Socio-Environmental Vulnerability and Geotechnologies as Contributions for Risks Cartography

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Abstract. The main aim of this paper is to perform a review of the methodological procedures for the modeling of socio-environmental vulnerability using geotechnologies and present case studies in selected areas in Brazil and Portugal. The study of vulnerability is based on GIS and Statistics, using factor analysis and principal component analysis for aggregation of statistical socioeconomic and environmental variables derived from census. The main factors with high vulnerability in counties of State of Sao Paulo – Brazil were related to the population concentration in urban areas such as high birth, crime and poverty and also rural exodus and some precarious condition of accommodation in the cities. In Central Region of Portugal vulnerability factors associated with economic contraction appeared, confirming that the country is facing the consequences of low birth rate and aging population. The model showed results consistent with the reality of most counties studied and will be improved in the way of a standardization of the analysis between the two countries, hoping to contribute with planners and public administrators in the studied regions and in other similar situations regarding the vulnerability and risks.

Keywords: Geothecnologies, Risks Cartography, Socio-Environmental Vulnerability

1. Introduction

The studies of vulnerability, hazards and risks are priorities in the intergovernmental agenda of countries all over the World, especially those participating in the United Nations action called International Strategy for Disaster Reduction (UN-ISDR). The World Conference on Disaster Reduction, which took place in 2005 in Kobe, Hyogo – Japan, defined the Hyogo

Framework for Action (2005 – 2015), a 10-year plan to make the World safer from natural hazards, which was adopted by 168 Member States of the United Nations.

The sessions of the UN-ISDR of 2009 and 2011 showed remarkable increase in the number of policies to manage risks. In the referred documents, it is interesting to note the concern with the urgency to broaden the scale of these actions and program actions to allow the reduction of risks in all the sectors, in a wide and systematic way, which constitutes a challenge for the researchers and the instituted public authorities. According to the UN-ISDR (2011), over the last decades the countries have enhanced their capacity to reduce the mortality risks associated with the weather, such as tropical cyclones and floods. The document emphasizes the increasing risk of economic losses due to hazardous events, which increases the vulnerability of less privileged populations. The increase in the capacity to manage situations of risk and the reduction in the vulnerability of low and medium income countries are still not enough to cope with the exposition to such events, mainly in the case of emerging countries. Factors as poverty, poor urban planning and fragile ecosystem and regional development contribute to the increase of risk.

Natural risks are defined as the ones associated with the functioning of natural systems (e.g. earthquakes, floods and mass movements) and technological risks are the ones which are consequence of the human activity (e.g. potential industrial accidents, potential accident in the transportation of hazardous substances, irregular occupations in lowland areas or hillsides).

The main aim of this paper is to perform a review of the methodological procedures for the modeling of socio-environmental vulnerability using geotechnologies and present case studies in selected areas in Brazil and Portugal.

This study is the result of research developed in the areas of Cartography and Geographic Information Systems, with emphasis on a new line of research which is being consolidated in the Laboratory of Spatial Analysis Applied to Public Policies in the Center of Analysis and Environmental Planning (CEAPLA) of UNESP, which corresponds to the use of Geotechnologies for the study of Social and Environmental Vulnerability and is part of the postdoctoral research by the author in CEGOT - University of Coimbra, in the period between 2011 and 2012, under the supervision of Professor Dr. Lúcio Cunha, from the University of Coimbra.

The research was developed in this context, centered in the application of methodologies and techniques which articulate Cartography and Physical Geography studies with their social use, mainly concerning the analysis of

natural processes and the human action on the factors which cause and increase vulnerability and crisis management actions supported by the cartography of risks and its modeling in the GIS environment.

2. Studies on Vulnerability and risks in Geography

There are several studies in the Geography field aiming to modeling the phenomena related with Society and the Environment through Geotechnologies. The study by Cutter (2012) mentions as example the case of the earthquakes in Haiti on 12/01/2010 with a moment magnitude scale of 7,0 (MMS) and in Chile on 27/02/2010 with a moment magnitude scale of 8,8 (MMS).

Other examples of differentiated impacts are the 2010 earthquake in Haiti (magnitude 7,0) and the earthquake of higher proportions in Maule, Chile (magnitude 8,8), almost one month later. The number of victims in Haiti was extremely high, estimated between 200000 and 250000 deaths (The New York Times, 2010) . In Chile the estimates point about 500 fatal victims, a significantly smaller number, despite the magnitude of the earthquake. (Cutter 2012, p.60)

Considering the data of the events disparities can be observed between the two countries which population and infrastructure conditions present different conditions of resistance and resilience to hazardous events, with direct consequences in the number of victims of the catastrophes. The application of vulnerability models can contribute with the local public authorities, regional and federal governments, to designate investments in priority areas in order to improve the population's living conditions and the infrastructure of the countries to face hazardous events.

