

Disaster waste: Characterization and quantification applied to an intense rain event

Caracterização e quantificação de resíduos de desastre de evento de chuvas intensas

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ABSTRACT

The amount and complexity of solid waste are intensified with the occurrence of natural disasters, compromising response and recovery actions, causing unplanned spending, environmental damage, and health impacts. The proper management of disaster waste requires knowledge of its characteristics such as quantity, composition, hazard, and management by the identified waste stream. This article aims at the characterization and quantification of disaster waste arisen from an event of intense rains, which occurred in 2013, in the municipalities of the State of Espírito Santo in Brazil. For characterization, an online survey instrument was developed and applied in institutions responsible for waste management. The survey was associated with a documentary analysis of photographic records and information obtained from the government database. Estimation of the amount of waste generated was carried out in a selected set using a method already applied in the south of the country. It was adapted to local characteristics and later compared with surveys carried out by the municipality. The characterization identified sediments, soil and mud, remains of vegetation, furniture, wood, and discarded scrap as the main generated waste. The estimated additional generation for durable consumer goods of around 1,700 tons of waste was lower than the municipal records (7,436.46 t) in the period. It was associated with the specific low weight of the considered affected goods and the inclusion of other residues in the data obtained in the city hall records. The methods used in the characterization and quantification presented application viability, through adjustments, and represented an important contribution to municipal disaster management to make cities able to face climate change, carrying out safe management of disaster waste.

Keywords: flooding; disaster debris estimation; disaster waste management; climate change.

RESUMO

A quantidade e a complexidade dos resíduos sólidos intensificam-se na ocorrência de desastres, comprometendo as ações de resposta e de recuperação e ocasionando gastos não planejados, danos ambientais e impactos à saúde. A adequada gestão de resíduos de desastres demanda conhecimento de características como quantidade e composição, e gerenciamento segundo fluxos específicos. Diante do exposto, este artigo objetivou a caracterização e a quantificação de resíduos de desastre, decorrentes de evento de chuvas intensas, ocorrido em 2013, em municípios do estado do Espírito Santo, no Brasil. Para a caracterização, um instrumento de pesquisa *online* foi elaborado e aplicado aos setores responsáveis pelo gerenciamento dos resíduos, associado a um levantamento e análise documental de registros fotográficos e de informações de banco de dados governamental. A estimativa da quantidade de resíduos gerados foi realizada em um município selecionado utilizando método já aplicado no sul do país, adaptado às características locais e, posteriormente, comparada com levantamentos feitos pela municipalidade. A caracterização identificou sedimentos, solo e lama, e restos de vegetação, seguido de móveis, madeiras e sucatas descartados como principais resíduos gerados. A estimativa da geração adicional para bens de consumo duráveis obtida, cerca de 1.700 toneladas, foi inferior aos registros municipais (7436,46 t) no período, o que se associou ao baixo peso específico dos bens sinistrados considerados, além da inclusão de outros resíduos nos dados da prefeitura. Os métodos utilizados apresentaram viabilidade de aplicação, mediante ajustes, representando importante contribuição para a gestão municipal de desastres, de modo a tornar as cidades aptas a enfrentarem as mudanças climáticas, efetuando um gerenciamento seguro dos resíduos de desastres.

Palavras-chave: estimativa de resíduos de desastres; inundação; gerenciamento de resíduos de desastre; mudanças climáticas.

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Introduction

Given the recognition of the seriousness of global warming and its relationship with extreme weather events, the international community has outlined goals and targets to address this issue. Considering the 17 Sustainable Development Goals (SDGs), which are components of the 2030 Agenda for Sustainable Development, two of them stand out: the SDG 11 —Sustainable cities and communities and the SDG 13 — Action against global climate change. Some of the goals established in these SDGs are the significant reduction of people affected by catastrophes; substantial reduction in direct economic losses, including water-related disasters (target 11.5); and strengthening of resilience and adaptive capacity to climate-related risks and natural disasters in all countries, through the integration of climate change measures into national policies, strategies, and planning, which are provided in Goals 13.1 and 13.2 (Nações Unidas Brasil, 2021a, 2021b).

Other international agreements, such as the Hyogo Framework for Action (2005–2015) and its successor, the Sendai Framework (2015–2030), reinforce the emphasis given by the international community to the impacts of disasters in order to act in the minimization of risks, improve preparedness for an effective response, and increase cities' resilience to extreme events (UNISDR, 2005, 2015).

An important disaster response action is the management of waste generated as a result of the event; such waste is called disaster waste (DW). The nature and intensity of the disaster are reflected in the quantity, quality, and danger of the resulting waste, which have different characteristics from municipal (urban) solid waste (MSW).

Estimates of DW generation show the extent of the problem. The earthquake that occurred in East Japan in 2011 generated 31 million tons of waste and a flood in the city of Joze in 2015, which affected a large part of the city and destroyed houses and generated an amount of DW equivalent to 3 years of MSW generation under normal conditions (JAPAN, 2018).

Some DR components represent a potential risk to health and the environment and should not be mixed with MSW, as their codisposition in landfills can lead to the leaching of unwanted hazardous chemical products (Agamuthu et al., 2015). García et al. (2017) reported that the large amount of debris generated after a disaster represents a risk factor for the population that have to face health problems and the need of rebuilding the city. Silveira et al. (2021) verified an increase of almost 300% in the record of waterborne diseases in the 3 months after the occurrence of flooding in an urban area in Brazil. The authors highlighted the importance of formulating and implementing policies to prevent disease outbreaks after hydrometeorological disasters.

