Risk Mapping in Urban Areas: Methodological Essay for Sample Area of Santos, São Paulo – Brazil

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Abstract. The mapping of densely urbanized areas is a constant challenge for cartographers and Geoscience professionals that rely on techniques of Digital Cartography and Geographic Information Systems (GIS), mainly due to the high concentration of buildings and the presence of varied urban occupation, housing people from different social statements in confined and reduced urban spaces, which makes difficult the mapping. Currently, there are many studies dealing with the vulnerability and risks supported by Geo-technology. In order to contribute to methodological reflections on the theme, this study proposes to apply established methodologies of Principal Components Analysis (PCA) and Multi-Criteria analysis (MCA), based on SPSS programs and ArcGIS r. 10.2, aiming to integrate thematic maps for studies of vulnerabilities and risks of mass movement in the sample area selected in Santos, SP-Brazil. The methodological procedure corresponded to the different integration techniques supported in Geo-technology, such as the mapping of the Urban Land Use based on interpretation of orthorectified images, the Slope based on 10 m contour lines and the Socio-environmental Vulnerability held by Factor Analysis (FA). The integration of thematic data by Multi-criteria Analysis (MCA) generated a synthesis map of the risk areas, accompanied by the quantitative analysis of the different thematic classes. It can be concluded that the methodology applied brought a qualitative contribution to traditional risk mappings in the area, especially with the contribution of the Land use data and the Socio-environmental vulnerability.

Keywords: Socio-environmental vulnerability, Risk, Geographic Information Systems

1. Introduction

The municipality has occupation features which are common in many urban occupations in countries around the world, whether developed or developing, characterized by the urban containment between the sea and the mountain, composed of an occupation pattern having on the one hand the relief which limits the regular occupation and, on the other hand, suffering the pressure from the population concentration and disorderly growth leading to the occupation of areas of hills and slopes potentially risky for sliding.

In this study, we intend to apply techniques of Digital Cartography and Geographic Information Systems (GIS) in order to contribute to methodological reflections on the theme, through methodologies of Principal Components Analysis (PCA) and Multi-criteria Analysis (MA), based on SPSS programs and ArcGIS r. 10.2. In this perspective, we intend to integrate thematic maps for studies of vulnerabilities and risks of mass movement in the sample area selected in Santos, SP-Brazil.

The economic development of Santos turned it into the principal city of the metropolitan region of Baixada Santista, created by the complementary State law 815, in July 30, 1996. The presence of the Port of Santos has an expressive municipal human development index (IDHM), which was 0.840 in 2010 and a GDP per capita greater than $ 75,000, according to the IBGE (2010). The attractive possibility of work fronts from the Port of Santos creates an expressive population growth, leading the poorest to occupy unsuitable areas. These characteristics lead to the emergence of segregation imposed residential areas which according to Corrêa (2013), are characterized by:

Slums, tenements, modest or poor dwellings built in the volunteer system and housing estates, many of which are recent or deteriorated, located mainly in the periphery or in the hazardous areas or in those already characterized by obsolescence, with precarious or no urban infrastructure, dirty and unsafe, make up the landscape of segregation imposed areas (Correa, 2013, p. 44).

Part of the motivations that lead researchers to develop this study is that mapping such areas considering both the physical and economical aspects, in order to subsidize the public powers, must be done not only in times of disasters, but mainly to meet the socio-economic profile of the population inhabiting such areas.

2. Literature Review

Risk studies based on selected works were developed by researchers in Geotechnologies from Brazil and abroad which allowed an overview of the state of the art and the methodological design of this study.

The main studies of vulnerability based on Geographic Information Systems (GIS) and statistic computer programs emerged in the late 1980's and in the 1990's, mainly with the researches of Blaikie et al. (1994) and Cutter (1996), through the factorial analysis of different variables and indictors, considering varied social, economic, political and cultural dimensions.

An disseminated concept of Vulnerability in the international literature is from Wisner et al. (2003) :

the characteristics of a person or group and their situation that influence their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard (an extreme natural event or process). It involves a combination of factors that determine the degree to which someone's life, livelihood, property and other assets are put at risk by a discrete and identifiable event (or series or 'cascade' of such events) in nature and in society (Wisner et al. 2003).

Another international contributions is from Tacnet, Batton-Hubert and Dezert (2010) who developed a mixed method which includes the application of the Analytical Hierarchy Process (AHP), specifically the Multi-Criteria Decision Analysis (MCDA) and the Belief Function Theory that allows to consider uncertain, imprecise and conflicting information applied to the study of vulnerability and risks arising from mountain river torrents and snow avalanches. According to the authors, different methods exist to support the decision making based on imperfect information. A brief analysis of the characteristics of the existing methods using both MCDA methods and theories for uncertainty management was proposed.

