FLOOD IMPACT ASSESSMENT IN THE ITAPOCU RIVER BASIN, BRAZIL

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By
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DECLARATION

Except where specific reference has been made to the work of others, the work embodied in this thesis is the result of investigation carried out by the author. No part of this thesis has been submitted or is being concurrently submitted in candidature for any degree at any other institution.

Rafael Silva Araújo

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Abstract

Brazil is a country with high inequality rates and an extensive disaster risk profile. The number of people affected by disasters increased after the rapid urbanization that the country has suffered in the past. Disasters tend to affect the poorest more severely. One important reason for this tendency is that the poorest tend to be pushed to live in riskier areas. Also, they have comparatively less resources to recover; therefore, disasters can enlarge inequalities. This study aims to propose a method for assessing if households are unequally affected by floods based on their income and propose adaptive measures. The method was applied to the Itapocu river basin, located in Santa Catarina State, Brazil, which has reported many losses due to flooding, is frequently hit by disasters, and is experiencing population growth. Flood events were assessed through rainfall analysis and hydrological simulations. Household income information was obtained from the 2010 census and then downscaled using a dasymetric approach. The "Grade Estatística" [Statistic Grid] was used as ancillary data to collect information on the number of households. Both flood and income information was combined to assess affected households, their distribution by income levels, and flood return periods. The results point out that flood events in the Itapocu river basin, especially ones with greater magnitudes, are likely to affect the lowest income households more severely. Finally, the study suggests the usefulness of building policies for better land use planning and investing in disaster management not only for protecting people's lives and assets but also as a tool for reducing inequality.

Keywords: inequality, floods, household income, impact assessment

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The author works for Geological Survey of Brazil (CPRM), Brazil

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LIST OF ABBREVIATIONS

AMVALI: Associação dos Municípios do Vale do Itapocu - Itapocu Valley Municipal Association

AMS: Annual Maximum Series

ANA: Agência Nacional de Águas - National Water Agency

CEPED: Center of Studies and Research on Engineering and Civil Defense – Centro de Estudos e Pesquisas em Engenharia e Defesa Civil

CEMADEN: The National Center of Disaster Monitoring and Alert – Centro Nacional de Monitoramento e Alertas de Desastres Naturais.

CPRM: Serviço Geológico do Brasil - Geological Survey of Brazil

DEM: Digital Elevation Model

FIDE: Disaster Information Form – Formulário de Informação de Desastre.

GLCC-v2: Global Land Cover Characterization

Grade Estatística - Statistical Grid

GRIPS: National Graduate Institute for Policy Studies

IBGE: Instituto Brasileiro de Geografia e Estatística – Brazilian Institute of Geography and Statistcs

ICHARM: International Centre for Water Hazard and Risk Management

IPCC: Intergovernmental Panel on Climate Change

JICA: Japan International Cooperation Agency

MAUP: Modifiable Areal Unit Problem

NSE: Nash Sutcliffe Model Efficiency Coefficient

NBR: Brazilian Normative, Brazilian Association of Technical Standards

POF: Pesquisa de Orçamentos Familiares - Consumer Expenditure Survey

PWRI: Public Works Research Institute

RRI: Rainfall Runoff Inundation

S2ID: Integrated System of Disaster Information – Sistema Integrado de Informação sobre Desastres

UFSC: University of Santa Catarina (Brazil) – Universidade de Santa Catarina

UN: United Nations

UNISDR: United Nations Office for Disaster Risk Reduction

USGS: United States Geological Survey

1 INTRODUCTION

1.1 Problem

Disasters do not affect the population equally. Usually, the most vulnerable sectors of society are more exposed to the hazards (Figure 1). However, that relation may vary with many factors such as type of hazard, local geography, and other regional issues (Hallegatte et al. 2017).

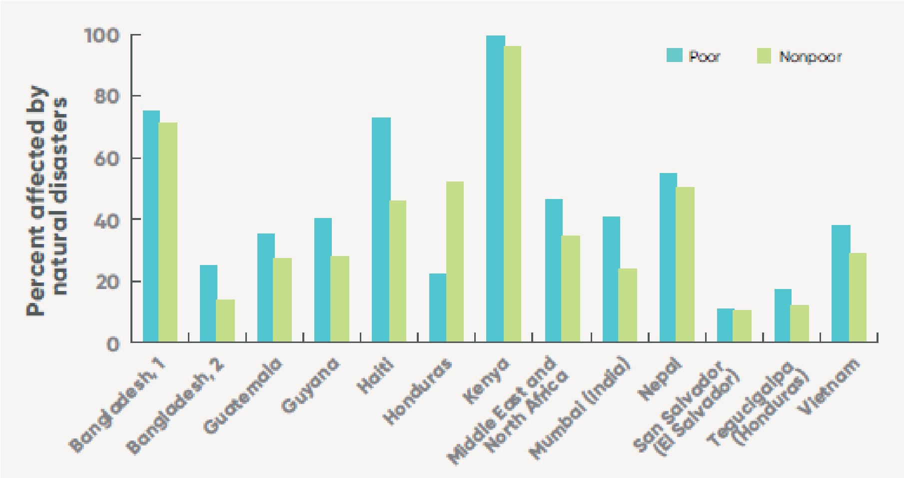


Figure 1 - Percent of poor and nonpoor affected by natural hazards, selected cases. Poor and nonpoor definitions vary between the countries. Source: Hallegatte et al. (2017).

When hit by a disaster, the poorest are also the ones that tend to suffer the most significant damages proportionally to their income, thus impacting their welfare and capability of people to accumulate wealth. On the other hand, the wealthier will suffer more total losses, since they have more income and assets. The disasters, therefore, contribute to increasing the inequality and poverty rates, since they impact negatively in the economic growth and affect more the ones with fewer resources (Hallegatte et al. 2017; UNISDR 2009; Wisner et al. 2004).

1.2 Background

Brazil records a high number of disasters every year; the most common are the water-related natural disasters. Droughts account for 51.31% of the affected people, flash floods 20.66%, floods 16.04%, the others sum up to 11.99% (CEPED 2012). The registers of natural disasters show an increasing trend in recent years. Between 1991 and 2012, 22% of the disasters occurred in the 1990s decade, and 56% occurred in the 2000s decade. The years of 2010, 2011, and 2012 alone accounted for a share of 22% (CEPED 2012). Apart from big disasters that draw much attention, the occurrence of frequent events with small scale, the so-called "extensive disasters," is the common type of disaster in Brazil, and little is known about on which extent they affect the welfare of the people (World Bank 2014; Hallegatte et al. 2017). Countries with extensive risk profiles tend to underestimate the effect of disasters (World Bank 2014), and due to Brazil's continental dimensions 8,515,767.049 Km² (IBGE 2019), it is very unlikely that a single big disaster interrupts the functioning of the country.

In 2010, 84% of the Brazilian population lived in urban areas, while 16% lived in rural areas. In the 1960s, that proportion was 45% urban and 55% rural (IBGE 2010). Unsafe territories often offer proximity to economic opportunities. For example, in the case of rural areas, the flooding prone areas may offer proximity to water sources; in the case of the urban, flooding areas may offer proximity to jobs and schools. Hazardous areas, therefore, can be attractive for the richer and the poorer, although land and housing markets may push the poorer to settle in the riskiest areas (Hallegatte et al. 2017, Husby et al. 2015). The accelerated urban growth and poor land use and planning led to occupancy of hazardous areas in Brazil (Figure 2), enhancing people's exposure and vulnerability to hazards (World Bank 2014; Robaina 2008).

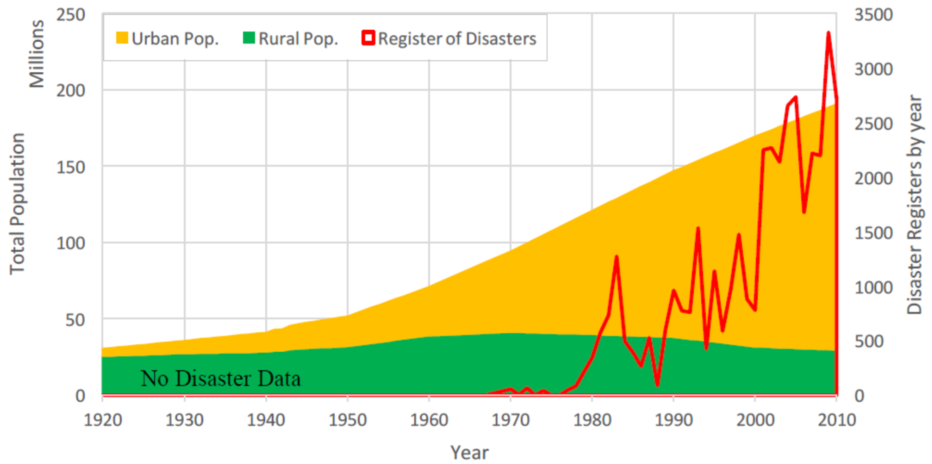


Figure 2 - Urban and Rural distribution, combined with total population from IBGE and disaster registers from S2ID. Source: Mickosz (2017)

Usually ranked amongst the nations with higher inequality rates in the world, there has been little change in Brazilians' inequality levels over the time (WIID 2020; World Inequality Lab 2018; Morgan 2017; Souza 2016). The income shares of the 10% richer and 10% poorer of the population can be seen in the graphs below (Figure 3), based on primary household survey data obtained from government statistical agencies and World Bank country (WDI 2018). Compared to both developed (Japan, Portugal, United States, and Canada) and developing countries (Mexico, Uruguay, Argentina, and Peru), Brazil has the most concentrated share in the 10% richer, and less significant share in the 10% poorer. Morgan (2017) made a study considering a novel combination of annual and nationally representative household survey data with detailed information on income tax declarations, from 200 to 2015. The result was even higher income inequality, with the top 10% income share above 54% for all assessed years. The top 1% income share is always higher than 26% in that assessment; meanwhile, the bottom 50% share fluctuates between 10% and 15%. Income taxes were also used by Souza (2016) from 1930 to 2013 with similar findings.

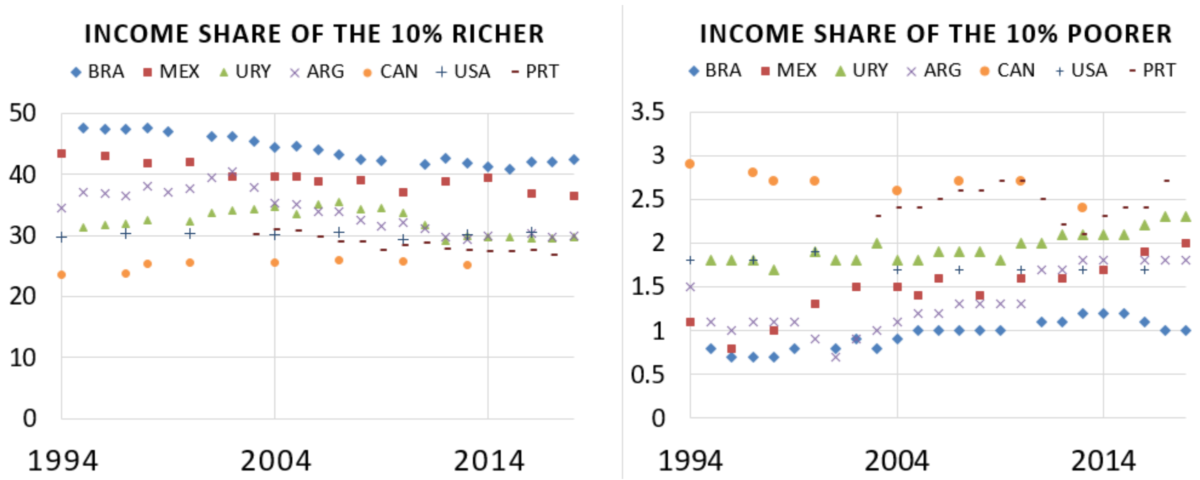


Figure 3 - Comparison of the Income share of the 10% richer (A) and the 10% poorer (B) of Brazil (light blue diamond dots) and other developing and developed countries. Source: WDI (2018).

As shown above, Brazil is a country with an extensive risk profile and high inequality rates that can be enlarged by natural disasters. Therefore, it is paramount that Brazilian society and policymakers invest in disaster management since it is a tool not only for saving lives and financial losses but also to reduce inequality and poverty.

This action is aligned with the United Nation's Sendai Framework for Disaster Risk Reduction. The signatory countries, including Brazil, are compromised to pursue the goal, guiding principles and priorities of actions to obtain the following outcome of the framework by 2030.

> The substantial reduction of disaster risk and losses in lives, livelihoods and health and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries. (UNISDR 2015, p 12).

The first priority of action of the framework is 'Understanding Disaster Risk,' in all its dimensions, including the hazard itself and the exposure of people and assets. The third priority is 'Investing in disaster risk reduction for resilience' through structural and non-structural measures to enhance the resilience of people, assets, environment, and as drivers for growth—poverty eradication also pervades many of the recommendations of the document (UNISDR 2015).

1.3 Objectives

The objectives of this study are to propose a method for assessing if the households of a given basin are unequally affected by floods based on their income. For being applicable in different areas, nationally available data was used;

To apply the method in the Itapocu river basin, located in the northern part of Santa Catarina State,

To propose adaptive measures for improving the safety of Itapocu river basin, based on the results of the methodology.

2 STUDY AREA

The Santa Catarina state registers disasters recurrently (CEPED 2012), and flooding losses account for 81% of its total losses by natural disasters (World Bank 2017). The Itapocu river basin is located in the northern part of the Santa Catarina state, in the south region of Brazil. It is a coastal basin that drains an area of 2919 km² (Figure 4). Its highest point is at 1,316m, in the Serra do Mar region, and the outlet is at the sea level. The coastline of this region has high precipitation amounts when compared with the surrounding areas, due to the orographic effect caused by the Serra do Mar range (Rodrigues 2015; CEPED 2012). The main river of this basin is the Itapocu River, with 86.8 km length, formed by the junction of the Novo River and the Humboldt River in the city of Corupá (Steinbach & Tomaselli 2013). Since it is entirely inside the Santa Catarina state, this river is under the state jurisdiction only.

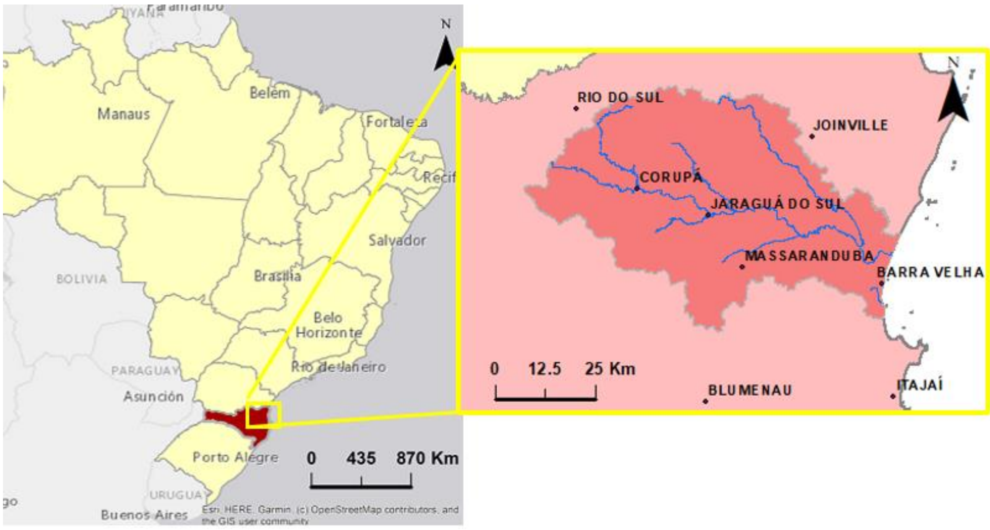


Figure 4 - Location of Itapocu river basin

According to Junior et al. (2018) the basin's area is divided by soil use as follows (Table 1).

Table 1 - Itapocu river basin area by soil use

Soil Use	Percentage	Soil Use	Percentage
Agriculture	15.8%	**Vegetated**	60.5%
Mining	0.2%	**Pasture**	14.1%
Urbanized	3.6%	**Reforestation**	5.3%
Water Bodies	0.6%	**Exposed Soil**	0.1%

The Itapocu River Basin belongs to the "Mata Atlântica" (Atlantic Forest) biome, which is comprised of the south, southeast, and part of the northeastern coast of Brazil. More than 72% of the Brazilians (more than 145 million people) live in the area of this biome; therefore it is the most endangered forest in Brazil, and one of the most endangered in the world. Originally, the vegetated area covered 1.315.460 km². Nowadays 12.4% of this areas remain (Hirota & Ponzoni 2008, Hirota et al. 2019). Because of its importance, the biome is protected by law, known as "Mata Atlantica Law". In Itapocu River Basin, 11 conservation unities with a total area of 263.74 Km² (Junior et al. 2018) protect this biome with different degrees of protection.

Twelve municipalities are totally or partially located in the basin. Amongst them, four are entirely inside the basin (Corupá, Jaraguá do Sul, Schroeder, Guaramirim, and Massaranduba). According to Junior et al. (2018), the human development index of 12 municipalities varies from 0.70 to 0.81, considered high or very high. The population of the basin is estimated in 265,929 dwellers (IBGE 2010), from which 78.88% live in urban areas, and 21.11% live in rural areas, according to the 2010 census. Additionally, there are traditional communities of indigenous people living in the downstream part of the basin, representing 0.4% of the total basin population (Figure 5).

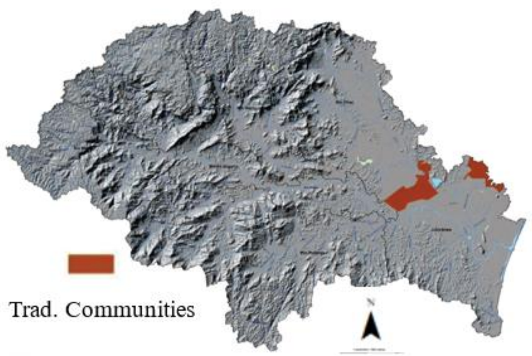


Figure 5 - Location of traditional communities. Source: Junior et al. (2018)

Figure 6 - Location of main settlements

The main urban area inside the Itapocu river basin is Jaraguá do Sul city (Figure 6), with a population of 143,123 people in 2010. In 1980, the population was 48,538, meaning it increased almost three times in 30 years. For 2019 the population is estimated to be 177,697 people. The demographic density also increased from 70.0 inhab./Km² to 268.7 inhab./Km², an increase of 3.8 times. That suggests that the population increased at a fast rate in this city, especially in the urban areas. A similar trend was observed in Guaramirim city, where the population increased 3.23 times from 1980 to 2010 and in Shroeder, where the population increased 3.83 times from 1980 to 2010 (IBGE 2019, SEBRAE 2013). This region is amongst the ones with the highest population and industrial growth in Santa Catarina state, and that growth causes pressure over water resources (Steinbach & Tomaselli 2013)

Many flooding events have been reported in this basin (1944, 1987, 1992, 1995, 2008, 2011, and 2014) (ANA 2020). In the 2014 event, the most significant flooding ever recorded, 123.262 people were affected, 17.942 people were displaced, and 11.167 houses were damaged (World Bank 2017). Additionally, the southern region of Brazil is expected to experience an increase in rainfall in the future (IPCC 2013), therefore worsening the flooding hazard in the basin.

If the main cities continue to grow at this same rate, the pressure on land for housing and agriculture will increase. Additionally, the demand over the nowadays preserved areas might also increase, representing a threat to the environment. This scenario poses a challenge to the public sector of the municipalities inside the basin since it is necessary to conciliate the population growth with disaster management and environmental protection to achieve sustainable economic growth.

According to the Water Resources Plan of Itapocu river basin, there are goals to be achieved by 2034: reduction of the losses of lives due to hydrological events to zero and reduction of the economic losses to 35% of the actual values, by adopting local and regional actions. The supporting actions to achieve this plan are to create a real-time flood alert system, increase the number of rain and discharge stations, and define critical water heights for flooding. For the environment, the goals are to propose new conservation areas, promote environmental education for the population, and recover degraded areas (Junior et al. 2018). Since the economy and the population of the municipalities in the Itapocu river basin are growing, to achieve such goals will demand cooperation and political consensus between many stakeholders.

3 MODEL DEVELOPMENT

3.1 Overall Methodology

The overall methodology of this work is to assess the population affected by the flood in the Itapocu river basin through five steps (Figure 7).

The first step is rainfall analysis to obtain the frequency of daily rainfall and design rainfall to be used in the final hydrological model. The second step is to build a hydrological model in the Rainfall-Runoff Inundation (RRI) program (Sayama 2017). Input data include topographic data, rainfall, cross-sections, land cover, and soil. Calibration and validation are performed by comparing discharge results with observed discharge and inundation extent with available survey results. The third step consists of downscaling census data to be further used. The fourth step is the combination of steps 2 and 3 to assess affected households in terms of income and return period. A damage assessment based on income and family expenditure is also performed. Finally, based on the results obtained in step 4, recommendations for improving the basin situation are proposed.

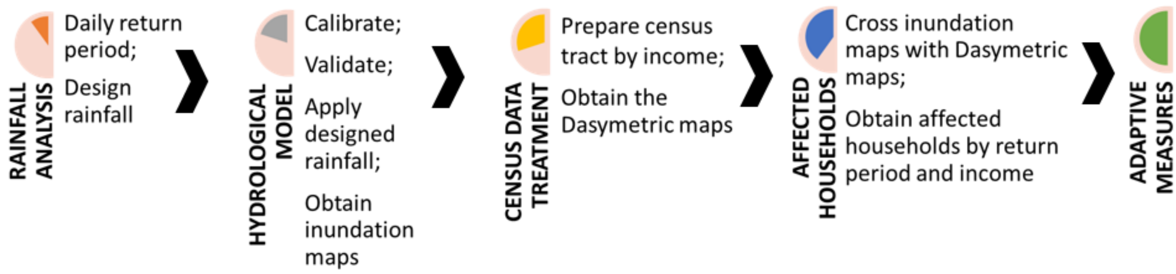


Figure 7 - Methodology flow

3.2 Rainfall Analysis

The data used in this step came from the National Water Agency (ANA) website, the Hidroweb platform.

