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Special Edition

Assessment of the potential use of construction and demolition waste as a component for the recovery of areas degraded by mining

Avaliação do potencial de uso de resíduos de construção e demolição como componente para a recuperação de áreas degradadas por mineração

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ABSTRACT

The evolution of modern civilization brings with it a series of challenges regarding the management of its waste. Proper disposal of construction and demolition waste (CDW) has become a challenge across the planet. Parallel to this challenge, there is another, that of recovering areas degraded by mining. The objective of the present work was to characterize through X-ray fluorescence (XRF), and X-ray diffraction (XRD) samples of CDW collected during the period from October 2018 to October 2019 in a recycling plant and to determine its potential as an element in the production of soils in the recovery of areas degraded by mining. Calcite and quartz were found in the CDW samples, as well as trace elements such as Fe, Mg, Mn, Cu, Zn, Ni, essential elements for plant nutrition, capable of restoring the chemical and physical conditions of soils. The results obtained showed that Chromium (Cr) and Barium (Ba) elements were found above the limits of CONAMA Resolution 420/2009 (Brazil). A comparison was made with Orden AAA/661/2013 (Spain), which guides the disposal of CDW in mining areas as a form of final disposal and mine closure. The presence of heavy metals is considered normal in Brazilian soils, some being considered essential micronutrients. The results provide data to affirm that the CDWs can be used in soil production to recover areas degraded by mining, through the application of tests on a larger scale and with a soil-water-plant interface.

Keywords: Soil recovery; Recycling; Construction and Demolition Waste

RESUMO

A evolução da civilização moderna traz consigo uma série de desafios quanto à gestão de seus resíduos. A destinação adequada de resíduos de construção e demolição (RCD) tem se tornado um desafio em todo o planeta. Paralelo a este desafio, surge outro, o de recuperar áreas degradadas por mineração. O objetivo do presente trabalho foi caracterizar através de Fluorescência de raios X (FRX) e difração de raios X (DRX) amostras de RCD coletados durante período de outubro de 2018 a outubro 2019 em uma central de reciclagem e determinar seu potencial como elemento na produção de solos em recuperação de áreas degradadas por mineração. Foram encontrados calcita e quartzo nas amostras de RCD, além de elementos traço como Fe, Mg, Mn, Cu, Zn, Ni, elementos essenciais para a nutrição vegetal, capazes de restaurar as condições químicas e físicas dos solos. Os resultados obtidos demonstraram que elementos Cromo (Cr) e Bário (Ba) encontraram-se acima dos limites da Resolução CONAMA 420/2009 (Brasil). Foi efetuada a comparação de parâmetros com a Orden AAA/661/2013 (Espanha), a qual orienta a destinação de RCD em áreas de mineração como forma de destinação final e fechamento de minas. A presença de metais pesados é considerada normal em solos brasileiros, sendo alguns considerados micronutrientes essenciais. Os resultados fornecem dados para afirmar que os RCD são passíveis de utilização em produção de solos para fins de recuperação de áreas degradadas por mineração, mediante aplicação de testes em maior escala e com interface solo-água-planta.

Palavras-chave: Recuperação de Solos; Reciclagem; Resíduos de Construção e Demolição

1 INTRODUCTION

Solid waste management has become one of today’s most critical global challenges (resulting in negative effects on the economy and sustainability, especially in emerging countries. Construction and demolition waste (CDW) contributes about 50% of the total annual global amount of solid waste generated (DAOUD *et al*., 2020).

In this sense, the most developed countries have sought solutions to this problem, prioritizing the issue in favor of sustainable construction, industrial growthand the importance of resource efficiency, such as the countries of the European block and the United Kingdom (GHAFFAR, BURMAN, and BRAIMAH, 2020).

CDW has been studied as an adsorbent material to remove toxic metals from effluents, as well as a component for cemented paste landfills in underground mining areas, road construction, non-structural works (WANG and CHEN, 2017; KUMARA *et al*., 2017; YLMAZ and ERCIKDI, 2021), but there are no reports in the literature on its use as a fertilizing element or as a reclaimer of degraded soils.

The National Solid Waste Policy - Federal Law No. 12,305/2010 (BRASIL, 2010) establishes the appropriate hierarchy in the integrated management of solid waste: non-generation, reuse, recycling, treatment, and proper final destination. Following the same logic, Resolution 307/2002 (BRASIL, 2002) of the National Council for the Environment (CONAMA) establishes guidelines, classification criteria, and procedures for managing civil construction waste in the country.

In Brazil, it is estimated that the generation of CDW is superior to 70 million tons per year, representing more than 50% of the mass of urban solid waste (REIS *et al*., 2020).

Currently, only 6.14% of this generated volume is recycled, and most of it is destined for inert landfills or in an abandoned land and/or roadsides, which, if not managed correctly, can cause numerous negative environmental impacts (FERREIRA *et al*., 2019).

In more developed countries, CDWs also generate problems, making management and final disposal difficult, given the associated environmental liabilities (CALVO, 2017; SUÁREZ-SILGADO *et al*., 2018; MENEGAKI and DAMIGOS, 2018). The example of Spain, which in 2012 generated 26 million tons of CDW, considering that these represented 20% of the total waste generated by that country, ranking sixth in the ranking of generators in the European Union (FERNANDEZ-NARANJO *et al*., 2016).

In Brazil, CDW generation amounts to 50% of the total waste generated in large urban centers (REIS *et al*., 2020).

The proper management of CDW is a relevant challenge on a global scale, considering the circular economy theory, especially for emerging economies where economic development induces the construction market’s growth (BAO and LU, 2020).

