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The urban environmental system perspective on socio-environmental risks of urban flooding

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Abstract: In the context of urban socio-environmental issues, floods stand out due to the amplitude of their impacts on building spaces and populations' lives. This problem has become an object of study in several knowledge areas, particularly from an interdisciplinary perspective, for understanding and identifying risks and socio-environmental vulnerabilities associated with hydrological disasters. The occurrence of extreme precipitation events recorded in Brazilian cities has also drawn attention of both public managers and agents, since the floods of urban rivers have caused, each year, serious 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.

Key words: hydrological disasters; risks and vulnerabilities; urban basin of Marrecas river; Francisco Beltrão/Paraná State

1 Introduction

Urban floods occur mainly due to the natural process in which rivers, streams and urban canals overflow to their larger bed, due to the sudden or gradual increase of water flow in the smaller bed (TUCCI, 2012; 2008). This type of event is the result of natural processes of the hydrological cycle, being observed both in urban and rural spaces.

In cities, river flooding and, consequently, flooding are caused by precipitation and surface runoff generated by soil sealing. Urban surface water is conveyed by drainage systems to water bodies which, in periods of higher flow, occupy their larger beds or flood plains (TUCCI, 2012; 2008). However, when the population occupies floodplains, problems are frequent and the consequences are disastrous.

As a result of recurrent extreme hydrological events, especially in urban agglomerations with higher soil waterproofing rate and high population density, urban floods are phenomena that are not restricted only to large

metropolises, being also observed in medium and even small cities.

In Brazil, rains with high intensity and short duration produce even more serious problems, associated with the characteristics of the terrain and drainage network, as well as the use and occupation of urban land. The high number of floods and the amplitude of the phenomena, as well as the socio-environmental problems that emerge from the complex relationship between society and nature in the urban space, are aspects observed from the perspective of disaster risk management.

In this context, the municipality of Francisco Beltrão-located in the Southwest region of Paraná-has a population estimated by the Brazilian Institute of Geography and Statistics (IBGE, 2021) of 93,308 inhabitants, and has recorded a significant number of urban floods in recent years. In the period between the 1980s - the year in which the first record was made-and 2021, the State Coordination of Protection and Civil Defense of Paraná (CEPDEC, 2021) recorded 34 occurrences related to flooding, flash floods, and heavy rains, accounting for a total of 34,180 people affected.

The record of occurrences is made by the 10th Regional Coordination of Protection and Civil Defense (CORPDEC), headquartered in Francisco Beltrão. Based on the Brazilian Disaster Codification (Cobrade) - a classification established by Normative Instruction No. 01, of August 24, 2012 (BRAZIL, 2012), occurrences are registered, stored and made available by the Paraná Civil Defense Computer System (SISDC), a digital platform used as a tool for monitoring disasters in the municipalities of Paraná.

Considering the historical process of urbanization, the banks of the Marrecas River gave way to the urban site of Francisco Beltrão and the expansion of the urban fabric also extended 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 galleries and extreme rainfall events cause flooding due to the increased volume of flow in the drainage systems. The map in Fig. 1 shows the location and hydrography of the urban perimeter of Francisco Beltrão in the context of the Marrecas River Basin.

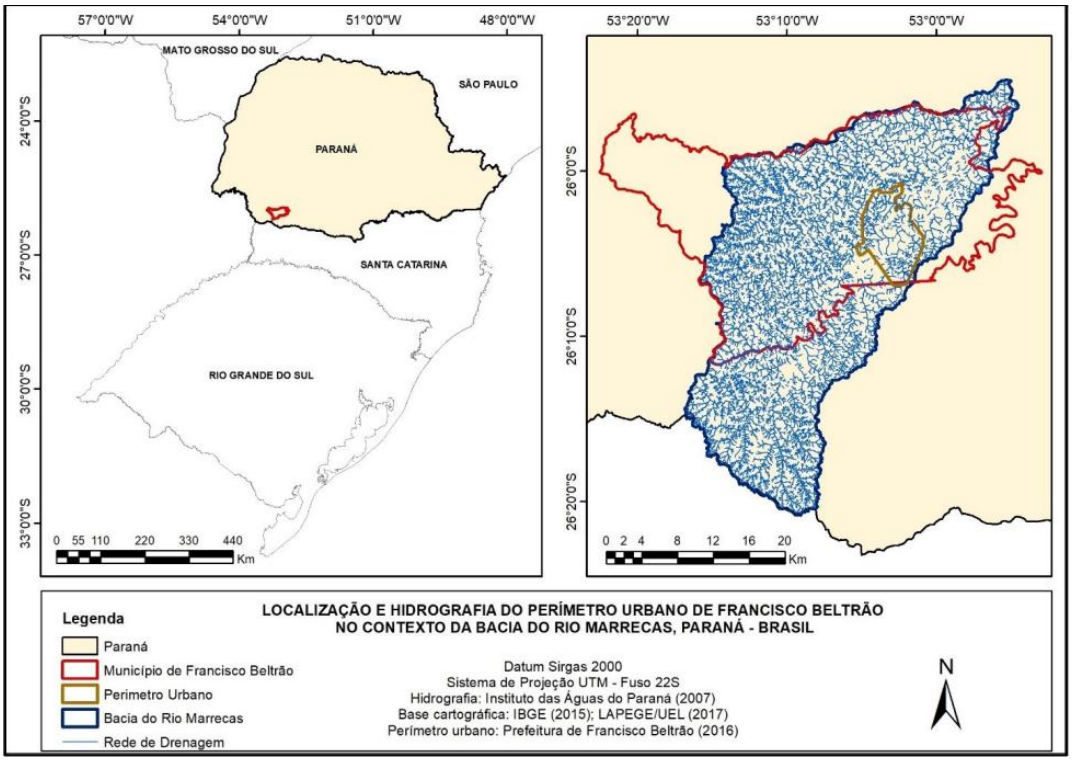

Fig.1. Location and hydrography of the urban perimeter of Francisco Beltrão/PR, Brazil. Source: Paraná Water Institute (2007). Prepared by the authors (2021)

The problems arising from urban expansion and the recurrence of hydrological disasters in the city of Francisco Beltrão motivated the study about the factors producing risks and socio-environmental vulnerabilities related to urban floods. This article therefore proposes a synthesis of the results obtained by mapping the areas at socio-environmental risk of urban flooding, based on the application of the Urban Environmental System (UES) methodology developed by Mendonça (2004).