Several theories have been proposed for decision making based on imperfect information. In the cited research ER – MCDA (Evidential Reasoning-Multi Criteria Decision Analysis), which is a combination of multi-criteria decision analysis and fusion of information, was applied. The authors highlighted that the ER – MCDA methodology contributes to the improvement of the traceability and the quality description of the decision making process. The extension of this methodology to spatial applications and especially to hazard and risk zoning maps is recommended.

Another study developed by Pourghasemi, Pradhan and Gokceoglu (2012) had as its main objective the production of landslide susceptibility maps of a landslide-prone at the Haraz watershed in Iran, using both the fuzzy logic

and the analytical hierarchy process (AHP) models. This study yielded thematic maps representing landslide conditioning factors such as degree, plan curvature, altitude, lithology, land use, slope and aspect. Based on such maps the authors produced distance from faults, distance from rivers, distance from roads, slope length (LS), stream power index (SPI), and topographic wetness index (TWI). To develop the Landslide susceptibility mapping the authors opted by using the fuzzy approach. The authors also opted to apply the analytical hierarchy process (AHP) which helps decision makers to find the best solution to the understanding of the problem. The process included several steps: (1) breaking a complex unstructured problem down into its component factors; (2) arranging such factors hierarchically; (3) attributing numerical values according to the relevance; and (4) synthetizing the rating to determine the factors priorities. The mapping included the use of aerial photographs and field works in 78 landslide locations. The authors concluded that:

[...] the results of the fuzzy logic model have shown the best prediction accuracy in landslide susceptibility mapping in the study area. They consider also that the results of landslide susceptibility mapping for the Haraz watershed of Iran is viable, the maps results may be helpful for planners and decision makers to plan actions in this area (Pourghasemi, Pradhan and Gokceoglu, 2012, p. 992).

The projects done in Brazil rely on Geo-technology internationally adopted, such as products of Remote Sensing and Geographic Information Systems (GIS). Examples developed in metropolitan areas since the 1990s were selected, in order to illustrate that even with the landscape diversity of a continental country as Brazil combined with aspects related to hazards and risks are reproduced fairly similar, due to the form of its urban occupation.

The research developed by Valente (1996) presented a methodology for the determination of risk areas with the use of Remote Sensing techniques and Geographical Information System for the watershed of Arroyo Feijó, in the metropolitan region of Porto Alegre RS, for 1993. The study area is characterized by high population density, existence of flood areas and erosion processes. Initially, the events considered dangerous were defined, with the predominance of flooding, preliminary susceptibility to the high and very high laminar erosion and areas with restriction to the urban use due to the low load capacity of soils. In this way, areas with probability of occurrence of hazardous events were identified for the determination of risk areas and, subsequently, its crossing with the urban area. The procedure was carried out in four steps: a) material selection and delimitation of the study area; b) processing and classification of orbital images Landsat/TM5; c) database modeling in SGI-340/INPE with implementation of topographic, pedologi-

cal and lithological data; d) cross-checking on SGI for determining the area with primary susceptibility to laminar erosion, with restriction to the urban use and to the areas prone to hazardous events and risk areas. When compared to traditional methods, the Geo-technology proved suitable for the study, and due to its simplicity, it is possible the continuous and multitemporal updating of data with reduced cost and time.

Christ and Herrmann (2004) developed a methodology applied to the mapping of areas with susceptibility to natural hazards in the watershed area of the River Itacorubi in the East sector of the central portion of the island of Santa Catarina, located in the municipality of Florianopolis SC. The authors applied geo-technologies to analyze areas susceptible to natural hazards arising from the urban expansion, evidenced on the slopes with accentuated declivities subject to landslides and in lowland areas with flat and low relief with occurrence of floods. In the adopted methodological procedures geological, geomorphological, soil, slope, shapes of the relief aspects as well as the land use were characterized. Interpretation of aerial photographs, satellite images and field works supported by Global Position System (GPS) devices were used. Apart from that, thematic maps of the analyzed aspects were drafted and for each identified characteristic a value (weight) was assigned to establish the classes of susceptibilities to natural landslides and flooding risks. The integration of thematic maps using digital processing techniques with the use of the Software Microstation GeoGraphics was accomplished, resulting in the final map of susceptibility. The authors comment that the mapping of areas susceptible to landslides, with different classes of risk hierarchically organized, is an important tool to the prevention of accidents, which enables the planning and the targeting of human occupations to adequate locations.

