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Assessment of economic impacts in flood events in Lages/SC, Brazil

Análise de impactos econômicos em eventos de inundações no município de Lages/SC, Brasil

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ABSTRACT

Flood processes become increasingly harmful to communities due to factors such as climate change and land use. This study aims to evaluate the economic damages of flood events in an area of the urban basins of Lages/SC. Thus, four plans were considered for economic evaluation: one referring to conditions without protective measures and three with the application of elevation of structures at different heights, as well as two scenarios of the evolution of urban occupation. The rainfalls were obtained through the Gumbel probabilistic model to estimate the maximum accumulated precipitations over 5 days, with the hydrological modeling carried out at the HEC-HMS. The hydrodynamic modeling was performed in HEC-RAS through the simulation of a 1D model. The HEC-FDA model was used to perform the risk reduction analysis of damage caused by floods, where the expected annual damages (EAD) were calculated for the four proposed plans as well as for the urban growth scenarios. The results showed that the application of the mitigating measure of raising the structures reduced the EAD by up to 83.10%. As for the scenario of the evolution of urban growth, there was an increase in EAD of 62.09%, in the interval of 20 years. The HEC-FDA model has been demonstrated as good software for assessing the economic damage of floods in different scenarios, showing results that can help decision-makers in the development of public policies.

Keywords: flooding; mitigation; socio-hydrology; HEC-FDA; urban growth.

RESUMO

Os processos de inundação tornam-se cada vez mais prejudiciais às comunidades, em razão de fatores como as mudanças climáticas e o uso do solo. Este estudo teve como objetivo avaliar os danos econômicos de eventos de inundações em área das bacias urbanas de Lages/SC. Foram considerados quatro planos para a avaliação econômica, um referente a condições sem medidas protetivas e três com a aplicação de elevação de estruturas em diferentes alturas, bem como dois cenários de evolução da ocupação urbana. As chuvas foram obtidas por meio do modelo probabilístico de Gumbel, para a estimativa das chuvas máximas acumuladas de cinco dias, com a modelagem hidrológica realizada no hydrologic modeling system (HEC-HMS). A modelagem hidrodinâmica foi executada no river analysis system (HEC-RAS), por meio da simulação de modelo 1D. O modelo HEC-FDA foi utilizado para a realização da análise de redução de risco de danos causados por inundações, em que foram calculados os danos anuais esperados (EAD) para os quatro planos propostos, bem como para os cenários de crescimento urbano. Os resultados demostraram que a aplicação da medida mitigadora de elevação das estruturas reduziu o expected annual damage (EAD) em até 83,10%. Já para o cenário de evolução do crescimento urbano, observou-se aumento do EAD em 62,09% no intervalo de 20 anos. O modelo FDA demostrou ser uma boa ferramenta para a análise dos danos econômicos de inundações em diferentes cenários, com resultados que podem auxiliar os tomadores de decisões na fomentação de políticas públicas.

Palavras-chave: enchentes; mitigação; sócio-hidrologia; HEC-FDA; crescimento urbano.

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Introduction

Scientific studies indicate that the effect of climate change combined with urban growth, and consequently, land-use change, contributes to increase the risk of flooding in urban areas (Nithila Devi et al., 2019; Tramblay et al., 2019; Avashia and Garg, 2020; Chen et al., 2020b; Reichstein et al., 2021; Ajjur and Al-Ghamdi, 2022).

Flood processes combined with land use changes can have both negative and positive impacts on communities. Among the negative impacts, land use change in urban areas favors an increase in the impacts of floods. As the soil becomes more impermeable (Liu et al., 2014; Pour et al., 2020), hydrological process such as infiltration reduce, while there is an increase in surface runoff, which can modify the water balance on the hydrological cycle, overload the drainage systems, and potentiate peak runoff (Adnan et al., 2020; Chen et al., 2020a). In addition, negative impacts on communities, such as waterborne and vector-borne diseases, along with psychological health problems, can be enhanced by the occurrence of flood events (Farias Asmus et al., 2013; Menne and Murray, 2013; Leite and Steffens, 2018; Paterson et al., 2018; Portela et al., 2020; Shokri et al., 2020).

Floods can also generate beneficial impacts, such as the growth of community spirit, recharge of underground water sources, nutrient transport, sediment distribution, and woody debris that contributes to aquatic habitat's complexity and diversity. In addition to soil enrichment and water availability for agriculture and livestock (Peters et al., 2015; Svetlana et al., 2015; Walker-Springett et al., 2017; Talbot et al., 2018).

Thus, it is known that humans have lived close to rivers since the beginning of time, for so many reasons that, even though beneficial in some cases, cause higher exposure to the risks of flooding in areas inhabited by riverside populations, who increasingly pass through this type of events (Viglione et al., 2014; Fang and Jawitz, 2019). To this extent, in the context of hydrological landscapes, lowlands, due to their proximity to the water table, are predisposed to have low water storage capacity and are prone to respond quickly to precipitation, independent of their location in the catchment, in such a manner that they concentrate risks for the communities who live in this landscape unit (Gharari et al., 2011).

Therefore, risk can be understood as the probability of a hazard occurring in a given region, along with exposure and vulnerability (Mianabadi et al., 2020). Human capacity to resist, recover, and adapt in a process that communities learn to deal continuously with land use change and climate change can be considered an important factor for risk composition in a given region (Marcelino et al., 2006; Sörensen et al., 2016). Thus, people who have been affected by past experiences of flood events seek to improve their levels of preparedness for future floods, often neglecting the possibility that future floods might have a greater magnitude, which can influence the efficiency of mitigation measures (Fox-Rogers et al., 2016).

Risk management is a useful tool in mitigating flood hazards, which can help reduce loss of life and economic damages to communities (Disse et al., 2020). In Brazil, the National Secretariat for Protection and Civil Defense manages natural disasters, such as floods, by a cycle separated into seven stages, namely, disaster impact, response, recovery, development, prevention, mitigation, and preparedness, which do not have a linear but cyclical nature (Carter, 2008).

Regarding the economic damages caused by flooding in northern Argentina and Uruguay, losses were estimated at US$ 2.5 billion in January 2019 this event also affected southern Brazil (WMO, 2020). Moreover, in the State of Santa Catarina, losses were estimated in the range of R$ 4.8 billion between the years 2000 and 2010 (Herrmann, 2014).

In Brazil, several studies have proposed methodologies for estimating flood damage, in the main through flood-damage curves, damage assessment forms, and equations to estimate damages (Machado et al., 2005; Corsi et al., 2012; Alves et al., 2013; Silva, 2015; Minervino and Duarte, 2016; Batista et al., 2020).

However, it is known that hydrological modeling has progressed a lot in recent years, mainly driven by easy access to computational capability, sophisticated instrumentation, remote sensing, and Geographic Information System (GIS) capabilities. To this extent, integration of hydrology with allied areas is occurring increasingly, for example, with economic studies (Singh, 2018; Müller and Levy, 2019).

The HEC-FDA was developed by the U.S. Army Corps of Engineers; this model can be coupled to hydrological and hydrodynamic models. The program provides the capability to formulate and evaluate flood damage reduction plans using risk-based analysis methods by estimating the expected annual damage (EAD), which can be used to compare different scenarios, that consider with and without project conditions and distinct analysis years in such a way that can support the development of a flood risk management plan (Lehman, 2016; Martínez-Gomariz et al., 2020). EAD is calculated by the integration of the damage-probability function; that being so, damage is estimated by multiple Monte Carlo sampling of discharge-exceedance probability, stage-discharge, and stage-damage relationships and their associated uncertainties (USACE, 2016; Stakhiv, 2021).

The HEC-FDA model has been applied in watersheds in Europe, Asia, and North America. These studies used the model to estimate flood damage considering scenarios without projecting, i.e., without application of flood control methods, and scenarios with projecting, i.e., with mitigation measures, such as dams and flood insurance programs (Cunha and Taveira-Pinto, 2011; Qi and Altinacar, 2011; Mohammadi et al., 2014; Lee et al., 2015; Mas, 2015; Van Dau et al., 2017; Difrancesco et al., 2020; Moosakhaani et al., 2020; Moosakhaani et al., 2022).

Furthermore, mitigation measures play a fundamental role in flood risk management, as they have the potential to reduce impacts on communities. Structural or non-structural measures can be adopted, such as flood detention basins, structural elevation, flood insurance, and flood warning (Arrighi et al., 2018; Jacob et al., 2019; Ruig et al., 2019; Sukhwani et al., 2019; Robinson and Botzen, 2020; Nofal and Lindt, 2021).

This study became necessary to fill the current research gap in view of studies that evaluate and quantify the economic impacts of flood events in the urban basins of Lages/SC. Thus, the main objective of this study was to evaluate the economic damage caused by flood events, considering scenarios without project and with building elevation, besides the effects of urban growth in the past 20 years.

Materials and Methods

Study area

The urban basins of the city of Lages, located in the mountainous plateau region of Santa Catarina State in southern Brazil, were adopted as the study area. This area was chosen due to the recurrent flooding that generates negative impacts on the riverside populations, with records of 20 significant flooding events between the years 1979 and 2017 (Liz, 2018). Figure 1 shows the location of the study area, as well as sectors 9, 10, 23, and 24 proposed by the Geological Survey of Brazil; these sectors were selected due to their high perception of flood risk and vulnerability (Lamberty and Mendonça, 2018). In addition, these areas coincide with the flood polygon shapefile observed during the flood events in 2005, 2008, and 2011, which were given by the municipal administration of Lages/SC.

According to Figure 2, the climate type in the study area is the humid temperate climate (Cfb) (Alvares et al., 2013). Moreover, the rainiest months of the year in Lages/SC, are September and October, while the least rainy months are April and May, according to the historical rainfall time series from 1941 to 2019.

