AN INTEGRATED FLOOD DAMAGE ASSESSMENT IN BRAZIL

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ABSTRACT

This study presents a framework to assess flood damage risk based on generalized and nationally available data; the approach begins from climate and rainfall analysis and hydraulic hydrologic simulations, followed by application of normalized flood depth - damage functions and comparison two different ways to approach maximum flood damage. The first as presented by the European Union Joint Research Committee, an estimation from Gross Domestic Product per capita; the second alternative combines a compilation of previous studies and proposes an estimation of maximum damage based on econometric parameters; making use of taxes and statistics for approaching the local socioeconomic profile of community and production sectors. The indicators were found in the flood records from 1967 flood event in the region of Porto Alegre, Rio Grande do Sul State from which the relation between those parameters and flood damage was taken.

Keywords: Flood, risk assessment, disaster management

INTRODUCTION

Flood risk management requires damage assessment in order to enable feasibility studies and to prioritize areas with higher economic return of the investment; economic studies associated to prevention of flood damage can also prove effective in reducing inequality (Yokomatsu, 2013). Some physical interventions can affect large regions either positively or negatively, well-designed physical countermeasures can benefit whole regions and therefore the cost-benefit analysis should include all areas affected. This study proposes a method for a flood damage estimation based on an integration of hydrologic analysis and economic analysis elaborated from nationwide available data producing results that could provide technical support for the decision making process of risk management.

From the analysis of rainfall pattern and extreme event frequency, the runoff and flood are calculated, damage functions are applied and the intersection with the community results the potential future physical damage.

THEORY AND METHODOLOGY

The flood damage evaluation is prepared from integration of rainfall analysis, hydrological model of rainfall event, and analysis of damage caused by each flood event. Rainfall analysis provides the relation between the intensity and the frequency probability of extreme events. The runoff and flood are calculated through Rainfall Runoff Inundation Model - RRI (Sayama, 2015), first for a lower spatial resolution of 3km mesh for the upper Uruguai River Basin, followed by second hydrological model in 300m mesh for the municipality area and interpolation to 30m mesh and the results are validated through simulation of past events and comparison with river discharge records and satellite imagery of flood events. From this approach, flood hazard maps are prepared for selected return periods.

Once flood affected areas are defined, the transformation of flood depth using normalized flood depth – damage curves (Huizinga, 2017) for agriculture, residential, commerce, industry and services and areas, which results in normalized damage function maps. The information on urban areas is used to prepare a

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map of percentage distribution of the municipality; a land use map is used to prepare the percentage distribution for agriculture and livestock. The product of the normalized damage map and the percentage distribution is a damage distribution map and the value sum of cells for the whole municipality equals the fraction of maximum damage for each return period.

The maximum damage for residential areas is calculated using two different methods for comparison of results, the method 1 is based on GDP, as described by Huizinga (2017) with some variations by considering, Municipality GDP or National GDP and by using direct results or considering a 60% un-damageable part; meanwhile the Method 2 is based on an adaptation of the method and values obtained by Machado (2005), which discretizes the residential damage per social class. For the economic activity sectors a new approach is proposed based on econometrics parameters, the physical damage caused by the floods is interpreted as the physical capital belonging to and economy activity sector. In this understanding, the maximum damage caused by floods could be calculated based in the efficiency, productivity and value added of a sector. The human capital and total factor of productivity concepts can be used to explain why some activities have larger revenues and value added for a fixed amount of physical capital. From past damage records a function was obtained and applied to the parameters of the municipality.

In order to obtain the econometric parameters, a data assimilation was made to improve the information of tax data using several official statistics data (IBGE, 2018). From the integrated data, the local economy profile is obtained based on the Locational Quotient Method, adapted from the method proposed by Brene (2013), with input of the data assimilation results, instead of directly using tax data and adjusted for fitting the results to the official statistics. The proposed framework was applied for the city of Irai, Rio Grande do Sul State, a small municipality in the Southern Region of Brazil, and validated by comparison with damage records.