Thus, there is a need to search for technical and viable solutions, from an economic point of view, for adequate integrated management of civil construction waste, with the least possible environmental impact.

In Brazil, generators are legally responsible for the correct management and management (BRASIL, 2002).

According to the Brazilian legislation, since 2004, construction and demolition waste cannot be disposed of in inappropriate places and should preferably be recycled. However, only a small portion returns to Brazil's civil construction production chain (NUNES and MAHLER, 2020).

In parallel, in another production chain, mining, there is a need to recover degraded areas, especially in the open, such as clay mining for ceramics and mineral coal extraction. Therefore, there is a need to consider that the use of produced soils in the recovery of degraded areas favors environmental conservation by reducing the use of borrow areas associated with CDW recycling, reducing the negative environmental impacts of disposing of these in landfills.

Although the CDW classified as "class A" by CONAMA (BRASIL, 2002) is noteworthy, it is considered inert waste. Oliveira (2002) concluded that concrete waste was presented as "non-inert" when subjected to acid rainwater. The author concluded that ions from the decomposition of these residues can contribute to the contamination of watercourses, altering their natural conditions.

In the same sense, several researchers warn that in the disposal or use of CDW in soil, there is a prior need to study and analyze the toxic potential of these residues because, in their characterization, the authors found toxic elements (SCHAEFER *et al*., 2007; TOWSEND *et al*., 2004; RAMALHO and PIRES, 2009; FILIZOLA *et al*., 2006, FERNADEZ-NARANJO *et al*., 2016; YU *et al*., 2018) thus it is necessary to test the toxicity of the residues using physicochemical techniques and from the use of bioindicators.

Thus, the objective of this work is to carry out the previous chemical characterization p utilizing X-ray Diffraction (DRX) and X-ray Fluorescence (FRX) of

CDW samples, "class A," according to CONAMA Resolution 307/2002, to verify chemical elements with potential for contamination and bioaccumulation, aiming to assess the environmental feasibility of using CDW in soil production in projects for the recovery of areas degraded by mining.

1.1 International scenario of CDW generation

At the international level, CDWs also characterize a problem for the integrated management of waste, representing high volumes, a problem aggravated in countries where the reduced territorial extension, and consequently, the production of natural resources, worsens the need for their reuse and recycling.

The generation of CDW in the European Union (EU) presents significant differences between its member states. The total solid waste generated for the year 2014 was 2.5 million tons. The percentage of CDW was high (Luxembourg: 85%, Malta: 75%, Netherlands, Germany, Denmark, and United Kingdom: 68, 53, and 48% respectively), and the recycling rate of this waste in 2014 was 88%, considering 28 EU countries. In the remaining countries of the European continent, it was 12%, with the CDW destined for landfills (SÚAREZ-SILGADO *et al*., 2018). For 2016, the amount of solid waste in Europe reached 322 million tons, with 35% CDW (TABOADA *et al*., 2020). In Table 1, you can see the percentage of CDW recycling in the European Union.

Table 1 – Recycling rate (%) of construction and demolition waste (CDW) in European Union countries

Country- Year	**2010**	**2012**	**2014**	**2016**	**2018**
European Union – 27 Countries (2020)	:	:	87	87	88
European Union – 28 Countries (2013-2020)	:	:	89	89	90
Euro area - 19 Countries (2015)	:	:	:	:	:
Belgium	17	18	32	95	97
Bulgaria	62	12	96	90	24

Continued...

Table 1 – Conclusion

Country- Year	**2010**	**2012**	**2014**		**2016**		**2018**	
Czech Republic	91	91	90		92		:	bc
Denmark	:	91	92		90		97	
Germany	95	94	:	c	:	c	93	
Estonia	96	96	98		97		95	
Ireland	97	100	100		96		100	
Greece	0	0	0		88		97	p
Spain	65	84	70		79		75	
France	66	66	71		71	e	73	
Croatia	2	51	69		76		78	
Italy	97	97	97		98		98	
Cyprus	0	60	38		57		64	
Latvia	:	:	92		98		97	
Lithuania	73	88	92		97		99	
Luxembourg	98	99	98		100		98	
Hungary	61	75	86		99		99	
Malta	16	100	100		100		100	
New Zealand	100	100	100		100		100	
Austria	92	92	94		88		90	
Poland	93	92	96		91		84	
Portugal	58	84	95		97		93	
Romania	47	67	65		85		74	
Eslovenia	94	92	98		98		98	
Slovakia	:	:	54		54		51	
Finland	5	12	83		87		74	
Swden	78	81	55		61		90	
Iceland	75	100	99		99		99	
Liechtenstein	:	:	:		:		:	
Norway	44	75	77		71		63	
Switzerland	:	:	:		:		:	
United Kingdon	96	96	96		96		98	
Montenegro	:	:	:		0		0	p
Macedonia	:	0	0		:		100	
Albania	:	:	:		:		:	
Serbia	:	:	:		80		81	
Turkey	:	:	:		:		0	
Kosovo (under United Nations Council Resolution 1244/99)	:	:	:		:		:	

: (not evaluated); bc (break in time series); c (confidential); e (estimated); p (provisional).
Source: Eurostat, 2021

In the United States (USA), 600 million tons of CDW were generated in 2018, more than double the amount of municipal solid waste generated. Demolition represents more than 90% of the total RCD generation in the US, while civil construction represents less than 10%. Approximately 455 million tons of CDW were directed for recycling, and 145 million tons were sent to landfills (EPA, 2021).

