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Urban population exposed to risks of landslides, floods and flash floods in Brazil

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Abstract
The knowledge about the urban population exposed to disaster risk is essential for planning prevention and response actions. The aim of this study was to analyze the exposure conditions of the population groups at disaster risk areas in 479 Brazilian municipalities. The methodological procedure was based on the association of census data and landslides, flash floods, and floods risk areas. The database was made up of socio-demographic and environmental data, which allowed the characterization of the residents and the houses at-risk areas. The results showed that the largest number of people exposed was in the Southeast region of the country, although, in proportional terms, in the Northeast region 15 out of every 100

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people lived in risk areas. These data could allow the selection of areas for priority actions, in order to help the implementation of regional public policies that promote the reduction of human losses in Brazil.
Keywords: at-risk population, census data, disaster exposure.

Introduction

Over the past decade, progress has been made in Brazil in order to identify disaster vulnerability in the context of environmental change (DEBORTOLI et al.; 2015), for the development of disaster risk indicators (ALMEIDA et al.; 2016) and social vulnerability to natural hazards for the entire country (HUMMELL et al.; 2016). Other initiatives have been dedicated to regional evaluation (MENEZES et al.; 2018; RONCANCIO; NARDOCCI, 2016), either to development of new methodologies or application of the existing ones (ALVES 2006; DESCHAMPS, 2006; ALMEIDA, 2010; GOERL et 2012, ASSIS DIAS et al.; 2017). All mentioned studies applied census tract from the demographic census, conducted by the Instituto Brasileiro de Geografia e Estatística (IBGE, in Portuguese) every 10 years. The more detailed analysis on an intra-urban scale restricts to the limits of these sectors, without the possibility of resizing them, due to the risk of over or underestimating the data.

In order to address this limitation, some studies on vulnerability have developed detailed data collection through interviews. Such method becomes restrictive for analysis at national scale, especially related to the high cost required for producing more detailed data. Therefore, demographic census data end up being the only data to support vulnerability assessment. On the other hand, the IBGE demographic census database originates from more detailed information, denominated as block face, which is a smaller unit of the census tract. This data is not available for the general public, in order to preserve the confidentiality of informants. However, this data has the potential to characterize the population and households exposed to disaster risk. Thus, the goal of this study was to analyze the conditions of population groups exposed in disaster risk areas in 479 critical municipalities, distributed in different regions of Brazil, based on data obtained with the method proposed by IBGE and Centro Nacional de Monitoramento e Alertas de Desastres Naturais – Cemaden, in Portuguese (IBGE; CEMADEN, 2018). Additionally, a detailed analysis was provided to present the characteristics of the population groups as well as their households, in order to contribute to a better understanding of the disaster risk in the country.

Although the high dynamics occupation is notorious in disaster risk areas in Brazil, and the data used in this study is from the 2010 year, the contribution of the present paper is to explore the potential of the database for characterization of exposed population groups in disaster risk areas. As an unprecedented database, it is noted that the results presented may show hitherto unknown realities.

In practical terms, the standardization of the procedure on a national scale is one of the great advantages of this type of methodology. Thus, this analysis could support monitoring and early warning issue, as developed by the Cemaden, a research unit of the Ministério de Ciência, Tecnologia, Inovações e Comunicações. In 2012, within the scope of the National Plan for Risk Management and Response to Disasters, 821 priority municipalities were selected to be monitored by this Center, as they have a history of mass movement-related disasters (landslides, debris flow, river undermining margins, fallen lands, falling or blocks of rock and erosive processes) and / or due to hydrological processes (floods, flash floods, urban floods). It is noteworthy that some municipalities that were not considered as a priority in 2012 also began to be monitored by Cemaden, since geologic or hydrologic risk maps were available (IBGE; CEMADEN, 2018). The specialists in Hydrology, Disaster, Meteorology and Geodynamics are responsible for the monitoring of the meteorological systems and hydrological and geodynamic conditions, as well as possible socio-environmental impacts caused by disasters (CEMADEN, 2019).

Disaster risks related to landslides, flash floods, and floods in the Brazilian urban context

The (re)occurrence of socio-economic impacts caused by hydro-meteorological disasters highlights the need for the inclusion of this theme in the Brazilian public policy agendas. Disaster prevention requires joint action, especially related to civil protection, housing, infrastructure, education, and health. Although efforts in this direction have been noted, especially in the last decade since the launch of the National Plan for Risk Management and Response to Disasters (COSTA; PIMENTEL, 2017), unfortunately, they have not been enough for effective disaster reduction in the country.

Geological and hydrological processes are part of the natural dynamics of the Earth's surface, however, the combination with the intensification of urban occupation in susceptible areas, such as floodplains and steep slopes, results in systems vulnerable to landslides and floods. If the social system is prepared to face these processes, social, economic, and environmental impacts will not be recorded. On the other hand, unprepared social systems would be unable to cope with their effects, even low magnitude processes.

These two scenarios are associated with concepts relevant to the present discussion. Hazards are natural or human-induced processes with the potential of affecting a particular social system, causing loss of life, socioeconomic impacts or environmental degradation (UNISDR, 2017). According to the Brazilian Classification and Code of Disaster (BRAZIL, 2017), disasters are related to two categories: i) natural, which is subdivided into geological, hydrological, meteorological, climatological, and biological, and all their respective subgroups; ii) technological, which may be related to radioactive substances, hazardous materials, urban fires, civil works, passenger transport, and non-hazardous cargo.

The social system is a portrait of conditions determined by physical, social, economic, or environmental factors that increase the susceptibility of an individual, community, or system to be affected by hazards, which characterizes the concept of vulnerability (UNISDR, 2017). Thus, disaster risk is determined probabilistically as a function of hazard, exposure, vulnerability and capacity; it is related to the potential loss of life, injury, or destruction or damaged of assets which could occur to a system, society, or a community in a specific period (UNISDR, 2017).

