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FLOOD DAMAGE ANALYSIS: A BRAZILIAN CASE STUDY

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Abstract: Worldwide floods stand out as some of the most recurrent and potentially destructive phenomena. Risk reduction management must consider dynamics involving structural risk elements called indicators. The objective of this paper was to simulate an extreme flood event in the Pirapama river basin, Pernambuco State, Northeastern Brazil, and to analyze some risk components, focusing on the application of damage models in the Brazilian scenario. The hydrological model HEC-HMS (Hydrological Modeling System) was calibrated in order to generate streamflow for ungauged areas. The model was able to identify the highest flood peaks and the statistic criteria were consistent with daily simulation. The parameters calibrated for the HEC-HMS model allowed us to generate results used as input flow in HEC-RAS (River Analysis System). The hydrodynamic model HEC-RAS performed steady flow simulations for the peak flow that occurred in 2010. Remote sensing products with high spatial resolution were used successfully to identify and calculate dwellings surface in the municipality of Cabo de Santo Agostinho. Flood damage estimates were performed through transferred depth-damage curves which is a methodological option verified in the literature. The two main Brazilian studies on this field were selected. The difference between the functions is just over BRL$72 per square meter, and around BRL$85 million for the entire area in the 2010 event (BRL$234.58 and BRL$149.11 million). Those values were adjusted for inflation until 2019. A combination of different methodologies is a way to try to overcome the lack of information, but much remains to be done to validate damage analysis, especially in what concerns to prevention.

Keywords: Risk analysis; Flood hazard; Hydrological modelling.

INTRODUCTION

The increase in frequency and magnitude of extreme natural events is a reality even if there is no agreed opinion about its origins – anthropogenic interference or environmental tendency. Floods stand out for their prominence among hazardous phenomena. High casualties and economic loss rates are some of the consequences (Guha-Sapir *et al*., 2016).

The combination of extreme events and the increasing population clusters establish a situation of risk. Such a complex concept needs to be addressed by all stakeholders, especially decision-makers. Thus, flood risk assessments along with damage analysis are some of the most important tools for risk management and consequently disaster risk reduction (Devi *et al*., 2019; Hasanzadeh Nafari *et al*., 2016).

The need for comprehension, assessment, and prediction of floods and its impacts led to the development of inundation modeling. Flood model applications require attention to scales, precision, and computational efficiency. Even though this is a much-explored field of research, many challenges must still be faced in modeling complexity and uncertainty (Teng *et al*., 2017).

In turn, losses can be categorized in direct and indirect damages. Direct damage is associated with the physical contact between floodwater and the affected item. And indirect damage exists when there is no contact with the water (e.g., business interruption, traffic, and transportation disruption). Both categories can also be classified as tangible or intangible, determined by the monetary value that may or may not be associated with the loss (Eckhardt *et al*., 2019; Garrote *et al*., 2016).

Direct monetary damages applied to dwellings are usually the most studied type of loss. Such losses are commonly estimated by depth-damage functions and their curves. This latter can be developed through an empirical approach or a synthetic methodology. The first one is based on historical data collected from past events, while the second tries to estimate the expected losses in case of a certain flood. The synthetic method is also known as "what-if" analyses (Thieken *et al*., 2005; Milograna, 2009).

Depth-damage curves can also be divided based on loss quantification processes. Absolute damages consider the complete monetary cost of affected assets, and relative damages focus on a depreciation percentage of values (i.e., replacement, and repair costs). The scarcity of flood damage data leads to the adaptation and transposition of loss models from one region to another. On these occasions, all the categories described previously must be considered, and adaptations must be performed (Almeida & Eleutério, 2019; Hasanzadeh Nafari *et al*., 2016; Cammerer *et al*., 2013).

In terms of theory, there is a broad and rich framework about disasters. One of the most accepted concepts were developed by the Intergovernmental Panel on Climate Change (IPCC), in which risk is produced by the interaction of hazard, exposure, and vulnerability (Álvarez *et al*., 2019, Birkmann *et al*., 2013).

Flood risk assessment is the basis for a solid development of policies regarding land use planning, disaster prevention, and investment prioritization. Thus, considering the probability of a flood and its potential consequences, it is clear the relevance of exposure identification, hazard simulation and damage estimation on flood risk studies (Obennaceur *et al*., 2019; Tîncu *et al*., 2019; Ribeiro Neto *et al*., 2016).

The objective of this paper is to simulate one of the largest flood events that have ever occurred in the Pirapama river basin, Pernambuco State, Northeastern Brazil, and to analyze some risk components, focusing on the application of damage models in the Brazilian scenario. We tested a combination of tools, e.g. hydrological models and synthetic curves, to get the risk components.