The SAU is a complex and open system, which is subdivided into three subsystems: a) the Natural Subsystem (terrain, air, water, vegetation and soil) and b) the Built Subsystem (housing, industry, commerce and services, transportation and leisure), both of which form the SAU's input ; and c) the Social Subsystem, in which the system's dynamics occur as a result of human actions and which constitute the system's attributes. In the Social Subsystem, the "dynamics of nature, a supra-human dimension, which surpasses the controls exercised by society when it manifests itself in extreme and impacting episodes" (MENDONÇA, 2004, p. 201). From this perspective, urban socio-environmental problems arise from the interaction between these three subsystems (output) and can be addressed from the perspective of urban socio-environmental planning and management (MENDONÇA, 2004).

The SAU is a complex and open system, which is subdivided, first, by three subsystems: a) Natural subsystem (relief, air, water, vegetation and soil) and, b) built subsystem (housing, industry, trade and services, transport and leisure), both form the input of SAU; e, c) social subsystem, in which the system's dynamics occur as a result of human actions and which constitute the system's attributes. In the social subsystem, the "dynamics of nature, a supra-human dimension, which surpasses the controls exercised by society when it manifests itself in extreme and impacting episodes" (MENDONÇA, 2004, p. 201). From this perspective, urban socio-environmental problems arise from the interaction between these three subsystems(output) and can be addressed from the perspective of urban socio-environmental planning and management (MENDONÇA, 2004).

In order to guide the understanding of this work, the first section presents the theoretical-methodological approach, through which the analysis of the subsystems and attributes that make up the Urban Environmental System applied to the management of socio-environmental risks of urban flooding was constructed. The second section describes the methodology used to collect and analyze data from the physical and social environments, which enabled: estimating the danger of flooding - using hydrological modeling; mapping social vulnerabilities - using Synthesis Cartography techniques; and mapping risk areas - by cross-referencing geospatial information. As a result, the third section summarizes the areas of socio-environmental risk to urban flooding in Francisco Beltrão. Finally, the fourth section concludes the proposed study.

2 Urban environmental system applied to studies of the socio-environmental risks of urban flooding

Studies aimed at understanding the problems arising from the relationship between society and nature in the urban environment seek a basis in readings that prioritize an approach to the complex view of reality, in an effort to identify and understand the interrelationships between social and ecological factors, local and/or regional, which shape and at the same time are shaped by urban socio-environmental dynamics (COELHO, 2004; MENDONÇA, 2004).

In this context, in 1997 the United Nations Development Program/United Nations Project Office (UNDP/UNOPS) published a training guide on urban environmental management for Latin America. The document presents theoretical concepts about the city from an environmental perspective and culminates with suggestions for urban environmental management, which presupposes complementarity and interaction between society and nature in the construction of urban environments.

The Regional Training Project on Urban Environmental Management (UNDP/UNOPS, 1997) demonstrates that the

dynamics of urban can be understood through a systemic analysis, whereby the urban environment is conceived as a global system divided into three subsystems or instances, made up of nature, society and human constructions.

In this article, the systemic approach applied to urban socio-environmental problems has the General Systems Theory (BERTALANFFY, 1968) as its theoretical-methodological foundation, which demonstrates how subsystems constantly exchange energy and matter with each other, and this exchange drives their evolution. While the system is formed by the set of components (subsystems) linked by energy flows, and functions as a unit (DREW, 1994). Therefore, in order to understand a system, it is necessary to observe how both internal and external interrelationships occur, and understand that every system has different variables and can therefore be susceptible to the possibility of generating different combinations and results through self-organization processes (CAMARGO, 2012).

By adopting a systemic view to understand the complex relationship between society and nature in cities, "urban metabolism" is understood as "the exchange of material, energy and information that takes place between the urban settlement 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 is an open system, where the city is the result of the interrelationships between natural and man-made elements. From this perspective, the environment in which the city is located is the result of human action on a particular feature of the earth's surface. The urban environment - also understood as an urban ecosystem - is therefore a product of human action at the interface with a given natural dynamic, or even with the elements of the physical environment, such as an urban agglomeration that is established along the banks of a major river and between the meanders of its tributaries (BRANDÃO, 2006).

Based on this premise, the flowchart in Fig. 2 shows the dynamics of the urban problem, and highlights the intercurrence of the following factors, generally observed: a) the precariousness of the elements made up of the social and builting subsystems; b) the depletion and deterioration of the resources that make up the Natural Subsystem, caused by the appropriation of the built subsystem; and c) the contamination of the Natural Subsystem, generated by the social subsystem (UNDP/UNOPS, 1997; MENDONÇA, 2004).

In the dynamics of urban problems, it is observed that the interaction between the three subsystems of the urban environment is marked by conflicts and social pressures that permeate the urban political, economic and cultural spheres, largely motivated by conditions of poverty and precarious access to housing and infrastructure systems, for example.

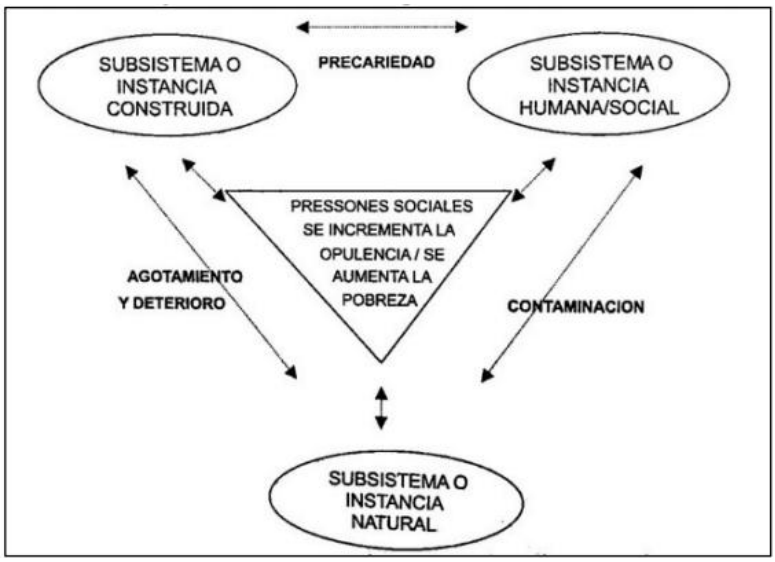

Fig. 2. Dynamics of urban problems Source: UNDP/UNOPS (1997, p. 65).

In most cases, the established social relations and the interaction between society and nature generate pressure on the proper organization of each subsystem. The conflicts that unfold in the urban environment, arising from a mistaken view about the appropriation/use of natural resources, end up highlighting the negative impacts and consequently, the imbalances responsible for the scenarios of exhaustion, deterioration and contamination of natural, social and built subsystems, thus compromising the quality of life in cities. (FARIAS, 2019a).