3.2.1 Rainfall Frequency

The concern of frequency analysis is to use a series of record measurements to assess the probability of the occurrence of an event of a given magnitude, known as the return period. The analysis is carried out to estimate the probability that a certain amount x in the series, for example, daily rainfall, will be exceeded, shown in eq. 3.1, where F(x) is the frequency of occurrence of x, and R(x) is the return period (Brutsaert 2005).

$$R(x) = \frac{1}{1-F(x)} \qquad 3.1$$

Because the observation of extreme phenomena is rare, and sometimes not recorded, a statistical curve must be employed to describe the behavior of less frequent values (Reiss & Thomas 2007)

In this study, rainfall of 12 stations and discharge of two stations (Appendix A) were analyzed in terms of the daily annual maximum return period using the Generalized Extreme Value (GEV) given by equation 3.2 and Gumbel distribution given by equation 3.2 when k=0 (Brutsaert 2005).

$$F(x) = e^{\left[-\left(1-k*\frac{x-\xi}{\alpha}\right)^{\frac{1}{k}}\right]} \qquad 3.2$$

where ξ: location parameter, α: scale parameter, k: shape parameter

To this day, rainfall events with high frequencies resulted in inundation that caused damage in the Itapocu river basin. The basin averaged rainfall return period for the 1987 inundation event was calculated as 19.07 years, and for the 1992 event, 6.32 years, for example. The biggest flooding event so far, which happened in 2014, was caused by a basin averaged rainfall with a return period of 59.11 years. Thus, the design rainfall was made for return periods of 2, 5, 10 and 20 years for assessing the most frequent floods, and 50 and 100 years for assessing the most damaging and less frequent events.

For each station, the Gumbel and GEV curves were potted in the Gumbel Probability paper, and the trendline of the rainfall annual maximum series (AMS) was plotted. The curves (GEV or Gumbel) that best approximated to the trendline of the AMS were selected for obtaining the return period.

3.2.2 Design Rainfall

A rainfall pattern for each return period must be designed to be input in a hydrological model. The effects of the rainfall on discharge and flooding vary greatly depending on how rainfall is distributed in the basin. For example, for the Itapocu river basin, the 2014 event generated the biggest discharge peak in all the Jaraguá do Sul station record (200 years return period discharge), caused by a basin averaged rainfall of a 59-year return period. But for individual stations, return periods vary greatly since the rain is not equally distributed over the basin (Table 2). The stations with the highest rainfall values are located just upstream of the main settlements, such as Rio Novo and Campo Alegre stations (Table 2). This pattern resulted in a severe flood, especially in the Guaramirim city. Therefore, even for a small basin such as the Itapocu, the rainfall pattern influences greatly in the flooding downstream.

Table 2 - Return period of the rainfall occurred on 08/06/2014.

Station	Rain (mm)	Return Period (years)	Station	Rain (mm)	Return Period (years)
ARAQUARI	135.9	4.53	**J. DO SUL**	150.8	18.41
ARROZEIRA	95.5	0.62	**L. ALVES**	88.73	1.32
B. AVENCAL	181	83.75	**P. SC301**	147.9	9.63
C. ALEGRE	150.4	81.43	**P. S. CUBAT.**	147.3	9.55
E. MOROS	151.2	3.42	**R. NOVO**	213.19	53.37
I. CENTRAL	90.08	1.98	**POMERODE**	102.6	5.03

The first attempt for designing the rainfall pattern was made by averaging the whole rainfall series of each station. The average rainfall is then divided by the total annual rainfall, creating a rainfall pattern that can be multiplied by the total annual rainfall for a given return period. However, peak rainfall events are erased by this method (Figure 8). In smaller basins, like the Itapocu river basin, the concentration time is short. Therefore, the intense rainfall episodes are the ones causing flooding. Thus, another method must be employed.

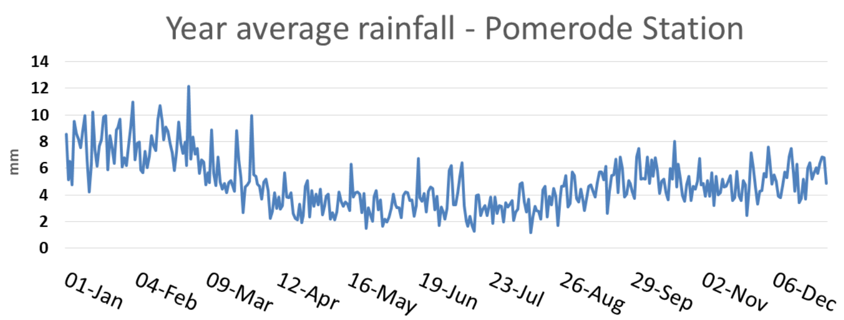


Figure 8 - Averaged rainfall series for Pomerode Station.

Another common approach is to adopt the pattern of a past rainfall event and use it for simulation. It can be done by dividing each station series by the total rainfall, and this pattern can be multiplied by the results of annual frequency analysis. The problem with this approach is that assessing an individual pattern might create a bias since it is not necessarily representative of the usual rainfall in the basin. Nevertheless, this approach was tested for the 2014 event, but after applying annual frequency analysis, the rainfall peaks were overestimated far too much. After applying the 10-year-return-period annual total rainfall to the 2014 pattern, the main event on July 8th yielded a daily rainfall with a more than 100-year return period for many stations. That result suggests that the annual rainfall return period is not directly linked to events that cause flooding in this basin.

The years with biggest discharge events were compared with their total annual rainfall return period (Table 3) to investigate the annual rainfall relation with floods in the Itapocu river basin. All those events occurred in years with a normal total annual rainfall, whose return period is usually less than one year. Thus, the annual return period was proved to be inefficient for assessing flooding in this basin, since no relation was found between the annual return period of a high total rainfall event and high discharge events in the past.

Table 3 - Total annual rainfall and respective return period.

DISCHARGE EVENT	TOTAL ANNUAL RAINFALL (mm)	RETURN PERIOD (GEV)
July 2014	2031.03	0.70
February 1987	2159.31	1.41
May 1992	1961.90	0.48
February 1995	1979.94	0.53
January 1989	2033.77	0.71

According to Rodrigues (2015) who studied extreme rainfall characteristics in the Santa Catarina coastline, more than 80% of the rainfall events with 5-day duration have rainfall concentrated within 1-3 days, with high-intensity rainfall happening within 24 hours. Therefore, the daily return period is better for determining the design rainfall.

The final method chosen for designing the rainfall was then developed, focusing only on rainfall events that resulted in high discharges in the Itapocu River. First, the dates of all the events that recorded above 713m³/s at the Jaraguá do Sul station (10-year return period discharge) were collected. The 1990 rainfall records were removed due to inconsistency (Table 4).

Table 4 - Date of the peak discharge events greater than ten years return period.

DATE	Discharge (m^3/s)	DATE	Discharge (m^3/s)
26/11/1944	1258.04	**29/05/1992**	1077.38
14/11/1969	735.50	**09/02/1995**	765.64
14/02/1987	960.44	**26/04/2010**	841.59
05/01/1989	805.36	**08/06/2014**	1878.86
01/09/1990*	955.52*		

The average rainfall peak duration was obtained for each station by averaging the duration of the rainfall events that resulted in high discharges listed in Table 4, as described in the flowchart below (Figure 9).

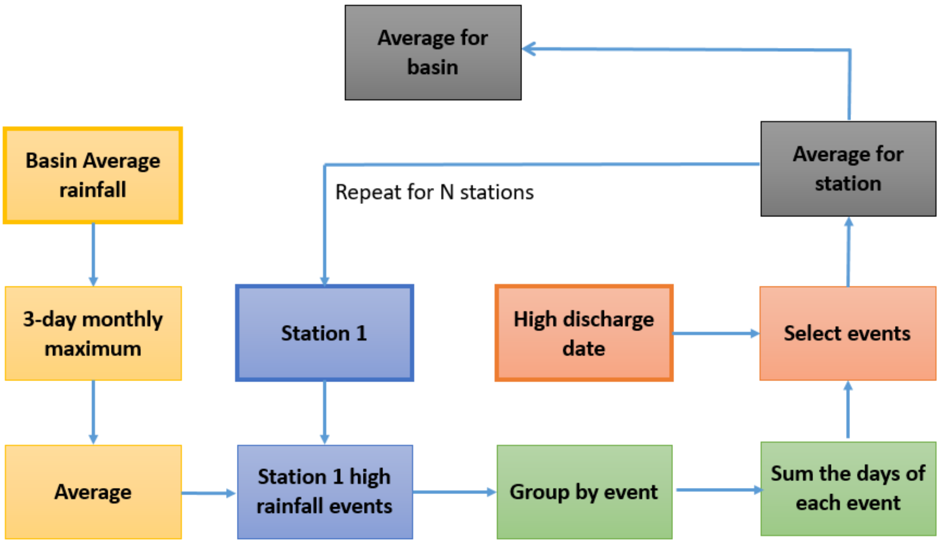


Figure 9 - Flowchart for obtaining the duration of the peak event of design rainfall.

From the series of average basin rainfall, the three-day monthly maximum values were obtained and averaged. The average three-day monthly maximum rainfall is 69 mm for the Itapocu river basin. Each station of the basin was then assessed using this value. The contiguous days when; 1 - the sum of the day and the two following days; or 2 - the sum of the day, the following and the previous day; or 3 - the sum of the day and the two previous days is greater than 69mm were considered as a part of a high rainfall event.

The results were then grouped by consecutive days. The duration of the events that coincide with any of the high discharge events was selected and averaged. The procedure was repeated for each station, and the results were then averaged for the whole basin. The average duration for a rainfall event that leads to a high discharge in Itapocu river basin is 7.23 days. Therefore, a peak of 7 days was set as the design rainfall.

The pattern of the design rainfall was determined by using the high discharge events listed in the previous step. In each station, the rainfall was selected according to the average duration (Figure 10), i.e., three days before and three days after the high discharge day. The average pattern was obtained for the 13 stations.

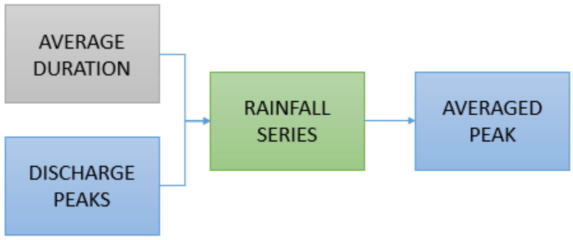


Figure 10 - Flowchart for obtaining the rainfall pattern

The average pattern was divided as follows. The seven days that correspond to the peak were divided by each respective highest rainfall, creating a multiplier pattern (Appendix B). Finally, by directly multiplying each day by the daily return period, the designed rainfall is obtained (Figure 11). Thus, each peak has at least one day that recorded the daily rainfall for a given return period, and the other days are proportional to it. More seven days of simply averaged rainfall were added prior to the peak, totalizing 14 days, to build the soil conditions for correct simulation. Therefore the high discharge day always happened on the 11th day of the rainfall record.

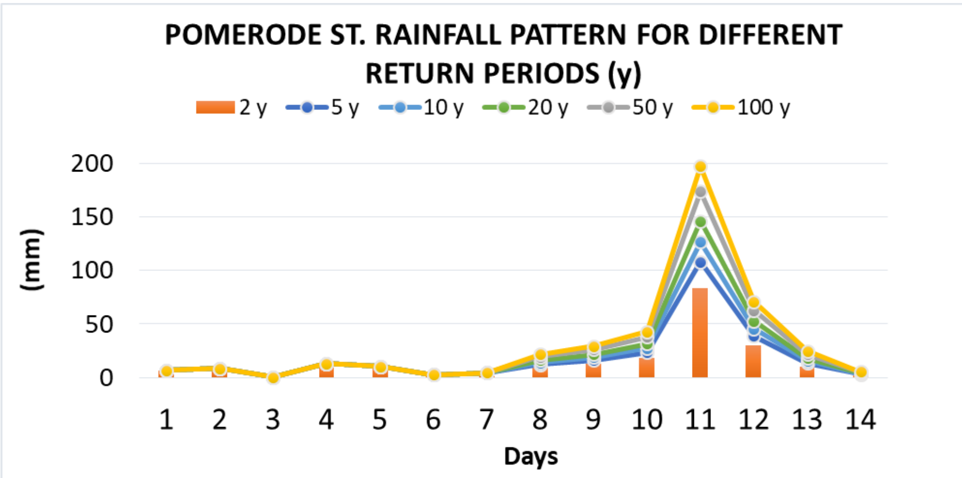


Figure 11 - Design rainfall pattern for Pomerode station. Days 1 – 7 are simply averaged. Days 8 – 14 are multiplied by the daily return period.

Additionally, four days of zero rainfall were added after the peak, for assessing the discharge decrease after the event. In total, the design rainfall had 18 days.

Although the designed main rainfall event has a seven-day duration, usually, higher intensities concentrate within 1-3 days for most of the stations. This value is coherent with the study made by Rodrigues (2015) for the Santa Catarina coastline, which found a 1-3 day duration for intense rainfall in the region.

3.3 Hidrological Model

3.3.1 The RRI Model

For the hydrological modeling of the Itapocu river basin, the Rainfall-Runoff Inundation (RRI) model was used. The model can simulate both the discharge and inundation simultaneously on a basin-scale (Figure 12). It uses a two-dimensional approach for dealing with the slope and a one-dimensional approach for dealing with the river channel. The model can simulate the lateral subsurface flow, which is important for mountainous areas, vertical infiltration, which is important for flat areas, and also the surface flow (Sayama, 2015).

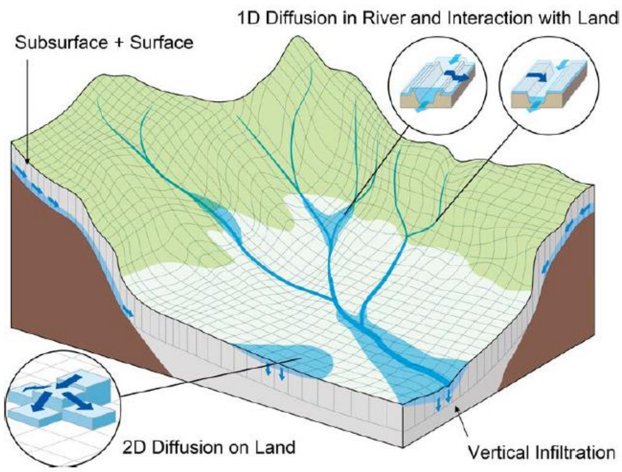


Figure 12 - Diagram of RRI model (Sayama 2013)

The governing equations are derived from the equations of Mass Conservation (3.3) and Momentum Conservation (3.4) for gradually varied unsteady flow (Sayama, 2015).

$$\frac{\partial h}{\partial t} + \frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y} = r \qquad 3.3$$

$$\frac{\partial q_x}{\partial t} + \frac{\partial u q_x}{\partial x} + \frac{\partial v q_x}{\partial y} = -gh\frac{\partial H}{\partial x} - \frac{\tau_x}{\rho_w} \qquad 3.4X$$

$$\frac{\partial q_y}{\partial t} + \frac{\partial u q_y}{\partial x} + \frac{\partial v q_y}{\partial y} = -gh\frac{\partial H}{\partial y} - \frac{\tau_y}{\rho_w} \qquad 3.4Y$$

The RRI model spatially discretizes the Mass Balance equation (3.3) as follows:

$$\frac{dy^{i,j}}{dt} + \frac{q_x^{i,j-1} - q_x^{i,j}}{\Delta x} + \frac{q_y^{i,j-1} - q_y^{i,j}}{\Delta y} = r^{i,j} \qquad 3.5$$

Where $q_x^{i,j}$, $q_y^{i,j}$ are the x and y direction discharges from a grid cell at (i,j).

For the Momentum conservation (3.4), RRI uses the following equations:

$$q_x = \begin{cases} -k_a h \frac{\partial H}{\partial x}, & (h \leq d_a) \\ -\frac{1}{n}(h - d_a)^{5/3} \sqrt{\left|\frac{\partial H}{\partial x}\right|}\ sgn\left(\frac{\partial H}{\partial x}\right) - k_a h \frac{\partial H}{\partial x}, & (d_a < h) \end{cases} \quad 3.6X$$

$$q_y = \begin{cases} -k_a h \frac{\partial H}{\partial y}, & (h \leq d_a) \\ -\frac{1}{n}(h - d_a)^{5/3} \sqrt{\left|\frac{\partial H}{\partial y}\right|}\ sgn\left(\frac{\partial H}{\partial y}\right) - k_a h \frac{\partial H}{\partial y}, & (d_a < h) \end{cases} \quad 3.6Y$$

Where $k_a$is the lateral saturated hydraulic conductivity and d_a is the soil depth times the effective porosity.

Water depths and discharges are calculated for each cell and time step using the given equations. RRI's algorithm allows the simulation of surface and subsurface flow. The equations in (3.6X) and (3.6Y) for the (h ≤ da) case describe the saturated subsurface flow based on the Darcy law. In contrast, the second equations for the (da < h) case describe the combination of the saturated subsurface flow and the surface flow. An important feature of RRI is that it assumes the water surface slope as the hydraulic gradient, differing from the kinematic wave model, where the gradient is considered to be equal to the topographic slope (Sayama 2013).

For steep areas where the lateral subsurface flow and the saturated excess overland flow dominate, equations (3.6X) and (3.6Y) are used. For plain areas where the infiltration excess overland flow dominates, the surface flow equations can be used together with the vertical infiltration as loss for event-based simulation, calculated with the Green-Ampt (3.7) infiltration model (Sayama 2013).

$$f = k_v \left[1 + \frac{(\emptyset - \theta_i)}{F}\right] S_f \quad 3.7$$

The channel geometry is assumed to be a rectangle whose shape is defined by width W, depth D, and embankment height He. When detailed geometry information is not available, the width and the depth can be approximated by the following function of upstream contributing area A [km2] (3.8 and 3.9) (Sayama 2013).

$$W = C_W A^{SW} S_f \quad 3.8$$

$$D = C_D A^{SD} S_f \quad 3.9$$

3.3.2 *Data sources*

Cross-section data was obtained through the Itapocu River Basin Committee intern reports (SIEASC 2020; e Global 2019) and from the National Water Agency (ANA) discharge stations. Daily discharge data and daily rainfall data were also obtained from ANA stations.

The Digital Elevation Model (DEM) used for this model is local data obtained through the Geological Survey of Brazil (CPRM). The inundation extents of past events were obtained from the CPRM website and the Itapocu river basin committee. They were merged to get the total inundated area by a survey.

3.3.3 *Model Preparation*

The overall methodology flowchart for simulation can be seen below (Figure 13). The input data should be prepared and inputted in RRI for assembling a model. After that, the model is calibrated and validated, and finally, by adding the design rainfall, inundation extents and depths are obtained.

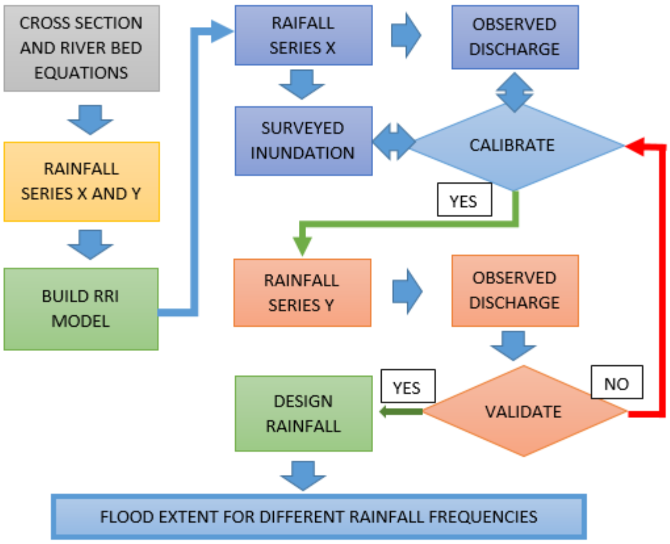


Figure 13 - Flowchart for building the hydrological model

In terms of discharge, the biggest events registered in the Jaraguá do Sul station happened in 1944, 1987, 1989, 1990, 1992, 2010, and 2014. The two biggest events occurred in 2014 with a peak discharge of 1878 m3/s and in 1944 with a peak discharge of 1258 m3/s. The 2014 event can be easily assessed, since twelve rainfall stations (Figure 3.8) were functional at that time, and the flood extent was mapped in the urban areas. This event was chosen for calibrating the model. The 1944 event, however, is very old and poorly gauged. However, the 1992 flood had a peak discharge of 1077 m3/s, and the data is available at twelve rainfall stations data (Appendix A). Therefore, it was chosen for calibration. Two discharge stations (Figure 3.9) were used for calibration and validation: Corupá station in an upstream location and Jaraguá do Sul station (Figure 3.7) in the urban area of Jaraguá do Sul city. Both have kept continuous records since the 1940s.

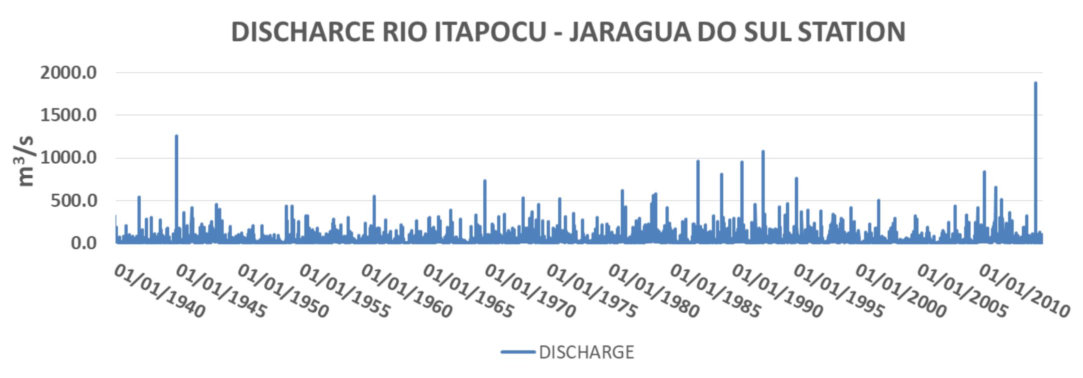


Figure 14 - The whole series of the discharge in Jaraguá do Sul station. The 2014 event is the most prominent peak, clearly visible at the end of the series. The 1944 event is also clearly visible at the beginning of the series.

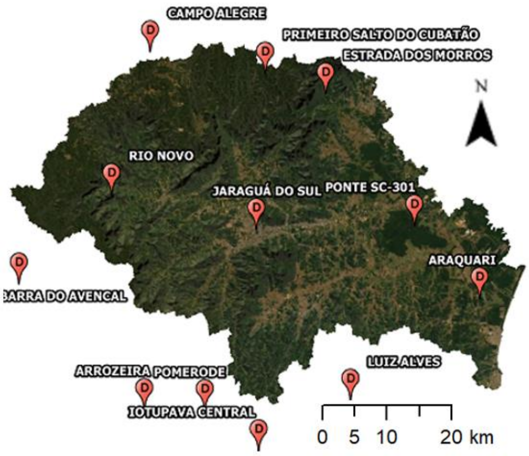


Figure 15 - Rainfall stations used for the calibration.

