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Post-consumer batteries: a case study of generation and formal disposal in the capital of Paraíba, Brazil

Pilhas pós-consumo: estudo de caso da geração e descarte formal na capital paraibana, Brasil

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ABSTRACT

Batteries, part of waste electrical and electronic equipment (WEEE), can contain heavy metals which, when disposed of inappropriately, cause damage to human health and the environment. Thus, this study aimed to identify the quantity generated and the disposal flow of post-consumer batteries in João Pessoa (capital of Paraíba), Brazil, to provide information that contributes to the reverse logistics system for this waste in the city. To this end, a mapping of the voluntary drop-off points (PEV) of batteries registered in the Green Eletron was carried out, with a simplified on-site checklist and data collection from a sample of 400 inhabitants, using an online form related to batteries consumed. The results showed that, of the PEV registered, only 19 had active collections, and of these, only 13 had a collector in a visible and easily accessible place. The majority of participants dispose of batteries in household garbage cans (62.6%), rate the provision of disposal information in establishments as poor (50.5%), are unaware of the existence of PEV in the city (67.3%), and are aware of the risks of incorrect disposal and the legal instruments available. However, they report that the lack of battery PEV would be one of the main difficulties for proper disposal; consequently, there are deficiencies in the current management of post-consumer batteries. Some suggestions for improvements to the success of reverse logistics are related to the installation of new PEV with homogeneous distribution and more significant publicity for existing points.

Keywords: solid waste management; reverse logistics; social participation; PEV; WEEE.

RESUMO

As pilhas, integrantes dos resíduos de equipamentos eletroeletrônicos (REEE), podem apresentar metais pesados em suas composições que, quando descartados de forma inadequada, acarretam danos à saúde humana e ao meio ambiente. Assim, este trabalho intencionou identificar a quantidade gerada e o fluxo de descarte de pilhas pós-consumo em João Pessoa (PB) a fim de fornecer informações que contribuem para o sistema de logística reversa desses resíduos na cidade. Para isso, foi realizado mapeamento dos pontos de entrega voluntária (PEV) de pilhas cadastrados na *Green Eletron*, com aplicação de *checklist* simplificado, *in loco*, bem como a coleta de dados em uma amostra de 400 habitantes, por meio de um formulário *online*, relacionados às pilhas consumidas. Os resultados identificaram que, dentre os PEV cadastrados, apenas 19 apresentaram situação de coleta ativa e destes, apenas 13 possuíam coletor em local visível e de fácil acesso. A maioria dos participantes realiza descarte de pilhas em lixeiras domiciliares (62,6%), classificam como ruim a prestação de informações de descarte nos estabelecimentos (50,5%), desconhecem a existência de PEV na cidade (67,3%), e possuem conhecimento sobre os riscos do descarte incorreto e os instrumentos legais disponíveis. Porém, relatam que a falta de PEV de pilhas seria uma das principais dificuldades para o descarte adequado; portanto, existem deficiências no gerenciamento atual de pilhas pós-consumo. Algumas sugestões de melhorias para o sucesso da logística reversa estão relacionadas à instalação de novos PEV com distribuição homogênea e maior divulgação dos pontos já existentes.

Palavras-chave: gerenciamento de resíduos sólidos; logística reversa; participação social; PEV; REEE.

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Introduction

The hazardous potential of post-consumer electronic equipment raises concerns about the significant volume of solid waste generated worldwide (Xavier et al., 2021) due to the accelerated rate of planned obsolescence favoring new waste streams (Shittu et al., 2021) which contain toxic and dangerous substances for the environment and health (Bressanelli et al., 2019). In Brazil, tons of batteries are produced every year (Almeida et al., 2020), mainly for use in various devices. In 2019 alone, 2,792 kt of electrical and electronic equipment were placed on the market in the country (Forti et al., 2020), with billions of household batteries being sold annually, equivalent to around six units of batteries per capita per year (Abrelpe, 2022).

Most batteries on the market contain mercury, except lithium (Li) batteries (Carvalho et al., 2019). That situation has raised environmental and public health issues that motivate many countries to consider used batteries hazardous waste and establish strict legislation to reduce the levels of metals such as mercury (Hg), cadmium (Cd), and lead (Pb) to the lowest technologically feasible levels (Silva et al., 2011). These heavy metals are toxic substances and harm health (Lima et al., 2015).

Even though batteries comply with the limit levels for Hg, Cd, and Pb established by Brazilian legislation (CONAMA Resolution nº 401/2008 [Brasil, 2008]), they still contain significant amounts of other heavy metals (such as manganese and zinc), which are not covered by legislation (Silva et al., 2011). These components are not biodegradable in most cases; therefore, in direct contact with nature, they contaminate the soil, water, and air, and thus become part of the geological and biological cycle, posing risks to living beings (Almeida et al., 2020) and contributing significantly to global warming (Bizerra et al., 2023). For human health, the most common risks related to electronic waste (e-waste) include respiratory problems, damage to the central nervous system, orthopedic problems, skin-related problems, cancer, etc. (Zhang et al., 2022). Soetrisno and Delgado-Saborit (2020) reinforce that the ingestion of heavy metals contained in e-waste, because they are bioaccumulative, can cause multiple abnormalities such as cell proliferation, thyroid abnormalities, adverse neonatal effects, mood swings, and lung abnormalities, among others.

