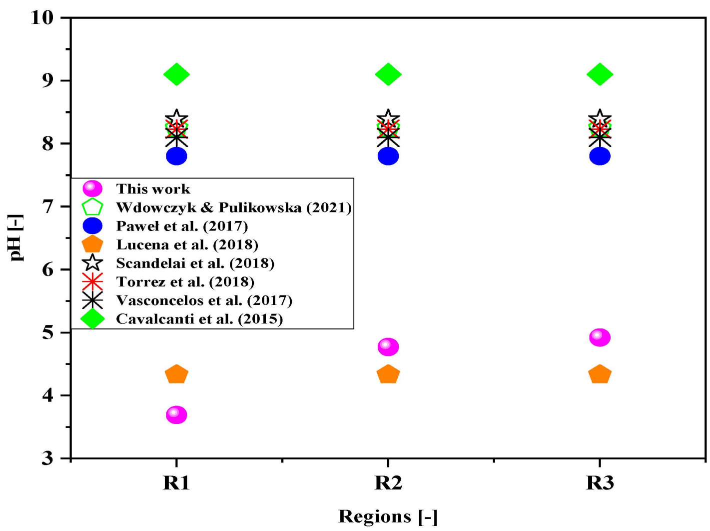

Figure 9. Comparison between the pH values raised by other authors and the pH values obtained in the research [13–19].

3.4.2. Total Dissolved Solids

Regarding the solids content, the values of total dissolved solids (TDS) were observed to be high for Regions 2 and 3, being 8040 and 8030 mg·L^{-1}, respectively, as shown in Figure 10. The results of the physical–chemical analyses for obtaining solids demonstrate the proximity with the research carried out by [18] for Region 1 (6035 mg·L^{-1}) and for Regions 2 and 3, the results are closest to the values obtained by [15], with solid concentrations in the order of 6903 mg·L^{-1} (Figure 10).

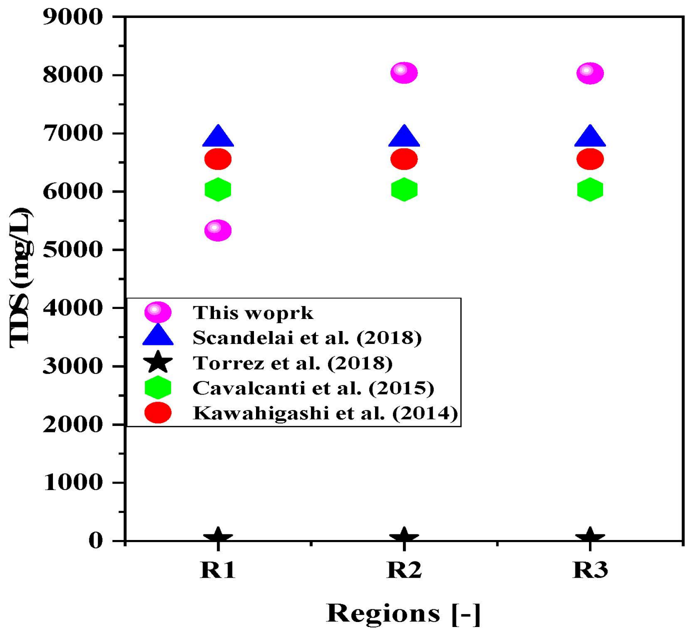

Figure 10. Comparison between the values of solids raised by other authors and the values obtained in the research [16,17,19,21].

3.4.3. Ammoniacal Nitrogen and Nitrate

A comparison of the results obtained with the values of ammoniacal nitrogen and nitrate was carried out, in which it was possible to verify low values of ammoniacal nitrogen, when compared with that raised by other authors. The information is closer to the analyses carried out by [16] in which the values for Regions 1 (161 mg·L^{-1}), 2 (230 mg·L^{-1}) and 3 (289 mg·L^{-1}) are close to the 224 mg·L^{-1} that is presented in the aforementioned author's research (Figure 11).

