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Vulnerability and socio-ecological risks: an integrated perspective of risks in Guaratiba (Rio de Janeiro – Brazil)

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Abstract
Through almost five centuries of occupation and the resulting processes of landscape transformation, ecological scenarios in the neighborhood of Guaratiba have become areas of production, residence, and urban transition. This historicity is a key element to understand local vulnerabilities and associated risks. Thus, within the scope of landscape management and under an integrative approach of vulnerabilities and risks, our objective in this study is to map and analyze socio-ecological vulnerabilities and risks in the study area. Research was structured on i) investigating the history of landscape use, occupation and transformation, ii) identifying vulnerable areas, and iii) classifying socio-ecological risks. Three methodological steps were used: (1) analysis of historical processes of land use and occupation in Guaratiba; (2) delimitation of Socio-ecological Landscape Units (SELU) in order to understand current levels of heterogeneity in the study area; and (3) modeling and characterization of identified socio-ecological risks. Based on the geoprocessing technique known as fuzzy logic, analysis led to a socio-ecological classification of risks, recognizing that such phenomena can only be understood by examining human presence in face of the relevance of events which can harm exposed groups. The investigation showed that four out of six delimitated landscape units have points on which there is a tendency of risks: SELU 2, SELU 4, SELU 5, and SELU 6. These areas suggest socio-ecological risks of the physical type, related to geomorphologic (landslides and floods) and environmental health dynamics.

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INTRODUCTION

The idea of vulnerability interacts with the dimension of social habitat – a context that conditions populations exposed to life threatening events, or subject to relevant consequences of socio-ecological risks (BRASIL, 2007; CARVALHO, 2010; LAVELL et al, 2012; LAYRARGUES, 2012; MANDAROLA JÚNIOR, 2014; PORTO, 2012; SAITO et al, 2015; VEYRETE, 2015). This paradigm motivated the present investigation about spaces in which such events occur, by means of mapping areas prone to risks classified as socio-ecological in the neighborhood of Guaratiba, municipality of Rio de Janeiro (state of Rio de Janeiro, Brazil).

This area was explored by Europeans as early as the 16th century (MANSUR, 2008; 2011; 2016) and went through an extended process of landscape transition that reveals, as time went by, a history of land struggles, expressed by transformations of ecological scenarios in productive areas, residential areas, and urban transition areas. The neighborhood went through economic periods that marked the history of Rio de Janeiro, with high agricultural productivity cycles followed by declines (MANSUR, 2008, 2011, 2016; MOTA, 2009). These cycles led to significant changes in processes of land use and occupation and altered local socio-ecological relations.

These alterations in ecological spaces and in territorial domains led to the formation of residential areas, a key component to understand local vulnerabilities and associated risks (PORTO, 2012).

Within this context of land use planning, and considering more recent urban expansion projects in the city of Rio de Janeiro, this article discusses urbanization processes that subject habitation uses to constant territorial and environmental conflicts, turning the former rural Guaratiba into a new area of public and private speculative interest.

This study seeks to understand vulnerable and risky contexts, if they exist, and pinpoint their locations. It is a continuation of a master's degree research, the objective here being to map and analyze socio-ecological vulnerability and risk based on the understanding of local spatial dynamics, in order to identify these risky areas and their respective classifications.

Research was performed on the Portinho river hydrographic system, encompassing the neighborhood of Barra de Guaratiba and part of the neighborhood of Guaratiba, in the municipality of Rio de Janeiro. The following methodological steps were taken: i) literature review about processes of socio-ecological vulnerabilities and risks; ii) delimitation of Socio-ecological Landscape Units (SELU) in the study area, to understand the spatial distribution of physical, ecological, and social elements of the landscape under study in its heterogeneity, in face of current processes of land use and occupation which define this landscape; and lastly iii) modeling and classification of socio-ecological risks, based on the systematization of geoprocessing tools and on the validation of empirical analysis in exploratory fieldwork and in interviews with focal groups.

This systematization allowed the research to evaluate socio-ecological vulnerabilities and risks from the modeling and characterization of SELUs. This is an integrative approach on different aspects, considering environmental health, geomorphology, and human and social aspects of the impacted population.

This diagnosis is considered to be a positive one, as it highlights the importance of democratic and participatory policies in land use planning and landscape management.

METHODOLOGICAL PROCEDURES

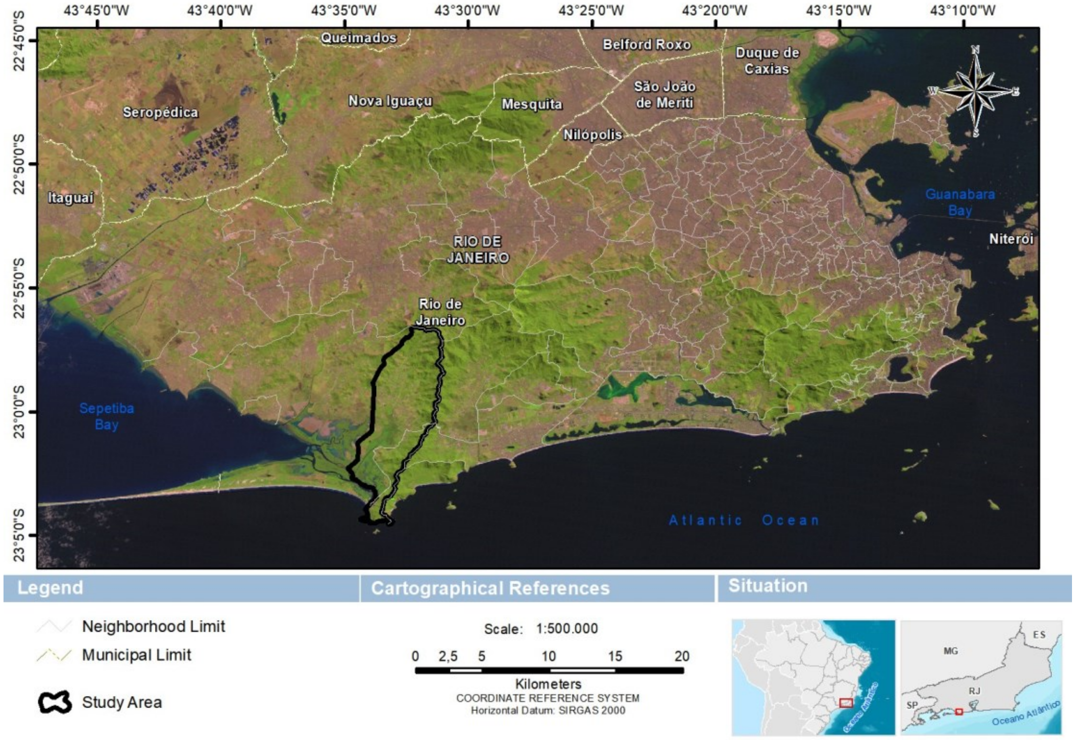
Characterization of the study area

The study area is located in the West side of the city of Rio de Janeiro, between latitudes 22º55'00"S and 23º05'00" S, and longitudes 43º35'00"W e 43º30'00"W (Figure 1). It encompasses the neighborhood of Barra de Guaratiba, as well as part of the neighborhood of Guaratiba, in addition to parts of territories under the jurisdiction of a state park (Parque Estadual da Pedra Branca, specifically the Ilha de Guaratiba sector of the park), and a state biological reserve - Reserva Biológica de Guaratiba (REBIO).

