Geography of natural hazards and vulnerabilities in urban rivers in Brazil - a case study in the Metropolitan Region of Fortaleza

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Abstract
The urban rivers in Brazil are synonymous of degraded, devaluated and denied environments for the society. These spaces had become the alternative access to housing for a mass of poor persons who cannot acquire a safe space in the city. The junction of poverty, improvised habitation, little infrastructure, with the occupation of prone spaces to the natural hazards, created territories of risks and vulnerabilities, that frequently coincide with urban fluvial environments. Thus, the main proposal of this article is to analyze the risks and the socio-environmental vulnerabilities of urban rivers in Brazil, having being chosen the Maranguapinho river hydrographic basin as case study area, located in the Metropolitan Region of Fortaleza - MRF, Northeastern Brazil, to the understanding of the inter-relations between social vulnerabilities and exposure to the natural risks, mainly the risks of flooding. The methodology used statistical techniques, cartographic overlapping, field research, to produce the Socio-Environmental Vulnerability Index - SEVI of the case study area. It was concluded that it has serious coincidences between the susceptible spaces to natural hazards processes, e.g floodings – natural process linked to the rivers' dynamics and its hydrographic basin, and the spaces of the city that present the worse social, economic, access the services and urban infrastructure index.

Keywords: Vulnerability, Risk, Natural Hazards, Urban Rivers, Brazil

1. Introduction

In 2008, Brazil was included among the thirteen countries had bitter experiences by natural disasters, which has questioned the belief that the country has not strongly affected by hazardous natural phenomena. That year, one hundred thirty-five people lost their lives in the State of Santa Catarina, due to widespread and intensity torrential rainfall, floods with landslides in sloped zone. In next 2009, the new natural disasters have struck again in Santa Catarina, and in almost all states of the Northeast in Brazil. Later that year, the summer-typical concentrated rainfall, also generated losses of lives and economic losses in several cities of States of Sao Paulo, Rio de Janeiro and Minas Gerais. On the first day of the year 2010, at least fifty-two people died in landslides widespread on the southern coast of the State of Rio de Janeiro, especially in Angra

dos Reis. And in January 2011, about nine hundred people lost their lives during multiple natural disasters in the mountainous region of Rio de Janeiro.

What is convergent, however, between these and other hazardous natural events? The increase of the consequences and recurrence of natural disasters is related to global environmental changes, especially the climate-related ones? Or, had these phenomena their effects magnified because of the specific physical structure of the territory taken in the affected areas? Or, again, due to the rapidly increasing population living in urban-rural conditions of vulnerability resulting from the occupation of spaces exposed to natural hazards and aggravated by their conditions of social susceptibility? Drawing attention to the fact that among the areas hit the most severe, it has been stood out those the abruptly urban sprawling phenomenon; but, why those cities are expanded and exposed to suddenly these phenomena? Specifically, who and where is the most vulnerable to natural hazards in the city? Who and where is the most vulnerable in the city?

In Brazil, given the physical environmental conditions, especially the climatic reasons under tropical and sub-tropical, and the ways of occupying space, the most recurrent natural hazards are related to substantial changes in the natural water cycle, and these environmental changes are most noticeable in cities. The structuring of the territory has fostered the frequency and magnitude of natural phenomena (natural or not so well ...), such as landslides with severe floods. Floods are usually natural phenomena, in addition to important changes in the forms of land use with land cover and settlement formation in cities, where the sealing of soil and retilinization of fluvial channels are configured as recurrent public actions (and private actions), such phenomena are enhanced and so have become potentially more dangerous. Indeed, it fits the problem of urban rivers. The rivers and river basins are historically attractive environments and produced a place for human occupation, however, in cities, especially those located in developing countries, the river environments are configured between the spaces most degraded, devalued and/or even denied by society, because of a paradigmatic change, which made the rivers cease to be attractive environments to become receptacles for excrement of society.

Moreover, in a highly uneven context in which cities have undergone a change, the edges of rivers and river basins have become the alternative access to urban land as well as the possibility of possession of a house, a large and growing contingent of urban poor. This relationship between the urban rivers (forgotten and denied), and improvised illegal occupation, poverty and segregation, have created a context of strong socio-spatial inequalities, while establishing territories at disaster risk, where they have overlapped different hazards (natural,

social etc..), and where have prevailed the social vulnerability linked to different exposure to potentially hazardous natural phenomena. Thus, what are the variables that make individuals (or groups of individuals) more vulnerable than others? These factors have dimensions that are outlined in space? That is, what aspects contribute to the socio-spatial distribution of different risks and vulnerabilities?

Why are individuals/communities that inhabit the edges of rivers and river basins in the Brazilian cities more vulnerable to flood events than other people? There is coincidence between areas exposed to natural hazards and poverty in *Brazil's cities*? If so, the definition and location of spaces in which risk has occurred coincidentally (and its cartographic representation) can form an important scope for policy makers, in order to guide/direct where investment should be allocated preferentially to increase the resilience of communities exposed, and thus reduce the risk of disaster? Given these serious questions, it was defined as objective of this paper to analyze natural hazards and social vulnerabilities of urban rivers in Brazil. A watershed located in the Metropolitan Region of Fortaleza - MRF, in northeastern Brazil, is the area of case study for understanding the interrelationships of social vulnerabilities and exposure to natural hazards, particularly ones associated with urban flooding.

2. Measuring Vulnerability: A Methodological Proposal

2.1 Social Vulnerability Index – SVI

To assess the social vulnerabilities of Maranguapinho river basin (Metropolitan Region of Fortaleza) and consequently, develop a proposed index, socioeconomic data were collected from the 2000 census of the *Instituto Brasileiro de Geografia e Estatística - IBGE*, whose smallest spatial unit of analysis is the census sector. Using the limits of the Maranguapinho river basin through geoprocessing GIS program ArcGIS 9.2, it was able to define 934 census sectors located within the basin (*fig. 1*). For the preparation of the Social Vulnerability Index - SVI, specific variables of the research on the 2000yr Census of IBGE were selected according to research methodological criteria with variables that characterize broad dimensions of vulnerability and social disadvantages, and that correspond to factors recurrently used by social sciences for similar studies.

Originally, fifty-nine variables were selected that, after compilation, resulted in 21 variables, since some variables of the research were based on the junction of two or more variables from Census 2000yr (Table 1).

