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PROPOSAL METHODOLOGY FOR ANALYSIS OF POPULATION VULNERABILITY AT HAZARD AREAS

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ABSTRACT

This work presents a discussion of the methodology used to establish the vulnerability associated with at-risk areas in Santa Maria city. The following were used in order to analyze vulnerability: urban-constructive variables, which define the Urban Vulnerability Index (InVU), in addition to further socio-economic variables and urban densification, which define the Human Vulnerability Index (InVH). The InVU is determined by the Urban-Construction Standard, identified through the analysis of occupation planning, housing characteristics and the available infrastructure. The InVH was determined by an analysis of Socioeconomic Variables and Densification. The socioeconomic variables used are the age range of the population, monthly income and the literacy rate.

Keywords: Vulnerability Index; Risk Situations; Methodology.

RESUMO / RÉSUMÉ

PROPOSTA METODOLOGICA PARA ANÁLISE DA VULNERABILIDADE DA POPULAÇÃO EM ÁREAS DE RISCO

Este trabalho apresenta uma discussão sobre a metodologia utilizada para estabelecer a vulnerabilidade associada às áreas de risco na cidade de Santa Maria. Para analisar a vulnerabilidade, foram utilizados: variáveis urbano-construtivas, que definem o Índice de Vulnerabilidade Urbana (InVU), além de variáveis socioeconômicas e densificação urbana, que definem o Índice de Vulnerabilidade Humana (InVH). O InVU é determinado pelo Padrão de Construção Urbana, identificado através da análise do planejamento de ocupação, características da moradia e infraestrutura disponível. O InVH foi determinado por uma análise das Variáveis Socioeconômicas e da Densificação. As variáveis socioeconômicas utilizadas são a faixa etária da população, a renda mensal e a taxa de alfabetização.

Palavras-chave: Índice de vulnerabilidade; Situações de Risco; Metodologia.

PROPOSITION MÉTHODOLOGIQUE POUR L'ANALYSE DE LA VULNÉRABILITÉ DE LA POPULATION DANS UNE ZONE DE RISQUE

Ce travail présente une discussion sur la méthodologie utilisée pour établir la vulnérabilité associée aux zones à risque dans la ville de Santa Maria. Pour analyser la vulnérabilité, nous avons utilisé: caractéristiques constructives et infrastructures urbaines, qui définissent l'indice de vulnérabilité urbaine (InVU) ajouté aux variables socio-économiques et à la densification urbaine, qui définissent l'indice de vulnérabilité humaine (InVH). L'indice InVU est déterminé par la norme de construction urbaine identifiée par l'analyse de la planification de l'occupation, des caractéristiques du logement et de l'infrastructure disponible. L'indice InVH a été déterminé par une analyse des variables socio-économiques et de la densité d'occupation. Les variables socio-économiques sont obtenues grâce à l'utilisation de la base d'information d'âge de la population; revenu mensuel et taux d'alphabétisation.

Mots-clés: Indice de Vulnérabilité; Situations de Risque; Méthodologie.

INTRODUCTION

When building their spaces, human beings make them suitable to their requirements. These transformations in the configuration of natural spaces, by the action of man, accompany changes related to the interests of the social and economic history of societies and countries. According to Carlos (1994), cities are constructed through the relationships between physical and social factors and should be understood as a process and not only as a form. For Sposito (2011), today's city is a cumulative result of all the other cities that have come before it, transformed, destroyed, rebuilt, and finally produced by the social transformations that have occurred through the ages.

The growth of cities in Brazil from the 1950s onwards has led to a process of disordered land occupation and has accentuated socio-spatial segregation (COSTA,1982). During the occupation of these spaces risk areas have arisen that represent an interaction between the natural and the social environments. Theoretically, natural events are a threat to everyone, but in practice, proportionately, they affect the most disadvantaged (ALCANTARA-AYALA, 2002).

The concept of vulnerability has gained increasing importance in the conceptual field of research on risk areas. The United Nations, through the International Strategy for Disaster Reduction (ISDR), has emphasized in its publications that reducing vulnerability is essential to reduce losses resulting from natural events, especially in developing countries.