In Asia, there is great variation between countries. Except for South Korea and Japan, in other countries on the continent, CDW management is deficient, with around 40% of the total waste generated being CDW and practically without recycling (SÚAREZ-SILGADO *et al*., 2018).

The generation of CDW varies widely between countries, which can be explained by temporal variation, when economic conditions are more favorable to civil construction, depending on the climate, in addition to the degree of incentive to civil construction.

There are still numerous difficulties in Latin America due to economic, social, and cultural factors, although Brazil is the first country to adopt CDM management legislation (SUAREZ-SILGADO *et al*., 2018).

For Scatolini and Bandeira (2020), the management of CDW in Brazil, despite the strict legislation on the subject, is still deficient, even when there is an excessive generation of CDW due to natural disasters. For the authors, there is a great wasted opportunity to reduce the post-traumatic stress of the affected communities and the managers responsible for this waste’s restoration and final destination.

1.2 CDW in the recovery of degraded soils

Despite advances in terms of legislation, the use of CDW in the recovery of degraded areas is rarely reported in the specialized literature. Lasso (2011) developed an experiment involving CDW “Class A” (CONAMA, 2002) as a corrective and soil conditioner for agricultural purposes with good results.

Fernandez-Naranjo *et al*. (2016), in turn, evaluated the future use of CDW in Spain in the recovery of areas degraded by mining according to European Union norms, due to a new directive from that nation for the disposal of these residues in mining areas. The authors found technical and environmental feasibility, noting only the high content of sulfates in the CDW, recommending adopting geotechnical waterproofing techniques to avoid percolation.

Restrepo, Bedoya, and Vega (2015) characterized and evaluated the CDW as an option for recovering urban soils in Colombia, concluding that it is technically and environmentally viable by deepening the techniques for characterizing and recycling these wastes.

Murcia *et al*. (2007) used CDW intercropped with waste marble and sewage sludge in soils degraded by mining in Spain, reporting an increase in colonization by fungi and bacteria in the soil under study.

López-Uceda *et al*. (2018) used CDW in the proportion of 25, 50, and 75% in volume together with the commercial substrate in the construction of green roofs. They obtained leaching results of toxic metals at levels below those allowed by the environmental standards of the European Union.

Reis *et al*. (2020) concluded that the wastewater from the treatment plant of CDW recycling plants are promising materials as low-cost phosphate adsorbents, as they contain many oxides and alkaline calcium compounds, which are effective in phosphate capture, concluding that the CDW filler can be used as an effective and cost-effective phosphate recovery adsorbent, being an advantage for wide application in agriculture.

CDW has also been studied as an adsorbent material to remove toxic metals from effluents and a component for cement paste landfills in underground mining areas (WANG and CHEN, 2017; KUMARA *et al*., 2017; YILMAZ and ERCIKDI, 2021).

However, all experts reaffirm the need to go deeper into environmental issues, especially the potential for contamination provided by CDW, to avoid the risk of bioaccumulation in associated ecosystems.

Due to the great variation in the generation and heterogeneity of waste that make up the CDW, there is a concern with the concentration of possible contaminants (SCHAEFER *et al*., 2007; TOWSEND *et al*., 2004; RAMALHO and PIRES, 2009; FILIZOLA *et al*., 2006, FERNADEZ-NARANJO *et al*., 2016).

Townsend *et al*. (2004) reported a high level of heavy metals in CDW In the same sense. In addition, Ramalho and Pires (2009) identified hazardous elements in recycled CDW in São Carlos, SP. Also, according to Schaefer *et al*. (2007), heavy metals leached from CDW composed of mortars, with Cu, Zn, and Cd being found in higher concentrations, with values found higher than those recommended by European directive 98/83/EC.

Yu *et al*. (2018) and Reis *et al*. (2020) recommend that all use of CDW should precede the assessment of the potential for contamination and bioaccumulation before its use as a soil reclaimer.

2 MATERIALS AND METHODS

For the execution of the present work, the “class A” civil construction and demolition waste collected in a CDW recycling center in a period of 12 months (October 2018 to October 2019) were chemically and mineralogically characterized by XRF and XRD to provide a more representative sampling in a temporal space, to evaluate its potential use in the recovery of soils degraded by mining.

Three samples of 20 kg of CDW were collected, by standard NBR 10.007/2004 (ABNT, 2004), at the 3R’S Reciclagem construction and demolition waste recycling center, in Criciúma, Brazil, municipality of 215,186 inhabitants (IBGE, 2020), the industrial and mineral hub of the State of Santa Catarina (SC), in the South region of Brazil, during one year (every four months), to obtain a final sample with greater representation in the sampled period.

It should be noted that the recycling plant operates producing recycled CDW from “class A” waste, according to CONAMA Resolution 307/2002, in a mixed form, that is, a material called “ash” (consisting of concrete and mortar) and a material called “red” (ceramics, ceramic blocks, bricks), which translates into a greater advantage in the present work, as the two residues result in a single product that has already been homogenized.

After collection, drying in an oven at 100˚C for 24 hours, the samples were quartered (separated 30 g), then processed in an orbital mill, sieved in a 200 mesh sieve and sent, after further quartering (5 g), to the Laboratory of Geotechnics of the Federal University of Rio Grande do Sul (UFRGS), to define minerals in the form of oxides, through the techniques of X-ray diffraction (XRD) and mineralogical characterization utilizing X-ray fluorescence (XRF), the remainder being reserved for carrying out the research.