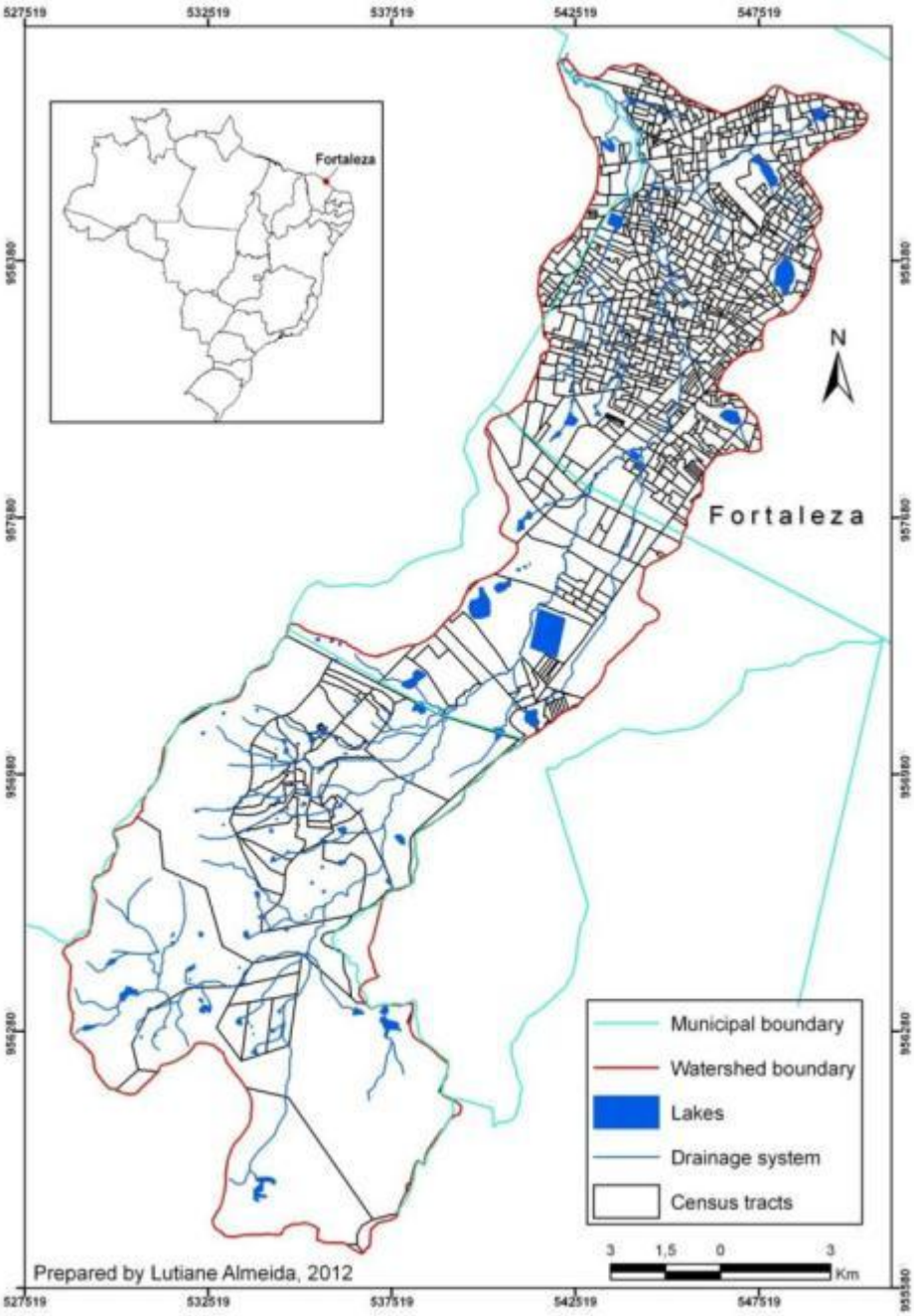

Fig. 1 Census sectors of Maranguapinho river basin.
Source: elaborated by Almeida (2012).

Table 1 Variables selected in according to the evaluation criteria of social vulnerability

EVALUATION CRITERIA OF SOCIAL VULNERABILITY	Variables
EDUCATION	V1 - Mean number of years of schooling of people responsible for permanent and private households
CONDITIONS OF HOUSING AND INFRASTRUCTURE	V2 - Precarious private households
	V3 - Private households with no water supply for the general network
	V4 - Permanent households without sanitation via general sewage network
	V5 - Permanent households without toilet
	V6 - Permanent private households with uncollected garbage
	V7 - Permanent households of more than four residents
AGE STRUCTURE	V8 - Responsible for permanent private households with 10 to 19 years old
	V9 - Responsible for permanent households of more than 64 years old
EDUCATION AND AGE STRUCTURE	V10 - Responsible for permanent private illiterate households
	V11 - Responsible for permanent private illiterate households with 10 to 19 years old
	V12 - Responsible for permanent private illiterate households over 64 years old
INCOME	V13 - Responsible for permanent private households with monthly income of up to 3 minimum wages
	V14 - Responsible for permanent private households with no monthly income
GENDER AND AGE STRUCTURE	V15 - Women responsible for permanent private households with 10 to 19 years old
	V16 - Women responsible for permanent private households with more than 64 years old
GENDER AND EDUCATION	V17 - Illiterate women responsible for permanent private households
AGE STRUCTURE	V18 - Persons from 0 to14 years old
	V19 - People over 64 years old
EDUCATION AND AGE STRUCTURE	V20 - Illiterate people from 5 to 14 years old
	V21 - Illiterate people over 64 years old

Source: Adapted from Census 2000 IBGE, by Almeida (2010)

For the preparation of an index of social vulnerability, it was used the multivariate analysis technique called factor analysis. To form homogeneous groups of sectors, it was used the statistical method Natural Breaks constant in the program ArcGIS 9.2. Factor analysis is a statistical technique that allows *reducing the amount of variables to factors* that explain a representative percentage of the total variability of the variables under study. To determine the vulnerability index for each census sector, primarily, were estimated for each sector, the values of each factor considered. The Social Vulnerability Index (SVI) of each sector is given by the arithmetic mean of the estimated values of the factors, that is:

$$SVI_i = (FACTOR_1 + FACTOR_2 + ... + FACTOR_m) / m, \; i = 1, 2, ..., 933, 934.$$

After the factor analysis performed, were obtained estimates of the factors for each sector of the population under study. 73.32% of the total variability of the twenty-one variables is explained by four factors. Thus subsequent analyzes were performed based on four factors retained. The four factors, thus, obtained correspond to the vulnerability level of *education* (*factor 1*), the *second factor* is related to the vulnerability caused by the *conditions of infrastructure and housing*, the *third factor* is related to vulnerability due to the overall population of *elderly* (over sixty-four years), and *factor 4* is related to vulnerability due to the overall population of *young people* (age range 10-19 years) (fig. 2).

After determining of factor loadings, it was estimated for each sector the corresponding value of each factor, allowing the situation of each sector in relation to the vulnerability associated with the four factors set forth herein.

And then, after establishing the definition of the factors and estimating their values for each sector, it was applied the technique Natural Breaks in ArcGIS 9.2 for formation of groups whose sections are homogeneous. For the formation of groups, it was considered the estimated values for the four factors in the sectors studied. With the average of the four factors, it was developed the general index to indicate the social vulnerability (SVI) each census sector. It is noteworthy that, the higher the value obtained for the average, greater vulnerability and higher average factor, the greater the vulnerability into about that.

Through the Natural Breaks method of ArcGIS 9.2 software, it was possible to divide census sectors into six vulnerability groups, distributed according to the average of factors:

1. **Very High Social Vulnerability**, with rates varying from 2.52 to 4.94;
2. **High Social Vulnerability**, from 0.82 to 2.14;
3. **Medium to High Social Vulnerability**, from 0.25 to 0.79;
4. **Medium to low Social Vulnerability** from -0.11 to 0.24;
5. **Low Social Vulnerability** from -0.44 to -0.12; and
6. **Very Low Social Vulnerability** from -1.01 to -0.45.

The average range of factors, that is, the Social Vulnerability Index, is from -1.01 to 4.94, with higher values representing the sectors with the greatest vulnerability. After defining the groups Social Vulnerability, the spreadsheet containing the index was transferred to the program ArcGIS 9.2, and then it was possible spatialize the results of vulnerability indicators.

Each value attributed to a given census sector could be represented on the Map of Social Vulnerability (*fig 3*), thereby providing spatial vision and comparison between the spatial patterns

of vulnerability to different census sectors, and several areas of the Maranguapinho river basin, and a spatial area conditions of social vulnerability in the Metropolitan Region of Fortaleza.