According to Catanho et al. (2020), climate change has led to an increase in disasters in all Brazilian regions. Such disasters are often associated with hydrological factors, such as floods, wet mass landslides, strong winds, and heavy rains. Another critical aspect was ev-

idenced in a study carried out by Souza et al. (2014) in the city of Recife, Brazil. Areas with low-income, high population density, and low Human Development Index were highlighted as more susceptible and vulnerable to disaster damages due to their social and economic conditions.

Costa et al. (2016), in a study carried out in Amazonas, identified that the efforts of public managers were focused on responses and not on the prevention of critical events, reinforcing the importance of public policies to face the risks related to climate change, attributing to local management plans the role of guiding such actions.

The DW has different characteristics depending on the type of event and the impacted environment, varying both in composition and in the potential for recyclability, hazardousness, and forms of management. When managed correctly, DW can enable reuse or sale of materials, contributing to social and economic recovery actions (Brown et al., 2011).

Crowley (2017) assessed the effects of the existence of DR management plans on disaster responses in 95 U.S. counties with major disasters declarations. He identified that the 49 locations that had such plans recycled almost two times as much wreckage as the others that required three times more Federal public assistance in financial contributions. Scatolini and Bandeira (2020) evaluated the reuse of building and demolition waste and disaster-caused displaced soil in the reconstruction of public and private works. The authors considered it a viable action once it contributes to reduce posttraumatic stress, both by the affected communities and by those who plan or execute response and resilience actions after natural disasters.

Events such as floods can generate debris, sediment, vegetation residues, ashes, wood, and waste derived from damaged furniture, electronics, and vehicles (OPAS, 2003; Günther et al., 2017). Such waste when managed in an emergency manner increases the risks of environmental contamination. It can also cause damage to final disposal plants due to the volume it occupies and make its recovery process unfeasible. Electronic equipment, for instance, can contain dangerous substances but at the same time presents the possibility of recovery (Rodrigues et al., 2015).

Seeking to comply with the precepts of the National Solid Waste Policy (PNRS), established by Federal Law No. 12,305/2010 for the optimization of structural and financial resources, as well as the mitigation of environmental impacts and the reduction of DW disposal in landfills, it is necessary to define in the disaster response and recovery actions planning several factors such as the most appropriate forms of DW destination, the infrastructure and storage logistics, treatment, recycling and final disposal of waste, and the estimation of their respective costs. Therefore, it is essential to characterize the waste in terms of typology and danger and quantify it according to each type of event (Tabata et al., 2016; Günther et al., 2017). Feil et al. (2015) highlighted the importance of prior knowledge about quantity and composition of generated waste for planning an effective management strategy.

According to the State Civil Defense and Protection Coordination—CEPDEC/ES, Espírito Santo (2019) presented a worrying scenario regarding the occurrence of disasters, especially those caused by hydrological factors, such as floods and landslides. This fact highlights the need to insert this topic on the local public agenda, seeking to mitigate losses and damage and promoting the resilience of cities.

In December 2013, the biggest hydrological disaster of the beginning of the century occurred in Espírito Santo; on that occasion, rainfall volume exceeded the average values expected for the month by up to 400%, affecting 55 of the 78 municipalities in the state, causing massive flooding and landslides. Of these 55 municipalities, 47 had an emergency situation (SE) declared. The extreme event affected 368,365 people, with more than 60,000 temporarily or permanently homeless and 26 deaths (Brasil, 2014; Espírito Santo, 2019).

As a technical support to enhance decision-making in DW management in Espírito Santo and in places with similar characteristics, the characterization and quantification of generated waste in the mentioned natural disaster in 2013 were the objectives of this study. Therefore, the study was carried out on the characteristics of the DW generated in municipalities of the state of Espírito Santo, which were affected by heavy rains, and its quantification for the Municipality of Vila Velha, ES.

Method

The critical event of heavy rains in the summer of 2013 in the State of Espírito Santo, Brazil, was selected as a study case for the measurement and characterization of disaster residues based on territorial coverage and its relevance to the region. The methodological strategy used is shown in Figure 1.

The study area was delimited based on the SE and State of Public Calamity (ECP) declarations related to rainfall in the years of 2013 and

2014 in the city. A survey of records on the website of the National Sanitation Information System (SNIS) was carried out on the disposal of waste in the period to compare the estimated values with the actual records reported by the municipalities. Municipalities that declared SE or ECP and informed the SNIS that they sent their waste to a landfill were selected as the sample of the study on the characterization of DW, which led to a total of 40 municipalities.

To quantify the waste generated in the critical event, using the generation estimation method, a representative municipality was selected due to the existence of data records and availability to participate in the study.

Disaster waste characterization

To identify the characteristics of the generated waste in the studied disaster, an instrument for the collection of primary data in simple and straightforward language was developed to facilitate and expand the participation of local management institutions. The questionnaire applied was structured in general questions about the municipality and specific questions related to the flows and procedures of DW management, registration of actions, and characteristics of the generated waste in the disaster that occurred in 2013 (Table 1).

Considering the possible lack of standardization and difficulty in recording data by the municipalities, the option “I do not have such information” was included. The instrument was submitted to a pretest with the civil defense technicians, then properly adjusted and finally made available through the platform *onlinepesquisa*, due to its remote, free, and easy access, which also includes the use of smartphones.