The study area has 47,31 square km, is covered by plenty of Atlantic Forest flora and biodiversity, lowland lake environments, and a rocky massif (Serra Geral de Guaratiba / Pedra Branca massif).

Portinho river, which gives its name to the hydrographic system selected here as the study area, has its source at around 200 m of altitude and flows into the Bacalhau Canal after approximately 14 km.

Figure 1 – Localization of study area in the municipality of Rio de Janeiro (state of Rio de Janeiro – Brazil).



Source: Lima (2017).

Guaratiba is the neighborhood that has the highest percentage of Atlantic Forest vegetation coverage (SMAC, 2011) in the municipality of Rio de Janeiro; landscape potential for this area and its economy is based on activities such as eco-tourism, seafood gastronomy, and strong real estate speculation.

Land use and occupation in the study area occur in a predominantly dense mountain and sub-mountain Ombrophilous Forest formation, in a secondary stage of succession (initial, intermediary, and advanced); there are also mangrove formations; saline fields; tree-shrub vegetation; and other anthropogenic formations, including areas with plantations of banana and ornamental species.

Topographical amplitude varies between 0 and 680 m in the Northeast face of the hydrographic system, composing a terrain with geomorphological units of river and sea-river plains (0-20 m), isolated hills (20-100 m), hills (100-200 m), and mountain ranges (altitudes above 200 m) in coastal and inland massifs (INEA 2011).

Forms of flux accumulation (flat terrain) correspond to 51 % of the study area. This terrain has a significant urban occupation, especially along the E-W road axis.

Geological groups correspond to Quaternary formations of River Sediments, and Pre-Cambrian formations in Granodiorite, Rio Negro, and Granitic Rocks units (REIS; MANSUR, 1995), in terrain belonging to the Guanabara Graben (FERNANDEZ, 2012).

In areas with rugged terrain, red-yellow clay soils are predominant. These are highly weathered mineral soils, very well developed, with medium clay texture, sometimes tending towards rocky; gneisses and granites make up the substratum in this area. It is worth noting that these soils belong to a class that has a considerable erosive tendency, possibly promoting water retention as well as hydraulic discontinuities, favoring the occurrence of ravines and gullets.

In areas of low declivity, there are level and wavy terrains, in which Gleysols predominate in environments subject to tidal activity. These soils are conditioned to being flooded during a good part of the year, the reason for them being called "soft soils". There are also sandy soils in parts of the sandbanks and indiscriminate soils in mangroves (EMBRAPA, 2013; INEA, 2010).

This stationary flooding is due to Planosols and their hydromorphic characteristic that leads to the formation of perched water tables in areas contained within the Guaratiba aquifer limits, and mangrove environments. This leads to a sensibility of the ecological system, due to underdeveloped pedogenesis, and to geotechnical issues that affect habitation. These circumstances create conditions of vulnerability for social groups that occupy these areas, because they are exposed to risks related to floods.

Another important characteristic is that state protected areas in the neighborhood cover around 74 % of the Portinho river hydrographic system (the other 26% have no legal protection). However, 100% of the area is contained within the Atlantic Forest Biosphere Reserve (RBMA), revealing the importance of a local natural resources management model that is integrated, sustainable, and participatory.

MATERIALS AND METHODS

The initial part of the research consisted in a bibliographic survey in order to establish conceptual approaches; this included different technical and academic publications, besides the official websites of public institutions.

Next, data surveys led to the acquisition of geo-referenced geographical data for geospatial analysis and map elaboration (vector data in shapefile format and satellite images), taken from institutional websites and provided by public institutions. Orbital images correspond to sensor Landsat 8 (2015), with a spatial resolution of 30 m, and Ortofotos (2015), with spatial resolution of 10 m.

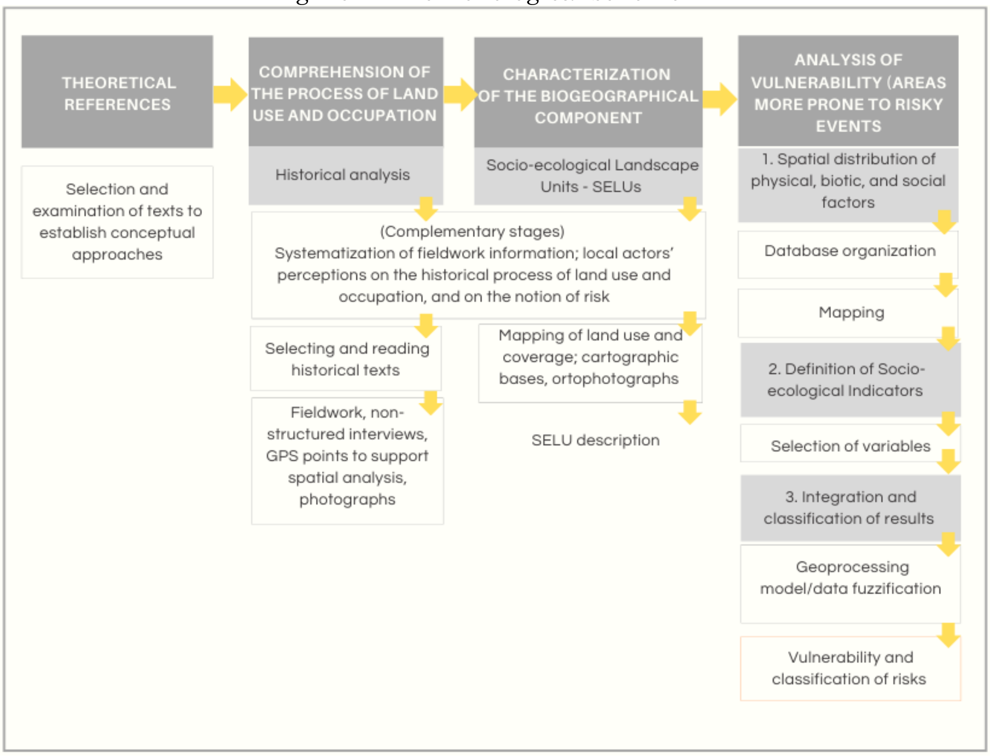
Two rounds of fieldwork were performed to obtain primary data, using GPS to acquire points of interest observed in the field or in photographs; in addition, non-structured interviews were conducted. This aided geospatial analysis, qualification, and description of results.

