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Papers

The Urban Environmental System perspective on socio-environmental risks of urban flooding

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Abstract
In the context of urban socio-environmental problems, floods stand out due to the amplitude of their impacts on built spaces and populations' lives. This problem has become an object of study in several knowledge areas, particularly from an interdisciplinary perspective, applied to understand and identify risks and socio-environmental vulnerabilities associated with hydrological disasters. The occurrence of extreme precipitation events registered in Brazilian cities has also drawn the attention of both public managers and agents since, every year, urban river floods cause severe damage to the population and services located in risk areas. Overall, floods in large, medium-sized, and even small cities are related to land use and land cover, as well as to rainwater management in urban spaces. Driven by these issues, this study presents results regarding the socio-environmental risks of urban flooding in Francisco Beltrão, a town located in Paraná State – Southern Brazil. It is based on the Urban Environmental System (UES) methodology, which is applied to identify social and environmental factors that intervene in the production of risks and vulnerabilities related to hydrological disasters. In the social subsystem domain, material losses related to urban flooding in Francisco Beltrão evidence the vulnerabilities of the affected population and the economic and social damage. On the other hand, regarding the natural subsystem domain, there is an increased hazard of extreme hydrometeorological events, which might lead to river flooding. Considering the urban socio-environmental system of Francisco Beltrão, the population's exposure to the flood hazard and the environmental degradation of urban rivers points to the use and occupation of risk areas.

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INTRODUCTION

Urban flooding occurs mainly through the natural process in which rivers, streams, and urban channels overflow into their major bed due to the sudden or gradual increase in the water flow of their minor bed (TUCCI, 2012; 2008). This event results from natural processes of the hydrological cycle, and it is observed both in urban and rural spaces.

In cities, river floods and, consequently, the flooding of their surrounding areas are caused by precipitation and the surface runoff resulting from soil sealing. Urban surface waters are conducted through the drainage systems to water bodies, which, during periods of higher flow, spread to their major beds and even the floodplains (TUCCI, 2012; 2008). However, when the population occupies the latter, problems become frequent and consequences catastrophic.

Since it results from recurring extreme hydrological events, especially those in urban agglomerations with higher rates of soil sealing and high population density, the urban flooding phenomenon is not restricted to large cities but is also observed in medium-sized and small ones.

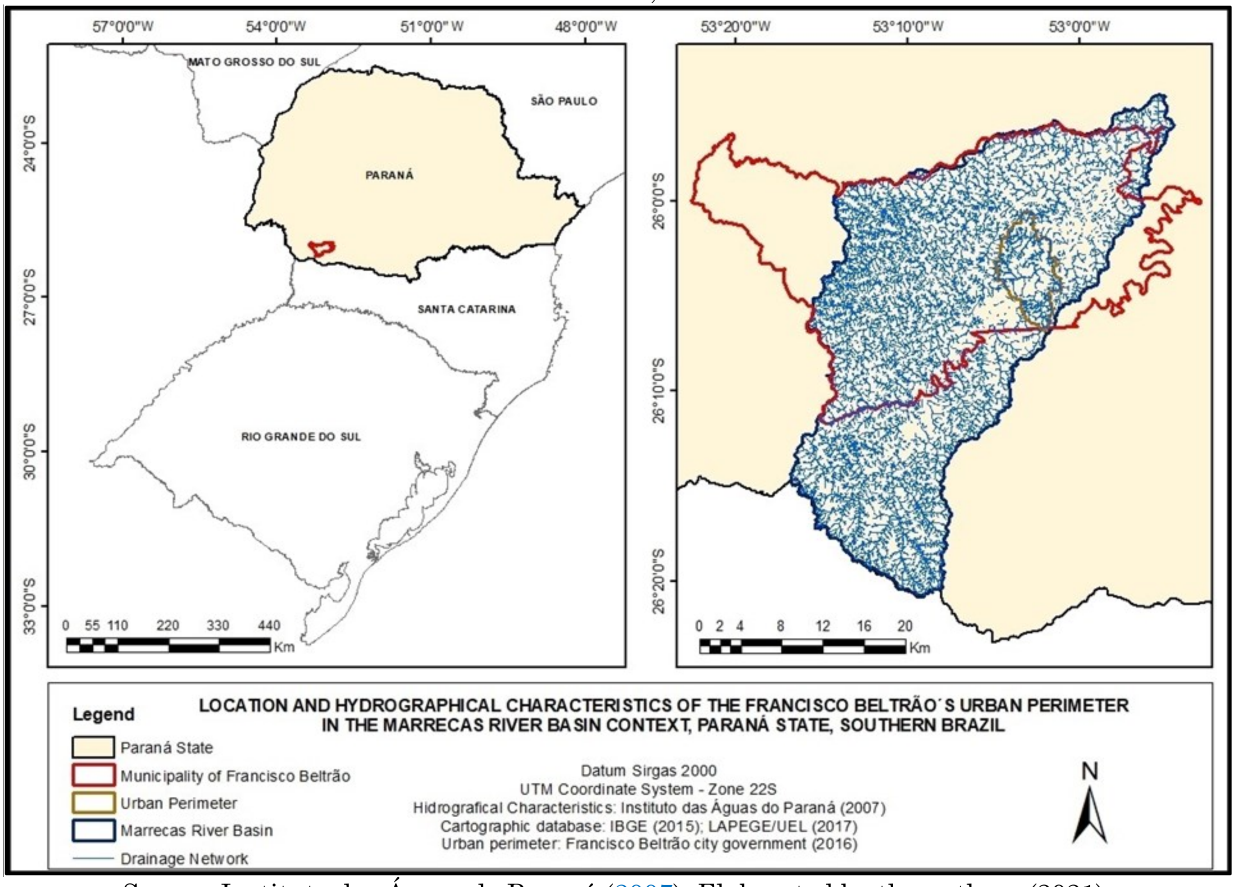
In Brazil, high intensity short-duration rainfall causes more severe problems, which are also related to topography characteristics, drainage network, and urban land use and land cover. In addition to the socio-environmental problems that arise from the complex society-nature relationship in the urban space, floods' high frequency and magnitude are also aspects observed from the perspective of the disaster risk management.

Embedded in this context is the municipality of Francisco Beltrão, located in the Southwest region of the Paraná State, southern Brazil, with an estimated population of 93,308 inhabitants, according to the Instituto Brasileiro de Geografia e Estatística (IBGE, 2020), it stands out for the number of urban floods reported in the past years. Between 1980 – when the first case was registered – and 2021, the Coordenadoria Estadual de Proteção e Defesa Civil do Paraná (CEPDEC, the Portuguese acronym for Paraná's State Coordination for Protection and Civil Defense, which is the state government agency responsible for the planning, coordination, control and guidance of all preventive, mitigation, preparedness, response and recovery measures related to protection and civil defense.) reported 34 occurrences related to floods, runoffs, flash floods, and heavy rainfall, affecting a total of 34,180 people (CEPDEC, 2021).