In the research of Andretta et al. (2013) the areas subject to geological risk in Gilberto Mestrinho, on the East side of Manaus AM were mapped and classified in the context of the project "Mapping of Risk Areas in the City of Manaus", developed by the Geological Survey of Brazil (CPRM). The work was developed with the support of aerial photographs, satellite images, topographic and hydrographic maps, survey of historical events, field analysis with description of soil, geology, geotechnical and anthropic factors which are responsible for the characterization and development of risks. In GIS environment maps of the geological-geotechnical features, anthropic components and the risk sectors were generated according to the classification criteria proposed by the IPT[1]. According to this Institute's methodolo-

[1] IPT – Institute for Technological Research (Instituto de Pesquisas Tecnológicas) - http://www.ipt.br/

gy the degrees of risk are observed and classified in four levels: from very low (R1) to very high (R4) risk level. The results of the research presented 21 areas identified as very high risk, with approximately 1320 dwellings on alert during periods of rain.

Freitas (2013) presented results concerning methodological procedures for the modeling of socio-environmental vulnerability using geo-technologies and presenting case studies in selected areas in Brazil and Portugal. The socio-environmental vulnerability mapping was performed for 17 counties in the Central Region of Portugal and 20 Brazilian municipalities in the State of São Paulo, through a census data collection intended to find indicators for criticality and support capacity. The methodology adopted for the analysis of vulnerability was based on studies by Mendes et al. (2009) and Cunha et al. (2011) of social vulnerability and natural risks for Portugal, having as reference the resilience capacity of populations and territories. The authors highlight the lack of economic dynamism from the counties and the aging of the population as main factors of socio-environmental vulnerability in Portugal. In Brazil the economy and the urban violence are considered as the main factors. Thus, it is possible to conclude that the social and economic factors have strong influence in the territorial differentiation of vulnerability.

These are some examples of the projects developed on the theme that allow observing the methodological possibilities in studies of risk.

3. Material and Methods

Preliminarily to the description of the adopted material and methodology in the project, the characterization of the study area is done. The choice of the study area is due to the fact of the intense urbanization of the municipality of Santos, founded in 1546 and located in the region of Baixada Santista with an area of 280,674 km², population of approximately 419,400 inhabitants and population density of 1,494 .26 (inhab/km²), according to the IBGE (2010). The municipality of Santos is located in the Serra do Mar, a set of cliffs that mark the eastern border of the Atlantic Plateau. Due to the topography and slopes variation, where a large part of the Atlantic forest areas are found surrounded by dense urban occupation, invasions and irregular constructions are historical. Such areas of high contrast are considered a priority in the analysis of vulnerability of natural hazards. In addition, there is a predominance of trade and services in the economic activities of the municipality leveraged by the presence of the port of Santos, the country's main port, opened in 1892, whose movement, in 2013, surpassed the mark of 114 million tons, according to the Port of Santos (2014).

Figure 1 illustrates the location of the study area corresponding to the Sample Area selected in the municipality of Santos (SP).

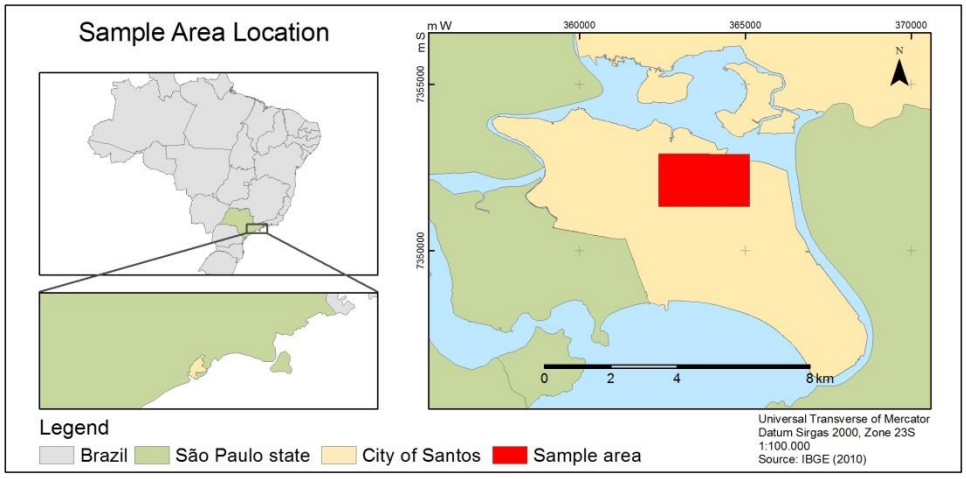

Figure 1. Location of the study area - sample area of Santos (SP).