The number of vulnerable people has increased in Brazil, due to the lack of land use planning and occupation (MARICATO; OGURA; COMARU, 2010). It can be also attributed to other factors, such as the structure of the housing market and the historical absence of the State in the implementation of housing policies in the country, restricting access to safe places for housing (CARDOSO, 2006). The growing tendency of people exposed to disaster risk areas is a reality to live with, related to an increasingly urban country and the impossibility of solving the housing problem in the short term. Although it is not possible to forecast all hazards, the consequences are predictable and can be minimized by reducing vulnerability (GONÇALVES, 2012).

For mitigating the damages caused by disasters, it is essential to promote the best knowledge about hazards and vulnerabilities, since only through the identification of exposed individuals and communities it is possible to define structural and non-structural measures. Moreover, it is possible to understand the different degrees of impact on social systems produced by the same hazard. In this sense, risk exposure (e.g. from the built environment), socioeconomic and demographic information can support knowledge of population characteristics that influence their readiness to respond and recover from disasters (CUTTER, 2011).

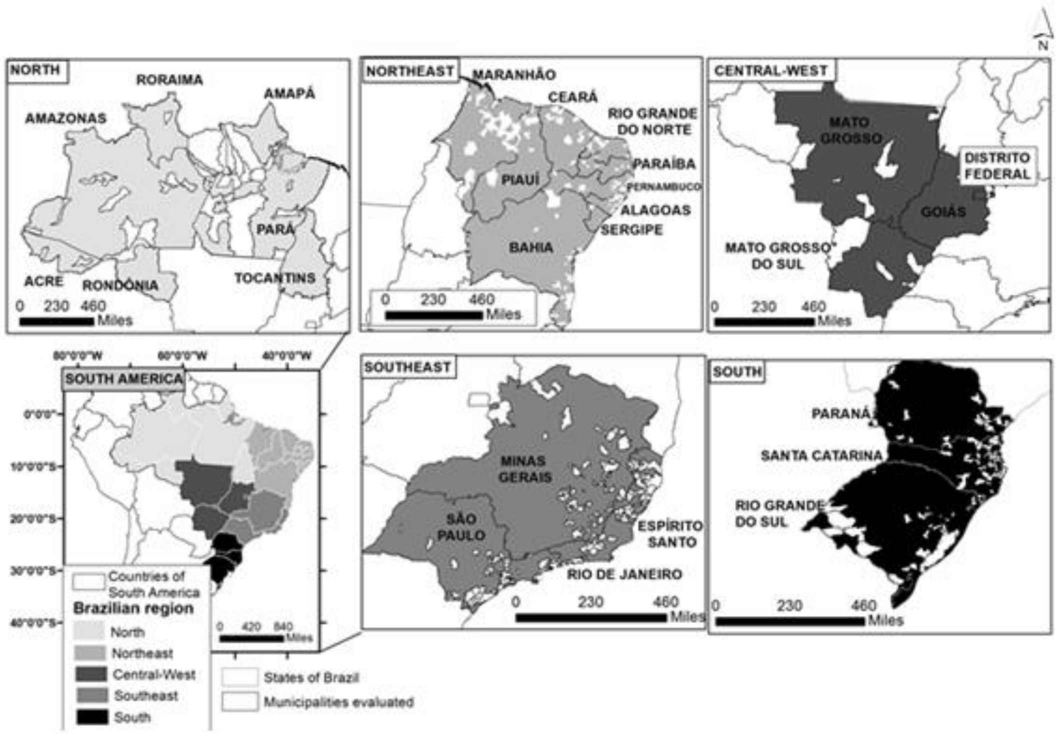
Studies on population vulnerability to disasters have been progressing gradually in Brazil, especially in the last ten years. From a theoretical point of view, many of them have highlighted the need to understand the vulnerability resulting from processes of inequality (CARMO, 2014), as a multidimensional concept (MARANDOLA; D'ANTONA, 2014), its relationship with development (AVILA; MATTEDI, 2017), and with the root causes and dynamic pressures (MARCHEZINI; WISNER, 2017). The application to various contexts of disasters has also been addressed, such as school vulnerability (MARCHEZINI, TRAJBER; MUÑOZ, 2018), in early warning systems (SAITO, 2018), and health (LONDE et al, 2018).

In public management, on the other hand, progress is still slow. Two actions should be highlighted within the scope of the federal government's National Plan for Risk Management and Response to Disasters (2012-2015). First, the mapping of landslide and flood risk areas conducted by the Serviço Geológico do Brasil, from 2011 to 2014, which allowed the estimation of exposed houses and residents of 821 Brazilian municipalities (CPRM, 2019). Such mapping was used for monitoring and alerting purposes, for prevention and response actions, and for the definition of containment works (SAMPAIO et al, 2013). The second action is the project 'Data and Analysis of Natural Disaster Vulnerability for Risk Mapping and Disaster Prevention Intervention Proposal' under the responsibility of the Secretaria Nacional de Proteção e Defesa Civil. The purpose of this project was to conduct a vulnerability survey among 275 Brazilian municipalities affected by disasters (SCHADECK et al, 2015). However, the lack of adherence among the methodologies applied in the survey did not allow the application of the results for prevention actions.

Material and Methods

This study presents an analysis of 479 municipalities distributed in different regions of Brazil, which are part of the 821 municipalities critical for national risk management and response to natural disasters (Figure 1).

Figure 1. Distribution of the municipalities evaluated per Brazilian region



The procedures adopted in this study consisted of the compatibility of the demographic census databases with landslides, flash floods, and flood risk maps to characterize the population groups exposed in risk areas of Brazil, detailed in IBGE and Cemaden (2018) and Assis Dias et al. (2018).

The 2010 census data was one of the databases used. In Brazil, since 1890, the census has been held every ten years, except in 1910 and 1930, when they were suspended for political reasons; and in 1990, when it was postponed to 1991 (IBGE, 2016). Decadal frequency is recommended by the

United Nations Department of Economic and Social Affairs to allow comparison of information for describing the present and predicting the future (UN, 2015). Although in the context of disaster risk theme, data collection should be more regular; the high cost of the census is a limiting factor for its execution (UN, 2006). For demographic analysis, the ten-year interval is acceptable to represent the portrait of the reality of a given area.

