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PHYSICAL AND CHEMICAL ATTRIBUTES OF SOIL AFFECTED BY MUNICIPAL SOLID WASTE DEPOSITION IN JARAGUÁ/BRAZIL

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Abstract: The proper destination of Municipal Solid Waste (MSW) has been the subject of countless discussions, not only among scholars in the area, but also in public policies that seek ways to reduce environmental impacts arising from the inadequate final destination of this waste. This work aimed to evaluate the physicochemical characteristics of the soil and possible contaminations by pollutant metals in a definitive deposition site of MSW in Jaraguá-Goiás. The sampling arrangement was defined in a 3x3 scheme, with three soil covers (L - dump, M - upstream, J - downstream) and three depths (2, 4, and 6m). The following physical-chemical soil parameters were evaluated: particle size, water pH, O.M., CEC, Ca, Mg, P, K, Cu, Fe, Mn, Zn, and the pollutants Cd, Pb, and Cr. The results indicated that the samples from the MSW deposition site analyzed are not contaminated, considering the limits established by Conama and Cetesb. However, these values showed a significant difference between the landfill, upstream, and downstream samples, which were statistically proven by a 5% probability analysis. The chemical attributes, such as Ca, Mg, K, Fe, Cr, Cu, Mn, and pH were found to have higher concentrationsin the landfill samples, while Pb, P, and Zn had higher contents in the upstream points.

Keywords: Environmental pollution; Dump; Controlled landfill; Sanitary landfill.

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ATRIBUTOS FÍSICOS EQUÍMICOS DO SOLO INFLUENCIADO PELA DEPOSIÇÃO DE RESÍDUOS SÓLIDOS URBANOS NO MUNICIPIO DE JARAGUÁ/GOIÁS

Resumo: A destinação adequada dos Resíduos Sólidos Urbanos (RSU) vem sendo pauta de inúmeras discussões, não só entre estudiosos da área, como também nas políticas públicas, buscando caminhos que possam diminuir impactos ambientais oriundos da má destinação final desses resíduos. Este trabalho objetivou avaliar osatributos físicos e químicos do solo, e possíveis contaminações por metais poluentes em local de deposição final de RSU na cidade de Jaraguá-Goiás. O arranjo amostral foi definido em esquema 3x3, sendo três coberturas de solo (L - lixão, M - montante, J - jusante) e três profundidades (2, 4 e 6m). Os seguintes parâmetros físico-químicos do solo foram avaliados: textura, pH em água, M.O., CTC, Ca, Mg, P, K, Cu, Fe, Mn, Zn e os metais poluentes Cd, Pb e Cr. Os resultados indicaram que as amostras do local de deposição de RSU analisadas não estão contaminadas, considerando os limites estabelecidos pelo Conama e Cetesb, contudo, estes valores apresentaram diferença significativa entre as amostras provenientes do aterro em comparação com amostras a montante e jusante, comprovadas estatisticamente através de uma análise a 5% de probabilidade. Os atributos químicos como, Ca, Mg, K, Fe, Cr, Cu, Mn e pH em águaapresentaram maiores concentrações nas amostras do aterro, enquanto Pb, P e Zn obtiveram maiores teores nos pontos à montante.

Palavras-chave: Poluição ambiental; Lixão; Aterro controlado; Aterro sanitário.

ATRIBUTOS FÍSICOS Y QUÍMICOS DEL SUELO INFLUENCIADOS POR LA DISPOSICIÓN DE RESIDUOS SÓLIDOS URBANOS EN EL MUNICIPIO DE JARAGUÁ/GOIÁS

Resumen: La disposición adecuada de los Residuos Sólidos Urbanos (RSU) ha sido tema de numerosas discusiones, no solo entre expertos en el campo, sino también en las políticas públicas, buscando soluciones que puedan reducir los impactos ambientales derivados de la disposición final incorrecta de estos residuos. Este trabajo tuvo como objetivo evaluar los características físicos y químicos del suelo, y posibles contaminaciones por metales contaminantes en un sitio de disposición final de RSU en la ciudad de Jaraguá-Goiás. El diseño de muestreo se definió en un esquema 3x3, con tres tipos de cobertura de suelo (L - vertedero, M - aguas arriba, J - aguas abajo) y tres profundidades (2, 4 y 6 m). Se evaluaron los siguientes parámetros fisicoquímicos del suelo: textura, pH en agua, materia orgánica, CTC, Ca, Mg, P, K, Cu, Fe, Mn, Zn y los metales contaminantes Cd, Pb y Cr. Los resultados indicaron que las muestras del sitio de disposición de RSU analizadas no están contaminadas, considerando los límites establecidos por el Conama y Cetesb. Sin embargo, estos valores mostraron diferencias significativas entre las muestras provenientes del vertedero en comparación con las muestras aguas arriba y aguas abajo, lo cual fue comprobado estadísticamente mediante un análisis con una probabilidad del 5%. Las características químicas como Ca, Mg, K, Fe, Cr, Cu, Mn y pH en agua presentaron mayores concentraciones en las muestras del vertedero, mientras que Pb, P y Zn obtuvieron mayores niveles en los puntos aguas arriba.

Palabras clave: Contaminación ambiental; Vertedero; Relleno controlado; Relleno sanitario.

Introduction

Industrial and technological advances, often seen as positive and inevitable in modern times, linked to population growth have resulted in a contemporary consumer society. It has produced significant amounts of waste of different natures and characteristics, generating environmental concerns about how such materials are disposed of to avoid soil and water contamination, whether surface or underground, resulting from leaching in the environmental decomposition process (AL-RUMAIHI et al., 2020; BERNARD,2017).

The disposal of Municipal Solid Waste(MSW) has been an issue constantly present in the world society, whether in the environmental, social, public health, and economic spheres. According to KAZA et al. (2018), 2.01 billion tons of MSWhave been generated in the world annually, with an estimated growth to 3.40 billion tons per year in 2050. The global discussion has as its apex the search for better ways of final disposal that reduces environmental impacts on a significant scale and creates sustainable ways to use these wastes (IWAI et al., 2012).

The disposal of MSW is seen as an emerging issue and of paramount importance. Worldwide, landfills are predominantly the main technique for waste disposal, being considered simple and economical for storing MSW. According to SAMADDER et al. (2016), the problem is in underdeveloped and developing nations, which have techniques similar to the conceptual landfill, but without base coatings or leachate collection and treatment systems, considered an inadequate environmental deposition of the solid waste.

As a way to minimize the environmental impacts arising from poor disposal of solid waste in countries such as Brazil, the National Solid Waste Policy (PNRS) was instituted through Law No. 12,305/2010. The law in question established a restructuring of solid waste disposal sites in municipalities in an environmentally sound manner through the implementation of sanitary landfills, resulting in the remediation and elimination of controlled dumps and landfills within four years after submission of the same (BRASIL,2010). The Brazilian Federal Senate, through Law No. 425/2014, extended the adaptation periods stipulated in the previous law in a staggered manner, limiting the maximum period to 2021 for municipalities with up to 50,000 inhabitants (BRASIL,2014).