The disorderly growth of cities generated mainly by private and speculative interests is considered a precondition for disasters. Poor urban populations, prevented from to access urban resources or unable to protect themselves from adverse environmental conditions are the most affected by the negative impacts of urbanization (Robaina, 2008).

This work presents a discussion of the methodology used to establish the vulnerability associated with risk areas in Santa Maria city, located in the center of Rio Grande do Sul state, 292 km from Porto Alegre, with area of approximately 1,788,129 km² (Figure 1).

According to the population census of 2010, the municipality is made up of more than 260 thousand people, 248,347 of whom reside inside the urban perimeter.

Since the 1960s, the population of Santa Maria has grown rapidly, from 85,000 inhabitants to almost 250,500 in the 2000s. The urbanization of the eastern sector is associated with the creation of the Federal University of Santa Maria (UFSM) and the inauguration of the Santa Maria Air Base in the 1960s. The urban expansion in the western part of Santa Maria was driven by the creation of the Industrial District in the 1970s.

However, the Industrial District did not thrive as expected, so that two concurrent processes occurred in the 1990s: the irregular occupation of the free space resulting from the non-implantation of industries and the transfer of the working class expelled from the more affluent areas (PINHEIRO, 2002).

Currently, the city evidences population densification, especially along the East-West axis, owing to the limitations to urban expansion in the south and southwest, due to the presence of extensive areas under military control and, to the north, because of the slopes of the edge of the Plateau.

