

# Socio-environmental vulnerability in the São Paulo Macro-metropolis' three main metropolitan regions: a socio-environmental indicators analysis indicators analysis

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**Abstract:** In this article, the concept of socio-environmental vulnerability is empirically operationalized, with the objective of analyzing situations of socio-environmental vulnerability on intra-urban scale, in a group of 62 municipalities in the three main metropolitan regions of the Macro-metropolis of São Paulo State. The methodology associates two concepts from the recent literature on vulnerability – one social and the other physical-environmental – through an index that integrates socio-demographic indicators from the 2010 Demographic Census with cartographies of areas susceptible to floods and landslides. The results show that 1.8 million people live in areas with high socio-environmental vulnerability that have significantly worse socioeconomic conditions than areas with low and moderate vulnerability, especially regarding the differences in sewage coverage, in the surroundings of households and in the population living in substandard settlements (slums).

**Keywords:** Socio-environmental vulnerability; socio-environmental indicators; Macro-metropolis of São Paulo State.

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## Introduction

The coming years and decades of the 21st century will see a greater frequency and intensity of extreme weather events, including storms, hurricanes, floods and droughts. In this scenario, socio-environmental vulnerability in urban and metropolitan areas is likely to increase significantly, especially in poor and developing countries such as Brazil. The urban populations of developing countries are also likely to grow significantly up to the middle of the century, further exposing large numbers of urban residents to hazards and vulnerabilities, both in countries in the South as well as in the North (MARTINE; OJIMA, 2013; MOSS et al., 2010; HUQ et al., 2007).

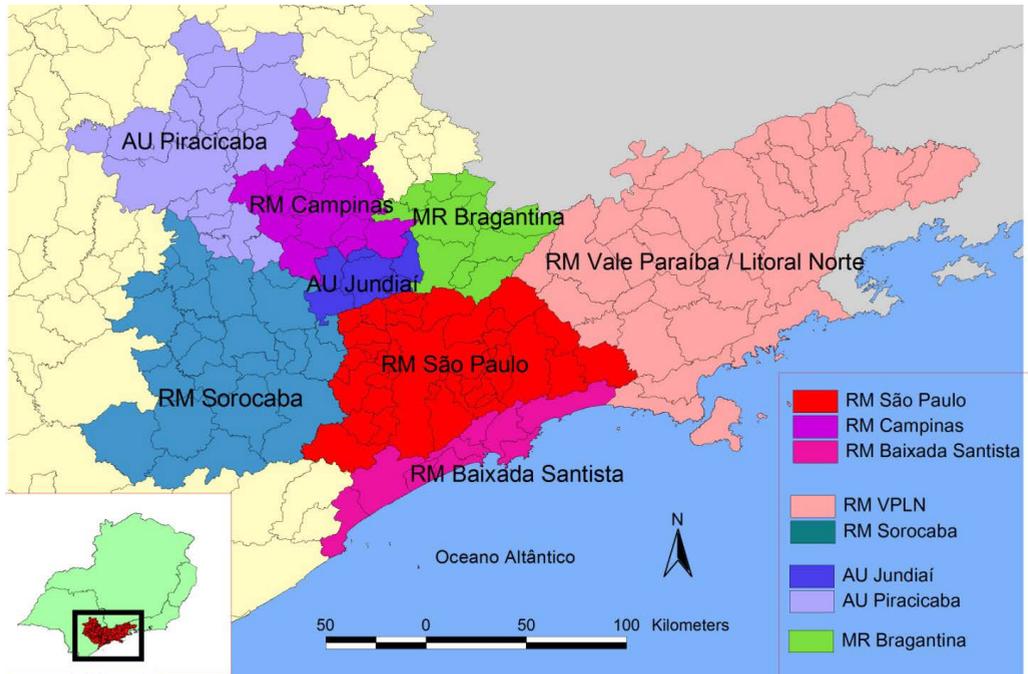
In face of these scenarios, issues of socio-environmental vulnerability pose new challenges in territories much larger than cities and metropolitan regions. According to the São Paulo Agency for Metropolitan Planning (EMPLASA), the Macro-metropolis of the State of São Paulo encompasses the metropolitan regions of São Paulo, Campinas, Baixada Santista, Sorocaba and Vale do Paraíba/Litoral Norte, as well as the urban agglomerations of Jundiaí and Piracicaba. It comprises approximately 180 municipalities within a 200 kilometer radius from the city of São Paulo. Thus, the so-called São Paulo Macro-metropolis (MMP) is the largest and most complex Brazilian urban system. It had 30.5 million inhabitants in 2010, corresponding to 75% of the population and 83% of the GDP of the State of São Paulo, and accounting for 27% of Brazil's GDP. Given its territorial size and socio-economic, demographic and environmental diversity, the São Paulo Macro-metropolis has significant problems and social and environmental vulnerabilities. These are likely to increase considerably in the coming years and decades (JACOBI et al., 2015; EMLASA 2015; Brazilian Institute of Geography and Statistics, 2010; NOBRE; YOUNG, 2011) (Figure 1).

In view of the above, this article develops an empirical operationalization of the socio-environmental vulnerability concept by creating a synthetic indicator (or index). The unit of analysis used for this index is the 2010 demographic census sectors. Our aim is to identify and conduct a spatial analysis of socio-environmental vulnerability at the intra-urban level in 62 municipalities comprising the three main metropolitan regions of the São Paulo Macro-metropolis - São Paulo, Baixada Santista and Campinas. Together, these three regions correspond to 77% of the macro-metropolitan population. This group of 62 municipalities includes the 39 municipalities that make up the São Paulo Metropolitan Region, the 9 municipalities of the Baixada Santista Metropolitan Region and 14 of the 19 municipalities in the Campinas Metropolitan Region (IBGE, 2010; EMLASA, 2015)<sup>1</sup>.