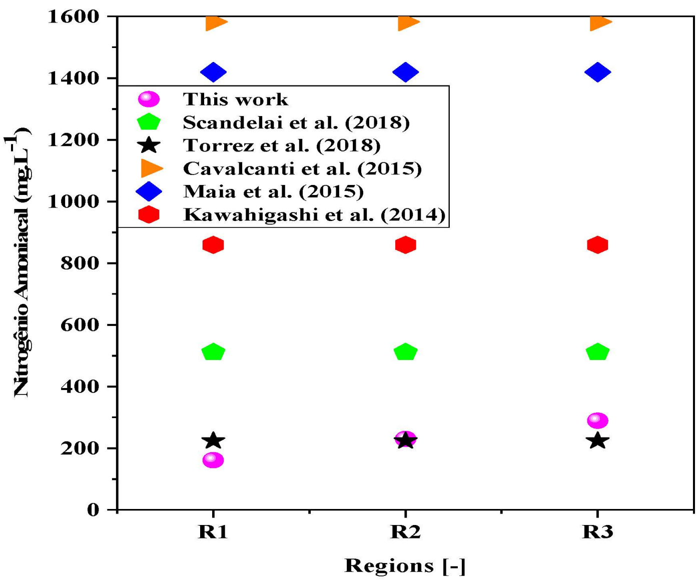

Figure 11. Comparison between the values of ammoniacal nitrogen given by other authors and the values obtained in the research [16,17,19–21].

For the nitrate values, it was possible to verify that the nitrate concentrations for Regions 1 (10 mg·L^{-1}), 2 (40 mg·L^{-1}) and 3 (40 mg·L^{-1}) are similar to the results of [15] (12.50 mg·L^{-1}) for Region 1 and the results of [16] (79.92 mg·L^{-1}) and [15] for Regions

2 and 3, where it approaches the mean value between the two concentrations verified (Figure 12).

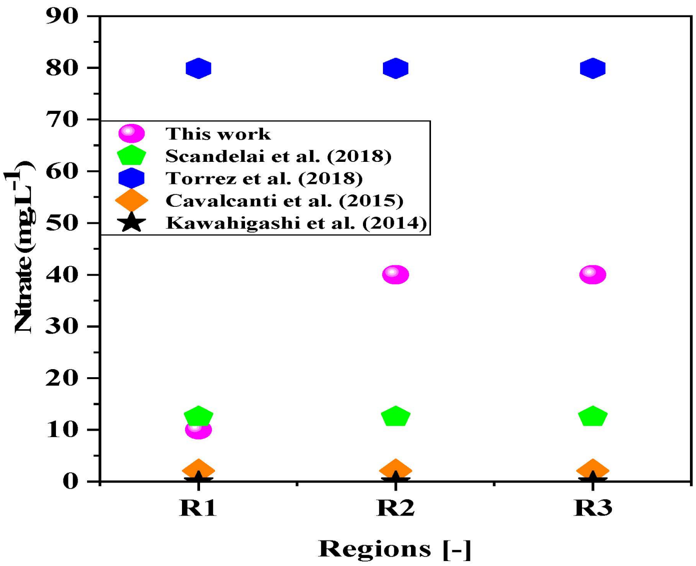

Figure 12. Comparison between the values of nitrate determined by other authors and the values obtained in the research [16,17,19,21].

3.4.4. Total Phosphorous

When compared to other research, the results of the analyses of the phosphorus series show the existence of proximity with the raised values. For Regions 1 and 2, phosphorus concentrations are consistent with those of the analyses performed by [19], at a value of 34 mg·L^{-1}. Meanwhile, the results of the analyses of the solubilized extract for Region 3 are closer to the values of [16,43], in the order of 221.19 mg·L^{-1} and 107.03 mg·L^{-1}, respectively (Figure 13).