All geographical data were projected for UTM 23S Coordinate Referencing System, Datum SIRGAS 2000.

Non-structured interviews were performed with the participation of a community leader, who suggested other informants who were also interviewed. Additionally, we participated in a workshop with residents from the sections of Araçatiba, Olaria, and Rua dos Guimarães. This step helped us record impressions from residents about processes of use and occupation and local risks. Non-structured conversations revolved around questions such as: “Is there any type of risk in this locality, and what would be the nature of this event?” “Are there rivers/canals nearby?” “: Do they usually originate floods?” “Are there floods?” “What is their nature?” “Are there records of diseases such as dengue fever, leptospirosis, or another kind?”.

Figure 2 displays a general depiction of the methodological steps.

Figure 2 - Methodological scheme



Source: Adapted from Lima (2017)

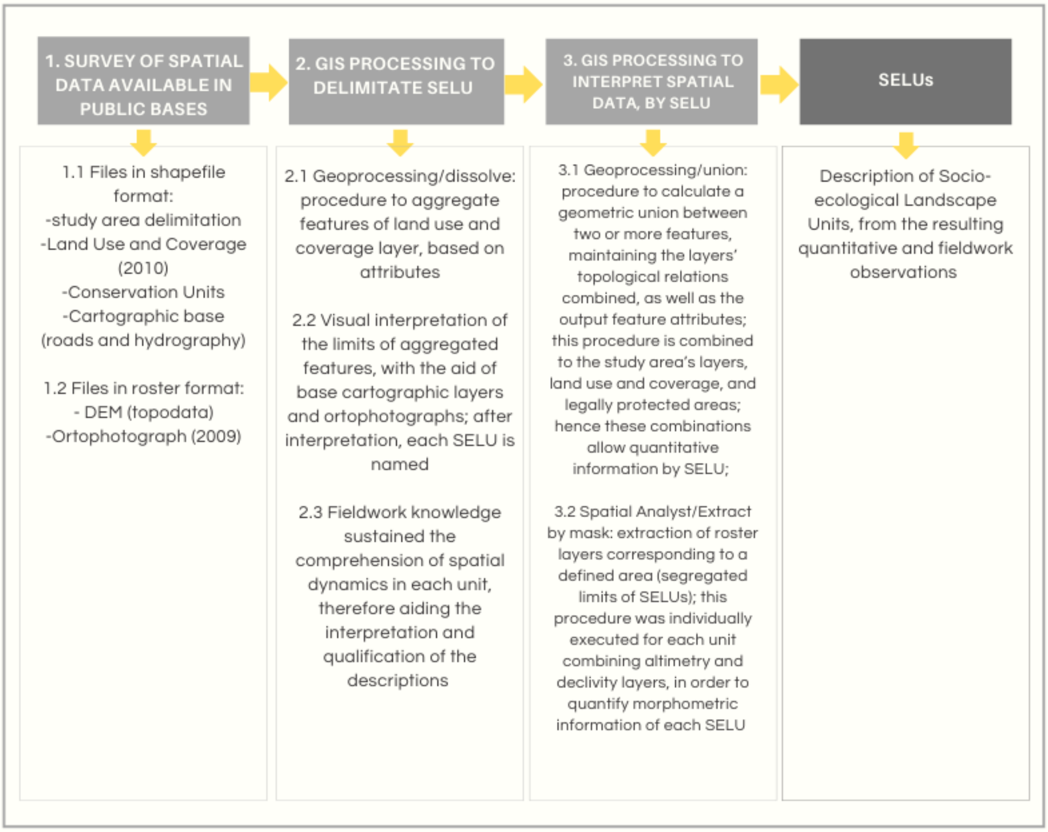
Delimitation of Socio-ecological Landscape Units

Socio-ecological interpretation of risks considers a place's historicity in the interpretation of its landscape (SOLÓRZANO et. al. 2016), plus the notion of vulnerability and risk presented by Porto (2012), whose idea of risk converges to the meeting of time, place, and people.

In this perspective, dividing the study area in units- the Socio-Ecological Landscape Units —- allowed us to understand the situation on the basis of local perspective, according to historical processes recognized in the study area, a specific dynamic in each place.

To better understand this stage of the research, Figure 3 displays a flowchart to explain how Socio-Ecological Landscape Units - SELUs were delimited.

Figure 3 – Work flowchart to delimit Socio-ecological Landscape Units (SELUs)



Source: Adapted from Lima (2017)

Geoprocessing model: vulnerability analysis and classification of socio-ecological risk areas

Environmental system modeling is defined by methodological procedures that use an integrated approach seeking to identify or comprehend types of spatial events or phenomena (CHRISTOFOLETTI, 1999). The author points to these perspectives in environmental analysis in order to consider the complexity of the system and of the components under scrutiny, as well as the relevance of a holistic approach to understand the spatial organization of physical elements and the (co)relations between them.

In this sense, spatial questions are the key to solving problems in a geospatial optics, in which procedures for environmental modeling must be systematically organized to subsidize new plans of thematic information.

Vulnerability analysis and risk area determination are based on a multi-criteria analysis that requires knowledge of the area and of the situations that favor the occurrence of some kinds of events. Hence, in the modeling process some stages are determined such as: 1) define the problem; 2) list the variables; 3) determine the values of each listed variable (weighing when possible); 4) re-classify data (adequacy to information plans); 5) combine layers; and 6) analyze results.

In order to achieve the purposes of this research, which include the spatial question "where are vulnerable areas located with greater suitability to related risks?", we propose a type of fuzzy multi-criteria analysis, based on set theory. The analysis provides techniques to evaluate discrete data inaccuracy, reducing the effects of spatial unsuitability on categorization, through continuous data (ZADEH, 1965; 1978).