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1 - The complete list of municipalities that constitute the metropolitan regions of São Paulo, Baixada Santista and Campinas can be found in the following links, respectively: <https://emplasa.sp.gov.br/RMSF>, <https://emplasa.sp.gov.br/RMBS> and <https://emplasa.sp.gov.br/RMC>.

**Figure 1. Municipalities, urban agglomerations and metropolitan regions that make up the São Paulo Macro-metropolis**



Sources: IBGE, Digital mesh of municipalities of the State of São Paulo, 2010. EMLASA, 2015.

Note: RM = Metropolitan Region. AU = Urban Agglomeration

### Brief literature review

Amongst the consequences of the acceleration of Brazil's urbanization process, from the second half of the 20th century onward, we can highlight: the creation of metropolitan regions, the verticalization and densification of urbanized areas, as well as urban expansion into peripheral areas. In general, Brazilian metropolises are constituted by a principal city concentrating commercial activities and services, as well as extensive urban peripheries with industrial and residential functions where low-income populations tend to predominate. In the fastest growing period of urbanization, the 1960s and 1970s, nine metropolitan regions were initially created: Belém, Fortaleza, Recife, Salvador, Rio de Janeiro, Belo Horizonte, São Paulo, Curitiba and Porto Alegre. The 1988 Constitution delegated to each Unit of the Federation (states) the responsibility to establish and institutionalize metropolitan areas. Thus, by 2000, 20 new metropolitan regions had been created throughout Brazil. In the State of São Paulo, the metropolitan regions of Campinas and Baixada Santista were established. More recently, we have seen the creation of the Vale do Paraíba/Litoral Norte and Sorocaba metropolitan regions (REIS; TANAKA, 2007; DAVANZO; NEGREIROS, 2006; EMLASA, 2015).

In recent decades, the São Paulo Metropolitan Region as well as other metropolitan regions in the state, have seen strong urban expansion toward the peripheral areas, incorporating vast urban territories into these metropolises. Expressive demographic growth and horizontal expansion of peripheral areas have made them more heterogeneous and have also contributed to the growth of poverty, vulnerability, and social and environmental inequalities. Studies on the Brazilian urbanization process have shown that urban expansion toward peripheral regions is associated to a demand for housing in cheaper areas. A lack of housing options in the private market and inadequate housing policies have led to an increase in precarious settlements, such as slums, and the occupation of irregular and illegal plots of land in areas without urban infrastructure and exposed to hazards and environmental degradation. One of the consequences of these processes is the concentration and intensity of social and environmental challenges in some parts of these metropolitan areas, with spatial overlap of poor socioeconomic indicators with risks of floods, landslides, strong environmental pollution and inefficient or non-existent public services. Thus, some areas in the periphery have a high concentration of negative indicators, with the emergence of “critical points” of social and environmental vulnerability (BONDUKI; ROLNIK, 1982; MARICATO, 1996; TORRES; MARQUES, 2001).

The major processes of expansion and degradation of peripheral areas in the State of São Paulo’s (and Brazil’s) metropolitan regions reveals a growing interdependence of social and environmental issues, such as the overlapping of social and health problems with environmental risks and conflicts. A concept that can be used to analyze the relations and interactions between the social and environmental dimensions of urbanization is socio-environmental vulnerability. This article defines this concept as the co-existence of social vulnerability and physical-environmental vulnerability (or susceptibility) (ALVES, 2006; 2013).

Empirical analyses of the vulnerability concept encompass a variety of perspectives that range from the social to the environmental. Cidade (2013) conducted a literature review of the different focuses of vulnerability, revealing the difficulties in developing a common conceptual basis. The object of the natural sciences is environmental hazards, whilst the social sciences focus on the socioeconomic processes that affect poverty. Thus, social vulnerability and physical-environmental vulnerability are two concepts that represent two distinct points of view and meanings of vulnerability. There has been, therefore, a search for points of convergence that account for both the social and physical-environmental dimensions of vulnerability (LINDOSO, 2017; CIDADE, 2013).

Canil et al. (2020, p. 401) conducted an extensive literature review where they identified two important aspects (or dimensions) of the vulnerability concept. The first is biophysical vulnerability, associated to the hard sciences and engineering. It emphasizes “the impact of the phenomenon in terms of lives, losses and damages”. The second aspect is social vulnerability, associated to the social sciences. It focuses on “the understanding of the internal factors of the system that turns it vulnerable to threats”. Canil et al. (2020, p. 403) also describe three main currents that represent the different conceptual legacies on vulnerability:

I) Risk-Threat (RT): a current that focuses on the aspects that produce vulnerabilities, that is, the material risk and the physical threat produced by exposure or proximity. It is guided by the probability of risk and the quantification of its impact. II) Social Construction of Risk (SCR): this current addresses the conditions of the individuals, groups and communities to long-term stress and specific external critical events. It focuses on the investigation of factors that may increase the capacity of human groups to tackle critical situations and recover from their effects. III) Integrated Approach (IA): this current analyzes the relations between the territory and the threat. It aims to integrate the two approaches above.