DATA

To compose a nationally applicable methodology, only data available countrywide was used in the process, even though it is known that the quality of the data varies within the country, for rainfall and river discharge the official data is more densely collected in some regions. The topography used is derived from satellite imagery and is expected to have more uncertainty in flat areas such as vast flood plains and coastal areas. For the information based on taxes, the quality varies according to the proportional amount of informality, which increases the proportional amount of activities that are estimated based in the statistics.

The data from rain gauge stations and fluviometric stations from the ANA - National Water Agency (Agencia Nacional de Aguas, in Portuguese) were used to calculate the probability density functions. The topography was obtained from the INPE - National Space Research Institute (Instituto Nacional de Pesquisas Espaciais, in Portuguese). The socio economic data was obtained from several official statistics from the IBGE - Brazilian Institute of Geography and Statistics (Instituto Brasileiro de Geografia e Estatistica) and from the tax data provided by the Ministry of Work. For validation of flood affected areas the images from Landsat (NASA, 2011) were reclassified using Isocluster Unsupervised Classification in ArcGIS.

RESULTS AND DISCUSSION

The processed satellite image from Landsat and the results of the calibrated simulation in RRI model for the 2011 flood event are displayed in Figures 1 and 2, respectively. The process achieved acceptable results, from which the simulation of design rainfall proceeded.

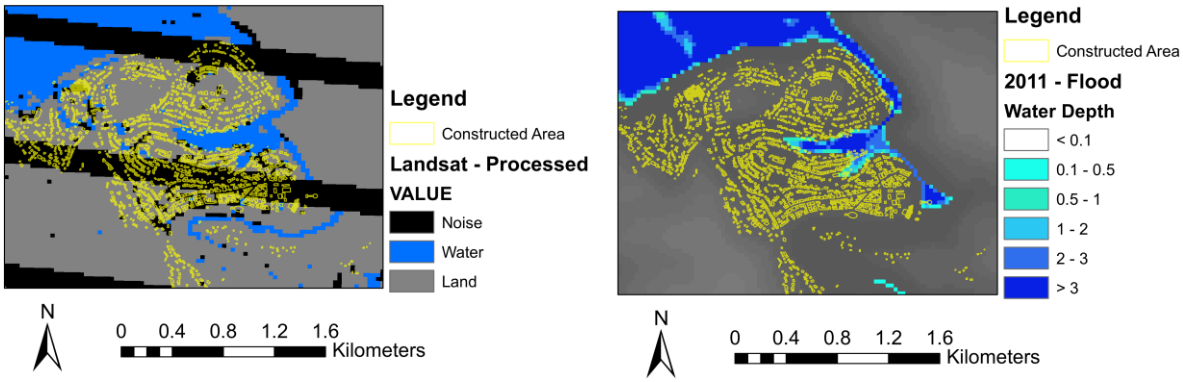


Figure 1 & 2- Processed image (left) and results of model calibration (right) for 2011 flood event.

The results of flood hazard maps for selected return periods reveal that the municipality main settlement is located in a flood prone area (Figure 3 & 4). The flood height in relation to normal river level can reach up to nearly 18m; and is validated by the height record of 1983 flood, when a rainfall similar to the design values for 50-year return period reached similar height values.