With the support of CEPDEC/ES, the instrument was sent through email to the Municipal Coordination of Civil Defense and Protection — COMPDEC and to the Municipal Government sectors responsible

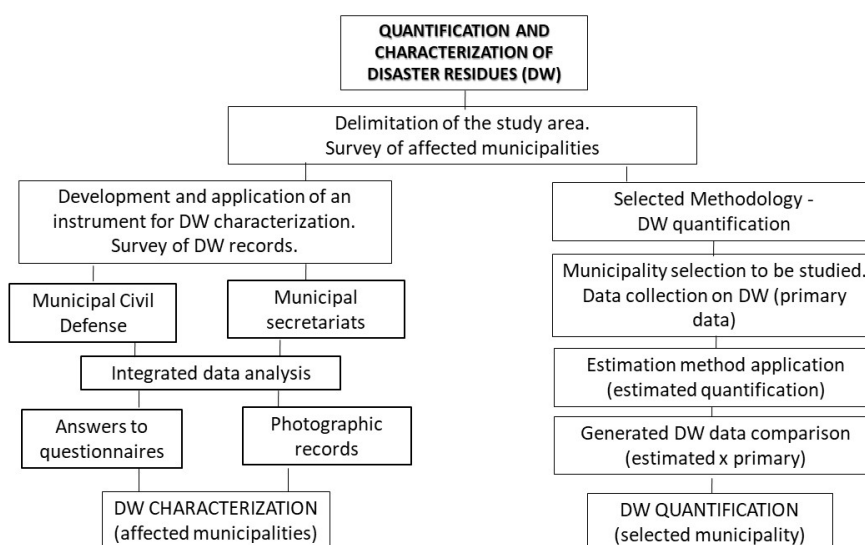


Figure 1 – Methodological strategy used in the study.

for solid waste management (Environment Department, Urban Services Department, and Department of Public Works, among others). The instrument was sent to the 40 municipalities selected for the study and was answered by municipal employees directly on the platform *onlinepesquisa* that was made available.

Additionally, photographic records of the 2013 disaster made available by the municipalities in the sample were collected and analyzed. Such records provided information about affected homes and waste disposed on the streets to qualitatively identify the types of generated DW.

Disaster waste quantification

Based on the literature review, the main methods of DW quantification were identified and evaluated concerning the data and equipment necessary for its application, as well as regarding the feasibility of using it for the event selected as a study case.

The main methods applied to quantify the identified DW generation were compared in terms of functionality and application requirements (Table 2), which led to the selection of the Durable Consumer Goods Quantification Method developed by Schreiner and Wenceloski (2016).

The durable consumer goods quantification method proposed and tested by Schreiner and Wenceloski (2016), which was chosen to estimate the DW generation in this study, is based on a calculation methodology used in Japan. This method considers the Brazilian profile in terms of consumption of durable goods and the construction pattern of buildings in the country and has been applied in another study case in southern Brazil.

The DW estimation basically considers the waste generated by the loss of durable consumer goods and civil construction waste (CCW) resulted from the destruction of homes. Therefore, the method variables were organized into two groups:

- forming variables that are predetermined, according to the context of the affected region and the characteristics of the event;
- dependent variables that arise from the mathematical relationships in the forming variables, corresponding to the result of calculations related to the prediction of the amount of generated waste, as outlined in Figure 2.

The standard house variable (SHV) is quantified as the mass, in tons (t), of generated CCW by a typical household in the region affected by the disaster. At the same time, the damaged goods variable (DGV) is provided by the quantification, also in tons, of durable consumer goods lost by a typical family in the region.

To estimate the amount of waste produced by the loss of durable consumer goods in the study selected disaster, the equations in Table 3 were adapted and used.

The quantification of lost goods in a standard house affected by a disaster was based on the minimum amount of furniture and appliances an average Brazilian family of class E has (Table 4). To estimate the values, Schreiner and Wenceloski (2016) used as a reference the Brazilian government's program *Minha Casa Minha Vida* and the established volume standards of these goods used by moving companies.

To obtain the DGV (E) in tons, Schreiner and Wenceloski (2016) used the volume of 18.30 m³ (Table 4) and the value of 0.0075 t/m³ for the apparent density of the waste generated by the lost goods, due to the lack of specific data on this issue applied to the Brazilian reality.

As part of the calculation, correction coefficients referring to social class and type of disaster are applied in the equations presented in Tables 5, 6, and 7.

Coefficients x and y make possible the adjustment of generated waste resulted from the loss of durable goods in a household according to social class and disaster intensity. The z coefficient, in its turn, refers to the type of natural disaster and also acts on the portion of CCW generated by an affected standard house.

To choose the correction coefficient (y) for disaster intensity, the description proposed by Castro (2010) and also adopted by Schreiner and Wenceloski (2016) was considered, in which the situation described in Level III (Table 8) was the one that most resembled the performed study case, being related to intensity 3.

As a selection criterion, it was considered that Municipal, State, and Federal governments were mobilized to face the disaster with recognition of an SE Declaration in both state and federal levels. In addition, to restore the normal situation of the region, the contribution of state or federal resources, such as the permission of Time of Service

Table 1 – Questions included in the survey sent to affected municipalities.

General questions about the municipality (n = 6)	Questions about DW (n = 12)
Municipality data Responsible person for providing information, work sector, and experience Contact number Percentage of the municipality affected by the disaster	Collection interruption and time of suspended services Municipal management body responsible for managing postdisaster DW Interruption of access and/or operation of the landfill used by the municipality Use of an emergency area for temporary storage of collected DW Extra action to the public cleaning routine to remove waste and debris after the disaster Time needed to complete the collection of DW Existence of records on the collected DW and the calculated amount. Need for an emergency contract for collection and/or final disposal of DW and/or road cleaning Occurrence of donations disposal (expired or deteriorated food, etc.) and the amount disposed Typology of collected DW

DW: disaster waste.