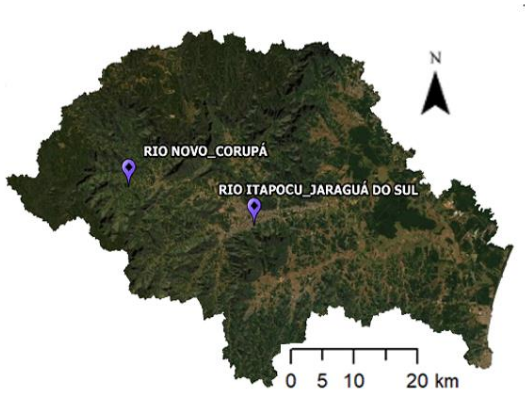


Figure 16 - Discharge stations used for calibration and validation.

The original resolution of 1m DEM was scaled up to be used in RRI. Since the model simulates a basin-scale inundation, it is not possible to input fine data, and it has to be resampled. The procedure, however, was manually supervised in the urban areas and compared with the profiles obtained from the finer data to ensure a good correspondence between the resampled data and the original DEM.

Many mesh sizes were tested in order to balance a manageable computational time required for modeling and parameter setting while maintaining the resolution as good as possible to allow the correct representation of flooding, especially in the urban areas. The final size that best fulfilled the requirements was nine arc seconds (approximately 270m) mesh. The simulation time was sufficiently reduced in order to allow the parameter setting, and the mesh size was small enough to allow the spatial and depth differentiation in the mid-stream of the basin, where the main settlements are located. As shown in Figure 17, the height of the floodplain is maintained. The channel information is lost, but it is added using the RRI model, based on the cross-sections and channel equations.

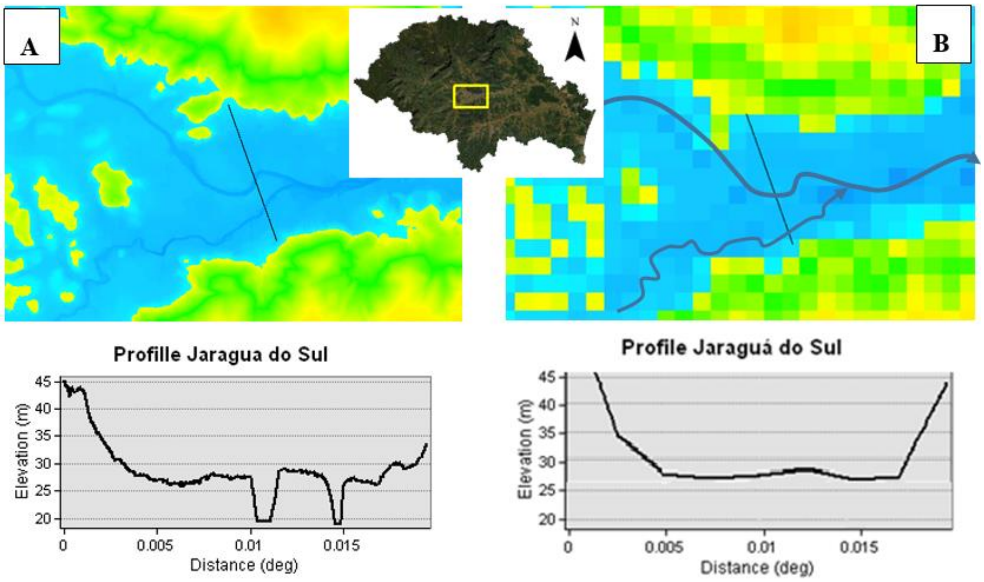


Figure 17 - Profile made in the confluence of the Itapocu River and the Jaraguá do Sul River in the Jaraguá do Sul City area. A - Original 1m resolution source data and B – 9 arc second resampled data.

For defining the channel width and depth, a combination between the upstream contributing equations and the available channel cross-sections was used. Since RRI assumes a rectangular shape for the channel, key cross-sections at Corupá, Jaraguá do Sul, and Guaramirim Urban areas were used to define a channel through the equations of upstream contributing area. Then, the capacity of 58 cross-sections in important areas of the rivers was calculated, and a rectangular shape was derived from this capacity (Figure 18). Those values were inputted manually in RRI to represent local variations of the channel (Figure 19).

The parameters used in the channel contributing equations were Cw 0.65, Sw 0.664, Cd 0.45, and Sd 0.34.

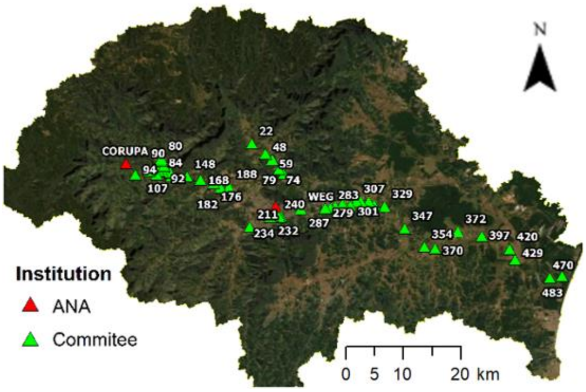


Figure 18 - Distribution of the cross-sections.

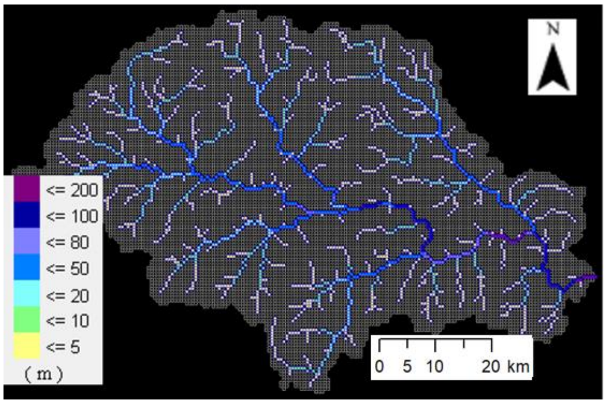


Figure 19 - RRI template showing river cells.

The RRI also uses soil classification and land use as input data. This data can come from local sources, or it can be directly imported by RRI using global data. The global data used by RRI is the GLCC-v2 (Global Land Cover Characterization) provided by the United States Geological Survey (USGS). For the Itapocu river basin, the global data gave a homogeneous soil classification as clay. The land cover identified 20 different classes. For RRI parameter creation, that large amount of classes is too detailed. Therefore, some generalization must be made for assigning the regions with different parameters. The land cover was, therefore, reclassified as Urban, Vegetated, and Cropland (Figure 20), which resulted in two-parameter regions (Figure 21).

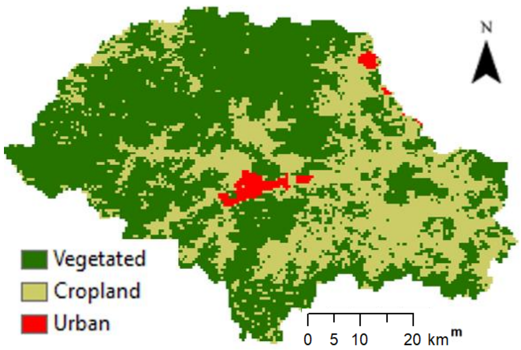


Figure 20 - Land cover map reclassified from RRI global data.

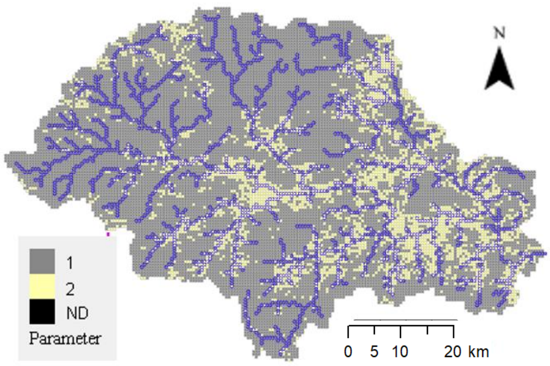


Figure 21 - Regions of homogeneous parameter setting in RRI.

3.3.4 Calibration and Validation

The model was calibrated for the 2014 flood event, which took place in early June. An 11-month series was chosen, ranging from 09/01/2013 to 07/31/2013. The calibration was performed both using observed discharge and comparing the highest inundation result of the model with the observed inundated area given by field survey.

The 2014 calibrated inundation has an area slightly overestimated in comparison with the one observed in the surveyed areas (Figure 22). The inundated area observed in the survey was 32.84 km², and the area in that same region given by the model is 46.22km², using the threshold of 0.3m for defining the inundation. Since the flood map brings no information about surveyed depths, there was no field evidence to set the best threshold for comparison. Therefore, calibration by comparing inundated areas was carried out only visually, focusing on the best fit of the discharge for defining the parameters. Another reason for the areal difference can be the cell size being too large to representing small inundated areas.

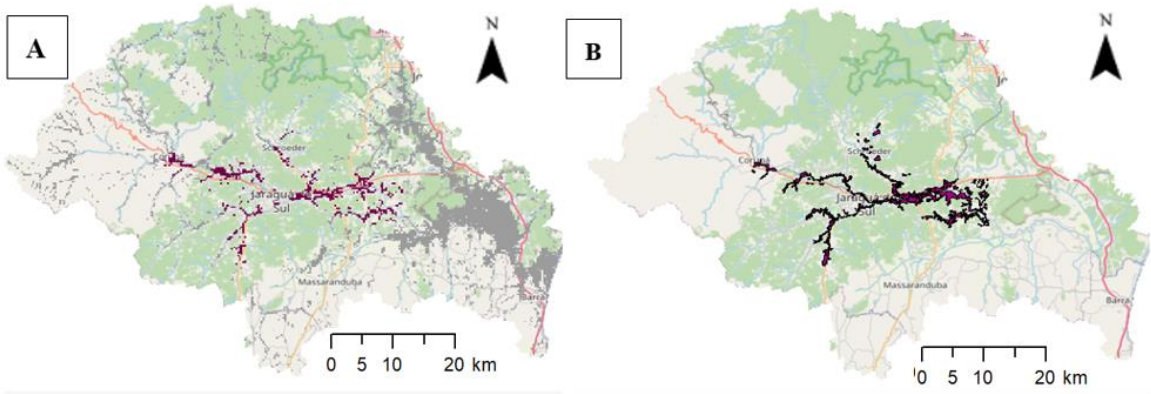


Figure 22 - Comparison between A - Inundated area (purple) given by the model and B - the surveyed inundation map for the 2014 event in the urban areas.

The high discharge events in this basin are characterized by a well-pronounced peak discharge with a short duration. Therefore, the calibration aimed to best fit this peak to produce a better response to flooding events. The Nash Sutcliffe Model Efficiency Coefficient (NSE) was then calculated for the period of 05/01/2014 to 07/31/2014; the results were 0.821 for Jaraguá do Sul station (Figure 23) and 0.852 for Corupá station (Figure 24).

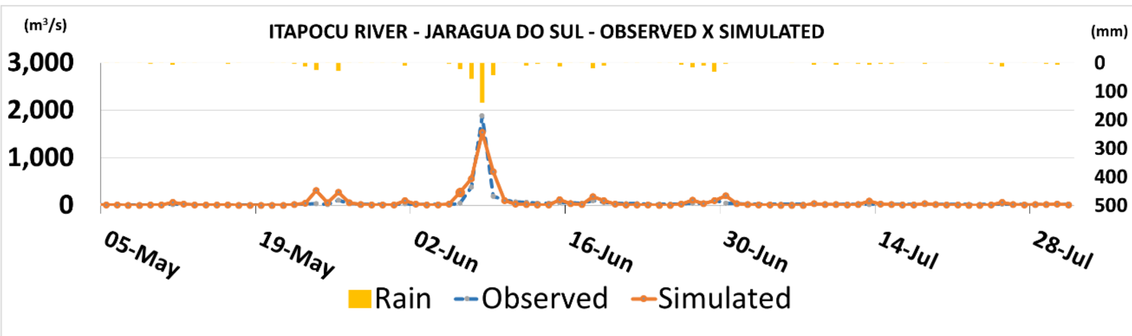


Figure 23 - Comparison between observed discharge at Jaraguá do Sul station and simulated.

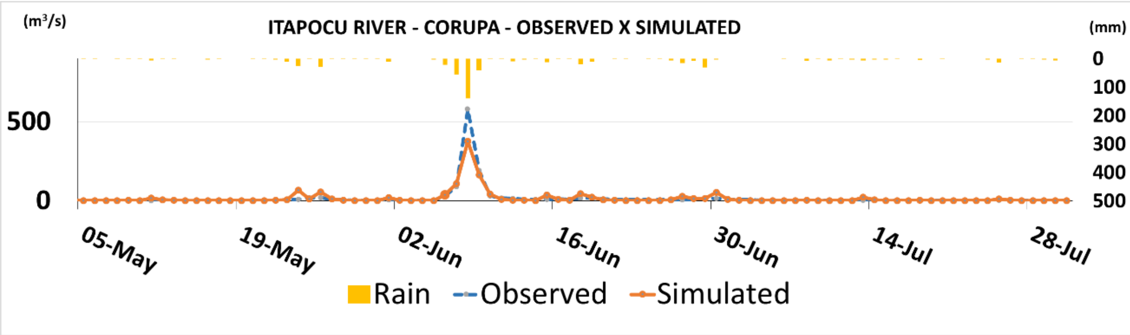


Figure 24 - Comparison between observed discharge at Corupá station and simulated

The inundated area given by the model was crossed with the household raster. That operation resulted in a total of 8,363 households affected by floods (more than 0.5m from street level) in the whole basin. According to an assessment made by the World Bank (2017), 11,167 households were affected by the 2014 flood. Some factors that can lead to this underestimation are the cell size adopted for the simulation (9 arc seconds ~270m), which is too general to represent small variations on the relief and uncertainties on the household data. Another reason can be the threshold of 0.5m to account for damaging the houses. Since the construction pattern varies in Brazil, some households might have suffered damage even with a lower inundation height.

The validation was performed using the 1992 event, which also occurred in early June. The series range was the same, from 09/01/1991 to 07/31/1992. A one-day shifting was observed, suggesting a problem with the calibration or a problem with the data. By examining the Integrated System of Disaster Information (S2ID) emergency state declaration data (Mickosz 2019), the city of Massaranduba reported flooding on May 28th (S2ID code 4210605), one day before the observed discharge in the Jaraguá do Sul station. Since the one-day shifting happened throughout all the series, the NSE was calculated for the period of 05/01/1992 to 07/31/1992 by manually correcting the shifting. The results were 0.865 for the Jaraguá do Sul station (Figure 25) and 0.805 for the Corupá station (Figure 26).

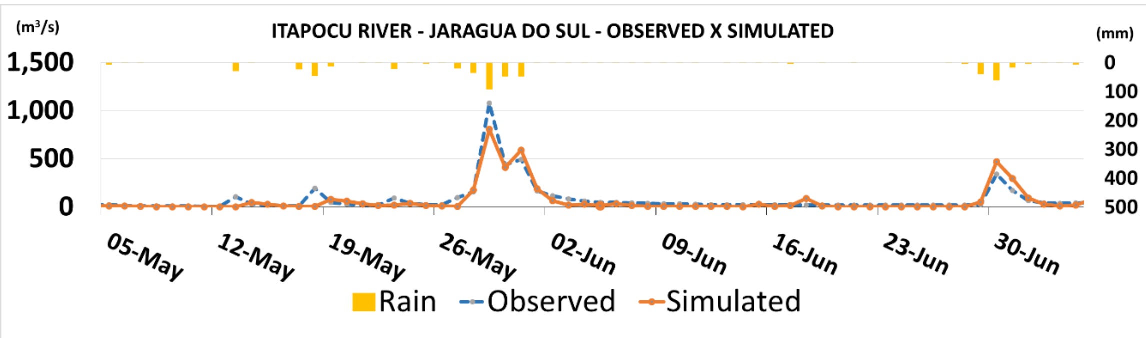


Figure 25 - Jaraguá do Sul station observed versus modeled discharge after shifting correction.

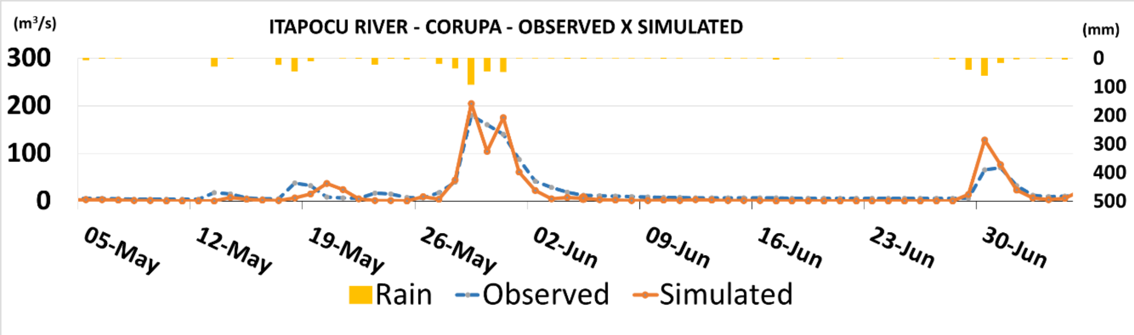


Figure 26 - Corupá station observed versus modeled discharge after shifting correction.

The data was validated for the 1987 event to double-check the shifting problem. The series range was from 06/01/1986 to 04/01/1987. Again, a one-day shifting was observed throughout all the series. By examining the S2ID data (Mickosz 2019), the city of Jaraguá do Sul reported flooding on February 13th (code 4208906), one day before the observed discharge in the Jaraguá do Sul station. That finding corroborates the assumption that the shifting possibly is related to a problem with the input data, either rainfall or discharge. The NSE was calculated for the period of 05/01/1987 to 07/31/1987 by manually correcting the shifting. The results were 0.828 for the Jaraguá do Sul (Figure 27) station and 0.623 for the Corupá station (Figure 28).

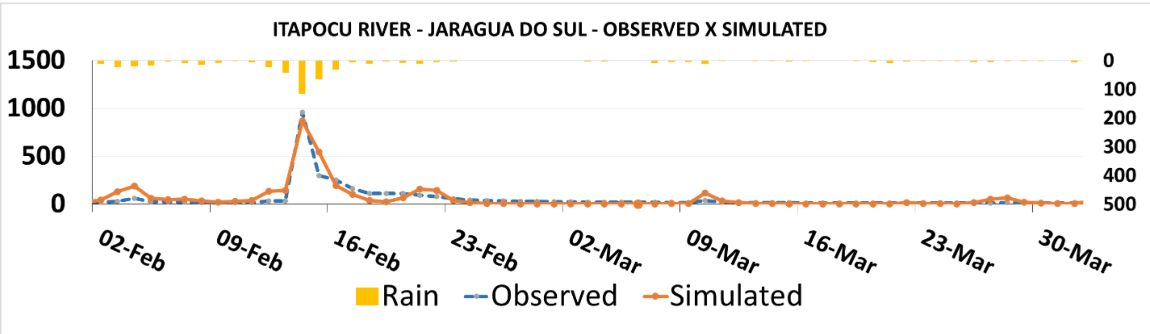


Figure 27 - Jaraguá do Sul station observed versus modeled discharge after shifting correction.

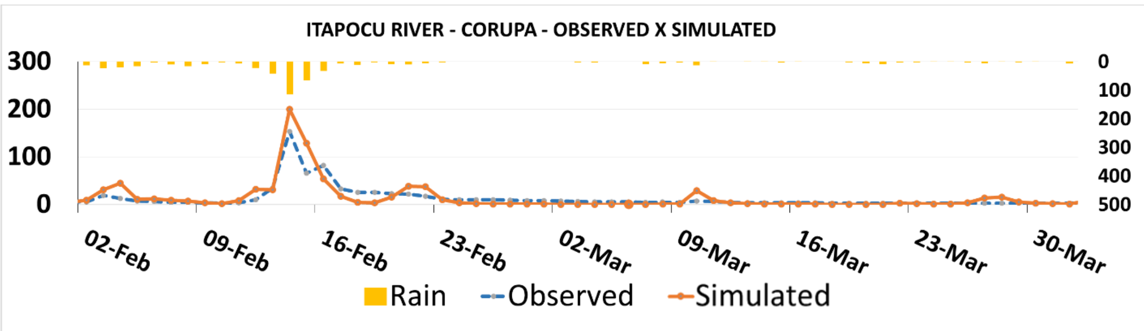


Figure 28 - Corupá station observed discharge versus modeled discharge after shifting correction.

The final parameters for the Itapocu river basin were set in RRI as follows (Table 5).

Table 5 - Parameter values for RRI

Parameter	Value 1	Value 2
River roughness	0.015	0.015
Slope roughness	0.15	0.15
River threshold (used to determine river cells)	30	30
Soil depth (m)	0.2m	0.2m
Ka (m/s)	0.267	0.0
Ksv (m/s)	0.0	0.0

3.4 Census Data Treatment

3.4.1 The Modifiable Areal Problem

Many works point out that the poorest are the most exposed to natural hazards (Hallegatte et al. 2017). On the national level, Bangalore (2018) used global data to make an assessment of exposure to floods in Vietnam using district-level poverty maps. For local community assessment, usually, a local household survey is done. Brower (2007) applied a questionnaire to identify the characteristics of the population affected by floods in Bangladesh. Nascimento (2007) applied a questionnaire on the affected population by floods in Brazil, following the Brazil criteria, which replaces income survey by the assessment of the educational level of the household members, access to public services, and quantification of certain assets to estimate a consumption level of a family. However, these methods require the application of a questionnaire on the interest population. For this study, the impact assessment was made unidimensionally, based on the household income provided by the census.

The 2010 Census is the best countrywide available data of this kind despite being ten years old. Therefore the results of analyzing this data will reflect the reality of the population in 2010 and might present some differences concerning the present-day situation.

The Census data is researched by houses and by people as fundamental units, but the individual information is not released to the public to preserve the privacy of the respondents. The data is therefore aggregated into an area unit, and only then it is released to the public access. The smallest unit of the Brazilian census is the census tract (IBGE 2011). This division of the territory respects the existing administrative boundaries, such as city boundaries, and its dimensions are set accordingly to the amount of population residing in the area. The limits of the areas can be revised if there is a change in the residing population (IBGE 2011; IBGE 2016).