Although there is a deadline stipulated by law for implementing sanitary landfills to control and minimize environmental impacts and preserve natural resources in solid waste disposal, the development of this technique directly collides with the financial issue of most Brazilian municipalities. Due to the investments attributed to the sector, public policies are not enough for most small municipalities to move towards technically adequate landfills. These factors have raised a constant discussion about the level of environmental contamination in cases of inadequate disposal of these wastes (IWAI et al., 2012).

Municipalities with a population of less than 50 thousand inhabitants are the main responsible for the inadequate disposal of waste. For LEITE et al. (2018), these are the main protagonists regarding the inadequate disposal of MSW in Brazil. Despite Law 12,305/10, complemented by Bill No. 425/2014, providing the end of controlled dumps and landfills by the maximum period of July 2021, public actions aimed at meeting the requirement are still incipient or non-existent or seek ways to contribute technically and financially with the installation of landfills provided for by Law (BRASIL, 2014).

In most small Brazilian municipalities, the collection and disposal of MSW is carried out inadequate, without any environmental concern. Associated with this is the fact that the increasing production of MSW, whether by consumption behaviors of people as well as the rapid advances of technology, generates environmental degradation due to inadequate disposal of these wastes, whether by contamination of the air, soil, and even water sources close to these waste disposal sites (ABDEL-SHAFY; MANSOUR, 2018), affecting not only natural resources, but also fauna and man, by the proliferation of disease-causing vectors (ALAM et al., 2020; GAO et al., 2019).

Given the above, the purpose of this research was to verify the possible soil contamination soil through the evaluation of chemical parameters of the soil, especially the concentration of metal pollutants in the soil under incorrect disposal of municipal solid waste generated in a municipality in the interior of the state of Low population density Goiás, Brazil, through the collection of 45 samples, arranged on the landfill, downstream and upstream, at depths of 2, 4, and 6m, with such reconnaissance drilling for environmental quality purposes established by NBR 15492 (ABNT, 2017).

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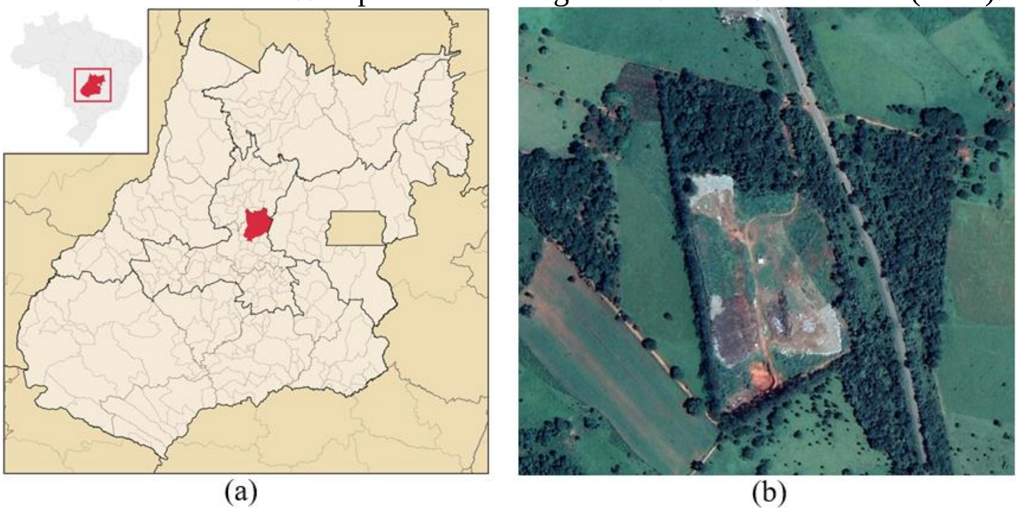
Material and methods

Description of the study area

The study was carried out in an area of final deposition of MSW in Jaraguá– GO, Brazil. According to IBGE (2018), the municipality has an estimated population of 49,667 inhabitants, located in the central region of the state. The destination area of MSW has an extension of approximately 5.78 ha, located at km 363 on the margins of Highway BR-153, whose geographic coordinates are: latitude 15° 46' 45" S and longitude 49° 18' 24 W (Figure 1).

Figure 1 - (a) Location of the municipality of Jaraguá on the map of Goiás. (b) Experimental area at the site of MSW deposition in Jaraguá-GO.Source: GOOGLE (2019).



The predominant climate in the region is of the Aw humid and hot tropical continental type (Aw of Koppen), with an annual average temperature between 24-25°C (CARDOSO et al., 2014). The soil in the region is of the Red Latosol type, vegetation is of the Cerrado type, located in the intermontane depressions, amidst the residual high relief of the Plateau do Alto Tocantins-Paranaiba and relief constituted by wide and gentle hills, altitude of 610m (EMBRAPA, 2011).

Characterization of the waste disposal site

The installation of the waste disposal site was carried out in 1995. Still, there was no technical study for the choice of this site, much less a sanitary infrastructure that aimed to reduce possible damage resulting from the growing generation of municipal waste together with the population and economic growth of the municipality.

Initially, the technique of controlled landfill on-site was developed, confirming the classification imposed by the State Department of Environment and Water Resources of Goiás in 2009. Still, due to the complete filling of the ditches over the years and for lack of physical space, it started a process of open dump deposition has taken place in recent years.

Data collection

The study was carried out in the MSW deposition area, that is, in direct contact between the soil and the residues, for the physicochemical characterization of the soil samples. For comparative purposes, samples were collected and analyzed upstream and downstream of the waste disposal area, seeking to observe and identify changes in physical-chemical characteristics in the region resulting from the inadequate disposal of municipal solid waste in the municipality.

The sampling points were georeferenced using GPS (Global Positioning System) equipment, model Garmin GPS map 62s, in fifteen points, five designated as L (solid waste disposal area - dump), five designated as M (area upstream of the dumpsite), and 5 called J (area downstream of the dumpsite), remembering that sites M and J are part of the portion of natural land adjacent to the area of contact with waste (Figure 2).

Figure 2 - Simple sample collection points. Source: Google (2019)

The choice of georeferenced points followed the following criteria: interconnection points between ditches executed between the periods of use of the controlled landfill technique; areas adjacent to the landfill, with level elevation points upstream of the landfill

(M), chemically characterizing the soil of the region, and points downstream (J), aiming at possible contamination by surface runoff and/or leaching.

Samples were collected from a total of 45 points, from three types of coverage (L - landfill site; M - land upstream of the landfill; J - land downstream of the landfill), collected at three depths (2, 4, and 6 m), removed at five points of each coverage, located between ditches of coverage L, on the perimeter adjacent to the dump, upstream, in coverage M, and the vegetation cover contour (green curtain) downstream, in cover J.