The occurrences are registered by the 10ª Coordenadoria Regional de Proteção e Defesa Civil do Estado do Paraná (CORPDEC, in the Portuguese acronym for 10th Regional Coordination of Protection and Civil Defense of the Paraná State, which is the regional level of the government agency), whose main office is located in Francisco Beltrão. Based on the Codificação Brasileira de Desastres (Cobrade, in the Portuguese acronym for Brazilian Classification and Codification of Disasters, is a normative instruction created from the classification used by the Center's International Disaster Database to Research on the Epidemiology of Disasters and the World Health Organization Health), the occurrences are registered, stored, and provided by the Sistema Informatizado de Defesa Civil do Paraná (SISDC, in the Portuguese acronym for Civil Defense Computerized System of the Paraná State), a digital platform used for monitoring disasters in the cities of the state. The classification shown by Cobrade was instituted through Normative Instruction N. 01, of August 24, 2012 (BRASIL, 2012).

Given the historical process of the Francisco Beltrão´s urbanization, the marginal banks of the Marrecas River gave way to the city's urban site, with the urban areas also expanding to the banks and meanders of its tributaries. Part of the watercourses are no longer visible on the surface, streams and rivers have been channeled into culverts, and extreme precipitation events cause flooding due to the increased flow volume in the drainage systems. Figure 1 shows a map with the location and hydrographical characteristics of the Francisco Beltrão´s urban perimeter, in the urban space as floods high frequency.

Figure 1 – Location and hydrographical characteristics of the urban perimeter of Francisco Beltrão, Paraná State, Brazil.



Source: Instituto das Águas do Paraná (2007). Elaborated by the authors (2021).

The problems arising from urban expansion and the recurrence of hydrological disasters in Francisco Beltrão motivated the analysis of the causing factors of socio-environmental risks and vulnerabilities related to urban flooding. In this sense, this study proposes a synthesis of the results obtained through the mapping of the areas of socio-environmental risks of urban flooding, which applied the Urban Environmental System (UES) methodology, elaborated by Mendonça (2004).

The UES constitutes a complex and open system, which is initially subdivided into three subsystems. The first two are the input of the UES and comprise the (a) Natural Subsystem (topography, air, water, vegetation, and soil) and the (b) Built Subsystem (housing, industry, trade and services, transports, and leisure). The third one is the (c) Social Subsystem, in which the system dynamics occur as a result of human actions, constituting the system's attributes. It is in the Social Subsystem that the "dynamics of nature manifests itself, the superhuman dimension that overcomes the controls exercised by society when manifested in extreme and impactful episodes" (MENDONÇA, 2004, p. 201). Urban socio-environmental problems result from the interaction among these three subsystems (output) and can be addressed from the socio-environmental urban planning and management perspective (MENDONÇA, 2004).

In order to ensure its understanding, we divided this study into four sections. The first section presents the theoretical-methodological approach through which the analysis of the subsystems and attributes that constitute the UES and its application to the management of socio-environmental risks of urban flooding was developed. The second section describes the methodology used to collect and analyze the physical and social environments data, which allowed us to estimate the flood hazard through hydrological modeling, map social vulnerabilities by applying Synthesis Cartography techniques, and map the risk areas by crossing geospatial information. As a result, the third section presents a synthesis of the areas of socio-environmental risk of urban flooding in Francisco Beltrão. Finally, the fourth section presents the conclusion of the study.

The urban environmental system applied to studies on socio-environmental risks of urban flooding

Studies aimed at understanding the problems that stem from the society-nature relationship in the urban environment are based on approaches that prioritize a complex perspective of reality. Overall, they seek to identify and understand the interrelationships between social and ecological factors, local or regional, that shape and, at the same time, are shaped by the urban socio-environmental dynamics (COELHO, 2004; MENDONÇA, 2004).

In this regard, the United Nations Development Programme/United Nations Office for Project Services (UNDP/UNOPS) released in 1997 a training guide on urban environment management for Latin America. The document presents theoretical conceptions regarding city spaces from an environmental perspective and provides suggestions for urban environmental management, which implies complementarity and interaction between society and nature to build urban environments.

According to their Regional Project for Urban Environmental Management Training (UNDP/UNOPS, 1997), the urban issues' dynamics can be understood through a systemic analysis in which the urban environment is conceived as a global system divided into three subsystems or instances comprising nature, society, and human-made structures.

In this study, the General Systems Theory (BERTALANFFY, 1968) is used as the theoretical and methodological framework of the systemic approach applied to socio-environmental urban problems. It demonstrates how subsystems constantly exchange energy and matter among themselves and how it stimulates their evolution. On the other hand, the system is composed of a set of components (subsystems) connected through energy flows and operating as a unit (DREW, 1994). Therefore, in order to understand a system, it is necessary to observe how both internal and external interrelationships occur since every system has numerous variables and, consequently, is susceptible to generating different combinations and results through self-organization processes (CAMARGO, 2012).

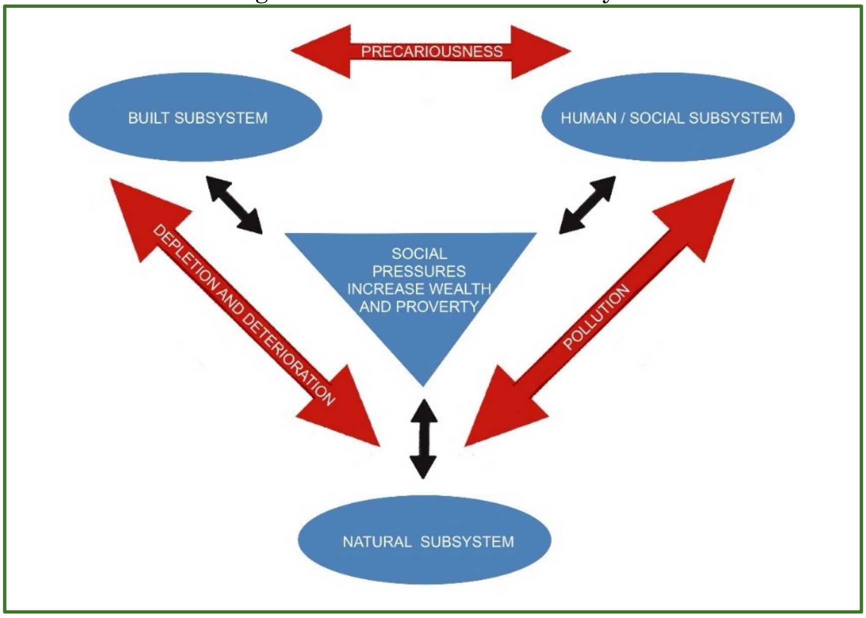
When the complex society-nature relationship in cities is addressed through a systemic perspective, the "urban metabolism" is understood as "the exchange of material, energy, and information that arises between the urban environment and its geographical context" (UNDP/UNOPS, 1997, p. 61). Thus, the formation of urban contexts is based on the interrelationships established between social and natural processes.

