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COVID-19 pandemic: Solid waste and environmental impacts in Brazil

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HIGHLIGHTS

• COVID-19 pandemic has hampered advances in sustainable development in Brazil.
• Some locations have suspended recycling programs to safeguard public health.
• Electric power enough to supply 152,475 households over a month could have been saved.
• Potable water enough to supply 40,010 people over a month could have been saved.
• The equivalent of US$ 781,000 has been disposed in landfills.

GRAPHICAL ABSTRACT

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ABSTRACT

The World Health Organization has recently declared South America the new epicenter of the COVID-19 pandemic, as Brazil has become one of the most affected countries. Besides public health and economic impacts, social isolation has also caused indirect environmental effects. The aim of this study was to assess environmental impacts caused by shifts on solid waste production and management due to the COVID-19 pandemic in Brazil. We have analyzed data from 30 cities, representing a population of more than 53.8 million people (25.4% of the Brazilian population). Unexpectedly, solid waste production in the main cities in Brazil has decreased during the social isolation period, possibly because of reduced activity in commercial areas. The latest data on solid waste in Brazil have revealed that more than 35% of medical waste has not been treated properly. Furthermore, improper disposal of facemasks has been reported in several cities and may increase the risk for COVID-19 spread. The suspension of recycling programs has hindered natural resources from being saved, with emphasis on 240,076 MWh of electric power and 185,929 m³ of potable water – respectively enough to supply 152,475 households and 40,010 people, over a month. Furthermore, total sale price for recyclable materials during the suspension of recycling programs reaches more than 781 thousand dollars, being these materials disposed in landfills – demanding an extra volume of 19,000 m³ – reducing landfill lifespan, and hence causing a double loss: economic and environmental.

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1. Introduction

Worldwide public health and economy have been severely affected by the COVID-19 pandemic, with deaths and increased economic vulnerability especially in middle-income countries (Chakraborty and Maity, 2020; UN, 2020). Recently, the World Health Organization has declared South
America the new epicenter of the COVID-19 pandemic (Feuer, 2020; WHO, 2020), as Brazil has become one of the most affected countries, being currently the second leading country in number of cases with 1,759,103 confirmed cases as of July 09, 2020 (Worldometers, 2020), albeit social isolation measures have been implemented in the Federal District on March 11, 2020, in São Paulo state and in Rio de Janeiro state on March 16, 2020 and March 17, 2020, respectively.

Besides the alarming socioeconomic impacts, indirect environmental impacts caused by social isolation have been described in several studies, reporting positive impacts such as cleaner beaches and environment noise reduction (Zambrano-Monserrate et al., 2020), immediate improvements in air quality (Bao and Zhang, 2020; Collivignarelli et al., 2020; Nakada and Urban, 2020), and in surface water quality (Braga et al., 2020; Yunus et al., 2020). Nevertheless, negative impacts related to increased solid waste generation and reduced recycling programs may produce medium- or long-term effects and thus constitute a reason for concern (Zambrano-Monserrate et al., 2020).

Kampf et al. (2020) have reviewed the persistence of coronaviruses on different surfaces and have reported viruses’ survival on metal for 5 days, on plastic for up to 5 days, on paper for 4 to 5 days, on glass for 4 days, and on aluminum for up to 8 h. Furthermore, one recent investigation on the stability of SARS-CoV-2 on several surfaces has reported viable SARS-CoV-2 virus on plastic for up to 72 h, on stainless steel for up to 48 h, and on cardboard for up to 24 h (van Doremalen et al., 2020). Considering that plastic plus paper/cardboard represent 64.6% of recyclable materials in recycling programs in Brazil, and because the majority of recycling centers in Brazil are based on manual waste sorting (Fidelis et al., 2020), COVID-19 infection risk for workers in recycling centers is high. Therefore, the Brazilian Association for Environmental and Sanitary Engineering has recommended the suspension of recycling programs in Brazil (ABES, 2020a).

The aim of this study was to assess environmental impacts caused by shifts on solid waste production and management due to the COVID-19 pandemic.