The choice for deep soil samples, as defined by Iwai (2012), is since the final disposal site for waste is transitional between a controlled landfill and an open dump, with trenches for waste disposal over the years of operation. In other words, there is a presence of waste deposited over a strip of approximately 5 meters from the soil profile at the site, in addition to the study's objective, which refers to reconnaissance drilling for environmental quality purposes, established by NBR 15492 (ABNT, 2017).

The samples were taken from the current surface with a mechanical propeller auger coupled to a tractor. They were packed in plastic bags (zip lock), labeled, and sent to the soil analysis laboratory accredited by the Ministry of Agriculture (MAPA) for physical-chemical characterization.

Laboratory analysis

To characterize the potential for contamination of polluting metals due to inadequate deposition of MSW, laboratory analyzes were necessary to obtain comparative parameters of physical and chemical nature. After collection, the soil samples were sent to the laboratory and immediately air-dried. Using a 2mm sieve, they went through the sieving process, aiming to obtain Air-Dry Fine Earth (ADFE) for soil particle size and chemical analysis.

Particle size - The particle size analysis was performed according to the Embrapa Soil Analysis Methods Manual (2017). The procedure began with weighing 30 g of soil (TFSA), with the addition of 100 mL of water and a 0.038 mol L^{-1} sodium hexametaphosphate solution plus 0.1 mol L^{-1} sodium hydroxide. The resulting mixture underwent a mechanical stirring process for 5 minutes, remaining at rest for 16 hours. After the rest period, the samples were shaken again in a mechanical shaker and washed with distilled water until the measurement of the 1000 mL beaker was completed. A new stirring process was carried out with a mechanical propeller stirrer, leaving it to rest again. With a 10 mL pipette, remove the suspension (clay), transferring the aliquots to tared containers. It is noteworthy that the sand is obtained by sieving and the silt fraction by the difference.

Chemical parameters - The determination of soil pH with electrode suspension immersion was performed according to the TEIXEIRA et al.(2017).The exchangeable cations (Ca^{2+}, Mg^{2+}, and Al^{3+}) were determined using an extracting solution of KCl mol L^{-1}, analyzed by volumetric, emission, or atomic absorption method (EMBRAPA, 2017).A potassium dichromate mixture ($K_2Cr_2O_7$) was used to determine and oxidize the soil organic matter. Combined use with concentrated sulfuric acid (H_2SO_4) works as an energy source to catalyze oxidation reactions. The analysis process was determined by the calorimetric method (QUAGGIO; RAIJ,1979).The extraction of chemical elements (Cu, Fe, Mn, P, and K) was performed using a chelating solution (DTPA) or mixed acid solution (Mehlich), called the modified Mehlich method (EMBRAPA, 2017). The determination was made by flame atomic absorption spectrometry and inductively coupled plasma optical emission spectrometry (ICP-OES), using appropriate lamps for each element. The K was read using a flame photometry method. The atomic absorption spectrophotometer used was the Perkin Elmer model AAnalyst 200. The flame photometer, brand Micronal model B262.The EPA 3050B method (USEPA, 1996) was chosen to digestCd, Cr, and Pb metal pollutants. The procedure included weighing a 1g sample (TFSA), digested by 10 mL of HNO3, heated in a digester block for 10 minutes at 95°C +5°C. The process was repeated, after cooling, with the addition of 5 mL of HNO_3 and heating again in a digester block for 120 minutes. After cooling, 2 mL of distilled water and 3 mL of H_2O_2 were added. The samples were returned to the block for another 120 minutes. Finally, after cooling again, another 5 mL of HCl and 10 mL of distilled water were added, going through the last heating process in a digester block for only 5 minutes at the same temperature as before.The suspensions were filtered and stored in plastic cups for determination using an atomic absorption spectrophotometer. For each reading, the device was calibrated with three base concentrations, in addition to the appropriate use of the correct lamp for each of the three cases, under radiation with an ideal wavelength.

Statistical analysis

The multivariate statistical method was used to analyze the analytical results obtained through an expressive number of variables. First, the Multivariate Analysis of Variance (MANOVA) of the data was carried out considering a 3x3 factorial scheme, considering the different areas of land cover (L - dump, J - Downstream, and M - Upstream) and subplots the depths (2, 4 and 6m), with five repetitions, established according to the criteria already described.The Principal Component Analysis (PCA) was used to interpret the data of the variables in question through a graphical presentation that represent the interrelationship between the independent variables, identifying the trend of data behavior, and interpretation regarding the influence that certain variables may have on others, or even explain adverse situations.Microsoft Office Excel and R software were used for statistical analyses described above to obtain the database, using a significance level of 95%.

Results and discussion

The results of the evaluations of the parameters of the soil samples collected in the three covers (L - dump, M - upstream, and J - downstream), at three depths (2, 4, and 6 m), are presented in Table 1, highlighting the average contents of the five sampling points of each treatment for the particle size analysis, chemical elements and polluting metals.

The soil samples analyzed did not have major fluctuations in their particle size classification, with samples at a depth of 2 m classified as sandy clay and at depths of 4m and 6m as loam sandy clay (EMBRAPA, 2017). The sandy characteristics of the samples may be one of the explanations for the low levels of heavy metals present in the collected samples.

It is observed that the contents of pollutant metals were below the limits established by CONAMA (2009) and CETESB (2016), in addition to limits set by countries such as the United States (USEPA, 2020), China (MEPC, 1995), Finland (MEF, 2007), and Canada (CCME, 2007). It is emphasized that the analysis of this study is based on an environmental character, based on the limits of the quality reference values (QRV), which must be rigorously used in the evaluation of soil contamination. Conana Resolution nº 420/2009 makes it clear, in a note, that the QRV limits must be defined by the federations, that is, each state of Brazil must proceed with the standard analyzes of the soils of its regions to stipulate a quality reference limit (CONAMA, 2009). The state of Goiás, where the present research was conducted, does not have completed studies that reference the QRV limits (REIS et al., 2017). Thus, many Brazilian studies choose to use the limits established by the Environmental Company of the State of São Paulo (CETESB, 2016). These limits are in mg kg^{-1}: Cd<0.5, Pb < 17, Cu < 35, Cr < 40, Zn < 60. Fe results and Mn are not established by CONAMA (2009) and CETESB (2016) because they are elements in abundance in brazilian soils, and no contaminant limits are presented for such elements.

A result similar to the work conducted by IWAI et al. (2012), SOUZA (2019), in addition to the study in the Campo Belo Sanitary Landfill - MG by MARQUES et al. (2021). Although the levels of pollutants above the limits established by current legislation are not yet noticed, it is possible to see significant differences between the three coverages and depths sampled (Table 1).

The deposition of solid waste at the site has been for 25 years, geologically considered a very short period. The data analyzed indicate a significant difference between the covers, pointing to higher concentrations of chemical components in the landfill area, which may indicate an ongoing contamination process, prompting the need for periodic monitoring of the site, with the possibility of an evolution of the levels of pollutant metals and consequently real contamination before the currently established limits.