In the literature on vulnerability, it is possible to identify versions of vulnerability that are focused on biophysical elements, social perspectives or approaches that seek to integrate both dimensions. Thus, the concept of socio-environmental vulnerability can be listed within this third group that seeks to integrate both the social and the environmental dimensions of vulnerability. Furthermore, it is important to highlight that:

In sociological approaches on this topic (MOSER, 1998; KAZTMAN et al., 1999), *social vulnerability* is analyzed in relation to individuals, families and social groups. Whereas in geography and in studies about risks and natural hazards (CUTTER, 1996), *environmental vulnerability* is discussed in territorial terms (regions, ecosystems). Thus, the disparity between the two research traditions on *vulnerability*, in terms of scale and type of object of analysis, needs to be considered when constructing a notion of *socio-environmental vulnerability* that aims to integrate both the social and environmental dimensions (ALVES, 2006, p. 47).

Recent decades have seen the growth of social vulnerability studies conducted by academic and governmental institutions. The concept of social vulnerability seeks to improve traditional approaches and the means of measuring poverty that have been based on monetary income and fixed measures, such as the poverty line. Thus, social vulnerability provides a broader perspective to the living conditions of the poorest social groups. It also considers the resources and strategies families deploy to address the impacts of the situations in which they find themselves (MOSER, 1998; KAZTMAN et al., 1999).

By contrast, studies about natural hazards and risk assessment gave rise to the notion of physical-environmental vulnerability. The physical-environmental approach to the concept of vulnerability has been mainly deployed in studies on natural hazards. Their aim is to identify areas at risk, by mapping susceptibility to natural hazards. These normally include the superimposition of maps of different characteristics of the physical environment such as soil, water, slope, etc. This approach is generally associated with engineering, the natural sciences (geology) and physical geography. Physical-environmental vulnerability studies give more emphasis to physical environmental characteristics and do not investigate in depth the social processes that interact with this environment

(CUTTER, 1996; MARANDOLA; HOGAN, 2004; LOPES, 2006; NASCIMENTO, et al., 2018). In these studies, the main focus is the susceptibility dimension, which can be defined as “a predisposition or propensity of land to the development (...) of physical processes that can generate natural hazards” (CPRM, IPT, 2014, p.3-4).

In recent decades the concept of vulnerability has acquired importance for scientific communities studying climate change and global environmental changes. In respect to climate change, the most common definition of vulnerability is that of the Intergovernmental Panel on Climate Change (IPCC). According to the 2007 IPCC report, vulnerability is the susceptibility and the inability of a system to cope with the adverse effects of climate change. Therefore, based on the IPCC definition, vulnerability has three components (or dimensions): the level of exposure, susceptibility and the ability to adapt. Exposure refers to the source of the disturbance. It is an element that is external to the system under analysis. Susceptibility relates to the internal characteristics of the system that make it more or less sensitive to a particular stimulus. Whereas capacity to adapt is the ability of the system to recover from environmental disturbances (IPCC, 2007; LINDOSO, 2017).

According to Lindoso (2017), in the literature there are different interpretations of susceptibility, exposure and vulnerability. This reveals the great complexity and multidimensionality of the concepts of social and biophysical vulnerability. This article will give more emphasis to the susceptibility dimension. Thus, the two dimensions of the concept of socio-environmental vulnerability represent two types of susceptibility, social (of the population) and physical-environmental (of the territory). In this way, the exposure dimension is also present, in that socially vulnerable populations are, in theory, more exposed to environmental hazards as they live in regions that are more susceptible to floods and landslides.

Given this brief literature review, it is important to develop indicators, methodologies and analyses that allow us to identify, characterize and measure the different levels of socio-environmental vulnerability in the São Paulo Macro-metropolis and other urban and metropolitan areas in Brazil. This can be done by identifying and characterizing the areas that are most susceptible to natural hazards and the population groups that are more vulnerable and, in this way, complementing qualitative information from Civil Defense bodies. This can contribute to policies of environmental disaster prevention and climate change adaptation (BRAGA et al., 2006; CARMO; VALENCIO, 2014).

## Methodology

In this study, the two meanings of the vulnerability concept are operationalized. The social vulnerability of the population, social groups, families and households, even if this is measured through the aggregation by areas (census sectors) of data from the 2010 demographic census and IPVS. And physical-environmental vulnerability, which refers to the fragility or susceptibility of the territory to physical processes that can lead to natural disasters, such as landslides and floods. That is, here susceptibility to landslides and floods is a proxy for the notion of physical-environmental vulnerability.

In places where there is a spatial overlap of social vulnerability areas (sectors) with physical-environmental vulnerability areas (susceptible to landslides and floods), socio-environmental vulnerability occurs. This overlapping is identified and measured by the spatial superimposition of two types of digital maps: 1) The Brazilian Geological Service's geotechnical cartographies of susceptibility to gravitational mass movements and floods and 2) The digital mesh of census sectors sourced from the 2010 IBGE Census. Both these maps encompass the 62 municipalities of the three main metropolitan regions of the São Paulo Macro-metropolis.

The main methodological procedures are described below. The aim is to operationalize the socio-environmental vulnerability concept by combining the two dimensions of vulnerability - social and environmental - in order to generate a 'socio-environmental vulnerability index'. First, physical-environmental vulnerability (susceptibility) was operationalized by means of an indicator that represents a percentage of the territory superimposed on areas of greater environmental susceptibility using census sectors as units of analysis. In this work, the following are considered to constitute environmental susceptibility: areas susceptible to gravitational mass movements (landslides and mass flow) and/or floods (CPRM; IPT, 2014).