In this context, Brazil enacted the National Solid Waste Policy (PNRS, *Política Nacional de Resíduos Sólidos*), Law nº 12.305/2010, which emphasizes shared responsibility for the life cycle of products, involving manufacturers, importers, distributors, traders, government, and consumers in waste management (Vargas et al., 2024). Article 33 of the PNRS stipulates that manufacturers of hazardous waste must structure and implement a reverse logistics system (Brasil, 2010). The return of waste and reverse logistics activities are ways of reducing damage by managing the end-of-life of products (Bouzon et al., 2016).

In October 2019, the Sectoral Agreement for implementing the Reverse Logistics System for Electrical and Electronic Products and their Components was signed. Subsequently, Decree nº 10.240 was published in February 2020 (Brasil, 2019), which formalizes its content. In addition, in 2022, Decree nº 10.936/2022 brought new regulations for PNRS (creation of the National Reverse Logistics Program), and Decree nº 11.043/2022 established the National Solid Waste Plan, the Planares, which established strategies, guidelines, and targets for waste-generating sectors over a 20-year horizon, initially for health waste, construction waste, and municipal solid waste (Brasil, 2022).

Through Decree nº 10.240/2020, the members of the production chain for household electrical and electronic products and their components (which include batteries) are committed to performing a series of actions to comply with the National Solid Waste Policy. By 2025, the 400 largest cities in the country must have reverse logistics services, and each must install a collection point for every 25,000 inhabitants (Brasil, 2020).

In the literature over the last five years, several authors have carried out studies related to the management of e-waste (Tsai et al., 2020; Shittu et al., 2021; Cardoso et al., 2023), reverse logistics (Kumar Singh et al., 2023; Vargas et al., 2024), the production of WEEE (Ismail and Hanafiah, 2020; Guarnieri et al., 2022), life cycle assessment (Ismail and Hanafiah, 2019; Corrêa Nunes et al., 2021), systematic review (Zhang et al., 2019; Bizerra et al., 2023; Ni et al., 2023), emphasizing the challenges and opportunities in a global context (Goodship et al., 2019; Sabbir et al., 2023) or a case study of a particular country (Puspita Sari et al., 2024; Mayanti and Helo, 2024). However, few studies characterize e-waste reverse channels based on actors' roles and interconnections (Vargas et al., 2024). No studies were found on compliance with the requirements of Decree nº 10.240/2020 in João Pessoa or other capitals, and batteries, even with a high consumption rate and annual disposal, do not appear as a focus for verification within reverse logistics activities.

This research aimed to verify the functioning and efficiency of reverse channels and compliance with Decree nº 10.240/2020 in the capital of Paraíba, João Pessoa. It intented to favor environmental sustainability by aligning stakeholders in the implementation of reverse logistics for waste batteries and encouraging consumer collaboration.

In this way, an analysis of the reverse logistics of post-consumer batteries in the study region was carried out, allowing an understanding of the barriers in the reverse system to the community's needs. This assessment reinforces the importance of cooperation between the public sector, the private sector, and civil society and is expected to contribute to developing more effective and sustainable strategies that can be replicated in other regions with similar characteristics.

Methodology

The study area was delimited, followed by the mapping of the commercial establishments to be visited based on the National Waste Electrical and Electronic Equipment Manager (Green Eletron, 2023) and the Municipal Urban Cleaning Authority (EMLUR, *Autarquia Municipal Especial de Limpeza Urbana*) registry. Subsequently, the amount of post-consumer battery generation in the selected area was estimated, and an online form was applied to the sample calculated for the population.

Study area

The research was conducted in João Pessoa, the capital of Paraíba state, in Northeastern Brazil (Figure 1). The estimated population of the municipality is 833,932 inhabitants, with a territorial area of 210,044 km², and a population density of 3,970.27 inhabitants/km² (IBGE, 2022), distributed in 64 neighborhoods and four zones (North, South, East, and West). The main economic activities are related to commerce and services, followed by public administration and industry, generating a gross domestic product of approximately R$20 billion (IBGE, 2019).

Registered points for the disposal of post-consumer batteries in João Pessoa

According to information on the João Pessoa council's website, in 2022, the city had six voluntary drop-off points (PEV) linked to the EMLUR that received post-consumer batteries. Based on information available on the website of the Green Eletron, in 2023, there were 26 registered establishments in the municipality receiving portable, alkaline, ordinary zinc-manganese, and rechargeable batteries.

Georeferencing was carried out (Figure 2), and the activities of the 32 points consulted were checked. During the on-site visit, a simplified checklist was applied, containing three questions: i. the collection being active; ii. the existence of some kind of information poster; and iii. the collector being positioned in a visible and easily accessible place, where the possible answers were only "yes" or "no". After identifying the activities of the registered PEV, the results were represented by employing new mapping.