X-ray diffraction (XRD) and X-ray fluorescence (XRF) techniques could determine the presence and amount of minerals. When applied to degraded soils, these minerals can improve their physical properties (aeration, infiltration) and provide essential nutrients (Ca, Mg, Fe, Mn, Cu, Zn, Ni) or beneficial to plants: Na, Si, Cu (RESTREPO; BEDOYA and VEGA, 2015).

For chemical characterization through X-ray diffraction (XRD) analysis, the powder method was used. In the powder sample, the pulverized or disaggregated material is deposited in a specific sample holder for powder, trying to preserve the disorientation of the particles where all the minerals or crystalline structures are analyzed.

The minerals and/or crystalline phases were identified by measuring the interplanar distances (“d” values) and the relative intensities of the peaks in the diffractograms.

The XRD was performed in a Siemens X-ray diffractometer brand (BRUKER AXS), model D-5000 (θ-2θ) equipped with a fixed Cu anode tube ($\lambda = 1.5406$ Å), operating at 40 kV and 25 mA at the primary beam and curved graphite monochromator in the secondary beam.

In X-Ray Fluorescence (XRF), the powder samples were analyzed in the angular range of 15 to 75° 2θ in a step of 0.05°/1s using divergence and anti-scatter slits of 2 mm and 0.2 mm in the detector.

For larger elements, sample preparation was performed using the cast sample technique; on the other hand, the smaller elements were prepared using the pressed tablet method. The presence of volatiles was evaluated using gravimetric techniques and is represented by LOI (Loss On Ignition). The X-ray fluorescence spectrometer (XRF) used was the RIX 2000 model from the Rigaku brand.

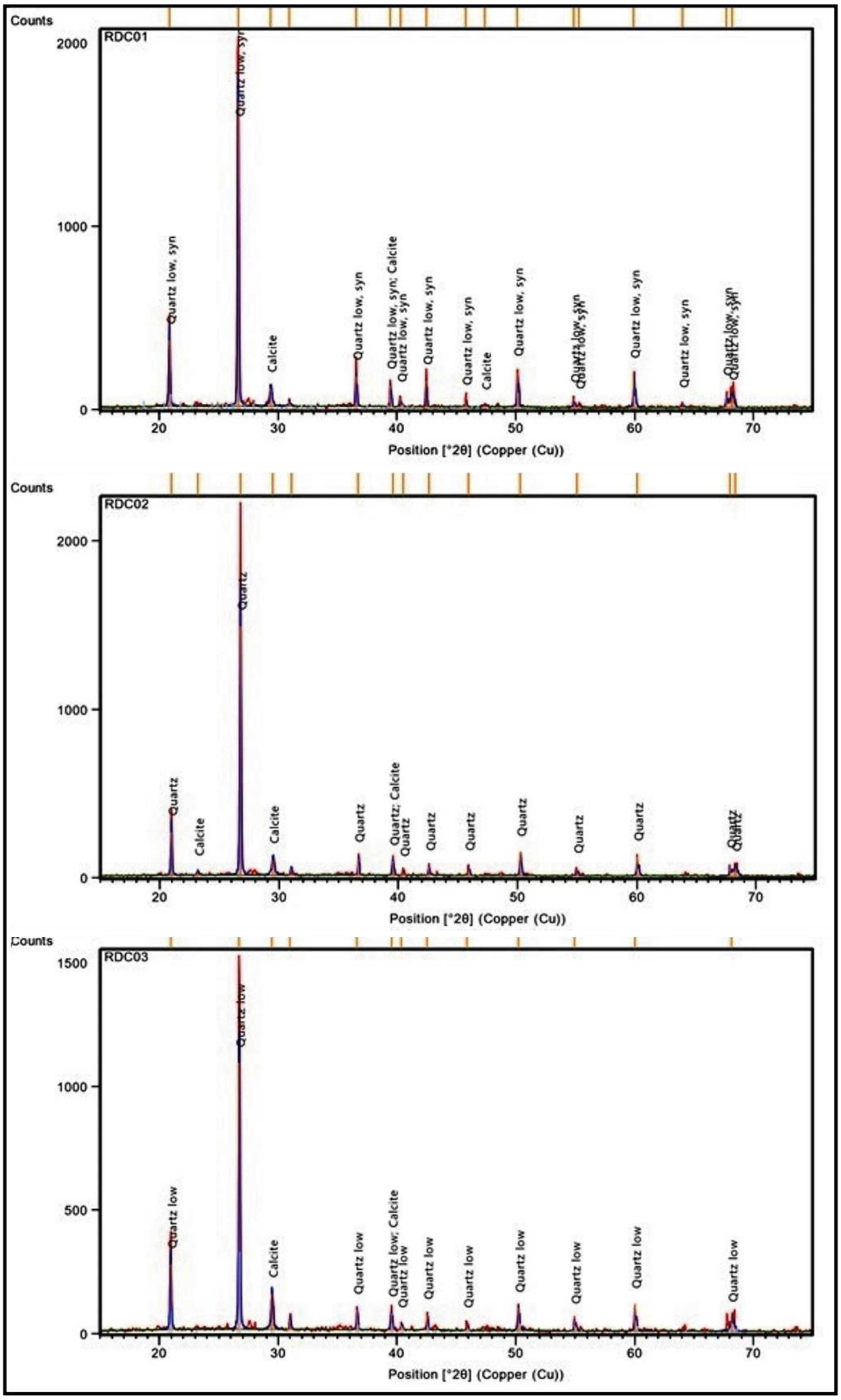
The statistical treatment of the data was performed using the Solver tool of Microsoft Excel® and Software Assistat®, consisting of calculation of means, standard deviation (SD), and coefficient of variation (CV).

