FLOOD IMPACT ASSESSMENT IN THE ITAPOCU RIVER BASIN, BRAZIL

Rafael Silva Araújo[1]
MEE19719

Supervisor: **Dr. Miho Ohara**[2]
Dr. Mamoru Miyamoto[3]
Prof. Kuniyoshi Takeuchi[4]
Prof. Hideo Fukui[5]

ABSTRACT

Brazil is a country with high inequality rates and an extensive disaster risk profile. Disasters tend to affect the poorest inhabitants and increase inequality. Therefore, this study aims to propose a method to assess whether households are unequally affected by floods based on their income, apply it to the Itapocu River basin located in Santa Catarina State, Brazil, and propose adaptive measures. Flooding was assessed through rainfall analysis and hydrological simulations. Household income information was obtained from the 2010 census and downscaled. Both flooding and income information were then combined to assess the distribution of affected households by income level and flood return period. The results indicated that flooding events in the Itapocu River basin affect the lowest-income households more frequently with events of greater magnitude. Therefore, investing in disaster management can be useful not only for protecting lives and assets, but also for reducing inequality.

Keywords: inequality, flood, household income, Itapocu

INTRODUCTION

Disasters do not affect the population equally. The most vulnerable sectors of society are those that suffer the greatest damage in proportion to their income, thereby impacting their welfare and capability to accumulate wealth. Therefore, disasters contribute to increasing the inequality rates because they affect people with fewer resources. Brazil is a country with high inequality rates; in 2018, the Gini index of Brazil was 53.9, which was one of the highest worldwide (World Bank 2018). The registers of natural disasters show an increasing trend in recent years. Droughts account for 51.31% of the affected people, flash floods 20.66%, and floods 16.04%, the others sum up to 11.99% (CEPED 2012). The country rapidly urbanized in the second half of the 20th century, but the poor land-use planning has led to a high proportion of the population living in hazardous areas. Therefore, it is paramount that Brazilian society and policymakers invest in disaster management because it is a tool not only for saving lives and reducing financial losses, but also for reducing inequality. The objective of this study is to propose a method to assess whether households are unequally affected by floods based on their income, apply it to the Itapocu River basin located in Santa Catarina State, Brazil, and propose adaptive measures.

STUDY AREA

Santa Catarina State registers recurrent floods (CEPED 2012). Flooding losses account for 81% of the state's total losses due to natural disasters (World Bank 2017). The Itapocu River basin is located in the northern region of Santa Catarina State in the southern region of Brazil (Figure 1). It is a coastal basin that drains an area of 2,919 km² and has experienced many flooding events (1944, 1987, 1992, 1995, 2008, 2011, and 2014) (ANA 2020). In the 2014 event, 123,262 people were affected by the floods, 17,942 people were dislodged, 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, thereby worsening the flooding hazard.

[1] Researcher in Geosciences at the Geological Survey of Brazil, Belo Horizonte, Brazil
[2] Senior Researcher at the Int. Centre for Water Hazard and Risk Management, PWRI, Tsukuba, Japan
[3] Researcher at the Int. Centre for Water Hazard and Risk Management, PWRI, Tsukuba, Japan
[4] Advisor of the Int. Centre for Water Hazard and Risk Management, PWRI, Tsukuba, Japan
[5] Professor of the National Graduate Institute for Policy Studies, GRIPS, Tokyo, Japan

METHODOLOGY

General overview

This study assessed the population affected by floods in the Itapocu River basin through five main steps (Figure 2). By analyzing the rainfall and its frequency (Step 1), a hydrological model of the basin was created (Step 2). In Step 3, the census data were downscaled to be combined with the hydrological model (Step 4). Finally, based on the evidence found in the study, I proposed measures that can be taken by the inhabitants and by the government to reduce the risk in the Itapocu River basin (Step 5).

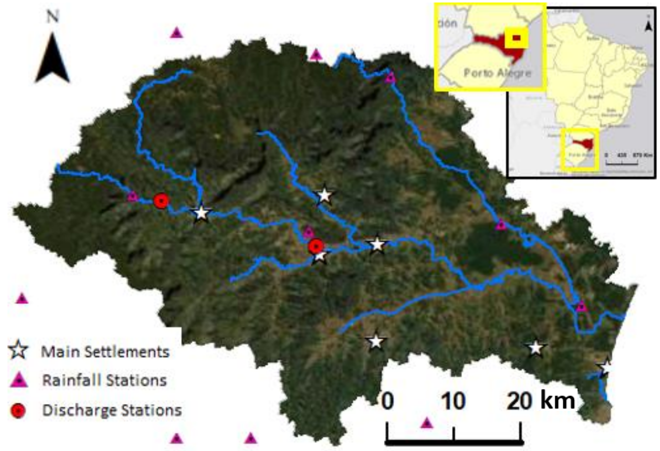


Figure 1: Itapocu River Basin and the location of the main settlements, discharge stations, and rainfall stations.