To carry out studies about the complex relationship between society and nature in cities, Mendonça (2004) took the concept of an Urban Ecological System (UNDP/UNOPS, 1997) as a basis and found the theoretical-methodological basis for the methodological proposal that conceives the city as a whole as an Urban Environmental System in the study carried out by Monteiro (1976) on the Urban Climate System - one of the first initiatives to deal with the city from a systemic point of view.

The conception of an urban environmental system seeks to highlight the interdisciplinary perspective in urban studies. The methodology points to ways of constructing an integrated and holistic reading of urban socio-environmental dynamics. Approaching urban socio-environmental problems in an integrated way interacts with the conceptions of the aforementioned studies and advances on previous propositions, since it proposes the subdivision of subsystems, for which suggestions and guidelines can be drawn up for urban planning and management, by means of a detailed diagnosis of local socio-environmental conditions (MENDONÇA, 2004).

Generally speaking, the SAU is subdivided into three subsystems (Natural, Social and Built), but it can be subdivided into a considerable number of subsystems, so that the researcher can adapt it according to the objectives of investigation and the particularities of the intrinsic driving factors to the area to be investigated.

However, it is important to note that the survey of the problems arising from the interaction between society and nature is a fundamental condition for the elaboration of studies and intervention proposals from the perspective of SAU. It happens that not all the problems that affect cities are derived from this interaction. Therefore, the identification of the type of problem that is intended to investigate is the first step to verify the possible application of the methodology (MENDONÇA; FARIAS, 2011).

Some examples of urban socio-environmental problems of interest to the studies and interventions in the perspective of SAU are: degradation of the terrain, soil and vegetation; air and water pollution; the generation of solid urban waste; irregular occupations, invasions and slum processes; and socio-environmental disasters, such as floods landslides in built areas, among others. The solution or mitigation of the impacts arising within this system will have direct implication in the quality of life of the populations involved (FARIAS,2019a).

By analyzing the urban space and trying to understand it from the perspective of the SAU, we seek to get closer to the phenomena (natural and social) that generate the contradictions of the multiple and complex realities of everyday urban life and, therefore, it is possible to associate the SAU with the concept of the urban ecosystem. The methodology finds support in the process of planning and building strategies to mitigate socio-environmental conflicts, in order to encourage a reorganization of the input elements in the system, the interrelationships between the intervening factors (attributes) and the problems (output) of the SAU, through feedback mechanisms, i.e. the responses of the processes and relationships relevant to the dynamics of nature and society, which can be identified in urban contexts (MENDONÇA, 2004).

In the case study presented here, the input elements of the Urban Environmental System are characterized by natural flows of matter and energy derived from social processes (input). This larger system is made up of the "Nature Subsystem" and the "Society Subsystem", and is subdivided into various subsystems, such as "N Subsystems" (climate, water, soil,

terrain and vegetation) and "S Subsystems" (housing, commerce and services, and infrastructure). Fig. 3 shows the methodological flowchart of the research described in this paper.

Fig. 3. Methodological flowchart of the research: SAU applied to the socio-environmental risks of urban flooding.
Source: MENDONÇA (2004). Prepared by the authors (2021).

The attributes comprise the social instances that shape the dynamics of the environmental system in the city of Francisco Beltrão, in relation to flooding. Characteristics belonging to the superstructure of society (economy, politics, among others) and the culture of the population that makes it up, as well as education and technology, prevail. It is therefore important to note that abrupt, episodic and impacting manifestations of nature, such as natural hazards, also appear as important dynamizers of the SAU (MENDONÇA, 2004).

It is understood that risk estimation considers the probability of the occurrence of an extreme event (danger) that could cause damage to the physical integrity of an individual or groups of individuals, in relation to possible environmental damage and economic and social damage to populations susceptible or vulnerable to adversities, whether of natural origin or resulting from human actions (SOTTORIVA, 2014; ZANELLA; OLÍMPIO, 2014; VEYRET, 2007).

In Brazil, the English term "hazard" is translated as "danger" or "threat". In some cases observed in the literature, the terms hazard and risk are commonly referred to as synonyms, but they are not. The terminology adopted by the United Nations International Strategy for Disasters Reduction (UNISDR, 2009, p. 20) defines natural hazard as "a natural process or phenomenon that can cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption or environmental damage". While the concept of risk refers to "the combination of the probability of an event and its negative consequences" (UNISDR, 2009, p. 25).

Kobiyana et al. (2006) clarifies that a hazard is a natural phenomenon that occurs at known times and in known regions and can cause serious damage to the areas under impact. Therefore, natural hazards are natural processes or phenomena that occur in the biosphere, which can constitute a harmful event and be modified by human activity, such as environmental degradation, deforestation, unplanned urbanization, among others.

In this article, the notion of risk adapted to urban flooding is used in a situation of uncertainty and probability that an extreme hydrological event could affect the subject or population in such a way as to compromise the integrity of their material and immaterial assets (psychological trauma, for example), and these assets are known to be vulnerable, causing

them damage and loss. In this way, the socio-environmental risks of flooding only occur in the simultaneous presence of a natural hazard and social vulnerability (FARIAS, 2019a).

In the context of cities, the diagnosis of the natural elements that constitute the danger of flooding (natural hazards) and the factors responsible for producing social vulnerabilities can vary depending on the environmental characteristics and the heterogeneity of social groups. When considering the social context, the problems triggered by the occurrence of socio-environmental disasters are subjectively faced (FARIAS, 2019a), according to the occurrence of the attributes listed in Fig. 2.

The factors that make it possible to estimate social vulnerabilities are numerous and "must be classified according to their importance, on a scale chosen with care according to the sites analyzed and the accuracy of the data available" (VEYRET, 2007, p. 43). In the case of urban environments, "vulnerability can be considered the only component that allows the occurrence of disasters to be under human control" (PINHEIRO, 2015, p. 51).

On the other hand, the extreme events that generate natural disasters, such as intense rainfall, severe storms, droughts, etc., are not conditioned to human action and are therefore "merely triggers of a disastrous process - leaving managers to focus on the perception of vulnerabilities, located in the receiving system" (PINHEIRO, 2015, p. 52).

When considering the systemic dynamics of the urban environment, various problems can be observed as a result (output) of the interaction between the various subsystems and "sub-subsystems" of the SAU, among them the socio-environmental risks related to urban flooding which, due to the recurrence and scale of the events, increasingly demand the attention of public authorities and the population. It is therefore important to emphasize that the main application of this methodology is to draw up proposals for solving urban socio-environmental problems from the perspective of urban planning and management, with emphasis on promoting public policies aimed at reducing the risks of hydrological disasters.