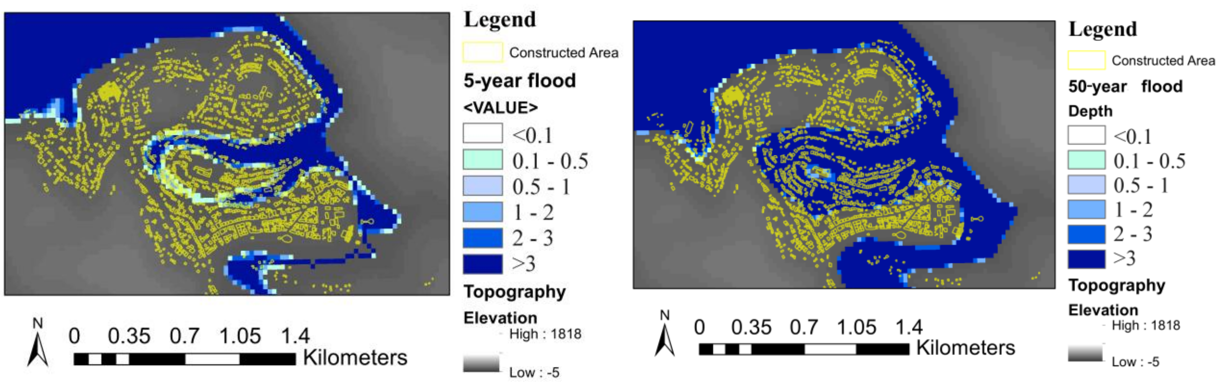
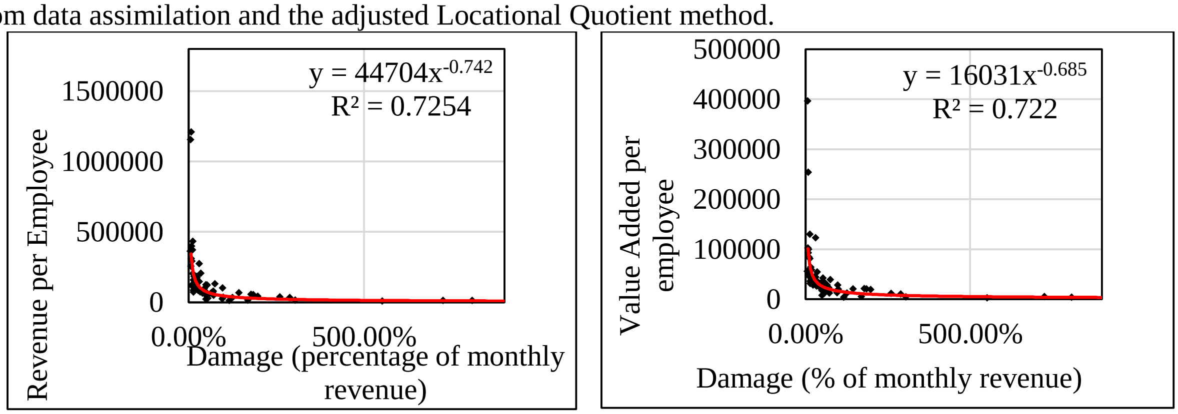
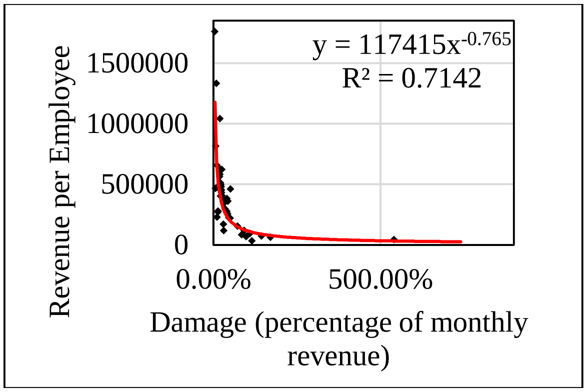


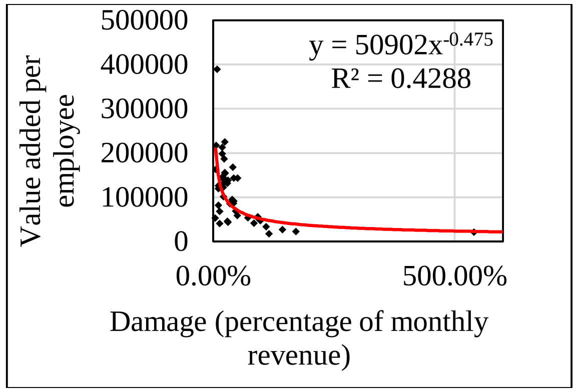
Figure 3 & 4 – Flood Hazard Map for return periods of 5 years (left) and 50 years (right) return period events in the municipality urban center.