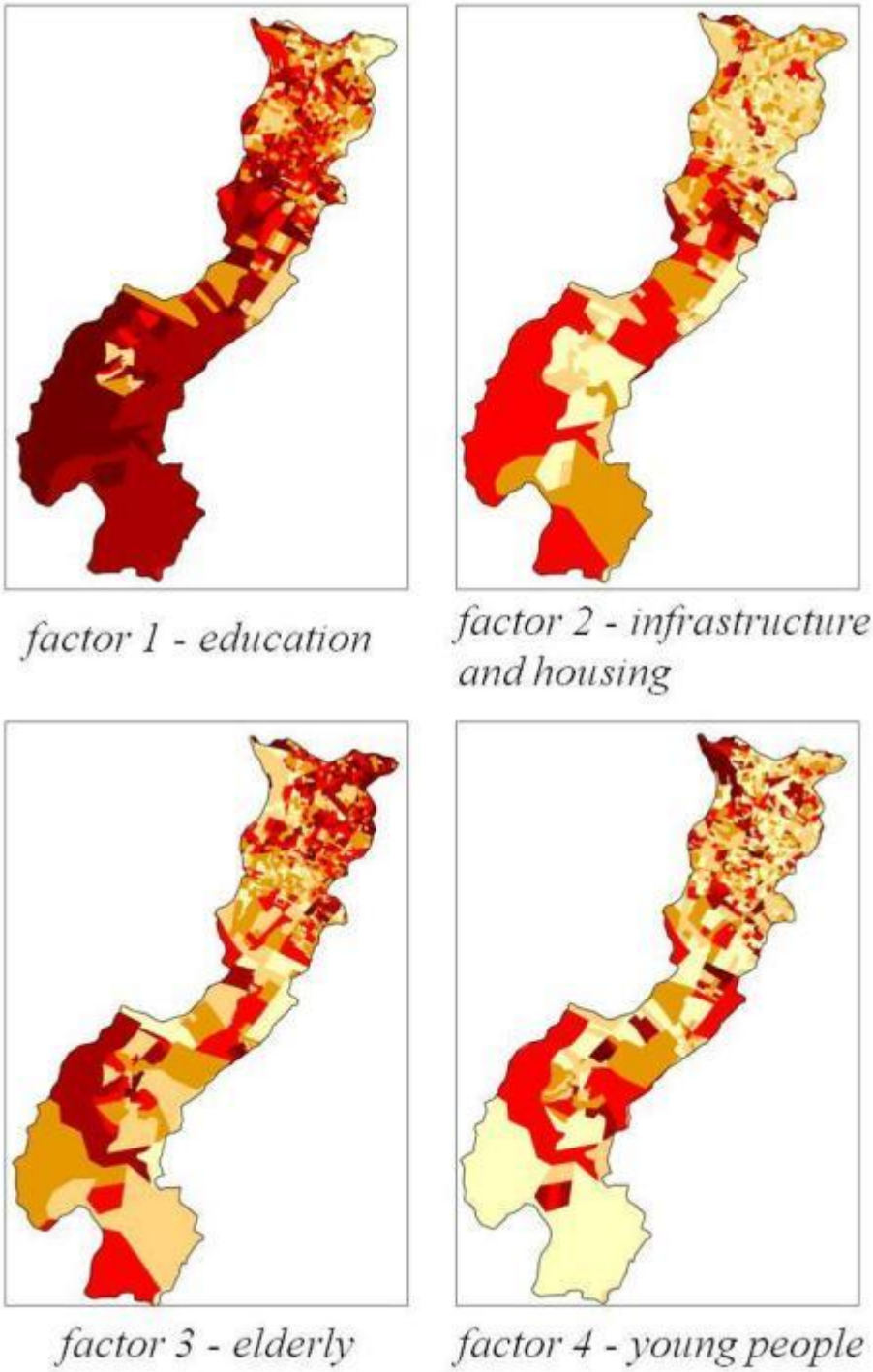

Fig. 2 Social Vulnerability, according to the factors "education", "infrastructure and housing", "presence of the elderly" and "presence of young people".
Source: elaborated by Almeida (2012).

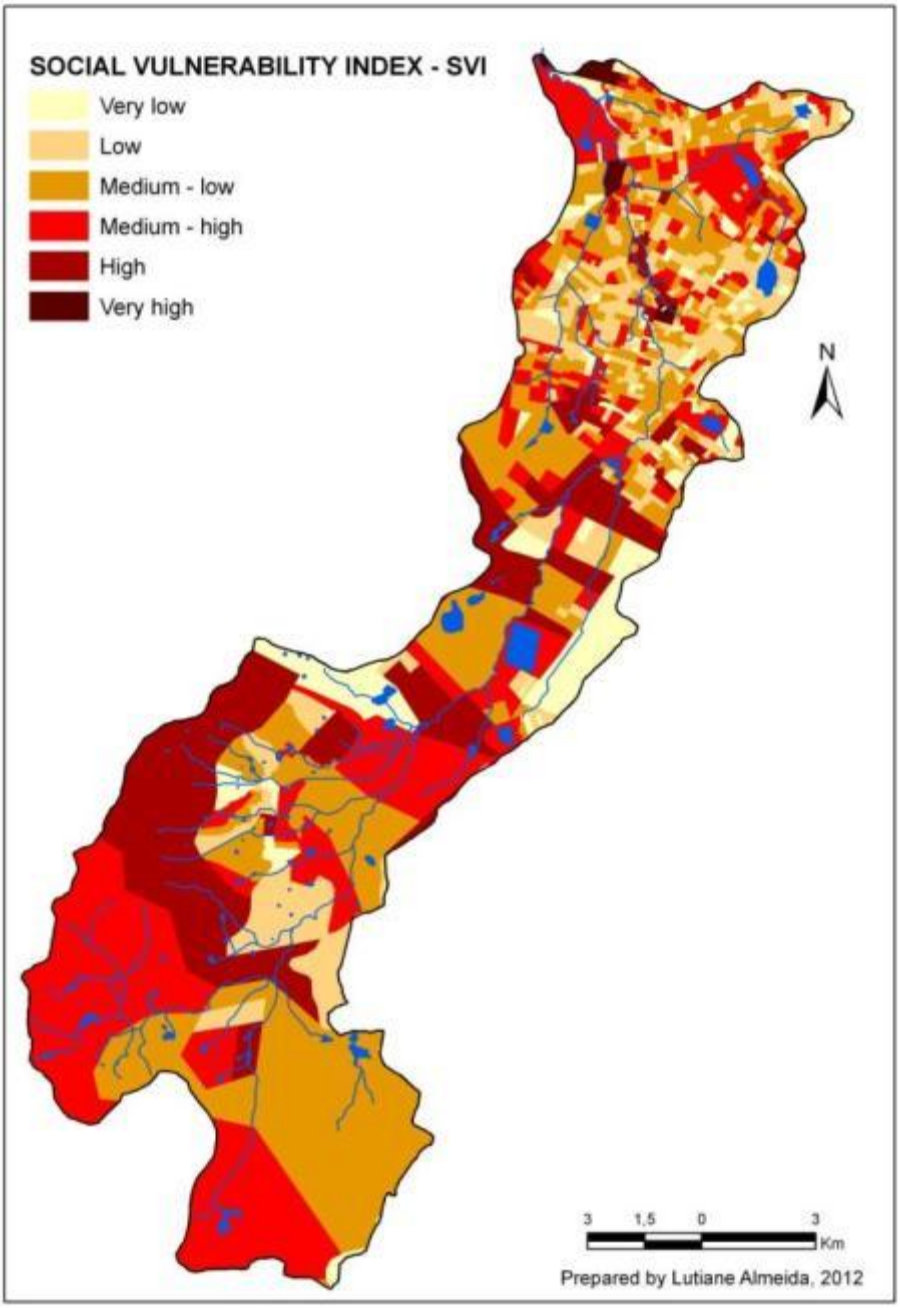

Fig. 3 Social Vulnerability Map of Maranguapinho river basin.
Source: elaborated by Almeida (2012).