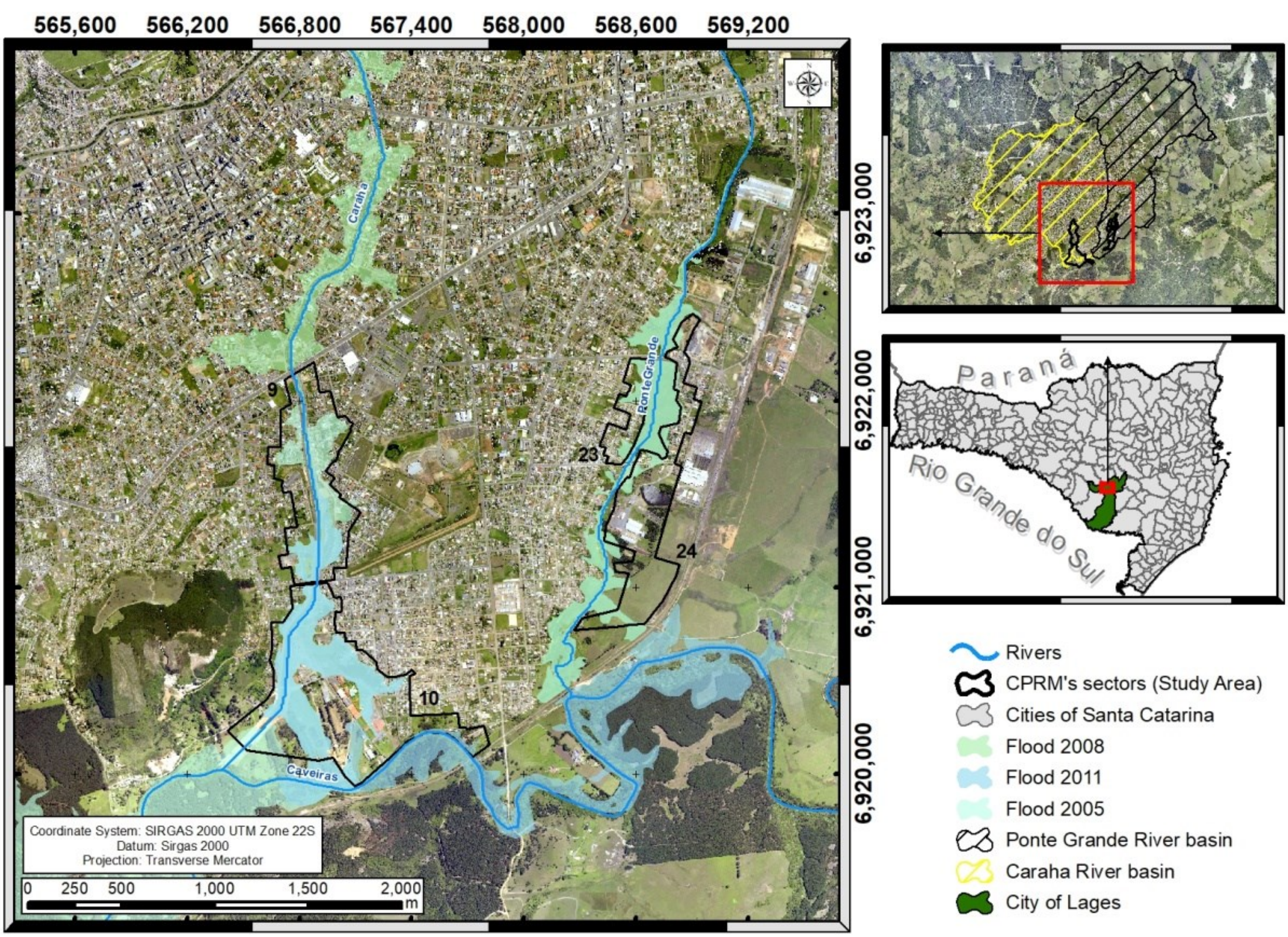

Figure 1 – Location of the study area.

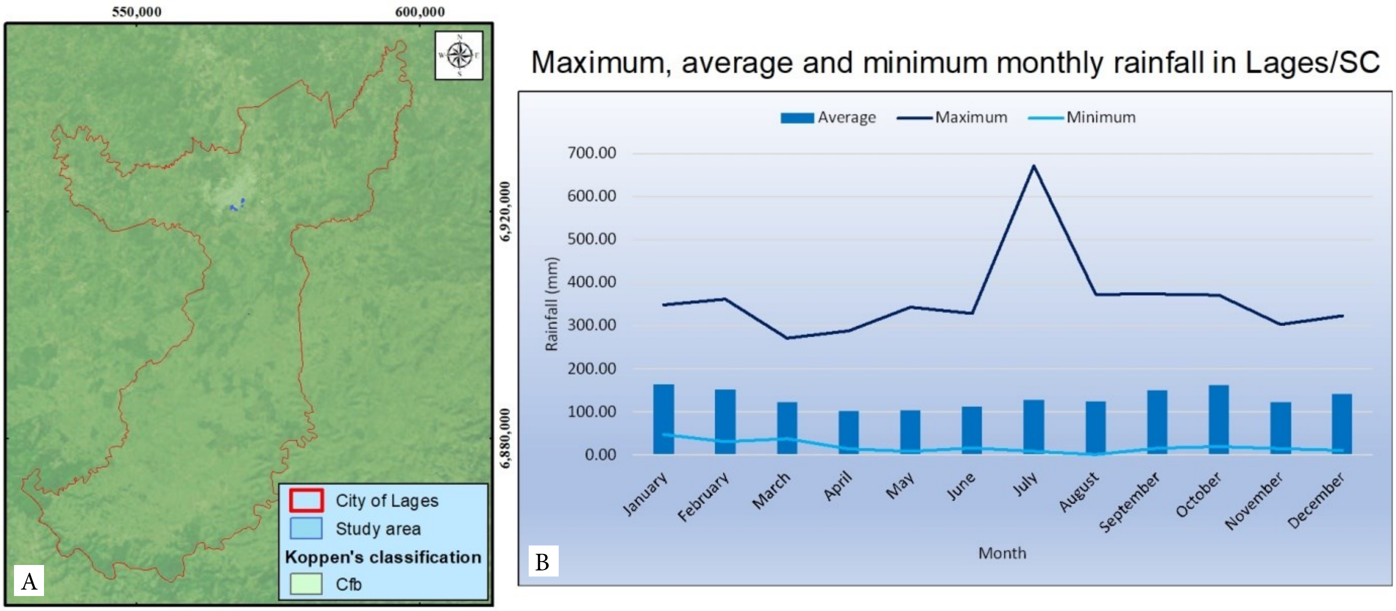

Figure 2 – Climate classification and monthly rainfall.

Hydrological modeling

Initially, eight hydrographs were computed in the hydrological modeling, referring to eight different return periods (3, 5, 10, 15, 25, 50, 100, and 500 years), needed for economic modeling in the HEC-FDA. It was decided to adopt the annual maximum 5-day rainfall, computed by the Gumbel model, considering that it is one of the most used probability distributions to estimate extreme rainfall (Ozonur et al., 2021). The HEC-HMS 4.6.1 was chosen to calculate the project hydrographs, transforming the rainfall-runoff in the studied urban basins.

The rainfall data were obtained through the historical series of two rainfall stations: the Experimental Station of Epagri (Code 2750005, Geographical Coordinates: lat. –27º48'30", long. –50º19'42"), which has data from March 1941 to March 2014, and the Station of Coral District (Code 2750046, Geographical Coordinates: lat. –27º48'25", long. –50º18'18"), which has data from April 2014 to June 2019, compiling 74 years of consistent data.

The Gumbel model was calculated for maximum 5-day rainfall; the model parameters beta and alpha were determined using the method of moments, while the empirical frequency was estimated using the Kimbal formula. In addition, the D coefficient and return periods were calculated for each year of the historical series.

To verify whether the annual maximum 5-day rainfall time series fit the Gumbel distribution, the Kolmogorov–Smirnov adherence test was applied, with a 1% level of significance ($p < 0.01$). This test was adopted because it is one of the most used in hydrology studies (Back and Bonfante, 2021). Thus, after analyzing the historical series, rainfall was estimated for all the return periods studied using the inverse Gumbel model (Equation 1).

$$h = \bar{h} - Sh\,\{0.45 + 0.7797 * \ln\left[\ln\left(\frac{TR}{TR-1}\right)\right]\} \quad (1)$$

Where:
h = rainfall for a given return period, mm;
$\bar{h}$ = average annual maximum 5-day rainfall, mm;
Sh = standard deviation of the annual maximum 5-day rainfall, mm.

Considering the temporal distribution of rainfall, it was decided to use the observed rainfall, recorded in the historical series, as a parameter for the maximum 5-day rainfall disaggregation, since rainfall disaggregation coefficients for the State of Santa Catarina only cover rains of up to 1-day duration (CETESB, 1986).

Therefore, the proposed methodology consisted of analyzing the observed rainfall events that were equivalent to the modeled rainfall by the Gumbel model, thus calculating the percentage of observed rainfall on each day of the event and using this factor for the distribution of modeled rainfall over time. It is considered that for modeled rainfall where there was not equivalent observed rainfall, the event with the closest return period for the rainfall distribution was used.

The hydrological modeling was computed from a calibrated model in HEC-HMS; this model represents the Ponte Velha Catchment, which covers the urban basins of Lages/SC, and was developed by the Hidro-Lages Project (Rafaeli Neto, 2019b). It should be noted that this model was not validated for a period after 2019, since the fluviometric station used in the model is no longer in operation. Thus, the project hydrographs were obtained from the calibrated model for each of the eight return periods.

Hydrodynamic modeling

The hydrodynamic modeling was performed in HEC-RAS 5.0.3, since it belongs to the HEC family of programs, in a way that provides a good level of coupling between the programs used in this study. In addition, this coupling of programs facilitated the input of data into the HEC-FDA model. It was decided to apply a 1D model for delineating the geometry of the study area in order to facilitate the import of the water surface profile into the FDA model, which requires cross-sectional data.

In this study, a high-resolution digital terrain model (DTM) was used for the hydrodynamic modeling, with a resolution of 30 cm; this DTM was available for the floodplain topographic surface of the Lages urban area, being one of the products of the Hidro-Lages Project. This DTM was obtained through an aerial photogrammetric survey carried out in 2019 using LiDAR (Light Detection and Ranging) technology and the orthorectification technique in an area of 25 km² (Rafaeli Neto, 2019a).