The association between the two databases cannot be done directly and automatically since they have different characteristics and applications. Therefore, there was no spatial correspondence between them. For this reason, the methodological challenge was to conciliate data from completely different geometries. For the association of census data with disaster risk areas, it was necessary to create a new territorial generalization aiming to make the two geometries compatible, which was named in Portuguese as BATER-Territorial Basis of Statistical Areas of Risk. The data generated through the BATERs represented an estimation, that is, it did not represent residents living in risk areas quantitatively.

The graphic delimitation of BATER was performed by visual interpretation to assess the spatial context of risk areas and census boundaries. For the spatial context of the risk areas, the density and construction patterns of the households in those areas were considered. For delimitation, eight assumptions were considered according to IBGE and Cemaden (2018):

a) The BATER results from the smallest possible area, from the intersection of the hazardous area and the census features.

b) Each census feature and each hazardous area belongs to only one BATER.

c) Risk areas in subnormal agglomerates were generalized, considering the similarities of occupation patterns and topographical features.

d) The BATER was also generalized in case the block face had similar construction patterns and density.

e) The BATER covered two or more hazardous areas, in cases of similarity of density pattern and construction.

f) For BATER associated with the hydrological risk were considered block faces on both sides of the street because it is very likely that both roads are affected by a flood.

g) For BATER associated with the landslide risk, the features of topography, shape, direction, and degree of slope were considered for BATER limits.

(h) The risk levels were not considered because the maps were produced by different institutions and based on distinct methodologies.

In the universe of more than 600 variables provided by the census, IBGE and Cemaden (2018) selected 183 variables to characterize the residents, such as age, gender, and literacy, among others; and 135 to characterize households, that is, access to basic services such as electricity, sanitation, water supply, and garbage collection (Table 1). The variables were also used to describe the municipalities, allowing comparative analysis between the situation of population groups residing in risk areas and the situation of the total population living in the municipality.

Table 1. Selected variables for characterization of households and population exposed to landslides, floods and flash floods risks in Brazil.

Resident variables group	Housing unit variables group
Number of residents and housing units	
Residents by group of age	Number of housing units without occupation
Residents by gender	Number of housing units by way of water supply
Residents by literacy	Number of housing units by the type of sewage disposal
Residents by income	Number of housing units by the type of garbage disposal
Residents by head of housing unit, by gender, literacy and income	Number of housing units by the existence of electric energy meter
Residents by housing unit occupation condition: water supply	Number of housing units by per capita household earning, by responsible and sex
Residents by housing unit occupation condition: sewage disposal	Number of housing units by number of residents
Residents by housing unit occupation condition: garbage disposal	Number of housing unit by type of housing unit
Residents by housing unit occupation condition: electric energy meter	Number of housing units by housing unit occupation condition

Source: Authors' elaboration with data from IBGE and Cemaden (2018)

As highlighted in Assis Dias et al. (2018) and IBGE and Cemaden (2018), the BATER produced using data by block faces contained the most detailed data at the census level. It meant that the level of disaggregation of data was closest to the size and distribution of risk areas in the territory. This represents an information gain because, until this moment, the census data used for association with risk areas originated solely from information aggregated by municipality or census tract.

Results and discussions

Table 2 presents general information about the Brazilian municipalities divided by the major regions and the 479 municipalities which are the focus of the present work.

Table 2. General information about the Brazilian municipalities and municipalities evaluated.

Region	Demographic data of Brazil			Data of 479 analyzed municipalities		
	Total number of municipalities*	**Total of habitants***	**Demographic density***	**Number of priority municipalities**	**Number of priority municipalities analyzed**	**Habitants of the analyzed municipalities***
Northeast	1.794	53.081.950	34.15	277	174	18.663.593
Southeast	1.668	80.364.410	86.92	292	156	35.702.009
South	1.188	27.386.891	48.58	142	100	8.429.702
North	449	15.864.454	4.12	81	37	5.777.132
Central-West	466	14.058.094	8.75	29	12	1.427.203
BRAZIL	5.565	190.755.799	22.43	821	479	69.999.639

*Demographic census, 2010.
Source: IBGE (2010), IBGE and Cemaden (2018)

Among the total number of municipalities analyzed, 29,535 landslides and flood risk areas were mapped. From the spatial distribution of risk areas and census data, 4,683 BATER polygons were created (Table 3). Most of the associated data came from block faces (85% of BATER polygons), while the remaining 15% came from census tracts.