First, the Geotechnical Susceptibility and Gravitational Mass Movement and Floods Cartographies were downloaded from the Brazilian Geological Service site<sup>2</sup> for the 62 municipalities in the three main MMP metropolitan regions, excluding the five municipalities of the metropolitan region of Campinas - Indaiatuba, Monte-Mór, Santa Bárbara, Valinhos and Vinhedo - for which there were no susceptibility data available in the site. Only the areas with high and medium susceptibility to gravitational mass movements (landslides) and floods for each of these 62 municipalities were selected. The areas defined as highly susceptible (to landslides and floods) generally concentrated most of the occurrences of these events. Areas of medium susceptibility encompassed the other occurrences of these two events, and areas of low susceptibility corresponded to the other areas of the municipalities where these events were very unlikely to occur (CPRM, IPT, 2014).

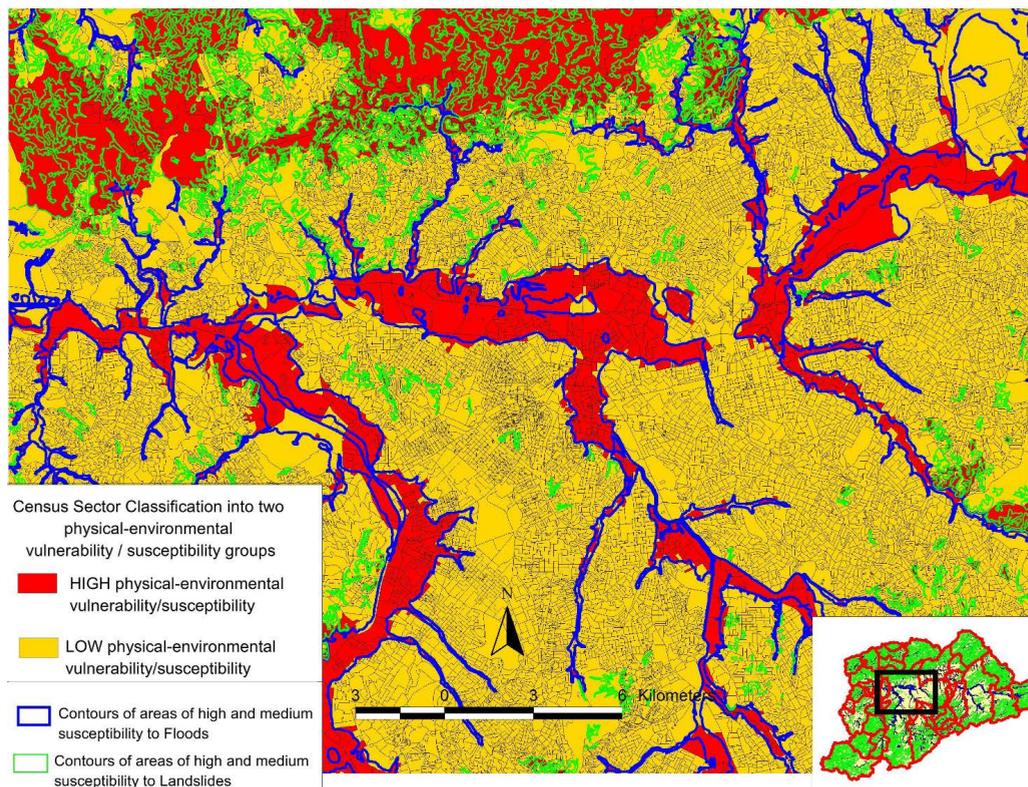
In order to produce the physical-environmental vulnerability (susceptibility) indicator, the digital spatial cartographies of high and medium susceptibility areas selected were superimposed onto the census sectors digital mesh derived from the 2010 IBGE Census for the 62 municipalities mentioned above, by using a Geographic Information System. The size and proportion of the area of each census sector superimposed onto environmental susceptibility areas was calculated. This provided a continuous quantitative variable that measures the percentage of the census sector territory that is made up of areas of high and medium susceptibility to landslides and/or floods. Finally, this continuous variable was converted into an ordinal categorical variable made up of two categories (groups), using the following criteria: 1) sectors with more than 50% of their territory made up

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2 - <http://www.cprm.gov.br/publique/Gestao-Territorial/Prevencao-de-Desastres/Cartas-de-Suscetibilidade-a-Movimentos-Gravitacionais-de-Massa-e-Inundacoes---Sao-Paulo-5088.html>

of areas of high or medium susceptibility to landslides and/or floods were classified as having high physical-environmental vulnerability; and 2) sectors where less than 50% of their territory made up of areas of high and medium susceptibility to landslides and/or floods were classified as having low physical-environmental vulnerability (see Figure 2).

**Figure 2.** Spatial overlapping of the cartographies of areas of high and medium susceptibility to landslides and floods onto the digital mesh of the 2010 IBGE census sectors of the 62 municipalities of the São Paulo Macro-metropolis' three main metropolitan regions (parts of the municipalities of São Paulo, Guarulhos and Osasco, 2010)



Sources: Brazilian Geological Service, Geotechnical susceptibility to gravitational mass movements and floods cartographies. IBGE, Digital mesh of the census sectors of the 2010 Demographic Census.

Note: In Figure 2 only some parts of the municipalities of São Paulo, Guarulhos and Osasco can be seen. This is to ensure better visualization of maps showing areas of high and medium susceptibility to landslides and floods superimposed onto the digital mesh of the 2010 IBGE census sectors. It is important to observe that all the analyses in this article include the 62 municipalities of the three main MMP metropolitan regions.