The 2010 Demographic Census was collected on August 1st on October 30th of 2010, using 316,574 census tracts. The method of data collection was through face-to-face interviews by the enumerator; the answer is recorded on a handheld computer or by completing a questionnaire (IBGE 2016).

Because the Census data is released in an area unit with no fixed dimensions, the analysis of the data without any correction may be biased (Lam 1983, Openshaw 1984). The bias that comes from aggregated data into an aerial unit is well known in Geography as the Modifiable Areal Unit Problem (MAUP). For the census data, the non-modifiable area unit can be considered as the households, since they are the unit of collection of the information. The modifiable area unit can be understood as the census tract since its boundaries are defined by the operational requirements of the census (Openshaw, 1984).

According to Openshaw (1984, 1977), the MAUP error can be composed of two main problems: the scale problem and the aggregation problem. The scale problem is the variation of the results that are obtained 'when a data of a small areal unit is aggregated into larger areal units.' The aggregation problem is the variation that comes on the 'many possible combinations of areal units of the same scale that can be used to display a set of information' (Figure 29).

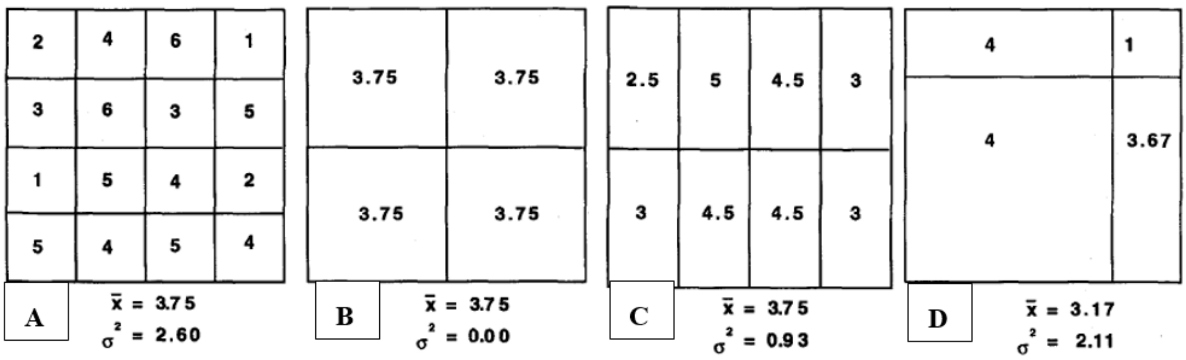


Figure 29 - Effects of MAUP error on the real data (A). Scale problem (B) and Aggregation problem (C and D). (Jelinski & Wu, 1996)

Interpreting the results of area aggregated data without considering this bias may lead to the ecological fallacy problem, which is closely related to the MAUP (Openshaw 1984).

An ecological fallacy occurs when it is inferred that results based on aggregate zonal (or grouped) data can be applied to the individuals who form the zones or groups being studied. In a geographical context, the individuals can either be zones prior to a subsequent aggregation or non-modifiable entities. (Openshaw 1984, p. 8)

That corresponds to assuming that the information inside the census tract is true for all the households inside that area, without considering that the information was previously aggregated. The information aggregated in the census tract is displayed as homogeneously distributed, but it is very unlikely that this situation reflects the reality. An example of misleading interpretation can be seen below. The census tracts with the highest number of households are located in the northeast of the image (Figure 30 A). Nevertheless, the city center is located in the southeast (Figure 30 B). The information is influenced by the size of the census tract.

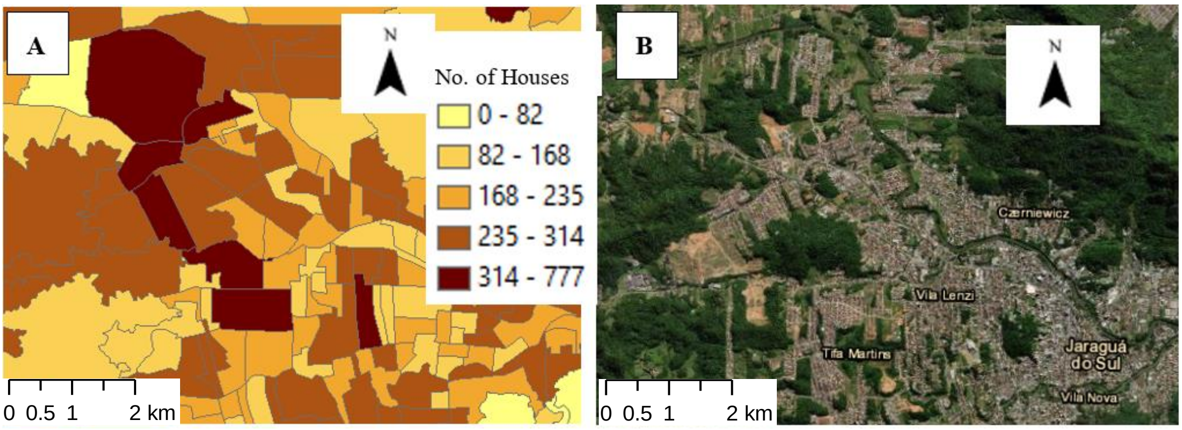


Figure 30 - (A) Census tract colored by number of households in Jaraguá do Sul city. (B) Satellite image shows the city center in the southeastern part of the image.

For inundation impact analysis, the assessment of the affected households is completely dependent on their position in space. Only the households that are located on the floodplain are expected to be affected. The geomorphology is not used as a rule for defining the census tracts' boundaries, so it is also expected that those aerial units will not be entirely located in the floodplains. Thus, the flooded areas will most likely affect the census tract only partially. In such a case, unless some correction is done in the data, the analysis may be led to the ecological fallacy problem (Figure 31).

One of the main errors that can happen in this kind of analysis is to count the affected population in empty areas. Since the census tracts are contiguous areas, they are also comprised of uninhabited areas, which are grouped with inhabited areas to form one census tract. For the population impact analysis by flooding, it is paramount to remove those empty areas to avoid the ecological fallacy problem (Figure 31).

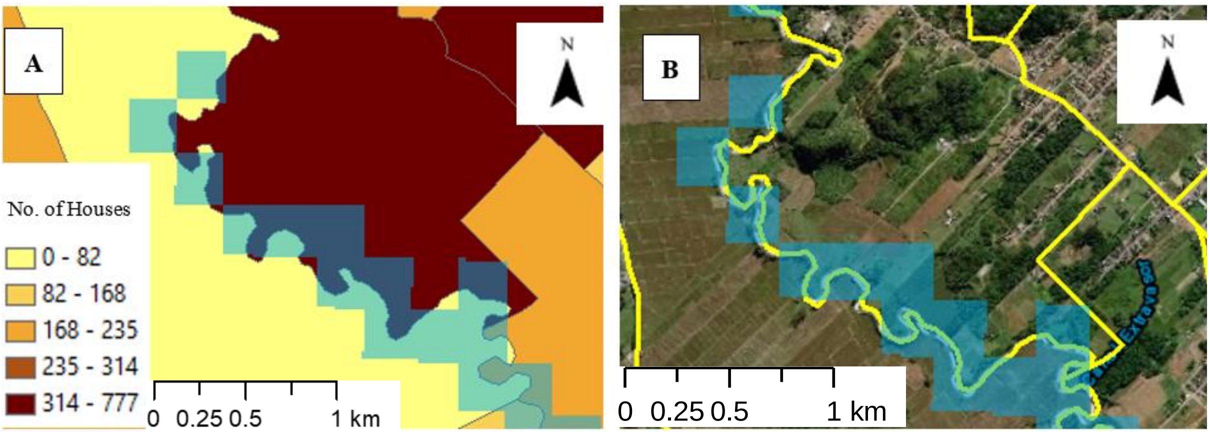


Figure 31 - Flooding area (blue) over affected census tracts in Schroeder city (A) Census tract colored by the number of households. Satellite image (B) shows the households are outside the flooding area.

3.4.2 Data Sources

The census tracts, the "Grade Estatística" in shapefile format, and tables containing the results of the 2010 census were downloaded from the IBGE website. For income data, a table named "Domicilio Renda" (Income Household – free translation) was used, which provides information about the income of the household *per capita*. From this table, the total of households in each census tract was extracted.

3.4.3 Error Map

For assessing the error between the Census tract information and the "Grade Estatística," an error map was assembled. A common variable between the census tracts and the "Grade Estatistica" was chosen to make comparisons. Since the "Grade Estatistica" only has information about the total population and total households inside the cell, the household information was chosen to make this analysis by making a comparison between the household density of the two products.

First, the household densities of the census tract and the Grade Estatística were calculated and transformed into raster. In a census tract, the data is assumed to be homogeneously distributed; therefore the census tract household density was calculated by dividing the household total by the tract area. After that, it was transformed into a raster with the same dimensions as the "Grade Estatística". The "Grade Estatística" is a fixed mesh; therefore, the household total was simply divided by the cell area to obtain a household density raster.

The result of this subtraction is the error map, which shows how much and in what location the census tract data underestimates or overestimates the household density in comparison with the "Grade Estatistica." This map also shows where the biases are more likely to happen (Figure 32).

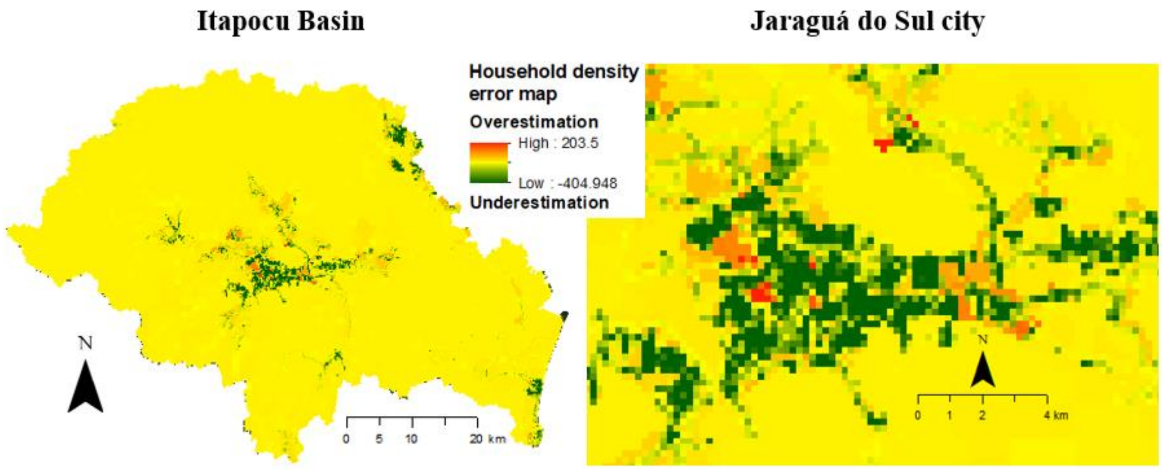


Figure 32 - Error maps between the "Grade Estatistica" and the Census tract. In the left, whole basin is portrayed and in the right the Jaraguá do Sul city is zoomed.

From the error map (Figure 32), it is possible to see that by assuming a homogeneous distribution of households in relatively large areas, the census tracts underestimate the number of households in the areas of high density, such as city area (green colors), as low as 404.2 households/km². Additionally, it overestimates the number of households in low-density areas (Red colors) as high as 203.5 households/km².

This assessment corroborates the studies from Oppenshaw (1983). The biases in total affected households will occur if the census tracts are the only data used to analyze the population affected by localized phenomena such as flooding.

3.4.4 Bias removal techniques

Many methods can be employed to remove bias from the analysis. Point and areal interpolations are performed without any ancillary data (Wu 2007; Lam 1983). Information from the census tracts can be also refined by using another product as ancillary data (Figure 33). These methods are known as dasymetric and were greatly improved after the GIS technology (Wu 2007; Mennis & Hultgren 2006; Eicher and Brewer 2001; Langford and Unwin 1994).

Dasymetric mapping is a technique applied to datasets that have been aggregated into zones whose boundaries are not derived from the variation of data itself but from some convenience of research. It consists of disaggregating data and using ancillary data that is related to the variation of the dataset, aggregating it into meaningful zones (Figure 33). The interpolation quality depends on how much the ancillary data is related to the data source (Mennis & Hultgren 2006). The dasymetric approach can improve the resolution of the source data, therefore, reducing the areal biases (Wu 2007; Mennis & Hultgren 2006; Eicher and Brewer 2001; Langford and Unwin 1994).

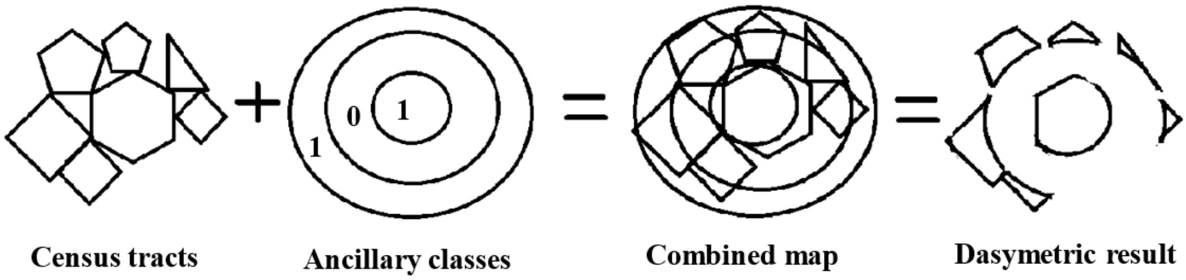


Figure 33 - Dasymetric mapping diagram showing the result of the combination between the census tracts and the ancillary classes.

The most common method of dasymetric mapping is the binary method, in which ancillary data has only two classes: populated and uninhabited (Gallego 2010; Wu 2007; Langford and Unwin 1994). Another type is the Intelligent Dasymetric Mapping method proposed by Mennis & Hultgren (2006). For this study, dasymetric maps were made by using the "Grade Estatística" as ancillary data.

For the 2010 census, IBGE released the "Grade Estatistica" additionally to the usual census tract related data. It represented an innovation in the Brazilian census because it consists of convenient mesh format available nationwide and contains information about the number of residents and the number of households inside each cell. The cell size of this mesh is 200x200m for urban and suburban areas and 1000x1000m for rural areas. It is released in shapefile format, and the population information is available in its corresponding attribute table (IBGE 2016). The size of the cells, both in urban and rural areas, are usually smaller than the census tracts. Therefore, the "Grade Estatistica" can be considered as data with better spatial resolution. Because of these characteristics, the data can be used as ancillary data to combine with the census tract.

In contrast with the usual census tracts, the mesh boundaries are independent of operational conveniences of the census works and are constant over time. The product additionally brings information about empty areas, convenient for avoiding the MAUP error and the ecological fallacy problem in the analysis of the census data (Bueno 2014).

3.4.5 Dasymetric maps

As discussed previously, a key factor for ensuring the quality of dasymetric maps is to adopt ancillary data that has a strong relationship with the source data distribution. The household income data is always related to households. Therefore, it is easily understandable that the household distribution is related to the source data distribution. Where there are no houses, no income data should be displayed. Additionally, the higher the concentration of households within a census tract area, the higher the probability of finding any of the income levels or whatever census tract data that is related to the households.

The "Grade Estatística" has both information about the total number of households and the total number of the population inside the cell, but there is no other information attached. Nevertheless, it can be used to build ancillary data with a strong relationship with income data. By linking the grid data with extra information that exists in the census tract, the possibilities of the "Grade Estatística" are expanded.

Dasymetric maps, in this case, are the result of multiplication, in GIS, of the household raster, obtained from the "Grade Estatística" and multiplier rasters obtained from the census tracts. An advantage of this approach is that it only requires census data. Because census data is nationally available, the method can be applied anywhere in the country for a wide variety of studies related to population, not only restricted to flood impact.

The multipliers were assembled in terms of the percentage of households that fall in a specific income level. Each variable (or level) of the census tract was transformed into a multiplier raster that reflects its percentage within the census tract's original boundaries. The resultant raster shares the total of households between the census tract levels according to their percentages (Figure 34). The procedures made for building dasymetric maps are summarized as follows.

1 – Derive the density of variables and the percentage of variables from the source data

2 – Transform each variable in terms of density and percentage to raster

3 – Directly multiply the percentage raster by the household raster

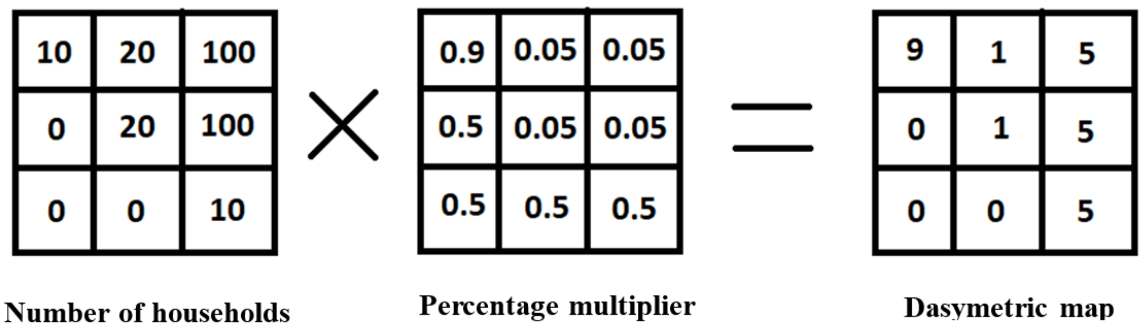


Figure 34 - Diagram for building the raster dasymetric maps from the "Grade Estatística".

The multipliers were, therefore, used to separate the household raster into income levels, this information is the basis for the assessment.

The income data is already divided by the census into ten income levels, based on the number of minimum salaries earned by the household shared by each household member (*per capita*). It is given in minimum salaries per month, separated in 10 levels.

The income levels originally found in the table are, from the lowest income to the highest: Households with no income; Households below 0.125 minimum salaries; Households between 0.125 and 0.25 minimum salaries; Households between 0.25 and 0.5 minimum salaries; Households between 0.5 and 1 minimum salaries; Households between 1 and 2 minimum salaries; Households between 2 and 3 minimum salaries; Households between 3 and 5 minimum salaries; Households between 5 and 10 minimum salaries; and households above 10 minimum salaries. Therefore, the multipliers of the index maps were built using the percentage of those levels with respect to the total number of households.

The preliminary data for twelve municipalities of the Itapocu river basin shows that many of the levels found in the census table are not expressive. The first three lower levels and the last highest level comprise less than 5% of the households. Therefore, they were aggregated into six meaningful levels for making dasymetric maps (Figure 35).

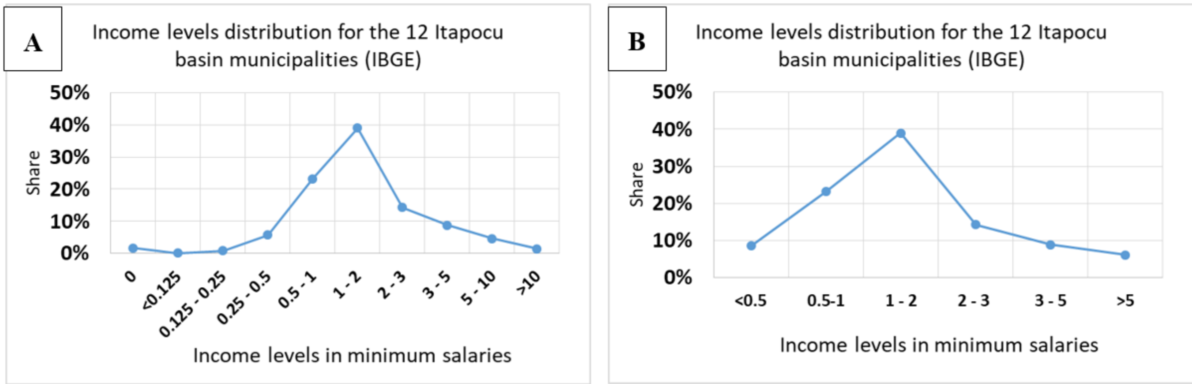


Figure 35 - (A) Original income levels distribution, (B) Aggregated income level distribution

The multiplier raster was finally assembled based on the aggregated income levels (Figure 35 B). It was then combined with the household raster, and a dasymetric map was obtained for each income level.

4 RESULTS AND DISCUSSION

4.1 Model Results

4.1.1 Hydrological Simulation Results

After calibration and validation, the final simulation was performed for 2-, 5-, 10-, 20-, 50- and 100-year return periods, using the design rainfall, resulting in the inundation maps. The inundation raster was classified based on a lower threshold for starting damage to the households.

Even though some households might suffer damage with low inundation levels, it is necessary to account for the lack of pattern in Brazilian constructions. Depending on the threshold adopted, the inundation area can vary considerably. Thus a low-level threshold of inundation might lead to overestimating affected households and damage. Nascimento (2007) adopted a lower threshold of 0.2m for the damage assessment of a medium-sized city in southeast Brazil. Dutta et al. (2003) adopted 0.4m for assessing inundation damage in Japan. Nagem (2008) assessed damage in an urbanized basin in Brazil using a threshold of 0.5m. Nagem determined the threshold by taking into consideration the elevation of the sidewalks from the streets, 0.15m, and the houses from the sidewalks, 0.35m. The lower threshold for defining the inundation area in Itapocu River Basin was set as 0.5m in accordance with Nagem (2008).

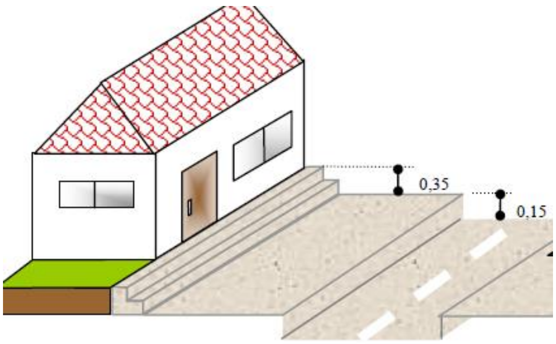
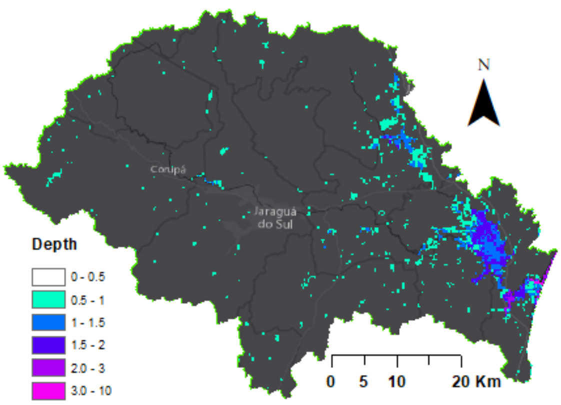
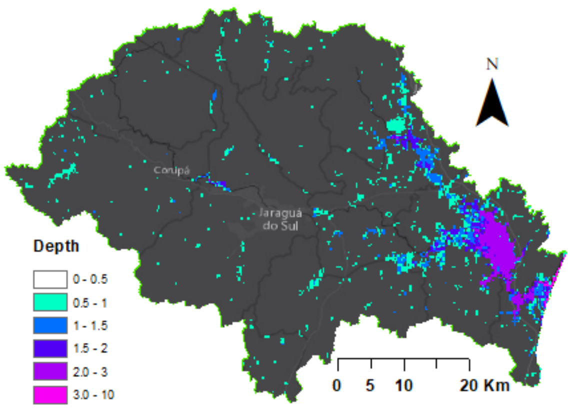


Figure 36 - Average height of constructions.
Source: Nagem (2008).