Given the continuous increase in the urban risk and the deterioration of the ecosystems, it is of utmost importance to elaborate integrated actions involving the Government and local partners to define policies in large scale aiming to benefit the society as a whole, especially children and homeless people.

It is in this context that the Geotechnologies emerge, specially the Geographic Information Systems, which represent powerful tools for the modeling of natural and technological risks and to map the socio-environmental vulnerability, contributing to establish a zoning of the levels of risks through the combination of periculosity, exposition and vulnerability maps.

In the Geography and Cartography fields there are several studies addressing the modeling of phenomena concerning the Society and the Environment through Geotechnologies. According to Marandola & Hogan (2004)

the first geographic studies with this approach emerged in the 80's, based on the natural phenomena which caused damages and exposed the populations to danger.

The natural hazards have demanded a great effort from the researchers involved with planning and management actions and with the relationship be-tween the human being and their environment.

[...]

The prognostic of probability of those phenomena [natural risks] occur was fundamental in that con-text. In this sense, the geographers widely developed what they called "risk assessment": evaluation of the risk of a danger [and accident of catastrophe] in a particular place (Marandola & Hogan 2004, p.31).

In this context, a greater expression of this type of research starts to emerge, involving natural hazards, providing subsidies for the introduction of the concept of vulnerability in the scientific world According to the authors, the vulnerability starts to emerge *as "an idea subjacent to the notion of capacity of answer"* of an environment or population to the risks (Marandola & Hogan 2004, p.32).

The use of independent statistic computer programs (or associated with Geographic Information Systems) for the study of vulnerability emerged in the late 1980's and in the 1990's, with particular reference to Blaikie et al. (1994) and Cutter (1996), who dedicated themselves to the study of vulnerability through the factorial analysis of different variables and indictors, considering the social, economic, political and cultural dimensions that, as a general rule, are the main objects of Geography.

By vulnerability the authors mean:

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).

Under's Cutter (1996) perspective, vulnerability is a complex concept, from which social, economic, political and cultural dimensions derive, and which definition has been also approached in epistemological perspectives, very different form the political, ecology, human ecology, physical sciences and spatial analysis.

The study by Mendes et al. (2009) and Cunha et al. (2011) proposes an index of social vulnerability to the natural and technologic risks for Portugal which incorporates, in addition to the standard exposition and biophysical vulnerability evaluations, the resilience and the infrastructural support capacities. The authors performed a previous evaluation of the social vulnerability for the municipalities of Portugal and an evaluation of the scale of the districts in 7 counties of the Centre Region, with the support of a Geographic Information System for the development of their analysis. The study is grounded on the concept of criticality and support capacity of the territory. In this context, the definition of Criticality is the set of individual and behavioral characteristics which can contribute for the rupture of the System and Support Capacity of a Territory is the set of territorial infrastructures which allow the community to react to a disaster. The methodology used for the analysis of social vulnerability was based on Factorial Analysis, including social and environmental aspects expressed in the Criticality and in the Support Capacity. The authors understand that, in this type of study, the place and the scale play a fundamental role, considering that, according to the territorial and socio-economic characteristics, a single model can present a good or bad performance. The experiment led the researches to the conclusion that the same global model was consistent in different scales, allowing the elaboration of risk mitigation strategies and civil protection measures adapted to the places studied (Mendes et al. 2009, p.81).

In the Brazilian scope, studies involving social vulnerability and cartographic representation stand out, among which are the ones developed in national and municipal scale, that, in general, have adopted Statistics Censuses data banks.

An example of the use of Geotechnology in the study of social vulnerability for the city of Sao Paulo was performed by Alves (2006), who studied he socio-environmental vulnerability through environmental indicators, in the most disaggregated scale possible; i.e., of census sectors. This methodology proposes a simple typology in which census sectors of the municipality of de Sao Paulo are classified in four categories of environmental vulnerability, resulting from a combination of two dimensions – environmental risk (proximity to water courses) and environmental degradation (poor sewerage coverage). Among the results presented by the author, within the group of high social vulnerability there are significant differences in the demographic and socio-economic conditions related to the different categories of environmental vulnerability. In some cases the social vulnerability is worsened by risk situations and environmental degradation, with significantly worse socio-economic conditions, in addition to a higher concentration of children and young people, than those with a lower level of environmental vulnerability. The author still detected critical areas, in which there is a

high concentration of problems and social and environmental risks with greater levels of poor population and suffering from social privation; therefore presenting less capacity to react to risk situations. Such results indicate areas of high socio-environmental vulnerability.