METHODOLOGY

Study area

The Pirapama river has almost 75 km of extension; its basin covers an area of approximately 630 km² in Pernambuco state, Brazil (**Fig. 1**). Economically important in terms of water supply, irrigation, and energy generation, this area is also ecologically relevant for the diversity of the ecosystems present in the region, including ten ecological reserves.

Pirapama river basin is characterized by a humid tropical climate with annual precipitation ranging from 1300 mm to 2300 mm, in the west-east direction. Vegetation follows the changes of the rainfall regime going from a rainforest in the eastern end to a dry forest in the western portion of the basin. The terrain is mostly in crystalline geological structures with a predominance of hills and altitudes above 60 m. Besides, the most commonly found soil types are argisols and latosols, distinguished by their strong acidity and low fertility, as well as their high susceptibility to erosion.

There are two main dams in the basin. The Gurjaú River Dam (an important tributary) was built in 1918 with a catchment area of 144 km² and a storage capacity of 3,200,000 m³. The main objective of this structure is to raise the water level to facilitate the withdrawal for the treatment plant. It does not work as an accumulation reservoir. The other reservoir is called Pirapama (storage capacity of 61 million cubic meters) and its dam is located in the municipality of Cabo de Santo Agostinho. It supplies water for the Metropolitan Region of Recife meeting approximately 3 million people.

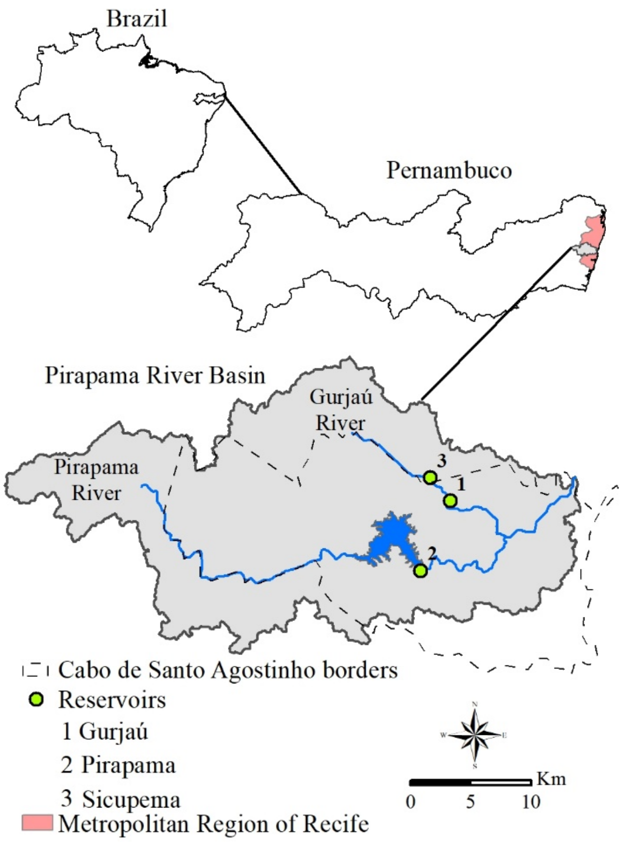

Fig. 1 Study area - Location map.

This study focuses on the municipality of Cabo de Santo Agostinho, which is located 33 km from the state capital, Recife. The city is part of the Metropolitan Region of Recife and has an estimated population of 198,383 inhabitants (IBGE, 2014).

Dataset used

The Digital Terrain Model (DTM) is a three-dimensional representation of the terrain and ground elevation. Three DTM were used in the research. The DTM from the Shuttle Radar Topography Mission (DTM_{SRTM}), with a spatial resolution of 30 meters, was used for the watershed delineation and sub-basins discretization for representation in HEC-HMS (Hydrological Modeling System) model. The second DTM was obtained from a survey accomplished with radar sensor onboard aircraft (DTM_{radar}) for geometry representation in HEC-RAS (River Analysis System). The DTM_{radar} has a resolution of 1,5 meters. The third product refers to the high-definition digital laser mapping (Light Detection and Ranging, LiDAR), obtained from the Pernambuco Three-Dimensional (PE3D) project performed by the state government. Besides the Digital Terrain Model (DTM_{LiDAR}), the PE3D project makes also available the Digital Elevation Model (DEM_{LiDAR}), which is a computational representation of the surface (topography), that is, the elevation of treetops, bridges, roofs, among others. Both DTM_{LiDAR} and DEM_{LiDAR} have a spatial resolution of 1 meter and they were used to identify dwellings in Cabo de Santo Agostinho. In the dwelling identification processes, we also used RapidEye satellite images, with a spatial resolution of 5 meters, corresponding to a mosaic of images of the period 2014-2015.

Daily hydrological data were obtained from the Brazilian National Water Agency (ANA) and the Water and Climate Agency of Pernambuco (APAC) hydrometeorological networks (**Fig. 2**). Two stations in the Pirapama River basin provided observed streamflow data for HEC-HMS calibration: 39192000 (drainage area of 90,35 km^2) and 39195000 (drainage area of 104,81 km^2). Bathymetries obtained from ANA's streamgauges (39200000 and 39220000) were inserted into the cross-sections and interpolated to represent the geometry of each channel in the HEC-RAS model.