Fuzzy procedures represent "spatial limits between two or more classes which are represented by transitional zones where the values of the variable are distributed continuously." (FERREIRA, 2014, p. 286, translated). The author explains how to determine areas of greater or lesser suitability to the phenomena under analysis. For core-areas, considered to have greater suitability, pixels are presented more homogeneously due to affinities determined by the objects in this class; for areas considered as borderline regions, or transitional zones, characteristics are presented with lesser affinities and, therefore, these zones are less suitable to the phenomena under analysis.

Next, Chart 1 presents the variables used in the geoprocessing model to indicate vulnerable areas and the reasons to choose these variables.

Chart 1. Variables used on the geoprocessing model.

Selected Variables	Description	Justification	Source
1 - Declivity	Represents slope areas of 0°-20°, 20°-30°, and >30°	Areas of high declivity suggest attention to processes of occupation; these groups were qualitatively defined	SRTM 30m, Topodata
2 – Morphology of slopes	Represents concave, convex, and flat terrains	Landscape morphology is an important indicator of occupation processes	Integrated mapping of high declivity areas, cavities analyzed from SRTM and contour lines
3 – Soils	Areas of susceptibility to erosion - Null, Moderate and Strong	Classes of soils with greater susceptibility to erosion, combined with other physical factors in heavy rain, may favor geomorphologic events (landslides)	Soils – Environmental Indicators of the State of Rio de Janeiro – INEA, 2010
4 – Vegetation coverage and land use	Anthropic agricultural areas, Anthropic non-agricultural areas, Forest formation, Grass formation, Pioneer formation, water	Processes of use and occupation are important in the assessment of risks, since they identify places where there is occupation.	SMAC, 2011

Source: Lima (2017).

The proposed model will reveal areas of higher suitability to certain risks through the combination of participating layers.

The classification of socio-ecological risks will correspond to fuzzy analysis results, that is, to the combination of spatially re-classified layers and qualitative analysis of fieldwork evidence, which allowed the analysis and qualification of these areas.

Chart 2 explains the conceptual model and flow work in the stages of: 1 – definition of variables; 2 – re-classification of attributes and transformation of data; 3 – definition of levels of suitability; 4 – a combination of layers; and 5 – analysis of results. These procedures were executed in model builder interface in ARCGIS10.4. software.

Chart 2. Conceptual model and flow work

<table>
<tr><td colspan="5">1 - Classification e standardization of variables</td></tr>
<tr><td>Tool</td><td colspan="2">Spatial Analyst / Reclassify</td><td>Spatial Analyst / Reclassify</td><td>Spatial Analyst / Reclassify</td></tr>
<tr><td>Input</td><td colspan="2">use (“uso”)</td><td>soils (“solos”)</td><td>Slope Morphology (“MorfoE”)</td></tr>
<tr><td>Parameter</td><td colspan="2">ordinate values</td><td>ordinate values of classes of erosion</td><td>Ordinate values</td></tr>
<tr><td>Output</td><td colspan="2">Reclass_uso</td><td>Reclass_solos</td><td>Reclass_MorfoE</td></tr>
<tr><td>Tool</td><td colspan="2">Spatial Analyst / Float</td><td>Spatial Analyst / Float</td><td>Spatial Analyst / Float</td></tr>
<tr><td>Input</td><td colspan="2">Reclass_uso</td><td>Reclass_solos</td><td>Reclass_MorfoE</td></tr>
<tr><td>Parameter</td><td colspan="2">-</td><td>-</td><td>-</td></tr>
<tr><td>Output</td><td colspan="2">Float_uso</td><td>Float_solos</td><td>Float_MorfoE</td></tr>
<tr><td>Tool</td><td colspan="2">Spatial Analyst / Divide</td><td>Spatial Analyst / Divide</td><td>Spatial Analyst / Divide</td></tr>
<tr><td>Input</td><td colspan="2">Float_uso</td><td>Float_solos</td><td>Float_MorfoE</td></tr>
<tr><td>Parameter</td><td colspan="2">10</td><td>10</td><td>10</td></tr>
<tr><td>Output</td><td colspan="2">Divide_uso</td><td>Divide_solos</td><td>Divide_MorfoE</td></tr>
<tr><td colspan="5">2 – Definition of degrees of suitability</td></tr>
<tr><td>Tool</td><td>Spatial Analyst / Fuzzy Membership</td><td>Spatial Analyst / Fuzzy Membership</td><td>Spatial Analyst / Fuzzy Membership</td><td>Spatial Analyst / Fuzzy Membership</td></tr>
<tr><td>Input</td><td>declivity (“declividade”)</td><td>Divide_uso</td><td>Divide_solos</td><td>Divide_MorfoE</td></tr>
<tr><td>Parameter</td><td>MS Large; 1 ; 1; None</td><td>MS Large; 1 ; 1; None</td><td>MS Large; 1 ; 1; None</td><td>MS Large; 1 ; 1; None</td></tr>
<tr><td>Output</td><td>FuzzyMe_declividade</td><td>FuzzyMe_Uso</td><td>FuzzyMe_solo</td><td>FuzzyMe_MorfoE</td></tr>
<tr><td colspan="5">3 - Combination of layers</td></tr>
<tr><td>Tool</td><td colspan="4">Spatial Analyst / Overlay</td></tr>
<tr><td>Input</td><td colspan="4">FuzzyMe_declividade; FuzzyMe_Uso; FuzzyMe_solo; FuzzyMe_MorfoE</td></tr>
<tr><td>Parameter</td><td colspan="4">gamma; 0,9</td></tr>
<tr><td>Output</td><td colspan="4">Vulnerability</td></tr>
</table>

Source: Lima (2017).

RESULTS AND DISCUSSION

Discussion on vulnerability and risk classification made for each of the delimitated SELUs correlates historical and current processes, emphasizing the environmental diversity in each unit.

Notions of vulnerability and risk presented here are related to the collective dynamics of historical processes and legacies at local levels examined from the dimension of social habitat, that is, essentially the presence of population subject to some type of harm to human life (BRASIL, 2007; CARVALHO, 2010; LAVELL et al, 2012; LAYRARGUES, 2012; PORTO, 2012; SAITO et al, 2015; VEYRETE, 2015).

The current context of land use planning in the Guaratiba neighborhood area is part of Rio de Janeiro’s well-known vulnerabilities to rains and landslides and an example of the relationship between health and territory as urban and rural landscapes are transformed.