Table 1 - Summary of multivariate analysis of variance (MANOVA) for the three coverages, three depths and interaction between location and depth for the physicochemical parameters: Texture, pH, Organic matter (OM), Calcium (Ca), Magnesium (Mg), Phosphorus (P), Potassium (K), Cation Exchange Capacity (CEC), Iron (Fe), Cadmium (Cd), Lead (Pb), Copper (Cu), Chromium (Cr), Manganese (Mn) and Zinc (Zn).

SV	DF	V. Pillai	F-ratio	Num DF	Den DF	Pr>F
Coverage	2	1,5885	5,3075	32	44	2,78e-07 *
Depths	2	1,1579	1,8907	32	44	0,0250 *
Coverage x Depths	4	1,9241	1,3903	64	96	0,0712
Residual	36	-	-	-	-	-
Total	44	-	-	-	-	-

*Significant by F test at 5% probability. SV = Sources of Variation, DF = Degrees of Freedom, V. Pillai = Pillai Trace Value, F = Fisher's F-Test, Num DF = Numerator Degree of Freedom, Den DF = Denominator Degree of Freedom, Pr = P-value.

The results of laboratory analyses were subjected to multivariate statistical analysis MANOVA (Table 1). The results indicated statistical significance at a probability level of 5% for both coverage (L - dump, J - Downstream, and M - Upstream) and depths (2, 4, 6m), but there was no statistical significance for the interaction between coverage and depth, corresponding to the nine treatments described in Table 1 (L2, L4, L6, J2, J4, J6, M2, M4, M6).

Whenanalyzing the P-value in Table 1, it can be observed that the difference between the analyzed chemical parameters in the multivariate statistical analysis was statistically significant at a 5% level of probability when comparing the points collected under the landfill with those upstream and downstream. Furthermore, statistical analysis indicated significant differences between the results obtained at the three collection depths (2, 4, and 6m). However, when comparing the nine treatments described in Table 2, which present an interaction between coverage and depth, the results were not statistically significant at a

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probability level of 5%, indicating that there are no significant differences between the samples.

Table2 - Descriptive analysis referring to the average, maximum and minimum contents, standard deviation (SD), coefficient of variation (CV) of the parameters [Texture - clay, siltand sand, pH, Organic Matter (OM), Calcium (Ca), Magnesium (Mg), Phosphorus (P), Potassium (K), Cation Exchange Capacity (CEC), Iron (Fe), Cadmium (Cd), Lead (Pb), Copper (Cu), Chromium (Cr), Manganese (Mn), and Zinc (Zn)] from samples upstream (M), Dump (L) and Downstream (J), at the three depths (2, 4 and 6m).

Tr.	Descr. Anal.	Clay %	Silt %	Sand %	pH	OM (g/kg)	Ca (cmol/dm^3)	Mg (cmol/dm^3)	P (mg/dm^3)	K (mg/dm^3)	CEC (cmol/dm^3)	Fe (mg/dm^3)	Cd (mg/kg)	Pb (mg/kg)	Cu (mg/dm^3)	Cr (mg/kg)	Mn (mg/dm^3)	Zn (mg/dm^3)
M (2m)	Mean	38	7	55	5,1	4,6	0,3	0,1	0,7	26,4	2,5	19,2	0,2	2,3	0,3	0,5	4,0	2,2
	Mini	37	7	53	4,8	4,0	0,2	0,1	0,4	16,0	2,3	15,0	0,1	0,9	0,1	0,1	2,0	0,4
	Max	39	8	56	5,4	7,0	0,5	0,2	1,2	34,0	2,6	23,0	0,3	5,1	0,8	0,8	7,0	6,3
	SD	1	1	2	0,3	1,3	0,1	0,0	0,3	6,7	0,1	3,9	0,1	1,7	0,3	0,3	2,0	2,7
	CV(%)	3	7	3	5,1	29,2	33,5	37,3	49,8	25,4	5,4	20,3	55,9	76,4	97,2	64,9	50,0	119,7
L (2m)	Mean	37	7	56	5,8	4,0	0,9	0,3	0,4	159,6	2,9	160,0	0,2	1,4	0,3	3,0	20,0	0,5
	Mini	37	7	56	5,4	4,0	0,2	0,1	0,3	54,0	2,1	34,0	0,1	0,6	0,1	0,0	9,0	0,1
	Max	37	7	56	6,2	4,0	2,9	0,8	0,5	240,0	5,3	351,0	0,2	1,9	0,7	8,4	37,0	1,8
	SD	0	0	0	0,3	0,0	1,2	0,3	0,1	79,9	1,3	167,2	0,1	0,6	0,3	4,1	12,1	0,7
	CV(%)	0	0	0	5,3	0,0	133,7	117,3	22,0	50,0	46,3	104,5	34,2	42,7	94,8	134,3	60,7	133,9
J (2m)	Mean	35	8	57	5,2	4,0	0,3	0,2	0,3	35,6	2,6	14,6	0,2	1,7	0,2	0,2	4,4	0,2
	Mini	34	7	56	5	4,0	0,2	0,1	0,3	12,0	2,4	13,0	0,1	0,4	0,1	0,0	3,0	0,1
	Max	37	8	58	5,4	4,0	0,5	0,2	0,4	88,0	2,8	18,0	0,2	3,2	0,2	0,4	6,0	0,4
	SD	2	1	1	0,2	0,0	0,1	0,1	0,1	29,9	0,1	2,1	0,0	1,0	0,1	0,2	1,3	0,1
	CV(%)	5	7	2	2,9	0,0	40,7	34,2	16,1	84,1	5,6	14,2	24,8	59,2	34,2	113,5	30,5	83,9
M (4m)	Mean	32	7	61	4,6	4,0	0,3	0,1	0,5	29,6	2,8	20,8	0,1	2,7	0,2	0,7	3,0	1,1
	Mini	20	6	53	4,2	4,0	0,2	0,1	0,3	20,0	2,3	9,0	0,1	1,5	0,1	0,1	2,0	0,4
	Max	39	8	74	5,4	4,0	0,3	0,1	0,9	40,0	3,4	37,0	0,2	3,8	0,3	1,7	4,0	3,0
	SD	8	1	9	0,5	0,0	0,1	0,0	0,2	9,2	0,5	10,4	0,1	0,8	0,1	0,6	0,7	1,1
	CV(%)	26	12	15	10	0,0	21,1	0,0	47,9	31,1	16,3	50,2	39,1	30,7	46,5	85,8	23,6	96,9
L (4m)	Mean	33	7	59	6,1	4,0	0,5	0,2	0,3	181,6	2,6	52,0	0,1	2,1	0,4	0,8	11,2	0,6
	Mini	27	6	56	5,1	4,0	0,2	0,1	0,2	42,0	2,1	17,0	0,1	1,1	0,1	0,0	9,0	0,1
	Max	37	9	67	6,8	4,0	1,7	0,6	0,3	326,0	3,8	105,0	0,2	3,4	0,8	1,8	15,0	1,6
	SD	4	1	5	0,8	0,0	0,7	0,2	0,1	131,5	0,7	39,8	0,1	1,1	0,4	0,7	2,4	0,7
	CV(%)	13	15	8	13	0,0	120,4	111,8	21,1	72,4	26,5	76,6	39,1	51,3	91,9	89,4	21,3	105,7
J (4m)	Mean	31	9	60	5,1	4,0	0,2	0,1	0,3	42,4	2,4	18,0	0,2	1,7	0,1	0,6	3,0	0,5
	Mini	31	9	60	4,9	4,0	0,2	0,1	0,2	24,0	2,2	15,0	0,2	0,6	0,1	0,0	2,0	0,1
	Max	31	9	60	5,3	4,0	0,3	0,2	0,3	86,0	2,5	24,0	0,2	2,2	0,2	1,3	5,0	2,1
	SD	0	0	0	0,2	0,0	0,1	0,1	0,0	25,9	0,1	3,7	0,0	0,6	0,0	0,6	1,2	0,9
	CV(%)	0	0	0	3	0,0	22,8	39,1	16,0	61,0	4,9	20,8	0,0	38,4	37,3	90,8	40,8	178,9
M (6m)	Mean	21	6	73	4,3	2,8	0,2	0,1	0,4	23,2	3,3	24,2	0,1	3,0	0,2	0,8	4,0	1,2
	Mini	12	4	58	4,2	2,0	0,2	0,1	0,3	14,0	2,8	8,0	0,1	1,3	0,1	0,1	2,0	0,4
	Max	34	8	84	4,4	4,0	0,3	0,1	0,5	46,0	3,6	66,0	0,2	4,0	0,5	2,1	10,0	2,7
	SD	8	1	10	0,1	1,1	0,1	0,0	0,1	13,7	0,3	23,8	0,1	1,1	0,2	0,8	3,4	1,0
	CV(%)	39	24	13	2	39,1	22,8	0,0	24,8	59,0	10,2	98,3	39,1	36,5	81,3	90,9	84,8	83,1
L (6m)	Mean	31	8	61	6	2,8	0,6	0,2	0,2	153,2	3,3	63,0	0,2	1,7	0,4	0,8	10,6	0,6
	Mini	27	6	58	4,4	2,0	0,2	0,1	0,2	44,0	1,7	15,0	0,1	0,8	0,1	0,0	6,0	0,1
	Max	34	9	67	6,9	4,0	1,8	0,5	0,3	380,0	5,4	177,0	0,2	2,6	1,1	2,2	19,0	2,8
	SD	3	1	4	1,2	1,1	0,7	0,2	0,0	137,4	1,4	66,8	0,0	0,7	0,4	0,9	4,9	1,2
	CV(%)	8	16	6	21	39,1	109,6	81,3	20,3	89,7	43,0	106,1	24,8	42,3	111,8	111,9	46,5	188,7
J (6m)	Mean	29	8	64	4,6	3,6	0,2	0,1	0,2	46,0	3,2	25,4	0,1	1,8	0,1	0,6	6,2	0,1