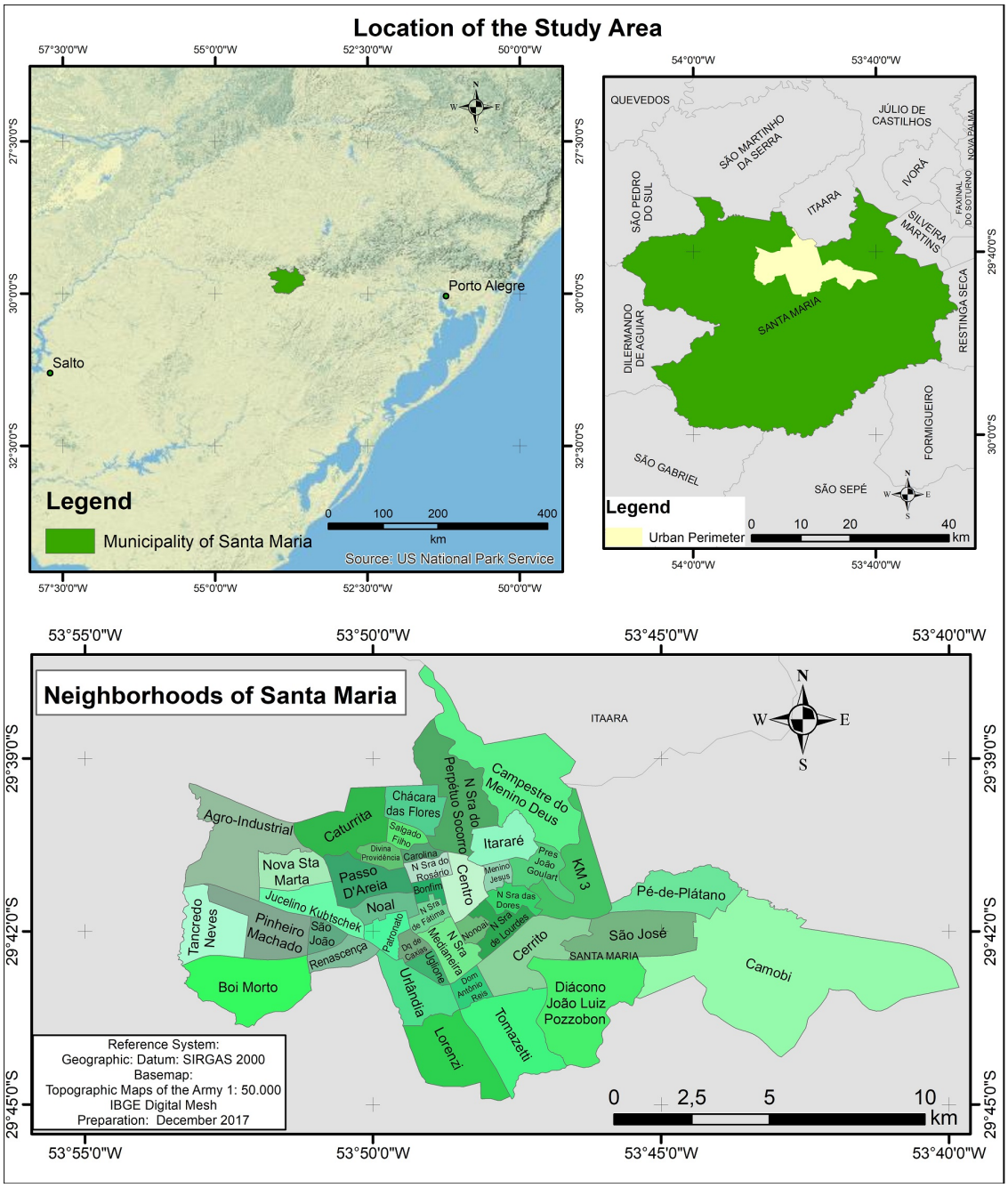

Figure 1: Location map of the urban area of Santa Maria / RS

METHODOLOGICAL PROCEDURES

The survey of the land ownership situation and the occurrence of areas susceptible to flooding and landslides was carried out by municipal government bodies (*Secretaria Municipal de Habitação e Departamento de Regularização Fundiária*) and the Municipal Risk Plan (2006).

Information on the 2010 Census Sectors was obtained from the *Instituto Brasileiro de Geografia e Estatística* (IBGE), through tables (Microsoft Excel) containing detailed information on the socioeconomic situation of the population.

Another important instrument for obtaining information was oral history (Haguette, 1987), which consisted of data collection through informal interviews with residents of the affected areas, collected during field work (Ávila,2015).

The cartographic base was created by the Geotechnical Units of Santa Maria, on the scale 1: 25,000 (Maciel Filho, 1990); political-administrative maps of the city on the scale 1: 15,000; as well as thematic zonings carried out in previous works (Avila & Robaina, 2014; Oliveira, 2004; Robaina et al, 2002).

To elaborate the cartographic database, DigitalGlobe images dated 11th September 2014, obtained from Google Earth Pro, were processed. A total of 50 image cut-outs formed a mosaic of the urban area of Santa Maria, the georeferencing was carried out using ArcGis10 software from the points obtained in Google Earth-Pro 2010 and from points collected in the field with global positioning equipment.

Thematic maps and vector bases obtained through the IBGE (2010) regarding the Census Sectors were also used, as well as general administrative information corresponding to the municipal urban perimeter (neighborhoods, roads, administrative boundary).

All the operations and analysis to compile this spatial information and to create cartographic products were made using Arcgis10 software, developed by ESRI.

RESULTS

Due to their flat relief, the areas located along the watercourses are easily occupied because there is no need for major changes to the terrain, making them attractive to the low-income population. In addition, they are disregarded by speculators, as they are not regulated areas for occupation. The hazards are associated with flooding and erosion of the riverbanks. This scenario includes the areas along the rivers, mainly the Cadena Arroyo and its tributaries (Oliveira, 2004).

In the western region of the city, in the communities located on hillsides, processes related to the headwaters are the most important. On the slopes of the Plateau, there are occupied areas where landslide processes can cause disasters.

ANALYSIS OF POPULATION VULNERABILITY

The concept of vulnerability seeks to translate the foreseeable consequences of a natural phenomenon for humans and society (Cunha & Dimuccio, 2002). For Lavell (1999), vulnerability refers to the propensity of a society or an element of society to suffer harm.

In order to analyze vulnerability, urban-constructive variables were used, which define the Urban Vulnerability Index (InVU), and the socio-economic variables and urban densification that define the Human Vulnerability Index (InVH) using several works as a base (Cutter, 1996; Cutter et al. 2003; Alexander, 2011; Freitas and Cunha, 2013.)