From this approach, we understand the classification of socio-ecological risks from the perspective of place, daily life, and participating actors. Socio-ecological risks are built, therefore, in the context of vulnerability that involves social groups and their cycles of exposure and response to extreme events that may favor the occurrence of harm and disease (GLASER, 2006).

In the next section, we will present the definition and characterization of Socio-Ecological Landscape Units in their respective classifications of vulnerability and socio-ecological risks.

Socio-ecological Landscape Units

Landscape Units are commonly used in methodologies applied in landscape diagnostics or in environmental studies (ANDORRA, 2014; BARCELONA, 2018; FÁVERO et al, 2007; HOYUELA JAYO, 2016; 2017; MAGALHAES et al, 2016; SILVA et al, 2013; TUDOR, 2014). Mapping Landscape Units is therefore understood as a tool to evaluate potentials and fragilities in these areas, recognizing their cultural values (CUSTÓDIO 2014; RIBEIRO, 2016) and corroborating legal instruments in Brazil’s national environmental policy, created by Law 6.938, in 1981 (BRASIL, 1981).

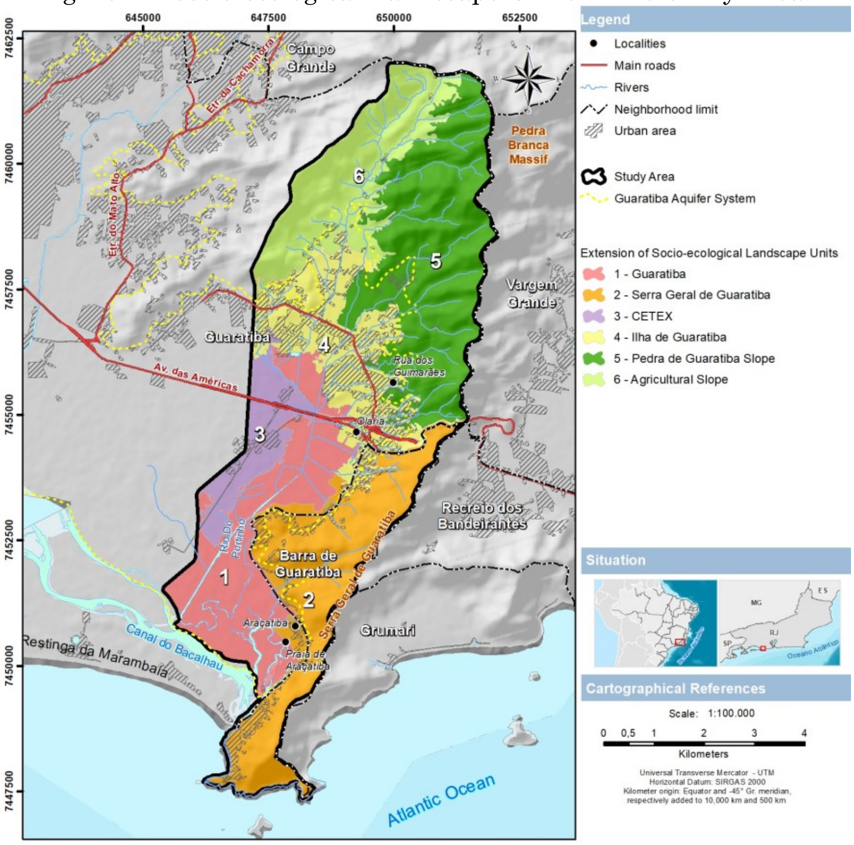
Considering this theoretical and legal framework, Socio-ecological Landscape Units (SELU) are defined by homogenous features or characteristics such as soil use and coverage;

physical, biotic, and social properties; environmental services; cultural symbolism; and identification (or lack thereof) of jurisdiction, since legal instruments are understood here as participants of historical processes, as they influence the degree of landscape transformation (LIMA, 2017).

The study area was evaluated under the optics of SELU, presenting a local characterization and current scenario in order to understand risk-related factors.

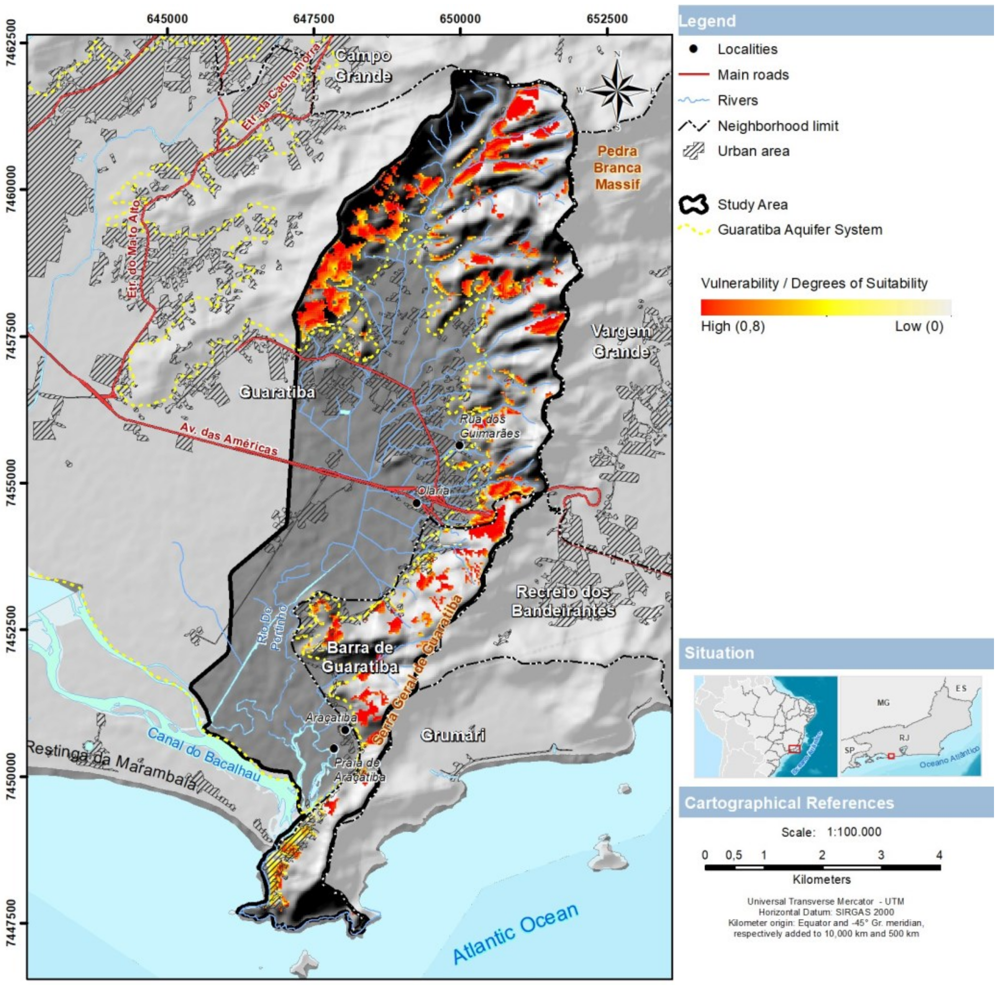
Figures 4 and 5 show maps representing SELUs and landslide models, in order to classify vulnerability and socio-ecological risks.