The material used for the development of the study is related to: a. cartographic documents from the Brazilian Institute of Geography and Statistics (IBGE 1:10,000) and the Municipality (SigSantos 1:1,000); the map of mass movement risks, based on the mapping of risk areas on steepy slopes, with possibility of landsliding from the Technological Research Institute (IPT) 2012, was also used as a reference; b. Orthophotos prepared on the scale 1:

1,000, from the year 2010, produced by EMPLASA[2]. c. for the social and environmental vulnerability mapping, socioeconomic data were collected from the 2010 Census of IBGE; d. The computer programs: statistical program SPSS, GIS ArcGIS r. 10.2 and AutoCAD Map 3D 2014. were used. The adopted methodology was divided in 3 stages, the first one dealt with the social and environmental vulnerability mapping, the second one corresponded to the mapping of physical aspects and the last one was related to the thematic data integration into GIS for the sample area of the municipality of Santos SP.

3.1. The Socio-environmental Vulnerability Mapping

The socio-environmental vulnerability was mapped having as reference the studies of Cutter (1996, 2011) which present integrating methods of physical and social vulnerability for analyses based on local characteristics. Other authors also cited as methodological references are Mendes et al. (2009) and Freitas and Cunha (2013) who adopted the criticality and the support capacity as parameters of the socio-environmental vulnerability mapping through GIS tools.

The vulnerability in this study was obtained through variables related to support capacity and criticality obtained from the 2010 IBGE Census for the municipality of Santos (SP). The map of socio-environmental vulnerability resulted from GIS mathematical operation of the product of the support capacity map with the criticality map, available at Bortoletto et al (2014). The census sector was the data collection unit, later aggregated into neighborhoods.

3.2. Physical Aspects and Urban Land Use Mapping

At this step the urban land use and the slope maps were prepared and the mass movement risk map produced by IPT was selected.

For the elaboration of the Urban Land use Map the following activities were conducted: a) definition of 14 thematic classes of the urban land use and vegetation; b) interpretative analysis of digital orthophotographs from 2010, on 1: 1,000 scale obtained from the Company Emplasa using the program AutoCAD Map (Autodesk); c) vectorization and data conversion in GIS ArcGIS format (shapefile); d) data exporting to ArcGIS; e) drawing up of the map of urban land use by adopting the UTM system and SIRGAS

[2] EMPLASA Company of Metropolitan Planning from State of São Paulo (Empresa Paulista de Planejamento Metropolitano) - http://www.emplasa.sp.gov.br/emplasa/

2000 Datum. It should be pointed out that the thematic class forest does not belong to the multi-criteria analysis for not characterizing a risk area.

For the Slope Map the following procedures were adopted: a. definition of the 6 classes of Slope; b. based on an altimetric representation composed of contours with equidistance of 1 meter and elevations obtained from the project SigSantos from the local government the numerical model of the terrain (MNT) with triangular base (TIN) was drafted; c. transformation of the triangular model (TIN) to raster format; d. calculation of slope on the basis of the spatial analysis tools of GIS ArcGIS; e. reclassification of the map in order to highlight areas with restriction for urban use (d> 30%) according to the Federal law 6766/79; f. preparation of the Inadequate Areas for the Urbanization Map, original scale 1: 1000.

The risk map produced by IPT in the Program of Technological Support to Municipalities (PATEM) and completed in 2012 was elaborated taking into account the risk classes from very low risk (R1) to very high (R4) risk. For the sample area selected on the basis of the topographical features, the type of risk mapped corresponds to mass movement or hillside sliding risk.

3.3 GIS Integration of Thematic Data

At this step the maps of urban land use, slope, risk of IPT and socio-environmental vulnerability were selected, and the sample area was defined motivated by the population concentration in areas of high slope and high vulnerability associated with the highest risk classes of the mapping from IPT.

The methodology for the thematic data integration was the multi-criteria analysis, through the Weighted Linear Combination (WLC). This technique has been chosen due to its effectiveness in combining different factors, criteriously predefined, which correspond to attributes correlated with each other, all of which influencing individually and as a whole.

The advantage of technical flexibility regarding the assignment of weights for classes and for themes must be highlighted, which allows several possibilities of analysis, in the search of a cartographic representation that reflects the local reality. After several attempts for adequate the weights to maps and thematic classes table 1 was obtained which presents the final configuration of subjects, classes and weights adopted for the processing of data in GIS, generating the Synthesis Risk Map of the Sample Area of Santos SP.