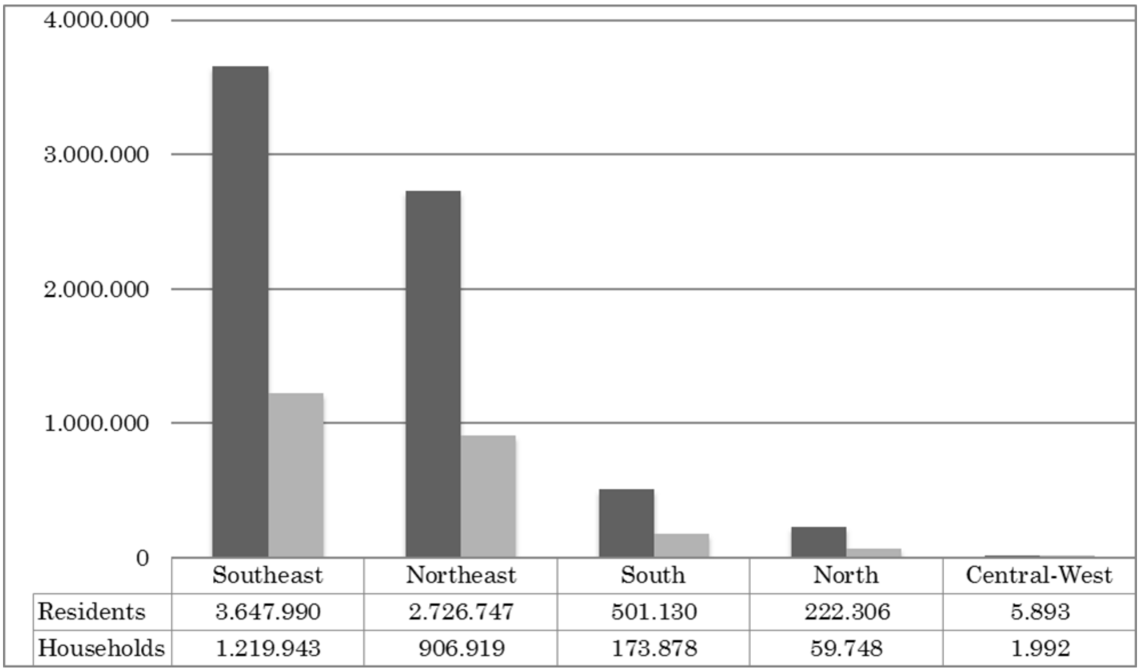
Table 3. Number of BATER areas and polygons created by region.

Regions of Brazil	Number of risk areas	Territorial extension (km²) of risk areas	Number of BATER polygons
Southeast	16.024	803	2.597
Northeast	5.532	520	1.071
South	6.789	749	764
North	1.149	268	223
Central-West	41	4	28
TOTAL	29.535	2.344	4.683

Source: IBGE e Cemaden (2018)

Figure 2 shows the estimated number of residents and households exposed to risk areas by region.

Figure 2. Estimated residents and households exposed in 479 municipalities by region.



Org. authors, 2019.

The Southeast region concentrated the largest number of mapped risk areas in the country, as well as BATER polygons created. In contrast, the risk areas in the region were small (0.05 km^2 on average) and located close to each other.

In the Northeast, it was estimated that over 2.7 million people were exposed to risk, although this region contained less than 65% of the risk areas compared to the Southeast. The risk areas in the Northeast had a larger territorial extension (0.09 km^2 on average), suggesting that there is a higher concentration of people in the risk areas of this region.

The Northern region contained the largest territorial extension of risk areas (average 0.23 km^2), as most of these are in municipalities located in large Amazon basins and, therefore, are associated with floods.

It is estimated that 10% of the resident population was exposed to the risk of landslides and/or floods, totaling 7,104,066 people in 2,131,160 households in the 479 municipalities evaluated in this study. The exposed population was concentrated on the eastern coast of Brazil. In the meso-regions (Metropolitan Area of Salvador, São Paulo, Belo Horizonte, Recife, Rio de Janeiro, Fortaleza, Central Espírito Santo, Zona da Mata Mineira, Vale do Itajai, Leste de Alagoas, and Leste Potiguar), there were more than 76% of the exposed population estimated in the municipalities analyzed.

Regarding the demographic characteristics of the municipalities, there was no significant difference in gender distribution, that is, approximately 52% of the exposed population were women and 48% men, of which 56% were responsible for the household. However, from the 10% responsible for non-literacy, most of them were women (54%). Wamsler et al. (2012) highlighted the crucial role of women's level of education as a determinant of the risk situation to which they are exposed. Women with higher levels of education may have higher income and better ability to adapt to risk. In addition, the response capacity and protection of social groups are affected by their income level, as emphasized by Torres (2000) and Marandola and Hogan (2005).

Neumayer and Plümper (2007), assessing the impact of disasters on life expectancy of men and women, pointed out that the greatest impact occurs in women, especially in women with low-income.

From the results obtained about the exposed residents, about 43% of them lived in households without income or with per capita income of up to half the minimum wage (the value being R$ 510.00 in July 2010, approximately US$ 280). Among the regions of Brazil, people living with per capita income of up to half the minimum wage was around 62% and 55% in the North and Northeast, respectively. In the South and Southeast, the percentages of people with income up to half the minimum wage were 21% and 36%, respectively. On the other hand, in all municipalities analyzed only 1.6% of the residents lived in households with per capita income above 5 minimum wages, which is considered the stratum of the population with the best economic situation.

Among the age groups, children and the elderly were the most vulnerable to disasters, because they need special care due to their greater dependence on autonomous mobility and lower ability to resist possible injuries (WISNER et al.; 2003). Considering the different ways of coping with each age group, Liu et al. (2002) argue that in contrast to most adults, children would not be able to react adequately to the materialization of risk. Similarly, older people tend to have greater difficulty in autonomous mobility and require help. In addition, these age groups tend to stay longer in their homes, and thus, may be more at risk. The age group of children most vulnerable was considered to be under 5 years of age, since until 2013, the compulsory entry to early childhood education was 6 years of age, according to Law 12796, 2013 (BRAZIL, 2013). The elderlies are those individuals over the age of 60, in accordance with the provisions of the Statute of the Elderly (BRAZIL, 2003). In the risk areas of the municipalities analyzed, it was estimated that 17% of the exposed population belonged to the most vulnerable age group, composed of children (9%) and the elderly (8%).

Different responses are expected from men and women, children, the elderly, and adults. The knowledge of these population groups can help, for instance, in the preparation of disaster contingency plans (MAZURANA et al.; 2013). Classification by age group could support the definition of priority areas for civil defense action during disasters. For example, by quantifying the number of people exposed by gender and age may help define evacuation actions. Locations with the highest concentration of children and the elderly deserve special attention and greater readiness to evacuate them. The estimative percentages of the exposed population between the ages of 6 to 14 years and 15 to 59 years were 16% and 66.4%, respectively.