3 RESULTS AND DISCUSSION

The chemical characterization of CDW allows us to assess the potential of these residues, properly recycled after segregation, and recovery of areas degraded by mining, especially in open-pit mining processes, thus avoiding possible generations of new contaminated sites and degraded soils.

The XRD analysis aimed to corroborate the crystalline phases present in the CDW. In Figure 1, it is possible to visualize the very similar crystalline phases, constituted by quartz (SiO_2) and calcite ($Ca(CO_3)$), present in the samples collected during twelve months, in a CDW recycling center in the municipality of Criciúma, SC, corroborating the origin of these materials consisting basically of concrete, mortar and ceramic, in its largest composition, as expected for this type of waste, presenting peaks of quartz (SiO_2) and $Ca(CO_3)$, with the absence of Al and Fe silicates, which is justified, in the case of quartz, by the fact that all SiO_2 is bound to quartz, corroborating these results with the one described by Lasso (2011); Restrepo, Bedoya, and Vega (2015).

Figure 1 – X-ray Diaphratograms of CDW Samples 1, 2 and 3



Source: Elaborated by the authors, 2021

Table 2 shows the XRF results, which agree with the results of the XRD evaluation, where the values are presented in percentage (%) of sample weight; in

Table 3, where the trace elements are presented, the values are presented in mg. Kg^{-1}.

Table 2 – X-ray fluorescence spectrometry: result in % by weight

Element	**SiO_2**	**Al_2O_3**	**TiO_2**	**Fe_2O_3**	**MnO**	**MgO**	**CaO**	**Na_2O**	**K_2O**	**P_2O_5**	**LOI**
Sample / S^1	0.09	0.04	0	0.03	0	0.02	0.01	0.07	0.02	0.01	-
CDW 1	64.88	8.72	0.65	3.74	0.05	1.7	9.86	Nd	1.40	0.06	8.94
CDW 2	48.59	10.97	0.87	4.35	0.06	3.29	16.23	Nd	1.28	0.08	14.28
CDW 3	52.43	10.91	0.84	4.28	0.06	2.56	14.70	Nd	1.36	0.09	12.79
Average	55.30	10.20	0.78	4.12	0.05	2.51	13.59	Nd	1.34	0.07	12.0
SD	8.52	1.28	0.12	0.33	0.006	0.79	3.25	-	0.06	0.02	2.75
CV	15.41	12.55	15.19	8	10	31.35	23.9	-	4.45	25.97	22.9

LOI: loss on ignition; SD: standard deviation; CV: Coefficient of variation; S1: Standard deviation of the methodology for the AC-E Granite Standard tabulated by Geostandards; Nd: Not detected.
Source: Authors' organization, 2021

Table 3 – X-ray fluorescence spectrometry: trace element result in mg. Kg^{-1}

Element	**S^1**	**Limit mg.Kg-1 of dry weight: Orden AAA/661/2013***	**Limit mg.Kg^{-1} of dry weight: Resolution CONAMA 420/2009****	**CDW1**	**CDW2**	**CDW3**	**Average**	**SD**	**CV**
Y	0.78	n/a	n/a	9.7	15.7	15.8	13.7	3.4	25.4
Pb	1.56	0.5	72	50.5	37.0	41.2	42.9	6.9	16.0
Ni	1.45	0.4	30	22.3	19.5	18.7	20.1	1.8	9.37
Cu	0	2	60	32.7	24.7	20.2	25.8	6.3	24.47
Sr	0.87	n/a	n/a	243.6	325.3	331.1	300	48.9	16.3
Zr	0.68	n/a	n/a	239.3	144.6	247.8	210.5	57.2	27.21
Zn	0.65	4	300	121.1	114.7	121.1	118.9	3.69	3.10
Nb	0.3	n/a	n/a	5.9	5.8	5.6	6.1	0.43	7.13
Rb	1.11	n/a	n/a	73.8	71.4	72.8	72.6	1.2	1.65
Cr	4.62	0.5	75	244.1	141	145.7	176.9	58.2	32.9
Ba	29.63	20	150	225.6	196.1	186.3	202.6	20.4	10.09

S1: Standard Deviation of the methodology for the JG1A Granite Standard tabulated by Geostandards; SD: Standard deviation; CV: Coefficient of variation; Na: not applicable; *Reference for inert waste landfills; **Soil quality prevention reference.
Source: Authors' organization, 2021

As for the trace elements, or minor elements, it can be seen that these are naturally present in Brazilian soils in different proportions, depending on the rock of origin, and these variations are attributed to the chemical and physical properties of each soil profile (HUGEN *et al*., 2013). Also, it is observed in Table 3, which are below the values determined by CONAMA Resolution 420/2009, which determines the Reference Value for Soil Quality (RVSQ) in Brazil, except the elements Cr and Ba.

The elements Cr and Ba are widely used in the production of civil construction materials, such as cement and ceramics, with Ba being used in the composition of ceramics and Cr in the production of cement, which, when going through the manufacturing process, can oxidize the chromium to its most toxic form, Cr(VI), is limited in the EU since 2005 to 2 mg. Kg^{-1} of soluble Cr(VI). In Brazil, the levels of Cr (VI) and Cr (III) in cement and derivatives are above the limits allowed by European regulations, even becoming an impediment to the export of these products (MATOS and NÓBREGA, 2009).