URBAN VULNERABILITY INDEX (INVU)

The InVU is determined by the Urban-Construction Standard identified through an analysis of occupation planning and the characteristics of the housing and the available infrastructure.

The way in which the occupation of urban space takes place is indicative of the degree of a community's organization. Occupations were defined as orderly and disorderly. Communities with a certain organizational level in the occupation of space are better prepared to face risk situations and facilitate the implementation of urban infrastructure and civil defense.

The quality and type of construction of the housing reflect the socioeconomic conditions of its inhabitants and the resistance of the buildings when affected by surface processes. The physical and structural characteristics of the dwellings are observed in relation to: i) housing size (100m²); (ii) the degree of completion of the construction (finished, precarious and unfinished); iii) type of construction material used (recycled, mixed, wood, masonry).

The available infrastructure is represented by a set of public or private installations and services. Two basic characteristics were observed under different conditions to evaluate the urban infrastructure: (i) availability of water and sewage (existing or non-existent) and (ii) type of road pavement (paved or

unpaved).

The sum of the values obtained (Table 1) resulted in four different categories of the InVU: Very High; High; Medium; and Low, as shown in Table 2.

Variable	Characteristics	Value	
Occupations	Orderly	0	
	Disorderly	1	
Housing	housings size	< 50m²	2
		50 –100m²	1
		>100m²	0
	Degree of constructions completion	finished	0
		precarious	1
		unfinished	2
	type of material	masonry	0
		wood	1
		mixed	2
		recycled	3
Infrastructure	availability of water and sewage	existing	0
		non-existent	1
	Road	paved	0
		unpaved	1

Table 1: Urban-constructive variables indicative of vulnerability

Sum	InVU
10 a 9	Very high
8 a 6	High
5 a 3	Medium
2 a 0	Low

Table 2: Urban Vulnerability Index (InVU) and the assigned weights.

HUMAN VULNERABILITY INDEX (INVH)

The InVH was determined by an analysis of Socioeconomic Variables and Densification. Socioeconomic variables were obtained through the database of the 2010 Demographic Census, analyzing the age range of the population, monthly income and literacy rates (Table 3).

Sector data in hazardous areas	Vulnerability indicators	Census Sector (43169070080036)
average household income until 1 monthly basic salary	sum of the population	Population > 10 years = 482 (100%) Population with 1 monthly basic salary = 171 (35%)
% population > 65 years	sum of the population over 65 years	Total population = 598 (100%) Young + seniors =212 (35%)
% population < 15 years	sum of the population less than 15 years	
% Illiteracy Person (>15 years)	Sum illiteracy person	Total Population = 416 (100%) Illiteracy Population = 25 (6%)
number of homes in hazard	% of homes	Total Housing = 161(100%) Hazard's housing = 69 (43%)

Table 3: Data by Census sector and respective vulnerability indicators

As it was possible to carry out *in situ* investigations, the effectiveness of using this basic

information was guaranteed. At-risk areas are distributed over 50 Census Sectors (FIGURE 2).