In this case study, the socio-environmental risks of urban flooding in Francisco Beltrão were represented spatially by means of hydrological modeling and synthesis cartography. "Marking risks on a map is equivalent to 'affirming the risk' in the space in question" (VEYRET, 2007, p. 60). In this way, mapping the risks associated with urban flooding is an instrument that forms the basis of a prevention policy aimed at reducing the risks of hydrological disasters. The cartography applied to the case of Francisco Beltrão sought to map, identify and analyze the areas at risk of urban flooding and, at the same time, allowed for the objectification of risk and its designation as a public problem.

3 Methodological procedures

The methodological procedures include a literature review on the dynamics of urban socio-environmental problems with an emphasis on the SAU proposal, especially with regard to socio-environmental risks to urban flooding. The research was carried out using a case study, a research strategy consisting of defining the problem, outlining the guiding questions, applying methodological procedures, collecting data, processing and analyzing the data and composing and presenting the results.

The survey of the physical characteristics of the Marrecas river basin made it possible to organize the input data for identifying the flood hazards present in the composition of the elements that make up the natural subsystem (input), namely: a) historical rainfall series and determination of design flows; and, b) delimitation of urban sub-basins and quantification of surface runoff. This procedure was applied to estimate the hazard and generate the flood patch, spatially represented on the map in Fig. 4.

The simulations of the spreading of water in the urban basin of the Marrecas River, based on the quantification of the effective rainfall, the portion of precipitation that will be transformed into surface runoff, was carried out using the

methodology proposed by the Natural Resources Conservation Service (NSCR). The methodology proposed by the Natural Resources Conservation Service (NSCR), formerly known as the Soil Conservation Service (SCS), was used to synthesize the flow hydrograph (PRUSKI et al., 2004; TUCCI, 2009). Rainfall events were simulated for return times of 2, 5, 10, 20, 50 and 100 years (Fig. 4).

To generate the urban flood hazard map, hydrological and hydraulic modeling techniques were used, using the 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, and geoprocessing in the Geographic Information System (GIS) environment developed by the Environmental Systems Research Institute (ESRI), the commercial software ArcGIS version 10.3.

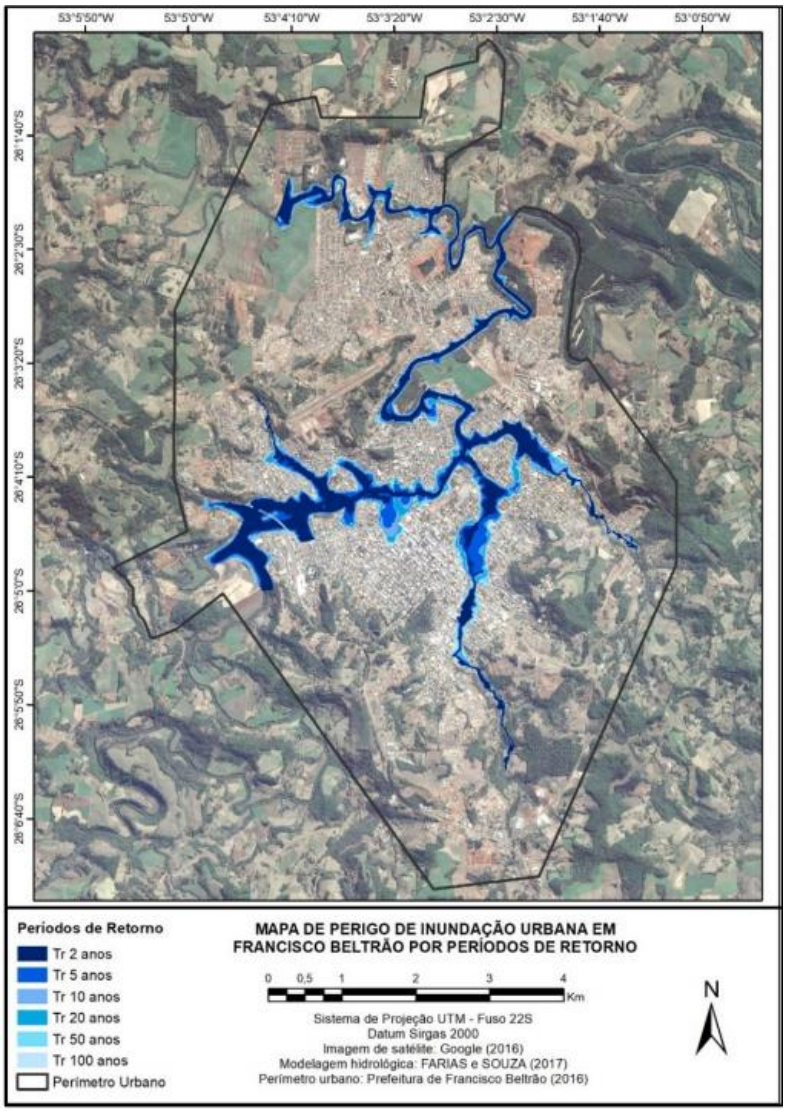

Fig. 4. Urban flood hazard in Francisco Beltrão/PR

Source: Agronomic Institute of Paraná (2016). Prepared by Farias (2019a).

In order to identify the risks of flooding in a given location, it is necessary to know the hydrological and hydraulic processes, which are the source of the data for delimiting the danger areas, i.e. the spaces that will be affected by the spreading of the waters. Estimating the floodplain by return times (Fig. 4) is the first procedure indicated when proposing the identification of socio-environmental flood risks, by combining the presence of imminent danger from extreme hydrological events and social vulnerability indices (FARIAS, 2019a).

The mapping of the areas of social vulnerability of the urban population of Francisco Beltrão (Fig. 5) was based on Synthesis Cartography, which made it possible to combine different quantitative variables through multi-criteria analysis, in combination and under different weights. In this way, new data was obtained that can facilitate understanding of the phenomenon it seeks to represent (SAMPAIO, 2012).

Variables that characterize aspects relevant to the disaster risk reduction macro-process (prevention, mitigation, preparedness, response and recovery phases) were considered, based on the 2010 Census survey (IBGE, 2011), namely: demographic density (weight 15%); housing conditions and infrastructure (weight 45%); age structure (weight 5%); education and age structure (weight 10%); and income (25%) (FARIAS, 2019a).