The urban environment constitutes an open system in which the city is a result of the interrelationships between natural and human-made elements. From this perspective, the environment in which the city is set is a result of human activity on a particular aspect of the Earth's surface. The urban environment – also understood as urban ecosystem – is, therefore, the product of a human activity that interfaces a given natural dynamics or elements of the physical environment, such as an urban agglomeration established along the banks of a main river and between the meanders of its tributaries (BRANDÃO, 2006).

Figure 2 shows a flowchart of the urban issues' dynamics, evidencing the usually observed following factors: a) the precariousness of the elements comprised of the Social and Built Subsystems; b) the depletion and deterioration of the resources that constitute the Natural Subsystem, which are caused by the Built Subsystem appropriation; c) the contamination of the Natural Subsystem, which results from inadequate intervention on the Social Subsystem (UNDP/UNOPS, 1997; MENDONÇA, 2004).

In this dynamics, conflicts and social pressures that permeate the urban, political, economic, and cultural spheres, which are mainly driven by poverty conditions and lack of access to infrastructure systems and housing, for example, characterize the interaction among the three subsystems of the urban environment.

Figure 2 – The urban issues' dynamics.



Source: Adapted from PNUD/UNOPS (1997, p. 65).

In most cases, the established social relations and the interaction between nature and society pressure each subsystem's organization. The urban environment conflicts that stem from a misunderstanding of the appropriation/use of natural resources highlight the negative impacts and, consequently, the imbalances responsible for the depletion, deterioration, and contamination of the Natural, Social, and Built subsystems, thus compromising cities' quality of life (FARIAS, 2019a).

Mendonça (2004) based his studies regarding the complex society-nature relationship in cities on an Urban Ecological System concept (UNDP/UNOPS, 1997). The author found in Monteiro's (1976) study on the Urban Climate System – one of the first efforts to approach the city from a systemic perspective – the theoretical and methodological framework to elaborate a methodological proposal that considers the city in its totality as an UES.

The UES concept aims to highlight the interdisciplinary perspective in urban studies. Moreover, this methodology indicates possibilities for developing an integrated and holistic understanding of the socio-environmental urban dynamics. The integrated approach to socio-environmental urban problems interacts with the aforementioned studies' concepts and moves toward the presented statements since it proposes the subdivision of the systems into "sub-subsystems" for which urban planning and management suggestions and guidelines can be developed through a detailed diagnosis of the socio-environmental local conditions (MENDONÇA, 2004).

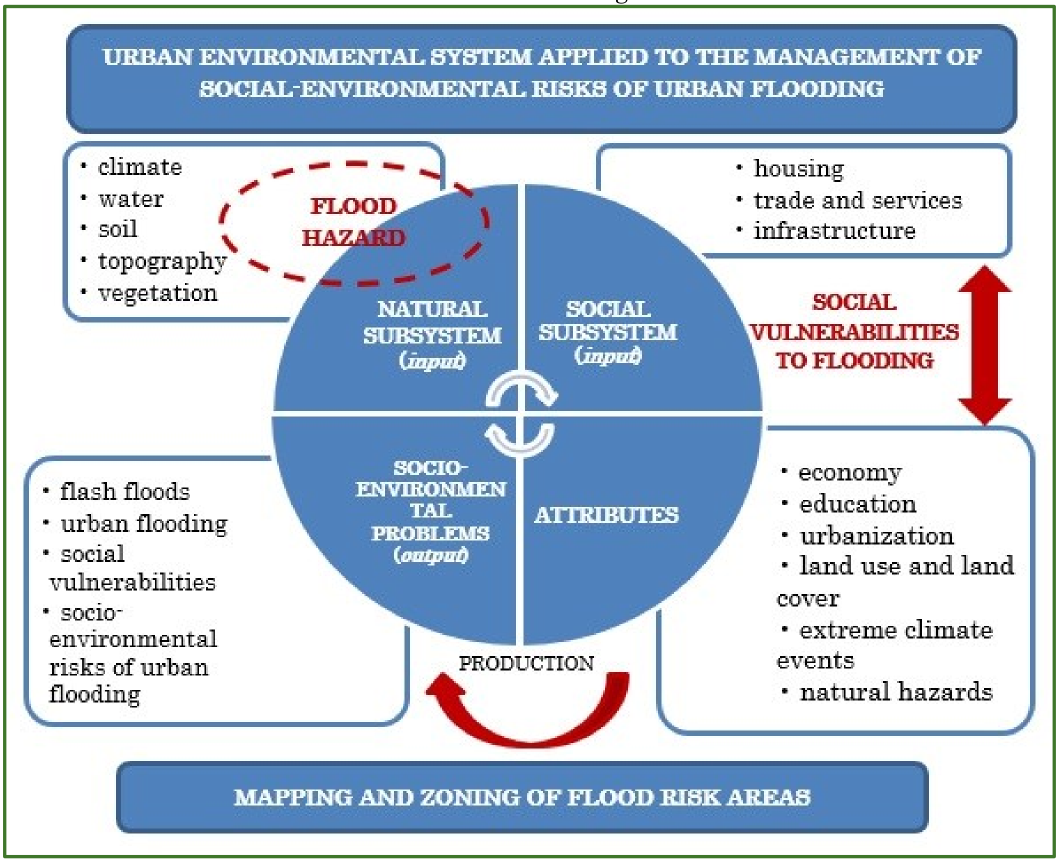
Despite UES being usually subdivided into three subsystems (Natural, Social, and Built), it can also be subdivided into several other ones, meaning researchers are able to adapt it according to their objectives and the specificities of the intrinsic driving factors of the investigated area. However, it is worth noting that determining the problems arising from the society-nature interaction is crucial for developing studies and intervention proposals under the UES perspective since not all problems that affect cities result from this relation. In other words, identifying the type of problem one intends to investigate is the first step to evaluate the potential application of this methodology (MENDONÇA; FARIAS, 2011).