It should be noted that once defined the weights and the influences of each thematic class the processing of data in ArcGIS was performed.

Thematic Maps, Classes and Associated Weights			
IPT Risk (Influence: 40%)	**Weight**	**Slope (Influence: 10%)**	**Weight**
R3	4	0-30%	1
R4	5	30-100%	4
Others	2	>100%	5
Vulnerability (Influence: 30%)		**Urban Land Use (Influence: 20%)**	
Very Low	1	Forest	0
Low	1	Standard Housing and Buildings	4
Medium	3	Substandard Housing	5
High	4	Cultivation Areas	3
Very High	5	Grass	2
		Other Uses	1

Table 1. Thematic maps, classes and associated weights in multi-criteria analysis

4. Results

The results achieved with the research are presented in the format of thematic maps and tables. Figure 2 presents the Socio-environmental Vulnerability Map (2a), Urban Land Use (2b), Inadequate Areas for Urbanization (2c) and the Risk Map from IPT (2d). Concerning the Social and Environmental Vulnerability the original map scale is 1: 10,000.

Table 2 presents the percentages of area by each class of vulnerability for the sample area.

Based on Figure 2a, that comprises 12 neighborhoods and an area of 3.13km² from Santos SP, it is possible to observe a predominance of medium (38.4%) and high vulnerability (33.9%) classes. Very high vulnerability areas correspond to 10.6% of the total, and are located mainly in Morro Jabaquara and Morro Penha neighborhoods. The main factors that define the vulnerability of the study area, in accordance with Bortoletto et al (2014) concerning the socio-economic aspects:

[...] Neighborhoods that indicate very high and high vulnerability classes are those which have strong influence of variables relating to the presence of children and youth (0 to 14 years of age), the elderly and the per-capita income. Concerning to territorial conditions infrastructure stand out variables including substandard housing and/or precarious settlements. (Bortoletto et al, 2014, p.14).

Socio-environmental Vulnerability	Area (km²)	%	Urban Land Use	Area (km²)	%
Low	0.53	17.1	Standard Housing and Buildings	2.36	75.5
Medium	1.20	38.4	Substandard Housing	0.19	6.0
High	1.06	33.9	Cultivation Areas	0.07	2.3
Very High	0.33	10.6	Grass	0.14	4.6
			Transport System	0.08	2.7
			Port Area	0.02	0.6
			Other Uses	0.26	8.3
Total	3.12	100.0	Total	3.12	100,0

Table 2. Area (km²) and percentage (%) of socio-environmental vulnerability classes and urban land use of the sample area – Santos SP.

The predominance of factors related to children, senior citizens and to the weak infrastructure defines the Socio-environmental Vulnerability in the study area.

In Figure 2b and table 2 for the Urban Land Use the predominance of conventional buildings can be noticed, totalizing 75.5% of the sample area. The buildings that compose the substandard housing occupy 6.0% of the area and are mainly found in the Morro Pacheco, Morro Penha and Monte Serrat. The sum of these buildings occupies 81.5% of the sample area. Grass and cultivation areas which occupy 5.9% of the sample area were also mapped. All other uses, for instance, public areas such as parks, gardens and avenues were grouped in the "other uses" class and correspond to 8.3% of the study area.