From a total of 7,104,066 residents exposed in the 479 municipalities, most of them (75%) lived in their own households (90%). Regarding the situation of the households, 24% of the households had inadequate sanitary sewers, that is, they did not have sewage collection or septic tanks. In context of landslide risks, attention to households with other forms of exhaustion other than through the collection network or septic tanks is imminent, because they reveal the precariousness of household conditions. In addition, it can help better understand human interventions that trigger landslides and increase population exposure. The relationship between inadequate sanitary sewers and the presence of rudimentary sumps in landslide risk areas has been approached by several authors as one of the anthropogenic conditions that trigger the occurrence of disasters (ALHEIROS, 2003; CARVALHO et al.; 2007; ARMESTO, 2012; MIRANDOLA; MACEDO, 2014).

The situation is more precarious in the Northern regions, where 67% of households in risk areas had inadequate sanitation, followed by Central-West with 54% and Northeast with 33%. The percentages for the South and Southeast regions were 18% and 16%, respectively.

The Synopsis of the Demographic Census (IBGE, 2010) points out that in Brazil, on average, 17% of households had no water supply by the general network. In the risk areas of the municipalities analyzed, the water supply generally had good coverage, with only 6% of households not being supplied by the general network. In the Northern region, 28% of households had no supply from the general network and about 11% of households of this region had no garbage collection.

Characterization of exposed population groups per Brazilian region

From the total resident population in Northern Brazil, it was estimated that 4% of the people lived at risk, totaling 222,306 people in 59,748 households distributed in 37 municipalities evaluated. The capitals of the northern states considered for this analysis were: Belém, PA; Boa Vista, RR; Manaus, AM; Porto Velho, RO; and Rio Branco, AC. From the total of BATER created, 51% of the generated polygons were associated with risk areas in these capitals, where it was estimated that 107,796 people were exposed in 27,861 households, distributed across the 861 risk areas mapped. It means that 48.5% of the estimated population at risk in the northern region lived in these capitals.

Also noteworthy is the concentration of 71% of the exposed population in the Southeast region living in 38 municipalities of the metropolitan regions of São Paulo, Rio de Janeiro, and Belo Horizonte, totaling 2,583,705 people. The distribution in the most vulnerable age groups was balanced, with 9.6% children and 8.6% elderly. Regarding household conditions, 16% had inadequate sanitary sewers and 6% had no meter.

In the South region, it was estimated that 501,130 people and 173,878 households were exposed to risk, distributed in 6,789 mapped risk areas. The concentration of children and the elderly was around 9%. More than half of the exposed population in the Southern region (282,893 residents) was concentrated in 55 municipalities distributed in Vale do Itajaí (24), Grande Florianópolis (12), Regiões Metropolitana de Curitiba (11) and Porto Alegre (8).

In the state of Santa Catarina, the Vale do Itajaí stood out, where 83% (5,650) of the risk areas mapped in the South region were estimated to have 153,616 exposed residents. The characterization indicates that 14% of the population living in 24 critical municipalities of Vale do Itajaí lived in risk areas. This region also stands out for its high susceptibility to disasters and the recurrence of landslides and floods, including the major ones. These events impact several municipalities located in the Itajaí and Itapocu river basins, which have often caused extensive damage and loss (JACOBI, MOMM-SCHULT; BOHN, 2013).

The Central-West region has 41 risk areas mapped in 12 critical municipalities, characterized by small polygons related to flood risk, landslides, and erosion processes, which are not associated with major events.

From the results obtained for this region, it was found that 5,893 people and 1,992 households were exposed to risk. Noteworthy were the municipalities of Corumbá and Campo Grande, both in the state of Mato Grosso do Sul, with 44% of the population exposed.

In the risk areas of the Central-West, there were more people living in households with up to half the minimum wage (36.5%) compared to all municipalities (23%). Approximately 52% of households in risk areas had inadequate sanitary sewers, much higher than the other areas in the 479 municipalities analyzed, which is 17% of households in this condition.

One of the significant characteristics observed from the northern region results was the presence of children in majority (13%), followed by the elderly (6%). In the other regions, the distribution was balanced, around 9% in each age group. This scenario may be related to the higher number of children per family and the lower life expectancy in the localities of this region. Another relevant point is the large number of exposed residents living in households with per capita income of up to half the minimum wage, totaling 138,211 people (62%). Considering the total population of the 37 municipalities evaluated, this percentage was 57%. Thus, when compared with the situation of the municipalities, it can be indicated that the population exposed to risk areas lived in worse economic conditions.

Households in risk areas in the Northern region presented the worst conditions for access to basic services; about 60% with inadequate sanitation, while in all municipalities this figure was 44%. It was estimated that 15,061 households (25%) had no main water supply and 21% had no energy meters, suggesting an irregular connection in these areas. These characteristics indicate the precariousness of households in the region and the high exposure of the population in disaster risk areas. The risk areas of the region are mainly flooded in the Amazon basins and the lack of sanitary exhaustion increases the possibility of contact with solid waste and the negative impact on people's health. In addition, irregular power supply and other forms of water supply are more likely to suffer from seasonality and the impact of adverse events as energy and access to water can be disrupted.

The Northeast region stood out for concentrating approximately 15% of the population of the analyzed municipalities exposed in risk areas, with a total of 2,726,747 people. In the context of metropolitan regions, it was estimated that more than 1.2 million and 631,000 people were exposed in Salvador and Recife Metropolitan Region, respectively. These totals refer to only 4 of the 13 municipalities of the Salvador RM and 11 of the 15 municipalities of the Recife RM.

Regarding household conditions, 33% of them had inadequate sanitary sewers. This percentage was higher than the average found in households at risk in the 479 municipalities analyzed, which indicated that approximately 24% of exposed households did not have adequate sanitation.

Another aspect that deserves attention concerns the economic conditions of the exposed population groups in the Northeast since 55% of the exposed residents lived in households with per capita income of up to half the minimum wage. This percentage was higher than that found for the 479 municipalities evaluated, that is, 43% of the population lived in this economic condition.