Estimated post-consumer battery generation

Since the demographic census reported annually is a complete count of the local population, and considering that the last update made available by the city government for population by neighborhood in João Pessoa was in 2010, it was necessary to update the data on inhabitants by neighborhood in the city. To do this, we used data from the 2022 demographic census and applied a growth rate reported by the state government for the last 12 years (2010–2022), equivalent to 15.26%, to the population already cataloged. Thus, it was considered that all neighborhoods in the city grew at the same rate, as shown in Equation 1.

$$P = P_0.(1 + t_c) \quad (1)$$

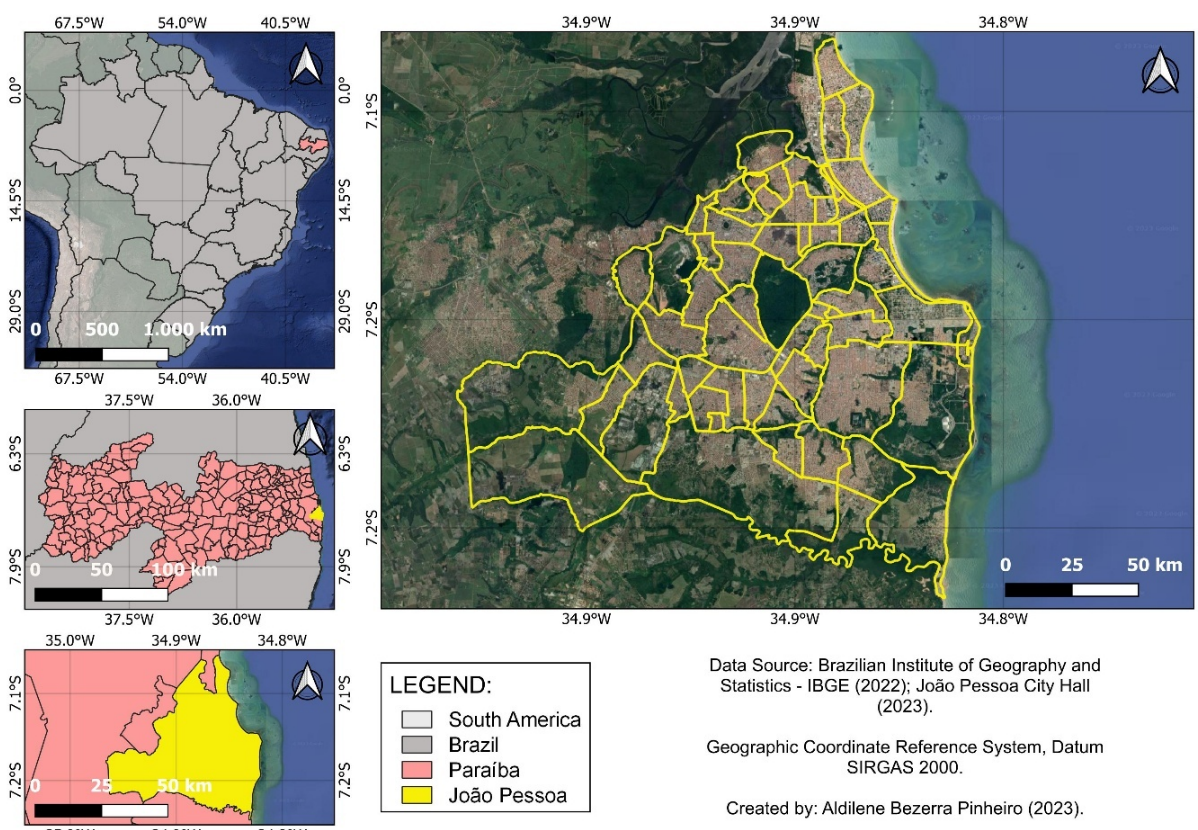

Figure 1 – Location of João Pessoa, Paraíba state, Brazil.