Figure 3 shows the geometry used in the study area, which covers parts of the Ponte Grande, Carahá, and Caveiras River basins. In terms of the number of cross-sections created per river, a total of 93 cross-sections were inserted in the model, considering a higher level of detail in the study area. Furthermore, regarding the Manning roughness coefficients data, a value of 0.035 $s.m^{-1/3}$ was defined for the main channels and 0.055 $s.m^{-1/3}$ for the right and left banks. The hydrodynamic simulation was carried out using unsteady flow analysis, while for the boundary conditions, junctions 13 (River Carahá), 8 (River Ponte Grande), and 4 (River Caveiras) were defined as inflow locations in the model, along with a cross-section for outflow. Thus, the project hydrographs, obtained in the hydrological modeling, were inserted in their respective inflow junctions, while for the outflow, the normal depth method was adopted with an input value of 0.001 $m.m^{-1}$.

A compilation of data was done in the HEC-RAS model before exporting to the HEC-FDA model, so the following data were compiled for all simulated return periods: total discharge (m³/s), minimum cross-section elevation (m), and water surface elevation (m).

Economic analysis: HEC-FDA model

The economic damage caused by floods was estimated using HEC-FDA 1.4.3; this model was chosen because it provides the capability to perform an integrated hydrological and economic analysis for flood damage evaluation. The HEC-FDA model has the following five main analysis steps:

- definition of a study;
- study configuration;
- hydrological engineering data;
- economics data;
- evaluation and computation of EAD.

Therefore, it is noteworthy that two damage reaches were delineated in the study configuration, which are specific geographical areas within a floodplain, as well as their respective index locations, which enable the aggregation of stage-damage functions from individual structures.

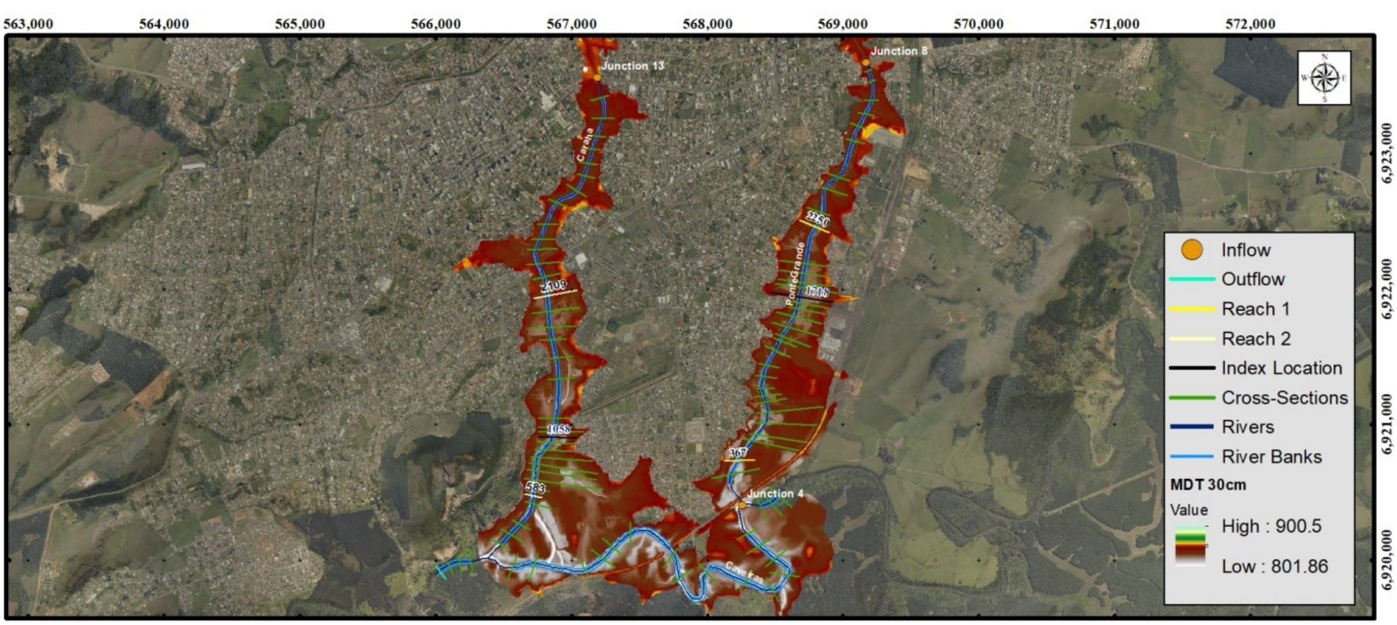

Figure 3 – HEC-RAS one-dimensional hydrodynamic modeling, geometric configuration.

Damage reaches are used in the definition and storage of consistent data for the plans and to aggregate structure damage information; these areas were delimited between a range of cross-sections for each river, as shown in Figure 3.

Thus, four plans were defined for this study: the plan without project conditions and three plans with the application of mitigation measures. It was decided to use the building elevation as a mitigation measure, considering three different heights. These heights were chosen according to the flood propagation in the Ponte Grande and Carahá River basins, obtained in the hydrodynamic modeling. In view of this, the water level at which flood propagation began to impact the buildings was verified, so that an average depth of 0.29 m was observed for these situations. In such a manner, it was determined to use the following heights for building elevations: 0.305 m (Plan 1), 0.610 m (Plan 2), and 1.000 m (Plan 3).

Moreover, it was decided to adopt two different periods for the study analysis years, with residential occupation scenarios in 2002 and 2022. These years were selected due to the availability of spatial data for the study area, such as orthophotos, building lots, and houses, which were retrieved from the Lages municipal government database.

In hydrological engineering, the data were imported from results obtained in the HEC-RAS, and the discharge-exceedance probability function with uncertainty was computed in the FDA using a graphical exceedance probability function, which is recommended when the discharge-exceedance probability function cannot be fitted by a Log Pearson Type III distribution (USACE, 2016). Likewise, the stage-discharge functions were computed in the FDA model; these functions were created from the eight water surface profiles imported into the HEC-FDA.

As for the economic data, only the residential damage category was considered in this study, while two structure occupancy types were defined: one-story without basements and two-story without basements. The depth-percent damage functions were inserted for each of the occupancy types; these functions were assigned for both economic damage to structure and content. Generic depth-damage relationships were adopted and provided in the Economic Guidance Memorandum 04-01 (USACE, 2003).

The attributes entered for the structure inventory were obtained from the Lages municipal government database, which contains shapefiles of building footprints and building lots. In addition, the 30 cm DTM was used to define the ground level value for each structure. In order to define the number of structures to be analyzed, it was decided to carry out a sampling based on the buildings in the study area, using the Cochran formula with a confidence level of 95%, a margin of error of 0.07%, and a population proportion of 50% variability, so that a previous sample of 196 structures was estimated. However, the small sample correction was applied to reduce the sample size, but it should be noted that the database was consolidated, considering only residential buildings located in the damage reaches, obtaining a sample of 158 structures. Furthermore, samples were spatially distributed using the "Create Random Points" tool in ArcGIS 10.5 (Figure 4).

The economic value of the sampled buildings was calculated using the evolutionary method (ABNT, 2001), since it can be used for property valuation. This method is based on the combination of two different methodologies.

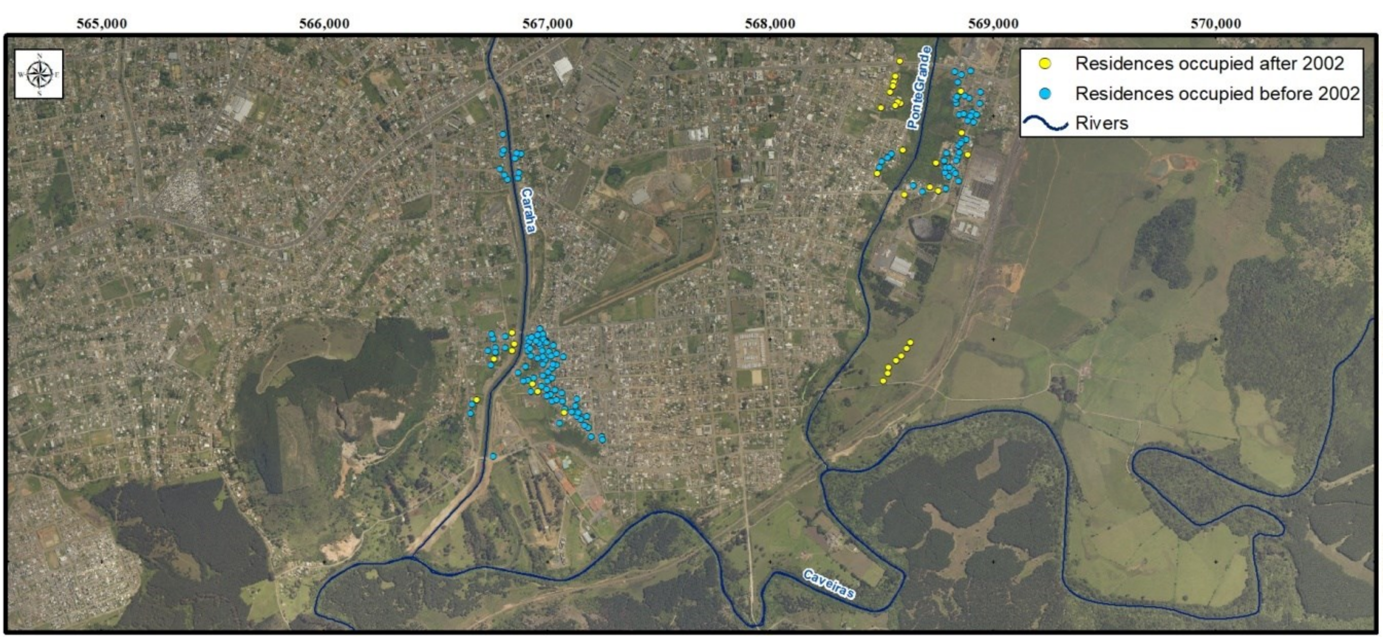

Figure 4 – Location of the sampled buildings.

Therefore, the direct comparative method and the cost quantification method were adopted in the valuation of properties, according to Equation 2.

$$VI = \frac{V_{CD} + V_{QB}}{2} \quad (2)$$

Where:
VI = total property value, R$;
V_{CD} = property value by the direct comparative method, R$;
V_{QB} = property value by the cost quantification method, R$.