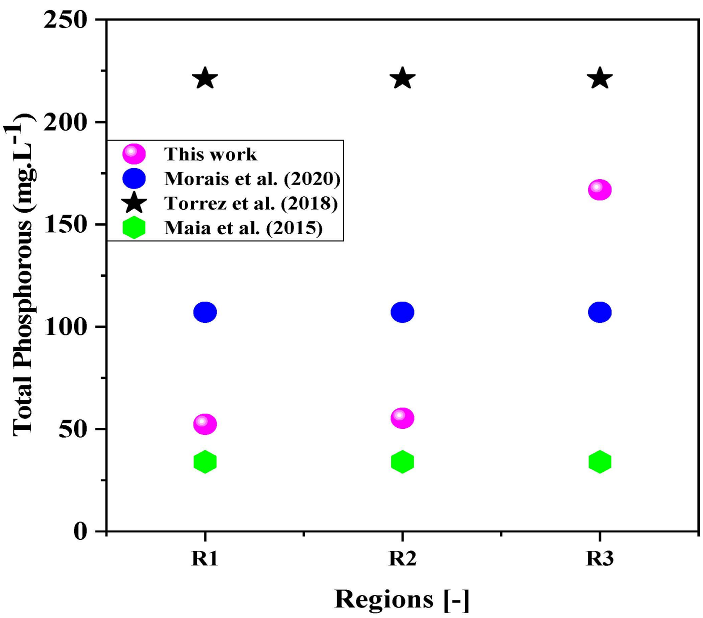

Figure 13. Comparison between the values of total phosphorous determined by other authors and the values obtained in the research [17,20,43].

3.4.5. Chemical Oxygen Demand

When comparing the COD values with those found by other authors, discrepancies between the maximum and minimum values are observed. The by-products arising from the degradation of solid waste, which generate leachate, have variable and complex characteristics, represented, in most cases, by substantial amounts of dissolved organic acids, biochemical oxygen demand and chemical oxygen demand [43]. Except for [16], the COD concentrations obtained are higher than those of the authors consulted. Therefore, the COD values for the solubilized extract of the residues are in an average range when compared with the sources consulted in this work; however, considering the proximity to COD concentrations of leachate from landfills, it makes it possible to detect the environmental risk represented by the solubilization of solid organic waste (Figure 14).

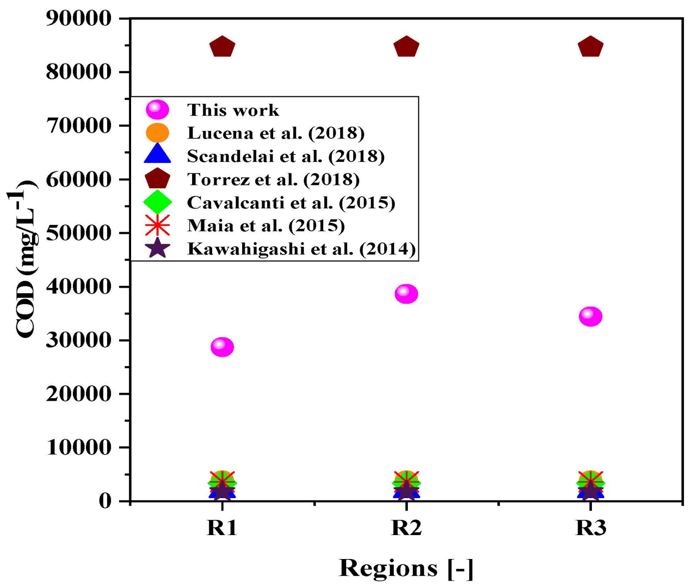

Figure 14. Comparison between the values of COD determined by other authors and the values obtained in the research [15–17,19–21].

After comparing the results of the other authors whose works were consulted, we note a similarity with the results of [16] for the case of pH, ammoniacal nitrogen, nitrate and phosphorus. The results of the analyses of the solubilized extract, in several of its parameters, still demonstrated proximity with the research carried out by [15–19]. With this information, one can see the similarity of pollutant concentrations in solubilized extracts of solid organic waste with leachate generated in landfills, emphasizing the ability of these liquid by-products of landfills to degrade environmental conditions when released into the environment. That is, not only the leaching conditions but also the simple solubilization of organic solid waste in water have a high potential for environmental contamination. In the work, limitations were found regarding the composition of the leached compounds; given their complexity, wide differences between the concentrations of pollutants were found in the experiments and in the literature, and it is suggested that, in future studies, researchers carry out groupings and classifications so that there is a quantification and more accurate prediction of the composition of these compounds.

