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Rainfall Threshold Analysis For Flooding Events In Bauru City

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SUMMARY: The current debate about global warming in recent decades and also the increase in the frequency and intensity of extreme natural events caused by hydro-meteorological and climatological events led to a greater emphasis on natural disasters studies. Rain is the trigger event with higher incidence of damage and can be classified as moderate rainfall; cold front with continuous rain; and heavy rains. The damage linked to urban drainage are typically rated into flash flooding, highlighting that floods are not always easily differentiated among gradual floods, flash floods, river floods and overflow. Cross-analysis of damage and their triggering events related to rain indicates that heavy rain is the most significant event for the occurrence of natural disasters related to drainage. This research analyses flood occurrence with daily/sub daily rainfall data and accumulated rainfall over consecutive days in order to discuss the triggering rainfall threshold event of disasters in Bauru-SP for the period of 2005 to 2015. Spacialized results of this research were compared with the risk distribution maps drawn up by the Civil Defense and Bauru Municipality. Rainfall data were obtained from weather station installed at IPMet. The occurrence probability of the events was estimated using the IDF (intensity, duration, frequency) equation parameterized for Bauru city. The results show that precipitation in previous days appears to have no significant influence on the occurrence of disasters. In addition, events with low return period can cause significant damage. However, it should be noted that the study was done with pontual data, and the pluviometric network is very scarce, so higher rainfall volumes than those recorded may have occurred nearby. The challenge of linking the spatial precipitation variability with risk assessment includes the merge of rainfall measurements with local radar and satellite information, which should be done in future studies. Spatial data allows a more comprehensive analysis of the prevailing phenomena acting in the region. Case studies can help in the implementation of early warning systems and prevention policies.

KEYWORDS: natural disaster database, flood area mapping, IDF equations, severe rainfall.

1 INTRODUCTION

Natural disasters are an issue increasingly present in daily life. Although some people associate disasters only with earthquakes, tsunamis, volcanic eruptions, cyclones and hurricanes, these also include processes and phenomena such as landslides, flood, subsidence and erosion, which can occur naturally or be induced by human activities (TOMINAGA *et al*, 2009).

The Brazilian researches on the natural disasters showed a significant increase from 2008. Rodrigues et al (2015) analyzed the scientific production in Brazil related to natural disasters and concluded that the research growth due to disasters are more frequent and to the publicity given to the results of the Intergovernmental Panel on Climate Change, in 2007.

Another important factor was the UNO (United Nations Organization) campaign: “Building Resilient Cities”, which mobilized more than 1.000 cities and local governments by 2011 (ONU, 2012).

In recent decades there has been a stepping up of the damage caused by natural disasters due to an intense process of urban concentration with no planning. Floods correspond to 55% of all disasters reported around the world in urbanized places. (KOBIYAMA *et al*, 2006; RECKZIEGEL and ROBAINA, 2005; LEAL *et al*, 2012; SAUSEN and NARVAES, 2013).

Droughts and floods are the most frequent types of natural disasters in Brazil (Figure 1), the first restricted northeast region. In Brazil, 37.1% of the municipalities reported to have been hit by overfloodings in recent years, and Bauru is inserted in this context (IBGE, 2014).

In 2015 the cost of all kind of disasters (natural and technological) was estimated at US $ 85 billion (REACTIONS, 2015). Given this context, a scientific study involving not only statistical analysis but also promoting the understanding of how the characteristics of the physical environment and rainfall influence the flood is relevant.

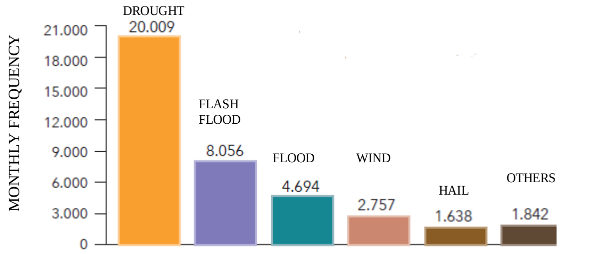

Figure 1. Total records of the most frequent natural disasters in Brazil, from 1991 to 2012.Fonte: CEPED, 2013.