Figure 4 – Socio-ecological Landscape Units in the Study Area.



Source: Lima (2017).

Figure 5 - Areas of vulnerability.



Source: Lima (2017).

In the characterization of vulnerable areas, the model yielded results classified by degrees of suitability, which varied between 0 and 0,8 (Figure 5). Qualitative definition of areas at risk of landslides considered values between 0,6 and 0,8 (core areas) as well as proximity to urban influence.

Values inferior to 0,6 did not represent core areas in the model, thus being less suitable to be considered areas of risk.

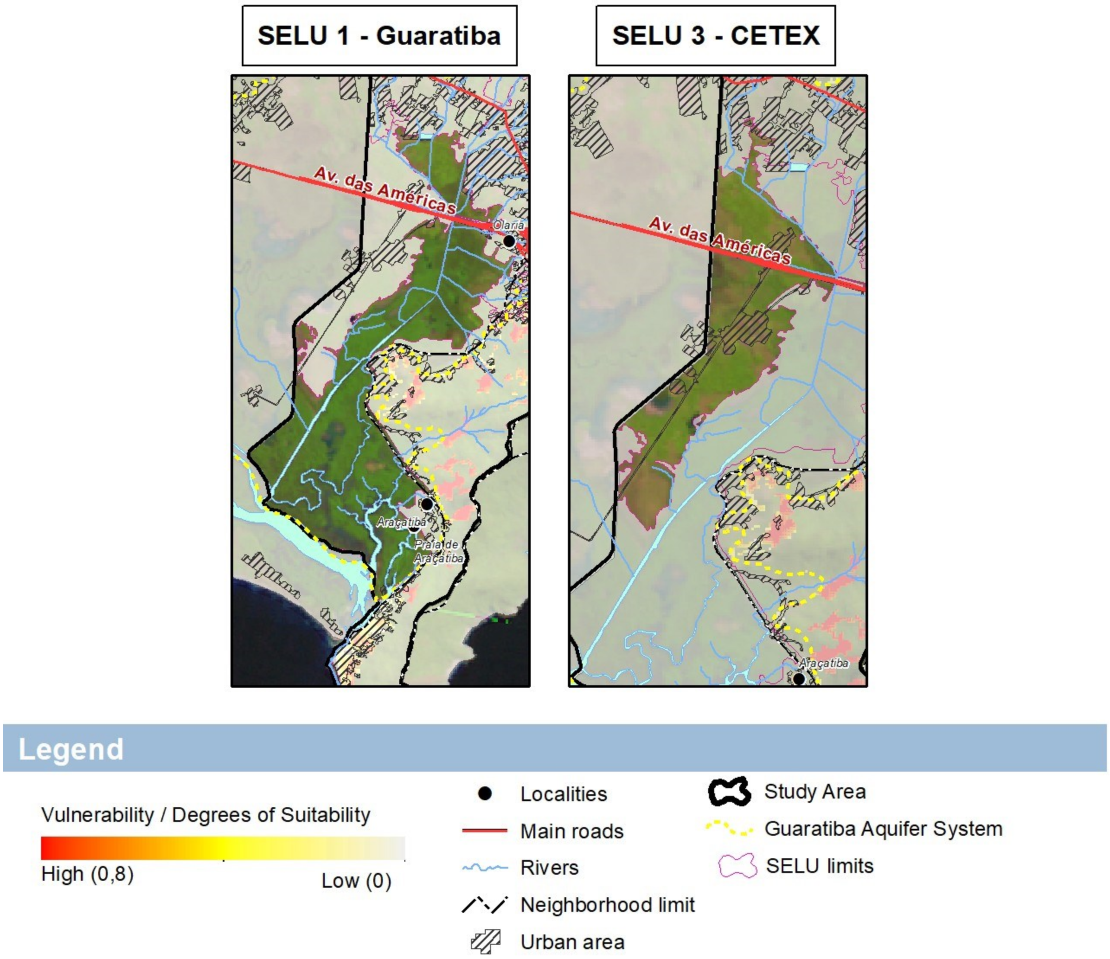
Therefore, the characterization of vulnerability and risk areas considered the following: 1) degrees of suitability in values superior to 0,6; 2) areas subject to floods (noted by resident populations); 3) simultaneous presence of mangroves and human occupation, as observed in fieldwork.

Areas not suitable to risks

In our fieldwork we saw that spatial dynamics in SELUs 1 and 3 are directly related to the context of protected areas under military and state guardianship, that is, there are restrictions to human occupation and therefore landscapes are ecologically more conserved.

In this perspective, SELUs 1 and 3 (Figure 6) are units where it wasn't possible to identify locally vulnerabilities or suitability to risks, either in the analysis based on the model or from information collected in interviews.

Figure 6 – Areas with no suitability to socio-ecological risks.



Source: Adapted from Lima (2017).