To apply the direct comparative method, the behavior in the real estate market was evaluated with the objective of estimating the square meter value of the study area. Thus, the properties for sale in the study area were surveyed by local real estate agencies in April 2022, verifying 13 properties for sale, with an average cost per square meter of R$ 674.40. As for the cost quantification method, the unit cost of civil construction (CUB) was adopted for economic valuation, using the average residential CUB in the State of Santa Catarina in April 2022, equivalent to the cost of R$/m³ 2,461.35. In this way, for both methods, based on the estimation of the square meter price, it was possible to calculate the cost of each structure by multiplying the area by the square meter price.

The Ground Stage was determined according to the value for the elevation of the ground at the structure; in view of this, it was analyzed whether the sample had elevated houses through observations on the GeoLages website, which has photos of the properties in the municipality, and through the most recent images available on Google Street View. Therefore, if there was not an elevation of the building, the foundation height was equal to zero meters, while when the buildings were raised, the estimated height was entered in the foundation height box. It should be noted that when a given building was elevated, if the raised height was higher or very close to that of a given plan, this structure was not considered in that plan. Thus, the without project condition has 158 structures, while Plans 1, 2, and 3 have 100, 114, and 130 structures, respectively, totaling an inventory of 502 structures.

In addition, considering the "year in service" box, the FDA adopted the default year of 1900 for all structures that were built and occupied before 2002, while for structures that were built and occupied after 2002, a subsequent year was entered in this box. Thus, the FDA understands that this structure does not exist in 2002 and should not be included in the stage-damage computations for the base year (2002) but only for the most likely future year (2022).

The depth-damage functions with uncertainty were computed after entering all data into the structure inventory, and 500 Monte-Carlo simulations were performed to compute the stage-aggregated damage function. The computation of expected annual damage (EAD) was performed, using a 5% residual damage associated with the 0.01 exceedance probability event as the target stage to compute output parameters. This combination was chosen because it was considered a good target stage based on HEC's experience (USACE, 2016).

Results and Discussion

Hydrological modeling

The historical series of the annual maximum 5-day rainfall presented an average of 147.4 mm and a standard deviation of 52.7 mm; in view of this, it was verified that the time series fits the Gumbel distribution, since the calculated D (0.06) was below the critical D (0.19), at the a significance level of 1%, according to the Kolmogorov–Smirnov adherence test. Pereira et al. (2017) showed that Gumbel distribution fitted well to the maximum 1-day rainfall in the city of Ipameri/GO, according to the results of the following adherence tests: Kolmorov–Smirnov, Anderson–Darling, and Chi-Square, considering a significance level of 1%.

Table 1 shows the maximum 5-day rainfall calculated by the inverse Gumbel model (Equation 1), as well as the total discharge at each junction, considering all the return periods.

Table 1 – Annual maximum 5-day rainfall and total discharge by return periods.

Return Period (Years)	5-Day Rainfall (mm)	Total Discharge – Junction 13 (m^3/s)	Total Discharge – Junction 8 (m^3/s)	Total Discharge – Junction 4 (m^3/s)
3	160.77	45.2	26.9	437.9
5	185.31	52.2	33.3	573.3
10	216.15	63.8	40.9	827.7
15	233.54	69	45.2	964
25	255.11	75.2	50.2	1135
50	284.01	81.1	58	1307.4
100	312.70	89.1	65	1503.7
500	379.00	107.7	81.1	1932.3

Hydrodynamic modeling

Figure 5 shows the water levels modeled for all return periods, highlighting minimum and maximum values as well as the inundation boundary in the study area, verifying the advance over the sample buildings.

The comparison between modeled floods and observed floods (events of 2005, 2008, and 2011) shows that the HEC-RAS model performed better at representing spatial distribution of inundation boundary in the Ponte Grande and Caveiras River basins, while for the Carahá River basin, there was a better representation of inundation boundaries from 100- and 500-year return periods, as shown in Figure 6. According to Rafaeli Neto et al. (2015), it was found through simulations that HEC-RAS model can be used to satisfactorily reproduce the floodplain of Ponte Grande, Carahá, and Caveiras River basins.

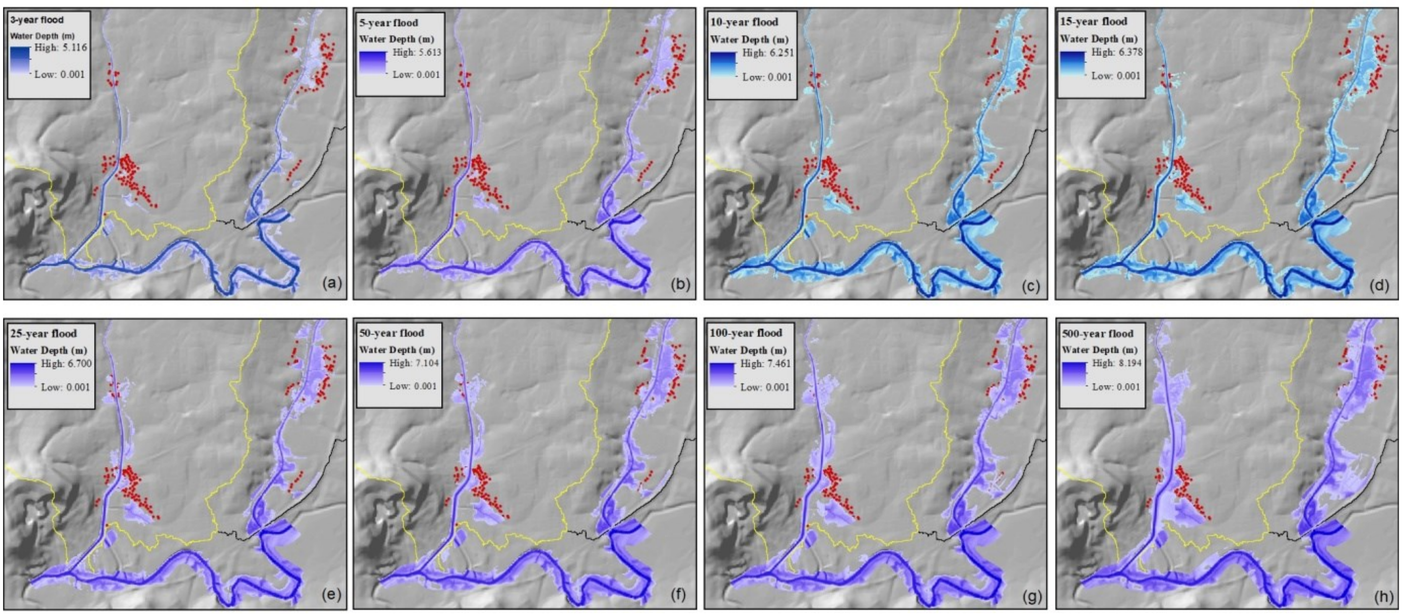

Figure 5 – Flooding mapping in the study area, for return periods of (A) 3, (B) 5, (C) 10, (D) 15, (E) 25, (F) 50, (G) 100, (H) 500 years.

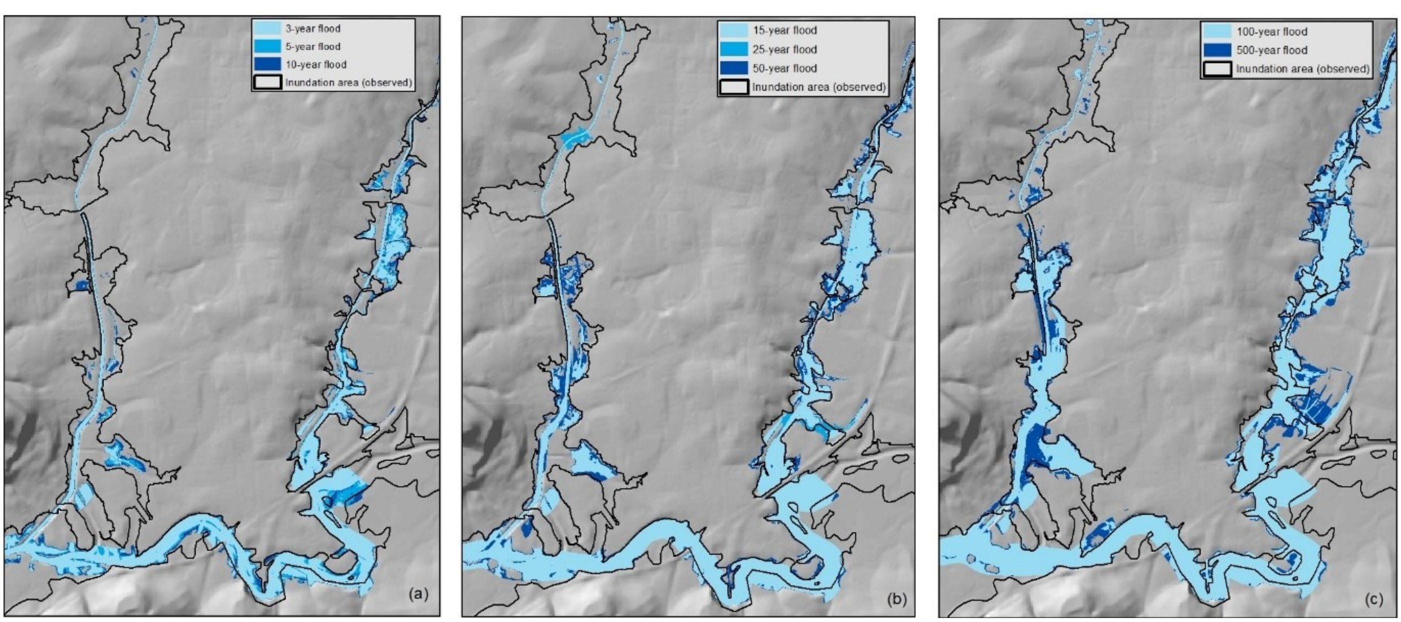

Figure 6 – Inundation boundary in HEC-RAS model and flood events observed in 2005, 2008, and 2011, for return periods of (A) 3, 5, and 10 years; (B) 15, 25, and 50 years; (C) 100 and 500 years.