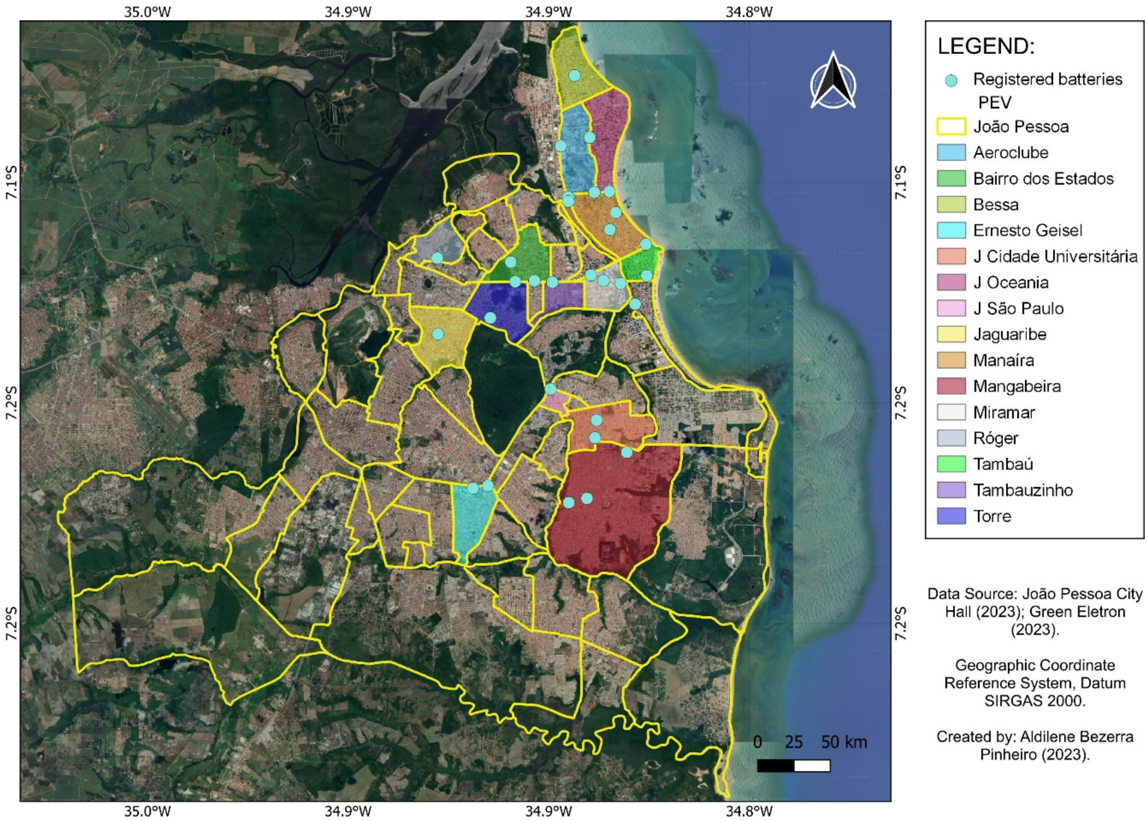

Figure 2 – Registered voluntary battery drop-off points in João Pessoa, Paraíba state, Brazil.

Where:
P = final population (2022);
P_0 = original population (2010); and
t_c = growth rate.

The estimated generation of post-consumer batteries for each neighborhood was based on literature data on the average battery consumption, which, according to Abrelpe (2022), would be the equivalent of around six units per capita per year. Thus, the calculation to be carried out is according to Equation 2.

$$C = P.c_p \quad (2)$$

Where:
C = number of post-consumer batteries;
P = population (2022); and
c_p = per capita battery consumption.

Situational analysis of post-consumer battery disposal

A questionnaire consisting of 19 questions subdivided into five parts was applied, involving the following aspects: a) socio-economic; b) acquisition of batteries; c) disposal of batteries; d) risks of improper disposal; and e) tools available.

In compliance with Resolution nº 466/2012 of the National Health Council of the Ministry of Health (Brasil, 2012), the research project, the questionnaire, and the free and informed consent form prepared for this investigation were submitted to and approved by the Research Ethics Committee of the Health Sciences Center of the Federal University of Paraíba - CEP/CCS, with a favorable opinion of nº 6.080.505.

The process used to determine the sample size was carried out following the methodology of Bartlett et al. (2001) for qualitative (categorical) data, employing the Cochran (1977) formula, according to Equation 3.

$$N_0 = ((t^2).p.q)/d^2 \quad (3)$$

Where:
N_0 = number of people in the sample;
t = desired confidence level;
p = positive variability;
q = negative variability; and
d = acceptable margin of error.

However, if this value is more excellent than 5% of the population considered, the correction formula (Cochran, 1977) should be applied, as shown in Equation 4.

$$N_1 = N_0/[((1 + N_0) \ / \ population)^2] \quad (4)$$

Where:

N_1 = adjusted sample size since the value obtained is more excellent than 5% of the population.

Thus, applying Cochran's methodology (1977), adopting a population of 833,932 inhabitants (IBGE, 2022), considering that t=1.96 (according to the Student's t-table, for 95% confidence), p=0.5, and q=0.5 (value accepted when the product between the variables p.q is unknown), and the margin of error (d) adopted in this research of 5%, we have that:

N_0= [(1.96)2×(0.5)×(0.5)]/(0.05)2=384

In this case, as the sample was less than 5% of the population ([825,796×0.05=41,289.8]>384), the correction formula (Equation 3) should not be applied. Considering possible losses, the estimated sample size was adjusted to 400 inhabitants. The questionnaire was drawn up online using the Google Forms tool. The interviewees were recruited using the snowball methodology, in which the profile for the sample members was specified in advance, a group of people matching the required data was identified, and the study proposal was presented. Participants answered the questionnaire and passed it on to others in their networks. In this way, the questionnaire targeted battery users aged over 18 living in João Pessoa (PB), between June and November 2023. All the results were analyzed using Microsoft Excel® descriptive statistics, and various graphs were elaborated.

Results and discussion

The results highlight the general battery reverse logistics scenario in the study area.

Active points for the disposal of post-consumer batteries in João Pessoa

After an on-site visit, it was found that of the six points reported by EMLUR, one was non-existent (Miramar), and the other five (Róger, Bairro dos Estados, Mangabeira, Jaguaribe, and Tambaú) were not responsible for receiving batteries, only other types of WEEE. Of the 26 points registered on Green Eletron's website, one was duplicated, so only 25 were considered for obtaining information. We found that three points were non-existent (Bairro dos Estados, Manaíra, and Jardim Oceania), three were inactive (Miramar, Manaíra, and Tambaú), and only 19 were actively collecting batteries. Of the 19 active collection points, only 13 had a battery collector in a visible and easily accessible place. Regarding having some information posters for the population on the availability of the reverse logistics service for batteries or its importance, none of the points visited showed a positive result. Figure 3 shows the new mapping of disposal point addresses with their respective activity identifications.