This research aims to relate the probability of flood occurrence and its spatial distribution in the city of Bauru, in the State of São Paulo (Figure 2), with the analysis of data daily/sub daily rainfall and accumulated rainfall in the period 2005-2015, to characterize the triggering rainfall disaster.

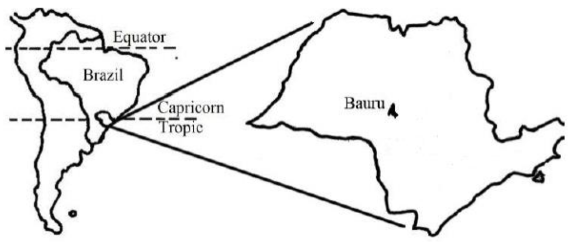

Figure 2. São Paulo state and Bauru city location.

2 BACKGROUND

2.1 Environmental disasters and resilient cities.

Disaster is the result of adverse events, which may be natural or produced by man, causing people impairments, material and environmental damages with consequent economic and social losses. To reduce their occurrence and intensity, preventive measures should be adopted (BRASIL, 2005; CERRI NETO, 2007; MARCELINO, 2008).

Risk is defined as the possibility of an accident, and the conditions of vulnerability of exposed people and properties. The security can be improved, depending on the individual and institutional capacities to address and/or take action to reduce the risk, which may expand due to exposure and vulnerability as well (ONU, 2012; RECKZIEGEL and ROBAINA, 2005).

The ability of a system to absorb, resist, maintain their functions and recover after a disturbance is called resilience. It is a promising solution to the recurrent difficulties encountered in risk management in urban environments. In order to face possible climate change and environmental risk, the resilient city is a network that involves interlinked concepts, as shown in Figure 3 (JABAREEN, 2012; SERRE and BARROCA, 2013).

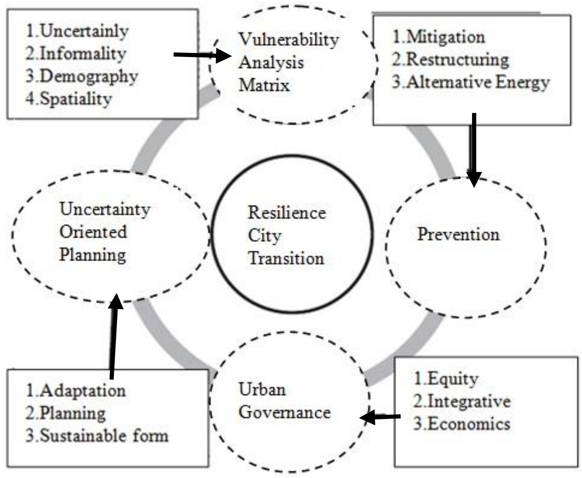

Figure 3. Framework of planning for a resilient city. Source: JABAREEN (2012).

Urban development has led to the increasing in the frequency of flood, that is caused by: the accumulative impervious areas, the reducing of the flow capacity by the canals silting, the infrastructure deficit of micro and macro drainage facilities that are undersized to the current demands (TUCCI and COLLISCHONN, 2000).

The classification of damages in floods, flash floods, river floods, overflow and inundation is not simple. Figure 4 illustrates a situation of a river that runs in an urbanized place, hit by heavy rains. The level of the river rises form its normal position to a maximum level, when the river still holds its natural bed, but even so causes disorders to the city because of the intense occupation of the riverbanks. River flood corresponds to the rising of the river level beyond its capacity, overflowing the lowlands areas. Overflow is linked to the drainage system deficit and corresponds to a momentary accumulation of water in urban area that can cause huge damages, but lasts a short time. Flash flood is also related to drainage system deficit associated to heavy rain. (KOBIYAMA *et al*, 2006, IPT, 2007, JACOB, 2014).