Some examples of socio-environmental urban problems relevant to studies and interventions following the UES perspective include land, soil, and vegetation degradation; air and water pollution; urban solid waste generation; informal settlements and slum formation processes; socio-environmental disasters, such as urban flooding, landslides in built-up areas, among others. The solution or mitigation of the resulting impacts occurring within this system directly affects the quality of populations' life (FARIAS, 2019a).

The urban space analysis and understanding from the UES perspective aims at a closer approach to the natural and social phenomena that create the contradictions of the multiple and complex realities of urban daily life, meaning it is possible to relate the UES to the urban ecosystem concept. The process of planning and developing strategies to mitigate socio-environmental conflicts supports this methodology. The propose is reorganize the input elements in the system, the interrelationships among intervening factors (attributes), and the problems (output) of the UES through feedback mechanisms, i.e., responses of processes and relationships relevant to the nature and society dynamics that might be identified in urban contexts (MENDONÇA, 2004).

In the case study presented here, the input elements of the UES are characterized by flows of energy and matter, both of natural order or derived from social processes. This larger system is composed of the Nature and Social subsystems and subdivided into several other subsystems, such as the "N subsystems" (climate, water, soil, topography, and vegetation) and "S subsystems" (housing, trade and services, and infrastructure). Figure 3 shows the methodological flowchart of the study by Mendonça described above.

Figure 3 – Methodological flowchart of the study: UES applied to the socio-environmental risks of urban flooding.



Source: MENDONÇA (2004). Elaborated by the authors (2021).

The attributes comprise the social institutions that shape the environmental system dynamics in the municipality of Francisco Beltrão and that are related to the flooding. Characteristics of the superstructure of society (economics, politics, among others) and the culture of its population, as well as education and technology, are the prevalent ones. Therefore, it is noteworthy that sudden, episodic, and impactful manifestations of nature, such as natural hazards, also appear as significant UES drivers (MENDONÇA, 2004).

Risk estimation includes the probability of occurrence of an extreme event (hazard) that might harm the physical integrity of an individual or groups of individuals. This is related to possible environmental damage and economic and social losses of populations susceptible or vulnerable to adversities, whether of natural or human nature (SOTTORIVA, 2014; ZANELLA; OLÍMPIO, 2014; VEYRET, 2007).

In Brazil, the term hazard is translated as *perigo* or *ameaça*. However, in some literature cases, the Brazilian Portuguese equivalents of hazard and risk (respectively, *perigo* or *ameaça*, as mentioned above, and *risco*) are commonly cited as synonyms even though they are not. The terminology used by the United Nations International Strategy for Disasters Reduction (UNISDR, 2009, p. 20) defines natural hazard as a "“natural process or phenomenon that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage”. On the other hand, the concept of risk refers to “the combination of the probability of an event and its negative consequences” (UNISDR, 2009, p. 25).

According to Kobiyana *et al*. (2006), a hazard is a natural phenomenon that occurs at a known time and region and that might cause severe damage in impacted areas. Hence, natural hazards are natural processes or phenomena that occur in the biosphere and that might constitute a harmful event, as well as be modified by human activity, such as environmental degradation, deforestation, unplanned urbanization, among others.

In this study, the notion of risk applied to urban flooding corresponds to an uncertain and possible situation in which an extreme hydrological event might affect an individual or a population, jeopardizing the integrity of their tangible and intangible goods (as in the case of psychological trauma, for example). Since these goods are acknowledged vulnerable, this event causes damage and financial loss. Thus, socio-environmental flood risks only occur in the simultaneous presence of a natural hazard and social vulnerability (FARIAS, 2019a).

In cities, the diagnosis of the natural elements of the flood hazards and the factors responsible for producing social vulnerabilities may vary according to environmental characteristics and the social groups' heterogeneity. When considering the social context, the problems triggered by socio-environmental disasters are subjectively faced (FARIAS, 2019a) according to the interaction between the attributes listed in Figure 2.

There are numerous factors that allow estimating social vulnerabilities, and they must "be classified by their relevance and on a scale carefully chosen according to the analyzed sites and the available data accuracy" (VEYRET, 2007, p. 43). In the case of urban environments, "vulnerability can be considered the only element that allows disasters to be under human control" (PINHEIRO, 2015, p. 51).

Extreme events that cause natural disasters, such as heavy rainfall, severe storms, and droughts, are not conditioned to human activity and, therefore, are "merely triggers of a disastrous process – leaving managers to focus on perceiving vulnerabilities in the receiving system" (PINHEIRO, 2015, p. 52).

When considering the systemic dynamics of the urban environment, several problems resulting (output) from the interaction between the various UES subsystems and "sub-subsystems" can be observed. Among them are the socio-environmental risks related to urban flooding that, due to the recurrence and amplitude of the events, increasingly demand the attention of both public authorities and population. Therefore, the main application of this methodology precedes the development of proposals for solving socio-environmental urban problems from an urban planning and management perspective, especially the promotion of public policies aiming at reducing the risks of hydrological disasters.

In this case study, the socio-environmental risks of urban flooding in Francisco Beltrão were spatially represented through hydrological modeling and synthesis cartography. According to Veyret (2007, p. 60), "marking risks on a map is equivalent to 'state the risk' in the corresponding space". Thus, mapping the risks related to urban flooding is a crucial tool for prevention policies aimed at reducing the risks of hydrological disasters. The cartography applied to the case of Francisco Beltrão intended to map, identify, and analyze the areas of urban flood risk whilst allowing risk materialization and its designation as a public problem.