2. Materials and methods

In this study, we have analyzed data from the Federal District, and all 26 state capital cities of Brazil plus 03 non-capital cities with more than 1 million people, totaling 30 cities, which were selected based on the following criteria: i) state capital cities may represent the features of each state, considering social, environmental and economic diversity among Brazilian states; ii) data availability; and iii) solid waste production associated with large cities with high urbanization rates. So far, a total of 636,778 COVID-19 confirmed cases have been reported for the 30 analyzed cities, being the number of cases for each city as for July 09, 2020 presented in Table S1.

For the assessment of the impacts on solid waste management system in Brazil, we have analyzed official time-series data (SNIS, 2019a), and the latest published data about solid waste management in Brazil (Brazili, 2019), made available by the National System for Sanitation Information. Estimates of sale prices for recyclable materials were obtained from the Business Association for Recycling (CEMPRE, 2020). Resources saved by recycling were calculated according to Eq. (1), adapted from Calderoni (2003), being resources data presented in Table S2. Environmental and economic impacts caused by the suspension of recycling programs were calculated using Eq. (1), considering 30 days of suspension only in cities where recycling programs were actually suspended.

\[ Resources_X = \sum_{i=1}^{n} \left( \frac{Rec.Mat_i \times \alpha_{R_i}}{365} \right) \times 30 \]  

where:

- **Resources** \( X \): Amount of resources of type \( X \) from recycling programs

\( Rec.Mat \): Daily amount of solid waste of type \( n \): \( 1 \): Plastic; \( 2 \): Paper; \( 3 \): Metal; \( 4 \): Glass

\( \alpha \): Transformation coefficient of amount of solid waste of type \( n \) to amount of resources of type \( X \)

The numbers of daily disposable facemasks potentially used in cities under study were estimated using Eq. (2) (Nzediegwu and Chang, 2020).

\[ TDF = \frac{Pop \times Urb \times FAR \times ADFPC}{10,000} \]  

where:

- **TDF**: Total daily disposable facemasks
- **Pop.**: Total population
- **Urb**: Urban Population (%)
- **FAR**: Facemask acceptance rate = 80%
- **ADFPC**: Average daily disposable facemasks per capita = 2

3. Results and discussion

Different levels of solid waste collection and recycling programs are observable on data referring to solid waste management in each analyzed city (Table 1). Recycling programs are not available in three (10%) of the studied cities, albeit one of these cities (Macapá-AP) has reported recyclable collection, probably by informal workers. Effectively recovered materials represent only 1%, pointing out: i) low levels of recycling programs in the studied cities; and ii) high rates of disposal of recyclable materials following collection due to decreased quality for recycling or low commercial price. Another important aspect is the recyclable collection system, which varies between door-to-door collection and voluntary deposit in containers for recyclables (Campos, 2014; Ibáñez-Forésa et al., 2018).

The Brazilian Association for Environmental and Sanitary Engineering has reported decreases in solid waste production, as follows: 16% in Rio de Janeiro-RJ, 12% in Brasilia-DF and Porto Alegre-RS, and 10% in Fortaleza-CE and Manaus-AM during the first week of April 2020, and 22% – achieving 50% in central and thus commercial area – during 30 days of partial lockdown in Belo Horizonte (ABES, 2020b). In the city of Campinas-SP solid waste production has decreased 15% during the first month of partial lockdown, albeit the recycling program has been suspended and the recyclable materials incorporated into the domiciliary solid waste collection (GI, 2020).

A recent study has foreseen an increase in solid waste production due to social isolation (Zambrano-Monserrate et al., 2020), which has not happened in Brazil. Because in Brazil up to 200 L-solid waste produced daily by commercial and service sectors are collected as domiciliary waste (Brazil, 2010), the reduction of commercial activities may explain the decrease in solid waste production.