After the procedures for normalizing, standardizing and weighting the variables, the synthesis process was carried out, with the aim of obtaining the social vulnerability indices of the areas affected by urban flooding in Francisco Beltrão in six classes, based on the studies proposed by Buffon (2016) and Almeida (2010), namely: Very Low, Low, Medium to Low, Medium to High, High and Very High. The classes were obtained using the Natural Breaks statistical method, a tool provided by the ArcGIS 10.3 commercial software. This resulted in a map of social vulnerability associated with urban flooding in Francisco Beltrão (Fig. 5).

In the case study, the proposed synthesis characterized the conditions of social vulnerability by census tract, based on the combination of 11 quantitative variables, under the analysis of their normalized and weighted values (FARIAS, 2019a). The identification of the input attributes of the social subsystem combined with the variables selected from the data provided by the 2010 Census (IBGE, 2011) resulted in the identification of areas of social vulnerability, shown on the map in Fig. 5.

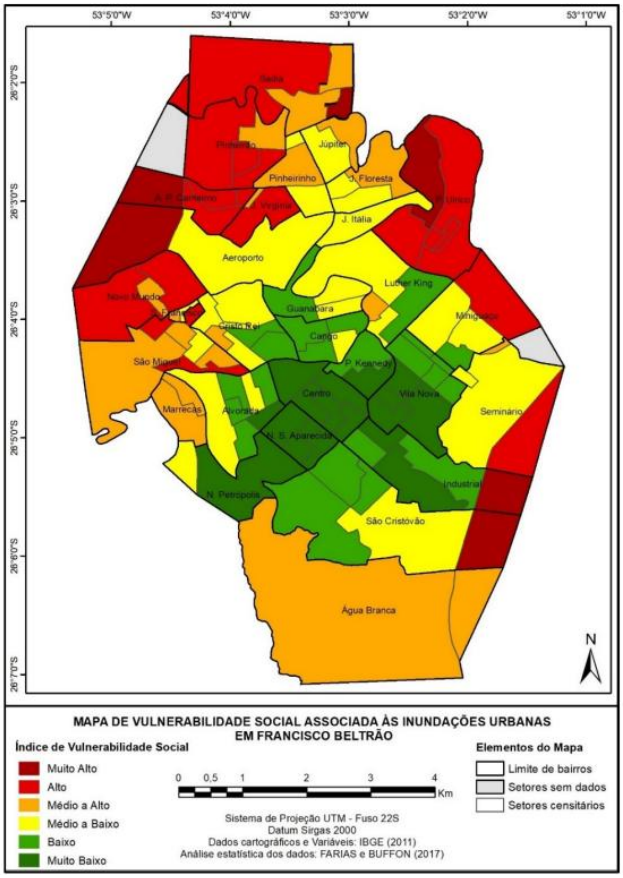

Fig. 5. Social vulnerability associated with urban flooding in Francisco Beltrão/PR

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

The cross-referencing of geospatial information considered the integration of natural (flood danger) and social (social vulnerability) attributes, and was carried out using Synthesis Cartography techniques in ArcGIS 10.3 commercial software, with the aim of demonstrating the different socio-environmental risk indices of the areas affected by flooding in the urban perimeter of Francisco Beltrão (output), as shown on the map in Fig. 6.

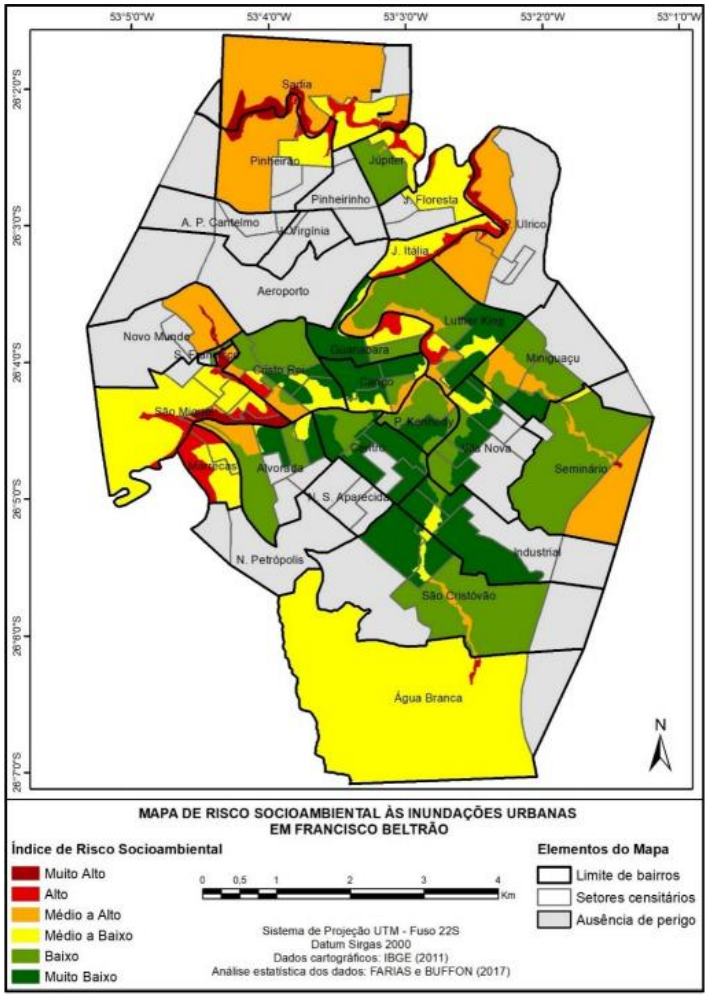

Fig. 6. Areas of socio-environmental risk to urban flooding in Francisco Beltrão/PR

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

The mapping of areas of socio-environmental risk to urban flooding in Francisco Beltrão was generated from a qualitative perspective, which involves multiple dimensions of analysis. Table 1 shows the synthesis made by cross-referencing the social vulnerability indices (SVI) with the presence of flood risk (IPI), at the census tract disaggregation level. This procedure was carried out for all the sectors in which the flood zone occurs, delimited by the return times indicated on the map in Fig. 4. By means of this cross-referencing, which resulted in a qualitative index of socio-environmental risk to urban flooding (IRSI) shown in Table 2, the map shown in Fig. 6 was generated, in order to represent the spatialization of the areas at socio-environmental risk of urban flooding.

Table 1. Summary of flood hazard indices (IPI) and social vulnerability indices (IVS)

IPI / IVS	A	B	C	D
1				
2				
3				
4				
5				
6				

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

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

Table 2. Socio-environmental flood risk index (IRSI)

IRSI (IPI x IVS)	
	Muito Alto
	Alto
	Médio a Alto
	Médio a Baixo
	Baixo
	Muito Baixo

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

The classification of socio-environmental risk areas for urban flooding, identified on the map in Fig. 6, served as the basis for the analysis presented below. To make it easier to locate these areas and summarize the results obtained, the neighbourhoods were grouped into four sectors, according to their geographical positions to the north, west, east and south, using the city center as a reference point. Details of the methodological procedures adopted to organize the cartographic products can be found in the works by Farias (2019a) and Farias and Mendonça (2019b).