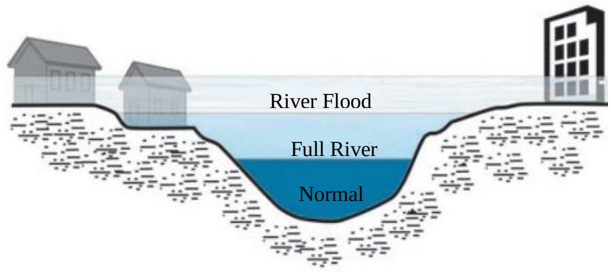

Figure 4. Evolution of the rising level of the river bed waters. Source: IPT, 2007.

3 METHODOLOGY

Pellegrina (2011) implemented a natural disaster database available on the site IPMet (http://www.ipmet.unesp.br/). This database is supplied with Civil Defense bulletins and local media. As default, Civil Defense only register a record when the damage directly affect the city and the population, otherwise the occurrences are not reported and so not included in the system. Such tool allows the risk determination areas, contributing to the warning systems efficiency, as well as to the logistics of the victim assistance agencies, urban planning and proposal of public policies.

For this work, searches were done on the IPMet (2016) - Natural Disasters Database, for the period from 2005 to 2015 in Bauru city. Only rainfall records related to flood damage were considered. The generated report provided information of damage and its location

It was considered the following triggering phenomena: heavy rain, hail, moderate rainfall, cold front / continuous rains. Damage considered: flash flood, overflow, overflowing rivers, person dragged by flood, river full and flood.

The rain gauge is located at IPMet dependencies and provides rain volume information every 5 minutes as shown in Figure 5. This information was crossed with the natural disaster database.

The rain gauge information was used to calculate the Return Period of each event, according to IDF- intensity-duration-frequency equation for Bauru using Martinez and Magni (1999).

$$I_{(t,T)} = A(t+B)^{-c} + d(t+B)^{-E}\left\{-F - G\left[\ln\left(\ln\left(\frac{T}{T-1}\right)\right)\right]\right\} \quad (1)$$

Where: i= rain intensity (mm/minutes)
t = storm duration (minutes)
T = return period (years)
Equation parameters: A = 35,4487; B = 20;
C = 0,8894; D = 5,9664; E = 0,7749; F = 0,4772;
G = 0,9010.
Valide for $10 \leq t \leq 1440$

Figure 5. Rain gauge installed at IPMet campus.

4 RESULTS

From 2005 to 2015 IPMET database recorded 71 days with rain that generated 191 events of damage related to floods.

The five most frequent addresses were: Nações Unidas, Alfredo Maia, Rodrigues Alves, Comendador José da Silva Martha Avenues and the neighborhood “Pousada da Esperança I” as shown in Figure 6.

The map of locations and frequency of events produced by Bauru Municipality and local Civil Defense shows that these critical points of flooding obtained through IPMet database have high or very high risk. The only location that has a low risk is the “Pousada da Esperança I” neighborhood (Table 1).

The years 2015, 2013 and 2007 correspond to those with the greatest number of rainy days that triggered disasters, Figure 8, with 2015 and 2013 were those with the most damage. 2008 registered fewer incidents, although it is not the year with less days of reported rain. The 191 damage records occurred in 71 days of the ten studied years, so some of these days registered damage in different points of the city (Figure 7).

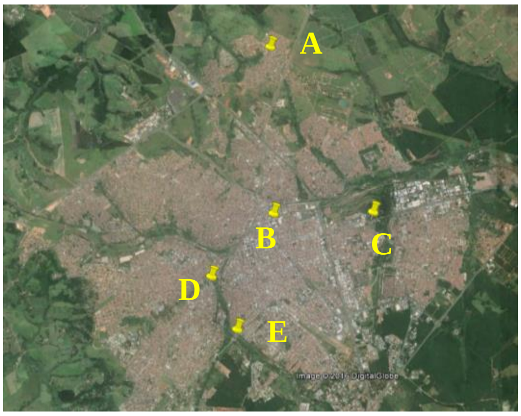

Figure 6. Spatialization of five critical flooding points in the Bauru city.