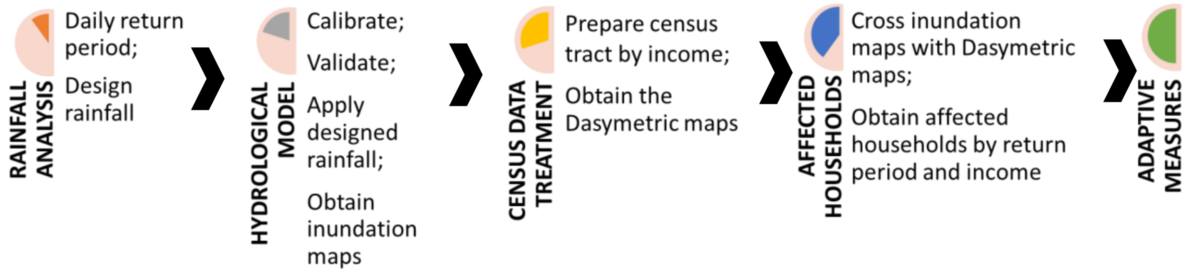


Figure 2: Methodology process summary.

Rainfall analysis

The rainfall frequency analysis was performed for 12 rainfall stations (Figure 1). The station with the shortest series had a 20 y record, while the station with the longest series had a 72 y record. Two discharge stations were used with 70 y of records. The rainfall and discharge were analyzed in terms of the daily annual maximum return period for each station.

The largest flooding event to date, which occurred in 2014, was caused by an average basin rainfall with a 59.1 y return period. Thus, the design rainfall was estimated for return periods of 2, 5, 10, and 20 y to assess the most frequent events and 50 y and 100 y to assess the most damaging and less frequent events.

The method chosen for designing the rainfall and for reflecting the daily rainfall return period was developed by averaging the rainfall events that resulted in high discharges in the Itapocu River. First, the dates of all the discharge events above 713 m^3/s (10 y return period discharge) for the Jaraguá do Sul station were selected (eight events). From the series of average basin rainfall, the average 3 d monthly maximum rainfall value was obtained and used to separate the significant rainfall events of each station.

The results that were coincident with the eight selected discharge events were then grouped by consecutive days and averaged for each station.

Hydrological model

For hydrological modeling, data from many different institutions were used (Table 1).

In terms of discharge, the most significant events registered at the Jaraguá do Sul station occurred in 1944, 1987, 1989, 1990, 1992, 2010, and 2014. The floods were modeled using the rainfall-runoff inundation (RRI) model (Sayama 2015) calibrated for the 2014 flood event, which was the largest event recorded in the discharge series with a peak discharge

Table 1: Data list

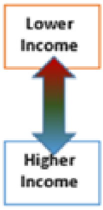
Data	Institution
Cross-section	Itapocu River Basin Committee; National Water Agency
Daily discharge and daily rainfall	National Water Agency
Digital elevation model	Geological Survey of Brazil
Inundation extents survey	Geological Survey of Brazil; Itapocu river basin Committee

of 1,878 m^3/s. The calibration was performed using both observed discharge and comparison with the observed inundated areas. The 1992 and 1987 events were chosen for validation. Two discharge stations were used for calibration and validation (Figure 1).

The digital elevation model was upscaled to 9 arc seconds to be used in the RRI model to balance the computational time required for calibration and to maintain fine resolution. To define the channel width and depth, the equations of the upstream contributing area were used. The data cross sections of the equivalent rectangular area were inputted manually to the RRI model to represent local variations in the channel. Land use and soil maps were imported from the RRI model.

Census data treatment

Table 2: Households by income level



Minimum Salary	Proportion of Households among total
< 1	30.9%
1–2	42.2%
2–5	22.7%
> 5	4.2%

The census (last available from 2010) was used for this assessment. The census tracts and tables containing the overall results were downloaded from the Brazilian Institute of Geography and Statistics (IBGE) website. The tables provide information about household income per capita. It is given in minimum salaries per month separated into 10 income levels varying from “no income” on the lowest end to “more than 10 times the minimum salary” on the highest income end. They were aggregated into four levels for this study, according to the “Brazil Criteria” of social classes (Table 2).