The data from 1967 flood damage in the city of Porto Alegre displayed a significant correlation between both revenue per employee and damage as percentage of revenue and between value added and damage as a percentage of revenue (Figure 5 to 8). After application of a logarithm transformation in the data a multiple linear regression was tested and presented an improvement in fitting for both cases of Commerce and for Industry & Services, this fitted functions were used for calculations of maximum damage with the values of revenue and value added for each one of the economic activities using the results from data assimilation and the adjusted Locational Quotient method.



Figures 5 & 6 - Relation between econometric parameters and flood damage for Industry and Services.





Figures 7 & 8 - Relation between econometric parameters and flood damage for Commerce.

The normalized direct damage, for the city of Irai, was calculated for return periods of 5, 10, 25, 50, 100 and 1000 years; Figure 9 illustrates the averaged values for Commerce, Industry and Services and a fitted normalized damage function. From this normalized damage, the two methods of calculation were applied, as previously described, as summarized in Table-1, for the Method 1 the calculation for National GDP and consideration of 60% un-damageable part and for the Method 2 the economic activity sectors were grouped from the integrated classification of the results of municipality statistics and tax data to the same three categories of Method 1, for comparison.

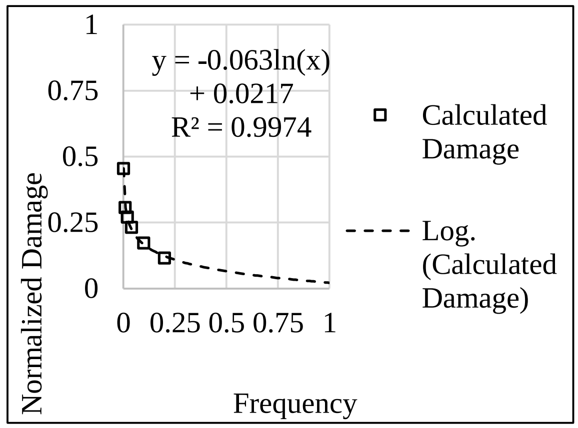


Figure 9 – Normalized Calculated Damage.

Table 1 – Results of Direct Damage Calculation (values of Brazilian Reais – R$ for 2010)

Return Period (years)						
	5	10	25	50	100	1000
Method 1:						
Residential	31,926,120	48,778,143	66,208,511	77,366,227	88,145,349	130,776,180
Industry &Services	19,762,572	29,629,780	39,938,265	46,494,905	52,947,766	78,442,798
Commerce	17,456,911	26,287,271	35,480,900	41,326,744	47,059,486	69,723,509
Method 2:						
Residential	3,927,631	6,207,428	8,425,586	9,836,998	11,218,417	16,627,331
Agriculture	187,108	226,001	269,739	305,299	339,520	460,552
Industry & Services	24,378	38,111	51,370	59,733	68,112	100,780
Commerce	1,055,552	1,652,670	2,230,667	2,595,459	2,958,968	4,378,861

The validation of the flood damage was done based on the records from the Integrated System of Disaster Information (Mikosz, 2018) and from the damage record provided by CEPED (2018), the rainfall event of June 2014 was selected due to the similarity with a 50 year return period, both sources reported a value of R$7.3 million for direct losses and CEPED also reported an additional R$ 8 million as indirect losses. The results from the calculation method proposed in the preset study, therefore, reached closer values to the damage records, even though, comparison of discretized damage was not a good match as same as total damage.