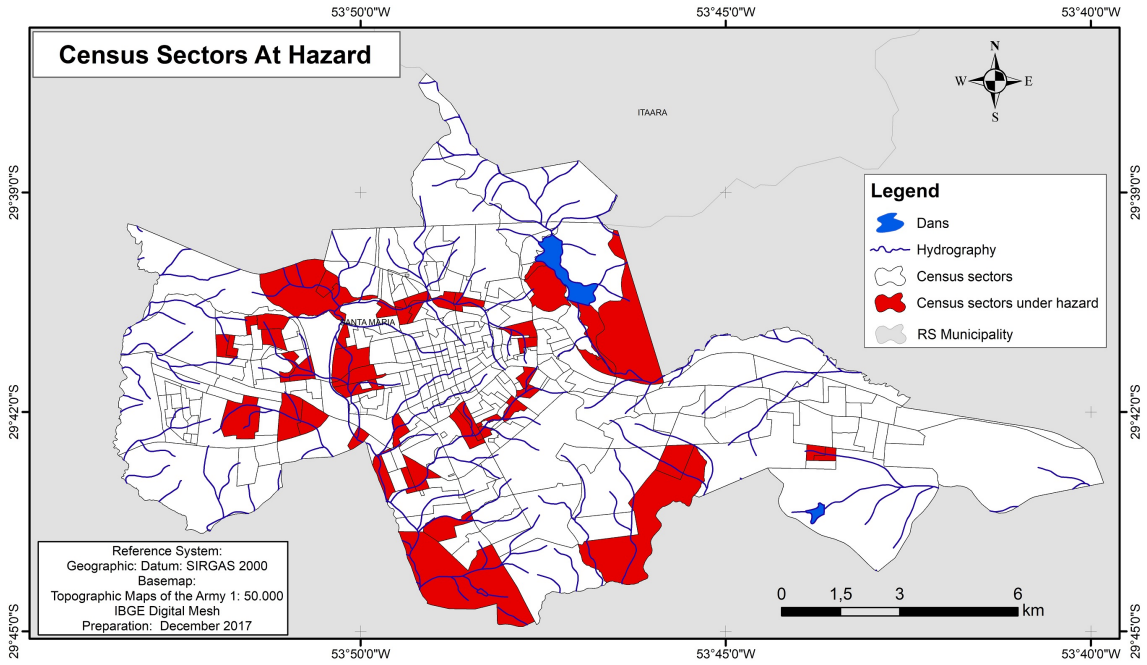

Figure 2: Census sectors at risk due to fluvial dynamics and slope processes.

The age of the population directly influences the capacity to confront disasters; thus, children and the elderly have less capacity to respond due to the difficulty of locomotion, the limitation of the workforce, fragile health and the greater need of assistance. People under the age of 15 and over 65 were defined as the most vulnerable. The basis of calculation was a percentage relation between the sum of the population aged under 15 years and over 65 years and the total population for each sector.

The second variable is the average household income, which defines the capacity to cope, recover and respond. In this sense, the areas with a high degree of vulnerability are found in the Census Sectors where a high percentage of the population receives up to a monthly minimum wage, considering the total population of the sector.

The third variable relates to the level of literacy. For the IBGE, a literate person is one who can read and write a simple note. The issue is associated with vulnerability due to the greater difficulty in understanding the processes causing disasters and the difficulty in disseminating information on prevention and post-accident organization. From this perspective, Census Sectors with high illiteracy rates give the areas under threat high levels of vulnerability.

Urban densification, especially when irregular, impacts on social vulnerability because of the high number of people that can be affected by disasters. Therefore, areas with a large quantity of housing have a greater degree of vulnerability.

The data obtained allowed the determination of vulnerability through (InVH) the following equation:

InVH = RM + SP + PA + NM

Census Sectors Images/field

In which:

RM -% of the population with an income of 1 minimum wage;

SP -% of the population over 65 and under 15 years;

PA -% of illiterate people above 15 years.

NM -% of housing in hazard areas;

The percentage results of each variable were divided into four class intervals (Table 4) and the sum of the values obtained resulted in four different classes of InVH: Very High; High; Medium; and

Low, as shown in Table 5.

Values	% of the population with monthly income of up to 1 basic salary	% of people without literacy above 15 years	% of the population over 65 and under 15 years	% of housing in hazard areas
1	7-15	0,5-2	22,5-26	<3
2	16-24	3-5	27-31	3-6
3	25-33	6-8	31-37	7-9
4	34-40	8-14	37-43	>9

Table 4: Socioeconomic variables and Densification

Sum	InVH
1-4	Low
5-8	Medium
8-12	High
13-16	Very High

Table 5: Classes of InVH

The final result of the vulnerability analysis was obtained through the correlation of InVU and InVH values. The organization and description of the Degree of Vulnerability of areas under threat from natural disasters are presented in Table 6.