The census data were aggregated in the Census Tract, which is an area unit with no fixed dimensions (Figure 3). The bias that exists when analyzing aggregated data (Openshaw 1984) can be reduced by employing techniques to refine the census tract data.

The percentage of the five income levels in the census tracts were calculated, and individual rasters were generated for each aggregated level. The rasters were then multiplied by the “Grade Estatistica” (Statistical Grid).

The Statistical Grid was also downloaded from the IBGE website, and was an innovation of the Brazilian 2010 census. It consists of a shapefile mesh of 200x200m in urban areas and 1000x1000m in rural areas, with household and population information inside each cell. The Statistical Grid was used to refine the census tract information using a process known as dasymetric mapping (Mennis & Hultgren 2006). (Figure 3). This method consists of crossing a source data with an ancillary data with strong relationship with the source data, to allow for example, removing data from empty areas. The statistic grid was transformed to raster in terms of the total of households in each cell. The raster was used to be multiplied by the census tract raster, yielding a final Dasymetric result.

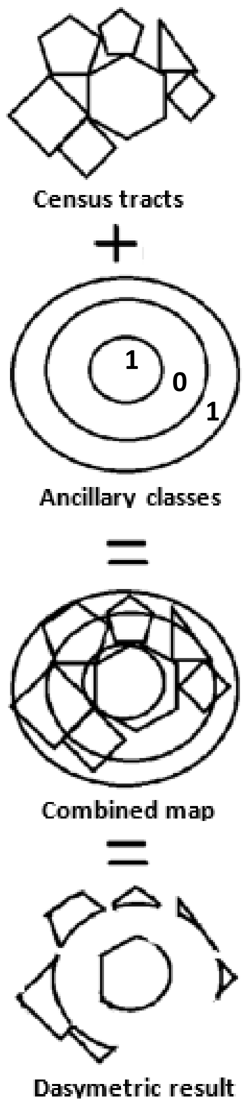


Figure 3: Dasymetric mapping diagram.

RESULTS AND DISCUSSION

Model calibration and validation

Calibration was performed using both the observed discharge and by comparing the highest inundation result of the model with the observed inundated area from the field survey, thereby resulting in comparable extents.

The Nash-Sutcliffe Efficiency (NSE) was then calculated for the calibration period of 05/01/2014 to 07/31/2014, and the result was 0.821 for the Jaraguá do Sul station (Figure 4) and 0.852 for the Corupá station.

The validation performed using the 1992 event obtained an NSE of 0.865 for the Jaraguá do Sul station (Figure 5) and 0.805 for the Corupá station. The validation performed using the 1987 event obtained an NSE of 0.865 for the Jaraguá do Sul station and 0.805 for the Corupá station.

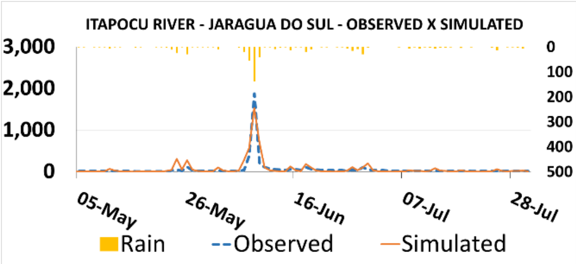


Figure 4: Discharge at the Jaraguá do Sul station for calibration of the 2014 event.

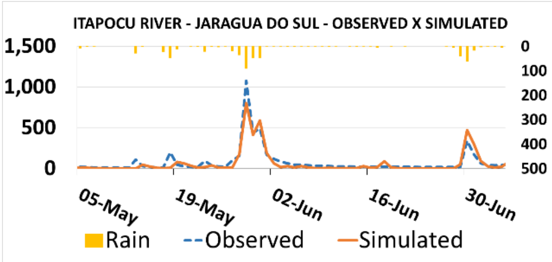


Figure 5: Discharge at the Jaraguá do Sul station for validation of the 1992 event.

Design rainfall

The average pattern was obtained for each station and divided as follows: the 7 d that corresponded to the peak were divided by each respective largest rainfall day, thereby creating a multiplier pattern. Finally, by directly multiplying each day by the station's daily return period, the design rainfall was obtained (Figure 6). Thus, each peak had at least 1 d that recorded the daily rainfall for a given return period, and the other days were proportional to this peak. More than 7 d of simply averaged rainfall were added prior to the peak, thereby totaling 14 d to build the soil conditions for the correct simulation, and 4 d of zero rainfall were added at the end of the series to assess the decrease in discharge after the event. In total, the design rainfall included 18 d.