Contamination by leached compounds represents a major challenge on the path to sustainable development, as it represents contamination of the environment if this liquid is not contained and treated properly. This study contributes to predicting the concentrations of these compounds so that, subsequently, treatment technologies can be adopted that appropriately consider the composition of these liquids.

4. Conclusions

When carrying out the gravimetric analysis of the collected urban household solid waste, we noted that the values of the proportions of organic matter are higher when compared to research carried out in the region of Belém do Pará. For this case, it must be considered that the residue has not undergone any compression process that would cause it to lose moisture; in this case, we considered that the increase in mass, when considering other studies, is due to the high moisture content of organic waste, in the order of 60%. The proportions of other materials are in a range close to that verified in research in the region.

The results of the physical–chemical analyses of the solubilized extract of the organic fraction of urban household solid waste indicate similarities according to the pH, total dissolved solids, nutrients and organic matter with leachate generated in landfills, thus also demonstrating the polluting potential of the solubilization of these materials in the environment. In addition to the physical–chemical analyses indicating the polluting potential of these materials, the noncompliance of the solubilized compound of these solid wastes with current Brazilian environmental and health legislation was also verified. For the treatment of these compounds, the use of the same technologies for the treatment of leachate from landfills is suggested, emphasizing physical–chemical treatment technologies and considering constant efficiency in the treatment process, regardless of microbial proliferation in reactors.

In order to avoid the environmental impacts arising from these materials, an efficient urban solid waste management system is necessary, in which the collection takes place in an integral way and can safely transport the waste to the treatment units. Also, in the treatment units, the handling of the material must be carried out properly so that liquid compounds with high polluting potential do not leak into the environment.

Author Contributions: D.O.P. contributed to the general development of the research, participation in the gravimetric characterization and in obtaining and analyzing the solubilized extract; F.P.d.C.A. contributed with participation in the gravimetric characterization and in obtaining and analyzing the solubilized extract; J.C.C.d.S. contributed to the collections and gravimetric characterization; J.F.H.F. contributed to the collections and gravimetric characterization; R.B.P.F. contributed to the collections and gravimetric characterization; Á.L.L. contributed to the collections and gravimetric characterization; Í.C.P.d.N. contributed to the collections and gravimetric characterization; J.P.C. contributed to the collections and gravimetric characterization; M.S.C.d.N. contributed to the collections and gravimetric characterization; T.d.S.G. contributed to the collections and gravimetric characterization; N.M.M. contributed to obtaining and analyzing the solubilized extract; I.W.d.S.B. contributed to obtaining and analyzing the solubilized extract; J.A.R.P. contributed to the logistics for carrying out the collections, N.T.M. contributed to the supervision and review of the research. All authors have read and agreed to the published version of the manuscript.

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References

1. Abdoli, M.A.; Ghasemzadeh, R. Evaluation and optimization of hydrothermal carbonization condition for hydrochar and methane yield from anaerobic digestion of organic fraction of municipal solid waste (OFMSW). *Fuel* **2024**, *355*, 129531. [CrossRef]
2. Afraz, M.; Muhammad, F.; Nisar, J.; Shah, A.; Munir, S.; Ali, G.; Ahmad, A. Production of value added products from biomass waste by pyrolysis: An updated review. *Waste Manag. Bull.* **2024**, *1*, 30–40. [CrossRef]