2.2 Physical Exposure to Floods Index - PEFI

The development of the Physical Exposure to Floods Index - PEFI of Maranguapinho river basin aims at creating a spatio-temporal model of the risk of exposure to flooding by the spatial extent of flood events, according to the frequency of these events, *ie,* probability of occurrence or the specific return period of floods. The PEFI was developed with substrate in the

delimitation of areas of the Maranguapinho river, according to those periods of return. The delineation of floodplains and to define the return periods were obtained based on the results of hydrologic and hydraulic studies of the Maranguapinho river basin, prepared by CEARÁ (2006).

On the methodology, the studies used an integrated basis computer applications in mapping (AutoCAD MAP 2000), in the formulation of Digital Elevation Models - DEMs and database for use in GIS (ArcView GIS 3.2) for hydrological simulations (HEC-HMS) and hydraulic simulations (HEC-RAS) (see *fig 4*).

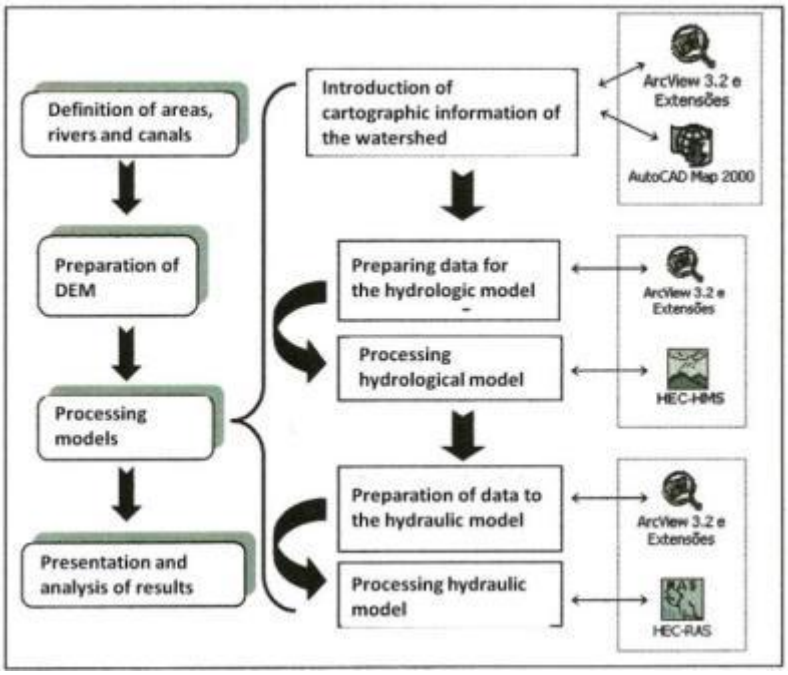

Fig. 4 Basic steps for the preparation of hydrologic and hydraulic studies of Maranguapinho river basin. Source: Adapted from Ceará, 2006.

To elaborate the PEFI, hydraulic studies allowed the identification of areas of flooding, for return periods 2, 5, 10, 20, 50 and 100 years.

Next, four intervals were delimited of return periods (RP) for the composition of PEFI in order to hierarchize spatiotemporal vulnerability to flooding in the Maranguapinho river basin, assigning the following classification:

A. RP ≤ 2 years - Physical Exposure to Floods VERY HIGH, according to the most likely (50%) of occurrence of flooding in the area covered by this index, exposed area: 10.67 km² (4.91% of the total area of the basin);

B. RP ≤ 20 years – Physical-spatial Exposure to Floods HIGH, given the 5% probability of occurrence of flooding in the area covered by this index, exposed area: 14.70 km² (6.77% of the total area of the basin);

C. RP ≤ 100 years – Physical-spatial Exposure to Floods MEDIUM - LOW, since the probability of flooding in the area covered by this index is 1%; exposed area: 16.70 km² (7.7% of the total area of the basin);

D. RP> 100 years - Physical Exposure to Floods VERY LOW, since the probability of flooding in the area covered by this index is less than 1%; exposed area:> 16.70 km².

In the production of the map corresponding to Physical Exposure to Floods Index - PEFI (*Map 4*), it has used the flood lines, produced by hydraulic studies for the preparation of the return periods selected in PEFI, and produced "shapes" for each interval in *ArcGIS 9.* Then the "shapes" produced were overlapped and assigned to them blue tone to represent the inundation areas (*Figs 5 and 6*).