The distribution of active battery PEV covers a total of 12 neighborhoods (out of 64 neighborhoods, equivalent to just 18.75% of the city), six of which are in the East of the city (Aeroclube, Bessa, Jardim Oceania, Manaíra, Miramar, and Tambauzinho), four in the South (Jardim Cidade Universitária, Jardim São Paulo, Mangabeira, and Ernesto Geisel), and two in the North (Torre, and Bairro dos Estados). Most PEV are located in neighborhoods with predominantly residential land use and commercial activities.

Estimated population by neighborhood and generation of post-consumer batteries

Applying the population growth rate over the last 12 years (2010 to 2022), equivalent to 15.26% (Paraíba, 2023), the estimated total population served by these active PEV would be around 258,278 inhabitants.

Given the total population of João Pessoa, its large number of neighborhoods, the number of different commercial establishments, the expectation of future development and, at the same time, the generation of WEEE, especially batteries (with an average annual generation equivalent to six units per person), it can be considered that there is a current shortage in terms of availability of collection points for the subsequent proper disposal of batteries. They are 19 PEV regularly registered to serve a city with more than 833,000 inhabitants and an estimated generation of 5,002,918 units of batteries, according to the data shown in Table 1. If type AA batteries are considered the most widely sold, this total of 5,002,918 units could be equivalent to around 100 tons of batteries per year.According to Decree nº 10.240/2020, one collection point should be installed for every 25,000 inhabitants in the city. João Pessoa would need at least 34 PEVs to meet this requirement; given its population, 15 more than the existing number. However, taking into account the large number of neighborhoods, the most appropriate minimum quantity for the city could be one PEV for every 25,000 inhabitants according to each neighborhood, to reduce the distance between PEV within the community, following Conte's (2016) idea that by combining an exemplary structure of collection points, providing information and awareness-raising activities for society, reverse logistics can present better results. Considering the city's territorial distribution, there is no homogeneous distribution of active PEV, nor was there any pattern to the selection of collection establishments, since the existing quantity is insufficient for neighborhoods of low or high economic vulnerability. However, the current legislation does not set collection targets or provide evidence that motivates manufacturers and importers to seek higher rates of battery return (Goeldner et al., 2020).

Analysis of the household flow of batteries in João Pessoa

Figure 4 indicates that the predominant general profile of the participants can be defined as female, between 21–30 years old, with completed higher education, living in the South of the city, in a household with 3–5 residents, and with a total family income of 2–5 minimum wages.

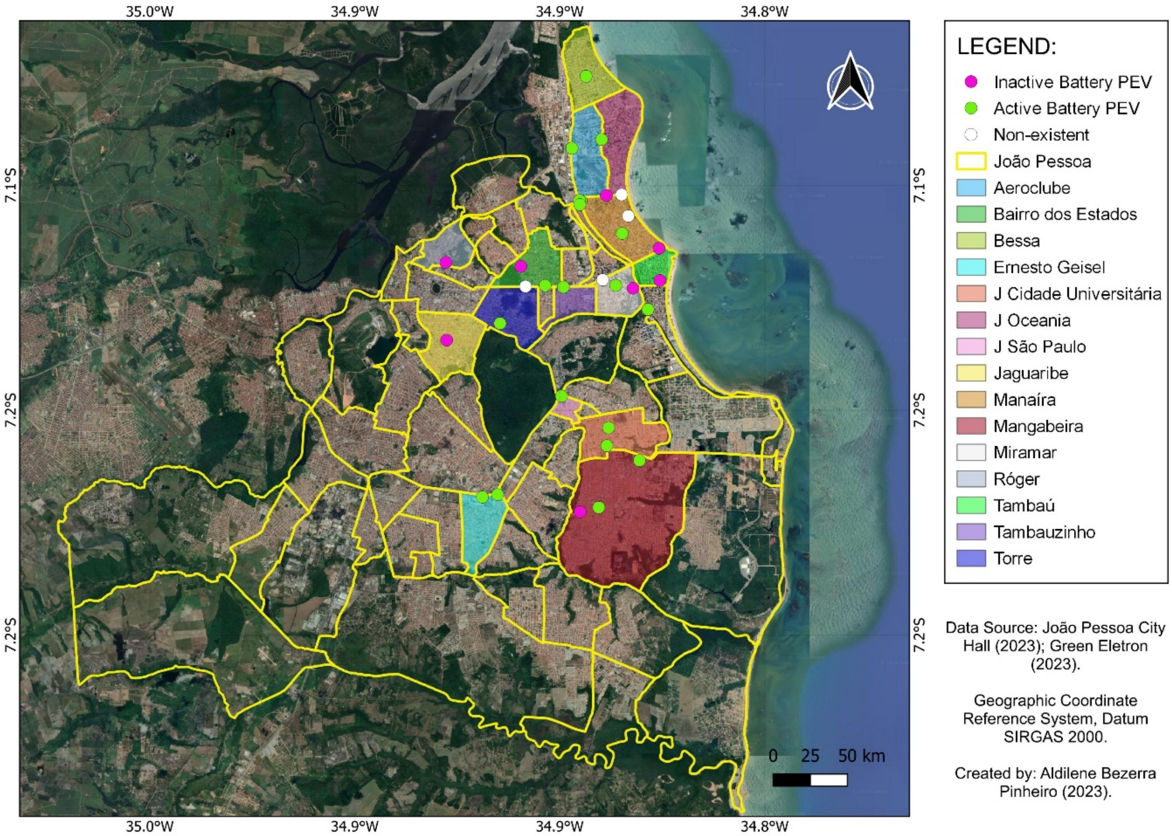

Figure 3 – Status of registered voluntary battery drop-off points for João Pessoa, Paraíba, Brazil.