Mini	25	6	60	4,5	2,0	0,2	0,1	0,2	20,0	3,0	15,0	0,1	0,8	0,1	0,1	3,0	0,1
Max	31	9	69	4,6	4,0	0,3	0,2	0,2	80,0	3,5	47,0	0,2	2,1	0,2	1,3	13,0	0,2
SD	3	2	5	0,1	0,9	0,1	0,1	0,0	23,9	0,2	14,9	0,1	0,6	0,0	0,5	4,6	0,0
CV(%)	12	21	8	1,2	24,8	22,8	39,1	0,0	52,0	6,2	58,5	39,1	31,3	37,3	85,3	74,3	37,3

It is noteworthy that the macronutrients, P, K, Ca, Mg, in addition to the cationic micronutrients Cu, Fe, Mn and Zn and the heavy metals Cd, Pb and Cr have limited movement in the soil profile promoted by leaching and percolation processes, even in highly weathered soils such as the Oxisols predominant in the studied area, thus justifying the non-detection of statistical differences between the concentrations of the referred ions in the different depths sampled from the soil.

Analysis of Principal Components (PCA)

Using the PCA technique, it was possible to reduce the 17 parameters analyzed into three principal components, called PC1, PC2, and PC3, which accumulated account for 60.33% of the total accumulated variance of the data, respectively explaining 29.63% for PC1, 17, 97% to PC2, and 12.73% to PC3. The number of principal components was defined using eigenvalues above 2.0, characterized by components with more relevant information.The three principal components defined for the analysis presented a satisfactory correlation coefficient (r) for all parameters, except Cd, Pb, and Mn, with values lower than 0.5; thus, it cannot be explained by the three principal components.

The values of the correlation coefficients (r), also called loadings (Table 3), are oscillating values between 1 and -1, which graphically represent the distribution of the points of the analyzed parameters. TEIXEIRA et al. (2014) considered correlation coefficients (r) above 0.5 or below -0.5 as significant, as they have a direct or inverse correlation between parameters above 50%, also considered by SANTOS (2007) as moderate correlations the strong.

The values of the correlation coefficients described as significant provide a linear combination with their respective principal components. Therefore, parameters such as pH (0.69), Ca (0.84), Mg (0.82), K (0.56), Fe (0.86), Cu (0.63), and Cr (0. 80) are explained by CP1, while the soil particle size, including clay (-0.76), silt (-0.58), and sand (.80), in addition to organic matter (-0.57) and CEC (0.68), are answered by PC2. PC3 also explains parameters such as P (0.76) and Zn (0.78).

The PCA technique provides a graphical analysis of the positioning of each sample, concerning the group or treatment to which it belongs, through the scores of the first two components, PC1 and PC2, with the component with the greatest response to variance,

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represented on the abscissa axis, and the subsequent component, on the ordinate axis. Figure 3 illustrates the distribution of samples within the Cartesian plane.

Table 3 - Summary of principal component analysis, eigenvalues and multivariate variances.