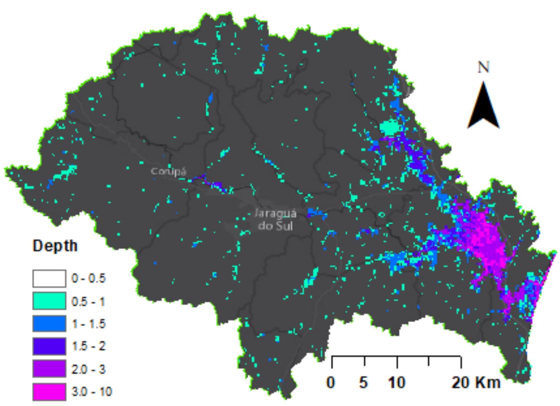
The individual inundation maps can be seen below (Figure 37). The overall results of the inundated area and affected households are summarized in Table 6.



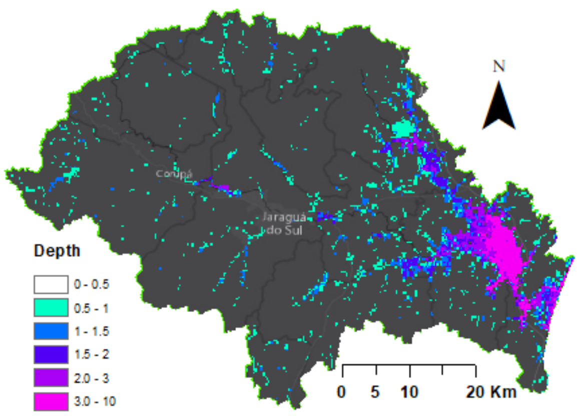
(A) 2 year return period inundation



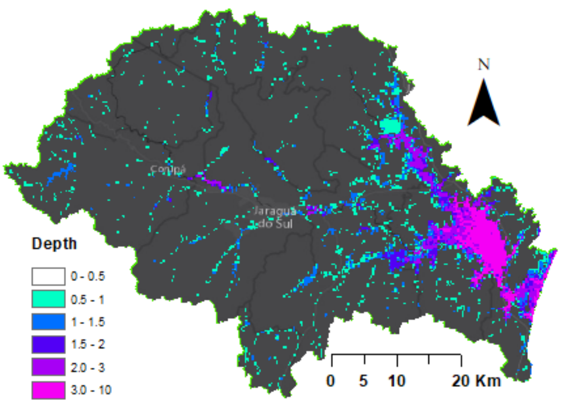
(B) 5 year return period inundation



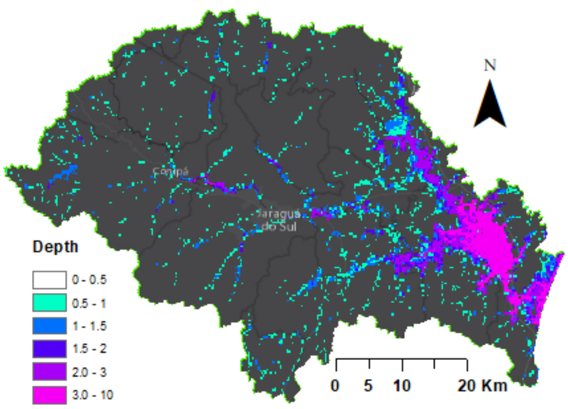
(C) 10 year return period inundation



(D) 20 year return period inundation



(E) 50 year return period inundation



(F) 100 year return period inundation

Figure 37 - Inundation maps for six return periods

The Hazard Map for the Itapocu river basin can be seen below, with the corresponding flood extents for the 2-, 5-, 10-, 20-, 50- and 100 year return periods (Figure 38). A bigger version of this map can be seen in the Appendix C. For the next step, each inundation event was considered individually.

Table 6 - Simulated Return periods, area and households affected.

Return Period	Inundated Area Km2	% of the basin	Households Affected	% of the total
2	155.9	5.3%	2,370	3.0%
5	237.9	8.2%	3,647	4.7%
10	285.7	9.8%	4,891	6.3%
20	330.8	11.3%	7,467	9.5%
50	386.1	13.2%	10,603	13.6%
100	425.5	14.6%	12,630	16.1%

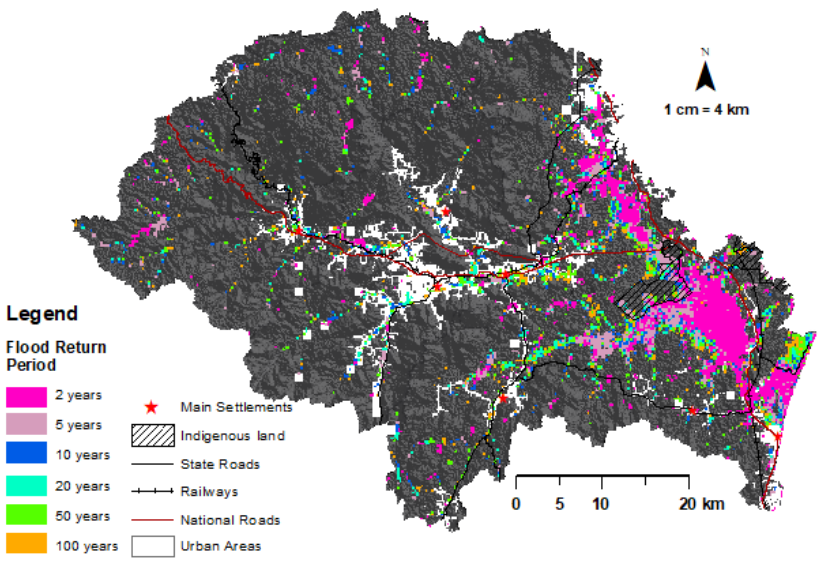


Figure 38 - Itapocu river basin hazard map for six return periods.

4.1.2 Dasymetric mapping results

The dasymetric maps successfully divided the households of the "Grade Estatistica" into the 6 aggregated income levels, as described in the previous section (Figure 35).

A comparison between the original census tracts boundaries and the dasymetric maps for the lowest (<0.5 minimum salaries) and the highest (>5 minimum salaries) income levels can be seen in

Figure 39 and Figure 40. The census tract information is distributed homogeneously in areas of variable dimension (Figure 39 A and Figure 40 A). After applying the dasymetric method, the information is upscaled to a regular mesh of 200 x 200m according to the "Grade Estatística" household distribution (Figure 39 B and Figure 40 B). This process successfully reduces the MAUP bias (Openshaw 1983) on the following analysis of the data, and the improvement of the spatial resolution of the data is significant when compared with the original census tract. The dasymetric maps for all income levels can be found in Figure 41. By analyzing the dasymetric maps, it is possible to identify the location of the dwellings by income level. For example, the highest income level in Itapocu river basin concentrates mostly in the Jaraguá do Sul city center (Figure 40 B), while the lowest is more dispersed towards the edges of the city and rural areas (Figure 39 A).

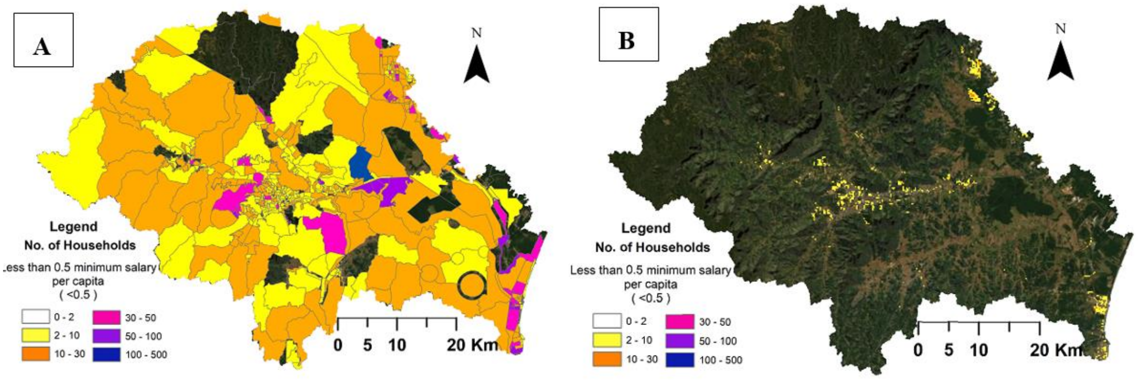


Figure 39 - Distribution of the lowest income households that earn less than 0.5 minimum salaries. (A) Census tracts original information and (B) Dasymetric map.

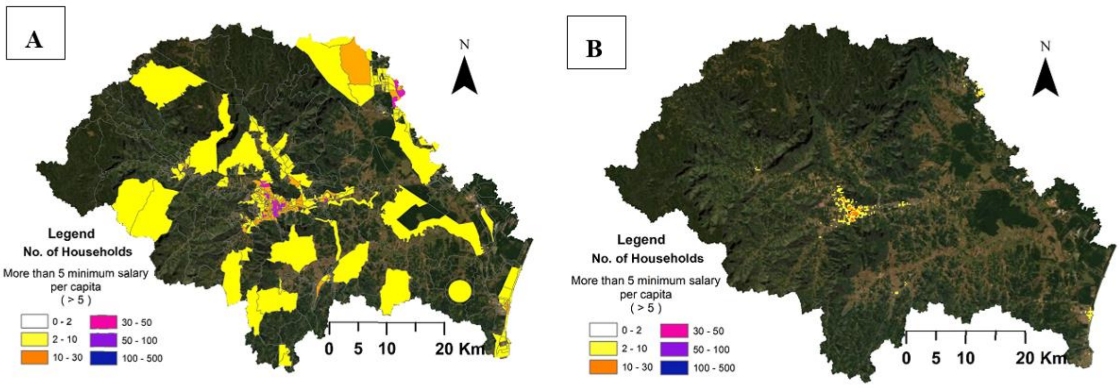
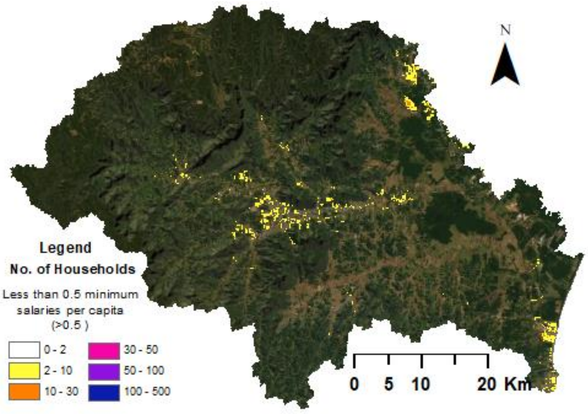
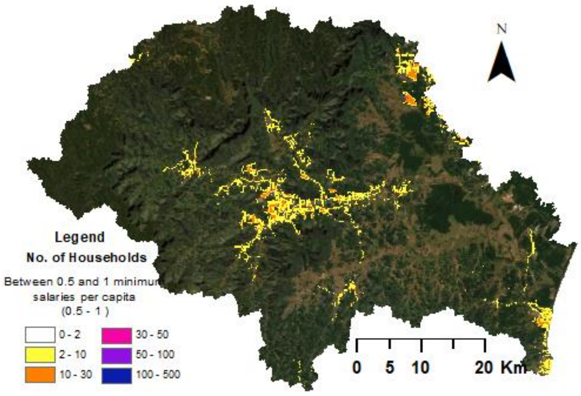


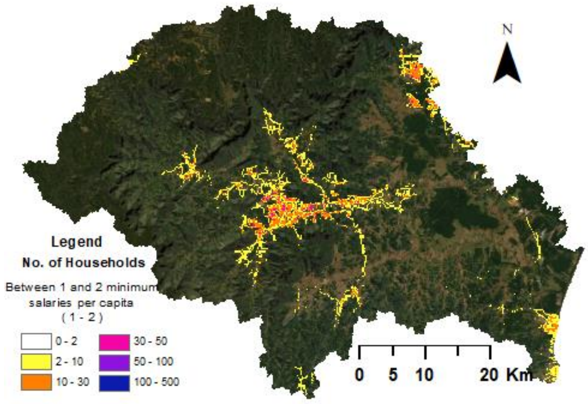
Figure 40 - Distribution of the highest income households that earn more than 5 minimum salaries. (A) Census tracts original information and (B) Dasymetric map.



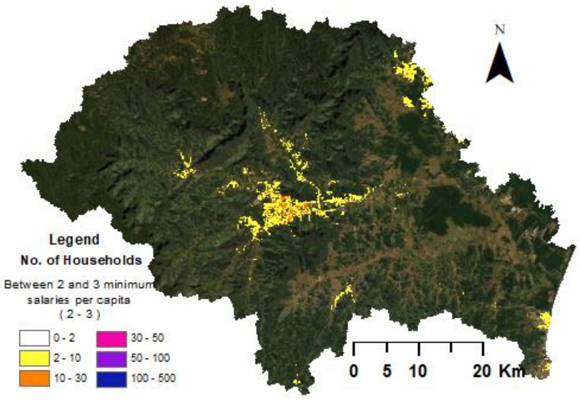
(A) - Households that earn less than 0.5 minimum salaries *per capita*



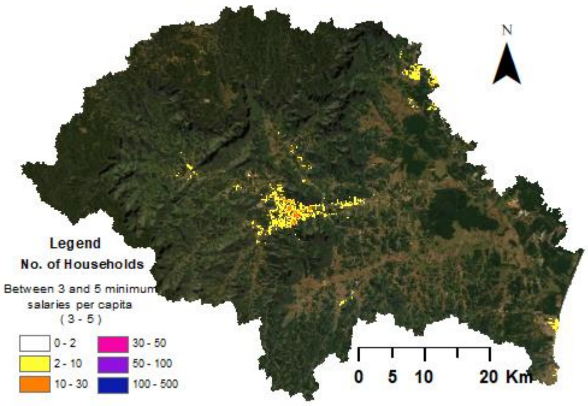
(B) - Households that earn between 0.5 and 1 minimum salaries *per capita*



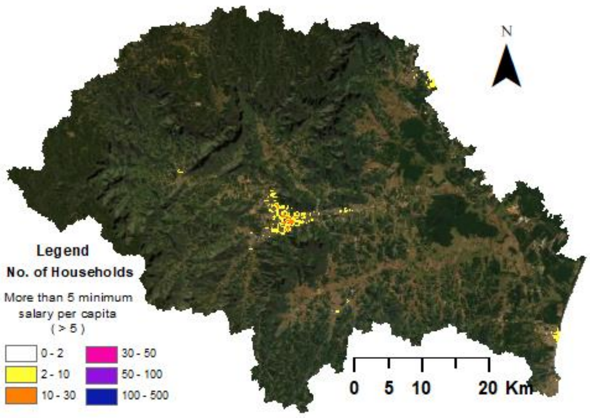
(C) - Households that earn between 1 and 2 minimum salaries *per capita*



(D) - Households that earn between 2 and 3 minimum salaries *per capita*



(E) - Households that earn between 3 and 5 minimum salaries *per capita*



(E) - Households that earn more than 5 minimum salaries *per capita*

Figure 41 - Dasymetric maps for the six aggregated income levels

From the dasymetric maps, a new share of households by income levels was obtained, considering only the cells that fall within the Itapocu river basin area (Table 7).

Table 7 - Households by income level

Lowest income

Minimum Salaries	Proportion of households in total	Minimum Salaries	Proportion of households in total
< 0.5	7.7%	**2 - 3**	14.7%
0.5 - 1	23.1%	**3 - 5**	8.0 %
1 - 2	42.2%	**> 5**	4.2%

Highest income

4.2 Estimation of affected households

Each return-period inundation raster was then multiplied by the dasymetric income raster to estimate the total number of affected households. This number is summarized in Figure 42, which shows the absolute number of affected households by income level for return periods of 2, 5, 10, 20, 50, and 100 years.

The data was analyzed from different perspectives. The number of affected households in each class was then divided by the number of the total affected households (Figure 43) to understand the ratio of the affected households by a flood event in comparison with the ratio of the households that exists in the basin (Table 7). Graphically, the values in Table 7 are represented by the red dotted line in the Figure 43. The number of affected households in each income layer was also divided by the total number of households existing in each layer. The result is summarized in Figure 44.

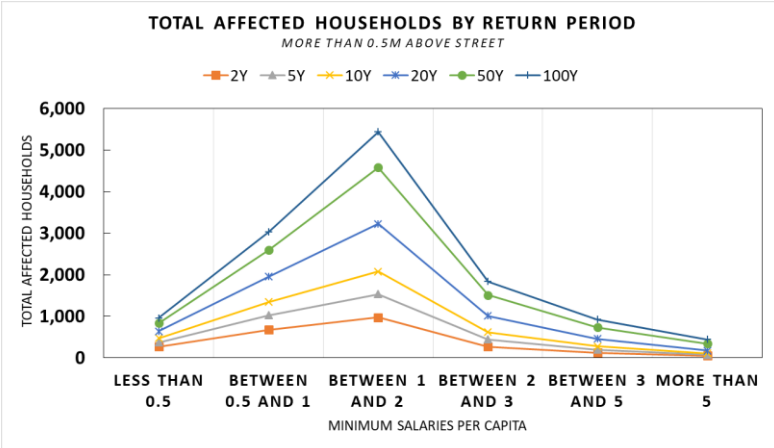


Figure 42 - Total number of affected households by each income level.

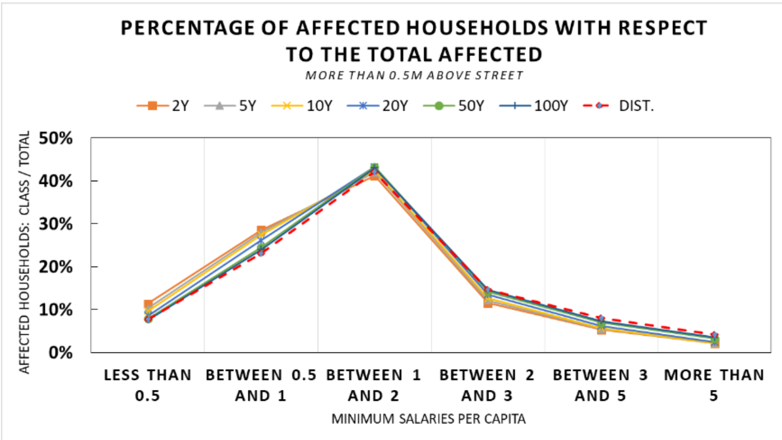


Figure 43 - Percentage of affected households with respect to the total affected. Ratio of households in the basin - red dotted line.

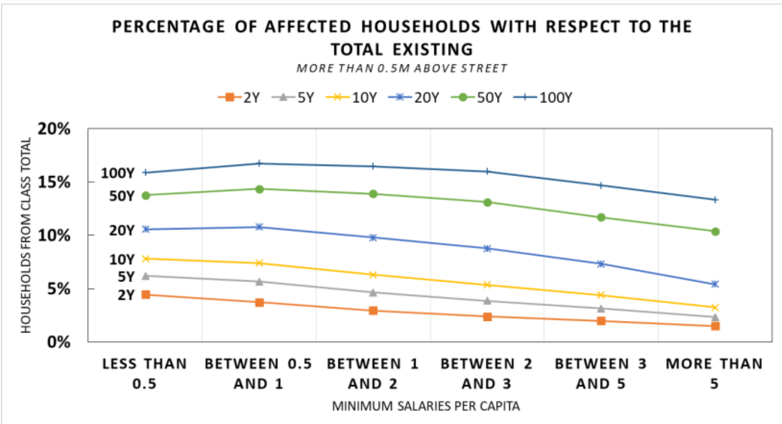


Figure 44 - Percentage of affected households with respect to the total of households inside each level.

For the total flooded area (above 0.5m from the street level), the absolute affected households (Figure 42) is higher in the middle-low income layer (Between 1 and 2 minimum salaries *per capita*) for all the return periods. That result is coherent with the distribution of the income levels inside the basin (Table 7), since it is the most populous layer accounting for 42.16% of the households. Therefore, this layer is expected to have more affected people. Figure 43 shows that, although the overall affected people follow the same pattern as the household income distribution graph (red dotted line), the pattern is not completely followed for the most frequent floods with the lower income levels slightly more affected. From Figure 44, which shows the affected households normalized by the number of households in each class, it is possible to see that the lowest three income levels are more affected by the floods. For the most frequent events, the lowest class is the most affected (Less than 0.5 minimum salaries), and for the less frequent events, the second-lowest is the most affected (Between 0.5 and 1 minimum salaries). The difference between the most affected lowest income levels and the least affected higher levels is the biggest at the 20-year return period flood, reaching 5.3%.

The number of households affected by severe events, with depths greater than 2m from the street level, was also assessed by the income layer. The result is summarized in Figure 45, which shows the absolute number of affected households by economic class for return periods of 2, 5, 10, 20, 50, and 100 years.

The number of affected households in each class was then divided by the total number of affected households to understand the ratio of the affected households by a flood event. The result is summarized in Figure 46. The number of affected households in each income layer was also divided by the total number of households existing in each layer. The result is summarized in Figure 47.