Figure 5 shows the predominance of annual purchase frequency (145 responses), batteries lasting between 3–6 months (144 responses), and a preference for buying the Duracell brand (276 responses). This situation may be an indication of greater consumption of alkaline batteries, corroborating the study by Silva et al. (2011) who reported that batteries are highly consumed, being the alkaline the great pioneers in sales since their introduction on the market, once they can have an operating time up to four times longer than ordinary batteries, depending on use.

Of the consulted inhabitants, 32.8% said they knew of a battery recycling center in the city. Still, only 20.8% previously reported that they disposed of batteries properly at a PEV, indicating the population's lack of information about how to dispose of post-consumer batteries in an environmentally appropriate way and the location of disposal points. This problem has already been recognized by Zhang et al. (2022), who pointed out that awareness of e-waste in developing countries is almost negligible since informal waste treatment is causing even more significant problems regarding environmental deterioration and impacts on human health.

Unfortunately, 62.6% of participants reported disposing of batteries in the household garbage can. These results are similar to those asked in the survey by Kemerich et al. (2012), in which 82% of respondents dispose of batteries with household waste. Therefore, society still needs constant consumer awareness campaigns regarding the disposal of batteries (Faria and Oliveira, 2019).

Companies cannot create a reverse logistics structure if consumers do not dispose of their waste at the right places. Although reverse logistics activity is based on Brazilian legislation, its practical realization occurs with cooperation between consumers, manufacturers, and public authorities (Carvalho et al., 2019). However, this question becomes justifiable, considering that 67.3% are unaware of PEV distributed in the city, making it evident that the lack of publicity about existing points or information posters in the community may favor improper disposal. As a result of not knowing where to dispose of the batteries, 26.8% said they accumulate in their homes. Still, according to Castro et al. (2022), the behavior of keeping this waste stored at home can be harmful considering the risk of leakage, which can result in damage to residents' health, as well as make it difficult to return the materials to the production cycle. However, it may be a kind of stopgap solution found by residents due to their lack of knowledge about suitable disposal points.

Table 1 – Estimated generation of batteries by neighborhood in João Pessoa, Paraíba state, Brazil.

Neighborhood	Socioeconomic vulnerability	Voluntary drop-off points found	Population - 2010 Census (inhabit)	Population estimated 2022 (inhabit)	Estimated generation of batteries (units)
Aeroclube	Very low	1	9,649	11,121	66,729
Água Fria	Low	0	6,269	7,226	43,354
Altiplano	Low	0	5,233	6,032	36,189
Alto do Céu	Medium	0	16,557	19,084	114,502
Alto do Mateus	Medium	0	16,281	18,765	112,593
Anatólia	Very low	0	1,162	1,339	8,036
Bairro das Indústrias	Medium	0	8,712	10,041	60,249
Bairro dos Estados	Very low	1	7,458	8,596	51,577
Bairro dos Ipês	Low	0	9,121	10,513	63,077
Bancários	Low	0	11,863	13,673	82,040
Barra de Gramame	High	0	353	407	2,441
Bessa	Very low	1	13,096	15,094	90,567
Brisamar	Very low	0	4,268	4,919	29,516
Cabo Branco	Very low	0	7,906	9,112	54,675
Castelo Branco	Low	0	11,642	13,419	80,511
Centro	Low	0	3,644	4,200	25,200
Cidade dos Colibris	Medium	0	4,095	4,720	28,319
Costa do Sol	Medium	0	1,790	2,063	12,379
Costa e Silva	Medium	0	8,208	9,461	56,763
Cristo Redentor	Medium	0	37,538	43,266	259,598
Cruz das Armas	Medium	0	25,549	29,448	176,687
Cuiá	Low	0	6,944	8,004	48,022
Distrito Industrial	High	0	1,899	2,189	13,133
Ernani Sátiro	Medium	0	8,641	9,960	59,758
Ernesto Geisel	Medium	2	14,184	16,348	98,091
Expedicionários	Low	0	3,625	4,178	25,069
Funcionários	Medium	0	15,848	18,266	109,598
Gramame	Medium	0	26,031	30,003	180,020
Grotão	High	0	6,159	7,099	42,593
Ilha do Bispo	High	0	7,986	9,205	55,228
Jaguaribe	Low	0	14,738	16,987	101,922
J. C. Universitária	Low	2	21,425	24,694	148,167
J. Oceania	Very low	1	15,283	17,615	105,691
J. São Paulo	Low	1	4,550	5,244	31,466
J. Veneza	Medium	0	12,812	14,767	88,603
João Paulo II	Medium	0	15,446	17,803	106,818
João Agripino	Low	0	1,161	1,338	8,029
José Américo	Medium	0	16,269	18,752	112,510
Manaíra	Very low	4	26,369	30,393	182,357
Mandacaru	High	0	12,593	14,515	87,088
Mangabeira	Low	2	82,539	95,134	570,807

Continue...