In order to operationalize social vulnerability, the São Paulo Index of Social Vulnerability (IPVS) was used. It is produced by the São Paulo State Foundation for Data

Analysis (SEADE), based on the 2010 IBGE Demographic Census findings. The 2010 IPVS is a typology of exposure to social vulnerability, represented in two dimensions - socioeconomic and family life cycle - by means of indicators such as household income per capita, the number of minor children, literacy and head of household's age and gender (SEADE 2013).

According to the 2010 IPVS methodology, all the census sectors of the State of São Paulo with at least 50 private households were classified into 7 vulnerability groups. Among the 62 municipalities of the three main MMP metropolitan regions, 91% of census sectors fell within this criterion (at least 50 private households) and were classified in one of the seven social vulnerability groups.

For this study's methodology, it was decided that the 7 IPVS groups would be re-organized and aggregated into two larger groups, referred to as high and low social vulnerability, bringing together groups with similar levels of socioeconomic vulnerability. Thus, IPVS groups 1, 2 and 3 were reclassified as having low social vulnerability - groups with high or mid-range socioeconomic status. IPVS groups 4, 5, 6 and 7 were reclassified as having high social vulnerability - groups with low socioeconomic status. If, on one hand, aggregation and re-classification reduces the diversity of social vulnerability situations, on the other, it makes the comparison between the groups much easier. It also simplifies any subsequent data cross-referencing exercise conducted with the two environmental vulnerability/susceptibility groups (SEADE, 2013).

Finally, the 'socio-environmental vulnerability index' (SEVI) was produced by combining the two socio-environmental dimensions - social vulnerability and environmental susceptibility/vulnerability. It consists of an ordinal categorical variable with four categories/groups, as described in Box 1.

**Box 1: Developing the socio-environmental vulnerability index by combining the environmental susceptibility and social vulnerability dimensions**

Dimensions		Socio-environmental vulnerability Index
Physical-environmental vulnerability/susceptibility LOW physical-environmental vulnerability/susceptibility	Social vulnerability LOW social vulnerability	
HIGH physical-environmental vulnerability/susceptibility	LOW social vulnerability	MODERATE with high environmental susceptibility (Group 2)
LOW physical-environmental vulnerability/susceptibility	HIGH social vulnerability	MODERATE with high social vulnerability (Group 3)

HIGH physical-environmental vul- nerability/susceptibility	HIGH social vulnerability	HIGH (Group 4)
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Sources: SEADE, São Paulo Social Vulnerability Index (IPVS 2010). Brazilian Geological Service, Geotechnical susceptibility to gravitational mass movements and floods cartographies. IBGE, Digital mesh of the census sectors of the 2010 Demographic Census.

The socio-environmental vulnerability index allows for the development of an intra-urban (census sectors) spatial analysis of the macro-metropolitan space, encompassing 62 municipalities in the three metropolitan regions. It uses a database constituting a set of social and environmental indicators derived from different sources (2010 Census, IPVS, Geological Service) for over 37,000 census sectors. It is important to highlight the analytical and methodological efforts made to integrate both the social and the physical-environmental concepts (or definitions) of vulnerability, each with different theoretical and epistemological traditions.

However, it is also important to note that, for the scale of analysis used in this work (IBGE census sectors), the findings do not allow us to identify risks associated to floods and landslides. In order to assess these risks, it is necessary to use a spatial scale of much greater detail. Therefore, it is worth stressing that the aim of this work is neither to identify flood and landslide risk areas, nor areas from where families and households should be removed. This work's findings only allow us to identify areas (territories) where socially vulnerable populations live and where there is a susceptibility (fragility, propensity) to physical processes that may lead to natural disasters such as floods and landslides.

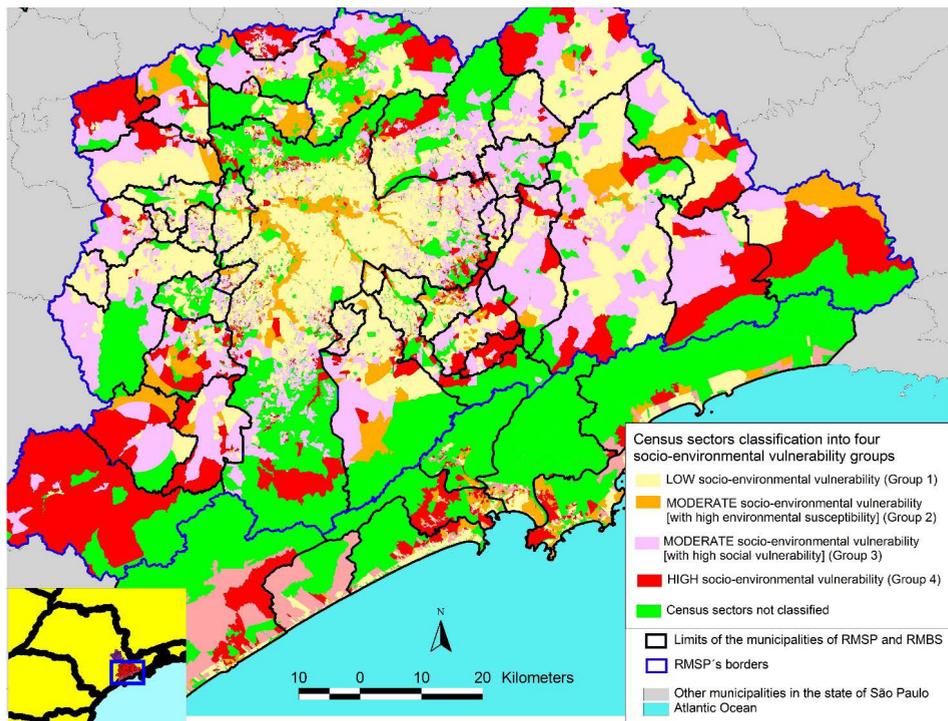
### **Results and discussion: comparative analysis of the four socio-environmental vulnerability groups**

The results of the empirical operationalization of the socio-environmental vulnerability concept are presented by analyzing the socio-environmental vulnerability index. In order to do so, a comparative analysis of the four socio-environmental vulnerability groups (shown in Figure 3) was conducted, with reference to socioeconomic and demographic indicators selected from the 2010 IBGE Demographic Census (see Table 1).