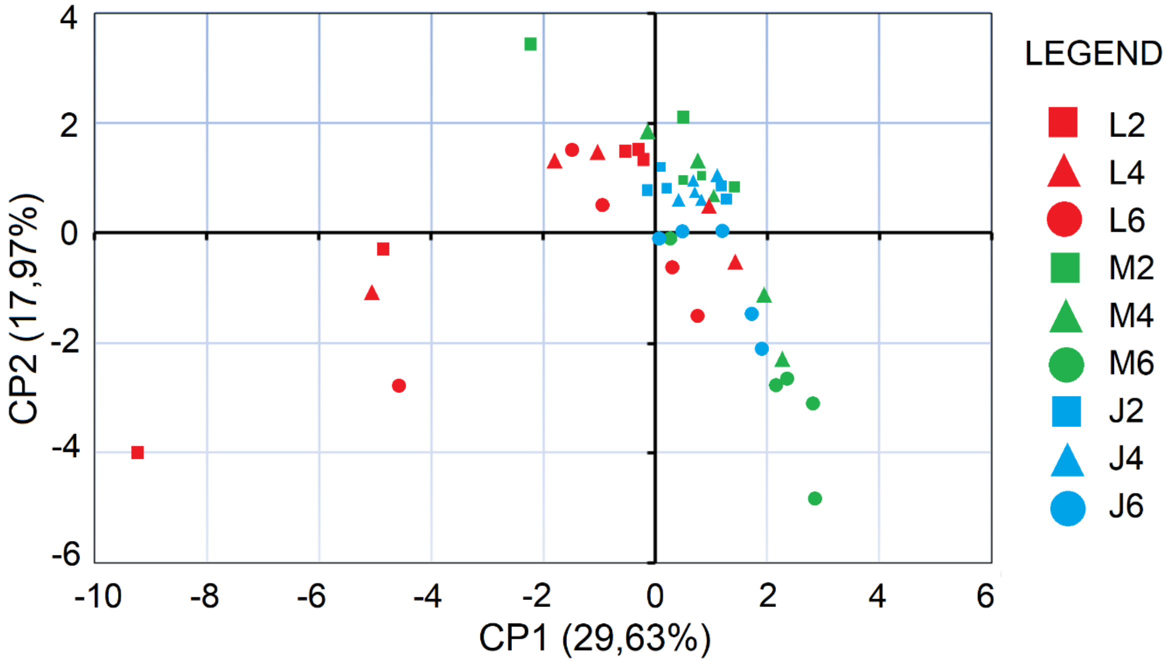
Parameters analyzed	Principal Components		
	PC1	PC2	PC3
	Correlation coefficients (r)		
Clay	0,48	-0,76*	0,05
Silt	0,13	-0,58*	-0,26
Sand	-0,46	0,80*	0,00
pH	0,69*	-0,31	-0,33
M.O	0,30	-0,57*	0,40
Ca	0,84*	0,39	0,12
Mg	0,82*	0,36	0,06
P	-0,02	-0,36	0,76*
K	0,56*	-0,09	-0,48
CEC	0,26	0,68*	0,15
Fe	0,86*	0,28	0,01
Cd	0,35	-0,15	0,14
Pb	-0,33	0,00	0,41
Cu	0,63*	0,05	0,21
Cr	0,80*	0,29	0,15
Mn	0,47	-0,05	-0,32
Zn	0,22	0,03	0,78*
λ – Eigenvalues	5,04	3,06	2,16
Total variance by PC	29,6%	18,0%	12,7%
Accumulated Total variance	29,6%	47,6%	60,3%

* Pearson correlation coefficients greater than 0.5

The red, green, and blue dots indicate the scores of samples in the landfill cover, upstream and downstream, respectively, with numbers 2, 4, and 6 being the depths of 2, 4, and 6m. It is observed that on the horizontal axis (CP1), there is a distance of a large part of the dump samplesconcerning the samples upstream and downstream, in addition to the fact that four of these samples are at a significant distance from the origin of the Cartesian plane, which indicates a greater contribution to explaining the variances.

The four points spaced to the left of the abscissa axis represent points of the landfill cover, being two points 2 m deep, one point 4 m, and the other 6 m deep, demonstrating that some of the landfill cover samples showed expressive results of chemical compounds contents when compared to the other points of analysis.

Figure 3 - Distribution of the scores of the principal components PC1 and PC2 of the 45 soil samples.



Figures 4 and 5 represent the distribution of scores for the principal components PC1 and PC3 and the components PC2 and PC3, respectively. In Figure 4, there is a clear separation of the upstream samples, answered by the principal component PC3 (vertical), with a 12.73% variance explained.

It is observed that the downstream cover has a homogeneous behavior when compared to other covers. There are no large oscillations between the chemical parameters analyzed in the five sampling points of this cover at the three depths,result attributed to uniform distribution of ions along the sampled soil profile.

The small fluctuation in the concentrations of metals downstream, as well as their low concentrations, is because there is currently no contamination in the landfill area and that upon possible future contamination of the site, the downstream points should be re-checked to identify the influence of the landfill area to the adjacent area downstream. It is noteworthy the presence of an extensive green curtain between both covers, forming isolation barriers that can contribute to the reduction of contamination between them. It also highlights the relationship between PC2 and PC3 (Figure 5), with the PC2 component in this analysis not

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favoring a separation between the three coverages. At the same time,PC3 (vertical) still portrays the difference in the upstream coverage.

Figure 4 - Distribution of the scores of the principal components PC1 and PC3 of the 45 soil samples.