Guarantee Fund withdrawal, a special fund designated for workers in specific situations, and the creation of the ES Reconstruction Card, a financial assistance offered to low-income families affected by the intense rains of December 2013, is required (Espírito Santo, 2014).

Municipality selection for the study case

The Municipality of Vila Velha, located in the Grande Vitória region, was selected for the application of the quantification method on the DW generated in the intense rains of December 2013. To this end, the following criteria were considered:

- ease of contact and access to information;
- existence of information on demolitions related to the disaster;

- availability of area images from the period of the disaster;
- information on the socioeconomic characteristics of the affected area;
- records of waste destination during the disaster period.

In order to create scenarios for waste generation close to reality, in addition to contributing to the refinement of the method used, records of home destructions or demolitions as a result of the disaster were obtained from the Municipal Coordination of Protection and Civil Defense—COMPDEC. The areas of the municipality effectively affected by the disaster were delimited using images (aerial photographs) to assess their actual damage, identifying streets, affected houses, and land characteristics.

Table 2 – Methods' characteristics for estimating disaster wastes.

Method/source	Operation	Application	
		Facilities	Limitations
Ground measurement (<i>Debris Estimating Field Guides</i>) (FEMA, 2010), EUA	Calculates the DW volume from the formula for calculating the volume of a cube, using data collected in the field.	- Uses low cost and simple operation equipment; - Uses primary data; - Provides DW estimation in short time to assist in response actions; - Allows the differentiation of groups of waste to facilitate management.	- Application immediately after the disaster; - Requires field work (labor, equipment and vehicles); - Requires data and support from the local administration to delimit the area affected by the disaster according to land uses (rural, urban, and industrial).
Remote sensing (FEMA, 2010), EUA	Use of aerial photographs and/or satellite images (before and after the disaster) to estimate DW generation with the aid of formulas.	- Provides DW estimation in short time to assist in response actions; - Small demand for field data; - Suitable for areas with difficult access; - Can be applied as a complement to other methods.	- Requires specialized labor; - Requires availability of aerial photographs and/or satellite images; - Application to previous disasters only possible with photographs from the period; - Estimation method recommended with validation of results through measurements on the ground or computer models.
Computer Models (Hazus Multi-Hazard) (FEMA, 2010), EUA		- Provides DW estimation in short time to assist in response actions; - No field survey required	- Requires previous records on generated DW in similar events; - Not yet available in Brazil.
Estimation through primary data collection (Rodrigues et al., 2016), Brazil	Qualitative survey with application of a questionnaire to residents of affected areas to collect data based on the event records.	- Uses primary data; - Requires participation of affected communities in data collection; - Allows the differentiation of groups of waste to facilitate management.	- Need of application right after the disaster; - Demands community involvement and selection of volunteers; - Focuses on the typology of lost assets (families).
Typical Japanese Method (Japan, 2018), Japão	Uses an equation that relates the construction typology, risks, and local statistical data on DW generation, depending on the disaster intensity.	- Allows prior estimation of DW according to disaster type; - No field survey required; - Simplified calculation.	- Requires records on DW generation due to the disaster; - Focuses on generated DW from homes and civil constructions; - Adapted to Japanese reality and construction standards.
Quantification of durable consumer goods (Schreiner and Wencelowski, 2016), Brazil	Based on the Typical Japanese Method, it relates variables such as standard house, average family, and disaster intensity for the calculation. Uses an equation.	- Developed in the Brazilian context; - Allows you to estimate lost consumer durable goods; - No field survey required.	- Requires specific information about impacts, affected area and affected households; - Allows application to previous disasters, but requires photographs of the period; - Focuses on generated DW from homes and civil constructions.

DW: disaster waste.

The identification of streets and houses affected by the extreme event was made using the vector format file (shapefile) of the territorial demarcation of the neighborhoods (provided by the Municipality of Vila Velha) and the geospatial data (shapefiles) developed in the research carried out by Langa et al. (2015), providing the outline for the delimitation of the flooded area in the municipality. This tracing, superimposed on the local images, with a spatial resolution of 0.25 m, in addition to information of land use and availability of public equipment included in the ES orthophoto mosaic mapping IEMA 2012-2015 and dated from the period of the disaster, made possible the manual count of households affected by the December 2013 rains.

Results

Disaster waste characterization

The characterization of the DW was based on information collected through an electronic questionnaire. In the first questionnaires sent to 40 municipalities, 17 (42.5%) responses were obtained. After a new attempt, 20 participants were reached. With incomplete information on one municipality, the final sample included 19 (47.5%) municipalities.

Results showed that in 2013, the final destinations of generated waste in the studied municipalities consisted of sanitary landfills

(75%), controlled landfills (15%), and open-air dumps (10%). Even for the municipalities that had a routine to control the weight of collected waste for disposal in landfills, the amount of DW was not recorded separately but added to the total amount of MSW. Therefore, there was no specific information about the amount of generated DW as a result of the extreme event studied.

The application of the questionnaire indicated that the main residues generated from the disaster were in this order: sediments, soil and mud, and vegetation remains, followed by discarded furniture and appliances and wood/scrap, as shown in Figure 3. The percentage expressed in the graph represents the relation between the number of times each of the waste typologies was indicated by the respondents and the number of answers obtained. None of the surveyed municipalities stated the necessity to discard donations received (expired water/food or other materials damaged due to storage difficulties, etc.).