4 Results and discussions

The identification of the hazard and the factors that produce social vulnerability was spatially represented using modeling and mapping techniques. Cross-referencing the flood hazard and social vulnerability maps gave rise to the main cartographic product of the research reported here: the map of socio-environmental flood risk areas, an important tool for managing hydrological disasters in the urban space.

In addition to the locations already under the attention of the Civil Protection and Defense agencies, the use of cartographic tools and resources made it possible to spatially represent the socio-environmental risk of flooding at levels ranging from Very Low to Very High. Risk areas were identified in 23 neighbourhoods, revealing a worrying statistic, considering that the current organization of urban space in Francisco Beltrão is delimited by 29 neighbourhoods. The results show that, of the 23 neighborhoods, 20 have critical risk areas.

In the case study, the critical area was defined as the one with the highest socio-environmental risk indices associated with urban flooding, corresponding to Very High, High and Medium to High. The following is a brief summary of the areas of socio-environmental risk to urban flooding in Francisco Beltrão. The full analysis is available in the work by Farias (2019a).

4.1 Summary of socio-environmental risk areas for urban flooding in Francisco Beltrão

Looking at the map in Fig. 6, it can be seen that the neighborhoods with the highest levels of socio-environmental risks and vulnerabilities are located on the geographical periphery of the urban perimeter of Francisco Beltrão. It is important to note that these areas correspond to the highest levels of social vulnerability (Fig. 5) which, combined with the danger of flooding (Fig. 4), are characterized by the highest levels of socio-environmental risk. These areas require emergency action based on effective guidelines for managing rainwater and reducing the risk of flooding, such as structural and non-structural urban drainage measures

In relation to the vulnerability produced in urban space, Acselrad (2006) states that the process of making people vulnerable to a given situation can be associated with three factors: individual, political-institutional and social. From this perspective, maps express social vulnerability in the face of urban flooding and can be used to locate processes that occur in the same spheres in which causalities manifest themselves and are often interrelated (FARIAS, 2019a).

This article proposes an analysis based on tables that indicate the most critical neighborhoods, i.e. the places that present Very High and Medium to High risk conditions, in order to represent the occurrence of the problems/causes identified in the different sectors, but with one factor in common: they occur in the peripheral regions of the city of Francisco Beltrão. These areas have gained prominence due to the urgency of actions and measures to mitigate the impacts of urban flooding on the various social orders and different amplitudes of occurrence.

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 the work of Buffon (2016), Table 3 presents the diagnosis of a critical socio-environmental risk area for each sector - except for the Center Sector, as there is no high risk - located in four neighborhoods of Francisco Beltrão, namely: Pinheirão neighborhood, in the North Sector (Very High risk); São Cristóvão neighborhood, in the South Sector (Medium to High risk); Miniguaçu neighborhood, in the East Sector (Medium to High risk); and, São Miguel neighborhood, in the West Sector (Very High risk).

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

In the urban environmental system of Francisco Beltrão, the flooding of the Marrecas River interferes significantly in the relationship between society and nature. In this relationship, a significant portion of the population represents the highest levels of social vulnerability and lives with the danger of flooding in risk areas.

From the perspective of rainwater management, the main urban problems resulting from the interrelationship between social and natural attributes in Francisco Beltrão's SAU are: a) an increase in soil sealing, erosion, sediment production and silting up of rivers, streams and canals; b) obstruction of micro- and macro-drainage systems for rainwater, caused by the accumulation of sediment and solid waste; and c) flooding and waterlogging.

As a result, disasters generate huge economic losses for the municipal government, in addition to the social and environmental damage identified through the fieldwork carried out in the study area between 2014 and 2019. After diagnosis, many families still live in properties with precarious infrastructure conditions and temporarily build houses in

the absence of basic urban services. The representative images, shown in Table 3, were selected with the intention of highlighting the contrasts between the different realities that manifest themselves in the space where hydrological disasters occur.

Chart 1. Socio-environmental risks to urban flooding in Francisco Beltrão/PR: attributes and representations of reality

Source: Farias (2019a)

Section	Sub Bacia	Bairro	Attributes	IRSI	Representative Images
Northern Sector	Rio Santa Rosa	Pinheirão	-Former urban development on the main bed of the Santa Rosa River (right bank). -Partial riparian forest and presence of agricultural cultivation. - Soil erosion. -Sanitation: deactivated septic tank. -Industrial effluent treatment ponds. -Housing complex under the "Minha casa, minha vida" program. Removal of families and inclusion in the Social Rent Program. -New settlements without infrastructure and in a disorderly manner (irregular).	Very high	 Figura 7  Figura 8
South Sector	Rio Lonquea dor	São Cristóvão	-Urban allotments on the main bed of the Lonqueador River (both banks). -Rectified and canalized water body. - Soil erosion. - Canal silting. - Riparian forest: absent - Good housing conditions in most cases. -Sanitation:sewage collection. Dumping of effluents into the water body. - Infrastructure: poor.	Medium to High	 Figura 9

Sector East	Córrego Urutago	Miniguaçu	Urban allotments on the larger bed of the Urutago stream (both banks). - Riparian forest: present in some stretches of the stream. - Good housing conditions in most cases. -Sanitation:sewage collection. Dumping of effluents into the water body. - Infrastructure: regular. - Increase in impermeable areas of the Jayme Canet Júnior Exhibition Park and consequently an increase in surface runoff.	Medium to High	Figura 10 
Setor West	Rio Marrecas	São Miguel	- Irregular settlements on the larger bed of the Marrecas River (left bank). - Informal housing. -Precarious housing conditions in most cases. - Riparian forest: only on the left bank. - Soil erosion. -Sanitation: presence of septic tanks. Dumping of effluent into the water body. - Infrastructure: absent. -Accumulation of solid waste.	Very high	Figura 11 

Looking at the scenarios described in Table 3, it can be seen that the processes responsible for the increase in social vulnerability indices produce the critical levels of flood risk measured and demonstrated in this article. The set of social attributes was considered on the spatial scale of the urban census sectors, where the processes that produce social vulnerability and the phenomena of flood risk are interrelated, integrated and manifested in the urban environmental system of Francisco Beltrão. Based on the results presented, it is clear that the vulnerability of individuals is aggravated by a process of exclusionary urbanization, especially in the outlying districts.