3. Methodological Procedures in the Case Studies in Portugal and Brazil

Considering some previously mentioned studies, expressed in the works by Freitas (2012), Freitas & Cunha (2012a) and Freitas & Cunha (2012b), the vulnerability analysis was carried out in a set of municipalities from Sao Paulo State – Brazil and in the Centre Region of Portugal.

The socio-environmental vulnerability mapping was performed for a set of 17 counties in the Centre Region of Portugal and 20 Brazilian municipalities, through a census intended to find indicative data concerning criticality and support capacity. The methodology adopted for the analysis of vulnerability was based on the studies about social vulnerability to natural and technologic risks for Portugal, having as reference the resistance and resilience capacity of populations and territories developed by Mendes et al. (2009) and Cunha et al. (2011).

Using the analysis of cartographic bases of the Digital Environmental Atlas, produced by the Portuguese Environment Agency and the censuses of the National Institute of Statistics of Portugal for the year of 2011 combined with some complementary data of the 2001 census, it as possible to map the main variables associated to the socio-environmental risks to which the population of such areas are exposed and specialize them through the use of thematic letters elaborated in GIS ArcGIS.

The vulnerability modeling was based on Factorial Analysis which aggregated social and environmental variables, using the statistic program SPSS R.18 and Geographic Information System (GIS) ArcGIS 9.3. The Principal Components Analysis in SPSS was adopted as a method of extraction in the Factorial Analysis performed; and as rotation method Varimax routine with Kaiser Normalization was used.

Through Factorial Analysis related to criticality and support capacity the socio-environmental susceptibility of the area was evaluated using the proposed vulnerability model.

Census data of the population and the characteristics of the counties indicating a hypothetical rupture of the System were collected for the analysis of criticality considering hazardous events associated to natural or techno-

logic risks, and 108 variables were selected according to the following groups: Economy and Living Condition, Population, Health and Social Protection, Lodging Conditions and Buildings, Territorial and Environmental Conditions, Education, Justice and Agriculture.

In a series of 3 executions of the SPSS statistic program 43 explanatory variables were obtained for each group of selected variables. From these explanatory variables it was possible to select 5 factors which detain 76% of the accumulated variance, considering the 17 counties studied. The communalities of the variables were all superior to 0, 88, value considered acceptable for a high communality indicates that the variable contributes for the formation of extracted factors.

After the calculation of Criticality, the thematic representation in ArcGIS was performed through the classification of its results, applying the classifier Natural Breaks (Jenks) in the first approximation, followed by manual classification.

In analogue procedure, the support capacity structure study of the 17 counties studied was performed, collecting the census data which could indicate the territorial infrastructure to permit the reaction of such communities in case of disaster associated to natural or technologic risks. Among these variables, 84 were selected according to the groups previously indicated, In a series of 3 executions of the SPSS statistic program it was possible to reduce to 41 explanatory variables of Support Capacity.

It was possible to select 5 factors from these variables, and these factors detain 73% of the accumulated variance. The communalities of the variables were all superior to 0, 83, which points to the significant contribution of these factors in the formation of the factors.

The Socio-environmental Vulnerability of the 17 counties was calculated using the data related to Criticality and Support Capacity expressed in the equation (1):

$$SV = C \times SC \qquad (1)$$

Considering:

SV = Socio-environmental Vulnerability

C = Criticality

SC = Support Capacity.

For the socio-environmental vulnerability mapping in Brazil a set of 20 municipalities from Sao Paulo State which compose the Metropolitan Re-

gions of Sao Paulo and Santos, Administrative Regions of Sorocaba and Registro were selected. The methodology adopted for the analysis of the vulnerability in Brazil was the same adopted for the Counties of Portugal, considering the analysis of cartographic basis and census data from the Brazilian Institute of Geography and Statistics (IBGE) for the year of 2012 and some complementary information of the previous census of 2000.