The results obtained in the characterization of waste are similar to those found by Barboza and Campos (2014), who identified mud, stone, soil, furniture scraps, large amount of paper, cardboard, household waste, bulky waste, and debris from damaged buildings as the main DW in the municipalities of Angra dos Reis, Betim, Itajaí, and São Paulo. Oliveira (2015) analyzed the impacts of a large rainy event in the city of São Paulo and registered the following types of generated waste according to reports from residents: mud, chairs, sofas, cabinets, beds, mattresses, computers, stereos and televisions, spoiled food, including grains and meat, and animal corpses. Such characterization is also in line with the findings of Günther et al. (2017) who claimed that floods can result in different types of waste, with varied composition, according to the area affected, which can generate bulky waste (vehicles, furniture, and appliances) and waste derived from clothes, shoes, food, and so on.

On the contrary, Agamuthu et al. (2015), when studying the generation and composition of types of DW generated in a flooding in Malaysia, concluded that they were heterogeneous in nature, with a predominance of CCW, which was attributed to the type of

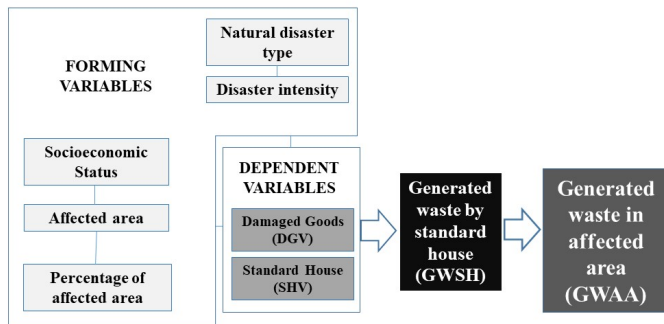


Figure 2 – Stages of the durable consumer goods quantification method.

Source: adapted from Schreiner and Wencelowski (2016).

Table 3 – Equations and variables used for disaster waste quantification.

Stage	Equation	Variables
1	$ DGV = x.y.DGV(E) $	DGV: damaged durable consumer goods waste generated by standard house (t) DGV (E): damaged durable consumer goods waste generated by a standard house of social class E (t) x: correction coefficient for the families' social classes y: disaster intensity correction coefficient
2	$ GWSH = DGV + SHV $	GWSH: total generated waste by damaged standard house (t) SHV: generated CCW by standard house (t)
3	$ GWAA = w.z.GWSH $	GWAA: total generated waste in affected area (t) w: quantity of disaster-affected houses z: correction coefficient by type of disaster

Source: adapted from Schreiner and Wencelowski (2016).

infrastructure impacted by the disaster, the intensity of the event, and the constructive pattern of the affected region. This result differs from what was found in this study, highlighting the need for specific studies applied to local characteristics to estimate DW generation.

Complementarily, the photographic records obtained from the municipalities were analyzed, and it was found that they were in accordance with the information obtained in the questionnaires (Figures 4 and 5).

Municipalities that develop predisaster management plans are more effective in DW management (Cheng, 2018). Waste management

planning must consider accurate and consistent estimates regarding the quantities and types of generated waste (FEMA, 2010).

The PNRS (Brasil, 2010) established a minimum content to be included in the Municipal Plans for Integrated Solid Waste Management. Such content is composed by the diagnosis of the solid waste situation that must cover origin, volume, characterization, and forms of final disposal; besides, the definition of operational procedures to be adopted in public services of urban cleaning and solid waste management, among other requirements, is also required. Therefore, it is understood that the DW should be included in the Municipal Plans for Integrated

Table 4 – Volume of durable goods existing in a standard house of social class E.

Furniture and appliances of a social class family E	Minimum quantity (unit)	Estimated unit volume (m ³)	Total estimated volume (m ³)
Double bed	1	2.00	2.00
Bedside table	2	0.25	0.50
Wardrobe	2	2.00	4.00
Single bed	2	1.00	2.00
Full size mattress	1	0.90	0.90
Single size mattress	2	0.45	0.90
Sink cabinet	1	0.45	0.45
Medium table	1	0.80	0.80
Chair	4	0.20	0.80
Medium sofa	1	2.20	2.20
Shelf	1	1.00	1.00
Television	1	0.25	0.25
Stove	1	0.50	0.50
Refrigerator	1	1.00	1.00
Washing machine	1	1.00	1.00
Total volume of durable goods (m³/standard house)			18.30

Source: modified from Schreiner and Wenceloski (2016).

Table 5 – Correction coefficients (x) for residues estimation according to social class.

Social class*	Correction coefficient for social class (x)
A	12.5
B	5.5
C	3.5
D	2.0
E	1.0

*Obtained based on the Socioeconomic Class stratification defined by the IBGE (A to E) based on the value of the minimum wage in 2013. Source: adapted from Schreiner and Wenceloski (2016).

Table 6 – Correction coefficients (y) for DW estimation according to disaster intensity.

Disaster intensity	Correction coefficient for disaster intensity (y)
0	0.0
1	0.2
2	0.4
3	0.6
4	0.8
5	1.0

Source: adapted from Schreiner and Wenceloski (2016).

Table 7 – Correction coefficient (z) for DW estimation according to natural disaster type.

Natural disaster type	Correction coefficient according to disaster type
Hailstorm	0.5
Flood	0.5
Windstorm	1.0
Landslide	2.0

Source: adapted from Schreiner and Wenceloski (2016).

Table 8 – Disaster intensity classification according to effects and damage to population.

Classification	Description
Level I	- Small intensity and small damages; - Easily overcome by the population affected.
Level II	- Damages of major importance; - Locally overcome (prepared and informed community).
Level III	- Large damages; - Mobilizes the three levels of the National System of Protection and Civil Defense.
Level IV	- Very large disasters, which exceed the community's capacity to overcome the disaster; - Inhabitants need external help, including international resources most of the time; - Mobilizes the three levels of the National System of Protection and Civil Defense.