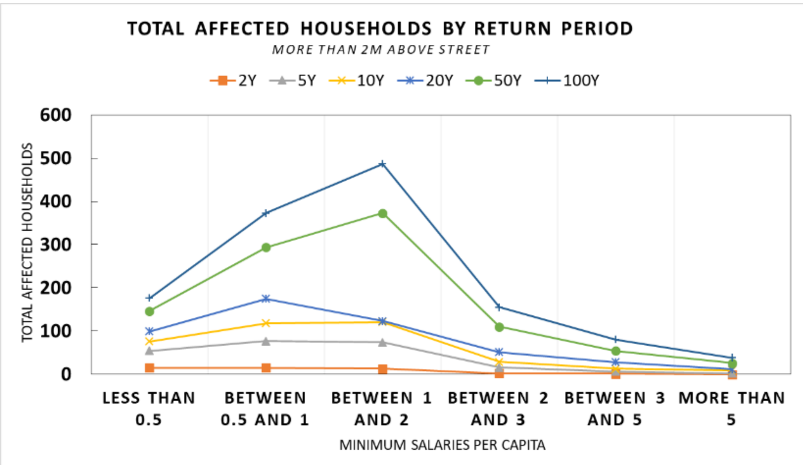


Figure 45 - Total number of affected households by each income level.

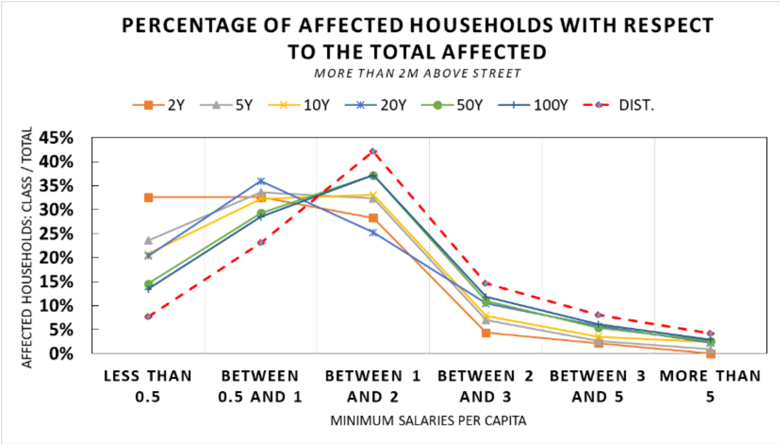


Figure 46 - Percentage of affected households with respect to the total affected. Ratio of households in the basin - red dotted line.

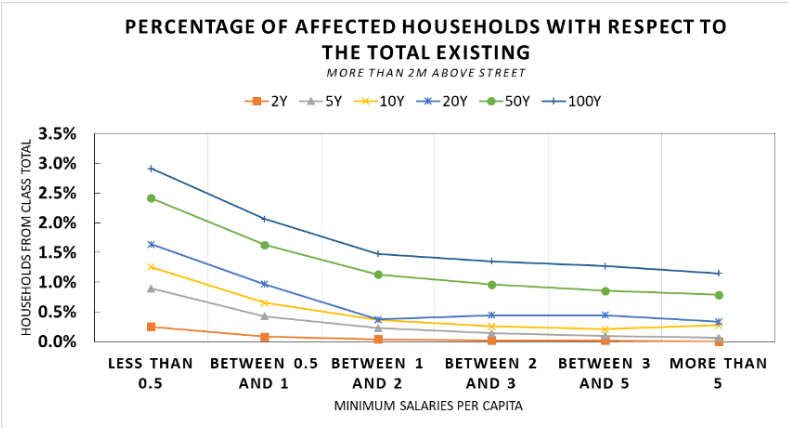


Figure 47 - Percentage of affected households with respect to the total of households inside each class.

For the flooded area by severe events (above 2m from the street level), the absolute affected households are higher in the lower-income levels (Figure 45) for all the return periods. The observed curve is skewed towards the lowest income when compared with the distribution of the levels inside the basin, which is represented by the red dotted line in Figure 46. Figure 46 also shows that the overall affected people follow a different pattern in comparison with the household income distribution graph. The highest three income levels have less affected people, and the lower income levels have more affected people. The lowest income layer, for example, represents 7.7% of the houses in the basin (Table 7), but for the 2-year return period flood, it accounts for 32.6% of the affected people. Meanwhile, the highest income layer represents 4.23% of the houses in the basin, but none of these households were affected. Figure 47, which shows the affected households normalized by the total number of households in each class, confirms that tendency, and it is possible to see that the lowest income levels are more affected than the others for all return periods.

4.3 *Supporting* studies

4.3.1 Recovery capability

A damage assessment was carried out to understand how long the inhabitants of each income layer would take to recover from an inundation. Since the Itapocu river basin only has data from the national government such as IBGE surveys and S2ID global damage records, it was necessary to utilize a general damage curve. Dutta (2003) derived general depth-damage curves for many structures. However, those curves can only be applied by knowing the average value of the assets, since they give damage in percentage damaged.

Due to the lack of damage surveys in Brazil and information on the value of assets, especially on the house contents, a Brazilian damage assessment made for a different region was employed. Nascimento (2007) built depth-damage curves for households in Itajubá city in southeast Brazil. These depth damage curves were compared by Fadel (2015) with a different model made for assessing household damage in the Rio Grande do Sul state in southern Brazil, yielding similar results. Leandro (2017) also used these damage functions as part of his damage assessment framework tested in Iraí city, Rio Grande do Sul state.

The economic and social characteristics of Itajubá and Jaraguá do Sul, the main city of Itapocu river basin, are relatable, although some differences exist. Itajubá is a medium-sized city of 90.658 inhabitants, 63% of the size of Jaraguá do Sul. The average income in Itajubá is 2.9 minimum salaries, and the average income in Jaraguá do Sul is 3.2 minimum salaries. The Human development index of Itajubá is 0,787, while that of Jaraguá do Sul is 0,803 (IBGE 2010). The indices of Jaraguá do Sul city are higher than those for Itajubá city; therefore, some underestimation on the damage in Jaraguá do Sul is expected by applying the same function to both cities. Since the population of the Itapocu river basin is highly concentrated in this city, an underestimation in the basin assessment is also expected, although attenuated by other regions in the basin with lower social indicators.

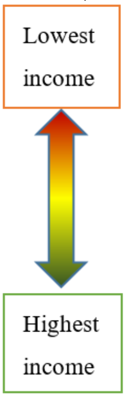
Nascimento (2007) made different depth damage curves according to four social classes A, B, C, and D - where A is the wealthiest class, and D is the poorest. That division was made following the Brazil Criteria (ABEP 2003), a methodology that aims to estimate the purchasing power of Brazilian households for commercial use. A questionnaire and a system of weights are used to classify the population into social classes, and an average income for each class is also divulged. Nascimento (2007) assessed the characteristics of the affected households, including an estimation on the value of their assets, by applying a questionnaire on the population. The final depth-damage curves give the damage by square meter of constructed area.

For applying the curves of Nascimento (2007) to this study, firstly, the average income of the social classes in the Brazil Criteria of 2002 (Br02) was divided by the average members of a household in the Itapocu river basin (HA). Since the questionnaire was applied in 2002, and the census data used for assessing the Itapocu river basin is from 2010, the values were corrected by the General Price Index-Market (IGP-M) given by the Central Bank of Brazil from 2002 to 2010. The result is the average income for each class, *per capita* in values of 2010 (Br10), according to equation 4.1.

$$Br_{10} = \frac{Br_{02}}{H_A} * IGPM \qquad 4.1$$

Then, the income levels of the Itapocu river basin were aggregated, and the weighted average of the income was calculated. The levels that had the best correlation with the (Br10) classes after the aggregation were chosen to aggregate the Itapocu households income levels into social classes (Ip10). The Pearson correlation coefficient between Ip10 and Br10 was 0.999. The six income levels were aggregated into four, according to the best correlation with (Br10), as summarized in Table 8.

Table 8 - Households by income level aggregated into social classes



Old levels (minimum salaries)	Proportion of households in total	New levels (minimum salaries)	Social class (ABEP 2003)	Proportion of households in total
< 0.5	7.7%	**< 1**	**D**	30.9%
0.5 - 1	23.1%			
1 - 2	42.2%	**1 - 2**	**C**	42.2%
2 - 3	14.7%	**2 - 5**	**B**	22.7%
3 - 5	8%			
> 5	4.2%	**> 5**	**A**	4.2%

The depth-damage functions of Nascimento (2007) (Figure 48) were also corrected using the IGP-M index from 2002 to 2010. The final equations are given per social class: equation (4.2) for damage of classes A and B (DAB); equation (4.3) for damage of class C (Dc); and equation (4.4) for damage of class D (DD). In all equations, X stands for the depth of inundation minus 0.3 to correct the difference in threshold adopted by Nascimento (2007) (0.2m) and this study (0.5m) to initiate damage.

$$D_{AB} = (100.83 + 43.29 * \ln X) * IGPM \qquad 4.2$$

$$D_C = (74.69 + 27.39 * \ln X) * IGPM \tag{4.3}$$

$$D_D = (18.05 + 33.36 * \sqrt[2]{X}) * IGPM \tag{4.4}$$

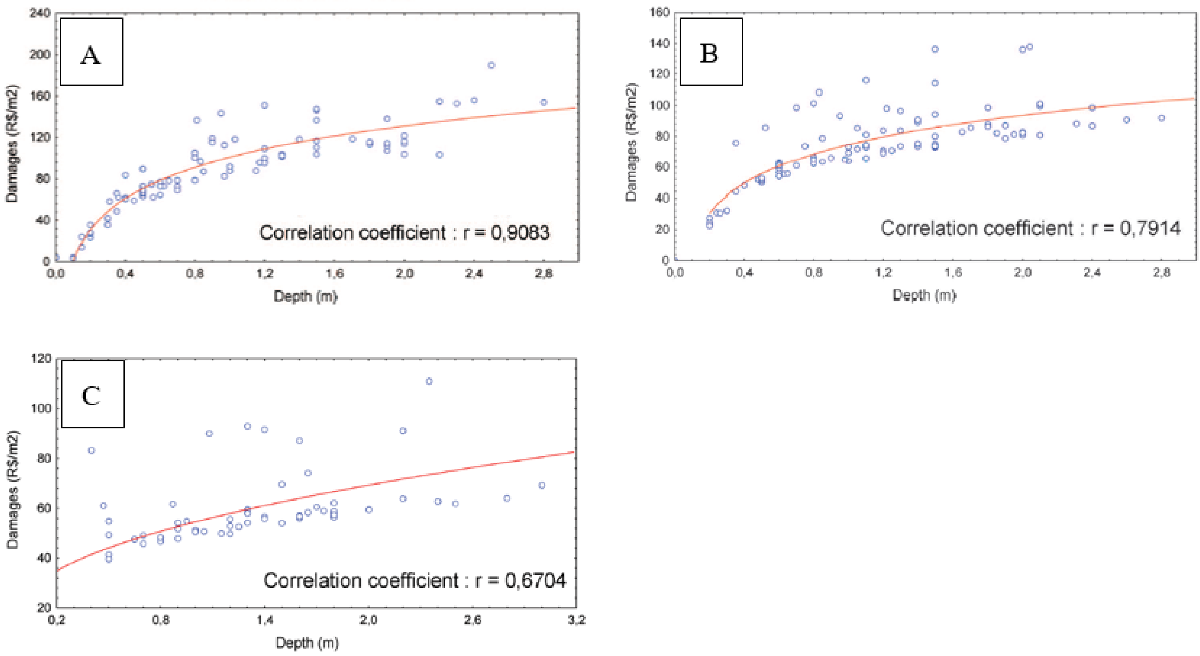


Figure 48 - Depth damage curves for (A) social classes A and B; (B) social class C; (C) social class D. Source: Nascimento (2007).

The final damage for social classes A (DF-A) and B (DF-B), class C (DF-C), and class D (DF-D) is obtained by multiplying the damage per meter square (DAB), (Dc) and (DD) by the average size of a one-story household in Brazil found in the norm NBR 12721:2006 (CUBm2 2006), which is the same used by Nascimento (2007) to build the damage curves. For social class A, the high standard house was adopted with 224.82m². For class B, the regular standard house was adopted with 106.44m². For class C and D, the low standard house was adopted with 58.64m².

Damage estimated due to floods of two different magnitudes, i.e., 0.5m inside the house (1m depth from street level) and 1.5m inside the house (2m depth on street level), is summarized in Table 9, along with percentages that this damage represents from the annual income of each class.

Table 9 - Final Damages for 0.5m and 1.5m depth flood.

SOCIAL CLASS X DEPTH	0.5m	% OF ANNUAL INCOME	1.5m	% OF ANNUAL INCOME
DF-A	35,898.90	23%	52,047.55	33%
DF-B	16,996.17	28%	24,641.67	41%
DF-C	7,118.99	24%	9,784.00	33%
DF-D	5,039.93	42%	6,748.95	57%

After obtaining damage for each social class, the annual income of each class was calculated based on the average income by social class for the Itapocu river basin (I10). The *per capita* monthly income was multiplied by the average number of family members of a household in the Itapocu river basin (HA) to obtain the monthly household income, and this value was further multiplied by 12 to obtain the annual household income for Itapocu river basin (IA10), according to equation 4.5. The income was calculated for each social class.

$$IA_{10} = I_{10} * H_A * 12 \qquad 4.5$$

The recovery capacity of the social classes was assessed in terms of income. After obtaining each annual income, the expenditure was assessed. For assessing the expenditure of each class, the Consumer Expenditure Survey (POF) (IBGE 2009) for Santa Catarina State was used. The expenditure in this survey is given by income levels, and the same procedure for aggregating the income levels into social classes used in the Itapocu river basin was employed to aggregate the POF data.

Firstly, the average income levels in the POF 2009 (Lp09) were divided by the average number of family members of a household in each layer, as given by the POF itself (HpA). The values were corrected by the General Price Index-Market (IGP-M) from 2009 to 2010. The result is the average income for each POF layer *per capita* in values of 2010 (Lp10), according to equation 4.6.

$$Lp_{10} = \frac{Lp_{09}}{Hp_A} * IGPM \qquad 4.6$$

Then, the income levels of the POF survey were aggregated into four social classes (A, B, C, and D), and their average expenditure was calculated. The levels with the best correlation with the (Br10) classes were chosen to separate the POF by social class (Pof10). The Pearson correlation coefficient between Pof10 and Br10 was 0.996. The Pearson correlation between Pof10 and Ip10 was also calculated, resulting in a 0.998 correlation. The income average assigned for each class for Br10, Pof10, and Ip10 can be seen in Figure 49.

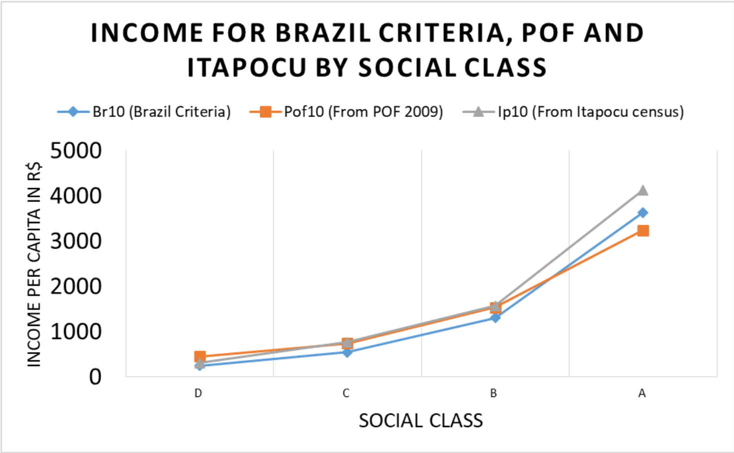


Figure 49 - Average household income *per capita* by social class for Brazil Criteria, POF 2009, and Itapocu census 2010. All values are corrected to 2010.

The Consumer Expenditure Survey – POF 2009 covers a wide variety of expenses by the families. They include expenses for food, housing, clothing, transportation, personal hygiene, health assistance, education, culture, taxes, and others. Inside these expenses, many were considered not essential and excluded.

In a disaster situation, it is reasonable to consider that families would reduce their expenditures to recover from the losses by rebuying assets, home appliances, and clothing lost in the flooding. The excluded expenses are the ones in investments, parties and ceremonies, games, traveling, jewelry, courses and activities, personal services, clothing, and housing (home maintenance, furniture, and home appliances). The households affected by floods will have to employ their recovery money for home repairing, buying new furniture, and home appliances. Therefore those expenditures were excluded to avoid being accounted for twice. The expenditure on taxes, general home bills, education, health, culture, personal hygiene products, and transportation was considered essential and was not excluded. The complete POF is found in Appendix D; the items highlighted in red were excluded from the total expenses.

Table 4.5 shows the (Pof10) for each social class; the total expenses in 2010 value (TE10) by directly correcting the POF 2009 total expenses (TE09) by the IGP-M index 2009-2010; and the essential expenses (EE10) by subtracting the above-mentioned items from the (TE10). Finally, the amount available for recovery (AR10) is obtained by subtracting the essential expenses (EE10) from the annual income (Pof10), as shown in equation 4.7.

$$AR_{10} = EE_{10} - Pof_{10} \qquad 4.7$$

Table 10 - Values of annual income, expenses and amount available for recovery form the POF.

SOCIAL CLASS	ANNUAL INCOME (Pof10)	TOTAL EXPENSES (TE10)	ESSENTIAL EXPENSES (EE10)	AMOUNT AVAILABLE FOR RECOVERY (AR10)
A	135,974.00	168,767.00	95,209.00	40,764.00
B	57,600.00	64,869.00	40,405.00	17,194.00
C	27,840.00	37,468.00	25,608.00	2,231.00
D	12,288.00	17,418.00	13,076.00	-788.00

As can be seen from the table, poorer social class D has more essential expenses than the annual income, thus accumulating debt. Class C has almost the same amount of essential expenses as income; therefore, the amount of money left is very small. For social classes B and A, there is more available money. Nevertheless, by looking at the total expenses (TE10), without removing any expenditure, all the social classes have more expenditure than the income (Pof10). It could be an effect of averaging the expenditures and income into the social classes.

From the POF 2009 itself (Appendix D), without averaging the expenditures by social class, it is clear that the lower two income levels (from the seven given by the original survey) have more expenditure than the income. The other five income levels have expenditures above the lower threshold of the level, which means some people inside all levels spend more than they earn.

Meyer & Sullivan (2003) discussed the same problem in U.S. surveys and related this problem to unaccounted additional income and over-reporting of expenditure. The unequal reduction on expenses between the social classes, however, seems coherent since the wealthiest classes have a wider variety of expenses and can rearrange their budget if necessary.

A simple case was made to assess the recovery capability of households based on their income. The assumptions made are that the flooding event does not change the family's income and that they can only rely on their income to recover from the damages suffered. Governmental help or savings were not considered. The total damage (DF-A, DF-B, DF-C, and DF-D) for a given inundation depth (Table 9) was divided by the amount available for recovery (AR10) (Table 10). An estimation of how many years each social class would take to recover from the damage by themselves is found in Table 11.

Table 11 - Estimation of time that each social class would take to recover by themselves, in a 0.5m inside home flood, and in a 1.5m inside home flood.

SOCIAL CLASS X FLOOD DEPTH INSIDE HOME	0.5m	1.5m
A (more than 5 minimum salaries)	0.88 years (~10 months)	1.27 years (~1 year and 3 months)
B (from 2 to 5 minimum salaries)	0.98 years (~11 months)	1.43 years (~1 year and 5 months)
C (from 1 to 2 minimum salaries)	3.19 years (~3 years 2 months)	4.38 years (~4 years and 4 months)
D (less than 1 minimum salary)	Cannot recover	Cannot recover

Within the limits of the assumptions made, Table 11 shows that social classes A and B can recover in less than one year from a flooding event of 0.5 depth inside the home. For a severer event of 1.5m depth, both classes take less than two years. Social class C takes more than three years for both events. Social class D has debt even when removing unessential expenditure, so by this kind of assessment, they cannot recover.

According to the X-Ray of Brazilian Investor (ANBIMA 2019), which assessed the profile of investors in the social classes A, B and C, 56.25% of the people in class C do not save any money. This value is 40.39% for class B and 25.29% for class A. Another survey, the Scenario of Savings and Investments of Brazilians (CNDL 2018), shows that 63% of the respondents form social classes C, D and E had to use their savings in the last three months before the survey. The most common reasons are the appearance of an unforeseen expense, payment of debts, shopping, insufficient income for the monthly expenses, and unemployment. On the other hand, for social classes A and B, a smaller number of the respondents (53.1%) had to use their savings in the last three months. The most common reasons are the appearance of an unforeseen expense, payment of debts, shopping, and insufficient income for the monthly expenses.

It shows that the lower-income social classes save less money and have to use the savings more frequently than the upper classes. Thus, they are more vulnerable to disaster events, such as flooding.

As an example, Figure 50 was constructed considering a hypothetical case where all social classes are hit by a 0.5m-deep flood every two years. In the figure, the black stars represent the flooding events, and the drops in the curves represent the damages suffered by each class. The damage costs (Table 9) are subtracted from an arbitrary initial property value, and the money available for recovery (Table 10) is then summed up to the value left after the damage. The values are put in perspective of the initial property value to emphasize the recovery capability, as shown in Table 11.

It is possible to graphically see that social classes A and B have enough annual income to fully recover and accumulate money before the next flood, represented by the black stars in the figure. Therefore, even though the flooding cause losses, the overall trend of the curve for them is positive. Class C also has money available for recovery (Table 10), but it is not sufficient to fully recover before the next flood. Therefore, the line shows a negative trend. For class D, since there is debt instead of money saved, the trend is always negative, and every flood event makes it steeper in the downward direction.

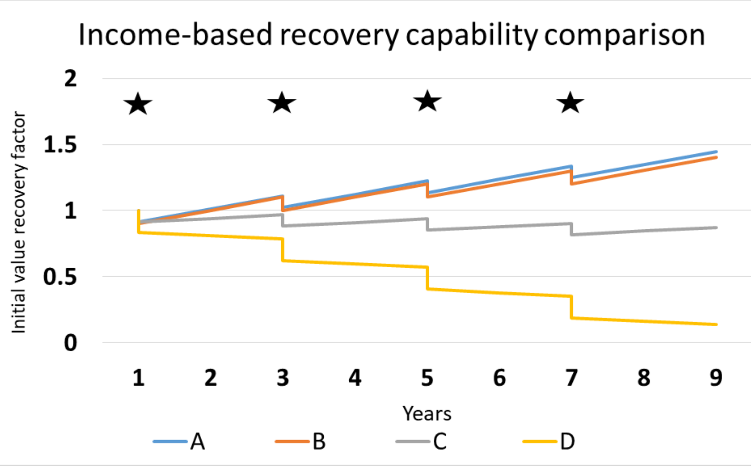


Figure 50 - Recovery capability of social classes A, B, C, and D for a two year return period flood with 0.5m depth.