The growth in the number of formal homes and informal settlements along the flood zones of Francisco Beltrão's urban rivers is part of the same phenomenon responsible for producing risks and vulnerabilities, and highlights the emergence of the socio-environmental problems identified in the case study. Therefore, based on the results obtained through the mapping and the discussions relevant to the dynamics of the urban problem, the thesis is defended that the

socio-environmental risk is greater for the population affected by flooding in the peripheral regions of the city of Francisco Beltrão, although the danger manifests itself in the same way in other locations in the urban river network.

5 Conclusion

The case study carried out in Francisco Beltrão highlighted the main impacts of floods on the urban environmental system, which are: a) material damage and losses; the removal of hundreds of people from the places frequently affected; b) the interruption of economic activities in the flooded areas; and c) water contamination due to the flooding of areas close to septic tanks and wastewater treatment plants. In this process, the water subsystem - which is part of the natural subsystem - is the first to show signs of urban environmental degradation.

In the aftermath of disasters, the difficulty faced by the population living in critical flood risk areas in recovering from the damage is one of the social aggravating factors that should be considered with rigorous attention by public bodies, especially municipal and state Civil Protection and Defense departments, as well as departments directly related to urban planning and infrastructure. Locating these areas on a map should be one of the priorities in actions aimed at reducing urban social vulnerabilities and, consequently, reducing disaster risks.

The synthesis of areas with a high socio-environmental risk of urban flooding (Very High, High and Medium to High) made it possible to identify and analyze some attributes contained in the sphere of socio-spatial relations which, with the intensification of the urbanization process on the urban water subsystem, produce scenarios of environmental degradation, vulnerabilities and economic and social conflicts.

It is therefore recommended to use the proposed mapping as a tool for socio-spatial analysis of the identified risks associated with urban flooding in the city of Francisco Beltrão. The spatial reading has a direct application to urban environmental zoning, through which it is recommended that the following be defined: spaces where there is a high risk and which 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; and other spaces where the risk is lower or even absent.

Understanding the risks of urban flooding from the perspective of the SAU stands out for its significant contribution to the planning and management of urban space, both in terms of the methodological aspect for identifying the intervening factors in urban socio-environmental dynamics, and for its applicability in specific actions. In this sense, the results obtained in the case study of the city of Francisco Beltrão can support other studies and the actions of government bodies and the various institutions involved in reducing the risk of socio-environmental disasters associated with urban flooding.

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Conflicts of interest

The author declares no conflicts of interest regarding the publication of this paper.

References

[1] ACSELRAD, H. Vulnerabilidade ambiental, processos e relações. In: Encontro Nacional de Produtores e Usuários de Informações Sociais, Econômicas e Territoriais, 2., 2006, Rio de Janeiro. Comunicação. Rio de janeiro: Instituto Brasileiro de Geografia e Estatística (IBGE), 2006. Disponível em: http://www.nuredam.com.br/files/divulgacao/artigos/Vulnerabilidade%20Ambientais%20Proce%20sso s%20Rela%E7%F5es%20Henri%20Acselrad.pdf. Acesso em: 05 out. 2021.

[2] ALMEIDA, L. Q. de. Vulnerabilidades socioambientais de rios urbanos: bacia hidrográfica do rio Maranguapinho, região metropolitana de Fortaleza, Ceará. Tese (Doutorado em Geografia) – Rio Claro: Universidade Estadual Paulista, Instituto de Geociências e Ciências Exatas. 2010. Disponível em: https://repositorio.unesp.br/handle/11449/104309. Acesso em: 11 out. 2021.

[3] BERTALANFFY, L. V. Teoria Geral dos Sistemas. Petrópolis: Editora Vozes, 1968.

[4] BRANDÃO, A. M. de P. M. Clima Urbano e enchentes na cidade do Rio de Janeiro. In: GUERRA, A. J. T.; CUNHA, S. B. (Org.). Impactos Ambientais urbanos no Brasil. 10 ed. Rio de Janeiro: Bertrand Brasil, 2006. p. 47-119.

[5] BRASIL. MINISTÉRIO DA INTEGRAÇÃO NACIONAL. SECRETARIA NACIONAL DE DEFESA CIVIL. CENTRO NACIONAL DE GERENCIAMENTO DE RISCOS E DESASTRES. Anuário brasileiro de desastres naturais: 2011. Brasília: Centro Nacional de Gerenciamento de Riscos e Desastres – CENAD, 2012. Disponível em: https://antigo.mdr.gov.br/images/stories/ArquivosD efesaCivil/ArquivosPDF/publicacoes/Anuario-de Desastres-Naturais-2011.pdf. Acesso em: 29 mai. 2022.

[6] BUFFON, E. A. M. A leptospirose humana no AURMC (aglomerado urbano da Região Metropolitana de Curitiba/PR) – risco e vulnerabilidade socioambiental. Dissertação (Mestrado em Geografia) – Curitiba: Universidade Federal do Paraná. 2016. Disponível em: https://acervodigital.ufpr.br/handle/1884/43110. Acesso em: 11 out. 2021.

[7] CAMARGO, L. H. R. de. A geoestratégia da natureza: a geografia da complexidade e a resistência à possível mudança do padrão ambiental planetário. Rio de Janeiro: Bertrand Brasil, 2012. CEPDEC - Coordenadoria Estadual de Proteção e Defesa Civil do Paraná. Ocorrências (globais) por Município – Francisco Beltrão. 2021. Disponível em: http://www.sisdc.pr.gov.br/sdc/publico/relatorios/oc orrencias_geral.jsp. Acesso em: 05 out. 2021.

[8] COELHO, M. C. N. Impactos ambientais em áreas urbanas – teorias, conceitos e métodos de pesquisa. In: GUERRA, A. J. T.; CUNHA, S. B. da. (Org.). Impactos ambientais urbanos no Brasil. 2. ed. Rio de Janeiro: Bertrand Brasil, 2004, p. 19-46.

[9] DREW, D. Processos interativos homem-meio ambiente. 3. ed. Rio de Janeiro: Bertrand Brasil, 1994.

[10] FARIAS, A. Inundações urbanas em Francisco Beltrão/PR: riscos e vulnerabilidades socioambientais. Tese (Doutorado em Meio Ambiente e Desenvolvimento) – Curitiba: Universidade Federal do Paraná. 2019a. Disponível em: https://acervodigital.ufpr.br/handle/1884/66322. Acesso em: 07 set. 2021.

[11] FARIAS, A. MENDONÇA, F. Modelagem e mapeamento de áreas de perigo de inundação urbana na cidade de Francisco Beltrão (Brasil). Physis Terrae, n. 1, p. 73-91, 2019b. Disponível em: https://doi.org/10.21814/physisterrae.405.