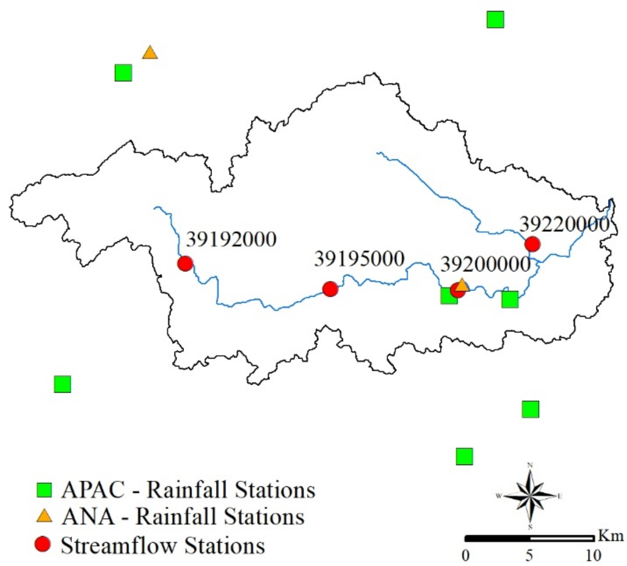

Fig. 2 Rainfall and streamflow stations.

Hydrological-hydrodynamic modelling

The research used the HEC-HMS model to simulate the rainfall-runoff processes throughout the Pirapama river basin, and the HEC-RAS model to simulate the flood routing along the main urban area of the municipality of Cabo de Santo Agostinho. Both models were developed by the US Army Corps of Engineers Institute for Water Resources-Hydrologic Engineering Center (CEIWR-HEC).

To represent the components necessary for flow calculation, the HEC-HMS separates its mathematical models into four broad categories, each with different methods available for calculation. The methods used in this study are listed below in their respective classes:

a) Loss model: it calculates the retained water that will not directly contribute to runoff. The method used was Soil Moisture Accounting (SMA), which simulates the movement and storage of water on the surface, vegetation, and underground;

b) Transform model: it evaluates the precipitation excess that will become runoff. The method chosen was the Soil Conservation Service (SCS) Unit Hydrograph, which needs the parameter Lag Time. Physical attributes were used to calculate the concentration-time (Kirpich equation) and, consequently, the Lag Time in each sub-basin, **Eqs. (1)** and **(2)**:

$$t_c = 57\left(\frac{L^3}{H}\right)^{0,385} \tag{1}$$

where t_c is the concentration time in minutes, L is the river length in km, and H is the difference in height between the most remote point of the river and the outlet in meters.

$$t_p = t_c \text{ x } 0,6 \tag{2}$$

where t_p is peak time, which represents the parameter Lag time;

c) Baseflow model: it determines contributions of the underground flow. The method chosen was the Linear Reservoir;

d) Routing flood model: it performs flow propagation in the main channels of the system. Muskingum-Cunge was the method used; its parameters are physical and were obtained from the channel characteristics acquired with Geographic Information System.

The assessment focused on the rainy season, with the time series divided into two periods, one from April 2000 to April 2009 (for calibration), and another from April 2009 to April 2014 (for validation). The hydrological model was initially calibrated and validated only for the drainage area of the stream gauges 39192000 and 39185000 (see **Fig. 2**). Three criteria were used in order to evaluate the model performance: Nash-Sutcliffe Efficiency (NSE), PBIAS (percentage bias) and coefficient of determination (R^2). The parameters calibrated were used for the simulation of the entire Pirapama river basin.

The hydrodynamic model HEC-RAS was applied to the areas of interest, i.e. the residential zones of Cabo de Santo Agostinho, where the population is more concentrated. The idea was to reproduce the inundation of the 2010 event, one of the most severe floods already registered in the region. Due to the short streamflow time series from the streamgauges, it was not possible to statistically determine the return period (Tr) of this event. Indirectly, it is possible to estimate the recurrence of the event taking as reference the values found in neighboring basins, like 160 years in the Ipojuca river basin, and 200 years in the Una river basin (Coutinho, 2014; Ribeiro Neto *et al*., 2015). We performed a steady flow simulation in the HEC-RAS using as input the discharge calculated by the HEC-HMS model. The HEC-RAS can calculate the discharge and water depth along the channel.

Hazard indicator and damage estimate

The concepts adopted in the present study will follow definitions established by the IPCC. Risk is the probability of a disaster, while disasters are a combination of three main elements: hazard, exposure, and vulnerability (Lavell *et al*., 2012).