Economic analysis: HEC-FDA model

Regarding economic valuation, Figure 7 shows the estimated property value of sampled buildings, which were obtained using the evolutionary method (Equation 2). To this extent, property values had an average price of R$ 531,454.36, with a maximum price of R$ 4,242,528.64 and a minimum price of R$ 151,252.90. It should be noted that factors such as quality of building construction, state of building conservation, and depreciation were not considered in this study.

Urban growth

Considering the urban growth, in the Ponte Grande River basin, a greater change in land use occurred, with a large expansion of buildings, while in the Carahá River basin, there was a more consolidated land use, with a smaller number of new buildings, between 2002 and 2022 (Figure 8). Among the 158 buildings sampled, 124 were occupied in 2002, while the new ones represented an increase of 27.41% in buildings. The Ponte Grande River basin presented the highest number of new buildings, with a total of 26 structures.

Table 2 shows the expected annual damage (EAD) computed using HEC-FDA, considering damage reaches established in the Ponte Grande and Carahá River basins, for the different urban growth scenarios.

Thus, there was an increase in expected annual damage of approximately 62.09%, between 2002 and 2022, with a significant increase of approximately 91.58% for the damage reach of the Ponte Grande River basin, demonstrating a high rate of urban growth in the flood-prone zones. It was noticed that all new buildings were located in the floodplain, so these structures aggregated the stage-damage functions for subsequent computation of the EAD, a fact that may explain the high increase in the expected annual damage. Therefore, it was verified that the urban growth towards flood-prone areas contributed to the increase in damage between the analysis years, enforcing the need for more strong control and inspection measures by public agencies to prevent economic losses and avoid the construction of new buildings in these areas.

According to Lemos et al. (2021), the effects of changes in land use and occupation in the Ponte Grande River basin are perceptible over time, with a percentage increase in the urban area class equal to 16.55, 34.92, and 41.71% for 1984, 2003, and 2019, respectively. Meanwhile, Mombach et al. (2018) verified that floods were considered the main problem of the Carahá River basin through interviews with local inhabitants.

In the study conducted by Tiepolo and Galligari (2021), the link between urban expansion and flood damage was analyzed in the Dosso Region of Niger between 2001 and 2020, verifying the expansion of human settlements to flood-prone areas due to factors such as population growth, a lack of awareness, and poverty. They identified a 14% increase in economic damage to human settlements located in urban areas caused by floods between 2004 and 2019.

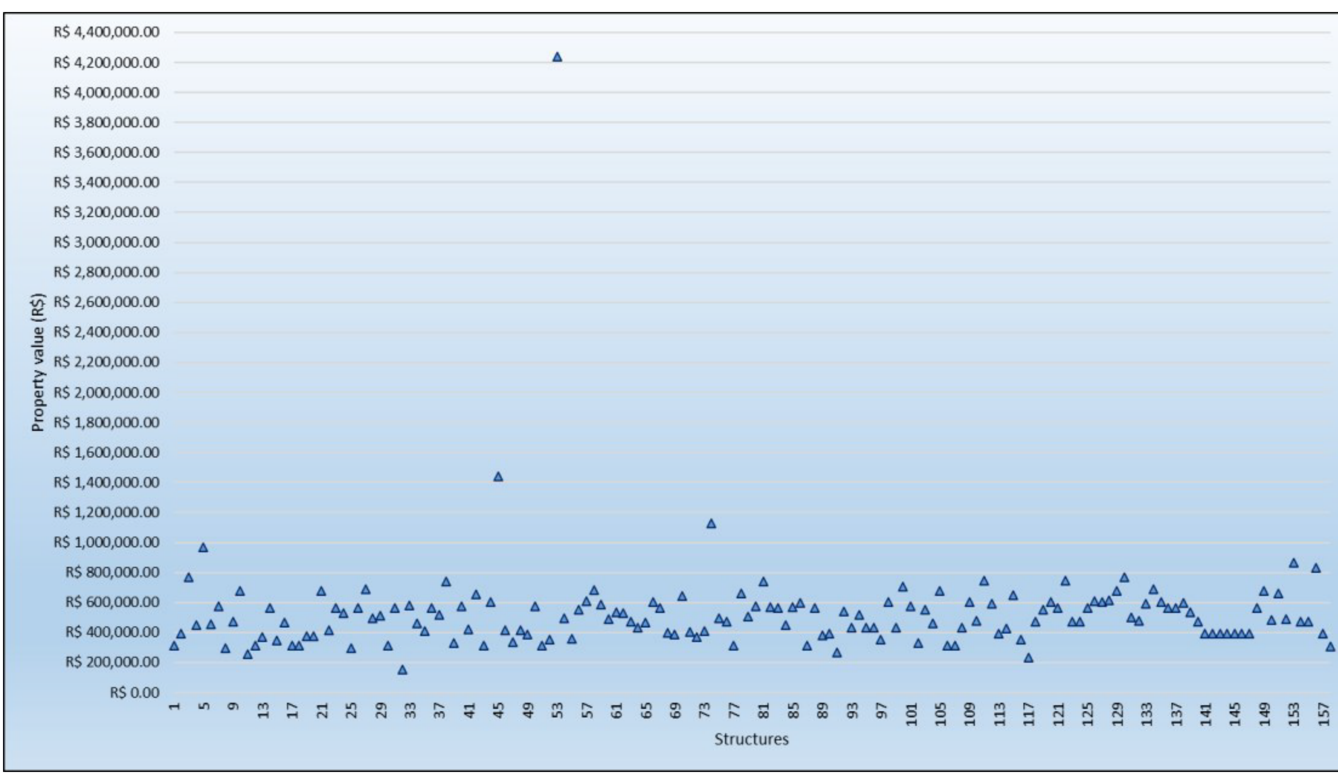

Figure 7 – Property values calculated using Equation 2*.
*Nominal values for April 2022.

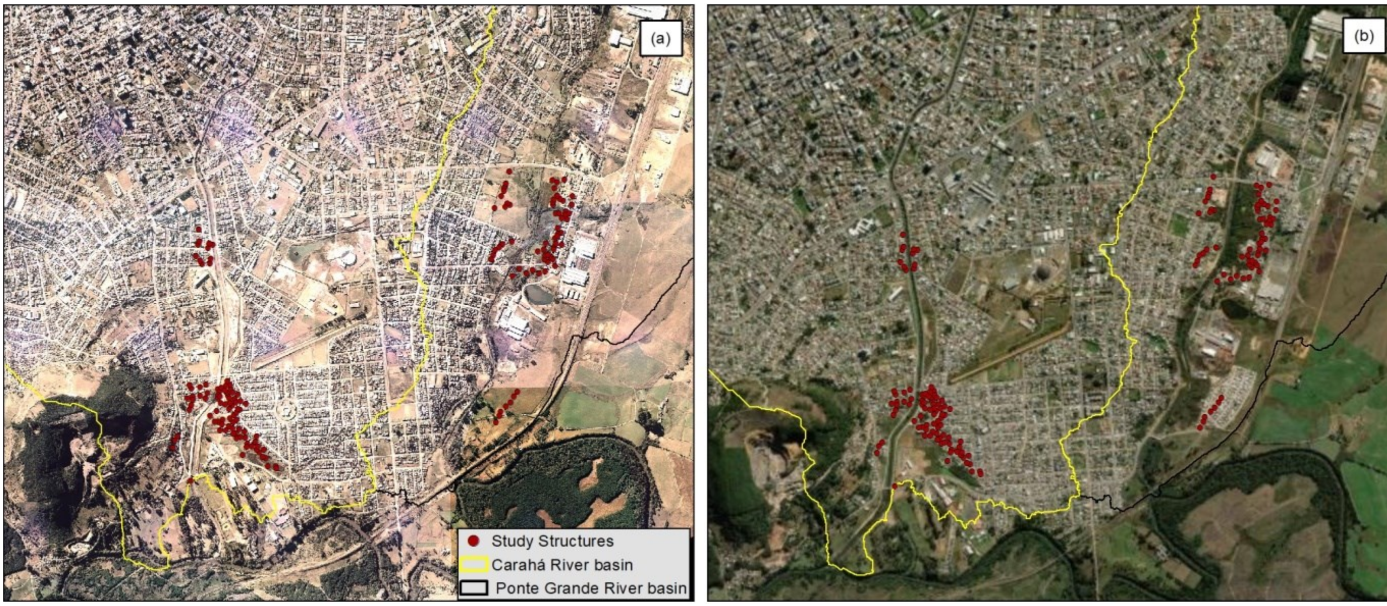

Figure 8 – Urban growth in the Carahá and Ponte Grande River basins, (A) 2002 and (B) 2022.

Table 2 – Expected annual damage (EAD), by analysis years*.

Damage Reach	EAD 2002 (R$)	EAD 2022 (R$)	Damage Increased (%)
Carahá River basin	120,869.47	153,091.92	+26.66
Ponte Grande River basin	145,221.20	278,216.72	+91.58
Total	266,090.67	431,308.64	+62.09

*Nominal values for April 2022.

Similarly, in a study performed in Lagos (Nigeria), urban expansion and land use changes were investigated for the period between 1990 and 2020, aiming to mitigate future flood damage in flood-prone areas. Their results suggested that urban growth areas are more vulnerable to flooding due to unsustainable growth (Koko et al., 2021). Furthermore, in similar studies developed in other countries, such as Chile and Canada, it was indicated that expansion of urban areas can increase exposure to risk in flood-prone areas (Rojas et al., 2017; Feng et al., 2021).

Thus, it is clear that the lack of suitable areas for new housing, along with factors such as urban growth, economic insufficiency, and vulnerable buildings, contribute to increasing flood damage in the study area.

Moreover, among the studies identified that used HEC-FDA for flood damage analysis, it is noted that none of them developed a study based on past land use, which can be compared with the results of this study (Cunha and Taveira-Pinto, 2011; Qi and Altinacar, 2011; Mohammadi et al., 2014; Lee et al., 2015; Mas, 2015; Difrancesco et al., 2020; Moosakhaani et al., 2020; Moosakhaani, et al., 2022). However, Van Dau et al. (2017) estimated flood damage due to potential climate change impacts in Vietnam, using the FDA model and considering current and future climate. Thus, flood damage was estimated at US$ 18.8 million in 2020 and US$ 20.7 million in 2080, resulting in an increase of approximately 10% in the expected annual damage, considering the RPC 8.5 scenario.