Barium in high soil conditions can be absorbed by plants and inhibit photosynthetic activity, affecting plant development and, consequently, productivity, evidencing the toxic effect of this chemical element (LIMA *et al*., 2012).

It is noteworthy, however, that as for the European regulation Orden AAA/661/2013 (SPAIN, 2013), all trace elements are above the limit allowed by the regulation (Table 3), corroborating the results obtained by Schaefer *et al*. (2007).

Orden AAA/661/2013 establishes the limits of toxic metals present in CDW for disposal purposes in mining areas as a solution for final disposal of CDW and open pit mine closure.

Heavy metals are relatively stable chemical elements, non-degradable, and with a density greater than four, which are highly toxic. In the soil, the risk of contamination by metals is increased by industrial, agricultural, and urbanization activities (HUGEN *et al*., 2013). They present highly differentiated forms of environmental and toxicological behavior according to the different chemical forms. This characteristic is due to its atomic structure, characterized by free d orbitals, reacting with electron acceptors (TAVARES, 2009).

After being released from the original rocks by weathering, due to their electronegativity, ionic rays, and different oxidation states, heavy metals can be precipitated or co-precipitated with secondary minerals, adsorbed on the surfaces of secondary minerals (clays or oxides of Fe, Al, and Mn) or from the organic matter present in the soil or even complexed and leached by the soil solution (ALLEONI *et al*., 2005).

Thus, considering the precautionary principle, it is noteworthy that there is a need to limit the application of CDW to the soil to avoid the accumulation of heavy metals over time (HUGEN *et al*., 2013).

In a process of recovering an area degraded by mining, it may become feasible to apply CDW in produced soils, since the recovered area will be destined for a purpose according to the environmental licensing process, different from an agricultural area, for example, where soil recovery aims to increase fertility, requiring corrections and more constant application of fertilizers and soil conditioners.

In the same sense, according to López-Uceda *et al*. (2018), laboratory conditions may overestimate the potential polluting effect of CDW leachate content compared to actual field conditions. The authors used CDW intercropped with the commercial substrate in the production of green roofs in Spain, obtaining content leached by rainwater with the presence of toxic metals, in six months, in conditions below the environmental safety standards of the European Union.

By the XRF analysis, as shown in Table 2, it can be seen that a large part of the constituent material of the sampled CDW is quartz, considered inert. However, it has a structuring function in the soil and can contribute to the physical properties of the same, in the increased water retention capacity, aeration, infiltration, and soil texture (LASSO, 2011; RESTREPO, BEDOYA and VEGA, 2015).

The addition of CDW to the soil under recovery can improve the physical characteristics of the soil, with an increase in porosity, due to the increase in the percentage of the sand fraction, considering the percentage of SiO_2 present in the CDW. The predominance of small-diameter pores in the superficial layers of the soil generates high potential energy and makes access to roots difficult yet provides low infiltration speed. These factors may be responsible for the low success of natural regeneration and reforestation in some mineral deposits (LUCENA *et al*., 2015).

In an experiment, Silva and Silva (2018) used CDW to form a hydraulic barrier in coal mining, recover an area degraded by mining, and successfully prevent acid mine drainage formation. In the proportion of 75/25, the mixture presented similar results to the natural soil, indicating the previous viability of using RCD in the recovery of areas degraded by coal mining, providing the CDW with physical characteristics appropriate to the recovery of degraded soils.

Soil water retention is directly related to the soil's water storage capacity, is based on the relationship between suction and volumetric moisture. Water retention in the soil occurs as a function of the structure at low potential values conditioned by the frequency of macro- and micro-pores and the particle size and mineralogy of the particles at high tensions (LASSO, 2011).

It is worth noting the average percentage of 13.59% of Calcite ($Ca(CO_3)$) in the analyzed samples, which can contribute to improve the chemical quality of the soil and raise the pH (LASSO *et al*., 2013), which makes the interesting material in the recovery of soils with lower pH.

This percentage is above the one LASSO (2011) found, a fact justified by the way the CDW recycling center operates, which is the source of the samples in this work when processing and producing mixed material: gray and red together.

The gray material has a higher carbonate content due to the higher concentrations of cement and mortar, associated with that found in the "red" CDW, basically consisting of ceramic, blocks, and bricks, however part of these with "grey" material adhered, mainly mortar.

CDWs are also a source of Ca, Mg, Mn, and micronutrients essential to plant organisms, as well as aluminum (Al) present in the form of oxides in ceramics and clays, and Iron (Fe) in the case of the presence of feldspars from the ceramic material, cement, and limestone used in the manufacture of civil construction inputs and materials.

It is noteworthy that the coefficient of variation was below 20% in most of the elements analyzed, which corroborates Lasso *et al*. (2013), concluding that there is a degree of standardization in the production of civil construction materials, as well as in the recycled CDW production process.

The addition of CDW to soils in recovery can favor essential nutrients, increasing the fertility of the produced soils.

Reis *et al*. (2020) obtained significant results in phosphate contents from CDW, using them as a phosphate adsorbent, removing the contaminant from aqueous effluents from an inert inorganic sludge of CDW as adsorbent material. The authors recommend the application of these residues to soils as a source of low-cost fertilizers.

Thus, the CDW with significant levels of essential minerals for plant production can have its fertilizer potential high, contributing to the removal of pollutants from effluents, being a viable alternative to be developed on a larger scale.

4 FINAL CONSIDERATIONS

CDWs have desirable characteristics for the recovery of soils in areas degraded by mining since they contain elements necessary for the good development of plants. In addition, they can provide improvements in physical and chemical aspects, improving the structure and texture of the soil, its aeration, and infiltration capacity.