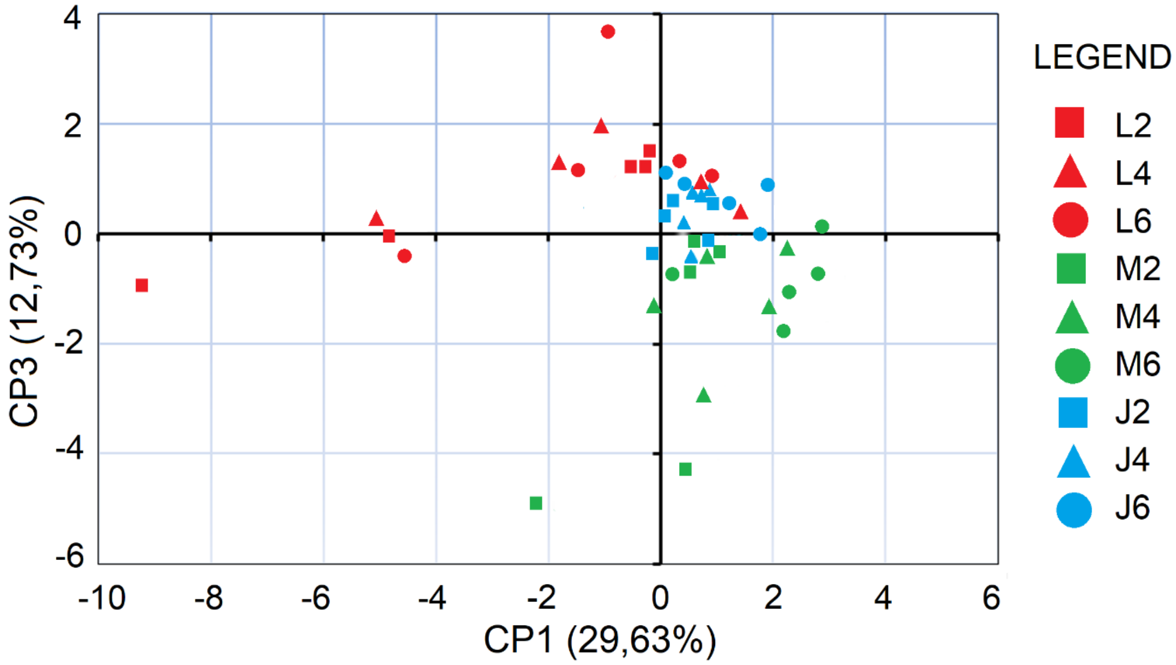
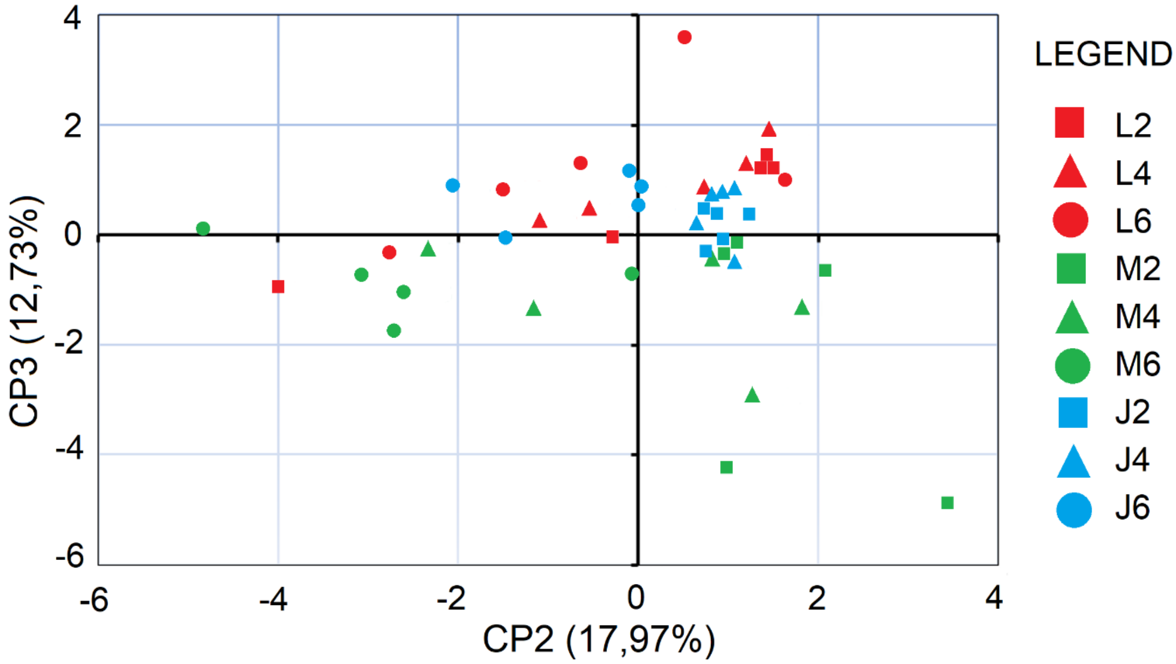


Figure 5 - Distribution of the scores of the principal components PC2 and PC3 of the 45 soil samples.



The eigenvectors describe the projections of the analyzed parameters within the Cartesian plane limited to a circle with a radius equal to 1, representing the limit of the

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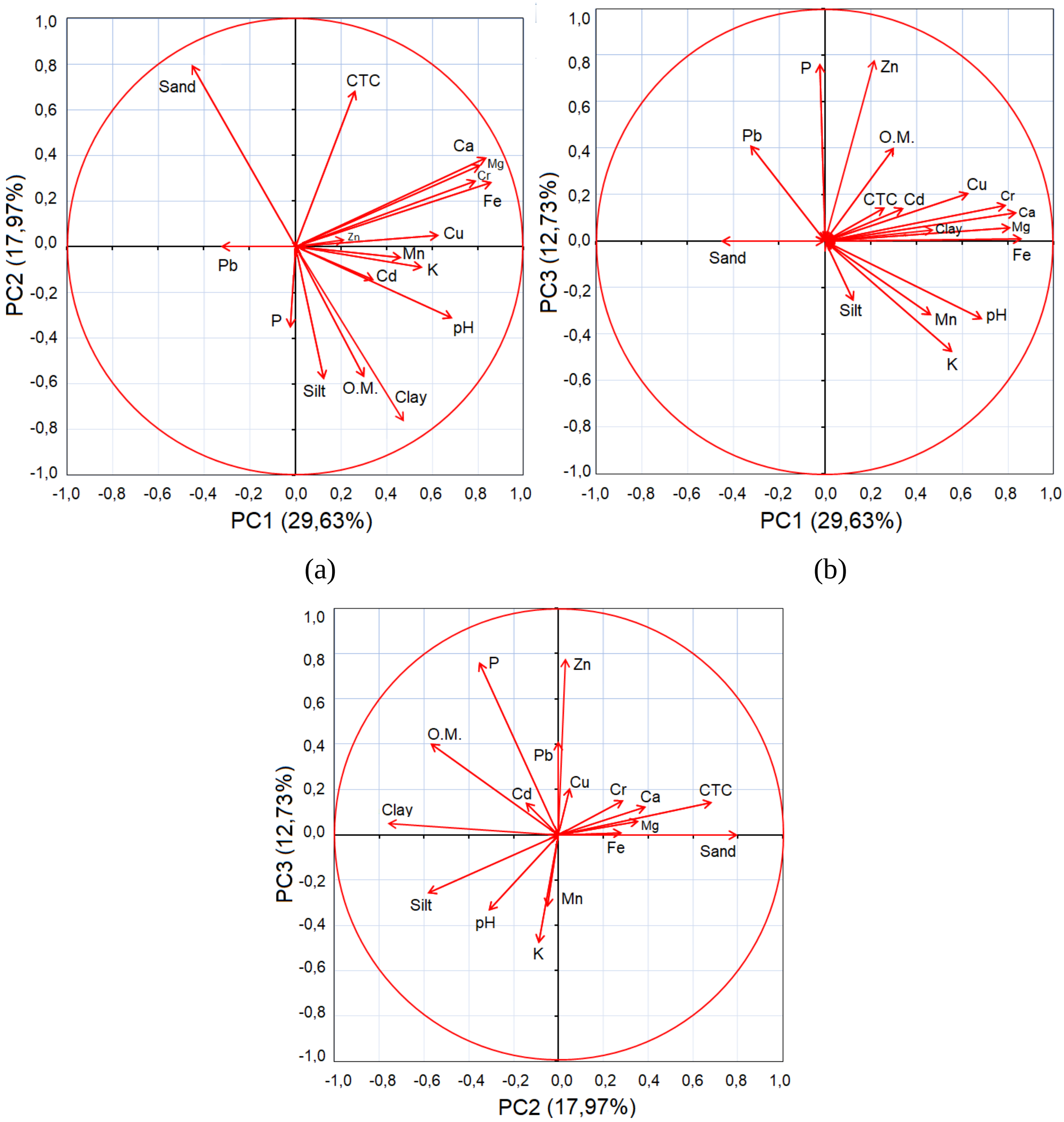
maximum correlation proposed by some parameters (Figure 6). It is noticed that variables such as Cr, Fe, and Cu metals are strongly related to Ca and Mg, while M.O. is strongly correlated to the fraction of clay and silt in the soil (Figure 6a). Still analyzing the eigenvectors of the relationship PC1 and PC2 (Figure 6a), it can be seen that sand is inversely correlated to the elements, which corroborates the assertions of CARVALHO; ZABOT (2012), that sandy soils have characteristics favorable to leaching, not retaining chemical elements such as polluting metals in the soil, consequently reducing the contents of these elements in soils with this particle size characteristic.