Flood mitigation measures

In preparing structures inventory, it was verified that 46% of the sampled buildings were elevated by using different techniques (e.g., stilt foundation, pile foundation, and slab on grade foundation). Figure 9A shows the buildings that were considered out of floodplain by HEC-FDA, as a result of the aggregate stage-damage computation, i.e., it represents the buildings, which the sum of ground stage and foundation height is greater than the water surface elevation; consequently, these structures are considered out of floodplain. In addition, the model computes total damage to structures for a given return period in order to make it possible to determine the beginning of flood damage by return period, considering all plans (Figures 9B, 9C, 9D, and 9E).

Thus, for the condition without project, a total of 23 buildings were considered out of floodplain, while for Plans 1, 2, and 3, there were a total of 17, 24, and 36 buildings, respectively. Regarding the beginning of flood damage, for the plan without project, damage began with a 5-year flood event, with two buildings damaged. While for most of the samples, the damage started between 10- and 25-year flood events in a total of 31 buildings. Moreover, it is possible to notice the beginning of damage in 44 properties between 50- and 500-year flood events.

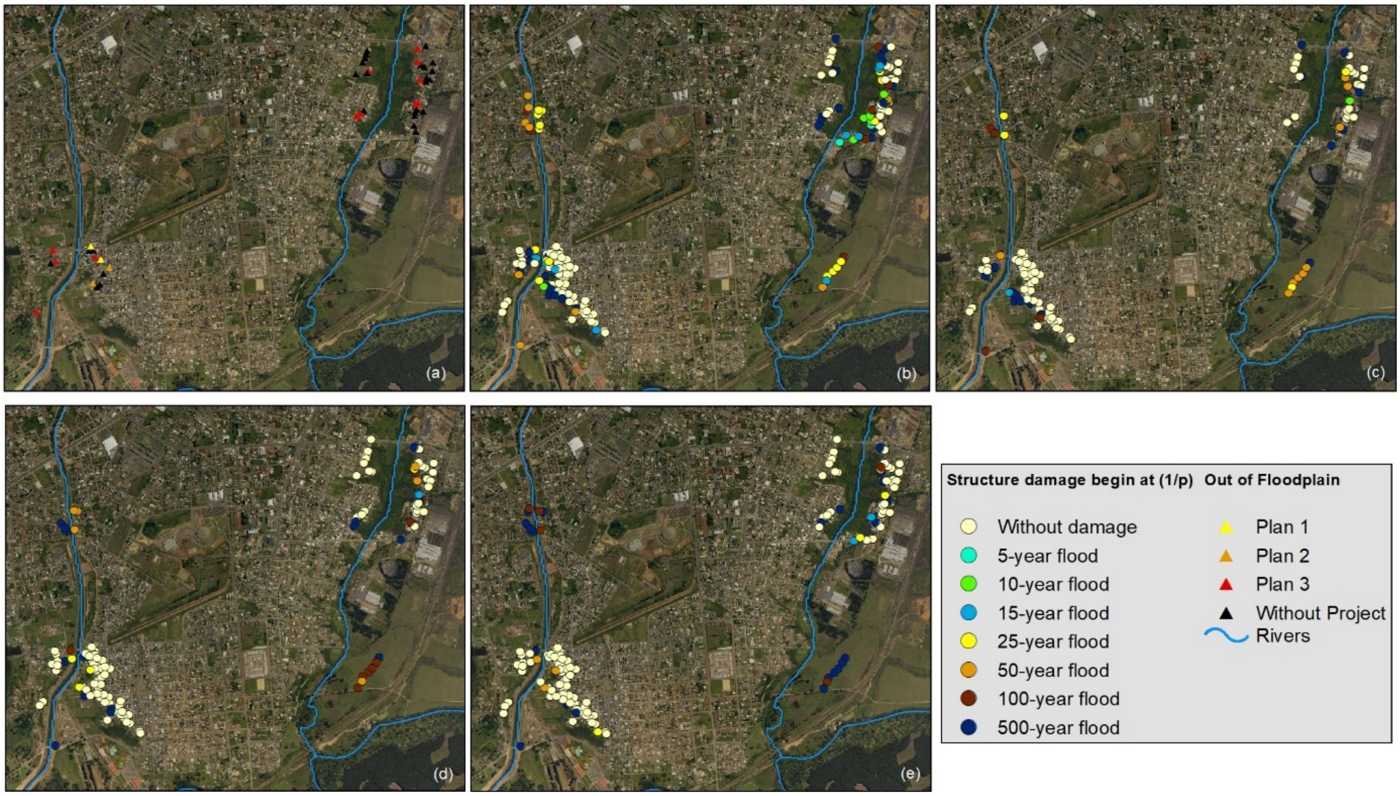

Figure 9 – Sampled buildings (A) out of floodplain; and return period, when damage begins, for scenarios (B) without project; (C) Plan 1; (D) Plan 2; (E) Plan 3.

In Plan 1, it was observed that damage started from the 10-year flood, with more buildings damaged from the 50-year flood events. In addition, there was an increase in buildings considered without damage for this plan compared to the plan without project conditions. Meanwhile, for Plans 2 and 3, damage started from the 15-year flood event, with more properties damaged from the 100-year return period. For these plans, the change in return period at the beginning of flood damage was equally noticeable as the elevation of the structure changed.

There was a considerable amount of buildings classified as being without damage in the Carahá River basin, considering all the evaluated plans, while the Ponte Grande River basin has a smaller amount of buildings without damage. This might have occurred due to the fact that the hydrodynamic modeling was better performed in the Ponte Grande River basin, resulting in a good representation of the inundation boundary for all return periods. However, in the Carahá River basin, the model had a good performance in representing inundation boundaries only for some return periods, in particular, the 100- and 500-year flood events (Figure 6).

Table 3 shows the expected annual damage computed by the HEC-FDA model, considering all plans.

Thus, after applying the mitigation measures, there was a reduction in the expected annual damage, with a decrease in flood damage of approximately 72.73, 78.74, and 83.10%, for Plans 1, 2, and 3, respectively, when compared with the results obtained in the plan without the project.

Table 3 – Expected annual damage (EAD), by Plan*.

Plan	EAD (R$)	Damage Reduced (R$)	Damage Reduced (%)
Without Project	431,308.64	0.00	0.00
Plan 1 (0.305 m)	117,599.90	313,708.74	72.73
Plan 2 (0.610 m)	91,692.29	339,616.36	78.74
Plan 3 (1.000 m)	72,890.26	358,418.39	83.10

*Nominal values for April 2022.

Therefore, results obtained in the economic modeling performed in the HEC-FDA showed that the building elevation measure contributed to the reduction of flood damage in the study area since this measure aimed to reduce its vulnerability to flooding by increasing the height of the plinth level from the ground.

Some studies that used HEC-FDA, for evaluating flood damage proposed plans with mitigation measures, such as dams, flood insurance, and different channel types. In these studies, benefits were found with the application of protective measures, such as a reduction in expected annual damage (Lee et al., 2015; Mas, 2015; Moosakhaani et al., 2020).

In a study carried out in the Bago region of Myanmar, it was observed that there were elevated houses, with average heights between 1.4 and 1.9 m, indicating that this type of house was mostly located in highly flood-prone areas, aiming to adapt to flooding. The results showed less flood damage in elevated houses in comparison with normal houses in two of the three townships under study. The authors highlighted that normal houses can more easily be damaged since this type of house is closer to the ground level, and, therefore, they conclude that flood damage can be significantly reduced by raising the level of the building foundation (Shrestha et al., 2021).

Meanwhile, in a study carried out in Los Angeles, building elevation measure was evaluated at 2, 4, 6, and 8 ft elevations. Their results claimed that elevation performed best in areas with high inundation depths, as well as that the investment costs for flood mitigation measures can be a barrier to their effective implementation (Ruig et al., 2019).

Another example of a study that evaluated building elevation measures to reduce flood damage was developed in North Carolina, considering elevation in combination with other mitigation measures, such as buyout, levees, and retention systems, in a total of 28 mitigation scenarios. The results indicated that the scenarios with the application of buyout and elevation can reduce flood damage by an amount of US$ 3.93 to US$ 49.56 million, which can be reduced even more if other mitigation measures are added. The authors conclude that a combination of home buyout policy and elevating buildings requires substantial funding, yet it provides significant protection for the buildings in flood-prone areas (Nofal and Lindt, 2021).

Therefore, it is evident that the building elevation measure can reduce flood damage, although studies are needed to evaluate the cost-benefit as well as whether it should be used in combination with other mitigation measures.

Conclusion

The flood damage analysis using HEC-FDA proved to be a good tool for formulating and evaluating flood damage reduction plans, which consider factors such as urbanization and application of mitigation measures to estimate flood damage associated with a maximum 5-day rainfall.

Thus, the results obtained in this study may be important for promoting public policies aimed at improving the quality of life. It is recommended to promote measures to prevent urban expansion in highly flood-prone areas, especially in the Ponte Grande River basin, which has shown greater urban expansion in the past 20 years.

In addition, it is suggested that the National Secretariat for Protection and Civil Defense along with other municipal government departments provide technical guidance to determine a minimum height of elevation at ground level, for buildings located in flood-prone areas, considering flooding mapping under different return periods. To encourage residents to adopt this adaptation measure, aiming to reduce and optimize resources, and mitigate damage to vulnerable buildings.

For future studies, it is recommended to evaluate more plans of mitigation measures, such as flood insurance and detention basins, among others, and to evaluate the cost-benefits of the proposed control measures.

Contribution of authors:

Primo, V. H. C.: Conceptualization; Literature review; Data curation; Formal analysis; Methodology; Investigation; Software; Writing. Rafaeli Neto, S. L.: Conceptualization; Project administration; Methodology; Resources.

References

Adnan, M.S.G.; Abdullah, A.Y.M.; Dewan, A.; Hall, J.W., 2020. The effects of changing land use and flood hazard on poverty in Coastal Bangladesh. Land Use Policy, v. 99, 104868. https://doi.org/10.1016/j.landusepol.2020.104868.

Ajjur, S.B.; Al-Ghamdi, S.G., 2022. Exploring urban growth–climate change–flood risk nexus in fast growing cities. Scientific Reports, v. 12, (1), 12265. https://doi.org/10.1038/s41598-022-16475-x.