For the analysis of criticality 75 variables were initially selected, according to the groups: Economy and Living Condition, Population, Health and Social Protection, Lodging Condition and Buildings, Territorial and Environmental Conditions, Education and Justice. The Factorial Analysis model resulted in 18 explanatory variables resulted, among which it was possible to select 5 factors that detain 67% of the accumulated variance, considering the 20 municipalities in study. The communalities of the variables were all superior to 0,78.

In analogue procedure, the support capacity study of 20 municipalities was carried out, selecting 54 variables, with a reduction to 38 variables which composed the model here presented. The Factorial Analysis model resulted in 17 explanatory variables from which it was possible to select 5 factors which detain 68% of the accumulated variance. The communalities of the variables were all superior to 0,706, which points to their significant contribution for the formation of the factors.

The calculation of the Socio-environmental Vulnerability of 20 municipalities was made using data concerning the Criticality and Support Capacity, similarly to what was exposed for Portugal.

4. Results

The results of this study are shown in tables and thematic maps. *Table 1* shows the main factors and their explanatory variables for Criticality and Support Capacity in the study area of the Centre Region of Portugal.

Factor	Criticality Variables (signal)	Support Capacity Variables (signal)
1	Housing Loan (+) Employment Rate (+) Familiar Agricultural Population (-)	Number of Companies and banks (+) Proportion of families with 1 lodging (-) Firefighters (-)
2	Lodgings with central heating (-) Effective growth rate (-) Resident population under 14 (-)	Lodgings with central heating (+) Buildings needing repair (-) Overcrowded Lodgings (-) Number of pharmacies (-)
3	Telephone access (+) Purchase power (-) Credit rating (-)	Vacant Buildings (+) Buildings needing repair in the urban area (+)
4	Rural Areas without agricultural use (+) Public investment on the Environment (+)	New Buildings (-)
5	School Evasion (-)	Classical Familiar Lodgings of Seasonal Use (+)

Table 1. Main factors and explanatory variables for the Criticality and Support Capacity in the study area of Portugal

The data in *Table 1* indicate that the main indicators of socio-environmental vulnerability for the study area of Portugal concerning criticality are related to the economic contraction that the country has currently been undergoing (e.g., the negative values for the effective growth rate and purchase power), followed by the small number of children and young people (negative values for resident population under 14) which is associated with low birth rate in the country and rural exodus (negative values for the familiar agriculture population). In terms of support capacity negative values are shown for the presence of firefighters, causing problems in the confrontation of wildfires, one of the main events annually recurrent in the country and which cause damages to the urban and rural populations, as well as aspects related to urban buildings aging in urban areas and buildings needing repair, opposing the negative values for new buildings.

Figure 1 shows the spatial representation of the results obtained concerning Socio-environmental Vulnerability of the 17 counties studied in Portugal.