InVH	InVU			
	Very high	High	Medium	Low
Very high	Grade IV	Grade IV	Grade III	Grade II
High	Grade IV	Grade IV	Grade III	Grade II
Medium	Grade III	Grade III	Grade II	Grade I
Low	Grade II	Grade II	Grade I	Grade I

Table 6: InVU and InVH correlation to indicate the respective degrees of vulnerability.

USE OF THE METHODOLOGY FOR VULNERABILITY MAPPING FOR NATURAL DISASTERS IN THE WESTERN ADMINISTRATIVE ZONE IN THE CITY OF SANTA MARIA.

The Western administrative zone has nine Census Sectors with areas under threat of disasters, located in four neighborhoods: Nova Santa Marta, João Goulart, Pinheiro Machado and Renascença (Ávila, 2015).

In the region, at-risk areas have a predominance of areas with very high InVH (Grade IV), marked by high rates of elderly / children and incomes lower than the minimum wage (Table 7). The InVU varies from very high to high as a result of the characteristics of the housing (Table 8). This is because the area has been recently occupied, presenting two aspects of conflict over land use and occupation: land ownership regularization and environmental legislation. The Table 9 shows the correlation between the InvH and InVU for these sectors, defining the degree of vulnerability. Figure 3 shows the spatialization of the Census Sectors with the degree of vulnerability.

Sector Code	% of the population with monthly income of up to 1 basic salary	% of people without literacy above 15 years	% of the population over 65 and under 15 years	% of housing in hazard areas	*Sum*	*InVH*
431690705130021	30	6	35	11	3+3+3+4=13	Very high
431690705130022	35	6	32	7	4+3+3+3=13	Very high
431690705130025	36	7,5	36	14	4+3+3+4=14	Very high
431690705130039	27	6,5	35	10	3+3+3+4=13	Very high
431690705130040	33	9,5	40	7	3+4+4+3=14	Very high
431690705130003	22	4	31	11	2+2+3+4=11	High
431690705130010	22	4	23	4	2+2+1+2=7	Medium
431690705130032	26	5	30	7	3+2+2+3=10	High
431690705130027	33	10	37	8	3+4+4+3=14	Very high

Table 7 - InVH of census sector in risk areas in Nova Santa Marta neighborhood

Sector Code	*sum*	*InVU*
431690705130021	9	Very high
431690705130022	8	High
431690705130025	10	Very high
431690705130039	9	Very high
431690705130040	8	High
431690705130003	2	Low
431690705130010	5	Medium
431690705130032	6	High
431690705130027	7	High

Table 8 - InVU of census sector in risk areas in Nova Santa Marta neighborhood

Sector Code	*InVH*	*InVU*	*Vulnerability*
431690705130021	Very high	Very high	Very high
431690705130022	Very high	High	Very high
431690705130025	Very high	Very high	Very high
431690705130039	Very high	Very high	Very high
431690705130040	Very high	High	Very high
431690705130003	High	Low	Medium
431690705130010	Medium	Medium	Medium
431690705130032	High	High	High
431690705130027	Very high	High	Very high