Hazard is the potentially damaging natural phenomenon (Rana & Routray, 2018). Exposure is in the geographical location of the elements that can be affected by the extreme natural phenomenon (Lavell *et al*., 2012). And vulnerability is related to the intrinsic characteristics of the exposed elements. In the case of cities, vulnerability relates to aspects such as demography, population density, land use, preparedness, and response, among others (Balica & Wright, 2010; Solín *et al*., 2018; Batista, 2015).

Impact parameters, also known as hazard indicators, are usually obtained from hydraulic modeling of events with pre-established return periods. The parameters are normally applied in flood risk mapping and cost-benefit analysis. The indicators can be water depth, velocity, and combinations of both as energy ($d + v^2/2g$), where d is the water depth and v the velocity. Kreibich *et al.* (2009) highlight the degree of correlations obtained between the indicators and the possible damage generated by an extreme flood event. Water depth and energy have the greatest correlations for structural damage in residential buildings. Energy has a potential portion (water depth), with greater influence, and a kinetic portion (velocity). The energy indicator is suggested as an appropriate impact parameter for structural damage predictions, based on observed post-event consequences.

Water depth was the main hazard indicator studied here. Water depth is an independent variable widely applied in damage estimate functions for tangible direct cost quantifications. Its influence is also associated with loss of movable property, interruption of economic activities, and impairment of the structure of buildings due to lateral pressure exerted on walls, for instance. This very useful indicator can be easily measured from the marks on building walls after events (Kreibich *et al*., 2009; Bouwer *et al*., 2009; Kelman & Spence, 2004; Yang *et al*., 2015).

Internationally accepted and scientifically recognized, loss functions, or depth-damage curves, are the primary tools in damage analysis. However, there is a permanent lack of data, and consequently, the inability to validate models, and damage estimates. For this reason, transferring functions is a methodological option widespread in the literature. In this latter case, it is necessary to be careful in choosing the curves so that one can better approach local characteristics (Molinari *et al*., 2019; Cammerer *et al*., 2013). For the present research, the two Brazilian studies in this field were selected for application in Northeastern Brazil.

Machado *et al*. (2005) established a loss function for the municipality of Itajubá, Minas Gerais State, southeastern Brazil. The data obtained refers to the flood of the year 2000, in which more than 70% of the urban area was affected. The damage to buildings and their contents were estimated through an empirical survey made through questionnaires and census data of the population, and another step based on the norm NBR 12721:2006 - Evaluation of construction costs for real estate development and other provisions for buildings.

This norm presents standard designs for different building types, which are defined by the number of floors, the number of dependencies per unit, different finishing work in the construction, the materials used and administrative expenses with labor and equipment, representing the partial cost of the construction work of a certain standard construction. Besides, the norm sets standard types of single-family homes: high, normal, popular and low.

The unit cost is defined by BRL$/m² (where BRL is Brazilian Real). The value is partial, primarily because several components of the final price are not included, and because it refers to a standard reference project. That is, this indicator enables a quantitative estimate based on a proportional value of a particular building type, and not on its actual price. Such a procedure has proven its reliability since buildings of the same type have similar depth-damage curves, regardless of their current value (Merz *et al*., 2007).

Following this idea, Machado *et al*. (2005) developed depth-damage functions for a residential area classified into different socioeconomic classes. These classes are defined in descending order of purchasing power by the Critério Brasil (Brazil Criterion in Portuguese) (ABEP, 2018), which is a scoring system that defines social classes based on the number of household items and the education level of the head of the family. The equation used in this research refers to classes C and D, and is represented by (Equation 3):

$$D = 68{,}6 + 21{,}6 \ln(d) \tag{3}$$

where D is the estimated damage per unit area (BRL$/m²) and d is flood depth in meters.

The other study was developed by Salgado (1995) and updated by Nagem (2008). Curves were resultant of a synthetic analysis, with damage estimated through a standard residential typology project (Equation 4):

$$CRE = 0{,}50 * CUB * PED * AIC \tag{4}$$

where CRE is the cost of damages to residences, CUB is the basic unit cost of construction, PED is the percentage of damaged building, and AIC is the flooded built area. The CUB is obtained from the above mentioned NBR 12721:2006. Its values are tabulated and published monthly by civil construction syndicates. The PED varies with the economic class and water depth.

To maintain a common comparative basis between the applied curves, the same construction type, and economic class was adopted for the entire residential area. According to Nagem (2008), classes C and D correspond to the typology 'low standard residence'. The CUB and PED parameters were then adjusted for these classes and typology. The spectrum of economic classes can be seen in **Table 1**.

The Flooded Built Area (AIC) considers the urbanization pattern of the site. Given the lack of data related to the lots and consecutively to the buildings, secondary data characterization of the urban center of the municipality of Cabo de Santo Agostinho was used, allowing the application of the curves.