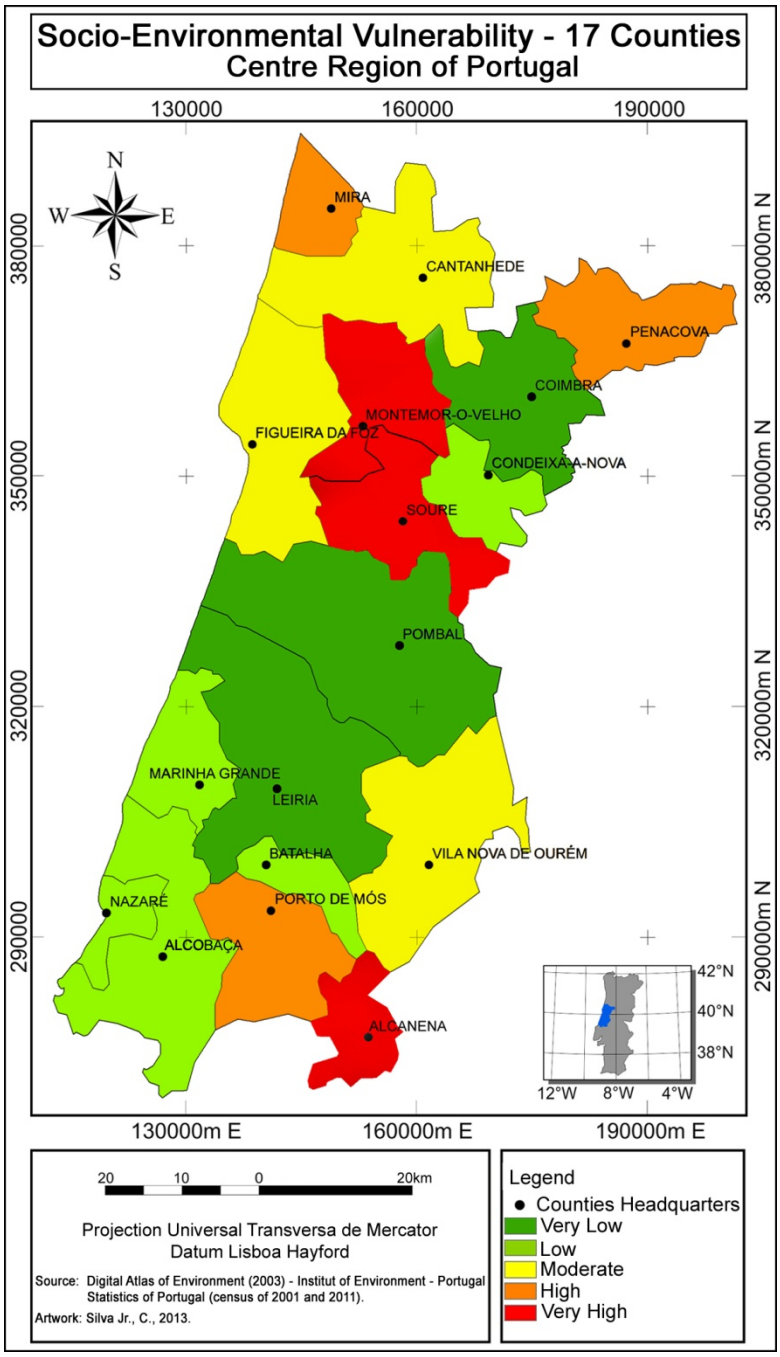

Figure 1: Socio-environmental Vulnerability of the 17 counties – Centre Region of Portugal.

Data presented in *Table 2* indicate that, in studied area in Brazil, the main vulnerability factors related to criticality are the presence of a young population (negative values for population aging), high birth and fertility rates.

Furthermore, factors related to criminality (drug trafficking, consummated theft, occurrence of crimes and death from AIDS, among others), poverty (positive values for the incidence of poverty) and problems related to education (evasion and school failure with positive values) stand out. As for support capacity, the retraction of rural development presented by the negative values for the agricultural GNP, rural exodus (negative values for rural domiciles and positive values for urban population), concentration of population in the cities (positive values for urbanization rate and resident urban population, among others) and the presence of slums deserve special attention.

Factor	Criticality Variables (signal)	Support Capacity Variables (signal)
1	Aging of the Population (-) Birth Rate (+) GNP added in Agriculture (-)	Value added to Agricultural GNP (-) Rural domiciles (-) Urbanization Rate (+) Urban Resident Population (+)
2	Consummated theft (+) Drug Trafficking (+) Crime Occurrences (+) Death from AIDS (+)	Percentage of domiciles in apartments (+) Registered Physicians and Dentists (+)
3	Presence of Children and Teenagers (+) Poverty Incidence (+) School Evasion (+)	Percentage of GNP added to Industry (+) and GNP per capita (+) Domiciles with enough space (+)
4	School Failure (+) Fertility Rate (+) Mortality by Aggression (+)	Collective domiciles (+) Hospital beds (+) Existence of Slums (+)
5	Population Growth Rate (+) Existence of risk areas with housing (+)	Vacant private domiciles (vacant) (+)

Table 2. Main factors and explanatory variables for Criticality and Support Capacity in the study area of Brazil

Figure 2 shows the spatial representation of the results obtained concerning the Socio-environmental Vulnerability of the study area in Brazil.