Although this graph suggests an accumulation of money throughout the years for some social classes and a reduction for others, it should not be understood that way, but only as a comparative assessment on their recovery capability, based on their income.

This assessment followed the premise that all the social classes would cut the same type of expenses and accumulate this money to recover by themselves and that they would continue doing so after the recovery. However, in reality, it is not reasonable to think that a family would live, only spending the essential expenses and accumulating money. It is also clear that social classes A and B do not need to cut as many expenses as classes C and D. Different families financially adapt to a disaster situation differently, based on their saved money, access to funding, credit, and other help.

Families affected by disasters, especially low-income ones, usually receive help from the government, such as money for renting a new home by the Law of Social Assistance (BRASIL 1993), donations from NGOs and civil societies, and help from municipalities. Such help varies from situation to situation and from municipality to municipality, and, due to its complexity, it was not included in this assessment. Nevertheless, depending on their access to aids, the recovery time of each family changes, and the downward trend of the recovery curve can be softened or changed to upwards.

4.3.2 Basin Population growth

The Itapocu river basin region is growing fast, both populationally and economically. The population of the five municipalities that are entirely inside the Itapocu river basin was assessed.

From 1980 to 2010, the population of Jaraguá do Sul city increased by 3 times; Guaramirim, 3.2 times; Corupá, 1.6 times; Shroeder, 3.8 times; and Massaranduba, 1.2 times (SEBRAE 2013). Based on the past population, a trend was calculated for each city. The trend was then averaged to obtain an average growth trend for the basin (Figure 51).

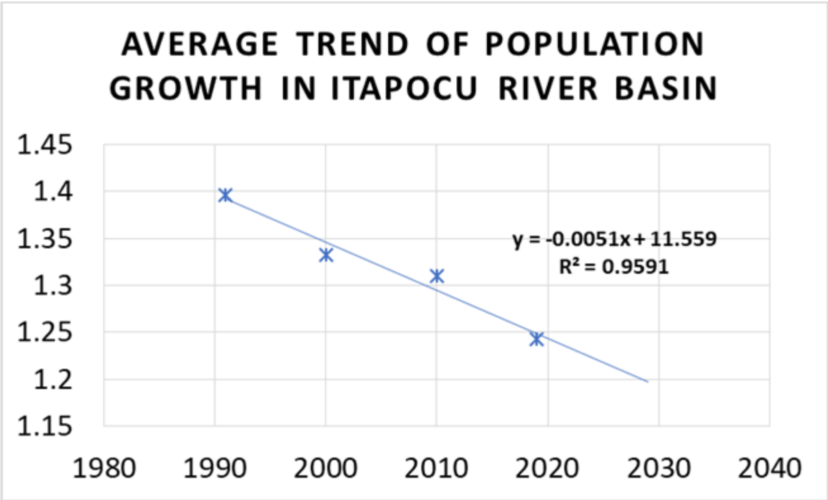


Figure 51 - Average population trend of the five municipalities completely inside the basin

The basin population in 2010 was 265,929 people, according to the "Grade Estatística." If the growing trend continues, by 2030, the population of the Itapocu river basin can reach up to 398,455, increasing by 1.5 times. It means an additional population of 132,527 in the basin. This number is similar to the entire population of Jaraguá do Sul in 2010.

Nowadays, 78.88% of the basin’s population lives in its urban areas and 21.1% in rural areas. If this proportion is maintained, in 2030, 104,537 people will be added to the urban areas and 27,976 to the rural areas. Population growth puts more pressure on the housing and agriculture sectors. If land use is not planned, more hazardous areas can be unadvisedly occupied, enlarging the disaster exposure of residents in the basin.

4.4 Concentration of vulnerable population

The results of the estimation of affected households show that the lower-income social classes in the Itapocu river basin are more likely to be affected by flooding hazards and take a longer time to recover from damage. Understanding which places subject to floods have a higher concentration of this type of household helps to address specific policies and measures. The 100-year return period was chosen for showing the maximum of affected low-income communities. The 5-year return period was also chosen for this assessment since the most frequent events are the ones that affect the lowest income population more severely. Therefore, the most frequently affected communities can also be shown.

Figure 52 (A and B) shows the 100-year and 5-year return period inundation crossed with the areas with a predominance (70% or more of the total living) of households with less than 2 minimum salaries of income *per capita* (Social classes C and D) displayed in light purple. Within these areas, the places with a high concentration (more than 40% of the total living) of the lowest income layer, earning less than 1 minimum salary *per capita* of (Social class D) are shown in deep purple. The people located in these areas are the ones that will have the most difficulty in recovering if no help is available, as described in the previous sections (Figure 50). It is possible to see from these maps that the communities with predominately low-income (social classes C and D) are located outside of the Jaraguá do Sul city center, in the suburban and rural areas both for frequent and infrequent events.

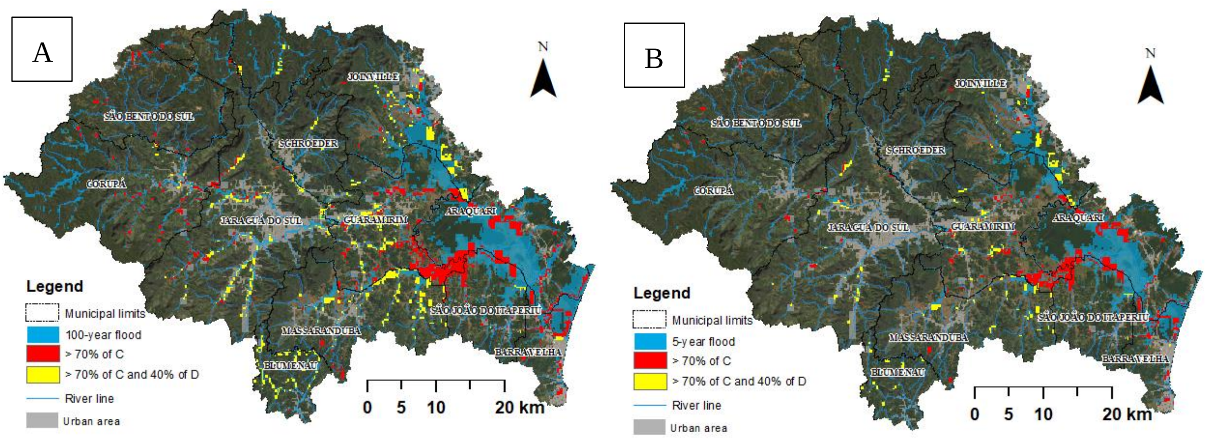


Figure 52 - Location of communities predominately low-income (Social classes C and D), for (A) 100 y flood and (B) 5y flood.

4.5 Discussions

Many hazardous areas are nowadays occupied in Brazil due to poor land-use planning (World Bank 2014; Robaina 2008). Unsafe territories often offer proximity to economic opportunities, therefore, they can be attractive for the richer and the poorer, although land and housing markets may push the poorer to settle in the riskiest areas (Hallegatte et al. 2017, Husby et al. 2015).

In the Itapocu river basin, the inhabited areas are located along the main rivers. High-income households concentrate mostly in Jaraguá do Sul city center (Figure 39), and low-income households are located in the suburban and rural areas (Figure 40, Figure 52). This suggests that, in the Itapocu river basin, the central area of Jaraguá do Sul city has the most valuable land. There are many reasons for that, including proximity to administrative structures, presence of commerce and entertainment, higher safety, and better accessibility. That the city center itself is safe from flooding can be another reason for the high value.

The results of the estimation of affected households point out that the frequent flood events tend to affect more unequally the low-income classes, which can indicate spatial segregation of the households in the basin based on the income capacity. Frequent events are more easily remembered and understood by the local population; therefore, the regions that are hit by these events might have a lower land price, thus attracting the lowest-income population.

However, even though the highest income levels are less affected when compared to the lowest ones, there are still high percentages of affected households, especially in the case of high-return-period floods. Hazardous areas might be attractive for higher-income people, due to the advantages of the city center proximity, thus elevating the number of high-income households affected by the flood. It is important to consider, however, that the construction patterns in Brazil vary, and people can modify their homes to avoid lower depth events by elevating their homes, for example. Making such modifications will always involve expenditure; therefore, the highest income households are expected to be more capable of protecting themselves, even though living in hazardous areas. In this study, a general elevation of 0.5m above street level was considered to enter the homes. In reality, however, the number of affected households will vary according to protection measures adopted by household owners.

The recovery capability shows that the upper social classes suffer greater damage since their assets are more valuable. Still, without considering external help, whenever hit by a flooding event, the low-income households would take around 3 times longer to recover than the high-income households. Additionally, it highlights the vulnerability of social class D, which has not enough income to recover in any assessed case. Class D is comprised of the two lowest income levels in the Itapocu river basin, which suffers the most from highly frequent and severe floods.

The results suggest that flooding events in the Itapocu river basin can contribute to increasing income inequality since the lowest-income layer is affected more frequently and heavily by disasters. Those events compromise the capability of residents to accumulate money and improve their living conditions. The lower-income social classes might experience impoverishment due to the frequent loss of their assets if no policy or help is addressed to support them.

Additionally, if the basin population continues following the same growth trend, the population can increase 1.5 times the 2010 population by 2030. Nowadays, 78.88% of the basin’s population lives in urban areas; meanwhile, the national urban population is 84%. Since the Itapocu river basin is still less urban than the national average, the economic and population growth might result in higher urbanization of the basin. Therefore, the exposure to floods and losses by disasters might increase, if no planning and policies are addressed to this matter.

The southern region of Brazil is expected to have an increase in rainfall in the future (IPCC 2013, Mickosz 2017). Therefore, high-intensity rainfall events are expected to become more frequent, increasing flood events in the Itapocu river basin. This alarming trend for the future highlights the necessity of increasing the resilience of the basin’s municipalities to disasters.

The adoption of specific measures for protecting the lower-income population and solutions for lowering flood damage for all the population will stimulate economic growth, generating long-lasting benefits for the residents of the Itapocu river basin. Additionally, policies for avoiding the occupancy of new hazardous areas can prevent damage and losses in the future.

These actions will help the Itapocu river basin to achieve the goals of its Water Resources Plan by 2034. Additionally, they will help the Santa Catarina State and Brazil to pursue the outcome of the United Nation's Sendai Framework for Disaster Risk Reduction to be completed by 2030.

5 ADAPTIVE MEASURES

Numerous studies identify an increase of rainfall in the future for Southern Brazil, meaning the flooding hazard in the Itapocu river basin is likely to increase. Additionally, the Itapocu river basin is expected to grow in population and economy in the next years, leading to an increase in the exposure to hazards. The results of this study point out that the lowest-income households are located in the areas subject to floods of higher severity and higher frequency; therefore, the flooding disasters have the potential to increase income inequality and poverty.

This situation poses a challenge to the government and urban planners, which should make more efforts in disaster risk reduction (DRR) in the Itapocu river basin, to improve the safety of lives and assets, and to avoid new hazardous areas to be occupied. Thus, preventing increasing the gap between the lowest-income households and the highest-income (Figure 50), ensuring that the economic growth reaches people from all social classes (Figure 53). For achieving this goal, some adaptive measures are proposed.

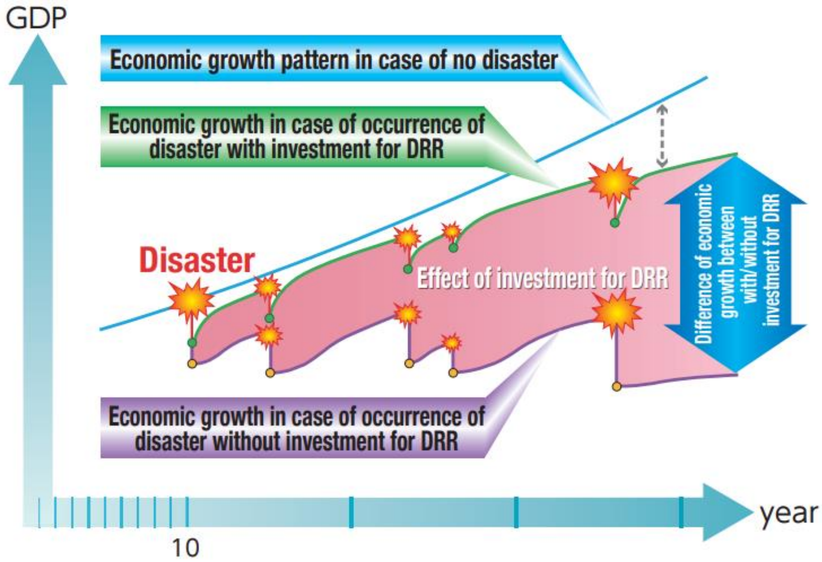


Figure 53 - Pattern Diagram of Investment for DRR and Economic Development. Source: JICA (2017)

1. The creation of an alert system for the Itapocu river basin is one of the priority actions of the Water Resources Plan of the Itapocu river basin for reducing the losses of lives and assets in the future. The plans for this alert system already exist, and the system is planned to be under the Itapocu Basin Committee. I emphasize the importance of such an alert system in this basin since the Itapocu river basin is located in a region with high rainfall records and the time between the peak rainfall and the flooding is less than one day. However, the basin is nowadays poorly gauged, and the majority of the stations measure daily rainfall manually. Hourly rainfall gauges, as well as hourly discharge stations, should be installed upstream of the main settlements. By measuring rainfall and discharge fast and accurately, implementing an alert system for the basin becomes possible. From this alert system, an accurate evacuation timeline can also be designed. By implementing such an alert system and an evacuation timeline, people can be prepared to save their assets and safely evacuate, decreasing the losses of the affected population while raising the awareness towards the flooding hazard.

2. For the completion of the alert system, effective risk communication should also be implemented to remove people from hazardous areas before high-rainfall events happen efficiently.

Coordination between the Civil Defenses and the National Center of Disaster Monitoring and Alert (CEMADEN) and the National Institute of Meteorology (INMET) should be encouraged.

3. I also recommend cost-benefit studies for hard measures in this basin, such as dry dams upstream of Corupá city. Similar solutions were suggested by the Japan International Cooperation Agency - JICA (2011) for the neighboring basin of Itajaí. By adopting hard measures along with policies oriented for disaster management and land use planning, the risks in the Itapocu river basin can be substantially reduced in the future.

4. Studies for increasing the width and depth of some river sections and building levees, especially in the urbanized areas of Guaramirim city, are also recommended. The combination of hard measures may be more efficient and reduce the costs than adopting only one.

5. Hazard maps should be developed for city areas. Before approving the construction of new homes, these maps should be consulted, and the hazardous areas should be avoided if ever possible. Low-density activities should be preferred in those areas (Agriculture, parks). For developing these maps, the collection of basic data should be improved. The actual flood hazard maps available for the Itapocu river basin are focused on the urban areas, based on past inundation surveys. Those surveys lack additional information such as inundated depth, georeferenced photos, and damage. The field survey of inundation should be made by all municipalities, following a common methodology. It is highly recommended that damage should be well documented and assembled into a database available for the general population and researchers. My suggestion is that such information is managed by the Itapocu river basin committee since it is an institution that connects all municipalities from a water resources point of view. The information should also be sent to the S2ID database by filling the form of Disaster Information (FIDE) to contribute to the building of the national statistics on disasters.

6. Policies for avoiding the overpricing of safe areas after releasing the hazard maps should be designed. According to the law of general urban policy guidelines (BRASIL 2001), the properties have to fulfill a social function, which should be expressed on the city master plan. Therefore, in this plan, some areas can be separated, for example, for being preferably bought by low-income households.

7. Low-income communities are scattered in suburban and rural areas (Figure 52). Families located in areas hit by severe events with high frequency should be preferably moved to a safer location (Figure 52 B). The situation pictured in Figure 52 should be investigated closely by the municipal governments since the map adopts general information. Additionally, supporting individual adaptation measures might bring effective results for reducing disaster risks, such as subsidizing improvements in house safety and home insurance.

8. The needs of the traditional communities in the basin should be investigated since their land is partially located in the flooding area. Knowledge of the safest areas inside their land should be shared through the appropriate agencies, such as the National Indigenous Foundation (FUNAI).

The government response can take much time; therefore, some measures can be adopted by the population to mitigate their losses due to flooding.

1. Inside inundation areas, homes should be built to be resilient against hazards, for example, by elevating the houses. Elevated houses are costlier than simple one-story houses, but as can be seen in the damage assessment, for social class D, the expected damage can reach up to 42% of the annual income in case of a 0.5m-deep inundation inside the house, and 57% of the annual income in case of a 1.0m-deep event. By avoiding inundation, residents should avoid not only tangible disaster impacts but also intangible ones yielding a positive relationship that cannot be expressed in financial terms.

2. For houses in already built areas, changing the use of the floors can reduce losses. For two-story houses, the most valuable assets should be placed on the upper floor, while the first floor should be reserved for less valuable and replaceable assets. For people living on the first floor, waterproofing the homes is efficient for avoiding less severe events. Although it is not an efficient measure against severe events, the costs of implementation are lower than for building another story or elevating the house. It can also be a solution for people that own only the first floor of an apartment building, for example. The commercial sector in a flood risk area can also benefit from this measure.

3. People in hazardous areas should include, in their routine, paying attention to weather forecasts and civil defense alerts. If they are able to move their assets to a safe location and evacuate in time, they can avoid many losses.

6 CONCLUSION

Disasters tend to affect the poorest more severely. Brazil is a country with an extensive risk profile and high-income inequality rates that can be enlarged by natural disasters. Therefore, this study proposed a method for assessing if the households of a given basin are unequally affected by floods, based on their income. It was tested in the Itapocu river basin, on southern Brazil using nationally available data, and adaptive measures for improving the safety of the basin were proposed. The method consisted of analyzing and designing the rainfall, building a hydrological model of the basin, downscaling and analyzing the census data, and crossing the inundation information with this data, in order to investigate the relation between the income and the affected households.

The estimation of affected households shows that for the overall flood, the affected households tend to obey the distribution pattern of households in the basin. The households categorized in the third-lowest income level (earn from 1 to 2 minimum salaries *per capita*), treated in this study as class C, are the ones with the highest number of households affected. However, the households at the lowest income level (that earn less than 1 minimum salary), or class D, are proportionally the more heavily affected, when severer events are considered.

In terms of the return period, less frequent events (high return periods) tend to affect the population at all levels more equally, according to the basin household distribution pattern. On the other hand, more frequent events tend to affect the population more unequally, affecting lower-income households more severely.

The results point out that flooding events in the Itapocu river basin contribute to increasing the inequality between the rich and the poor since the lowest income layer is affected more frequently and heavily by disasters. Additionally, those events compromise the capability of residents to accumulate money and improve their living conditions. The upper social classes suffer greater damage since their assets are more valuable. Still, without considering external help, whenever hit by a flooding event, the low-income households would take longer to recover than the high-income households. The most vulnerable social class D cannot recover without help.

The adoption of specific measures for protecting the lower-income population and of solutions for lowering flood damage for all the population will stimulate economic growth, generating long-lasting benefits for the residents of the Itapocu river basin. Additionally, policies for avoiding the occupancy of new hazardous areas can prevent damage and losses in the future.

These actions will help the Itapocu river basin to achieve the goals of its Water Resources Plan by 2034. Additionally, they will help the Santa Catarina State and Brazil to pursue the outcome of the United Nation's Sendai Framework for Disaster Risk Reduction to be completed by 2030.

7 RECOMMENDATIONS AND FUTURE WORKS

This study was conducted using the data from the 2010 census, which is the newest available. Notwithstanding, the population characteristics are dynamic along the time. Because of the COVID-19 pandemic, the Brazilian 2020 census was delayed. As soon as the census data is released, I recommend the revision of this assessment, based on the new data. Since this assessment requires available national data, I recommend the use of the methodology in other basins for testing and improving.

This study assessed the affected population based on income data. For future studies, other aspects of the population besides income can be assessed, since poverty is multidimensional.

Numerous studies identify an increase of rainfall in the future for Southern Brazil, meaning the flooding hazard in the Itapocu river basin is likely to increase. Nevertheless, this study did not quantify the effects of climate change in this basin due to time limitations. Climate change effects should be considered for disaster management; therefore, for future works, I recommend that they are specifically quantified for the Itapocu river basin.

This study focuses on flood risk on a basin scale, using a dataset of 9 arc seconds. The consideration of risks inside the city areas requires higher resolution data. For future works in this basin, it is recommended that hazard maps are developed for the city areas.

Due to the lack of local data, this study adopted a general damage function. With the availability of local data, damage functions specifically for this basin can be designed in future assessments.