The difference DEM_{LiDAR}-DTM_{LiDAR} can inform which areas are above the ground (roofs and trees) and which ones represent the terrain. A 2.5-meter threshold was used to identify the built environment since it is understood that the ground floor of any building is on average 3 meters high. Therefore, with this threshold, it would be possible to identify all buildings, including houses. However, we would still have tall trees in this product. Vegetation was then removed using the Normalized Difference Vegetation Index (NDVI), calculated through cloud-free RapidEye satellite images.

Finally, it was necessary to identify the residential areas, since the damage functions to be analyzed were developed for such a constructive typology. In order to identify the residential areas, we used the Land Use Law zoning (LUOS nº2179/2004) for the municipality of Cabo de Santo Agostinho. The following zones were selected:

- Residential Urban Zone I;
- Residential Urban Zone II;
- Residential Urban Zone III;
- Urban Zone of Residential Expansion.

As an example, one can consider a low-standard house, with 50 m² of built area, registering depths of 1.10 m in the 2010 event. Its CUB would be BRL 1511.78 (value of December 2019), PED is 0.137 according to Nagem (2008), AIC equal to 50 m² and the CRE (final damage) would be BRL 5177.85.

Table 1. Economic clases (ABEP, 2018; NAGEM, 2008).

Class	Average family income (BRL)	Residence type
A	23345.11	High standard
B1	10386.52	Medium standard
B2	5363.19	Medium standard
C	2965.69	Low standard
D	1691.44	Low standard
E	708.19	Popular

RESULTS AND DISCUSSION

Model simulations

Simulation precision depends on various factors, among which uncertainties, inherent to the modeling process, are the greatest responsible for accuracy limits. Many parameters in HEC-HMS related to groundwater and soil are good examples of uncertainty (Wallner *et al.*, 2012; De Silva *et al.*, 2014; Halwatura & Najim, 2013). Nevertheless, the simulations produced reliable results in this application, except for some values in station 39192000, where R^2 was not acceptable, and NSE was adequate but not satisfactory according to the classification proposed by Moriasi *et al.* (2007). These coefficients maintained a medium level of quality for calibration and validation, with the highest streamflows sometimes overestimated, and sometimes underestimated (**Table 2**). The model was able to identify the highest flood peaks in both stations, but with a tendency to underestimate flow values in both calibration and validation (**Fig. 3**).

Table 2. Statistical coefficients, where the first value corresponds to station 39192000 and the second to station 39195000.

Coefficients	Calibration	Validation
Observed Mean Flow	2.65/7.66	1.88/6.51
Simulated Mean Flow	2.02/7.77	1.84/7.48
NSE	0.44/0.62	0.67/0.55
PBIAS	-23.90/1.47	-1.92/14.99
R^2	0.45/0.59	0.66/0.56

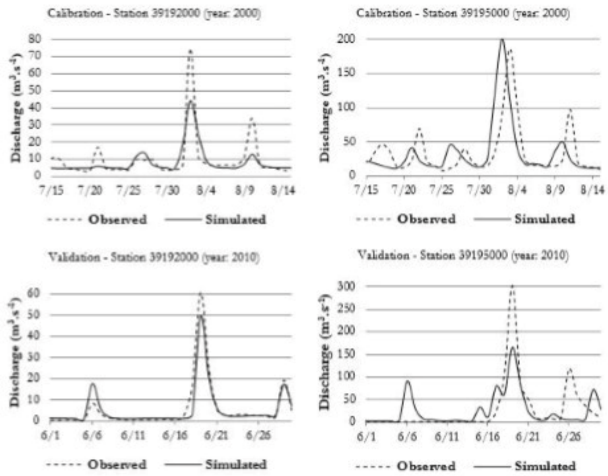

Fig. 3 Simulated and observed streamflows in two rain seasons selected.

The performance was coherent with a daily dataset as pointed out by Meenu *et al.* (2013), in their Tunga-Bhadra river basin model in India. Better results were found in simulations that used monthly precipitation data.

Simulated results presented a considerable variance, from good to medium values both in calibration and validation. Considering all the conditions and results, the model created was deemed to be adequate for the study area. A similar result was presented by Chantterjee *et al.* (2014) in a study with HEC-HMS applied in the Damodar River, India. Ribeiro Neto *et al.* (2015) also found analogous results with an application in the Una river basin, Pernambuco state, Brazil.

The parameters calibrated for the HEC-HMS model were used to generate results used as input flow in HEC-RAS. **Fig. 4** helps to visualize the reaches simulated with HEC-RAS and the input discharge calculated with HEC-HMS (Q2, ΔSB-1, ΔSB-2, ΔSB-3), where ΔSB-1, ΔSB-2, ΔSB-3 are the incremental discharge in the sub-basins SB-1, SB-2 and SB-3 respectively. The flow Q1 was obtained from the streamgauge 39200000. **Table 3** presents the values of discharge used in the HEC-RAS simulation. With the model responding favorably, it was possible to generate flood maps appropriate to the configuration provided by topographic data for the region (DTM_{radar}).