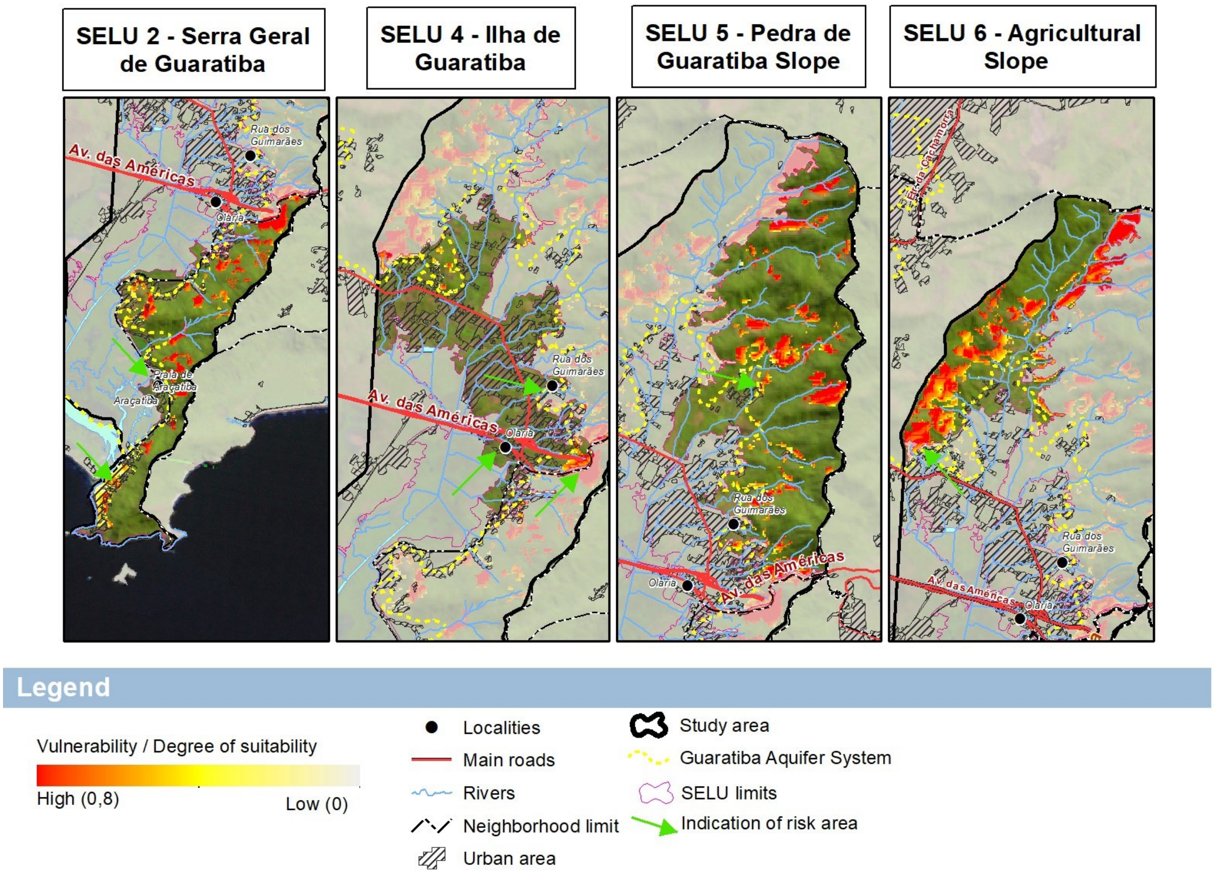
SELU 1 – Guaratiba: In this unit, mangrove formations (77%) and saline fields (15%) are the predominant environments. The area is a flat terrain with 0 to 10% declivity and 0 to 32 m altimetric amplitude; 99% of the area is protected under state jurisdiction of a biological reserve (Reserva Biológica de Guaratiba - REBIO). Land cover in this unit consists of mangrove formations distributed in lake environments with permanent tidal influence. Urban areas are less than 1% (only in the outskirts).

SELU 3 – CETEX: This unit is 100% located in areas under state, municipal, and military jurisdictions, with restrictions to urban occupation. Land uses correspond to 36% of secondary vegetation, 36% of grass/shrub vegetation, 12% of urban areas, and 4% of saline fields.

Areas suitable to risks

The model showed degrees of suitability between 0,6 and 0,8 for geomorphological risks in the following units (Figure 7); research considered also qualitative fieldwork analysis on flood and health risks.

Figure 7 – Areas with suitability to socio-ecological risks.



Source: Adapted from Lima (2017).

SELU 2 – Serra Geral de Guaratiba: The unit is predominantly covered by secondary vegetation formations on rugged terrain, with significant urban influence (12%) affecting also mangrove formations. The terrain is rugged, with altimetry between 1 and 469 m. 94% of the unit is covered by two protected areas: a state park with restricted use (Parque Estadual da Pedra Branca) and a municipal area categorized by a "sustainable use" type of environmental protection (Área de Proteção Ambiental da Pedra Branca).

Land use in the unit corresponds to 61% secondary vegetation, 12% urban areas, 12% tree-shrub vegetation, 8% agriculture, 1% rocky outcrop.

This SELU is part of the demographic expansion axis in the city of Rio de Janeiro, expressed here through the center lines of Burle Marx Ave. (formerly Barra de Guaratiba Road), Americas Ave., and freeways and bus corridors inaugurated in 2012, all of which created a road connection between the neighborhoods of Santa Cruz, Guaratiba, Recreio dos Bandeirantes, and Barra da Tijuca. Road development corresponded to the project of great sports events to take place in Rio de Janeiro (FIFA World Cup in 2014, Summer Olympics in 2016).

There are some occupied areas around main road accesses where the transition between mangrove limits and residential areas is visible. These situations demonstrate fragile local territorial management in regards to habitation for vulnerable populations, exposing these groups to harm from infectious diseases like leptospirosis and dengue fever, related to environmental conditions (CHAIBLICH, 2016; LIMA & CHAIBLICH, 2015). These diseases are dependent on exposure to precarious sanitation and flood situations, as shown below (Figure 8): this is a vulnerable environment that we classify as suitable to a biological type of socio-ecological risk, in the context of environmental health.

Figure 8 – Mangrove area very near a residence (SELU 2)

Source: Juliana Valentim Chaiblich, December/2015.

At the locality of Araçatiba, residents perceive no clear presence of risks. However, one resident related that every 10 years there are events influenced by tidal flood areas near houses. Here, residents' perception of risks is very much related to the discussion presented by Marandola Júnior (2014), who highlights feelings of fear and incertitude as common among residents, specifically because of land tenure issues and the ensuing possibility of removal from the area.

This unstable situation is due to the context within the implementation of REBIO (created in 1974) and the existence of houses. The Army has made notifications within the Secretaria de Patrimônio da União - SPU (an agency that records and manages all real estate belonging to the country's federal union) since the first houses were built in the 1950s. Years later, these residences would be contained within the limits of a restricted use protected area, under state management. This means it is not possible to execute infrastructural work like sanitation, interventions, and improvements. Hence the anxiety, insecurity, and fear that mark future perspectives of families and the day-to-day life of the local population.

SELU 4 – Ilha de Guaratiba: This unit has 42% overlay with areas under state and municipal protected jurisdictions. Terrain is predominantly flat, with altitude ranging from 0 to 171 m. The environment around mangroves favors the occurrence of floods due to the terrain's hydromorphic characteristics, besides being completely within the limits of the Guaratiba aquifer and subject to stationary flooding dynamics.