From the maximum damage evaluation from the econometric parameters, we can conclude that a less developed economic sector would be proportionally more affected by flood damage while the more developed sectors would be proportionally less affected. This can be explained in terms of Human Capital concept if we consider that a highly specialized worker, such as an architect or engineer, would produce a very high revenue and value with low value of physical capital, such as a computer and a desk, while in other activities, such as lodging, the revenue comes basically from temporary renting a high physical value built environment.

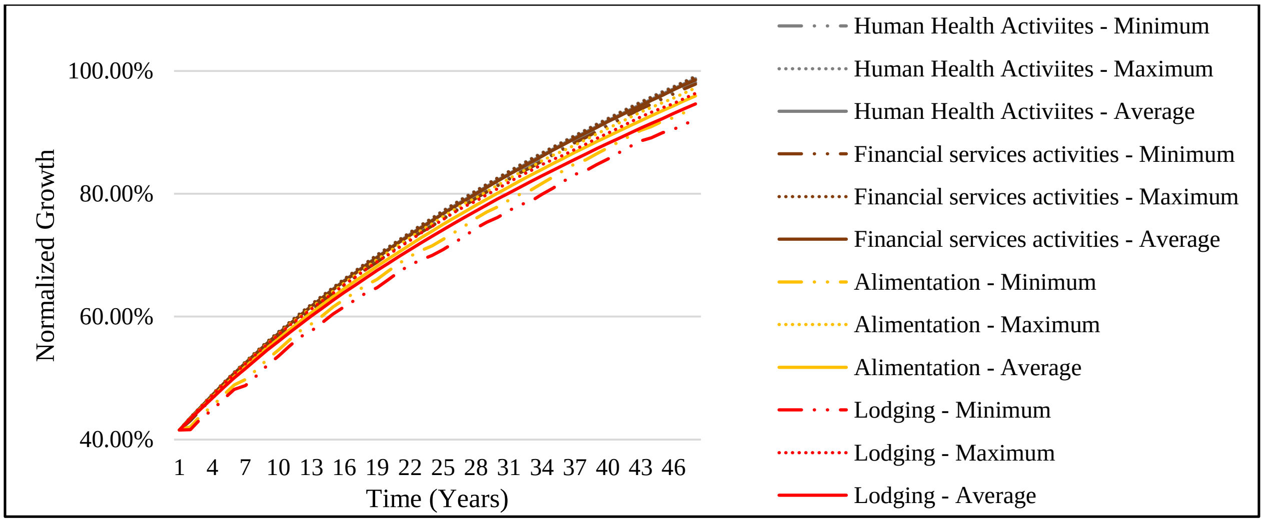


Figure 10 - Results of Monte Carlo simulation of Solow Model growth including flood damage.

The effect of this relation between econometric parameters and maximum damage is exemplified in the Figure 10, which displays the results of applying the normalized damage from the function illustrated in Figure 9 in a Solow model of growth through a Monte Carlo type simulation, by creating multiple scenarios from randomization of the probability of flood event and application of the normalized damage function presented in Figure 9. Although values cannot be interpreted directly as several simplifying assumptions were made, this implies that flood damage by itself acts as an intensifier of inequality.

CONCLUSIONS AND RECOMMENDATIONS

The overall objectives were satisfactorily achieved, the method proposed resulted a better performance than the existent alternatives in the present for assessing financial impact of floods without direct field research and based only in existent data. Although direct survey of financial assets is more precise, this approach can enable a faster and cheaper supply of information and comparison of damage costs in different regions.

The method can still be further improved, both from perfecting each step, exhausting processing capability, increasing number of events for validation or recalibration. Digital elevation models with higher resolution could be used to improve the results. Rainfall analysis could benefit from additional considerations of bias caused by change in the spatial distribution of the rain gauges over time.

Probably the step that deserves the most improvement is the interpretation of econometrics data, the validation of the relation between maximum damage and the econometric indicators proposed should be done with recent datasets and the construction of new damage functions based on recent data is recommended. This is important because of several currency changes and inflation and because changes in the productive systems occurred with recent changes in usage of technology in the most varied sectors.

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