Table 1 shows that the 23.5 million inhabitants (in year 2010) of the 62 municipalities of the São Paulo Macro-metropolis' three main metropolitan regions were distributed as follows in relation to the four socio-environmental vulnerability groups. In the areas (census sectors) with low socio-environmental vulnerability (Group 1) there were, in 2010, 13.5 million inhabitants, corresponding to 57.4% of the population of the MMP's three main metropolitan regions. In areas with moderate socio-environmental vulnerability [with high environmental susceptibility] (Group 2) there were 1.6 million inhabitants (6.7% of the macro-metropolitan population). In the areas with moderate socio-environmental vulnerability [with high social vulnerability] (Group 3) there were 6.4 million inhabitants, or 27.3% of the macro-metropolitan population. Finally, in the

areas with high socio-environmental vulnerability (Group 4), there were 1.8 million inhabitants, that is, 7.6% of the population of the 62 municipalities forming the MMP's three main metropolitan regions (Table 1). It is worth noting, however, that 222,000 inhabitants (less than 1% of the population of the 62 municipalities) were not classified by IPVS and, for this reason, could not be included in the SEVI classification.

**Figure 3: Classification of the census sectors in the 62 municipalities of the São Paulo Macro-metropolis' three main metropolitan regions into the four socio-environmental vulnerability groups (RMSP and RMBS, 2010)**



Sources: SEADE, São Paulo Social Vulnerability Index (IPVS 2010). Brazilian Geological Service, Geotechnical susceptibility to gravitational mass movements and floods cartographies. IBGE, Digital mesh of the census sectors of the 2010 Demographic Census.

Note: Figure 3 only represents the municipalities in the São Paulo (RMSP) and the Baixada Santista metropolitan regions (RMBS). The Campinas Metropolitan Region (RMC) was not included so as to allow for a better visualization of the four socio-environmental vulnerability groups at the intra-urban scale. It is important to note that all the analyses in this article include the 14 RMC municipalities, making up the 62 municipalities of the three main MMP metropolitan regions.

To assist with data description and the interpretation of this article, from here onward, any reference to the São Paulo Macro-metropolis (or MMP) represents the set

of 62 municipalities of the three main metropolitan regions of this Macro-metropolis, as explained in the introduction to this article. Furthermore, we consider “environmental susceptibility” and “physical-environmental vulnerability” to be synonymous (or equivalent).

When the levels of basic sanitation coverage among the four socio-environmental vulnerability groups are compared, it can be seen that waste collection is almost universalized in the São Paulo Macro-metropolis. That is, in all four groups almost 100% of households have waste collection. In relation to water supply, whereas in the two low social vulnerability groups (Groups 1 and 2) almost 100% of households have access to this service, in the two high social vulnerability groups (Groups 3 and 4) less than 96% of households have access to water supply (see Box 1 and Table 1).

In relation to sewage services, there are considerable differences between the four groups. Whereas in areas of low socio-environmental vulnerability (Group 1), 93.4% of households have access to the sewage network, in the areas of high socio-environmental vulnerability (Group 4) coverage falls to 66.5%. This means that a significant number of households, no less than one third of Group 4, have no access to the sewage network. In Group 3 (low environmental susceptibility and high social vulnerability), the percentage of residents in households with access to the sewage network is 73.4%, that is, significantly higher than in Group 4. This shows that the lack of sewage services occurs mainly in households situated in areas where there is a spatial overlap between social vulnerability and environmental susceptibility.

When analyzing the characteristics of the environment around these households, significant differences between the four groups can be observed, in particular between Group 4 and the other groups. As Table 1 shows, in the seven variables related to households' environment (no formal identification of address, lack of public lighting, unpaved streets, streets without sidewalks, treeless streets, open sewers and litter build up), indicators for Group 4 are far worse than for the other groups, especially with regard to treeless streets (43.9% of households), no formal identification of address (33.7%), streets without sidewalks (31.5%), unpaved streets (13.6%) and open sewers (10.3%) (Table 1).

With regard to skin color, the percentage of black or mixed-race people is significantly greater in the two higher social vulnerability groups (3 and 4). They constitute up to 56% of the population in the high socio-environmental vulnerability census sectors. In the low socio-environmental vulnerability group, this percentage is below 30% (Table 1).