It is noteworthy that these two indicators point to the most critical situations of disaster exposure in the Northeast region. It was estimated that 854,012 residents, that is 21% of the exposed population in the Northeast, lived in these critical conditions, with inadequate sanitation and per capita household income up to half the minimum wage. Furthermore, the 32 municipalities analyzed were located in the metropolitan regions of Recife, Fortaleza, Salvador and Leste Alagoano, and had 63% of the population in this condition.

The Southeast region had the largest number of people at risk in Brazil, with an estimated 3,647,990 people living in 16,024 risk areas mapped across 156 critical municipalities. In this region, the main highlight was the economic conditions of population groups living in risk areas, where 36% of exposed population lived in households with per capita income up to half the minimum wage; by observing all the municipalities analyzed, it was found that 20% of the population lived in this condition, showing that in the risk areas of the Southeast had the largest proportion of the poorest stratum of the population.

Conclusion

The results from the evaluation of 479 municipalities, related to the data in intra-urban scale, allowed to realize the social and economic conditions of the population groups exposed in disaster risk areas in Brazil. The data showed two critical and specific situations of the exposed residents: the worst economic situation of the families and the higher concentration of households with inadequate sanitary sewer compared to the situation of the municipalities. Among the municipalities analyzed, 27% of the residents lived in households with per capita income of up to half the minimum wage.

However, when evaluating residents exposed to risk areas specifically, this percentage reached 43%. The results of analysis of the sewage variable also revealed a similar situation, that is, while 17% of households in the 479 municipalities had inadequate sanitation, this figure reached 24% of households in risk areas.

The analysis by Brazilian regions showed specific exposure scenarios. If, on the one hand, the Southeast region concentrated the largest number of people exposed, on the other hand, in the Northeast region, for every 100 residents in the region, 15 lived exposed to the risk of landslides or floods. In the Southeast, it was found that the 38 municipalities assessed in the metropolitan regions of São Paulo, Rio de Janeiro, and Belo Horizonte concentrated 71% of the exposed population of the region. In the southern region, it was found that more than 50% of the population at risk also lived in the large subregions, such as the Vale do Itajaí, Grande Florianópolis, and the metropolitan regions of Curitiba and Porto Alegre.

The method developed by IBGE and Cemaden (2018) shows the potential of using the demographic census data for disaster prevention purposes. Several applications can be performed at other stages of disaster risk management, to help reduce human losses. The possibility of replicating the methodology based on new demographic censuses, allowing temporal monitoring of the data, is another advantage of the method. These aspects reinforce the need for a continuous survey of censuses, to enable the implementation of public policies on disaster risk reduction in the country.

The results could support the identification of areas that require priority actions in the social and economic sectors, relevant to assist in the implementation of regional public policies that promote the reduction of human losses in the country. In addition, the results also showed that it is necessary to articulate with other public policies related, for example, to housing, sanitation, and education, in order to reduce the risk of disasters in Brazil.

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References

ALHEIROS, M. M.; SOUZA, M. A. A.; BITOUN, J.; MEDEIROS, S. M. G. M.; AMORIM JÚNIOR, W. M. **Manual de ocupação dos morros da região metropolitana do Recife**. Programa Viva o Morro, 1ª ed. FIDEM, Recife, 360p, 2003.

ALMEIDA, L. Q. Vulnerabilidade social aos perigos ambientais. **Revista da ANPEGE**, 6(06), 151-176, 2010. https://doi.org/10.5418/RA2010.0606.0010

ALMEIDA, L. Q.; WELLE, T.; BIRKMANN, J. Disaster risk indicators in Brazil: A proposal based on the world risk index. **International Journal of Disaster Risk Reduction**, 17, 251-272. 2016. https://doi.org/10.1016/j.ijdrr.2016.04.007

ALVES, H. P. D. F. Vulnerabilidade socioambiental na metrópole paulistana: uma análise sociodemográfica das situações de sobreposição espacial de problemas e riscos sociais e ambientais. **Revista Brasileira de Estudos de População**, 23 (1), 43-59, 2006. https://doi.org/10.1590/S0102-30982006000100004

ARMESTO, R. C. G. **Caderno 4: ação da água da chuva no planeta Terra**. Parte 2. 2012. Available in: <http://www.cprm.gov.br/publique/media/cadernoIV_17_09_2012.pdf>. Acessed: March 12, 2015

ASSIS DIAS, M. C.; SAITO, S. M.; FONSECA, M. R. S. Aplicação de dados censitários para caracterização da população exposta em áreas de risco de deslizamentos em Blumenau, Santa Catarina. Available in: <http://www.seer.ufu.br/index.php/revistabrasileiracartografia/article/view/44040>. Acessed: June 19, 2018. **Revista Brasileira de Cartografia**, 69(1), 2017.

ASSIS DIAS, M. C.; SAITO, S. M.; DOS SANTOS ALVALÁ, R. C.; STENNER, C.; PINHO, G.; NOBRE, C. A.; LIMA, C. O. Estimation of exposed population to landslides and floods risk areas in Brazil, on an intra-urban scale. **International Journal of Disaster Risk Reduction**, 31, 449-459. 2018. https://doi.org/10.1016/j.ijdrr.2018.06.002

AVILA, M. R. R.; MATTEDI, M. A. Desastre e território: a produção da vulnerabilidade a desastres na cidade de Blumenau/SC. **Revista Brasileira de Gestão Urbana**, v. 9, n. 2, 2017. http://dx.doi.org/10.1590/2175-3369.009.002.ao03

BLAIKIE, P.; CANNON, T.; DAVIS, I.; WISNER, B. **At risk: natural hazards, people's vulnerability and disasters**. Routledge. 2004

BRASIL. Lei 12796. **Altera a Lei no 9.394, de 20 de dezembro de 1996**, que estabelece as diretrizes e bases da educação nacional, para dispor sobre a formação dos profissionais da educação e dar outras providências. Brasília: Presidência da República, 2013. Available in: <http://www.planalto.gov.br/ccivil_03/_Ato2011-2014/2013/Lei/L12796.htm#art1, 2013>. Acessed: June 14, 2016.