They can result in an improvement in the cation exchange capacity (CEC) due to the presence of minerals and essential trace elements for the development of living plant organisms. Furthermore, the presence of carbonates can increase pH, contributing to a more effective recovery in acidic soils.

Thus, the correct use of properly segregated and recycled CDW, after careful sample analysis of its chemical composition, in the recovery of sites degraded by mining, can pave the way for closing the waste cycle of two large production chains: mining and construction civil society, favoring full sustainable development by deepening studies with the soil-water-plant interface.

REFERENCES

ALLEONI, L.R.F.; BORBA, R.P.; CAMARGO, O.A. Metais pesados: da cosmogênese aos solos brasileiros. *In*: **Tópicos em Ciência do Solo**, Viçosa, MG, Sociedade Brasileira de Ciência do Solo vol. IV, p.1-42, 2005.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS-ABNT. **NBR 10.007:** Amostragem de Resíduos sólidos. Rio de Janeiro, 2004. 21p.

BAO, Z.; LU, W. Developing efficient circularity for construction and demolition waste management in fast emerging economies: Lessons learned from Shenzhen, China. **Science of the Total Environment**, v. 724, p. 138264, 2020.

BRASIL. **Lei Federal nº 12.305** de 02 de agosto de 2010 - Institui a Política Nacional de Resíduos Sólidos; altera a Lei no 9.605, de 12 de fevereiro de 1998; e dá outras providências. Available in: http://www.planalto.gov.br/ccivil_03/_ato2007-2010/2010/lei/l12305.htm. Last acess on: july 4, 2019.

BRASIL. Ministério do Meio Ambiente. **Resolução Conama n. 307,** de 5 de julho de 2002.Estabelece diretrizes, critérios e procedimentos para a gestão dos resíduos da construção civil. Diário Oficial da União, 2002.

BRASIL. Ministério do Meio Ambiente. **Resolução Conama n. 420**, de 30 de dezembro de 2009. Dispões obre os critérios e valores orientadores de qualidade do solo quanto à presença de substâncias químicas e estabelece diretrizes para o gerenciamento ambiental de áreas contaminadas por essas substâncias em decorrência de atividades antrópicas. Diário Oficial da União, 2009.

CALVO, S.M.R**. Residuos peligrosos de la construcción en Costa Rica y sus impactos al ambiente.** Trabalho final de graduação: Engenharia Ambiental, Escola de Química: Instituto Tecnológico da Costa Rica, 2017. 82 fl.

CONSELHO DA UNIÃO EUROPÉIA. **Directiva 98/83/CE** de 3 de novembro de 1998 relativa à qualidade da água destinada ao consumo humano. Jornal oficial das comunidades europeias. Available in: https://www.iasaude.pt/index.php/saude-vigilancia/aguas/legislacao-documentacao-agua-consumo-humano/658-diretiva-98-83-ce. Last acess on: setember 18, 2019.

DAOUD, A.O. *et al*. An investigation into solid waste problem in the Egyptian construction industry: A mini-review. **Waste Management & Research**. V. 38:4, p. 371-382, 2020.

EPA - United States Environmental Protection Agency. Sustainable management of construction and demolition material. Available in: https://www.epa.gov/smm/sustainable-management-constructionanddemolitionmaterials. Last access on July 20, 2021.

EUROSTAT - European Statistical. Recovery rate of construction and demolition wast. Available in: https://ec.europa.eu/eurostat/databrowser/view/cei_wm040/default/table?lang=en. Last acess on: june 2, 2021.

ESPANHA. **Orden AAA/661/2013**, de 18 de abril, por la que se modifican los anexos I, II y III del Real Decreto 1481/2001, de 27 de diciembre, por el que se regula la eliminación de residuos mediante depósito en vertedero. BOE, núm. 97, de 23 de abril de 2013, páginas 31080 a 31111 (32 págs.). Available in: https://www.boe.es/eli/es/o/2013/04/18/aaa661. Last acess on: setember 18, 2019.

FERNÁNDEZ-NARANJO *et al*. Recycled construction and demolition waste in mining rehabilitation. **Translation on Ecology and the Environment**, vol.202: 28-35, 2016.

FERREIRA, R.L.S. Avaliação das propriedades físicas, químicas e mineralógicas da fração fina. **Cerâmica** 65, 139-146,2019.

FILIZOLA, H.F.; GOMES, M.A.F.; SOUZA, M.D. **Manual de procedimentos de coleta de amostras em áreas agrícolas para análise de qualidade ambiental:** solo, água e sedimentos. Embrapa Meio Ambiente, 2006.

GHAFFAR, S.H.; BURMAN, M.; BRAIMAH, N. Pathways to circular construction: An integrated management of construction and demolition waste for resource recovery.**Journal of Cleaner Production,** 244: 11871, 2020.

HUGEN,C; MIQUELLUTI,D.J; CAMPOS,M.L, *et al*. Teores de Cu e Zn em perfis de solos de diferentes litologias em Santa Catarina. **R. Bras. Eng. Agríc. Ambiental**, v.17, n.6, p.622–628, 2013.

INSTITUTO BRASILEIRO DE GEOGRAFIAE ESTATÍSTICA – IBGE. Criciúma –SC. Available in: http://www.ibge/cidades. Last acess on: feberuary 20, 2020.

KUMARA, G.M.P *et al*.. Reviews on the applicability of construction and demolition waste as low-cost adsorbents to removeheavy metals in wastewater**. International Journal of Geomate**. Vol.14, pp.44-51, 2018.