3.1. Impacts on recycling programs

Being Brazil a middle-income country, the purpose of recycling is mainly income generation, besides resource recovery (Conke, 2018). The Brazilian legislation regarding solid waste (Brazil, 2010) encourages the integration of informal workers into the formal recycling sector, being the organization as a cooperative an important means to reduce socio-economic fragilities (Fidelis et al., 2020; Ibáñez-Forésa et al., 2018). Considering the continental size of the country with its cultural and economic diversity, solid waste management also varies from similar to low-income countries to similar to high-income countries (Cetrulo et al., 2018). Informal workers such as waste pickers, itinerant traders, and middlemen constitute one important characteristic of recycling programs in Brazil (Conke, 2018), and even formal workers conduct manual waste sorting in recycling centers. Therefore, the
Brazilian recycling system is highly vulnerable to the effects caused by the COVID-19 pandemic, considering both environmental and economic impacts of the suspension of recycling programs in Brazilian cities due to the COVID-19 pandemic (Table 2).

As a measure to avoid SARS-COV-2 transmission in recycling centers, there is an automated segregation at least 6581 formal workers have been affected by the COVID-19 crisis (Table S4). As a consequence of the suspension of recycling programs using manual waste sorting in recycling centers, there is a high rate of turnover in recycling centers (Fidelis et al., 2020), at least 6581 formal workers have been affected by the COVID-19 crisis (Table S4).

Furthermore, total sale price for recyclable materials during the suspension of recycling programs reaches more than 781 thousand dollars, being these materials disposed in landfills demanding an extra volume of 19,000 m³ – reducing landfill lifespan, and hence causing a double loss: economic and environmental.

An important income loss has been reported because of the suspension of recycling programs using manual waste sorting in recycling centers, albeit this measure was intended to safeguard public health, and therefore some city governments – for example, Belém-PA and São Paulo-SP – have approved emergency financial support for recycling-related workers (MPF, 2020; Jovem Pan, 2020). Because there is a high rate of turnover in recycling centers (Fidelis et al., 2020), at least 6581 formal workers have been affected by the COVID-19 crisis (Table S4).
In locations where recycling programs have not been suspended, sales for recycling materials have also been compromised because some sectors – such as recycling facilities and also middlemen – of the complex solid waste management system are not fully working (Conke, 2018; Peduzzi, 2020).

3.2. Impacts on medical waste

The latest data on medical waste in Brazil has shown installed treatment capacity for 479,653 t/year, and an annual production of 252,948 t, being 63.8% of this amount properly treated (ABRELPE, 2020).

Based on the evidence that medical waste production has increased up to 6 fold in Wuhan, China due to the COVID-19 pandemic (Calma, 2020), a recent study has foreseen an increment in medical waste production (Saadat et al., 2020). Assuming a 2 fold increase in medical waste in Brazil, the current treatment capacity would be exceeded. Moreover, although Brazil is one of the developing countries with most studies on its medical waste (Ansari et al., 2019), improper management of medical waste in small medical units is still a reason for concern (Moreira and Günther, 2013).

The COVID-19 pandemic has become more critical in Brazil in middle April 2020, and non-official preliminary data report an increment in medical waste production in May 2020 (Azevedo et al., 2020). By contrast, estimates on medical waste production in Brazil in the first week of April 2020 point out a 17% decrease in collected and treated waste (ABETRE, ABLP, ABRELPE and SELUR/SELURB, 2020), possibly because of the suspension of non-emergency medical and odontological appointments from late March 2020 on, and also improperly disposal among domiciliary waste (Azevedo et al., 2020). Furthermore, increasing use of personal protective equipment such as facemasks and gloves (Calma, 2020; Zambrano-Monserrate et al., 2020), both in hospitals and in general, also increases the chances for inappropriate disposal leading to environmental- (Saadat et al., 2020) and public health- (Nzediegwu and Chang, 2020) risks associated with potentially infective material.