Table 3. Boundary conditions in the HEC-RAS model.

Location	ID	Flow (m^3/s)
Upstream Pirapama	Q1	410.43
Upstream Gurjaú	Q2	100.99
SB-1 Incremental flow	ΔSB-1	55.78
SB-2 Incremental flow	ΔSB-2	64.62
SB-3 Incremental flow	ΔSB-3	234.93

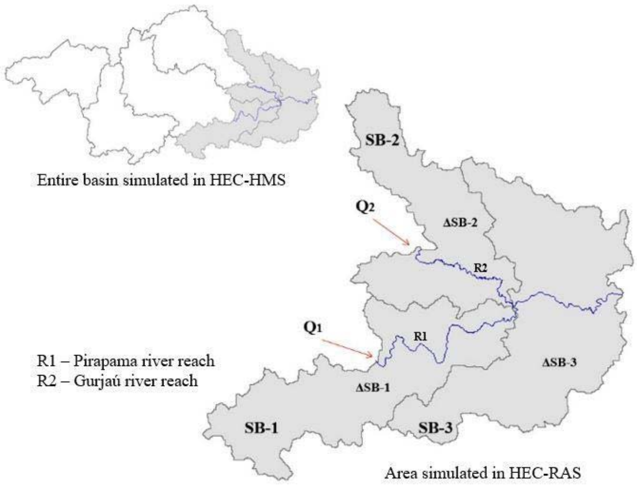

Fig. 4 HEC-RAS boundary conditions scheme.

The estimate of the roof surface

Roof identification proved satisfactory (**Fig. 5**). Buildings were defined and vegetation was separated and subtracted after some tests regarding the NDVI thresholds. Altogether, the method identified 56,847,129.76 m² of roofs for the entire municipality. From this number, 2,799,759.89 m² were located within residential zones, and 184,327.00 m² were affected by the simulated flood (**Fig. 6**).

In the Pirapama River basin, water depth presented high values. Most of the affected residences registered more than 2 meters of water depth, which is quite high (**Table 4**), and depths above 3 meters characterized approximately half of all the values obtained. Remembering that above 3 meters it can be considered that the water covered the entire ground floor. Based on established flood indicator thresholds, the Pirapama River basin presents the highest level of hazard regarding water depth (Coutinho, 2016; Ribeiro Neto *et al.*, 2016, Kreibich *et al.*, 2009; Wright, 2008).

Fig. 5 Calculated roofs and a satellite image for comparison.

The methodology, however, still fails to certify that all identified roofs are in fact residences. This information is important since the functions applied are exclusive to residential areas. To make the study feasible, a simplification was performed, considering all buildings within the residential areas defined by law as houses.

Table 4. Percentage of pixels per depth class (Residences).

Water depth (m)	Pixel percentage (%)
0.0 – 0.5	6.66
0.5 – 0.75	2.33
0.75 – 1.0	2.30
1.0 – 1.5	3.96
1.5 – 2.0	4.16
2.0 – 2.5	8.42
2.5 – 3.0	21.43
> 3.0	50.82

Damage assessment

Several uncertainties are associated not only with damage estimation but also with the development of corresponding damage functions, which may influence final results. As highlighted by Molinari *et al.* (2019) it is preferable to diminish uncertainty, but a better understanding of its extent is a major advance. Moreover, in the absence of observed data, a comparative analysis can be performed.

Calculated damages show the magnitude of what could happen in this area, taking into account the particularities of the hydraulic model used. Thus, the extrapolation of such factors cannot be performed directly, without observing possible differences in dimensions, geographic characteristics, population occupation and existing buildings.