Table 9: Correlation of InVU and InVH to indicate the degree of vulnerability

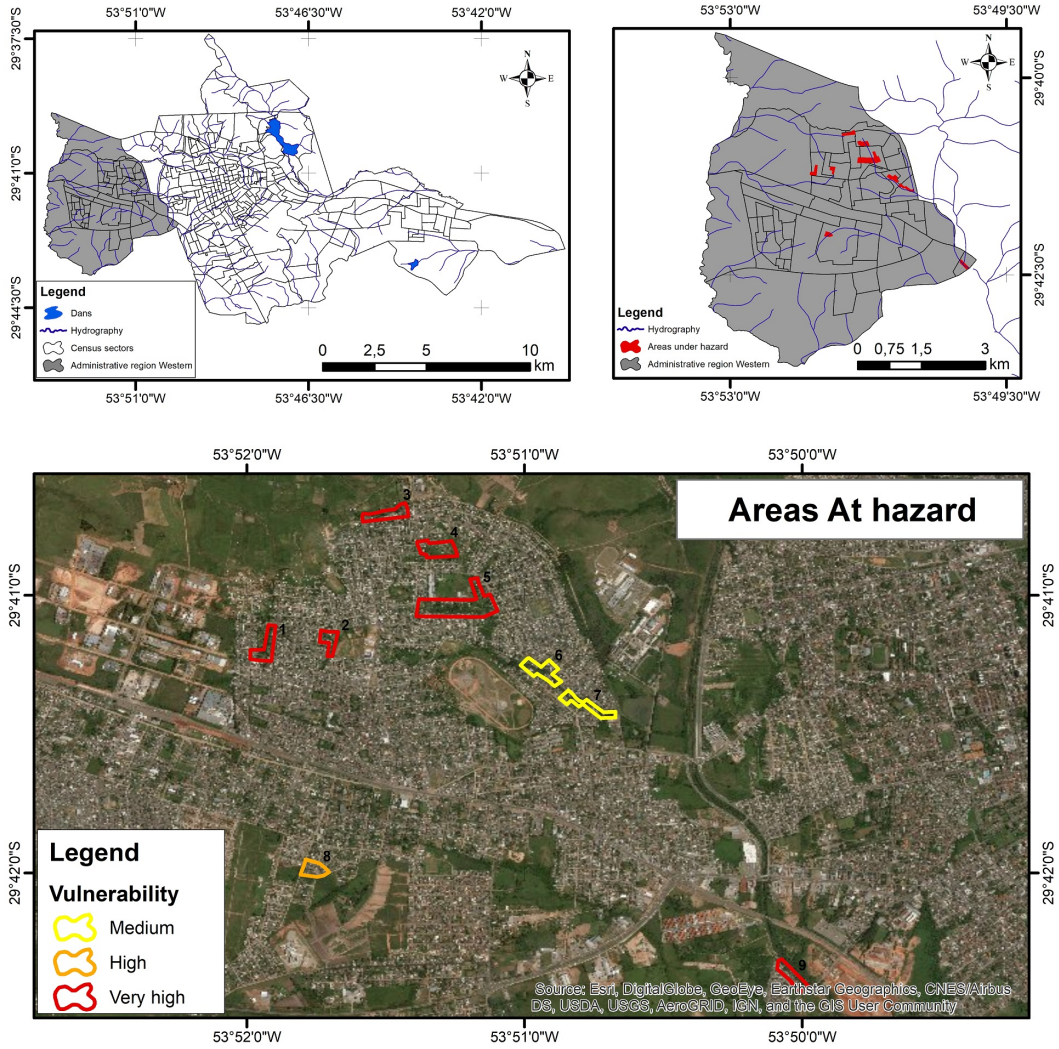

Figure 3: Areas at risk of fluvial dynamics processes, administrative region Western. 1 – Census Sectors: 431690705130021; 2 – 431690705130022; 3 –431690705130039; 4 – 431690705130040; 5 – 431690705130025; 6 –431690705130003; 7 – 431690705130010; 8 – 431690705130032; 9 –431690705130027.

The census sectors codes 431690705130021, 431690705130022, 431690705130025, 431690705130039 and 431690705130040 are located in the Nova Santa Marta neighborhood. In this area hazards are related to the fluvial dynamics associated with the headwaters that correspond to the tributaries of the Cadena Arroyo.

All the Sectors showed very high degrees of vulnerability (Grade IV). As it is a recently occupied area, it has suffered intense of structural, social and environmental modifications. Different levels of intervention occur in the headwaters and arroyos (Figure 4), depending on the socioeconomic condition of each family. However, the findings indicate that, most of the time, this interference is carried out without proper infrastructure and services, accelerating erosion processes, increasing the threats and risks to the population.

Figure 4 - Characteristics of occupation and at-risk situations in Census Sectors 431690705130021, 431690705130022, 431690705130025, 431690705130039 and 431690705130040.

The census sector number 431690705130003, with medium vulnerability, is located next to the Vila Jóquei Clube housing estate, in the Juscelino Kubitschek neighborhood. The area covered by the Sector has around 238 households, of which 25 (11%) are located in the tributaries on the right margin of the Cadena Arroyo and are subject to river dynamics processes.