METHODOLOGICAL PROCEDURES

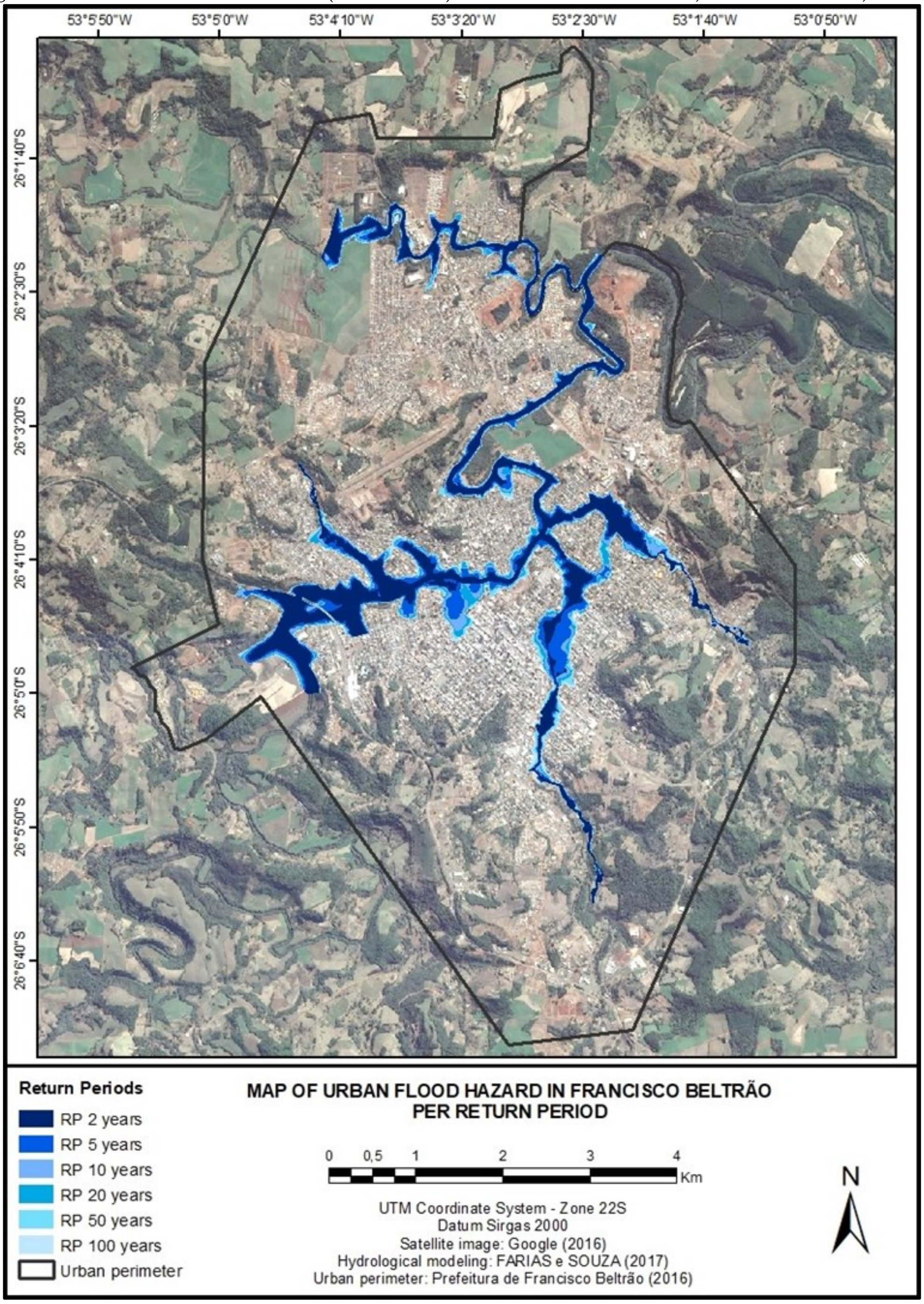
The methodological procedures of this study include a literature review on the dynamics of the socio-environmental urban problem with emphasis on the UES proposal, especially regarding the understanding of the socio-environmental risks of urban flooding. The research is based on a case study, a strategy consisting of defining the problem, establishing the guiding questions and methodological procedures, collecting, treating and analyzing the data, and arranging and presenting the results.

Data collection on the physical characteristics of the Marrecas River basin allowed the organization of input data to identify the flood hazard present in the elements of the Natural Subsystem (input), namely: a) historical rainfall data and determination of design flows; b) delimitation of urban sub-basins and quantification of surface runoff. This procedure was applied to estimate the hazard and determine the flood area, which is represented in the map in Figure 4.

The input data of the Urban Environmental System of Francisco Beltrão regarding the physical aspects of the Natural Subsystem allowed us to simulate the Marrecas River basin spread of water based on the quantification of the effective rainfall, i.e., the portion of total precipitation that will turn into surface runoff. The methodology proposed by the Natural Resources Conservation Service (NSCR), formerly named Soil Conservation Service (SCS) (PRUSKI et al., 2004; TUCCI, 2009) was used to elaborate the flow hydrograph. The simulated return periods of rainfall events were 2, 5, 10, 20, 50, and 100 years (Figure 4).

In order to generate the urban flood hazard map, hydrological and hydraulic modeling techniques were applied using two free software developed by the U.S. Army Corps of Engineers: Hydrologic Modeling System (HEC-HMS), version 3.5, and River Analysis System (HEC-RAS), version 5.0.3. In addition, a technique of geoprocessing in a Geographic Information System (GIS) environment developed by the Environmental Systems Research Institute (ESRI) was applied using the commercial software ArcGIS, version 10.3.

Figure 4 – Urban flood hazard (flood area) in Francisco Beltrão, Paraná State, Brazil.



Source: IAPAR (2016). Elaborated by Farias (2019a).

To identify the flood risk of a given location, it is necessary to know the hydrological and hydraulic processes that provide data for delimiting the hazard areas, that is, the spaces that will be affected by the water spread. The flood area estimation per return period (Figure 4) is the primary procedure indicated to identify socio-environmental flood risks since it combines the presence of increased danger of extreme hydrological events and social vulnerability indices (FARIAS, 2019a).