This unit stands out for its significantly urbanized spatial pattern (46%), with some productive areas corresponding to 8% of agriculture, as well as 28% of tree-shrub vegetation, and 4% secondary vegetation.

This unit, like SELU 2, is part of the road axis that connects the neighborhoods of Santa Cruz, Guaratiba, Recreio dos Bandeirantes, and Barra da Tijuca in the context of the aforementioned infrastructural developments in the city of Rio de Janeiro.

In this unit we visited the localities of Olaria, and Guimarães St. Residents related different kinds of flood episodes. At Guimarães St. there is a flood dynamic related to rain, as the street is located in a terrain that was originally the confluence of two rivers (their names are not identified in cartographic data). The street is almost entirely paved and its level is above the houses' level. We observed in some houses a sort of small wall built to prevent floods from coming in.

At Olaria, the floods are due mainly to rain waters that come from Americas Ave. Side accesses and houses are also leveled below the main road due to construction work to broaden this major avenue. Two local residents related dengue fever notifications in the locality between 2015 and 2016. The risk of flooding is therefore added to the vulnerability of part of the population to diseases like dengue fever, due to proliferation of vectors such as mosquitoes.

A historical event happened in this area in April 2010 (Figure 9): a high magnitude landslide at Grota Funda Rd, neighborhood of Guaratiba. This event became one of the top 50 geological-geotechnical accidents in the city of Rio de Janeiro recorded between 1966 and 2016. The model presented high suitability for risk in this area and therefore highlights a socio-ecological risk of landslides.

Figure 9 – Grota Funda Rd. landslide gullies, April/2010

Source: GEO-RIO (2016).

SELU 5 – Pedra Branca Slope: This unit has 59% overlay with state-protected areas. Secondary vegetation is predominant in the unit's land use, with the notorious presence of banana plantations (agriculture) and pastures (grass-shrub vegetation); urban influence is low (1%) in the surroundings. Altitude varies between 6 and 680 m in a terrain marked by the morphology of flatlands and the sudden rise of Pedra Branca massif.

Land use presents 70% of secondary vegetation, 11% of agriculture, 10% of grass-shrub vegetation, and 9% of tree-shrub vegetation.

In this unit, spots that indicate suitability to risk events coincide with situations of rugged terrain, that is, areas of high suitability for mass movements overlaying urban areas in altitudes varying around 30 m. This characterizes events of socio-ecological risks related to geomorphological dynamics.

The limits of the state park are above 100 m of altitude and land use mapping does not record urbanized areas here; therefore the spots generated by the model that indicate attention to the terrain are not considered areas of risk.

SELU 6 – Agricultural Slope: This unit is located on the slopes of Pedra Branca massif, with altitudes between 13 and 498 m; 60% of its area is within a state environmental protection unit. In its land cover there is a predominance of secondary vegetation; significant presence of agricultural activities (banana and decorative landscaping species); and low urban influence (approximately 2%).

Forest formations are predominant, with 40% of secondary vegetation, 24% of agriculture, including decorative landscaping species, 21% of tree-shrub vegetation, 8% of grass-shrub vegetation, and 5% of Ombrophilous forest.

To the Northeast, there are no areas that indicate residences overlaid to the spots generated in the model. However there are urban areas occupying terrains between 15 and 60 m that are near areas with higher suitability to geomorphological risks of landslides.

FINAL CONSIDERATIONS

Delimitating SELUs allowed us to grasp the diversity of environments and the heterogeneous spatial matrix, important features to understand spatially localized risk contexts and current social dynamics of the landscape in the study area of the neighborhood of Guaratiba.

This mapping reflected areas with similarities in each unit, such as residences and their coexistence with protected areas. An important stage in the integrative approach to vulnerability, risk, and in understanding existing socio-ecological interactions is to consider scales and historical processes of use and occupation. This coexistence is closely related to the area's growth processes, and possibly to situations of vulnerability, risk, and environmental conflicts such as residences existing within the territory of a biological reserve (locality of Araçatiba) which are precarious due to being in an area owned by the state and slated for restricted use.

It is relevant to consider the importance of using Geographical Information Systems and geo-informational techniques in the evaluation of risk areas, underlining the fuzzy method adopted in this study. It allows a more precise evaluation when high suitability values are analyzed. Figure 9 stands out as a record of a high-magnitude event in the history of risk events in the city of Rio de Janeiro.

The proposed model contributed highly to an evaluation of risky events of geomorphological nature. Other interpretations were based on environmental analysis, fieldwork observations, and previous knowledge of the area. It is important to extend the analysis based on the fuzzy method in flooding zones, since these areas weren't generated for the purposes of this research and this is a critical issue in Guaratiba.

As main results of our attempt to analyze vulnerability processes and socio-ecological risks, our research showed that the most relevant risk classifications in the area are: environmental health and physical, related to flood dynamics, in SELU 2 and SELU 4; geomorphological dynamics for houses near high declivity areas in SELU 2, SELU 4, SELU 5, and SELU 6. SELUs 2 and 4 are worth noticing in the sense of a fragility in local urban planning in relation to occupation under the physical conditions in these environments: rugged terrain, hydromorphic characteristics, a situation of territorial interest conflicts in Araçatiba, and the occurrence of harm and disease that condition vulnerability and risks for the local population.

In this context, the element of perception in the evaluation of vulnerable areas and populations stands out due to the complexity of the issue. Risk assessment is not just about considering physical environments and environmental events. The nature of the anxieties experienced by those who live in these habitats. suggests risks or dangerous situations to these populations, as well as the consequent fragility of current policies towards these emergencies. Considering both a qualitative approach and the historicity of occupation in this type of study contributes to the identification of relevant results along with the analysis of local population perception as an important and perhaps necessary element in holistic approaches to vulnerability and risk evaluation for local urban planning.

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AUTHORS' CONTRIBUTION

Maria Luciene da Silva Lima conceived the study, carried out fieldwork, analyzed data and wrote the text. Alexandro Solórzano was the research advisor, participated in the fieldwork and contributed to the academic review as a whole and writing of the text. Luiz Felipe Guanaes Rego was co-supervisor of the research, contributed to the methodological review of the research and writing of the text with a specialty in Geographic Information System. Marcelo Motta de Freitas was a collaborator, participating in the field work, characterization of the study area and writing the text with a specialty in physical geography. Bianca Pereira Alvim Porto collaborated with the research, contributed with data analysis, critical review and writing of the text, specializing in environmental health and vulnerability.

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