The classification of the InVU is low, since the area has a well-developed urban structure, with paving in the main streets and a water supply network. The housing is masonry, with dimensions ranging from 50 m² to over 100 m².

The 431690705130010 sector was classified as medium vulnerability of the population. The area has problems related to fluvial dynamics (tributary of the Cadena Arroyo), associated with bank erosion. It is a densely populated sector, but the rate of housing in risk areas is 4%.

The socioeconomic situation, housing and infrastructure characterize InVH and InVU as a medium vulnerability, Figure 5.

Figure 5 - Characteristics of occupation and hazard situations in Census Sectors 431690705130003 e 431690705130010

The Sector 431690705130032 is part of the Vila Ecologia housing unit, adjacent to the Pinheiro Machado neighborhood. Part of the area is susceptible to flooding due to the proximity of the stream (a small tributary channel of the Cadena Arroyo, as shown in Figure 6). Of the 645 households located in this sector, seven percent are in an area under threat of disaster.

Figure 6 - Characteristics of occupation and at-risk situations in Census Sectors 431690705130032.

Sector 431690705130027 is inserted in the Renascença neighborhood, next to the community

with same name, with a population of approximately 450 people, it has a very high InVH and high InVU, characterizing a very high vulnerability. (Figure 7). The hazards are mainly associated with bank erosion.

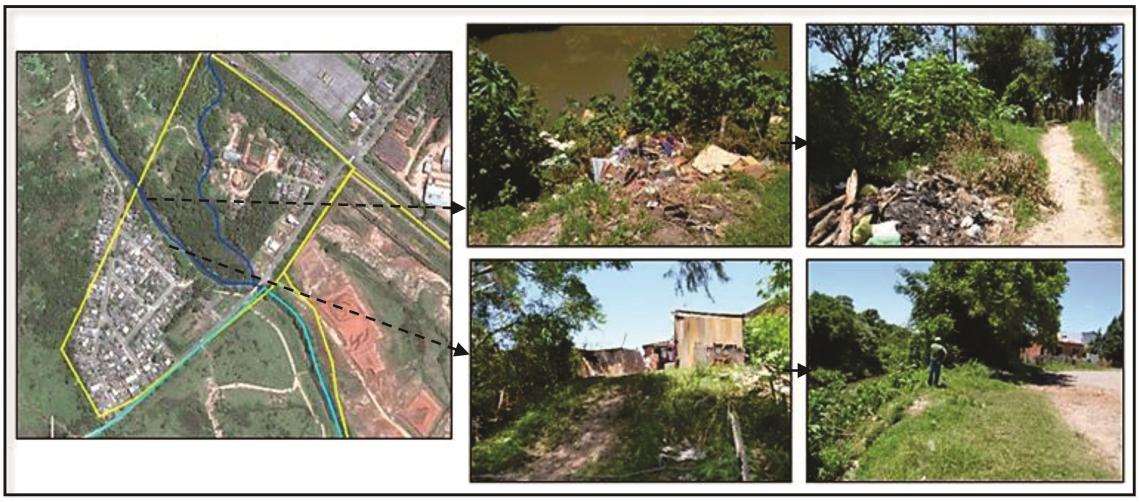

Figure 7: Occupation characteristics and at-risk situations in Census Sector 431690705130027.

CONCLUSION

Santa Maria's urban growth of reveals numerous inequalities, with characteristics in common with many medium-sized cities. The concentration of income and more developed urban services are found in the center; the quality and the area of coverage are reduced as occupation is directed towards the peripheral regions.

Vulnerability is not synonymous with poverty; however, unfavorable socioeconomic situations diminish the chances of recovery after a disaster.

When analyzing the history and the informal interviews, it was found that residents in risk areas are often aware of and clear about the problems they face.

Although they have areas or limits superior to the polygons established for risk, it is possible to affirm that, with good field control, the Census Sectors can be used.

The methodology employed, using socioeconomic data and housing and infrastructure characteristics, enables the population's different degrees of vulnerability to natural disasters to be established, validated by field work.

Studies in other cities should use the same methodology to evaluate the results obtained.

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