LASSO, P.R.O. **Avaliação da utilização de resíduos de construção civil e demolição reciclados (RCD-R) como corretivos de acidez e condicionadores de solo.** Tese. Universidade de São Paulo: Programa de Pós Graduação em Ciências, 2012. 122 fl.

LASSO, P.R.O *et al*. Avaliação do uso de resíduos de construção e demolição reciclados como corretivo da acidez do solo. **R. Bras. Ci. Solo**, 37:1659-1668, 2013.

LIMA, E.S.A; SOBRINHO, N.M.B.A; MAGALHÃES,M.O.L; *et al*. Absorção de bário por plantas de arroz (oryza sativa l.) e mobilidade em solo tratado com baritina sob diferentes condições de potencial redox. **Quim. Nova**, Vol. 35, No. 9, 1746-1751, 2012.

LÓPEZ-UCEDA, A.; *et al*. Risk assessment by percolation leaching tests of extensive green roofs with fine fraction of mixed recycled aggregates from construction and demolition waste. **Environ Sci Pollut Res** 25:36024–36034, 2018.

MATOS, W.O; NOBREGA, J.A. Especiação de cromo em cimentos e derivados de cimento brasileiros. **Quim. Nova**, Vol. 32, No. 8, 2094-2097, 2009.

MENEGAKI, M; DAMIGOS, D. A review on current situation and challenges of construction and demolition waste management. **Green and Sustainable Chemistry**, v.13: 8–15, 2018.

NUNES, K. R. A.; MAHLER, C. F. Comparison of construction and demolition waste management between Brazil, European Union and USA. **Waste Management & Research**, Vol. 38: 4, 415-422, 2020.

OLIVEIRA, M.J.E. **Materiais descartados pelas obras de construção civil: Estudo dos resíduos de concreto para reciclagem**. Tese de Doutorado. Instituto de Geociências e Ciências Exatas. Universidade Estadual Paulista, 2002.191 fl.

RAMALHO, AM; PIRES, A.M.M. Viabilidade do uso agrícola de resíduos da construção civil e da indústria cerâmica: atributos químicos. In: CONGRESSO INTERISTITUCIONAL DE INICIAÇÃO CIENTÍFICA-CIIC. Campinas, 2009. **Anais...** Instituto Agronômico de Campinas, 2009.

REIS, G. S.; *et al*. Adsorption and recovery of phosphate from aqueous solution by the construction and demolition wastes sludge and its potential use as phosphate-based fertiliser. **Journal of Environmental Chemical Engineering**. n.8, 2020.

RESTREPO, E, M.; BEDOYA, L.O.; VEGA, N, O. Residuos de La construcción: uma opción para la recuperación de suelos. **Revista EIA**, v 12, n. 2: 55-60, 2015.

SCATOLINI, F.; BANDEIRA, R.A.M. Desastres como oportunidade de implementação de políticas de gerenciamento de resíduos de construção e demolição no Brasil: chuvas de Nova Friburgo (RJ), 2011. **Eng Sanit Ambient**. v.25 n.5, p. 739-752, 2020.

SCHAFER, C.O.; ROCHA, J. C.; CHERIAF, M. Estudo do comportamento de lixiviação de argamassa produzidas com agregados reciclados. **Exacta,** v.5, n.2: 243-252, 2007.

SILVA, T.C.; SILVA, C.R. **Estudo do comportamento geotécnico de misturas de solo argiloso e resíduos de construção civil para aplicação como barreira hidráulica em áreas degradadas.** Universidade do Extremo Catarinense – UNESC: Trabalho de conclusão de curso: Engenharia Civil, 2018. Available in: http://repositorio.unesc.net/handle/1/6315. Last acess on: feberuary 20, 2020.

SUÁREZ-SILGADO, S; MOLINA, J.D.A; MAHECHA, L; *et al*. Diagnóstico y propuestas para la gestión de los residuos de construcción y demolición en la ciudad de Ibagué (Colombia). **Gestión y Ambiente** 21(1): 9-21, 2018.

TABOADA, G. L.; *et al*. Exploratory data analysis and data envelopment analysis of construction and demolition waste management in the European economic area. **Sustainability**, 12, 4995, 2020. DOI:10.3390/su12124995.

TAVARES, S.R.L. **Fitorremediação de solo e águas em áreas contaminadas por metais pesados proveniente da disposição de resíduos perigosos.** Rio de Janeiro: UFRJ/COPPE, 2009. 415 fl.

TOWNSEND, T.; *et al*. Heavy metals in recovered fines from construction and demolition debris recycling facilities in Florid. **Science of the Total Environment**, v.332:1-11, 2004.

VEINTIMILLA, J.A.R. **Metodología para el control y manejo de residuos de construcción y demolición de edificaciones de la ciudad de Machala**. Dissertação: Mestrado. Unidade Acadêmica de Engenharia Civil: Centro de Estudos de Pós-Graduação. Univeridade de Machala, Equador, 2017.52 fl.

WANG, C; CHEN, X. Preparation and characterization of granular zeolite material from construction and demolition waste for lead removal. **Desalination and Water Treatment** 1–6, 201, 2017.

YILMAZ, T; ERCIKDI, B. Efect of construction and demolition waste on the long-term geo-environmental behaviour of cemented paste backfll. **International Journal of Environmental Science and Technology**, 2021.

YU, D.; *et al.* Characterizing the environmental impact of metals in construction and demolition waste. **Environmental Science and Pollution Research**, 25:13823–13832, 2018.

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