Source: adapted from Castro (2010).

Solid Waste Management to guide or improve the adoption of more sustainable and viable managing practices.

It was also found that the generated DW estimation made in this study can also contribute to the inclusion of DW in the Contingency Plan — PLACON, a document that records the strategic

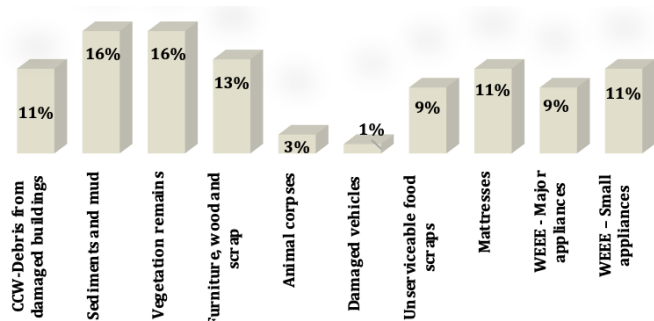


Figure 3 – Percentage distribution of generated types of waste by heavy rains in 2013, according to information from municipalities, Espírito Santo, Brazil.

action planning for disasters, prepared by the municipality. In order to prepare the municipality for an effective response to the disaster, it is understood that the prior direction of the logistics that involves the collection and disposal of waste during and after the disaster, involving the definition of actions, responsibilities, procedures, financial resources, equipment, and necessary personnel for the restoration of normality conditions, should be contemplated in this plan.

Disaster waste quantification: durable consumer goods

The application of the quantification method of durable consumer goods was carried out in the Municipality of Vila Velha once it was the only municipality that reported in the questionnaire the amount of collected DW in the characterization stage. This municipality had 91 neighborhoods, and among them, 86 were affected, at different scales, by the episode of heavy rains in December 2013.

After delimiting the flooded area in the Municipality of Vila Velha by the disaster (Figure 6), the affected households were counted, and local socioeconomic characteristics information was collected.



Figure 4 – Discarded residues after heavy rain disaster in 2013, Municipality of Serra, Espírito Santo, Brazil—durable consumer goods. Source: archive of the Municipality of Serra, ES.

The data obtained were applied to the equations of the used method. The calculation was performed by neighborhood, considering the generation variations defined in the method, according to the socioeconomic profile of each location.

The authors of the method used as reference obtained the number of affected households (w) from the population density (inhabitant/ km^2), determined for the evaluated region. In order to refine this type of data in this study, remote sensing was used from satellite images and aerial photogrammetry from the period studied, superimposed on the delimitation of the influence area considered in the study. Thus, the value of w corresponded to the number of homes affected by the disaster.

Among the affected neighborhoods, the Pontal das Garças neighborhood was selected for a preliminary study to verify the applicability of the method in the study case due to the intense damage suffered. The neighborhood has 585 inhabitants (2010 Census *apud* SEMPLA, 2013) and remained with its territory, in its entirety, immersed under water for several days, as illustrated in Figure 7. According to the local municipal administration, the cleaning, collection, and disposal of generated DW in the event occurred in the period from January to April 2014.

The occurrence of the release of Time of Service Guarantee Fund withdrawal for the inhabitants of the flooded areas guided the identification of the disaster intensity that affected the Municipality of Vila Velha in 2013. Thus, the correction coefficient referring to the disaster intensity level 3 was used once 60% of durable household goods were lost and turned into waste.

Based on the information from COMPDEC, there was no collapse or need for demolition of homes as a result of the disaster assessed in the Municipality of Vila Velha. Therefore, when applying the generated DW estimation method, the portion referring to the volume of generated CCW in the total destruction of a SHV was not considered.

According to the report of the Municipal Secretariat of Planning, Budget and Management of Vila Velha (SEMPA, 2013), the average monthly income in the Pontal das Garças neighborhood in 2010 was R\$ 911.43, so the correction coefficient for the social class E was used. For the other neighborhoods that make up the study region, the coefficient considered the following distribution between classes: C (4.6%), D (29.9%), and E (65.5%), based on the information of average monthly income for each affected neighborhood contained in the SEMPLA report.

The application steps of the generated DW estimate calculation method, selected for the neighborhood studied, are provided in Table 9.

The application of the selected and adapted method resulted in an estimate of additional 15.20 t of generated waste in Pontal das Garças neighborhood, which is a result of lost durable goods disposal. It is noteworthy that the value for the per capita mass of MSW collected that year by the municipal service of Vila Velha was 0.8 kg/inhabitant/day (SNIS, 2013). These data allowed us to estimate that the daily generation of RSU was around 0.47 tons and a monthly generation of RSU was 14.10 tons in Pontal das Garças neighborhood.

Adopting the same method for the other districts of the municipality that comprise the flooded area, the estimated global value of 1,708.85 tons of DW was obtained. It is noteworthy, however, that the method used does not include the portion of sediments, mud, and vegetation remains, which make up part of the amount of DW, as seen in the characterization carried out. According to the local municipal administration, the cleaning, collection, and disposal actions of the generated DW at the event took place from January to April 2014. In the available data, however, the DW is not separated from the other municipal collected waste. Thus, the amount registered by the municipality corresponds to household waste added to the waste collected in the cleaning actions of the DW.



Figure 5 – Discarded residues after heavy rain disaster in 2013, Municipality of Serra, Espírito Santo, Brazil—residues of vegetation, sediments, and mud.
Source: archive of the Municipality of Serra, ES.