Recently, a few studies have depicted improper disposal of facemasks in distinct parts of the world, such as Soko Islands, Nigeria, Portugal, and Canada (Kalina and Tilley, 2020; Fadare and Okoffo, 2020; Prata et al., 2020). During the social isolation period in Brazil, the press has reported inappropriate disposal of facemask in several cities analyzed in this study such as Campinas-SP, Campo Grande-MS, Goiânia-GO, João Pessoa-PB, Palmas-TO, São Luís-MA and São Gonçalo-RJ. Using the criteria described by Nzediegwu and Chang (2020), an estimate show that more than 85 million facemasks may be daily disposed (Fig. 1). Considering the high demand of disposable facemasks and in order to control improper disposal, the Ministry of Health of Brazil (MS, 2020) and the Brazilian Health Regulatory Agency (ANVISA, 2020) have recommended the use of disposable masks only by health personnel, and the use of homemade reusable fabric facemask by population in general, according to the World Health Organization recommendations. One recent study has assessed the effectivity of cotton facemask as an alternative to disposable facemasks and has concluded that daily use of washable cotton facemask by healthy people in community is a suitable measure (Ho et al., 2020).

3.3. Impacts on solid waste collection in São Paulo megacity

São Paulo is the largest city in Brazil, producing the highest amount of solid waste in the country, being data regarding solid waste collection monitored by an information system maintained and made available by the city government (São Paulo, 2020a).

Time-series data on solid waste production from January to April over the last 11 years (Fig. 2) reveal some impacts on solid waste production caused by social isolation measures in the city of São Paulo, Brazil. As a result of environmental education campaigns as well as inspection of irregular waste disposal by the city government (São Paulo, 2020a), before the COVID-19 pandemic the following situations have been observed: i) variations in domiciliary solid waste collection, with a stable trend; ii) increasing recyclable collection; iii) increasing voluntary deposit in containers for recyclables; and iv) decreasing amount of solid waste on streets. In April 2020, during the COVID-19 pandemic and consequent partial lockdown, the following situations have been observed: i) the lowest (276,684 t) domiciliary solid waste collection over 11 years; ii) increased recyclable collection; iii) decreased voluntary deposit in containers for recyclables; and iv) the lowest (3887 t) amount of solid waste on streets over 11 years.

3.4. Future perspectives and challenges

The COVID-19 pandemic has caused several impacts on the solid waste management system in Brazil, considering socioeconomic and environmental effects, and hence has hampered advances in sustainable development. The suspension of recycling programs over a month has
hindered natural resources from being saved, with emphasis on 24,076 MWh of electric power and 185,929 m³ of potable water – respectively enough to supply 152,475 households and 40,010 people, over a month. Recycling-related workers have experienced economic issues, albeit the government has approved emergency financial support.

Given behavior shifts in the post-pandemic period, the solid waste management system may demand adjustments seeking to: i) increase both recycling capacity and environmental education, considering the increment in the use of disposable utensils and also packages from food delivery and online shopping; ii) encourage training of waste pickers for adoption of safe methods for recyclable sorting; and iii) monitor both the production and the installed capacity for medical waste treatment, in order to assess an eventual need for system expansion.

**CRediT authorship contribution statement**

**Rodrigo Custodio Urban:** Conceptualization, Methodology, Formal analysis, Investigation, Writing - original draft, Writing - review & editing. **Liane Yuri Kondo Nakada:** Conceptualization, Methodology, Investigation, Writing - original draft, Writing - review & editing.

**Declaration of competing interest**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

**Appendix A. Supplementary data**

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2020.142471.

**References**

ABES, 2020a. Recomendações para a gestão de resíduos em situação de pandemia por coronavírus (COVID-19). ABES: Rio de Janeiro. http://abes-dn.org.br/?p=33224 (accessed 10 May 2020).

ABES, 2020b. Pesquisa da ABES aponta redução da geração de resíduos domiciliares em capitais brasileiras no período de isolamento pela pandemia da Covid-19. http://abes-dn.org.br/?p=33570 (accessed 20 May 2020).

ABETRE, ABIP, ABRELEP e SELUR/SELURB, 2020. Gestão de resíduos na proteção contra a Covid-19. http://web-resol.org/textos/gestao_de_residuos_na_protecao_contra_a_covid.pdf (accessed 23 May 2020).