**Table 1: Socio-economic and demographic indicators per socio-environmental vulnerability group. Set of 62 municipalities in the São Paulo Macro-metropolis' three main metropolitan regions, 2010**

Socioeconomic and demographic indicators	Socio-environmental Vulnerability			
	HIGH (Group 4)	MODER- ATE High social vulnerability (Group 3)	MODER- ATE High envi- ronmental susceptibility (Group 2)	LOW (Group 1)
Resident population	1,794,787	6,421,511	1,582,968	13,522,538
Number of households	505,906	1,825,494	512,671	4,454,883
Distribution of resident population (%)	7.62	27.27	6.72	57.43
Distribution of total households (%)	6.84	24.69	6.93	60.26
Households with waste collection (%)	98.38	99.21	99.80	99.85
Households with water supply (%)	93.67	95.80	98.27	98.90
Households with sewage supply (%)	66.53	73.42	91.42	93.37
Households with no formal identification of address (%)	33.70	23.26	10.92	8.28
Households with no public (street) lighting (%)	8.82	5.07	1.65	0.96
Household in unpaved streets (%)	13.59	9.31	2.59	1.22
Households in streets without sidewalks (%)	31.53	21.63	6.49	3.97
Households in treeless streets (%)	43.87	35.24	18.94	17.52
Households with open sewers (%)	10.29	7.23	2.51	1.95
Litter build up (%)	8.60	6.23	4.11	2.58
Percentage white people (%)	42.34	45.48	63.24	67.88
Percentage black and mixed-race people (%)	56.19	52.97	35.04	29.62
Up to 4 years of age (%)	8.44	7.96	6.19	5.79
Up to 10 years of age (%)	19.90	18.78	14.23	13.25

Up to 17 years of age (%)	34.37	32.67	24.48	22.92
Households with per capita income of up to 1/4 minimum salary (%)	8.05	6.94	1.86	1.46
Households with per capita income of up to 1/2 minimum salary (%)	29.66	26.96	10.14	8.35
Average household income (reais)	1,373	1,483	3,504	3,779
Average household income (min. sal.)	2.69	2.91	6.87	7.41
Average household income per capita (reais)	386	420	1,130	1,240
Average household income per capita (min. sal.)	0.76	0.82	2.21	2.43
Population in substandard settlements (slums)	712,715	1,570,984	84,082	218,834
Population in substandard settlements (slums) (%)	39.71	24.46	5.31	1.62

Sources: IBGE, 2010 Demographic Census findings and Digital mesh of the census sectors of the 2010 Demographic Census. SEADE, São Paulo Social Vulnerability Index (IPVS 2010). Brazilian Geological Service, Geotechnical susceptibility to gravitational mass movements and floods cartographies.

In terms of age structure of the population, the differences between the four groups are also significant. The high socio-environmental vulnerability areas have a higher concentration of children and young people. While in areas of low socio-environmental vulnerability (Group 1) under-17s make up 22.9% of the population, in high socio-environmental vulnerability areas (Group 4) this figure is much higher (34.4%).

The differences between the four groups are much greater in terms of income. If we take as an example the percentage of households with an average income per capita below half a minimum salary, differences are considerable. In areas of high socio-environmental vulnerability, this figure is significant - 29.7% of households earn below this level in comparison with just 8.4% in areas of low socio-environmental vulnerability. Findings also reveal that there is a wide variation in terms of average household income between groups. Whereas in the low socio-environmental vulnerability areas, the average household income can be up to 3,779 reais (7.4 minimum salaries at 2010 levels), in high socio-environmental vulnerability areas, the average household income is only 1,373 reais (2.7 minimum salaries). The average household income per capita is three times greater in low vulnerability areas (1,240 reais) in comparison with high socio-environmental vulnerability areas (386 reais)

(at 2010 values)<sup>3</sup> (Table 1).

The percentage of people living in substandard settlements (areas with slums characteristics, according to IBGE classification) is a variable that makes the association between social vulnerability and the lack of urban infrastructure explicit and may also reveal environmental susceptibility (TASCHNER, 2000; ALVES, 2013). In areas classified as having high socio-environmental vulnerability (Group 4), no less than 39.7% of the population live in substandard settlements, that is, in areas classified as slums. In areas of high social vulnerability and not susceptible to landslides and floods (classified as Group 3), the percentage of the population living in substandard settlements is much lower (24.5%). In low social vulnerability areas (Groups 1 and 2) very low percentages of the population reside in substandard settlements, only 1.6% in Group 1 and 5.3% in Group 2 (Table 1).

A synthesis of the findings shows that as well as presenting greater concentrations of children and young people, high socio-environmental vulnerability areas (census sectors) have significantly worse socioeconomic characteristics than low socio-environmental vulnerability areas, and even than the intermediary groups of moderate socio-environmental vulnerability (Groups 2 and 3). Among the variables that are most different between areas of high socio-environmental vulnerability and the other three groups, we highlight sewage coverage, the characteristics of the environment around households (no formal identification of address, open sewers, treeless streets, unpaved streets and streets without sidewalks) and most particularly the proportion of the population living in substandard settlements. Furthermore, almost all socioeconomic indicators in high socio-environmental vulnerability areas (Group 4) are worse than those in Group 3, that is, high social vulnerability areas that are not susceptible to landslides and floods.

Thus, findings reveal that in some territories throughout the MMP, environmental susceptibility is strongly associated with, and spatially overlaps, areas of social vulnerability, leading to high socio-environmental vulnerability. One of the main factors that explains this is the large concentration of substandard settlements (slums) in high socio-environmental vulnerability areas. Often, in these areas building is prohibited, as such areas are considered inappropriate for occupation by urban planning and environmental legislation, either because they are areas of environmental hazards, or because they are Permanent Preservation Areas (APPs). Frequently, these (public or private) lands are occupied by precarious settlements that become slums. Furthermore, these high socio-environmental vulnerability areas are often more accessible to the lower income population because they are undervalued by the real estate market, as they are not appropriate for occupation due to a lack of urban infrastructure and their susceptibility to landslides and floods (ALVES, 2006; 2013).