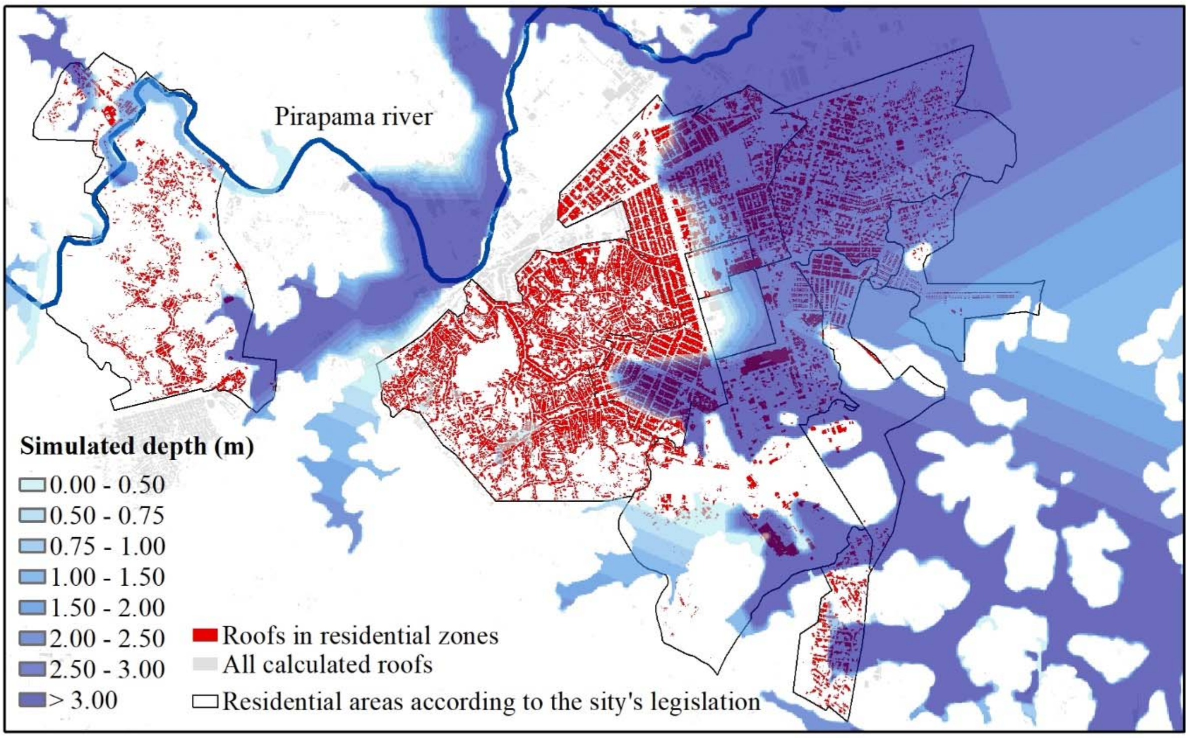

Fig. 6 Hazard and exposure map.

Noting the differences between the equations, the difference between the damages is around BRL72/m^2, totaling approximately BRL85 million (**Table 5**). Those values were adjusted for inflation until 2019.

Table 5. Damage function results .

	Eq. from Machado *et al.* (2005)	Eq. from Nagem (2008)
Residential exposed area (m²)	1,184,327.00	1,184,327.00
Total damage (BRL)	234,582,760.01	149,112,244.18
Damage/area (BRL/m²)	198.07	125.90

Differences were expected since there are two different methods of depth-damage curve construction. Nagem (2008) adopts and adapts the methodology of Salgado (1995). Standard projects were selected as representative of the constructions in the flood-prone area. Those projects were presented to civil construction professionals who quantified the damage, associating it with various flood heights. Since these values could vary according to the professional's experience, average indices were established to quantify the losses. Thus, for each flood height, the components that could be damaged and the respective monetary value of their losses were identified. The total damage of the building is considered as the replacement cost of the property, adjusted by a depreciation factor.

In Machado *et al.* (2005), the damage function to residential buildings was developed by empirical research, with data obtained by field sampling. There was a detailed survey of the damage left by the 2000 flood in the study area. Losses were in turn estimated as repair costs and accounted for through reform budgets.

Some of these differences are reinforced in the spatial analysis of damages per square meter (**Fig. 7**). In the application of Nagem (2008), the emphasis is placed on intermediate damage classes, while in Machado *et al.* (2005), higher damage indices spread over larger areas. The depth has a great influence on this second method, being its main function parameter. The high depths obtained in the simulation carried out in Cabo de Santo Agostinho support this result.