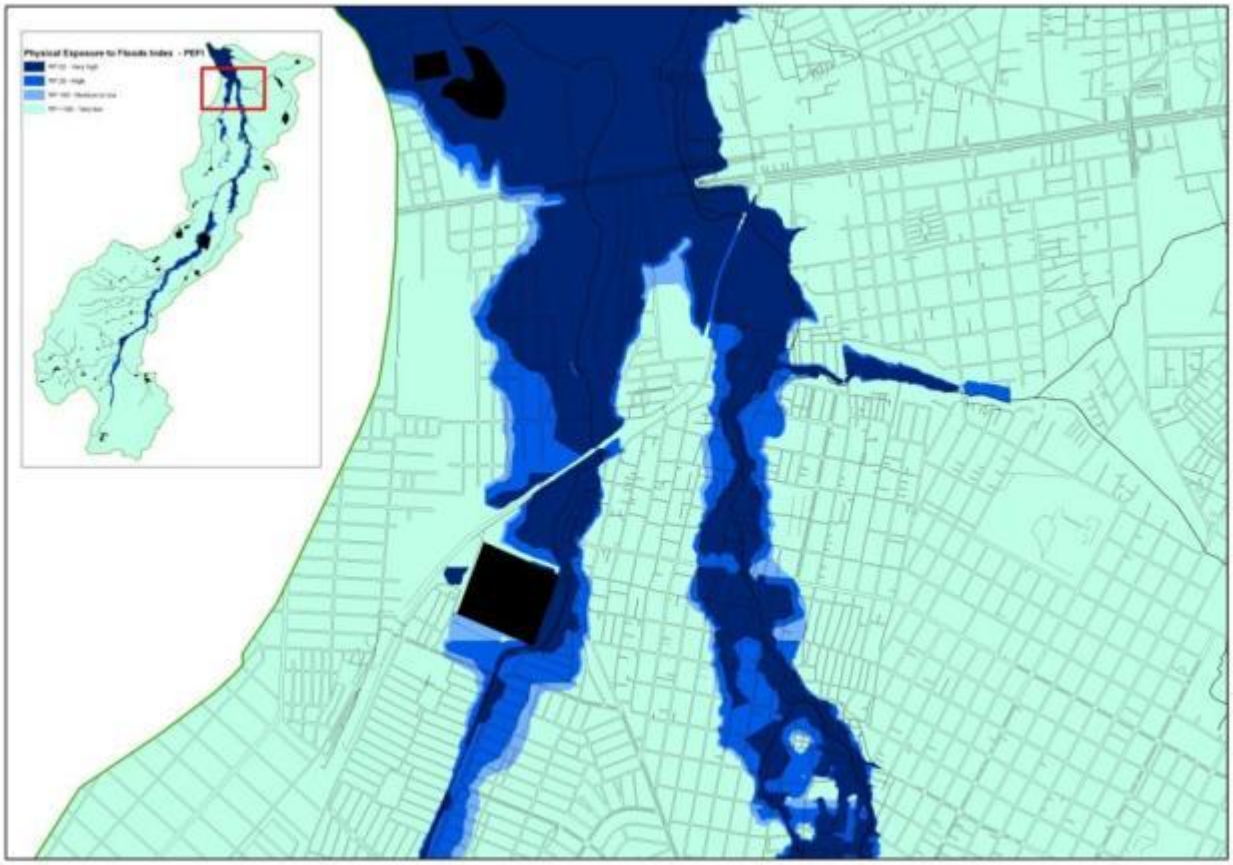

Fig. 5 Cutting of the PEFI Map (Figure 6). Detail of the lower course of the river.
Source: elaborated by Almeida (2012), according to CEARÁ (2006).

According to the overlay of census sectors to areas corresponding to return periods of flood designed to PEFI, it is estimated that a contingent of up to 200,000 people are at risk of flooding in the Maranguapinho river basin. The areas at risk of flooding vary according to the

probability of occurrence of an event given area of specific extension. In the case of return periods defined for the IEFI, the areas of extension of flooding, to return periods of 02 years, 100 years and 20 years are respectively 10.67 km ² (4.91% of the total area of the basin which is 217.15 km ²), 14.70 km ² (6.77% of the total area of the basin), and 16.70 km ² (7.7% of the total area of the basin).

Given the lack of data on the influence of coastal dynamics in the reports, it is estimated that the extent of the flooding areas and population group exposed to this phenomenon are higher than that set out in this research. In this case, the absence of data on coastal dynamics is configured as a limitation on the practical use of PEFI, as it neglected an environmental aspect relevant to understand the effects of flooding in the Maranguapinho river basin (*figure 6*).

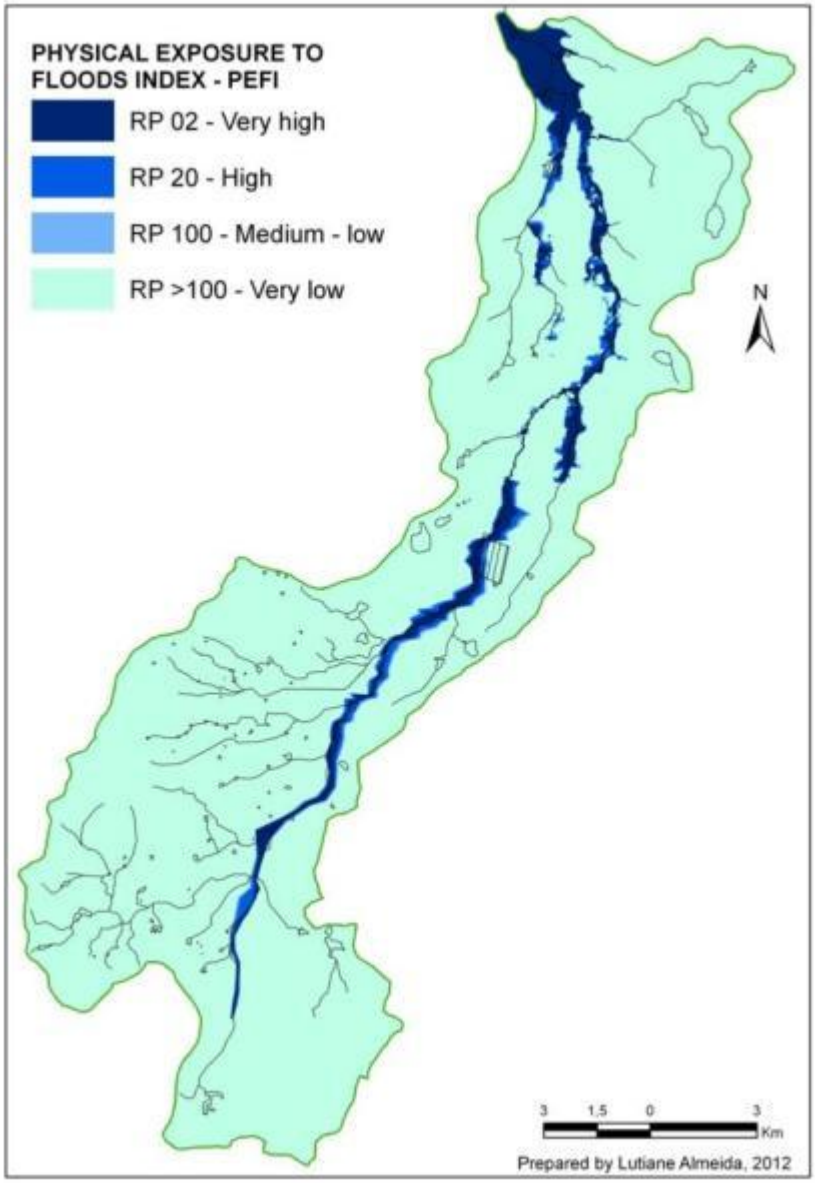

Fig. 6 PEFI Map
Source: elaborated by Almeida (2012), according to CEARÁ (2006).

2.3 Socio-environmental Vulnerability Index– SEVI

The integration or overlay maps produced with retaining the Social Vulnerability Index - SVI and the Physical Exposure to Floods Index - PEFI, allowed the identification and location of spaces where there is coincidence of risks and social and environmental vulnerabilities, resulting in the final product this paper, the Socio-environmental Vulnerability Index– SEVI of the Maranguapinho river basin, represented graphically by the thematic map of socio-environmental vulnerability. Initially a map legend and the respective groups of Socio-environmental vulnerability were defined through the intersection of groups of vulnerability indices produced earlier (*Fig 7*). It was proposed the crossover between the groups of vulnerability (social and physical) supported in their proportionality, *ie,* groups with similar hierarchies (eg, high social vulnerability/high physical vulnerability).

Overlaying several maps performed using the ArcGIS 9.2 followed the legend developed earlier and integrated census sectors of social index with the areas of spatial extent of floods of physical index, which showed proportional vulnerability indices, thus forming homogeneous groups of socio-environmental vulnerability and enabling the identification and location of spaces occurring coincidence of social and environmental vulnerabilities.