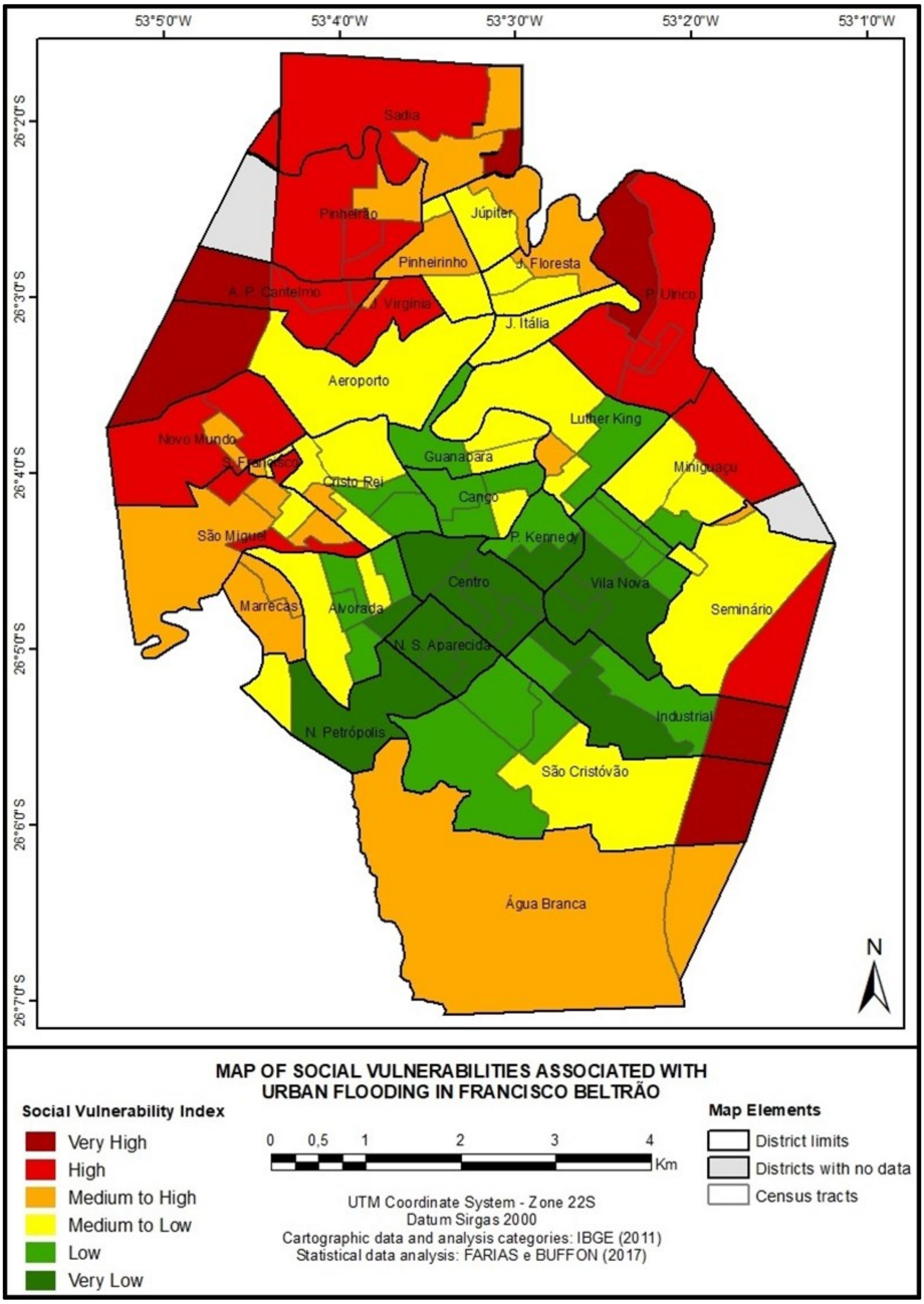
The mapping of the areas of social vulnerability of Francisco Beltrão's urban population (Figure 5) was carried out based on the synthesis cartography, which enabled the combination of different quantitative variables through multicriteria analysis, both in a combined manner and under different weights. Thus, this process allowed us to obtain new data that may facilitate the understanding of the phenomenon we aim to represent (SAMPAIO, 2012).

We considered variables that characterize aspects relevant to the disaster risk reduction macro process (prevention, mitigation, preparedness, response, and recovery phases), and they were based on the 2010 Brazilian Census data (IBGE, 2011). Their values are as follows: population density (15%); housing conditions and infrastructure (45%); age structure (5%); education and age structure (10%); and income (25%) (FARIAS, 2019a).

After variable normalization, standardization, and weighting, a synthesis process was performed to obtain the social vulnerability indices of the areas affected by urban flooding in Francisco Beltrão. In accordance with the studies by Buffon (2016) and Almeida (2010), the indices were divided into the six following classes: Very Low, Low, Medium to Low, Medium to High, High, and Very High. They were obtained through the Natural Breaks statistical method, a tool provided by the ArcGIS commercial software, version 10.3. As a result, a map associating social vulnerability and urban flooding in Francisco Beltrão was obtained (Figure 5).

In the case study, the proposed synthesis characterized social vulnerability conditions by census tract using a combination of 11 quantitative variables and analyzing their normalized and weighted values (FARIAS, 2019a). The association between the identification of the social subsystem's input attributes and the variables selected from the data provided by the 2010 Brazilian Census (IBGE, 2011) resulted in the identified areas of social vulnerability, which are presented in the map in Figure 5.

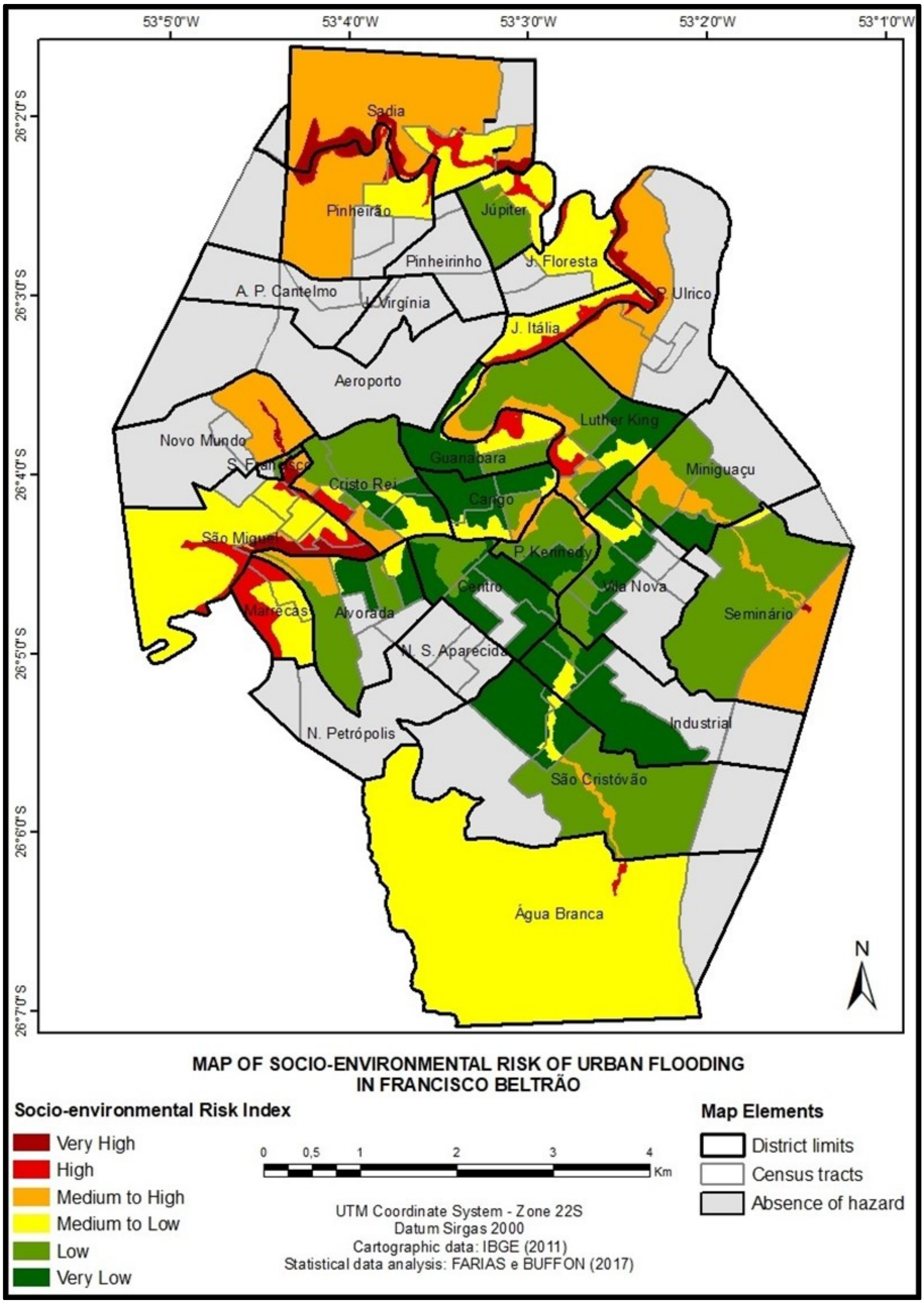
Figure 5 – Social vulnerability associated with urban flooding in Francisco Beltrão, Paraná State, Brazil.