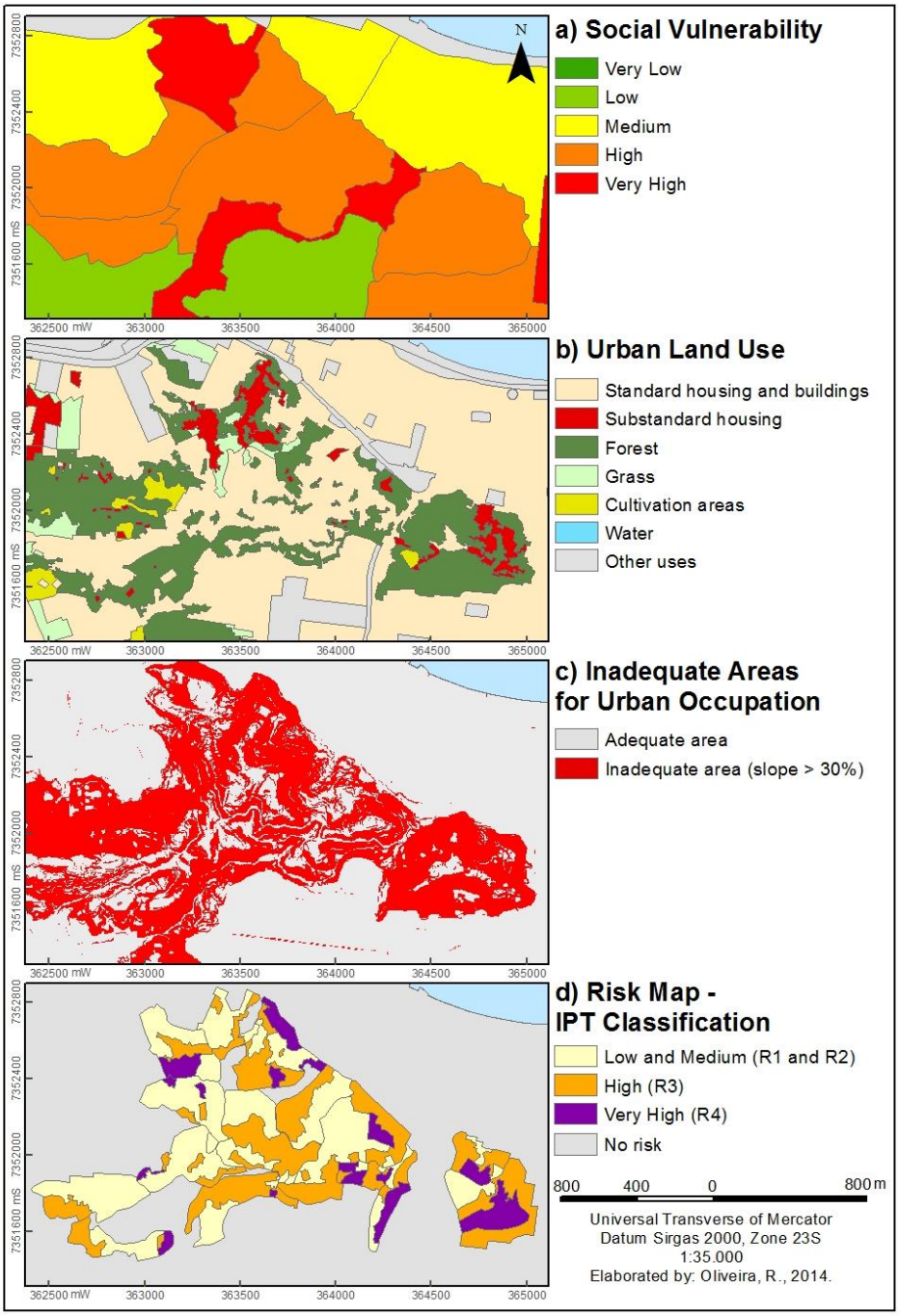

Figure 2: Thematic Maps: 2a) Socio-Environmental Vulnerability; 2b) Urban Land Use; 2c) Inadequate Areas for Urban Occupation; 2d) Risk Map from IPT

The map of Inadequate Areas for Urban Occupation, illustrated in Figure 2c, has the original scale of 1: 1000 and highlights areas with slope of 30% or more. Analysing the quantitative aspects of Figure 2 it is possible to observe that 22.1% (0.7 km²) corresponds to areas unsuitable or inadequate for urban occupation.

In the Risk Map prepared by the IPT, Figure 2d, high-risk areas (R3) predominate in 9.9% of the study area, getting very high risk areas (R4) the steepest slopes, largely without the original vegetation cover, many of them irregularly occupied.

The Synthesis Risk Map presented in Figure 3 was obtained through the application of the Multi-Criteria analysis. The quantitative results of the generated map are exposed in table 3, with areas in km² and percentages (%) of risk classes.