BRASIL**. Lei nº 10.741, de 1º de outubro de 2003**. Dispõe sobre o Estatuto do Idoso e dá outras providências. Diário Oficial da União. 2003. Available in: <http://www.planalto.gov.br/ccivil_03/leis/2003/l10.741.htm>. Acessed: October 11, 2018.

BRASIL. Ministério da Integração Nacional. Publicações: **COBRADE: codificação, classificação, definição e simbologia dos desastres.** Available in: <http://www.mi.gov.br/publicacoes-sedec>. Acessed: August 28, 2017.

CARDOSO, A. L. Risco urbano e moradia: a construção social do risco em uma favela do Rio de Janeiro**. Cadernos Ippur**, v. 20, n. 1, p. 27-48, 2006.

CARMO, R. L. Urbanização e desastres: desafios para a segurança humana no Brasil. In: Carmo, R. L.; Valencio, N. (Org.). **Segurança Humana em contextos de desastres**. 1ed.São Carlos: Editora Rima, , p.1-14. 2014. Available at: <https://www.nepo.unicamp.br/publicacoes/livros/segurancahumana/segurancahumana.pdf>. Acessed: November 10, 2018;

CARVALHO, C. S.; MACEDO, E. S. D.; OGURA, A. T. **Mapeamento de riscos em encostas e margem de rios**. Brasília: Ministério das Cidades, 2007.

Cemaden (2019). **Municípios monitorados.** Available in: <https://www.cemaden.gov.br/municipios-monitorados-2/>. Acessed: June 10, 2019.

COSTA F, S. C.; PIMENTEL M. A. Integrated Flood Risk Management And Local Communities In Portugal And Brazil: Theoretical Contributions. **Geograpphy Papers**, 2017,63. http://dx.doi.org/10.6018/geografia/2017/294901

CPRM. **Setorização de riscos**. Available in: http://www.cprm.gov.br/publique/Gestao-Territorial/Geologia-de-Engenharia-e-Riscos-Geologicos/Setorizacao-de-Riscos-Geologicos-4138.html. Acessed: June 9, 2019.

CRED-UNISDR. (2015). **The human cost of weather related disasters** - 1995-2015. Available in: https://www.unisdr.org/files/46796_cop21weatherdisastersreport2015.pdf. Acessed: March 16, 2017.

CUTTER, S. L. A ciência da vulnerabilidade: modelos, métodos e indicadores. **Revista Crítica de Ciências Sociais**, n. 93, p. 59-69, 2011. https://doi.org/10.4000/rccs.165

DEBORTOLI, N. S.; CAMARINHA, P. I. M.; MARENGO, J. A.; RODRIGUES, R. R. An index of Brazil's vulnerability to expected increases in natural flash flooding and landslide disasters in the context of climate change. **Natural Hazards**, 86(2), 557-582. 2017. https://doi.org/10.1007/s11069-016-2705-2

DESCHAMPS, M. Estudo sobre a vulnerabilidade socioambiental na Região Metropolitana de Curitiba. **Cadernos Metrópole**, 1(1), 191-219. 2008. https://doi.org/10.1590/8716

GOERL, R. F.; KOBIYAMA, M.; PELLERIN, J. R. G. M. Proposta metodológica para mapeamento de áreas de risco a inundação: estudo de caso do município de Rio Negrinho–SC. **Boletim de Geografia**, 30(1), 81-100, 2012. http://dx.doi.org/10.4025/bolgeogr.v30i1.13519

GONÇALVES, C. D. "Desastres naturais". Algumas considerações: vulnerabilidade, risco e resiliência. **Territorium**, [S.l.], n. 19, p. 5-14, dez. 2012. ISSN 1647-7723. Available in: <https://impactum-journals.uc.pt/territorium/article/view/3067>. Acessed: June 9, 2019.

HALLEGATTE, S.; VOGT-SCHILB, A.; BANGALORE, M.; ROZENBERG, J. **Unbreakable: Building the Resilience of the Poor in the Face of Natural Disasters. Climate Change and Development**. 2017. Washington, DC: World Bank. World Bank. Available in: <https://openknowledge.worldbank.org/handle/10986/25335>. Acessed: November 19, 2018.

HUMMELL, B.M.L. CUTTER, S.L. EMRICH, C.T. Social vulnerability to natural hazards in Brazil. **International Journal of Disaster Risk Science** 7: 111, 2016. https://doi.org/10.1007/s13753-016-0090-9,