When comparing the amount found with urban cleaning service final destination data, in the period from January to April, it was found that the amount of MSW collected in 2014 (71,733.21 t) exceeded the average for the years 2012, 2013, and 2015 (64,296.75 t), resulting in an extra difference (7,436.46 t), which was attributed to the DW. In addition to this significant increase in the collected amount, it is important to mention the presence of bulky waste demands-specific logistics, increase of transportation rides, and extra costs related to them.

In Table 10, based on the daily average of MSW collected in Vila Velha in the assessed regions, there is a comparison with the estimated generated DW by the method applied in terms of equivalent days of operation of the regular MSW collection that was needed to clean the regions affected by the disaster.

Brown et al. (2011) affirmed based on data from the time of the study that, depending on the nature and severity of the disaster, the

volume of DW could reach the equivalent of 5–15 times the annual rate of MSW generation, under conditions of normality of the affected community. In an estimate carried out for the flood that occurred in 2015, in the city of Joinville, using the same method adapted for this study, Schreiner and Wenceloski (2016) found an amount of DW equivalent to 15 days of daily generation in the region lower than that obtained in Pontal das Garças (32 days) and close to the result for the total of affected neighborhoods (14 days) in the Municipality of Vila Velha.

It is worth considering that Schreiner and Wenceloski (2016) included the portion of generated CCW as a result of standard house demolitions for the estimate made in Joinville, and the study case in Vila Velha considered exclusively the portion of durable goods lost and expected that the application of the method would result in a value proportionally lower than that of the municipality in the south of the country. It is believed that the adjustment made

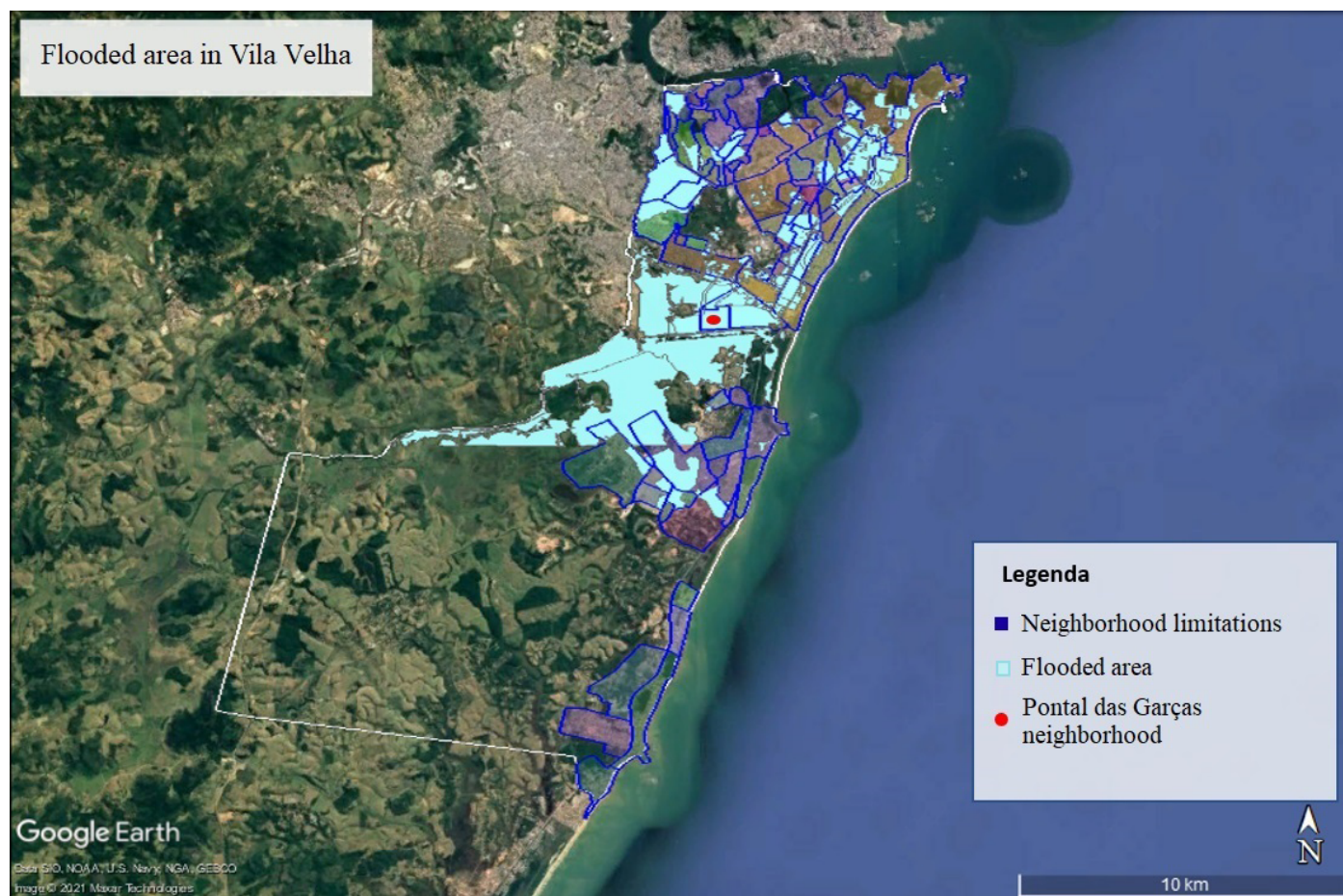


Figure 6 – Representation of affected area by the event in 2013, in the Municipality of Vila Velha.

to obtain the number of affected households may have influenced the result.

When comparing the total estimated DW for the disaster (1,708.85 t) with the increase in the amount of MSW collected and destined in 2014 (7,436.46 t), it is observed that the urban cleaning service record is about four times higher, which may be related to the long period of time required to clean and remove the DW (120 days), with the possibility of generation and disposal of several residues as a result of the postdisaster, including the CCW and residues retained in the macro-drainage system.