3. Silva, C.O.; Santos, G.M.; Silva, L.N. A degradação ambiental causada pelo descarte inadequado das embalagens plásticas: Estudo de caso. *Rev. Eletrônica Gestão Educ. Tecnol. Ambient.* **2013**, *13*, 2683–2689. [CrossRef]
4. Associação Brasileira de Empresas de Limpeza Pública E Resíduos Especiais—ABRELPE. *Panorama 2022*; ABRELPE: São Paulo, Brazil, 2023.
5. Brasil Ministério do Desenvolvimento Regional. *Diagnóstico Temático do Manejo de Resíduos Sólidos Urbanos*; SNIS: São Paulo, Brazil, 2022.
6. Sheila de Araujo, C. *Impactos Ambientais Causados pelo Lixão Desativado da Cidade de Delmiro Gouveia—AL. 2020. 58 f. TCC (Graduação)—Curso de Engenharia Civil*; Universidade Federal de Alagoas: Delmiro Gouveia, Brazil, 2020.
7. Ruan Gonçalves, F. Proposta de padronização cartográfica para carta-imagem emergencial de inundação Impactos ambientais decorrentes do lixão da cidade de Condado-PB. *Geogr. Ensino Pesqui.* **2017**, *21*, 142–151. [CrossRef]
8. Luo, H.; Zeng, Y.; Cheng, Y.; He, D.; Pan, X. Recent advances in municipal landfill leachate: A review focusing on its characteristics, treatment, and toxicity assessment. *Sci. Total Environ.* **2020**, *703*, 135468. [CrossRef] [PubMed]
9. Arunbabu, V.; Indu, K.; Ramasamy, E. Leachate pollution index as an effective tool in determining the phytotoxicity of municipal solid waste leachate. *Waste Manag.* **2017**, *68*, 329–336. [CrossRef]
10. Abiriga, D.; Vestgarden, L.S.; Klempe, H. Long-term redox conditions in a landfill-leachate-contaminated groundwater. *Sci. Total. Environ.* **2021**, *755*, 143725. [CrossRef] [PubMed]
11. Gu, Z.; Feng, K.; Li, Y.; Li, Q. Microbial characteristics of the leachate contaminated soil of an informal landfill site. *Chemosphere* **2022**, *287*, 132155. [CrossRef]
12. da Silva, J.N.; da Cunha, L.S.; de Oliveira, N.E.C. O Uso De Parâmetros Físico-Químicos Na Delimitação De Contaminação Por Lixiviado Em Áreas Degradadas Por Resíduos Sólidos Urbanos. Uma Revisão Sistemática De Literatura Com Ênfase Em Metanálise. *Rev. Bras. Geogr. Física* **2022**, *15*, 1587. [CrossRef]
13. Wdowczyk, A.; Szymańska-Pulikowska, A. Analysis of the possibility of conducting a comprehensive assessment of landfill leachate contamination using physicochemical indicators and toxicity test. *Ecotoxicol. Environ. Saf.* **2021**, *221*, 112434. [CrossRef]
14. Paweł, W.; Marta, K. Phthalate release in leachate from municipal landfills of central Poland. *PLoS ONE* **2017**, *12*, e0174986.
15. Lucena, L.G.; Rocha, E.M.R.; da Silva, F.L.H.; Cahino, A.M. Otimização multivariada do processo foto-Fenton solar na remoção da demanda química de oxigênio em lixiviados de aterros sanitários. *Eng. Sanit. Ambient.* **2018**, *23*, 499–507. [CrossRef]
16. Scandelai, A.P.J.; Martins, D.C.C.; Pinaffi, C.D.; Tavares, C.R.G. Caracterização de lixiviado de aterro sanitário e propostas de tratamento. *Colloq. Exactarum.* **2018**, *10*, 36–43. [CrossRef]
17. Torrez, V.M.; del Quindío, U.; Tejada, A.A.; García-Alzate, L.; Sanabria, L.P. Caracterización de lixiviados como alternativa que contribuya a la mitigación de contaminantes. *Rev. ION* **2018**, *31*, 59–63. [CrossRef]