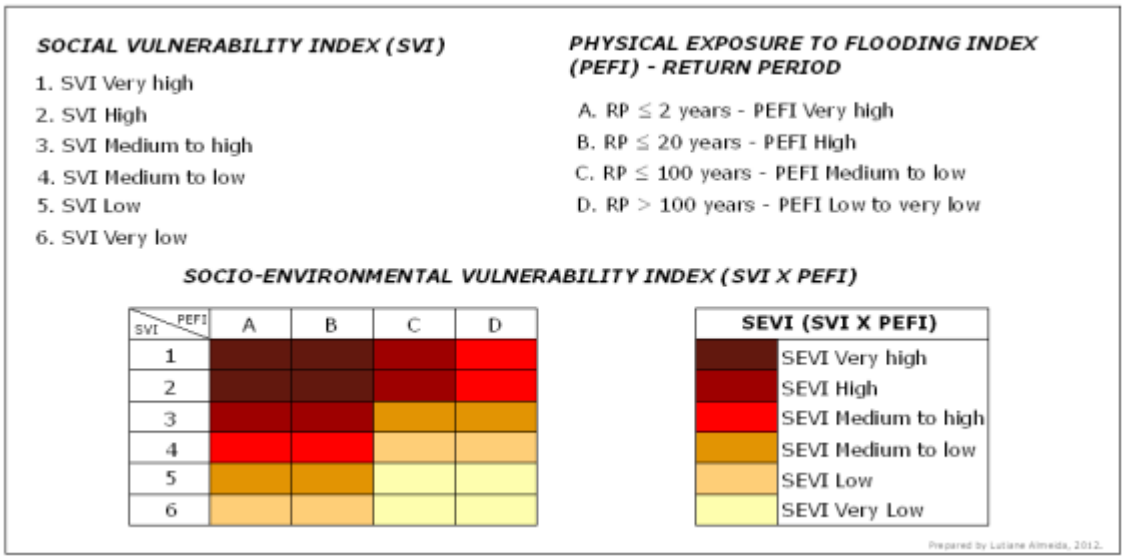

Fig. 7 Methodology for the preparation to the map of Socio-environmental Vulnerability - SEVI.
Source: prepared by Lutiane Almeida (2012).

Source: prepared by Lutiane Almeida (2012).
Note: SVI - Social Vulnerability Index; PEFI - Physical Exposure to Flooding Index; (+ or -) degree of vulnerability.

3. RESULTS

According to the Socio-environmental Vulnerability (figure 12), it is possible to distinguish *four patterns of spatial distribution* of vulnerable areas, which are formed both in the justification of the main hypothesis of this research and expose some limitations of search results.

Pattern 1 - regions of the basin detaining conditions from high to very high socio-environmental vulnerability (according to the census sectors), located in the northern portion of the basin (western portion of the city of Fortaleza), in more dense urban spaces, and along the main channel and tributaries of the urban Maranguapinho river. This pattern confirms the main hypothesis of this paper - that there is spatial coincidence between regions with heavy social vulnerabilities associated with intense physical exposure to natural phenomena exacerbated by human action, such as flooding, *ie*, there is overlap of various risks, in specific areas of the basin (see *Fig 8*);

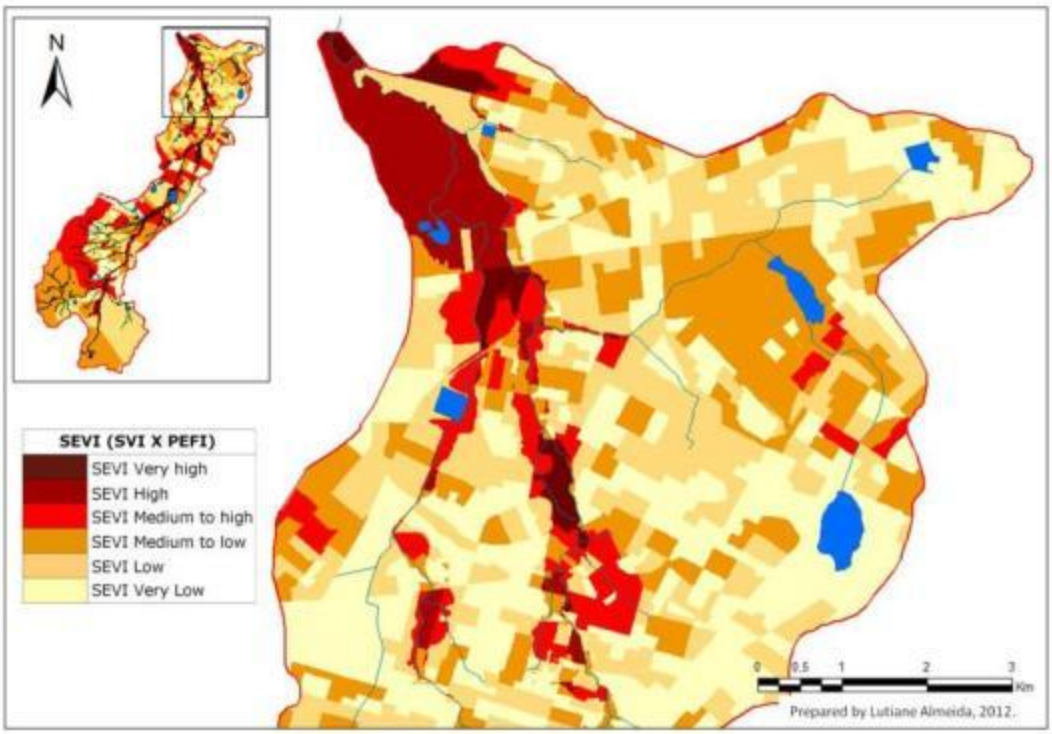

Fig. 8 Area of Maranguapinho river basin corresponding to spatial pattern 1 of Socio-environmental vulnerability.
Source: prepared by Lutiane Almeida (2012).

The pattern 2 - central portion of the basin, corresponding to peripheral regions of Fortaleza and territorial limits with other municipalities, where there is a tendency to "spreading" of vulnerability due to the occurrence of spatially larger census sectors than the pattern 1, while, where there is less urban density and population density. However, these regions with high socio-

environmental vulnerability also have coincided, even if less accurate compared to the pattern 1, with the space heavily exposed to the occurrence of floods (*see Fig 9*);

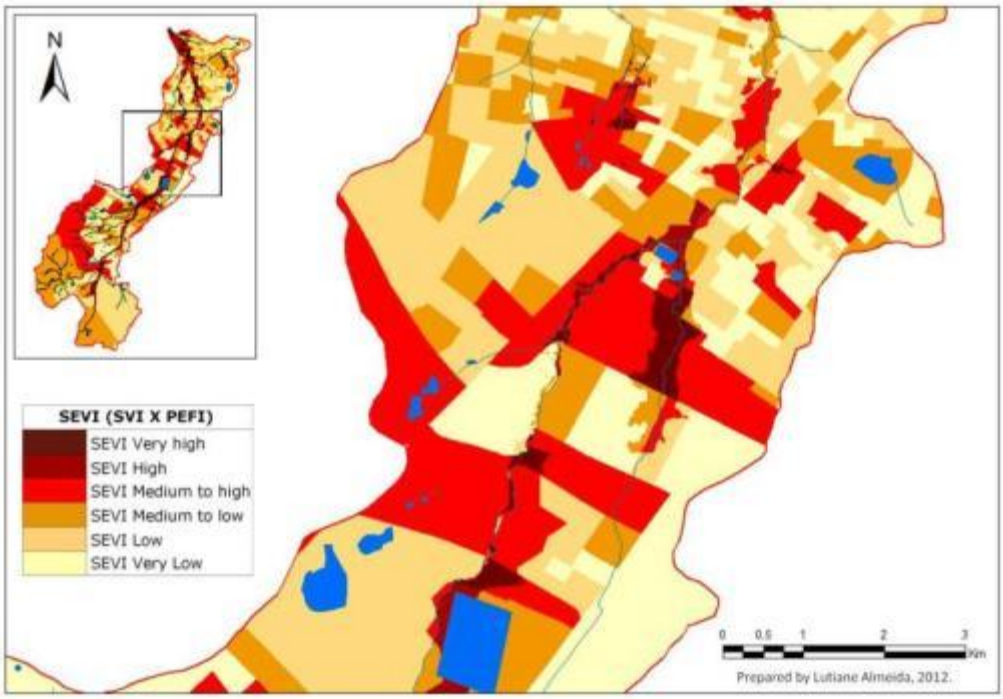

Fig. 9 Area of Maranguapinho river basin corresponding to spatial pattern 2 of Socio-environmental vulnerability.
Source: prepared by Lutiane Almeida (2012).