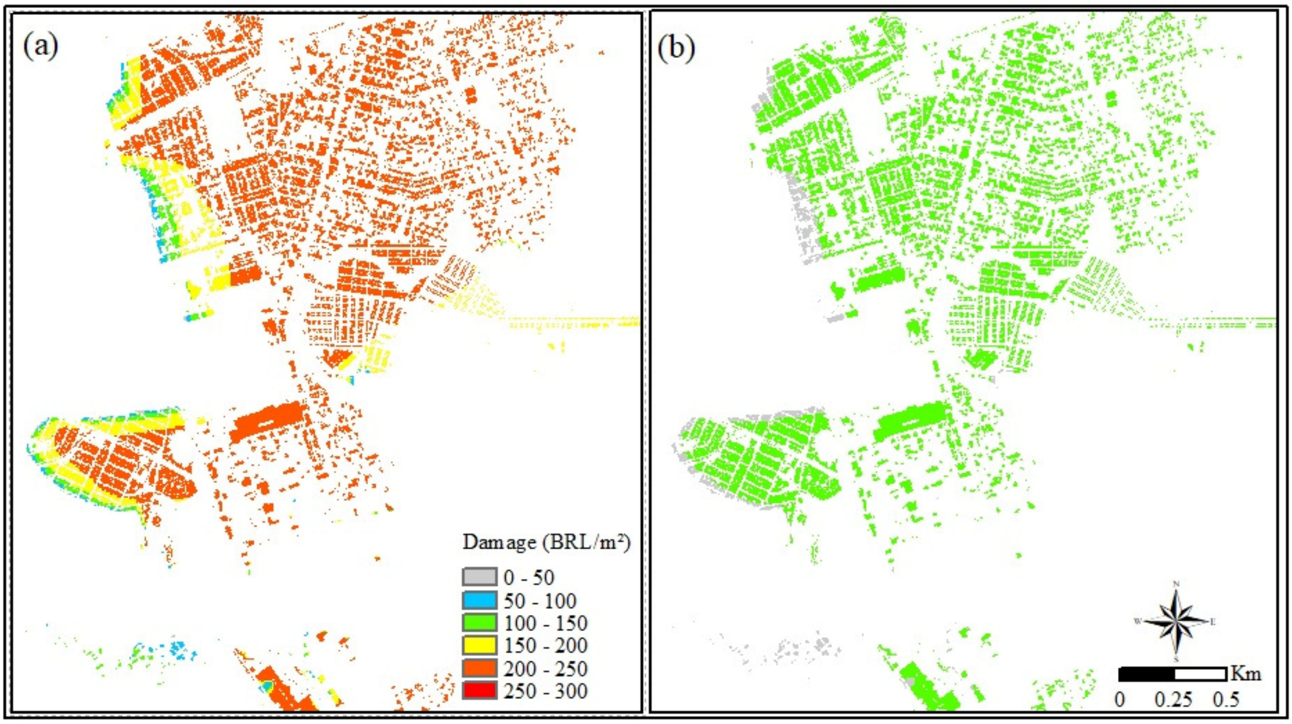

Fig. 7 Damage map for the equation from Machado *et al*. (2005) (a) and Nagem (2008) (b).

Nevertheless, similarities exist, both Nagem (2008) and Machado *et al*. (2005) generalized certain parts. All of the authors established type projects for the area of interest, setting construction standards-based, among other aspects, on the finishing of buildings. The similarities, however, fail to diminish the particularities and uncertainties that end up differentiating both methods and their results, which was highlighted by the application carried out in Cabo de Santo Agostinho.

In the study of Pathirana *et al*. (2011), the authors developed a model that incorporated the equation developed by Machado *et al*. (2005), with application to an area of 19 hectares in the city of Porto Alegre. The total damage associated with the simulated flood, with a duration of 2 hours and a return period of 50 years, was BRL 297,000.00, a value much lower than that found in the municipality of Cabo de Santo Agostinho. However, it must be considered that the indicator water depth plays a crucial role in the characterization of the costs. With most depths reaching very low values, the results of Pathirana *et al*. (2011) are justified. In the same way, the simulation in Cabo de Santo Agostinho responds consistently to the high depths recorded in its main urban area, with average water depth values reaching 2.83m in 2010.

The existing functions must be unique for each type of building and occupation (e,g, residential, commercial, industrial). The choices made in this study sought to overcome information deficiencies. However, the homogeneous classification of all buildings as houses does not correspond to the real scenario and creates new uncertainties (Win *et al*., 2018; Garrote *et al*., 2016; McGrath *et al*., 2015).

Thus, as in Albano *et al*. (2017), it is noteworthy that the applied curves were not developed for the study area, which corroborates that there is an epistemic uncertainty throughout the process. Challenges remain on the lack of a standardized, reliable, comparable and consistent database (Molinari *et al*., 2019). This deficiency makes it difficult to develop local curves, to validate loss models, and consequently to improve risk analysis accuracy.

CONCLUSIONS

The present study sought to understand the behavior of floods through its components. This approach is interpreted as a tool for every stakeholder, contributing to a more comprehensive knowledge of risk and disaster management.

Hydrological and hydraulic models were used successfully for hazard mapping. Statistical coefficients used to evaluate the calibration of the parameters had acceptable values for the objectives of the study. The flow peaks were satisfactorily detected by the model, with correspondence between the maximum flows and their time of occurrence. The streamflow time series from HEC-HMS contributed effectively to hydraulic modeling. This latter produced the inundation map referring to the 2010 extreme event.

Exposure was defined by identifying the items present within the floodplain boundaries. And the damage, which may be associated with vulnerability, was assessed more as a comparative analysis between the models that were developed in Brazil. The good quality of the dataset used was important to make possible the flood damage analysis, especially the digital terrain models and images with high spatial resolution. The use of DTM_{LiDAR}, DEM_{LiDAR} and RapidEye image had satisfactory results for estimating the roof surfaces.

The combination of different methodologies is a way to try to overcome the lack of information, but much remains to be done to validate damage analysis, especially in what concerns prevention. We reaffirm the need to establish a database regarding disasters, causes, and consequences, so future researches can be developed and compared with the support of observed information and the real characteristics of the studied regions.

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