Table 10 – Disaster waste estimate comparison between the Pontal das Garças neighborhood and the total of regions affected by heavy rains in 2013 with the MSW daily average generation, Vila Velha, ES.

Assessed regions	Estimate DW*** (t)	MSW average (t/day)	Regular collection period of MSW (days)
Pontal das Garças	15,20	0,47*	32
Total of 86 affected neighborhoods	1708,85	535,8**	14

MSW: municipal solid waste; *estimated based on SNIS (2013); **daily MSW average collected by urban cleaning service for years 2012, 2013, and 2015; ***method adapted from Schreiner and Wencelowski (2016).



Figure 7 – Flooded neighborhoods after the December 2013 rains, Espírito Santo, Brazil.

1: Pontal das Garças neighborhood; 2: Darly Santos Highway; 3: Araçás neighborhood.

Source: Pereira (2017).

Table 9 – Application of disaster waste estimate method in Pontal das Garças, Vila Velha, Espírito Santo, Brazil.

Equation	Applied values	Criteria
$DG\text{V (E)} = d \cdot DG$	$d = 0.0075 \text{ t/m}^3$ $DG = 18.30 \text{ m}^3$ $DGV\text{ (E)} = 0.14 \text{ t}$	- Bulk density (d) proposed by Schreiner and Wencelowski (2016) - Total volume of durable goods of standard home class E (DG)
$DGV = x \cdot y \cdot DG\text{V (E)}$	$x = 1$ $y = 0.6$ $DGV = 0.084 \text{ t}$	- Social class social E - Disaster intensity level 3
$GWSH = DGV + SHV$	$SHV = 0$ $GWSH = 0.084 \text{ t}$	- No demolition of affected houses
$GWAA = w \cdot z \cdot GWSH$	$w = 362$ $z = 0.5$	- Quantity of affected houses in Pontal das Garças (w) - Flood (z)
Total generated DW—gwaa (t)		15.204 t

SH: standard home; DGV (E): generated residues by damaged durable consumer goods in a social class E standard home (t); DGV: generated residues by damaged durable consumer goods in standard home (t); SHV: generated CCR by damaged standard home (t); GWSH: total amount of generated residues by damaged standard home (t); GWAA: total amount of generated residues in the affected region (t).

When studying the flooding that occurred in the Municipality of São Luiz do Paraitinga, São Paulo, in 2010, Oliveira (2015) recorded reports that an amount of 2,000 trucks full of DW was removed after the disaster.

It is also noted that the value of the specific weight variable (0.0075 t.m^3) brought from the calculation formula of the adopted method is low and may contribute to underestimated DW values. Furthermore, the method used did not include the estimated weight of vegetation residues, sediments, and mud, and these typologies were significantly cited by the municipalities in the stage of characterization of the disaster residues generated in the event.

In the list of furniture and appliances from the Brazilian class E family (Table 2) stands out the wood and waste from electrical and electronic equipment (EEER). Bringhenti et al. (2019), when analyzing recyclables from selective collection in Brazilian condominiums, obtained the respective specific weight values: 0.296 t.m^3 (wood) and 0.238 t.m^3 (EEER). These values substituted in the formula (Table 9) resulted in DGV values (E), respectively, equal to 5.42 t and 4.35 t, which would be about 39–31 times higher than that used in the estimate (0.14 t), drawing attention to the importance of this parameter.

Although this work has sought to improve the calculation of the amount of waste by the method of Schreiner and Wenceloski (2016), minimizing the uncertainties in obtaining information on the number of homes affected and the amount of CCW generated, it is still verified that some aspects should be reviewed for an improvement to the method, once it has initially raised the need to adapt the value that refers to the specific weight of the waste.

Conclusions

The adaptation of the selected DW generation estimation method proved to be adequate for the study case carried out in the Municipality of Vila Velha, ES after the disaster caused by heavy rains in December 2013.

The analysis of the photographic records of the disaster in comparison with the information provided by the municipalities indicates the need for a more in-depth assessment of the real losses of durable consumer goods. There is a need to understand which goods are effectively discarded by the population and which ones continue to be used after cleaning and repairs. Therefore, a study with this objective is recommended.

The survey results pointed to the need to strengthen municipal public management regarding the registration and systematization of information related to disaster management and, specifically, waste from disasters.

It was noted that the DW was destined to landfills, while it is recommended actions that aim for its valorization and minimization, in compliance with the PNRS, favoring the reduction of costs, the extension of the useful life of landfills, and mitigating environmental impacts or even generating some revenue.

The research also revealed the need for more studies applied to the local context of DW generation and for greater dissemination of issues related to DW in order to promote the inclusion of this type of waste in the planning of disaster risk management and in the integrated management of solid waste, with a view to improve disaster preparation, response and recovery actions, and inclusion of logistics procedures and costs related to packaging, transport, and final treatment of the DW.

Contribution of authors:

Mello, D.P.P.: Data curation, Methodology, Formal analysis, Investigation, Validation, Writing — original draft, Writing — review and editing. Bringhenti, J.R.: Conceptualization, Methodology, Formal analysis, Investigation, Validation, Writing — original draft, Writing — review and editing. Bianchi, D.P.Z.: Conceptualization, Methodology, Formal analysis, Writing — review and editing. Monte, L.S.: Data curation, Investigation, Statistical analysis. Günther, W.M.R.: Conceptualization, Methodology, Writing — original draft, Writing — review and editing, Funding acquisition, Administration of projects, Resources.

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