The pattern 3 is showing the followings; located in the southwest region of the basin, following the main river channel, with areas characterized by high social and environmental vulnerabilities. These are regions with high exposure to flooding, but urban and sparsely populated. In this case, the socio-environmental vulnerability is potential if there would be the future urban density in this region. Thus, this feature is configured as a result of this limitation of the study, since the overlap of the regions exposed to floods occurred with census sectors, they do not always represent the actual conditions and demographic characteristics of urban area, but a practical definition an area to be searched according to the practical objectives of the IBGE (see *Fig 10*);

The pattern 4 is in the southern basin, and the area corresponding to the location of several springs from the Maranguapinho river, there are regions configured as medium to high vulnerability. However, this condition is partial, since they are census sectors with rural characteristics, spatially large and low urban densities and population densities, despite holding high social vulnerability, aspect to be taken more into account in the case of planning to the allocation of resources for investments in reducing social and environmental inequalities that region of the river basin (see *Fig 11*).

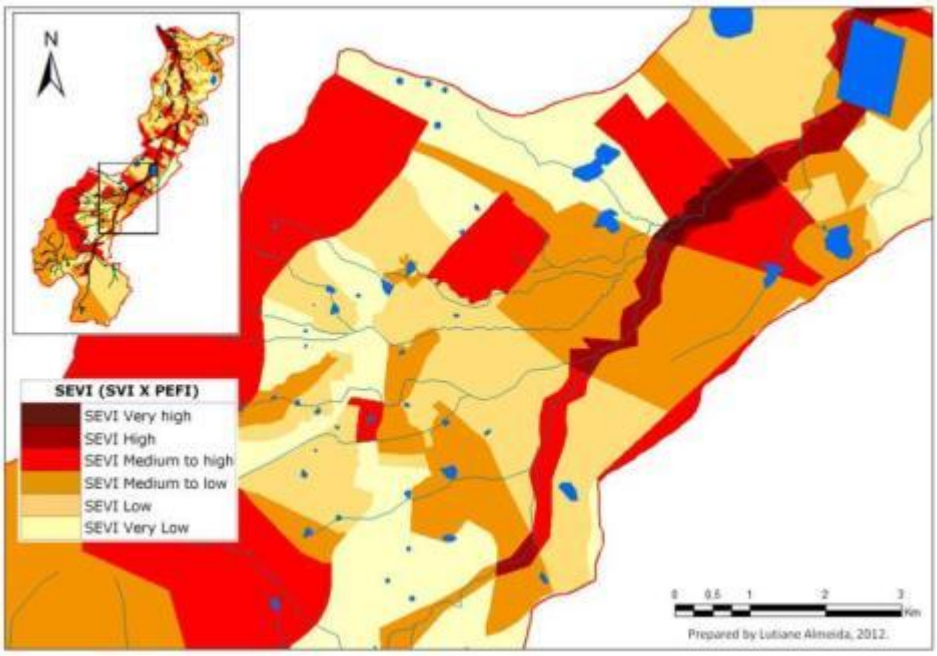

Fig. 10 Area of Maranguapinho river basin corresponding to spatial pattern 3 of Socio-environmental vulnerability.
Source: prepared by Lutiane Almeida (2012).

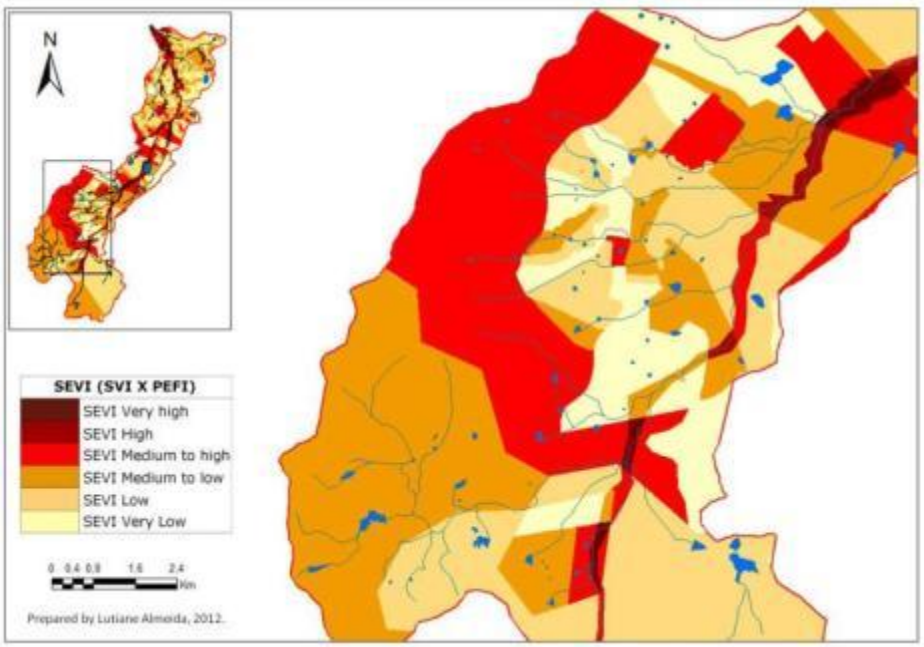

Fig. 11 Area of Maranguapinho river basin corresponding to spatial pattern 4 of Socio-environmental vulnerability.
Source: prepared by Lutiane Almeida (2012).