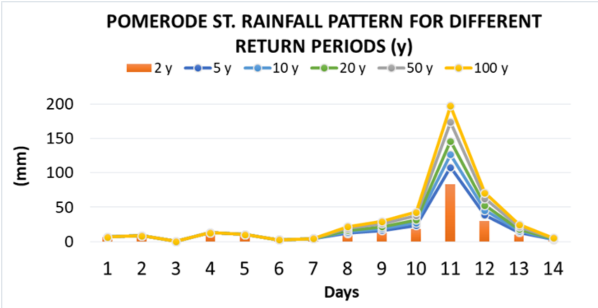


Figure 6: Design rainfall pattern for the Pomerode station. Days 1–7 are simply averaged. Days 8–14 are multiplied by the daily return period.

Model results and affected households

The final simulation resulted in inundation maps for 2, 5, 10, 20 50, and 100 y return periods (Figure 7) and the inundated areas, as described in Table 3. The lower threshold for defining the inundation area was set taking into consideration the elevation of households as 0.5 m from the street level.

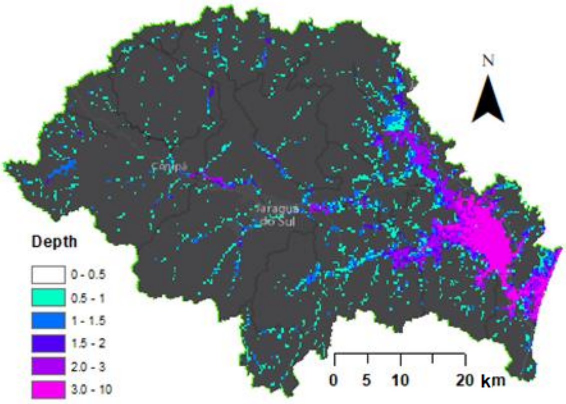


Figure 7: Inundation map for 100 year return period.

The final dasymetric map was a raster that was obtained by distributing the households in the Statistic Grid by each income level (Figure 8). It has a cellsize of 200x200m, the same as the Statistic Grid, therefore the downscaling the original census tract information.

Table 3: Simulated return periods and affected areas and households

Return period	Inundated area (km²)	% of the basin	Affected households	% 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%

The inundation raster of each return period was then multiplied by the dasymetric maps to estimate the total number of affected households by income level and by return period. This number was then analyzed from different perspectives by the absolute total of affected households and by the ratio of affected households (by total and by class total).

For each return period, the affected households were analyzed in terms of the total inundated area, when water starts invading the households (water 0.5 m above street level) and extreme inundated areas, when the damages to the households and danger to the residents are higher (water 2.0 m above street level to 1.5 m inside the house). Figures 9 and 10 show the percentage of affected households for the five income levels in both situations. The basin income distribution is also shown for comparison.

Concerning the total inundated area (Figure 9), the overall affected households followed a pattern similar to the income distribution inside the basin (Table 2), represented by the red dotted line in the figure. However, the lower-income level (<1 minimum salary) was proportionally more affected for the most frequent return periods.

Concerning the extreme event inundated area (Figure 10), the overall affected households followed a different pattern than the income distribution inside the basin (Table 2), red dotted line in the figure. The highest income levels had less affected households, and the lowest income level (<1 minimum salary) had the most significant share of affected households despite being less numerous than those in the 1–2 minimum salary level.

The Dasymetric maps show that high-income households concentrate mostly in Jaraguá do Sul city center, and low-income households are located in the suburban and rural areas. This suggests that, in the Itapocu river basin, the central area of Jaraguá do Sul city has the most valuable land.

The results point out that the low-income population is more likely to be affected by flooding of higher frequency and severity. That can indicate a spatial segregation of the safest areas in the basin based on the income capacity. By using the 5 year return period flood and the Dasymetric maps, the location of the affected communities where the number of inhabitants of lower income is high could be obtained (Figure 11). These communities are scattered in rural and suburban areas, therefore, policies concentrating on individuals might be effective, such as subsiding improvements in house safety and insurance.

Even though the highest income levels were less affected, they still had high percentages of affected households, especially for high return period floods. The highest income classes are expected to be more capable of protecting their homes from hazards, since adapting the homes to prevent damage involve some expenditure. The number of affected households will vary according to the protection measures adopted by the household owners. Cost-benefit studies for hard measures such as dry flood dams are useful because they can substantially reduce the damage suffered by all the population, especially from frequent events.

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.