Source: IBGE (2011). Elaborated by Farias (2019a).

The crossing of geospatial information considered the integration of natural (flood hazard) and social (social vulnerability) attributes and it was performed using Synthesis Cartography techniques in the ArcGIS software, version 10.3. The objective of this procedure was to demonstrate the different socio-environmental risk indices of the areas affected by floods in the urban perimeter of Francisco Beltrão (output), as it is shown in the map in Figure 6.

Figure 6 – Areas of socio-environmental risk of urban flooding in Francisco Beltrão, Paraná State, Brazil.



Source: IBGE (2011). Elaborated by Farias (2019a).

The mapping of Francisco Beltrão's areas of socio-environmental risk of urban flooding was conducted from a qualitative perspective, which encompasses numerous analysis dimensions. Table 1 shows the synthesis obtained by crossing the social vulnerability indices (SVI) with the presence of flood hazard (FHI) at the census tract level of disaggregation. This procedure was carried out for all tracts affected by the flood area, which is delimited by the return periods indicated in Figure 4. The crossed data resulted in a qualitative index of socio-environmental risk of urban flooding (SRFI), which is shown in Table 2. Furthermore, it also contributed to creating the map in Figure 6, which represents the spatialization of the areas of socio-environmental risk of urban flooding.

Table 1 – Synthesis of the flood hazard index (FHI) and social vulnerability index (SVI)

SVI \ FHI	A	B	C	D
1	(dark red)	(dark red)	(red)	(orange)
2	(dark red)	(dark red)	(red)	(orange)
3	(red)	(red)	(light green)	(light green)
4	(orange)	(orange)	(green)	(green)
5	(light green)	(light green)	(dark green)	(dark green)
6	(green)	(green)	(dark green)	(dark green)

Source: Adapted from ALMEIDA (2010). Elaborated by Farias (2019a).

Based on the methodology proposed by Almeida (2010) for studies on socio-environmental risks of urban flooding, six classes were obtained through the synthesis procedure: Very High, High, Medium to High, Medium to Low, Low, and Very Low, as presented in Table 2.

Table 2 – Socio-environmental risk of urban flooding index (SRFI)

SRFI (FHI x SVI)	
(dark red)	Very High
(red)	High
(orange)	Medium to High
(light green)	Medium to Low
(green)	Low
(dark green)	Very Low

Source: Adapted from ALMEIDA (2010). Elaborated by Farias (2019a).

The classification of the areas of socio-environmental risk of urban flooding, shown in the map in Figure 6, provided the basis for the following analysis. In order to facilitate the location of such areas and the composition of the obtained results, Francisco Beltrão's districts were grouped into four sectors, according to their geographical positions (North, West, East, and South) and using the city downtown as a reference point. A detailed description of the methodological procedures used for organizing the cartographic products is present in the studies by Farias (2019a) and Farias and Mendonça (2019b).

RESULTS AND DISCUSSIONS

The identification of hazard and social vulnerability-producing factors was spatially represented through modeling and mapping techniques. The data crossing of the flood hazard and social vulnerability maps resulted in the main cartographic product of our study: the areas of socio-environmental risk of flooding map, which is an essential tool for the management of hydrological disasters in urban spaces.

In addition to the locations that are already assisted by the Protection and Civil Defense agencies, the cartographic tools and resources allowed the spatial representation of different levels of socio-environmental risk of flooding, ranging from Very Low to Very High. Risk areas were identified in 23 districts, revealing an alarming statistic since the current organization of Francisco Beltrão's urban space divides it into 29 districts. The results show that 20 of the 23 identified districts present critical risk areas.

In the case study, critical areas were defined as those whose classification presented the highest indices of socio-environmental risk associated with urban flooding, which corresponds to the Very High, High, and Medium to High levels. In the following, we provide a brief overview of Francisco Beltrão's areas of socio-environmental risk of urban flooding. The complete analysis is available in the study by Farias (2019a).

Overview of the areas of socio-environmental risk of urban flooding in Francisco Beltrão

The analysis of the map in Figure 6 reveals that the districts with the highest indices of socio-environmental risks and vulnerabilities are located on the geographical periphery of Francisco Beltrão's urban perimeter. It is noteworthy that these areas present the highest social vulnerability indices (Figure 5), which, when associated with flood hazard (Figure 4), result in the highest socio-environmental risk indices. These localities demand emergency actions based on effective guidelines for stormwater management and flood risk reduction, such as structural and non-structural urban drainage strategies.

Regarding the vulnerability created in the urban space, Acselrad (2006) states that turning subjects vulnerable to a situation is related to three factors: individual, political-institutional, and social. From this perspective, maps express social vulnerability to urban flooding and can be used to locate processes operating in the same spheres in which causalities occur and often interrelate (FARIAS, 2019a).

In this study, we propose an analysis based on the most critical districts – that is, the places presenting Very High and Medium to High risk – in order to represent the interaction between the problems and causes that are identified in different sectors but share a common factor: the occurrence in the peripheral regions of the city of Francisco Beltrão. These areas have been brought into focus due to the required urgency of actions and strategies to mitigate the impacts of urban flooding on the various social orders and different occurrence rates.

Pinheiro (2015) points out that identifying, locating, and understanding the causes of vulnerability and risk production processes are recommended procedures for disaster risk management and reduction. In this sense, inspired by Buffon's study (2016), Table 3 presents the diagnosis of one critical socio-environmental risk area per sector but downtown, as it presented no increased risk. The areas are located in four districts of Francisco Beltrão, namely: Pinheirão, in the Northern Sector (Very High risk); São Cristóvão, in the Southern Sector (Medium to High risk); Miniguaçu, in the Eastern Sector (Medium to High risk); São Miguel, in the Western Sector (Very High risk).