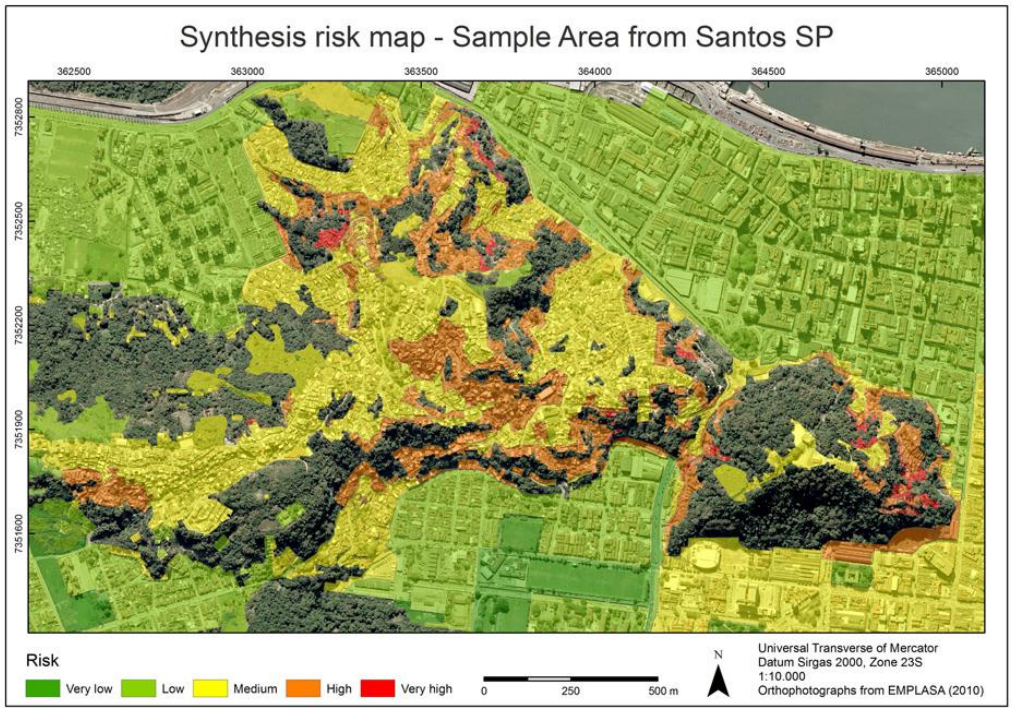

Figure 3. Synthesis risk map from multi-criteria analysis superimposed on orthophotograph – sample area of Santos SP.

Risk	Area (km²)	Percent (%)
Very Low (1)	0.13	4.4
Low (2)	1.62	51.7
Medium (3)	1.00	32.3
High (4)	0.34	10.8
Very High (5)	0.03	0.8
Total	3.12	100.0

Table 3. Risk classes and their occupied area in m² and percent (%)

Analyzing Figure 3 and table 3 it can be observed that low (51.7%) to medium risk (32.3 percent) areas predominate in the Sample Area. However, the areas of high (10.8%) and very high (0.8%) risk correspond to sectors with a predominance of buildings, mostly in precarious conditions (substandard). Looking for confirmation of those results through the overlaying of the Synthesis Risk with the Urban Land Use Maps it is observed that the very high risk class (5) is composed of the built areas 91.8% of which corresponding to substandard buildings.

The High risk class (4), is composed of 20.5% of the built environment as precarious (or substandard) urban clusters or isolated buildings and 78.5% of conventional buildings. These results indicate the serious situation of buildings in areas identified as very high risk class (5), which must be a priority in the mass movement preventive actions of public power. It can be observed that the Synthesis Risk Map illustrated in Figure 3 contributes to the expansion of risk areas mapped by IPT, bringing to the risk mapping the vulnerability determined for the area having as a basis the socioeconomic data from the 2010 Census.

5. Conclusion

Based on the results it can be concluded that the methodology adopted for the mapping of risk areas supported by geo-technologies has effectiveness in the cartographic representation of the vulnerability. The combination of physical and environmental maps with the socio-environmental vulnerability map contributes in the detection of the expansion of risk areas concerning to mass movement. The mapping originally produced by IPT is a reference that may have its use expanded through the combination with other physical maps, such as slope and urban land use, as well as socioeconomic aspects provided by the Census Bureau, which allows the public administra-

tor to guide planning actions with greater range and with compatibility with the social and economic reality of neighborhoods and urban sectors.

The GIS has allowed the development of database that can be continuously amplified, with endless possibilities of analysis. The multi-criteria analysis proved to be a flexible and reliable alternative in the processing of the physical and socioeconomic data collection, with potential to the mapping of mass movement risk. It should be noted that after applying the methodology for the sample area, we intend to conduct field work to assess the results here obtained and perform replication for the entire municipality and other regions of the State of São Paulo - Brazil.

It is believed that the products developed can be basis for local, state and federal interventions with regard to socio-environmental risks in the urban areas. The applied methodology can be easily replicated for other regions of Brazil and the World, with similar behavior in society and the environment.