[12] GOOGLE EARTH. Imagem de satélite do município de Francisco Beltrão/PR. Programa on line. Disponível em: http://www.google.com/intl/pt-PT/earth/index.html. Acesso em: 21 dez. 2016.

[13] IBGE - Instituto Brasileiro de Geografia e Estatística. Cidades@. Paraná. Francisco Beltrão. Panorama. 2021. Disponível em: https://www.ibge.gov.br/cidades-e estados/pr/francisco-beltrao.html. Acesso em: 12 out. 2021.

[14] IBGE – Instituto Brasileiro de Geografia e Estatística. Geociências. Downloads. Rio de Janeiro: IBGE, 2015. Disponível em: https://www.ibge.gov.br/geociencias/downloads geociencias.html. Acesso em: 10 set. 2021.

[15] IBGE – Instituto Brasileiro de Geografia e Estatística. Base de informações do Censo Demográfico 2010: Resultados do Universo por setor censitário. Rio de Janeiro: IBGE, 2011.

[16] IAPAR – Instituto Agronômico do Paraná. Médias históricas em estações do IAPAR – Francisco Beltrão. 2016. Disponível em: http://www.iapar.br/arquivos/Image/monitorament o/Medias_Historicas/Francisco_Beltrao.htm. (Dados informados por e-mail). 2016.

[17] INSTITUTO DAS ÁGUAS DO PARANÁ. Bacia hidrográfica do rio Marrecas. 2007. Disponível em: https://www.iat.pr.gov.br/Pagina/Mapas-e-Dados Espaciais. Acesso em: 10 set. 2021.

[18] KOBIYAMA, M. et al. Prevenção de desastres naturais: conceitos básicos. Curitiba: Editora Organic Trading, 2006. Disponível em: http://logatti.edu.br/images/prevencaodesastres.pdf. Acesso em: Acesso em: 13 mar. 2022.

[19] LAPEGE – LABORATÓRIO DE PESQUISA EM GEOGRAFIA FÍSICA. Base de Dados SHP e Raster. Londrina: Programa de Pós-Graduação em Geografia (PPGeo), Universidade Estadual de Londrina, 2017. Disponível em: http://www.uel.br/laboratorios/lapege/pages/base de-dados-shp-e-raster.php. Acesso em: 10 set. 2021.

[20] MENDONÇA, F. FARIAS, A. Riscos e vulnerabilidades socioambientais urbanos: perspectivas e desafios no contexto da pós modernidade. In: NEVES, L. S. (Org.) Anais do 5° Seminário Sobre Sustentabilidade: Artigos Selecionados. Curitiba: Juruá Editora, 2011. p. 73-85.

[21] MENDONÇA, F. S.A.U. Sistema Ambiental Urbano: uma abordagem dos problemas socioambientais da cidade. In: MENDONÇA, F. (Org.) Impactos socioambientais urbanos. Curitiba: Editora da UFPR, 2004. p. 209-218.

[22] MONTEIRO, C. A. F. Teoria e clima urbano. São Paulo: IGEO-USP. Tese (Livre-Docência), 1976.

[23] PINHEIRO, E. G. Gestão Pública para a redução dos desastres: incorporação da variável risco de desastre à gestão da cidade. Curitiba: Appris, 2015.

[24] PNUD – PROGRAMA DE LAS NACIONES UNIDAS PARA EL DESARROLLO. UNOPS – OFICINA DE SERVICIOS PARA PROYETOS DE LAS NACIONES UNIDAS. PROYECTO REGIONAL DE CAPACITACION EN GESTION AMBIENTAL URBANA. Guia metodologica de capacitacion en gestion ambiental urbana para universidades de América Latina y el Caribe. Nova York: UNDP/UNOPS, 1997.

[25] PREFEITURA DE FRANCISCO BELTRÃO. Mapa da cidade de Francisco Beltrão. (Atualizado em 2016). Francisco Beltrão: Secretarias, 2021. Disponível em: https://www.franciscobeltrao.pr.gov.br/secretarias/obras-e-urbanismo/mapas/. (Dados informados por e-mail). 2016.

[26] PRUSKI, F. F. BRANDÃO, V. dos S. SILVA, D. D. da. Escoamento Superficial. 2. ed. Viçosa: Universidade Federal de Viçosa, 2004.

[27] SAMPAIO, T. V. M. Diretrizes e procedimentos metodológicos para a cartografia de síntese com atributos quantitativos via álgebra de mapas e análise multicritério. Boletim de Geografia, Maringá, v. 30, n. 1, p. 121-131, 2012. https://doi.org/10.4025/bolgeogr.v30i1.9701

[28] SOTTORIVA, P. R. S. et al. Atendimento de saúde a múltiplas vítimas e em catástrofes. 2. ed. Curitiba: SAMU Internacional Brasil, 2014.

[29] TUCCI, C. E. M. Gestão da drenagem urbana. Distrito Federal: CEPAL. Escritório no Brasil/IPEA, 2012. Disponível em: https://www.cepal.org/sites/default/files/publication /files/38004/LCBRSR274_pt.pdf. Acesso em: 23 fev. 2022.

[30] TUCCI, C. E. M. (Org.). Hidrologia: ciência e aplicação. 4. ed. Porto Alegre: Editora da UFRGS/ABRH, 2009. TUCCI, C. E. M. Águas urbanas. Estudos Avançados, v. 22, n. 63, p. 97-112, 2008. Disponível em: https://doi.org/10.1590/S0103- 40142008000200007

[31] UNISDR – UNITED NATIONS INTERNATIONAL STRATEGY FOR DISASTER REDUCTION. Terminology on Disaster Risk Reduction. Geneva: UNISDR, 2009, p. 20-25. Disponível em: https://www.unisdr.org/files/7817_UNISDRTermin ologyEnglish.pdf. Acesso em: 13 mar. 2022.

[32] VEYRET, Y. Os riscos: o homem como agressor e vítima do meio ambiente. São Paulo: Contexto, 2007.

[33] ZANELLA, M. E. OLÍMPIO, J. L. S. Impactos pluviais, risco e vulnerabilidade em Fortaleza-CE. In: MENDONÇA, F. (Org.) Riscos Climáticos: vulnerabilidades e resiliência associados. Jundiaí: Paco Editorial, 2014. p. 115-136.

Authors' Contribution

Ariadne Sílvia de Farias conceived the study, collected and analyzed the data, organized the maps and wrote the text. Francisco Mendonça guided the methodology adopted, took part in preparing the study and reading, discussing and correcting the text.