The areas were cataloged in order to demonstrate the correlations between the high indices of flood hazard and social vulnerability, which were respectively obtained through hydrological modeling techniques and Synthesis Cartography (FARIAS, 2019a; FARIAS; MENDONÇA, 2019b).

In the urban environmental system of Francisco Beltrão, Marrecas River's floods significantly interfere with the society-nature relationship. In this context, a significant share of the population represents the highest levels of social vulnerability and have to live with flood hazards in risk areas.

From the perspective of stormwater management, the main urban problems arising from the interrelationship between social and natural attributes in Francisco Beltrão's UES are as follows: a) increased soil sealing, erosion, sediment production, and aggradation of rivers, streams, and channels; b) clogging of micro and macro stormwater drainage systems, caused by the accumulation of sediments and solid waste; c) river floods, floods, flash floods.

Consequently, in addition to the social and environmental damage identified through the fieldwork conducted between 2014 and 2019, disasters cause high economic losses for the city's public management. Numerous cases of families who remain in properties with poor infrastructure conditions and, due to lack of essential urban services, are forced to improvise were reported. The representative images in Table 3 were selected to highlight the contrasts between the different realities existing in spaces where hydrological disasters occur.

Chart 1 – Socio-environmental risks of urban flooding in Francisco Beltrão/Paraná State, Brazil: attributes and representations of reality

SECTOR	SUB-BASIN	DISTRICT	ATTRIBUTES	SRFI	REPRESENTATIVE IMAGES
Northern Sector	Santa Rosa River	Pinheirão	- Former group of urban lots located on the major bed of the Santa Rosa River (right bank). - Partial riparian forest and presence of agricultural cultivation. - Soil erosion. - Sanitation: deactivated septic tank. - Industrial waste treatment plants. - Housing complex of the Brazilian government social housing program "Minha casa, minha vida". Families were removed from the area and were included in the program. - New settlements built with no infrastructure and in a disorderly manner (informal).	Very High	 Figure 7  Figure 8

SECTOR	SUB-BASIN	DISTRICT	ATTRIBUTES	SRFI	REPRESENTATIVE IMAGES
Southern Sector	Lonqueador River	São Cristóvão	- Urban lots in the major bed of the Lonqueador River (both banks). - Straightened and channelized waterbody. - Soil erosion. - Channel aggradation - Riparian forest: absent - Good housing conditions in most cases. - Sanitation: sewage collection. Waste disposal into the waterbody. - Infrastructure: poor	Medium to High	 Figure 9
Eastern Sector	Urutago Stream	Miniguaçu	- Urban lots in the major bed of the Urutago stream (both banks). - Riparian forest: present in some parts of the stream. - Good housing conditions in most cases. - Sanitation: sewage collection. Waste disposal into the waterbody. - Infrastructure: regular. - Increased impervious surface areas in the Jayme Canet Junior Park and, consequently, increased surface runoff.	Medium to High	 Figure 10

SECTOR	SUB-BASIN	DISTRICT	ATTRIBUTES	SRFI	REPRESENTATIVE IMAGES
Western Sector	Marrecas River	São Miguel	- Informal settlements on Marrecas River's major bed (left bank): - Informal housing. - Poor housing conditions in most cases. - Riparian Forest: present only on the left bank. - Soil erosion. - Sanitation: presence of septic tanks. Waste disposal into the waterbody. - Infrastructure: absent. - Accumulation of solid waste.	Very High	Figure 11 

Source: Farias (2019a).

According to the scenarios described in Table 3, the same processes increasing social vulnerability indices are also responsible for the critical levels of flood risk measured and demonstrated in this study. The social attributes were considered in the urban census tracts' spatial scale, in which the processes producing social vulnerability and flood hazard phenomena are interrelated, integrated, and manifested in the Urban Environmental System of Francisco Beltrão. Based on these results, we point out that subjects' vulnerability is aggravated by an exclusionary urbanization process, especially in peripheral areas.

The growing number of formal housing and informal settlements along the flood areas of the urban rivers of Francisco Beltrão encompasses the same phenomenon responsible for risks and vulnerabilities, revealing the urgent nature of the socio-environmental problems identified in this case study. Therefore, based on the results obtained through the mapping techniques and the relevant discussions on the urban issues' dynamics, we support the thesis that the population affected by flooding in the peripheral areas of Francisco Beltrão faces a higher socio-environmental risk than those of other urban river network locations, although the hazard is the same.

CONCLUSIONS

The case study carried out in Francisco Beltrão revealed the main impacts of flooding on the Urban Environmental System, which are as follows: a) material damages and losses; removal of hundreds of people from frequently affected areas; b) disruption of economic activities in flooded areas; c) water contamination due to the flooding of areas near septic tanks and wastewater treatment plants. In this process, the water sub-subsystem – which constitutes the natural subsystem – is the first to show signs of urban environmental degradation.

One of the aggravating social factors that must be carefully considered by public agencies, especially the municipal and state coordination of Protection and Civil Defense, in addition to the ones directly related to urban planning and infrastructure, is the difficulty of populations living in critical flood risk areas in recovering from damages after disaster occurrences. Locating these areas on a map should be one of the priorities in efforts to reduce urban social vulnerabilities, which, consequently, reflect in disaster risk reduction.

The synthesis of areas with increased socio-environmental risk of urban flooding (Very High, High, and Medium to High) allowed us to identify and analyze some attributes of the social and spatial relations that, with the intensified urbanization process on the urban water sub-subsystem, lead to scenarios of environmental degradation, vulnerabilities, and economic and social conflicts.

Therefore, we recommend using the proposed mapping as a tool for the social and spatial analysis of the identified risks, which are related to urban flooding in Francisco Beltrão. Spatial interpretation has direct application in urban environmental zoning, through which the following elements may be defined: spaces with high risk and that should concentrate priority actions aimed at reducing social vulnerabilities and building urban socio-environmental resilience; spaces where occupation should be regulated and, sometimes, even prohibited; other spaces where risk is lower or even absent.

The understanding of urban flood risks through the UES perspective stands out for its significant contribution to urban space planning and management both for the methodological aspect of identifying the intervening factors of urban socio-environmental dynamics and for its applicability in isolated initiatives. In this sense, the results obtained in the case study of Francisco Beltrão may support other studies, as well as the efforts of government agencies and other institutions engaged in reducing the risk of socio-environmental disasters related to urban flooding.

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AUTHORS' CONTRIBUTION

Ariadne Sílvia de Farias conceived the study, collected, analyzed the data, organized the maps and wrote the text. Francisco Mendonça guided the methodology, adopted and participated in elaborating the research, and read, discussed, and corrected the text.