18. Vasconcelos, D.V.; Silva, L.L.S.; Guerra, I.L.; Campos, J.C. Estudo da tratabilidade de lixiviado gerado em um aterro controlado. *Ambient. Agua Interdiscip. J. Appl. Sci.* **2017**, *12*, 467. [CrossRef]
19. Cavalcanti, A.S.; izário Filho, H.J.; Guimarães, O.L.C.; Siqueira, A.F. Modelagem neural e análise estatística do processo de degradação de chorume por foto Fenton solar. *Rev. Ambient. Água* **2015**, *10*, 89–106. [CrossRef]
20. Maia, I.S.; Restrepo, J.J.B.; Castilhos, A.B.D., Jr.; Franco, D. Avaliação do tratamento biológico de lixiviado de aterro sanitário em escala real na Região Sul do Brasil. *Eng. Sanit. Ambient.* **2015**, *20*, 665–675. [CrossRef]
21. Kawahigashi, F.; Mendes, M.B.; Assunção Júnior, V.G.D.; Gomes, V.H.; Fernandes, F.; Hirooka, E.Y.; Kuroda, E.K. Pós-tratamento de lixiviado de aterro sanitário com carvão ativado. *Eng. Sanitária Ambient.* **2014**, *19*, 235–244. [CrossRef]
22. Pastore, C.; Barca, E.; del Moro, G.; di Iaconi, C.; Loos, M.; Singer, H.P.; Mascolo, G. Comparison of different types of landfill leachate treatment by employment of nontarget screening to identify residual refractory organics and principal component analysis. *Sci. Total Environ.* **2018**, *635*, 984–994. [CrossRef]
23. Oliveira, L.F.; Silva, S.M.C.P.; Martinez, C.B.R. Assessment of domestic landfill leachate toxicity to the Asian clam Corbicula fluminea via biomarkers. *Ecotoxicol. Environ. Saf.* **2014**, *103*, 17–23. [CrossRef]
24. Silva, E.M.D. Ecotoxicidade de Resíduos Sólidos Urbanos e de Lixiviado Gerado em Aterro Sanitário. Ph.D. Thesis, Curso de Pós-Graduação em Engenharia Civil e Ambiental, Universidade Federal de Campina Grande, Campina Grande, Brazil, 2022.
25. Franco, H.A.; Rocha, M.V.d.C.; Filho, S.T. Impacto Ambiental do Extrato Solubilizado de Borra de Café sobre Organismo Terrestre. *Front. J. Soc. Technol. Environ. Sci.* **2020**, *9*, 404–413. [CrossRef]
26. Jovelino, J.R.; de Brito, A.L.F.; Muniz, A.C.S.; da Silva, P.P. Estabilização/solidificação: Caracterização, classificação e aplicação no tratamento e gerenciamento de resíduos sólidos de laboratórios químicos. *Holos Environ.* **2020**, *20*, 539–558. [CrossRef]
27. Schneider, J.B.; Moraes, C.A.M.; Brehm, F.A. Avaliação ambiental da estabilização por solidificação de BTEX oriundo de resíduo de adsorvente composto por cinza de casca de arroz e carvão ativado em argamassa. *Rev. Tecnol. Soc.* **2020**, *16*, 67–69. [CrossRef]
28. Silva, W.B.C.D.; Barroso, S.H.D.A.; Cabral, A.E.B. Avaliação da aplicação de cinzas pesadas de termelétrica em blocos intertravados de concreto para pavimentos. *Rev. Matéria* **2020**, *25*. [CrossRef]
29. Thode Filho, S.; da Paixão, C.P.S.; da Silveira Maranhão, F.; Franco, H.A. Avaliação ecotoxicológica do extrato solubilizado de bagaço de cana-de-açúcar residual via germinação de sementes de alface (*Lactuca sativa* L.). *Rev. Estud. Ambient.* **2019**, *21*, 46–55. [CrossRef]
30. Nardino, D.A.; Paiva, V.; Nunes, F.; Sgorlon, J.; Gomes, M.; Menezes, M. Reutilização de Resíduos de Curtume na Fabricação de Blocos de Concreto para Pavimentação: Avaliação das Características do Resíduo. In Proceedings of the XI Congresso Brasileiro de Engenharia Química em Iniciação Científica (CBEQIC), São Paulo, Brazil, 19–22 July 2015.