References

Andretta ER, Ladeira LFB, Santos JM, Lima RHC (2013) Mapeamento das Áreas de Risco no Bairro Gilberto Mestrinho, Zona leste de Manaus – AM. Estudos Geológicos, 23(1):3-11. ISSN: 1980-8208. http://www.cprm.gov.br/publique/media/art_andretta_mapeam.pdf. Accessed 10 October 2014

Blaikie, P.; Cannon, T., Davis, I. Y Wisner, B. (1994) At risk: Natural hazards, people's vulnerability and disasters. Routledge, London

Bortoletto KC, Freitas MIC, Rossetti LAFG, Oliveira RBN, Leite A (2014) Indicadores Socioeconômicos e Ambientais para a Análise da Vulnerabilidade Socioambiental do Município de Santos – SP. In: Congresso Brasileiro de Cartografia (CBC), 26. Proceedings... Gramado RS, 1:001–016

Corrêa RL (2013) Segregação Residencial: Classes Sociais e Espaço Urbano. In: Vasconcelos PA, Corrêa RL, Pintaudi SM (Orgs). A Cidade Contemporânea: Segregação Espacial. São Paulo: Contexto, 1: 39-59

Cristo SSV de, Herrmann MLP (2004) Metodologia Aplicada a Análise de Áreas Susceptíveis a Riscos Naturais no Setor Leste da Bacia Hidrográfica do Rio Itacorubi, Florianópolis SC, Brasil. http://www.cfh.ufsc.br/~gedn/sibraden/cd/EIXO%202_OK/2-26.pdf. Accessed 10 October 2014

Cunha, L.; Mendes, J.M.; Tavares, A.; Freiria, S. (2011) Construção de modelos de avaliação de vulnerabilidade social a riscos naturais e tecnológicos. O desafio das escalas. In: Santos, N.; Cunha, L. (org.) Trunfos de uma Geografia Activa. Imprensa da Universidade de Coimbra, Coimbra

Cutter SL (1996) Vulnerability in Environmental Hazards. Progress in Human Geography 20(4):529-539. http://webra.cas.sc.edu/hvri/docs/Progress_Human_Geography.pdf. Accessed 12 October 2012

Cutter SL (2011) A Ciência da Vulnerabilidade: Modelos, Métodos e Indicadores. Revista Crítica de Ciências Sociais 93:59-69. http://rccs.revues.org/165. Accessed 16 June 2014

Freitas MIC, Cunha L (2013) Cartografia da Vulnerabilidade Socioambiental: Convergências e Divergências a partir de algumas Experiências em Portugal e no Brasil. Urbe, Revista Brasileira de Gestão Urbana 5(1):15-31 doi.org/10.7213/urbe.7783

Instituto Brasileiro De Geografia E Estatística IBGE (2010) Censo: Demográfico. http://www.cidades.ibge.gov.br/xtras/perfil.php?lang=&codmun=354850. Accessed 5 march 2013

Mendes JM, Tavares A, Cunha L, Freiria S (2009) Vulnerabilidade Social aos Riscos Naturais e Tecnológicos em Portugal. In Guedes Soares C, Jacinto C, Teixeira AP, Antão P (Orgs). Riscos Industriais e Emergentes. Lisboa: Edições Salamandra, 1:67-84. http://www.academia.edu/875342/Vulnerabilidade_Social_aos_Riscos_Naturais_e_Tecnologicos_em_Portugal. Accessed 4 September 2012

Porto de Santos. Companhia Docas do Estado de São Paulo CODESP (2014) Resumo Histórico. http://www.portodesantos.com.br/historia.php. Accessed 9 November 2014

Pourghasemi HR, Pradhan B, Gokceoglu C (2012) Application of fuzzy logic and analytical hierarchy process (AHP) to landslide susceptibility mapping at Haraz watershed, Iran. Nat Hazards (2012) 63:965–996. doi: 10.1007/s11069-012-0217-2. http://link.springer.com/article/10.1007%2Fs11069-012-0217-2. Accessed 27 October 2014

Tacnet J-M, Batton-Hubert M, Dezert J (2010) A two-step Fusion Process for Multi-Criteria Decision Applied to Natural Hazards in Mountains. In: Workshop on the Theory of Belief Functions. Proceedings... Brest, France, 1:1-6. http://arxiv.org/pdf/1005.0896v1.pdf. Accessed 27 October 2014

Valente ALS (1996) Uma Metodologia para Determinação de Áreas de Risco, através de Geoprocessamento e Sensoriamento Remoto. In: Simpósio Brasileiro de Sensoriamento Remoto, 8. Proceedings... Salvador BA, Brasil, 1:417-420. http://marte.sid.inpe.br/col/sid.inpe.br/deise/1999/02.03.08.46/doc/T2.pdf. Accessed 10 October 2014

Wisner, B, Blaikie, P, Cannon T, Davis, I (2003) At Risk: natural hazards, people's vulnerability and disasters. Routledge, 2003 (first published in London in 1994)