IBGE . **Metodologia do censo demográfico 2010**. Rio de Janeiro: IBGE. 720 p.ISBN 978-85-240-4309-3. Available in: <https://biblioteca.ibge.gov.br/visualizacao/livros/liv95987.pdf>. 2010. Acessed: July 10, 2018.
IBGE (2010). **Sinopse do censo demográfico**. Available in: <https://ww2.ibge.gov.br/censo2010/apps/sinopse/index.php?dados=10&uf=00>, 2010. Acessed: July 10, 2018.
IBGE (2016) **Base de Faces de Logradouros do Censo 2010**. Available in: <ftp://geoftp.ibge.gov.br/recortes_para_fins_estatisticos/malha_de_setores_censitarios/censo_2010/base_de_faces_de_logradouros> , 2016. Acessed: July 10, 2018.
IBGE e Cemaden (2018). **População em áreas de risco no Brasil**. Available in: <https://www.ibge.gov.br/geociencias-novoportal/organizacao-do-territorio/tipologias-do-territorio/21538-populacao-em-areas-de-risco-no-brasil.html?=&t=acesso-ao-produto>. Acessed: September 15, 2018.
JACOBI, P. R.; MOMM-SCHULT, S. I.; BOHN, N. Acción y reacción. Intervenciones urbanas y el papel de las instituciones en post-desastre en Blumenau (Brasil). **Revista EURE-** Revista de Estudios Urbano Regionales. 2013 Jan 2, 39(116). Available in: <https://www.eure.cl/index.php/eure/article/view/227/576>. Acessed: April 10, 2017.
LIU, X.; YUE, Z. Q.; THAM, L. G.; LEE, C. F. Empirical assessment of debris flow risk on a regional scale in Yunnan Province, southwestern China. **Environmental Management**, 30(2), 249-264.; 2002. https://doi.org/10.1007/s00267-001-2658-3
LONDE, L. R.; MOURA, L. G.; COUTINHO, M. P.; MARCHEZINI, V.; SORIANO, E. (2018). Vulnerabilização, Saúde E Desastres Socioambientais No Litoral De São Paulo: Desafios Para O Desenvolvimento Sustentável. **Ambiente & Sociedade**, 21, e01022. https://dx.doi.org/10.1590/1809-4422asoc0102r2vu18l1ao
MARANDOLA JR, E.; HOGAN, D. J. Vulnerabilidades e riscos: entre geografia e demografia. **Revista Brasileira de Estudos de População**, 22(1), 29-53. 2005. DOI: http://dx.doi.org/10.1590/S0102-30982005000200009
MARANDOLA JR, E.; DANTONA, A. O. Vulnerabilidade: problematizando e operacionalizando o conceito. **Segurança humana no contexto dos desastres**. 1ed São Carlos: RiMa, p. 45-61, 2014.
MARCHEZINI, V.; WISNER, B. Challenges for vulnerability reduction in Brazil: insights from the PAR framework. In: MARCHEZINI, V. et al. Challenges for vulnerability reduction in Brazil: insights from the PAR framework. **Reduction of vulnerability to disasters: from knowledge to action**. São Carlos: Rima, p. 57-96, 2017.
MAZURANA, D.; BENELLI, P.; WALKER, P. How sex-and age-disaggregated data and gender and generational analyses can improve humanitarian response. **Disasters**, 37, S68-S82. 2013. https://doi.org/10.1111/disa.12013
MENEZES, J. A.; CONFALONIERI, U.; MADUREIRA, A. P.; DE BRITO DUVAL, I.; DOS SANTOS, R. B.; MARGONARI, C. Mapping human vulnerability to climate change in the Brazilian Amazon: The construction of a municipal vulnerability index. **PloS One**, 13(2), e0190808, 2018. https://doi.org/10.1371/journal.pone.0190808
MIRANDOLA, F. A.; DE MACEDO, E. S. Proposta de classificação do Tecnógeno para uso no mapeamento de áreas de risco de deslizamento. **Quaternary and Environmental Geosciences**, 5(1), 2014. https://doi.org/10.5380/abequa.v5i1.34764
NEUMAYER, E.; PLÜMPER, T. The gendered nature of natural disasters: The impact of catastrophic events on the gender gap in life expectancy, 1981–2002. **Annals of the Association of American Geographers**, 97(3), 551-566. 2007. https://doi.org 10.1111/j.1467-8306.2007.00563.x
RONCANCIO, D. J.; NARDOCCI, A. C. Social vulnerability to natural hazards in São Paulo, Brazil. **Natural Hazards**, 84(2), 1367-1383, 2016. https://doi.org/10.1007/s11069-016-2491-x
SAITO, S. M. Vulnerabilidades No Contexto De Sistemas De Alerta De Risco De Desastres. **Revista Gestão & Sustentabilidade Ambiental** 7 (2018): 618-630.

SAMPAIO, T. Q.; PIMENTEL, J.; SILVA, C. R.; MOREIRA, H. F. A atuação do Serviço Geológico Do Brasil (CPRM) na gestão de riscos e resposta a desastres naturais. In: **Anais.. VI Congresso de Gestão Pública – CONSAD**. Brasília, 16 a 18 de abril de 2013. Available in: <http://consad.org.br/vi-congresso-consad-trabalhos-apresentados/>. Acessed: June 9, 2019.

SHADECK, R.; SANTOS, M. S.; SCHNORR, T. M.; PEIXOTO FILHO, G. E. A atuação da secretaria nacional de defesa civil (Sedec) na gestão de riscos e resposta a desastres naturais In: **Anais VI Congresso de Gestão Pública – CONSAD**. Brasília, 16 a 18 de abril de 2013. Available in: <http://consad.org.br/vi-congresso-consad-trabalhos-apresentados/>. Acessed: June 9, 2019.

TORRES, H. D. G. A demografia do risco ambiental. **População e meio ambiente:** debates e desafios. São Paulo: Senac, 53-73. 2000

UN (2006). **Conference Of European Statisticians:** Recommendations For The 2010 Censuses Of Population And Housing. 213p. Available in: <http://www.unece.org/fileadmin/DAM/stats/publications/CES_2010_Census_Recommendations_English.pdf>.

UN (2015). Department of Economic and Social Affairs. **Principles and Recommendations for Population and Housing Censuses**. 316p. Available at: <https://unstats.un.org/unsd/demographic-social/Standards-and-Methods/files/Principles_and_Recommendations/Population-and-Housing-Censuses/Series_M67rev3-E.pdf>.

UNISDR, United Nations International Strategy for Disaster Reduction. (2015). **Sendai framework for disaster risk reduction 2015– 2030**. Available at: <http://www.wcdrr.org/uploads/Sendai_Framework_for_Disaster_Risk_Reduction_2015-2030.pdf>. Acessed: August 19, 2018.

WAMSLER, C.; BRINK, E.; RENTALA, O. Climate change, adaptation, and formal education: the role of schooling for increasing societies' adaptive capacities in El Salvador and Brazil. **Ecology and Society**, 17(2), 2012. http://dx.doi.org/10.5751/ES-04645-170202

ZHANG, N.; HUANG, H.; SU, B.; ZHANG, H. Population evacuation analysis: considering dynamic population vulnerability distribution and disaster information dissemination. **Natural Hazards**, 69(3), 1629-1646, 2013. http://dx.doi.org/10.1007/s11069-013-0767-y