31. Silva, A.D.S.; Ribeiro, L.D.S.; Paiva, W.D.; Melo, M.C.D.; Monteiro, V.E.D. Avaliação do potencial tóxico dos resíduos sólidos urbanos da cidade de Campina Grande-PB. *Matéria* **2015**, *20*, 840–851. [CrossRef]
32. Medeiros, C.R. Determinação de Compostos Fenólicos em Extratos Aquosos de Resíduos Sólidos por Microextração em Fase Sólida e Cromatografia a Gás Acoplada à Espectrometria de Massas. Master's Thesis, Universidade Federal de Santa Catarina, Florianópolis, Brazil, 2013.
33. Rodrigues, N.L.V.B.; Pawlowsky, U. Testes de toxicidade aguda através de bioensaios no extrato solubilizado dos resíduos classe II A-não inertes e classe II B-inertes. *Eng. Sanitária Ambient.* **2007**, *12*, 8–16. [CrossRef]
34. Assunção, F.P.d.C.; Pereira, D.O.; Silva, J.C.C.d.; Ferreira, J.F.H.; Bezerra, K.C.A.; Bernar, L.P.; Ferreira, C.C.; Costa, A.F.d.F.; Pereira, L.M.; Paz, S.P.A.d.; et al. A Systematic Approach to Thermochemical Treatment of Municipal Household Solid Waste into Valuable Products: Analysis of Routes, Gravimetric Analysis, Pre-Treatment of Solid Mixtures, Thermochemical Processes, and Characterization of Bio-Oils and Bio-Adsorbents. *Energies* **2022**, *15*, 7971. [CrossRef]
35. Fesseha, S.N.; Bin, F. The Assessment of Solid Waste Products Management in Ethiopians Municipal Urban Areas. *Int. J. Soc. Sci. Manag.* **2015**, *2*, 165–179. [CrossRef]
36. *ANBT. NBR 10.006/2004*; Procedimentos para a Obtenção de Extrato Solubilizado de Resíduos Sólidos. Associação Brasileira De Normas Técnicas: Rio de Janeiro, Brasil, 2004.
37. American Public Health Association. *23th Standard Methods for the Examination of Water and Wastewater*; APHA: Washington, DC, USA, 2017.
38. Brasil Ministério da Saúde. *Portaria GM/MS Nº 888, de 4 de maio de 2021. Altera o Anexo XX da Portaria de Consolidação GM/MS nº 5, de 28 de Setembro de 2017, para Dispor Sobre os Procedimentos de Controle e de Vigilância da Qualidade da Água para Consumo Humano e seu Padrão de Potabilidade*; Brasil Ministério da Saúde: Rio de Janeiro, Brazil, 2021.
39. Conselho Nacional de Meio Ambiente. *Resolução nº 357, de 17 de Março de 2005. Dispõe Sobre a Classificação dos Corpos de Água e Diretrizes Ambientais Para o Seu Enquadramento*; CONAMA: Rio de Janeiro, Brazil, 2005.
40. *NBR 10.007*; Amostragem de Resíduos Sólidos. ABNT—Associação Brasileira de Normas Técnicas: Rio de Janeiro, Brazil, 2004.
41. Menezes, R.O.; Castro, S.R.; Silva, J.B.G.; Teixeira, G.P.; Silva, M.A.M. Análise estatística da caracterização gravimétrica de resíduos sólidos domiciliares: Estudo de caso do município de Juiz de Fora, Minas Gerais. *Eng. Sanitária Ambient* **2019**, *24*, 271–282. [CrossRef]
42. *ANBT. NBR 10.004/2004*; Resíduos Sólidos—Classificação. Associação Brasileira De Normas Técnicas: Rio de Janeiro, Brazil, 2004.
43. Morais, M.; Morais, C.D.N.; Furtado, C.M.; de Menezes, R.S.; Rebouças, F.S.; Torres, O.S.; Chaves, H.P. Análise Físico-Química e Microbiológica do Lixiviado do Aterro Sanitário de Rio Branco-AC. *S. Am. J. Basic Educ. Tech. Technol.* **2020**, *7*, 282–292.