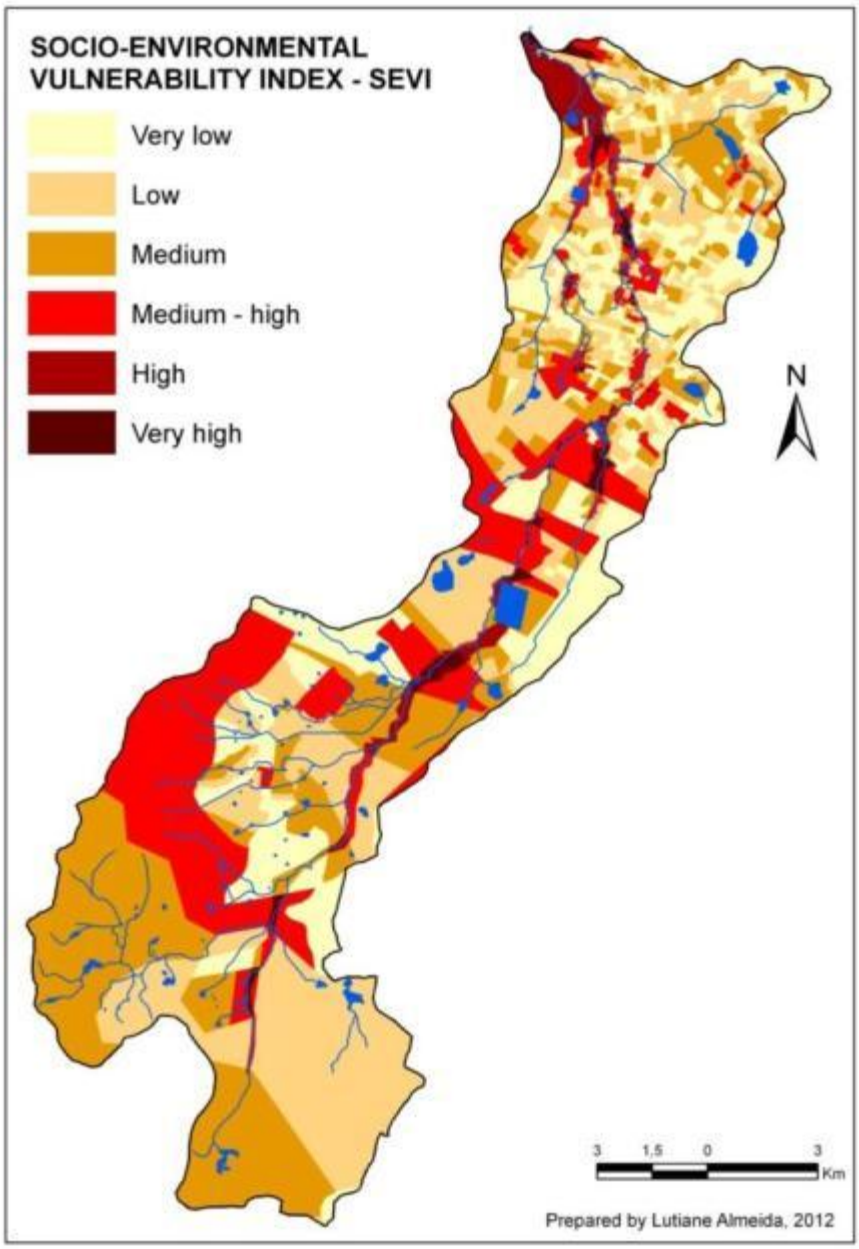

Fig. 12 SEVI Map.

Source: prepared by Lutiane Almeida (2012).

4. Conclusion

The main objective of this paper was to analyze the social and environmental vulnerabilities of the urban rivers, using the Metropolitan Region of Fortaleza - MRF, northeastern of Brazil as an area of study for understanding the interrelationships of physical exposure to natural hazards, social susceptibility to these events, in addition to the segregation and poverty in urban areas. The leading hypothesis of the research was that there is an overlap in certain areas of risk in cities in

Brazil, *ie*, there is coincidence between the areas prone to hazardous natural processes, natural phenomena such as floods, and the spaces of the city that have the most vulnerable communities from the viewpoint of its social, economic indicators and access to services and urban infrastructure ones. Put another way, those least resourced spaces have occupied the spaces risk of the city.

This overlapping context of risks and vulnerabilities in specific areas of towns and cities in Brazil undergoes also by the overlapping of socio-cultural dimensions associated with the way as society deals with the territories exposed to physical and natural dynamics, and the one of more vulnerable urban population survival in terms of access to basic urban services. One of the main paradoxes of modern society is the dichotomy between man and nature. This gap between society and nature, linked to developments in science and technology with the main historical mentor René Descartes, contributed to the alleged overcoming of natural laws by man. For cities, a major (if not the principal) symbols alleged modification, improvement, detachment and denial of nature, natural environments have been taken long as holders of insecurity.

In Brazil, the process of devaluation and abandonment of so-called Permanent Preservation Areas[1] (PPA) is historical, which includes fluvial environments, its margins, canals, wetlands, areas subject to flooding, often considered by society and by the Government, hazardous and unhealthy spaces.

This devaluation, coupled with the demographic explosion of Brazilian cities from the 1960s, and the problems arising from migration and population concentration, such as housing deficit, have caused a large contingent of people lacking sufficient income to acquire decent homes, provided with urban infrastructure, access to public services and located in environmentally safe spaces, occupy the margins of rivers and urban streams, thus creating an intense dialectical conflict between poverty and natural dynamics, resulting in areas of natural and social risks. There is then in this context, *urgency for valorization of urban river environments*, ie, providing these spaces of a specific function in the environment of cities. The creation of public parks, recreational spaces, linked to the allocation of space for expansion of the periodic flood waters are some examples. Thus, while there is appreciation of river environments, it also gives one of the pillars of flood risk management, prevention of disasters caused by the disorderly occupation of areas exposed to natural hazards.

[1] Permanent Preservation Areas (PPA) are provided in the Brazilian Forestry Code, Law No. 4771 of 1965, which include forests and other forms of natural vegetation located along rivers, springs, mountains, slopes, wetlands etc.

Risk management, nevertheless, as public policy in Brazil, is still somewhat neglected, as suggested by Almeida and Pascoalino (2009). There is a substantial concentration of investments in what is called "crisis management" or "disaster management", ie public action happens in order to remedy the consequences of hazardous events and causing material damage and human losses, as the case of heavy rainfall, flooding and landslides occurred in November 2008 in the State of Santa Catarina, southern Brazil. Furthermore, There are many conceptual problems regarding the definition of what process the government must act: on the risk (with actions of prediction, prevention and protection) and/or about the disaster (repair)? There is still much uncertainty in relation to concepts of risk, hazard, vulnerability and disaster, in Brazil. e, There is therefore an urgent need to incorporate the concepts of risk, hazard and vulnerability to the risk management system in Brazil, in addition to the development of academic research on these topics.

Moreover, even though the definition, understanding and operationalization issues, depending on the complexity and multidimensionality, it can be secure that the concept of vulnerability can help identify the socio-spatial characteristics of particular communities (and individuals) that influence their response and recovery capabilities in the face of natural hazards, as emphasized by Cutter et al. (2003). Similarly, the operationalization of the concept of vulnerability can be useful in identifying priority areas for investment that can improve the resilience of communities that appear more prone to natural hazards by social vulnerability. Thus, the use of the concept of vulnerability and its operationalization can help make decisions that enable the reduction of risks of natural disasters. The methodology for the operationalization of this concept is based on the attempt to measure them (Birkmann, 2006), made possible by the overlap of two specific indicators of vulnerability: physical exposure to natural hazards and social susceptibility to these processes.

Socio-environmental Vulnerability Index - SEVI, final result of this article, far from holding an optimal methodology for the representation of the overall vulnerability of a particular community, it lacks refinements that require more time for research on alternative operationalization of this concept, the incorporation other variables of vulnerability assessment, and access to other data sources. However, the methodology employed in this paper, both statistical analyzes, the hierarchy of the spatial and frequency of natural hazards, is considered robust enough to support at the same time, accomplishment of new researches on the subject and the direction of investment priorities in areas identified as most vulnerable. Furthermore,

SEVI can be used as a complement to other types of social and environmental indicators and assist in a more substantiated analysis of the problems of Brazilian metropolises, not exclusively.

With regard to the operationalization of the concept of vulnerability in this research, we can conclude that, according to the indicators developed for the Maranguapinho river basin, included in the Fortaleza metropolitan context, there is a pressing need for investment in priority factors, such as education, urban infrastructure (notably environmental sanitation *lato sensu*), housing policies, specific policies for young and old people, in the spaces where they identified the coincidence of social vulnerabilities and exposure to risks of flooding. It was concluded also that there is a need for assessing the spatiotemporal evolution of social and environmental vulnerabilities, in order to know how the vulnerability indicators evolve over time and space, as advocated by Cutter et al. (2003) and Cutter and Finch (2008). It can be concluded also that the final result of this research, the Vulnerability Socio-environmental Map confirms the hypothesis of this paper, by demonstrating the coincidence between the areas of greatest exposure to flood risks and the spaces that hold the highest indicators of social vulnerability.

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