Figure 6 - Two-dimensional projection of the eigenvectors of the principal components PC1 and PC2 (a), PC1 and PC3 (b) and PC2 and PC3 (c).



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(c)

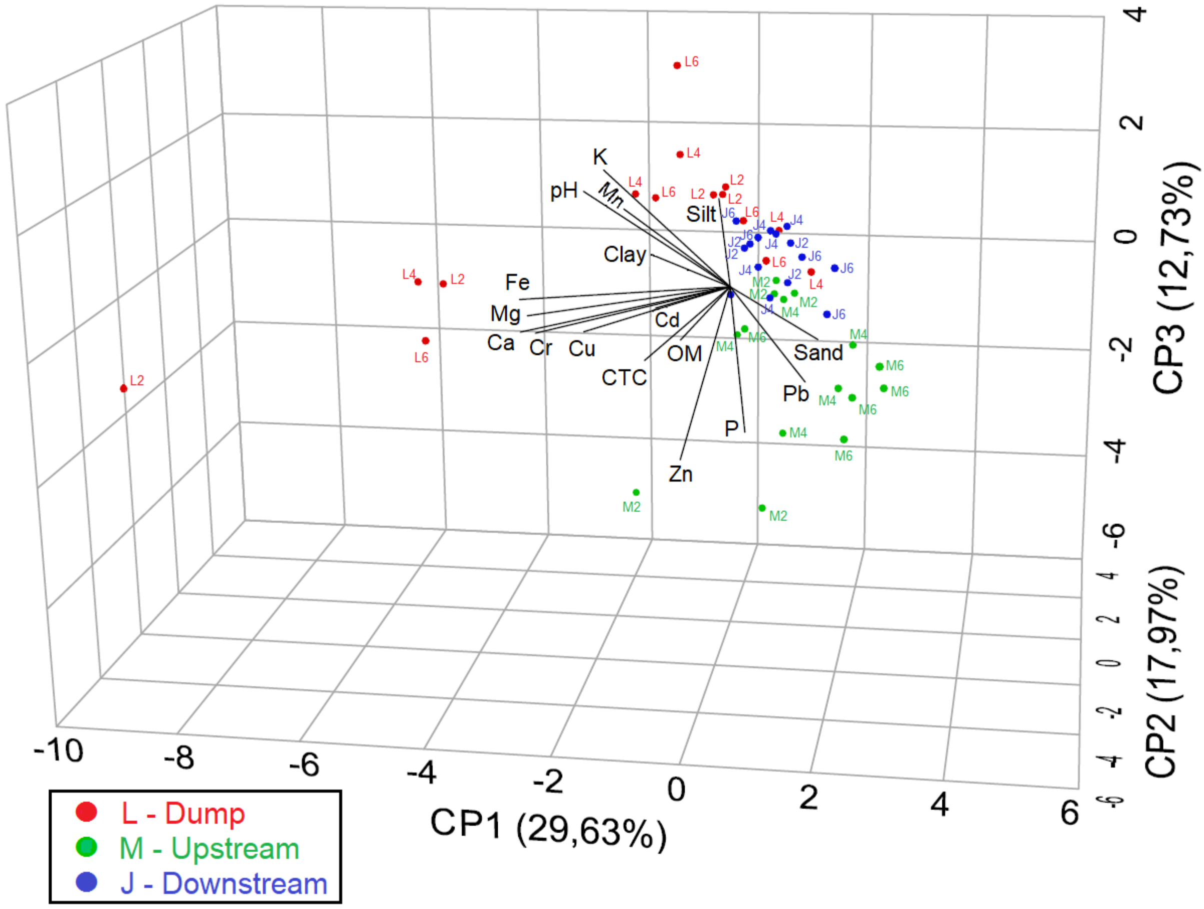
Relating PC1 and PC3, there is a significant correlation of the Cu, Cr, Ca, Mg, and Fe eigenvectors with the clay fraction. At the same time, parameters such as Zn and P, are correlated only with each other, answered by PC3 (Figure 6b). It is also verified the existence of a correlation between the elements Zn and P through analysis of the ordinate axis. In contrast, for the component PC2 (horizontal), the correlation between organic matter and clay stands out (Figure 6c).

To better demonstrate the results of the eigenvectors, that is, the relationship of the physical-chemical parameters of the soil analyzed together with the scores of the soil samples of each treatment, in addition to incorporating all the two-dimensional analyzes described in the PCAs, a three-dimensional graph was created (Figure 7), incorporating the results of the distribution of scores and eigenvectors for the three principal components analyzed PC1, PC2, and PC3. It can be verified the relationship between the scores and the eigenvectors of the variables in question. Most of the parameters analyzed presented behavior aimed at the negative coordinates of PC1, which is directly associated with the landfill coverage scores. Such parameters mentioned would be Ca, Mg, K, Fe, Cr, Cu, Mn, pH, and soils with higher percentages of clay.

On the other hand, parameters such as Pb, P, Zn, and sand in the particle size composition are associated with the upstream sample scores. MARQUES et al. (2021) also pointed out such results for Pb, noting that even for the upstream coverage, the variation between the collected points was high, which could be a characteristic of the soil in the region. No highlighted element is positively correlated to the coverage in question for the downstream samples, which reinforces the assertion of homogeneity between the downstream samples, possibly due to the environmental protection generated by the green curtain (vegetal coverage) existing in the limits of the dumping ground.

From the results obtained, it can be verified that higher concentrations of pollutant metals occurred in the landfill area. The soil of this location also presented higher clay contents in the particle size composition. In contrast, in the upstream soil, there are low concentrations of chemical parameters analyzed, except for Pb, P, and Zn, which have a higher concentration than the other studied coverings. It is also noteworthy that the soils in the sampled area have a clayey-sandy loam particle size.

Figure 7 - Three-dimensional projection of the scores and eigenvectors of the principal components PC1 and PC2 and PC3.



Conclusions

•The chemical composition of the soil solution under MSW deposition presents higher levels of pollutant metals, and other chemical elements analyzed, except for Pb, P, and Zn concerning the areas free from MSW deposition.

•There is no soil contamination by polluting metals when comparing the concentrations of metals analyzed in the samples from the MSW deposition area to the limits established by CONAMA (2009) and CETESB (2016), as well as the foreign soil limits defined by USEPA (2020), MEPC (1995), MEF (2007) and CCME (2007).

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