ABRELEP, 2020. Panorama dos resíduos sólidos no Brasil 2018/2019. ABRELPE, São Paulo.

Ansari, M., Ehrampousha, M.H., Farzadkia, M., Ahmadie, E., 2019. Dynamic assessment of economic and environmental performance index and generation, composition, environmental and human health risks of hospital solid waste in developing countries; a state of the art review. Environ. Int. 132, 105073. https://doi.org/10.1016/j.envint.2019.105073.

ANVISA, 2020. Orientações gerais – Máscaras faciais de uso não profissional. Agência Nacional de Vigilância Sanitária, Brasília http://portal.anvisa.gov.br/documents/219201/430788/NT_M%C3%A1scaras.pdf/8f95705f-2f0f-43c0-b6d5-699f4d4c66f7. (Accessed 24 May 2020).

Azevedo, T., Barcello, F., Tsai, D., Cremer, M., Gaudereto, F., Coluna, I., Albuquerque, I., Alencar, A., Zimbres, B., Brandao Jr., A., Costa Jr., C., Piatto, M., Quintana, G., Potenza, R., 2020. Impacto da pandemia de COVID-19 nas emissões de gases de efeito estufa no Brasil. SEEG. https://seeg-br.s3.amazonaws.com/OC/nota_tecnica_FINAL.pdf.

Bao, R., Zhang, A., 2020. Does lockdown reduce air pollution? Evidence from 44 cities in northern China. Sci. Total Environ. 731, 139052. https://doi.org/10.1016/j.scitotenv.2020.139052.

Brasil, 2010. Presidência da República. Casa Civil. Lei n° 12.305, de 02/08/2010. Institui a Política Nacional de Resíduos Sólidos; altera a Lei n° 9.605, de 12 de fevereiro de 1998; e dá outras providências. http://www.planalto.gov.br/ccivil_03/_ato2007-2010/2010/lei/l12305.htm (accessed 20 May 2020).

Brasil, 2018. 2018 Statistical Yearbook of electricity 2017 baseline year. EEP. Brasília http://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-160-topico-168/Ambiente2018v1.pdf (accessed 29 May 2020).

Brasil, 2019. Sistema Nacional de Informações sobre Saneamento: Diagnóstico do Manejo de Resíduos Sólidos Urbanos – 2018. SNS/MDR, Brasília.

Calderoni, S., 2003. Os bilhões perdidos no lixo (The Billions Lost in Garbage). 4 ed. São Paulo, Humanitas.

Calma, J., 2020. The COVID-19 pandemic is generating tons of medical waste. https://www.theverge.com/2020/3/26/21194647/the-covid-19-pandemic-is-generating-tons-of-medical-waste (accessed 20 May 2020).
Moreira, A.M.M., Günther, W.M.R., 2013. Assessment of medical waste management at a primary health-care center in São Paulo, Brazil. Waste Manage. 33, 162–167. https://doi.org/10.1016/j.wasman.2012.09.018.

MFP, 2020. Covid-19: MPs e Defensorias recomendam a municípios do Pará proteção a catadores de material reciclável. http://www.mfp.mp.br/pt/sala-de-imprensa/noticias-pa/covid-19-mps-e-defensorias-recomendam-a-municipios-do-para-protecao-a-catadores-de-material-reciclavel (accessed 22 May 2020).

MS, 2020. Ministério da Saúde do Brasil - Nota informativa nº 3/2020-CCGAP/DESF/SAPS/MS. Ministério do Saúde do Brasil, Brasília http://portal.antaq.gov.br/wp-content/uploads/2020/04/1586014047102-Nota-Informativa.pdf. (Accessed 23 May 2020).

Nakadà, L.Y.K., Urban, R.C., 2020. COVID-19 pandemic: impacts on the air quality during the partial lockdown in São Paulo state. Brazil. Sci. Total Environ. 730, 139087. https://doi.org/10.1016/j.scitotenv.2020.139087.