### Final considerations

In this article, the concept of socio-environmental vulnerability was empirically operationalized by developing an index, integrating the socio-demographic indicators from the 2010 IBGE Census with cartographies representing areas susceptible to floods

3 - In 2010 the minimum salary was 510 reais.

and landslides. Its aim was to analyze socio-environmental vulnerability at the intra-urban scale in a set of 62 municipalities in the three main metropolitan regions of the São Paulo Macro-metropolis.

Findings show that certain areas, spread throughout the territory of the MMP's main metropolitan regions, have a strong concentration and spatial overlap of situations of environmental susceptibility and social vulnerability, leading to high socio-environmental vulnerability. The comparative analysis between the four groups showed that high socio-environmental vulnerability areas have significantly worse socioeconomic conditions than areas of low socio-environmental vulnerability and even when compared with the two intermediary groups of moderate vulnerability. This is particularly so in relation to sewage coverage, the characteristics of the environment around households and the percentage of the population living in substandard settlements (slums).

Findings also show that 1.8 million people live in areas classified as highly socio-environmentally vulnerable (susceptible to floods and landslides). These are significant and worrying figures, given the likelihood of increased intensity and frequency of extreme weather events in future years and decades, in a context of climate change (NOBRE; YOUNG, 2011). Therefore, this article aims to contribute to the development of indicators and methodologies to identify and characterize areas of greater susceptibility to natural hazards and the population groups that are most vulnerable, contributing to policies to prevent environmental disasters and foster climate change adaptation in the urban and metropolitan areas of São Paulo Macro-metropolis.

Further, the article seeks to make an empirical and methodological contribution to studies on social and environmental vulnerability in urban areas. It does so by employing a methodology that integrates socio-demographic and environmental indicators, using publicly available data and open software to analyze socio-environmental vulnerability at the intra-urban scale and spatially focusing on a macro-metropolitan area that encompasses 62 municipalities in the three metropolitan regions of the MMP. These methodologies and indicators can be replicated and adapted to other urban and metropolitan areas of the State of São Paulo and Brazil, as they use the digital meshes of census sectors derived from the IBGE 2010 Demographic Census and geotechnical cartographies of susceptibility to gravitational mass movements and floods, available from the Brazilian Geological Service (IBGE, 2010; CPRM; IPT, 2014; ALVES, 2013).

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# Vulnerabilidade socioambiental nas três principais regiões metropolitanas da Macrometrópole Paulista: uma análise de indicadores socioambientais

Humberto Prates da Fonseca Alves

São Paulo. Vol. 24, 2021

*Artigo Original*

**Resumo:** No presente artigo, operacionaliza-se empiricamente o conceito de vulnerabilidade socioambiental, com objetivo de fazer uma análise de situações de vulnerabilidade socioambiental em escala intraurbana, em um conjunto de 62 municípios das três principais regiões metropolitanas da Macrometrópole Paulista. A metodologia procura associar dois conceitos da literatura recente sobre vulnerabilidade – um social e outro físico-ambiental –, por meio de um índice que integra indicadores sociodemográficos do Censo Demográfico 2010 com cartografias de áreas de suscetibilidade a inundações e deslizamentos. Os resultados revelam que 1,8 milhões de pessoas vivem em áreas com alta vulnerabilidade socioambiental, que possuem condições socioeconômicas significativamente piores do que áreas com baixa e moderada vulnerabilidade, com destaque para as diferenças na cobertura de esgoto, no entorno dos domicílios e na população residente em aglomerados subnormais (favelas).

**Palavras-chave:** Vulnerabilidade socioambiental; indicadores socioambientais; Macrometrópole Paulista.

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# Vulnerabilidad socioambiental en las tres principales regiones metropolitanas del Macrometrópolis Paulista: análisis de indicadores socioambientales

Humberto Prates da Fonseca Alves

São Paulo. Vol. 24, 2021

*Artículo original*

**Resumen:** En este artículo, se operacionaliza empíricamente el concepto de vulnerabilidad socioambiental, con el objetivo de analizar situaciones de vulnerabilidad socioambiental a escala intraurbana, en un grupo de 62 municipios de las tres principales regiones metropolitanas del Macrometrópolis Paulista. La metodología busca asociar dos conceptos de la literatura reciente sobre vulnerabilidad – uno social y otro físico-ambiental –, a través de un índice que integra indicadores socio-demográficos del Censo Demográfico de 2010 con cartografías de áreas susceptibles a inundaciones y deslizamientos de tierra. Los resultados revelan que 1.8 millones de personas viven en áreas con alta vulnerabilidad socioambiental, las cuales tienen condiciones socioeconómicas significativamente peores que las áreas con vulnerabilidad baja e moderada, con énfasis en las diferencias en la cobertura de alcantarillado, alrededor de hogares y en la población que vive en aglomerados subnormales (barrios marginales).

**Palabras-clave:** Vulnerabilidad socioambiental; indicadores socioambientales; Macrometrópolis Paulista.

**Como citar:** ALVES, H.P.F. Vulnerabilidad socioambiental en las tres principales regiones metropolitanas del Macrometrópolis Paulista: análisis de indicadores socioambientales. *Ambiente & Sociedade*. São Paulo, v. 24, p. 1-20, 2021.

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## ERRATUM

In the article Socio-environmental vulnerability in the São Paulo Macro-metropolis' three main metropolitan regions: a socio-environmental indicators analysis indicators analysis, with DOI number: <http://dx.doi.org/10.1590/1809-4422asoc20200030r2vu2021L1AO>, published in the journal Revista Ambiente & Sociedade, Vol 24, On page 01

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