Alvares, C.A.; Stape, J.L.; Sentelhas, P.C.; Gonçalves, J.L.M.; Sparovek, G., 2013. Köppen's climate classification map for Brazil. Meteorologische Zeitschrift, v. 22, (6), 711-728. https://doi.org/10.1127/0941-2948/2013/0507.

Alves, A.; Bianchini, C.D.; Malheiros, M.; Quartieri, M.T.; Salvador, P.F.; Eckhardt, R.R., 2013. Correlação entre o Nível Atingido e os Prejuízos Causados pelas Inundações do Rio Taquari no Município de Cruzeiro do Sul-RS. Destaques Acadêmicos, v. 5, (4), 217-229.

Arrighi, C.; Rossi, L.; Trasforini, E.; Rudari, R.; Ferraris, L.; Brugioni, M.; Franceschini, S.; Castelli, F., 2018. Quantification of Flood Risk Mitigation Benefits: A Building-Scale Damage Assessment through the RASOR Platform. Journal of Environmental Management, v. 207, 92-104. https://doi.org/10.1016/j.jenvman.2017.11.017.

Associação Brasileira de Normas Técnicas (ABNT), 2001. NBR 14653-1: Avaliação de bens Parte 1: Procedimentos gerais. Rio de Janeiro: ABNT, 11 p.

Avashia, V.; Garg, A., 2020. Implications of land use transitions and climate change on local flooding in urban areas: an assessment of 42 Indian cities. Land Use Policy, v. 95, 104571. https://doi.org/10.1016/j.landusepol.2020.104571.

Back, A.J.; Bonfante, F.M., 2021. Evaluation of generalized extreme value and gumbel distributions for estimating maximum daily rainfall. Brazilian Journal of Environmental Sciences, v. 56, (4), 654-664. https://doi.org/10.5327/Z217694781015.

Batista, L.; Ribeiro Neto, A.; Coutinho, R., 2020. Flood damage analysis: a Brazilian case study. Journal of Urban and Environmental Engineering, v. 14, (1), 150-160. https://doi.org/10.4090/juee.2020.v14n1.150160.

Carter, W.N., 2008. Disaster management: a disaster manager's handbook. Philipines: Asian Development Bank, 416 p.

Chen, Y.; Wang, Y.; Zhang, Y.; Luan, Q.; Chen, X., 2020a. Flash floods, land-use change, and risk dynamics in mountainous tourist areas: a case study of the Yesanpo Scenic Area, Beijing, China. International Journal of Disaster Risk Reduction, v. 50, 101873. https://doi.org/10.1016/j.ijdrr.2020.101873.

Chen, X.; Zhang, H.; Chen, W.; Huang, G., 2020b. Urbanization and climate change impacts on future flood risk in the Pearl River Delta under shared socioeconomic pathways. Science of the Total Environment, v. 762, 143144. https://doi.org/10.1016/j.scitotenv.2020.143144.

Companhia Ambiental do Estado de São Paulo (CETESB), 1986. Drenagem urbana: manual de projeto. 3. ed. São Paulo: CETESB, 464 p.

Corsi, A.C.; Azevedo, P.B.M.; Gramani, M.F., 2012. Damage valuation arising from flood in São Luiz do Paraitinga (SP). Revista de Gestão Ambiental e Sustentabilidade, v. 1, (2), 124-142. https://doi.org/10.5585/geas.v1i2.26.

Cunha, S.; Taveira-Pinto, F., 2011. Application of a Flood Risk Analysis Methodology to the River Banks of Peso Da Régua. In: Jornadas de Hidráulica, Recursos Hídricos e Ambiente. Anais, (2), 103-112.

DiFrancesco, K.; Gitelman, A.; Purkey, D., 2020. Bottom-up assessment of climate risk and the robustness of proposed flood management strategies in the American River, CA. Water, v. 12, (3), 907. https://doi.org/10.3390/w12030907.

Disse, M.; Johnson, T.G.; Leandro, J.; Hartmann, T., 2020. Exploring the relation between flood risk management and flood resilience. Water Security, v. 9, 100059. https://doi.org/10.1016/j.wasec.2020.100059.

Fang, Y.; Jawitz, J.W., 2019. The evolution of human population distance to water in the USA from 1790 to 2010. Nature Communications, v. 10, (1), 430. https://doi.org/10.1038/s41467-019-08366-z.

Farias Asmus, G.; Mello, A.Y.; Seixas, S.R.C.; Batistella, M., 2013. Análise sociodemográfica da distribuição espacial de ocorrências de diarréias agudas em áreas de risco de inundação, Caraguatatuba-SP. Revista Vitas, (6), 1-26.

Feng, B.; Zhang, Y.; Bourke, R., 2021. Urbanization impacts on flood risks based on urban growth data and coupled flood models. Natural Hazards, v. 106, 613-627. https://doi.org/10.1007/s11069-020-04480-0.

Fox-Rogers, L.; Devitt, C.; O'Neill, E.; Brereton, F.; Clinch, J.P., 2016. Is there really "nothing you can do"? Pathways to enhanced flood-risk preparedness. Journal of Hydrology, v. 543, (part b), 330-343. https://doi.org/10.1016/j.jhydrol.2016.10.009.

Gharari, S.; Hrachowitz, M.; Fenicia, F.; Savenije, H.H.G, 2011. Hydrological landscape classification: Investigating the performance of HAND based landscape classifications in a central European meso-scale catchment. Hydrology and Earth System Sciences, v. 15, (11), 3275-3291. https://doi.org/10.5194/hess-15-3275-2011.

Herrmann, M.L.P., 2014. Atlas de desastres naturais do estado de Santa Catarina: período de 1980 a 2010. Florianópolis: IHGSC, 219 p.

Jacob, A.C.P.; Rezende, O.M.; Sousa, M.M.; Ribeiro, L.B.F.; Oliveira, A.K.B.; Arrais, C.M.; Miguez, M.G, 2019. Use of detention basin for flood mitigation and urban requalification in Mesquita, Brazil. Water Science and Technology, v. 79, (11), 2135-2144. https://doi.org/10.2166/wst.2019.212.

Koko, A.F.; Yue, W.; Abubakar, G.A.; Hamed, R.; Alabsi, A.A.N., 2021. Analyzing urban growth and land cover change scenario in Lagos, Nigeria using multi-temporal remote sensing data and GIS to mitigate flooding. Geomatics, Natural Hazards And Risk, v. 12, (1), 631-652. https://doi.org/10.1080/19475705.2021.1887940.

Lamberty, D.; Mendonça, R.R., 2018. Setorização de áreas em alto e muito alto risco a movimentos de massa, enchentes e inundações. Lages: CPRM.

Lee, J.; Kim, D.; Kim, J.; Han, D.; Kim, H.S., 2015. Flood damage reduction plan using HEC-FDA Model. Journal of Wetlands Research, v. 17, (3), 237-244. https://doi.org/10.17663/jwr.2015.17.3.237.

Lehman, W., 2016. Lifecycle problems in consequence estimation. E3S Web of Conferences, v. 7, (10), 05010. https://doi.org/10.1051/e3sconf/20160705010.

Leite, M.L.; Steffens, S.R., 2018. Desastres naturais: aspectos psicológicos e transtorno de estresse pós-traumático oriundos de uma inundação. Anuário Pesquisa e Extensão Unoesc, v. 3, e19667. (Accessed Apr 18, 2023) at:. https://periodicos.unoesc.edu.br/apeusmo/article/view/19667.

Lemos, M.R.; Becegato, V.A.; Becegato, V.R.; Rosini, D.N., 2021. Estudo do desenvolvimento urbano da bacia hidrográfica do Rio Ponte Grande, em Lages/SC. Revista Ibero-Americana de Ciências Ambientais, v. 12, (1), 347-361. https://doi.org/10.6008/CBPC2179-6858.2021.001.0029.

Liu, J.; Wang, S.Y.; Li, D.M., 2014. The analysis of the impact of land-use changes on flood exposure of Wuhan in Yangtze River Basin, China. Water Resources Management, v. 28, (9), 2507-2522. https://doi.org/10.1007/s11269-014-0623-1.

Liz, M.S.M., 2018. Influência do Rio Caveiras nas Inundações dos Rios Carahá e Ponte Grande. Dissertação de Mestrado, Curso de Ciências Ambientais, Universidade do Estado de Santa Catarina, Lages. Retrieved 2020-11-28, from https://pergamumweb.udesc.br/biblioteca/index.php.

Machado, M.L.; Nascimento, N.; Baptista, M.; Gonçalves, M.; Silva, A.; Lima, J.C.; Dias, R.; Silva, A., 2005. Curvas de danos de profundidade versus profundidade de submersão: desenvolvimento de metodologia. Revista de Gestão de Água da América Latina, v. 2, (1), 35-52.

Marcelino, E.V.; Nunes, L.H.; Kobiyama, M., 2006. Mapeamento de risco de desastres naturais do estado de Santa Catarina. Caminhos de Geografia, v. 8, (17), 72-84. https://doi.org/10.14393/RCG71715273

Martínez-Gomariz, E.; Forero-Ortiz, E.; Guerrero-Hidalga, M.; Castán, S.; Gómez, M., 2020. Flood Depth–Damage Curves for Spanish Urban Areas. Sustainability, v. 12, (7), 2666. https://doi.org/10.3390/su12072666.

Mas, A.D.P., 2015. Study on flood management plan in Surabaya City. Journal of the Civil Engineering Forum, v. 1, (2), 51-56. https://doi.org/10.22146/jcef.23891.

Menne, B.; Murray, V., 2013. Floods in the WHO European Region: Health Effects and Their Prevention (Accessed Apr 18, 2023) at:. http://www.euro.who.int/pubrequest.

Mianabadi, A.; Derakhshan, H.; Davary, K.; Hasheminia, S.M.; Hrachowitz, M., 2020. A novel idea for groundwater resource management during megadrought events. Water Resources Management, v. 34, (5), 1743-1755. https://doi.org/10.1007/s11269-020-02525-4.

Minervino, A.C.; Duarte, E.C., 2016. Loss and damage affecting the public health sector and society resulting from flooding and flash floods in Brazil between 2010 and 2014 – based on data from National and Global

Information Systems. Ciência e Saúde Coletiva, v. 21, (3), 685-694. https://doi.org/10.1590/1413-81232015213.19922015.