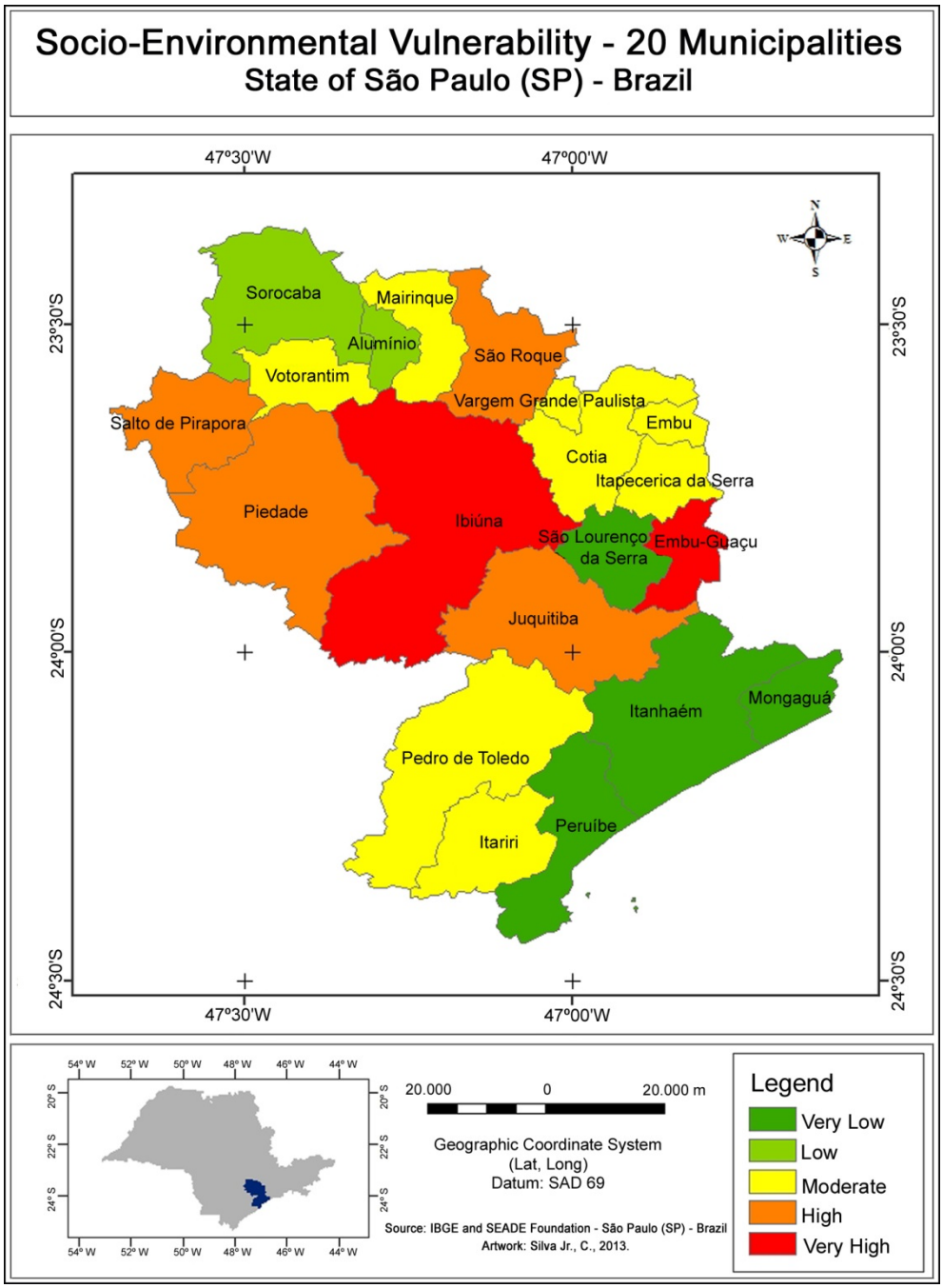

Figure 2: Socio-environmental Vulnerability of the 20 municipalities – Sao Paulo State - Brazil.

In a general view, it can be considered that the results obtained point the lack of economic dynamism from the counties and the aging of the population as main factors of socio-environmental vulnerability in the Portuguese context. In Brazil the main factors are associated to economy and urban violence. Both results indicate the preponderance of the social and economic factors in the territorial differentiation of vulnerability, distinguishing regions with different levels of socio-environmental vulnerability; i.e., with populations or territories more or less provided with conditions for the confrontation and recovery from manifestations of natural, technologic or mixed risks.

5. Conclusion

The results of the study point the suitability for use of Geotechnologies in studies on socio-environmental vulnerability, which should be one of the pillars of public policies intended for the populations living in areas of greater vulnerability, in local, regional or national scales. The application of the methodology indicates coherence between the results obtained and the geographic and socio-economic knowledge which is present in the areas of study. The factorial analysis and the spatial representation through statistical analysis computer programs and GIS, for the study area, allowed a summarized view of the Brazilian and Portuguese realities, evidencing the main socio-environmental problems in a clear and objective way. The accessibility and facility of execution and replication of the methodology, proved by the coherence of the results obtained both for Brazil and Portugal allow its adoption as the first step in the elaboration of preventive actions related to socio-environmental risks. This study is another academic contribution to the public administration in terms of vulnerability and risks for Portugal, Brazil and other countries presenting similar socio-economic and environmental contexts.

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