Table 1 – Continuation.

Neighborhood	Socioeconomic vulnerability	Voluntary drop-off points found	Population - 2010 Census (inhabit)	Population estimated 2022 (inhabit)	Estimated generation of batteries (units)
Miramar	Low	1	9,500	10,950	65,698
Muçumagro	High	0	6,431	7,412	44,474
Mumbaba	Medium	0	8,799	10,142	60,850
Mussuré	High	0	55	63	380
Oitizeiro	Medium	0	29,125	33,569	201,417
Padre Zé	High	0	6,964	8,027	48,160
Paratibe	Medium	0	12,396	14,288	85,726
Pedro Gondim	Very low	0	3,360	3,873	23,236
Penha	Medium	0	772	890	5,339
Planalto da Boa Esperança	Medium	0	6,213	7,161	42,967
Ponta do Seixas	Low	0	474	546	3,278
Portal do Sol	Low	0	4,136	4,767	28,603
Róger	Medium	0	11,130	12,828	76,971
São José	High	0	7,078	8,158	48,949
Tambaú	Very low	0	10,163	11,714	70,283
Tambauzinho	Low	1	4,932	5,685	34,108
Tambiá	Low	0	2,541	2,929	17,573
Torre	Low	2	15,103	17,408	104,446
Treze de Maio	Low	0	7,760	8,944	53,665
Trincheiras	Medium	0	6,995	8,062	48,375
Valentina	Low	0	22,452	25,878	155,269
Varadouro	Medium	0	4,384	5,053	30,318
Varjão	Medium	0	17,766	20,477	122,863
Total					**5,002,918**

Source: adapted from João Pessoa (2011) and Paraíba (2023).

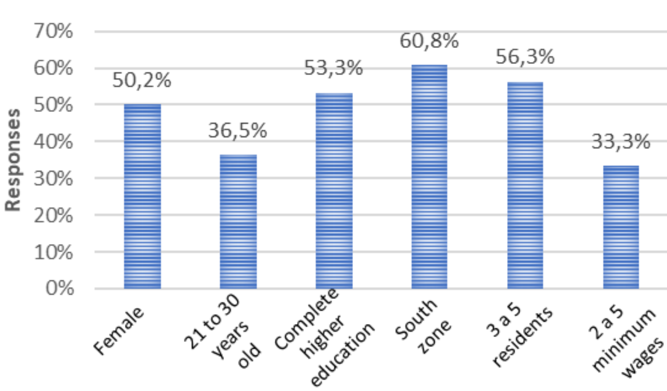

Figure 4 – Histogram of predominant socioeconomic profile.

In this sense, the results (Figure 6) defined the predominant general profile regarding battery disposal as: disposal in household garbage cans (62.6%); classifying the provision of disposal information in establishments as poor (50.5%); and being unaware of the existence of PEV in the city (67.3%). The results confirm that part of the post-consumer batteries containing hazardous substances are sent for disposal with municipal solid waste, requiring actions for their proper management.

Most participants (70.2%) demonstrated knowledge of some elements of the chemical composition of batteries and the damage that can arise when they are disposed of inappropriately. These data may be related to higher level of education (53.3% completed higher education), confirming Castro's et al. (2022) findings that the level of education has a direct influence on an individual's knowledge of environmental risks. According to the author, the likelihood of disposing of waste batteries as unsorted waste decreases by 17.7 and 53.3% if residents are well aware of the environmental and health dangers related to incorrect disposal.

The predominant general profile regarding the risks of battery disposal was identified as having knowledge of one of the chemical elements present in batteries (Lead, 154 responses), knowing that due to the chemical composition, improper disposal can generate risks (349 responses), and knowing that soil contamination is one of these risks (337 responses), as shown in Figure 7. These data may indicate awareness of environmental issues involving the risks of improper waste disposal for the environment and human health. Still, there is a lack of actions to promote greater environmental awareness and effective participation in reverse logistics, reinforcing the second hypothesis of the research.

As for the aspects related to the tools available, the participants showed that they knew the concept of shared responsibility (224 responses), knew the concept of reverse logistics (219 responses), and thought that the lack of battery PEV was one of the main difficulties for proper disposal (284 responses). Thus, the results suggest that inappropriate disposal and accumulation of batteries in homes may be due mainly to the limited availability and publicity of PEV in the city, as well as a lack of awareness-raising about the damage caused by incorrect battery disposal. Accordingly, Vargas et al. (2024) emphasize that there are few collection points available to the community and that it is imperative that companies, manufacturers, and public bodies take responsibility for creating means of enabling families to cooperate in environmental protection.

Goodship et al. (2019) and Sabbir et al. (2023) recognize in their studies that despite some progress, there are several challenges to implementing reverse logistics on a global scale, including insufficient collection volume to sustain the operation financially: technological shortcomings; illegal export of WEEE; and even tax aspects. Although electronic parts and components of waste equipment are highly reusable, collection and recycling rates are still unsatisfactory, failing to recover materials of high economic value, which are discarded or burned (Forti et al., 2020).