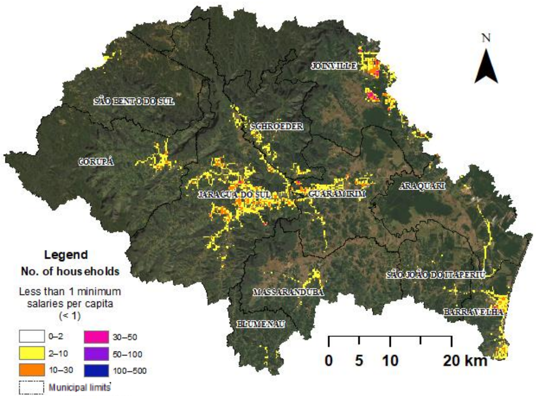


Figure 8: Dasymetric map of the households that earn less than 1 minimum salary per capita.

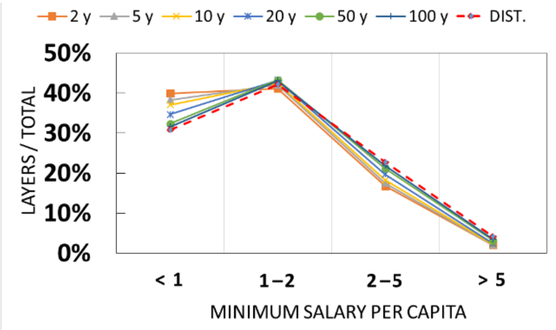


Figure 9: Percentage of affected households to the total affected households for the overall flooding area.

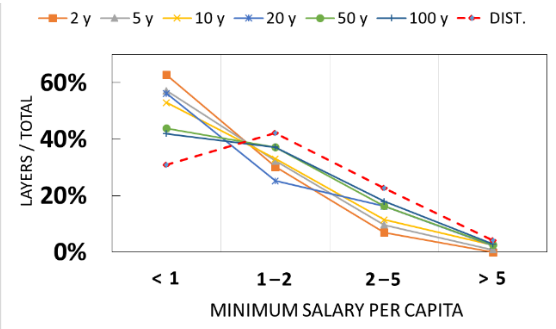


Figure 10: Percentage of affected households to the total affected households for severe events with more than 1.5 m depth inside the house.

CONCLUSIONS AND RECOMMENDATIONS

Brazil is a country with an extensive risk profile and high-income inequality rates that can be enlarged by natural disasters. This study proposed a method for assessing if the households of a given basin are unequally affected by floods, based on their income, tested it in the Itapocu river basin, on southern Brazil using nationally available data, and proposed adaptive measures for improving the safety of the basin.

For the overall flood, the affected households tend to obey the distribution pattern of households in the basin. The households that earn from 1 to 2 minimum salaries per capita are the ones with the highest number of households affected. However, the households that earn less than 1 minimum salary per capita are the more heavily affected when severer events are considered.

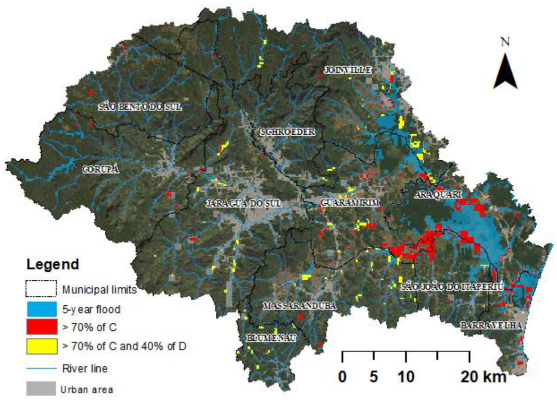


Figure 11: Location of the two lowest income levels in the Itapocu basin (red and yellow)

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.

This study used the 2010 census, but the population characteristics are very dynamic. When the new census is released the study should be revised.

To improve future assessments, more efforts should be made to collect data. Hourly gauges should be installed upstream of the main settlements. By accurately measuring the rainfall, it would be possible to implement an alert system for the basin.

Numerous studies identify an increase of rainfall in the future for Southern Brazil, therefore climate changes should be quantified in future assessments.

ACKNOWLEDGMENTS

I would like to express my gratitude to my supervisors, Dr. Miho Ohara, Dr. Mamoru Miyamoto, Prof. Kuniyoshi Takeuchi, and Prof. Hideo Fukui. I also want to thank my fellow researchers. To JICA, GRIPS, ICHARM, and their staff for maintaining this program and providing support. To Lucas Mickosz, Karine R. Holler, and AMVALI. To the Geological Survey of Brazil and to Jorge Pimentel for allowing me this opportunity. To my coworkers in Brazil, especially to my supervisor Natália Dias Lopes. To Ms. Mikiko Nakamura, to my family and friends for their support, especially to my sister Raquel Araújo.

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