Mohammadi, S.A.; Nazariha, M.; Mehrdadi, N., 2014. Flood damage estimate (quantity), using HEC-FDA model case study: the Neka River. Procedia Engineering, v. 70, 1173-1182. https://doi.org/10.1016/j.proeng.2014.02.130.

Mombach, G.N.N.; Wahrlich, J.; Clauberg, A.P.C.; Beninca, L.S.; Simioni, F.J., 2018. Valoração ambiental de um rio urbano: uma aplicação do método de valoração contingente em Lages, Santa Catarina. Brazilian Journal of Environmental Sciences, (47), 116-129. https://doi.org/10.5327/Z2176-947820180272.

Moosakhaani, M.; Salimi, L.; Sadatipour, M.T., 2020. Developing flood economic loss evaluation model in residential and commercial sectors case study: Darband and Golab Darreh Rivers, v. 4, (3), 215-229. https://doi.org/10.22097/eeer.2020.212510.1127.

Moosakhaani, M.; Salimi, L.; Sadatipour, M.T.; Niksokhan, M.H., 2022. Game theoretic approach for flood risk management considering a financial model. Environmental Engineering Research, v. 27, (6), 1-11. https://doi.org/10.4491/eer.2021.368.

Müller, M.F.; Levy, M.C., 2019. Complementary vantage points: integrating hydrology and economics for sociohydrologic knowledge generation. Water Resources Research, v. 55, (4), 2549-2571. https://doi.org/10.1029/2019WR024786.

Nithila Devi, N.; Sridharan, B.; Kuiry, S.N., 2019. Impact of urban sprawl on future flooding in Chennai City, India. Journal of Hydrology, v. 574, 486-496. https://doi.org/10.1016/j.jhydrol.2019.04.041.

Nofal, O.M.; Lindt, J.W.V., 2021. High-resolution flood risk approach to quantify the impact of policy change on flood losses at community-level. International Journal of Disaster Risk Reduction, v. 62, 102429. https://doi.org/10.1016/j.ijdrr.2021.102429.

Ozonur, D.; Pobocikova, I.; Souza, A., 2021. Statistical analysis of monthly rainfall in Central West Brazil using probability distributions. Modeling Earth Systems and Environment, v. 7, 1979-1989. https://doi.org/10.1007/s40808-020-00954-z.

Paterson, D.L.; Wright, H.; Harris, P.N.A., 2018. Health risks of flood disasters. Clinical Infectious Diseases., v. 67, (9), 1450-1454. https://doi.org/10.1093/cid/ciy227.

Pereira, D.C.; Duarte, L.R.; Sarmento, A.P., 2017. Determinação da curva de intensidade, duração e frequência do município de Ipameri – Goiás. Civil Engineering e-Journal. v. 13, (2), 233-246. https://doi.org/10.5216/reec.v13i2.43330.

Peters, D.L.; Caissie, D.; Monk, W.A.; Rood, S.B.; St-hilaire, A., 2015. An ecological perspective on floods in Canada. Canadian Water Resources Journal, v. 41, (1-2), 288-306. https://doi.org/10.1080/07011784.2015.1070694.

Portela, F.C.; Kobiyama, M.; Goerl, R.F., 2020. Panorama brasileiro da relação entre leptospirose e inundações. Revista Geosul, v. 35, (75), 711-734. https://doi.org/10.5007/1982-5153.2020v35n75p711.

Pour, S.H.; Wahab, A.K.A.; Shahid, S.; Asaduzzaman, M.; Dewan, A., 2020. Low impact development techniques to mitigate the impacts of climate-change-induced urban floods: current trends, issues and challenges. Sustainable Cities and Society, v. 62, 102373. https://doi.org/10.1016/j.scs.2020.102373.

Qi, H.; Altinakar, M.S., 2011. A GIS-based decision support system for integrated flood management under uncertainty with two dimensional numerical simulations. Environmental Modelling and Software, v. 26, (6), 817-821. https://doi.org/10.1016/j.envsoft.2010.11.006.

Rafaeli Neto, S.L., 2019a. Aerolevantamento da planície topográfica de inundações. Lages; Universidade do Estado de Santa Catarina, 205 p.

Rafaeli Neto, S.L., 2019b. Relatório Técnico - Parte 1: Modelagem Hidrológica. Lages: Universidade do Estado de Santa Catarina, 67 p.

Rafaeli Neto, S.L.; Ricardo, G.S.; Mendes, C.F.; Cunha, M.B., 2015. Modelagem hidráulica dos eventos de inundações em Lages (SC). In: Congresso Brasileiro de Gestão Ambiental, 6, 1-7. Anais. Porto Alegre.

Reichstein, M.; Riede, F.; Frank, D., 2021. More floods, fires and cyclones - plan for domino effects on sustainability goals. Nature, v. 592, (7854), 347-349. https://doi.org/10.1038/d41586-021-00927-x.

Robinson, P.J.; Botzen, W.J.W., 2020. Flood insurance demand and probability weighting: the influences of regret, worry, locus of control and the threshold of concern heuristic. Water Resources and Economics, v. 30, 100144. https://doi.org/10.1016/j.wre.2019.100144.

Rojas, O.; Mardones, M.; Rojas, C.; Martínez, C.; Flores, L., 2017. Urban growth and flood disasters in the coastal river basin of South-Central Chile (1943–2011). Sustainability, v. 9, (2), 195. https://doi.org/10.3390/su9020195.

Ruig, L.T.; Haer, T.; Moel, H.; Botzen, W.J.W.; Aerts, J.C.J.H., 2019. A micro-scale cost-benefit analysis of building-level flood risk adaptation measures in Los Angeles. Water Resources and Economics, v. 32, 100147. https://doi.org/10.1016/j.wre.2019.100147.

Shokri, A.; Sabzevari, S.; Hashemi, S.A., 2020. Impacts of flood on health of Iranian population: infectious diseases with an emphasis on parasitic infections. Parasite Epidemiology and Control, v. 9, e00144. https://doi.org/10.1016/j.parepi.2020.e00144.

Shrestha, B.B.; Kawasaki, A.; Zin, W.W., 2021. Development of flood damage assessment method for residential areas considering various house types for Bago Region of Myanmar. International Journal of Disaster Risk Reduction, v. 66, 102602. https://doi.org/10.1016/j.ijdrr.2021.102602.

Silva, E.D., 2015. Avaliação econômica de danos causados por inundações: aplicação ao município de Montenegro-RS. In: Simpósio Brasileiro de Recursos Hidrícos, 23, 1-10. Anais.

Singh, V.P., 2018. Hydrologic modeling: progress and future directions. Geoscience Letters, v. 5. https://doi.org/10.1186/s40562-018-0113-z.

Sörensen, J.; Persson, A.; Sternudd, C.; Aspegren, H.; Nilsson, J.; Nordström, J.; Jönsson, K.; Mottaghi, M.; Becker, P.; Pilesjö, P.; Larsson, R.; Berndtsson, R.; Mobini, S., 2016. Re-thinking urban flood management-time for a regime shift. Water, v. 8, (8), 332. https://doi.org/10.3390/w8080332.

Stakhiv, E.Z., 2021. The centrality of engineering codes and risk-based design standards in climate adaptation strategies. Water Policy, v. 23, (Suppl. 1), 106-127. https://doi.org/10.2166/wp.2021.345.

Sukhwani, V.; Gyamfi, B.A.; Zhang, R.; Alhinai, A.M.; Shaw, R., 2019. Understanding the barriers restraining effective operation of flood early. International Journal of Disaster Risk Management, v. 1, (2), 1-17. https://doi.org/10.18485/ijdrm.2019.1.2.1.

Svetlana, D.; Radovan, D.; Ján, D., 2015. The economic impact of floods and their importance in different regions of the world with emphasis on Europe. Procedia Economics and Finance, v. 34, 649-655. https://doi.org/10.1016/s2212-5671(15)01681-0.

Talbot, C.J.; Bennett, E.M.; Cassell, K.; Hanes, D.M.; Minor, E.C.; Paerl, H.; Raymond, P.A.; Vargas, R.; Vidon, P.G.; Wollheim, W., 2018. The impact of flooding on aquatic ecosystem services. Biogeochemistry, v. 141, 439-461. https://doi.org/10.1007/s10533-018-0449-7.

Tiepolo, M.; Galligari, A., 2021. Land use policy urban expansion-flood damage nexus: evidence from the Dosso. Land Use Policy, v. 108, 105547. https://doi.org/10.1016/j.landusepol.2021.105547.

Tramblay, Y.; Mimeau, L.; Neppel, L.; Vinet, F.; Sauquet, E., 2019. Detection and Attribution of flood trends in Mediterranean basins. Hydrology And Earth System Sciences, v. 23, (11), 4419-4431. https://doi.org/10.5194/hess-23-4419-2019.

United States Army Corps of Engineers (USACE), 2003. EGM 04-01: Generic depth-damage relationships for residential structures with basements. CECW-PG, 17 p.

United States Army Corps of Engineers (USACE), 2016. HEC-FDA: Flood Damage Reduction Analysis - User's Manual. CECW-PG, Davis-CA, 392 p.

Van Dau, Q.; Kuntiyawichai, K.; Plermkamon, V., 2017. Quantification of flood damage under potential climate change impacts in Central Vietnam. Irrigation and Drainage, v. 66, (5), 842-853. https://doi.org/10.1002/ird.2160.

Viglione, A.; Di Baldassarre, G.; Brandimarte, L.; Kuil, L.; Carr, G.; Salinas, J.L.; Scolobig, A.; Blöschl, G., 2014. Insights from socio-hydrology modelling on dealing with flood risk - roles of collective memory, risk-taking attitude and trust. Journal of Hydrology, v. 518, (part A), 71-82. https://doi.org/10.1016/j.jhydrol.2014.01.018.

Walker-Springett, K.; Butler, C.; Adger, W.N., 2017. Wellbeing in the aftermath of floods. Health & Place, v. 43, 66-74. https://doi.org/10.1016/j.healthplace.2016.11.005.

World Meteorological Organization (WMO), 2020. WMO Statement on the State of the Global Climate in 2019. Switzerland: WMO, 44 p.