In Brazil, although it is legally provided for in the PNRS, the biggest obstacles to the implementation of reverse logistics may be related to: i. the inconsistency in the classification of WEEE, which leads to problems in defining environmental and labor safety obligations about its recycling; ii. the non-implementation of tax exemptions or subsidies for recycling companies; iii. the inefficiency of WEEE collection channels; and iv. the non-closure of the recycling cycle on the national territory, since Brazilian companies do not have the technology for all stages of WEEE processing or due to the associated cost.

To increase the significance of collection in João Pessoa, public and private organizations could invest in a bonus system to incentivize consumers to dispose of their waste. There could also be more publicity about the risks associated with incorrect disposal and the homogeneous distribution of PEV in the cities to reduce the distance traveled and facilitate widespread adherence, as well as the implementation of treatment and reuse methods, such as urban mining, which would prevent the waste of non-renewable resources, contributing to a circular economy, being an alternative or complement to primary mining.

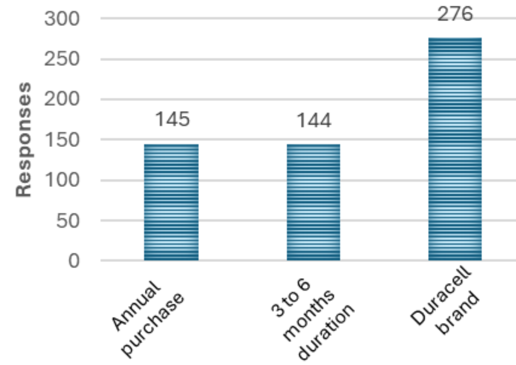

Figure 5 – Histogram of predominant aspects of battery acquisition.

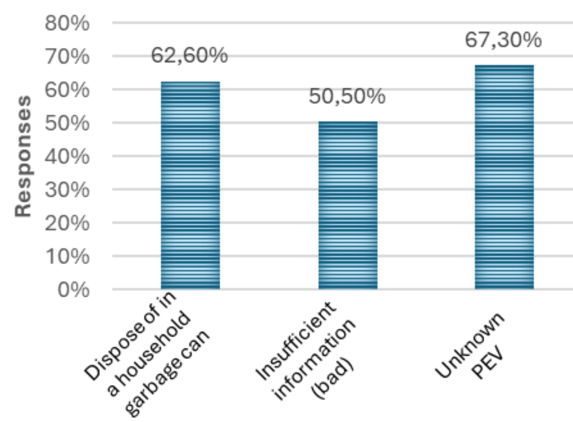

Figure 6 – Histogram of predominant aspects of battery disposal.

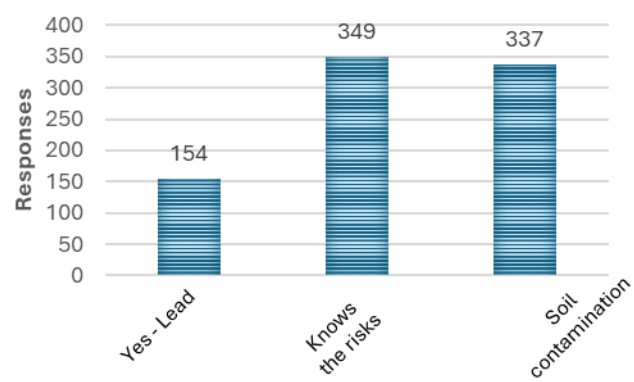

Figure 7 – Histogram of predominant aspects of battery disposal risks.

Conclusion

In the survey of registered points and mapping, it was observed that João Pessoa does not comply with Decree nº 10.240/2020, with a deficit of 15 PEV about the minimum quantity required. Applying the form to the population showed that battery consumption varies according to how long they last. Over 70% of people accumulate batteries or dispose of them incorrectly because they are unaware of PEV available in the city. Part of the batteries consumed are sent for disposal with solid urban waste, requiring actions for their proper management, and there are not enough environmental awareness actions to guide the population on the environmentally appropriate disposal of post-consumer batteries.

The research was limited to participants who were battery consumers living in João Pessoa and only visited establishments registered for formal disposal with the responsible management company (Green Electron). We recognize the absence of members of informal collections, such as collectors or unregistered establishments. As a qualitative-quantitative study, generalizations are limited, considering the unique scenarios of each municipality in terms of political management, the level of implementation of the PNRS, and the general functionality of the e-waste reversal channels.

As a contribution to the field, this study made it possible to verify that reverse logistics and its reverse distribution chains for batteries are still areas that deserve greater recognition and adherence from producing and importing companies, as well as more significant publicity of the location of existing PEV, to widen the circle of sensitized consumers. Finally, applying this research to cities comparable to this case study would provide valuable contributions to the national scenario of reverse logistics for electrical and electronic waste and its components in terms of compliance with Decree nº 10.240/2020.

Authors' contributions

Pinheiro, A.B.: data curation, formal analysis, investigation, methodology, software, writing – original draft, writing – review & editing. **Netto**, A.V.S.: supervision, project administration, review. **Rocha**, E.M.R.: conceptualization, supervision, project administration; review.

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