APPENDIX-A: COORDINATE OF CROSS-SECTIONS, DISCHARGE AND RAINFALL STATIONS USED FOR BUILDING THE MODEL AND SOURCE INSTITUTION

Cross Sections			
Institution	Code/Name	E	W
COMMITEE	483	731271,21	7058255,19
COMMITEE	470	729528,42	7057998,51
COMMITEE	450	726103,57	7057176,2
COMMITEE	429	724754,08	7060931,91
COMMITEE	397	720136,09	7064638,41
COMMITEE	372	716804,78	7065431,12
COMMITEE	370	713585,75	7062794,83
COMMITEE	354	712093,74	7063109,45
COMMITEE	347	709375,33	7066012,65
COMMITEE	329	706599,55	7069495,51
COMMITEE	319	705155,16	7069755,41
COMMITEE	314	704410,7	7070297,16
COMMITEE	310	703279,11	7070343,37
COMMITEE	307	702677,89	7070365,52
COMMITEE	301	701854,95	7069733
COMMITEE	294	700904,88	7069982,23
COMMITEE	293	700719,99	7069909,7
COMMITEE	287	699719,46	7069624,87
COMMITEE	283	699076,97	7069398,92
COMMITEE	279	698293,8	7069347,58
COMMITEE	241	691987,77	7068067,48
COMMITEE	240	691809,02	7068110,66
COMMITEE	234	690929,27	7068162,74
COMMITEE	232	690598,78	7068032,54
COMMITEE	211	687696,07	7066561,33
COMMITEE	188	684873,37	7072851,07
COMMITEE	182	683717,7	7072755,96
COMMITEE	176	682742,58	7073476,48
COMMITEE	168	680945,15	7074026,4

COMMITEE	148	679080,02	7074543,51
COMMITEE	134	676895,84	7074666,74
COMMITEE	130	676733,22	7075177,34
COMMITEE	124	675599,17	7075358,24
COMMITEE	119	675079,32	7075438,33
COMMITEE	116	674817,09	7074908,52
COMMITEE	107	673773,5	7075412,66
COMMITEE	94	671820,23	7074904,5
COMMITEE	92	675813,38	7075927,77
COMMITEE	90	675862,06	7076211,94
COMMITEE	84	675500,11	7077019,45
COMMITEE	80	675463,85	7077379,82
COMMITEE	79	692576,21	7074750,66
COMMITEE	74	691945,28	7075430,37
COMMITEE	59	690990,82	7077038,56
COMMITEE	48	690065,85	7077949,66
COMMITEE	22	688196,34	7079519,73
COMMITEE	WEG	694883	7069264
ANA	CORUPA	670535.1	7076669.93
ANA	JAR_DO_SUL	691383.25	7069727.27

Coordinates of the cross sections used

Discharge Stations			
Station Name	**Code**	**lat**	**lon**
JARAGUA_DO_SUL	82350000	-26.48	- 49.08
CORUPÁ	82320000	-26.42	-49.29

Discharge stations used for discharge and cross section information. Source National Water Agency

Calibration Rainfall Stations			
Station Name	**Code**	**lat**	**lon**
ARAQUARI	2648020	-26.56	-48.72
ARROZEIRA	2649008	-26.74	-49.27
BARRA_DO_AVENCAL	2649065	-26.55	-49.48

CAMPO_ALEGRE	2649057	-26.19	-49.27
ESTRADA_DOS_MORROS	2648034	-26.25	-48.98
IOTUPAVA_CENTRAL	2649010	-26.80	-49.08
JARAGUA_DO_SUL	2649037	-26.46	-49.09
LUIZ_ALVES	2648002	-26.72	-48.93
PONTE_SC301	2648028	-26.45	-48.83
PRIMEIRO_S_CUBATAO	2649060	-26.22	-49.08
RIO_NOVO	2649064	-26.41	-49.33
POMERODE	2649002	-26.74	-49.17

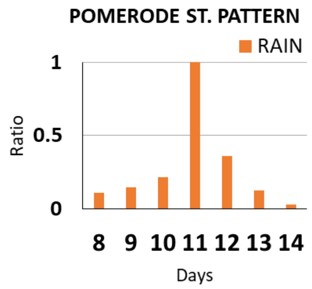
Rainfall Stations used in RRI for the calibration. Source National Water Agency

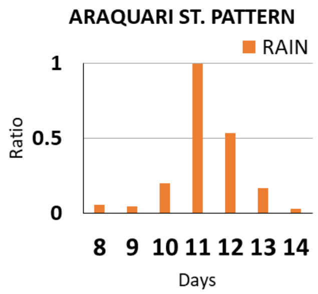
Validation Rainfall Stations			
Station Name	**Code**	**lat**	**lon**
ARAQUARI	2648020	-26.56	-48.72
ARROZEIRA	2649008	-26.74	-49.27
BARRA_DO_AVENCAL	2649065	-26.55	-49.48
CAMPO_ALEGRE	2649057	-26.19	-49.27
ESTRADA_DOS_MORROS	2648034	-26.25	-48.98
IOTUPAVA_CENTRAL	2649010	-26.80	-49.08
JARAGUA_DO_SUL	2649037	-26.46	-49.09
LUIZ_ALVES	2648002	-26.72	-48.93
SCHROEDER	2649068	-26.43	-49.06
PRIMEIRO_S_CUBATAO	2649060	-26.22	-49.08
RIO_NOVO	2649064	-26.41	-49.33
POMERODE	2649002	-26.74	-49.17

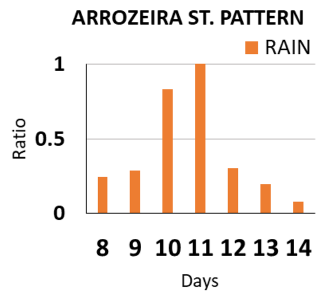
Rainfall Stations used in RRI for the validation. Source National Water Agency

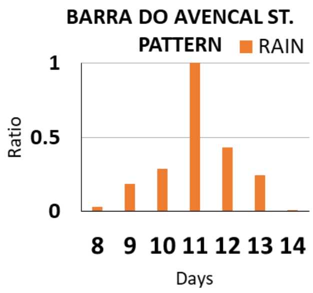
APPENDIX-B: THE RAINFALL PATTERNS FOR THE DESIGN RAINFALL

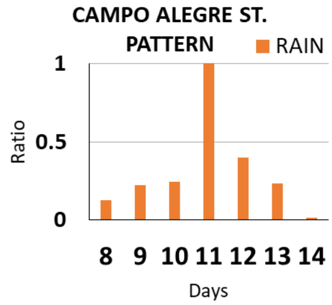
Pattern for the 7 day designed peak, averaging 8 rainfall events.

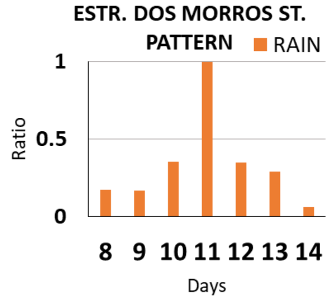


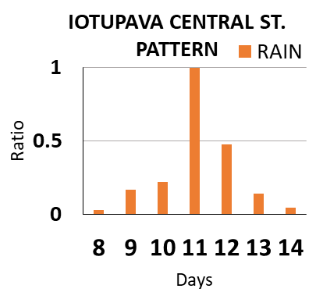


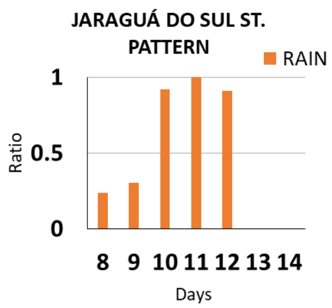


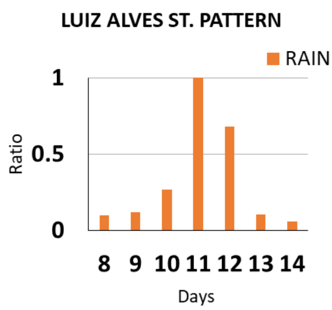


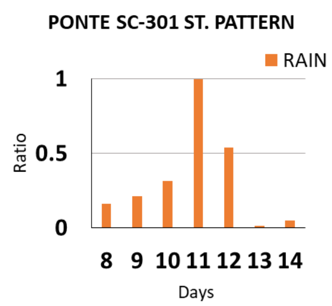


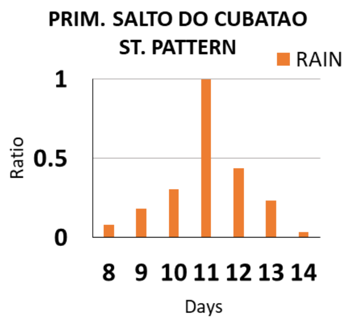


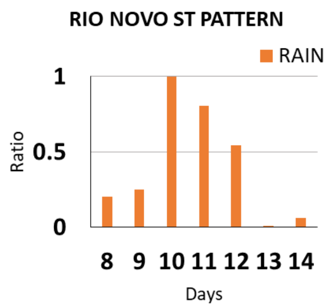




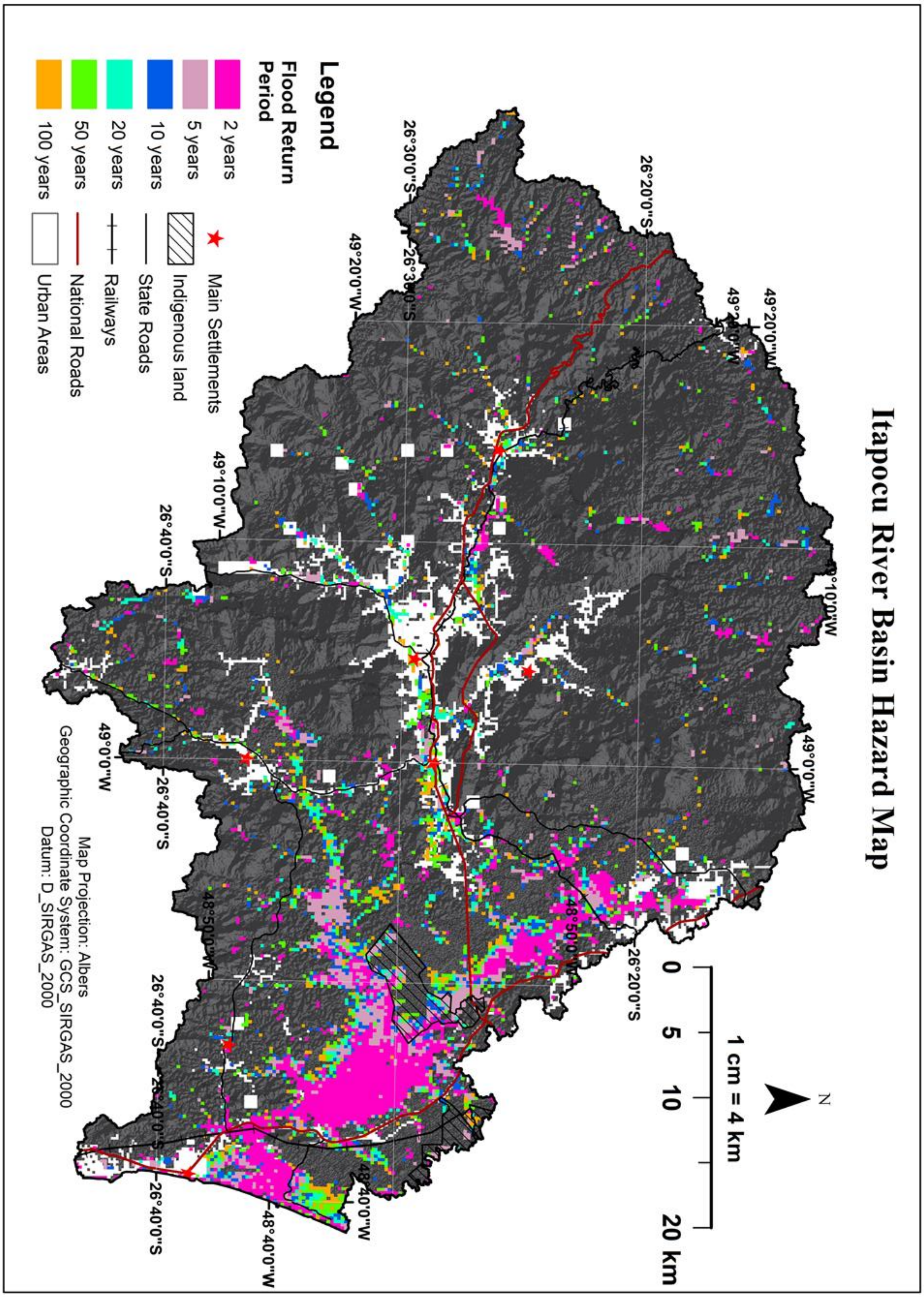








APPENDIX-C: HAZARD MAP FOR ITAPOCU RIVER BASIN



APPENDIX-D: THE CONSUMER EXPENDITURE SURVEY – POF 2009

The expenses highlighted in yellow are the headings of the below expenses. The expenses Highlighted in red were removed to calculate the essential expenses.

Tabela 1.3.22.1 - Despesas monetária e não monetária média mensal familiar, por classes de rendimento total e variação patrimonial mensal familiar, segundo os tipos de despesa, com indicação do número e tamanho médio das famílias - Santa Catarina - período 2008-2009

(continua)

Tipos de despesa, número e tamanho médio das famílias	Despesas monetária e não monetária média mensal familiar (R$)							
	Total	Classes de rendimento total e variação patrimonial mensal familiar						
		Até 830 (1)	Mais de 830 a 1 245	Mais de 1 245 a 2 490	Mais de 2 490 a 4 150	Mais de 4 150 a 6 225	Mais de 6 225 a 10 375	Mais de 10 375
Despesa total	3 509.58	1 100.12	1 360.05	1 925.16	3 367.03	5 795.32	7 228.62	16 608.55
Despesas correntes	3 144.19	1 074.96	1 323.74	1 860.17	3 147.89	4 929.19	6 583.09	13 209.22
Despesas de consumo	2 804.09	1 029.10	1 252.99	1 742.70	2 880.55	4 429.17	5 722.85	10 563.81
Alimentação	471.38	220.27	259.52	341.55	489.71	765.25	811.61	1 308.42
Habitação	1 003.24	434.55	535.20	707.54	1 086.59	1 482.22	1 856.10	3 027.08
Aluguel	**443.95**	**211.23**	**258.95**	**346.82**	**461.51**	**636.68**	**697.29**	**1 311.03**
Aluguel monetário	49.92	34.04	38.10	44.04	51.09	67.72	84.08	62.79
Aluguel não monetário	394.03	177.19	220.85	302.78	410.42	568.96	613.22	1 248.25
Condomínio	**17.26**	**0.65**	**2.67**	**3.33**	**5.62**	**53.54**	**50.31**	**116.31**
Serviços e taxas	**210.44**	**96.51**	**130.08**	**156.03**	**222.45**	**329.28**	**366.03**	**529.12**
Energia elétrica	74.17	42.84	54.36	66.55	82.49	95.79	108.17	118.04
Telefone fixo	34.45	15.06	24.84	26.10	42.93	50.54	47.65	71.09
Telefone Celular	26.03	5.19	8.93	13.46	22.47	48.91	69.61	111.81
Pacote de telefone, TV e Internet	19.22	1.82	3.77	7.81	19.54	47.26	48.68	73.37
Gás doméstico	15.85	12.21	15.49	15.29	16.54	17.98	17.87	18.20

Água e esgoto	23.15	16.82	18.35	21.27	25.05	26.79	28.09	40.71
Outros	17.56	2.57	4.36	5.55	13.43	42.03	45.96	95.89
Manutenção do lar	150.26	67.84	57.22	85.88	201.70	204.43	361.38	391.25
Artigos de limpeza	16.72	5.79	10.46	13.16	20.06	23.57	26.71	39.51
Mobiliários e artigos do lar	82.48	23.04	35.06	48.81	84.98	124.58	180.03	347.59
Eletrodomésticos	69.54	25.83	34.64	48.33	78.91	97.28	149.82	196.40
Consertos artigos do lar	12.60	3.64	6.12	5.19	11.36	12.87	24.53	95.87
Vestuário	164.92	49.06	65.59	109.15	170.64	248.24	345.28	634.59
Roupa de homem	40.02	13.34	17.56	27.73	39.37	53.88	85.55	159.63
Roupa de mulher	50.41	13.10	17.03	32.06	53.25	81.81	104.17	198.83
Roupa de criança	19.85	7.89	11.39	13.59	22.92	31.14	40.29	45.51
Calçados e apetrechos	45.93	12.31	17.34	31.68	46.16	69.00	92.51	185.65
Jóias e bijuterias	6.95	2.21	2.03	2.94	6.82	10.26	18.37	37.38
Tecidos e armarinhos	1.75	0.22	0.24	1.14	2.12	2.15	4.39	7.59
Transporte	667.45	155.71	201.67	310.21	677.42	1 123.44	1 561.64	3 351.69
Urbano	32.07	21.30	26.97	28.72	32.11	43.51	47.67	44.91
Gasolina - veículo próprio	132.25	52.38	55.57	80.73	167.79	209.46	240.21	402.34
Álcool - veículo próprio	12.30	1.27	2.13	5.16	15.81	22.20	28.89	54.57
Manutenção e acessórios	71.77	10.34	21.45	50.57	81.11	131.49	109.37	272.32
Aquisição de veículos	343.84	59.70	76.20	119.79	316.91	595.62	978.69	1 995.02
Viagens esporádicas	45.27	6.90	16.25	13.37	29.10	70.46	92.91	402.86
Outras	29.95	3.82	3.09	11.87	34.59	50.69	63.90	179.68
Higiene e Cuidados Pessoais	58.52	21.22	27.94	43.12	62.73	98.89	101.68	163.86
Perfume	19.72	5.20	9.61	15.07	23.08	33.26	32.80	48.73
Produtos para cabelo	5.84	2.64	3.88	4.79	6.40	11.46	8.92	5.44
Sabonete	2.92	2.29	1.56	2.16	2.91	4.64	3.59	8.64
Instrumentos e produtos de uso pessoal	30.04	11.10	12.89	21.11	30.33	49.52	56.37	101.06
Assistência a saúde	162.91	78.05	75.88	107.37	142.13	253.56	394.28	545.56
Remédios	77.46	52.49	46.93	67.99	79.51	99.19	131.52	147.82
Plano/Seguro saúde	31.99	1.97	7.75	6.63	22.67	54.55	106.17	237.71
Consulta e tratamento dentário	10.42	2.41	1.11	5.64	9.73	23.40	31.89	29.31
Consulta médica	11.62	4.14	7.60	9.49	12.07	13.18	21.69	36.01
Tratamento médico e ambulatorial	2.51	0.48	1.47	0.51	0.38	3.00	4.99	30.74

Serviços de cirurgia	10.29	3.36	3.95	2.31	1.64	28.94	52.74	32.77
Hospitalização	4.60	0.59	0.73	2.47	2.70	12.19	19.57	7.91
Exames diversos	7.32	11.22	3.16	7.45	7.08	7.85	10.42	3.41
Material de tratamento	5.63	0.79	2.67	4.19	5.32	10.42	14.66	11.96
Outras	1.06	0.61	0.50	0.70	1.03	0.84	0.64	7.93

Tabela 1.3.22.1 - Despesas monetária e não monetária média mensal familiar, por classes de rendimento total e variação patrimonial mensal familiar, segundo os tipos de despesa, com indicação do número e tamanho médio das famílias - Santa Catarina - período 2008-2009

(conclusão)

Tipos de despesa, número e tamanho médio das famílias	Despesas monetária e não monetária média mensal familiar (R$)							
	Total	Classes de rendimento total e variação patrimonial mensal familiar						
		Até 830 (1)	Mais de 830 a 1 245	Mais de 1 245 a 2 490	Mais de 2 490 a 4 150	Mais de 4 150 a 6 225	Mais de 6 225 a 10 375	Mais de 10 375
Educação	74.43	8.86	14.91	21.90	59.19	146.53	258.19	403.86
Cursos regulares	21.94	-	3.04	3.30	15.35	44.09	85.84	145.65
Cursos superiores	19.05	1.22	0.44	5.33	16.98	43.25	65.34	95.44
Outros cursos e atividades	19.88	2.69	4.61	5.90	13.70	38.78	71.32	112.26
Livros didáticos e revistas técnicas	3.19	0.60	1.06	1.60	2.36	5.18	9.94	15.92
Artigos escolares	5.84	4.04	4.23	4.30	7.31	6.72	10.79	9.60
Outras	4.52	0.30	1.53	1.47	3.50	8.51	14.96	24.99
Recreação e cultura	59.85	15.23	21.05	32.54	61.18	99.67	134.01	263.39
Brinquedos e jogos	12.25	3.73	5.17	7.18	11.54	19.98	28.01	50.79
Celular e acessórios	7.92	2.13	4.05	5.83	7.80	14.65	16.89	18.55
Periódicos, livros e revistas não didáticos	10.19	2.05	2.30	4.28	7.93	17.31	19.83	75.01
Recreações e esportes	17.23	3.53	6.08	7.94	18.85	28.58	44.12	74.49
Outras	12.26	3.79	3.45	7.31	15.06	19.15	25.16	44.55
Fumo	14.76	15.19	16.10	12.24	14.14	22.13	11.08	18.93
Serviços pessoais	24.99	6.16	8.11	14.11	21.49	48.56	51.93	116.43
Cabeleireiro	16.28	4.71	6.38	10.76	15.39	29.48	33.65	58.22
Manicuro e pedicuro	4.93	0.47	1.02	1.98	3.90	12.09	12.51	24.19
Consertos de artigos pessoais	0.36	0.01	0.07	0.22	0.63	0.68	0.28	1.25
Outras	3.42	0.98	0.64	1.16	1.58	6.31	5.49	32.77

Despesas diversas	101.65	24.81	27.02	42.97	95.34	140.68	197.05	729.98
Jogos e apostas	7.39	1.75	3.52	5.51	6.26	13.06	10.61	32.61
Comunicação	6.79	3.90	4.71	5.71	10.98	7.96	3.25	10.56
Cerimônias e festas	24.71	4.53	6.19	12.27	32.37	39.82	59.41	92.15
Serviços profissionais	30.75	11.03	4.71	8.90	21.79	35.96	33.45	344.56
Imóveis de uso ocasional	7.38	1.13	3.46	2.23	5.37	7.36	21.36	60.87
Outras	24.62	2.47	4.43	8.36	18.56	36.53	68.95	189.23
Outras despesas correntes	340.09	45.87	70.76	117.47	267.34	500.02	860.23	2 645.41
Impostos	160.79	29.29	37.54	59.97	111.40	223.18	432.16	1 251.85
Contribuições trabalhistas	89.52	7.54	16.66	38.30	94.73	158.90	223.58	475.67
Serviços bancários	7.43	0.94	1.65	2.80	6.11	21.92	20.70	23.41
Pensões, mesadas e doações	34.65	5.44	9.13	7.39	17.53	30.39	61.23	437.31
Previdência privada	15.96	0.18	0.69	0.25	13.07	30.09	23.25	183.80
Outras	31.75	2.47	5.09	8.74	24.50	35.54	99.31	273.38
Aumento do ativo	307.76	12.56	24.19	41.17	163.73	773.91	500.18	3 059.88
Imóvel (aquisição)	190.97	-	10.96	7.93	91.98	554.06	238.34	2 033.02
Imóvel (reforma)	116.73	12.33	13.23	33.12	71.74	219.86	261.83	1 026.87
Outros investimentos	0.07	0.23	-	0.13	-	-	-	-
Diminuição do passivo	57.63	12.59	12.11	23.82	55.42	92.22	145.35	339.45
Empréstimo	34.46	6.64	5.78	13.79	33.50	79.37	84.53	152.68
Prestação de imóvel	23.17	5.95	6.34	10.03	21.92	12.85	60.83	186.77
Número de famílias	**1 976 291**	**217 273**	**245 815**	**654 847**	**413 570**	**221 898**	**136 289**	**86 598**
Tamanho médio da família	**3.09**	**2.53**	**2.83**	**3.04**	**3.36**	**3.39**	**3.46**	**3.04**

Fonte: IBGE, Diretoria de Pesquisas, Coordenação de Trabalho e Rendimento, Pesquisa de Orçamentos Familiares 2008-2009.

Notas: 1. O termo família está sendo utilizado para indicar a unidade de investigação da pesquisa "Unidade de Consumo", conforme descrito na introdução.

2. Classes de rendimento total e variação patrimonial mensal familiar inclui os rendimentos monetários, não monetários e variação patrimonial.

(1) Inclusive sem rendimento.

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