Table 1: Points of flooding according to the map of classification by Civil Defense.

	Location	Risk classification by civil defense
A	Pousada da Esperança I	low
B	Nações Unidas	very high
C	Rodrigues Alves	high
D	Alfredo Maia	very high
E	Comendador J. da S. Martha	very high

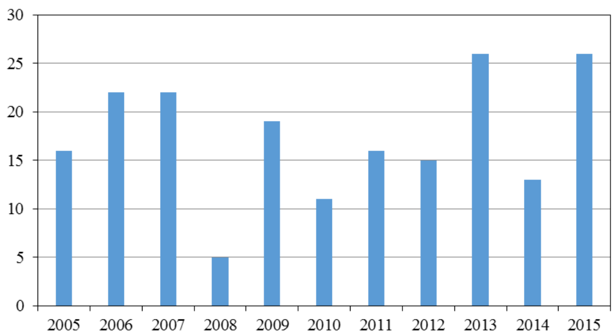

Figure 7. Amount of local damages recorded annually in Bauru for the period 2005-2015.

The year with the greater number of days with occurrences was 2015, with 15 days (Figure 8), recording a meaningful greater number of days with rain which generated damage linked to flooding, then the precedent years.

2015 was an atypical year (Figure 9), with 1713.1mm, that is the highest record above the long run average rainfall (1511 mm in 30 years hydrological serie). 2011 and 2009 also had above average annual rainfall in Bauru. Relating to temperature 2015 registered an annual temperature average of 23.8º C that was higher than the annual average over an historical series of 30 years. The annual average maximum temperature for 2015 was (29.6ºC) higher than the last 15 years with an average of 28.2 ºC (FIGUEIREDO and PAZ, 2010).

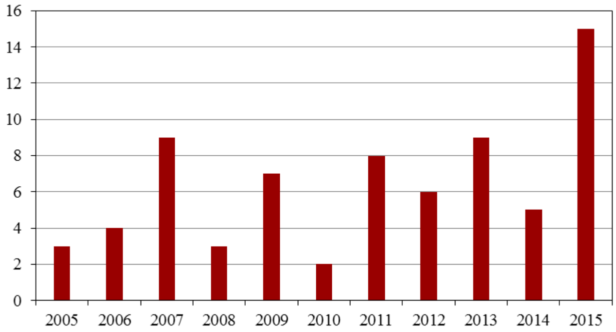

Figure 8. Days with rain that triggered some type of damage.

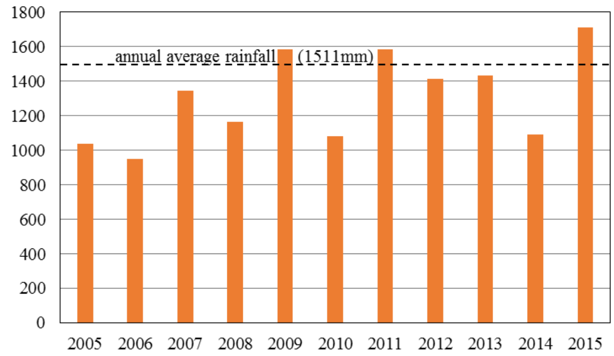

Figure 9. Annual rainfall (mm) in the city of Bauru and average annual rainfall (mm)

Table 2 presents the 71 damages occurrence days. On Jan 8th 2006 occurred the highest number of damages, total 13, in different locations of the city. The days circled mean the dates with the value of T (return period) greater than 2 years. Days signed with a rectangle indicate those one with number of occurrences greater than 6. Days: 30/11/2010, 15/03/2012, 23/11/2015 and 25/12/2015 were also the only ones, within the 191 records studied, that the event “person dragged by flood” appeard.

The return period recommend for drainage for commercial areas and traffic arteries should be amid 5 and 10 years (TUCCI *et al*, 1995). Tables 3 and 4 joins IPMet database records with the rain data, considering only the events with return period greater than 2 years, minor than that one used for drainage design.

Among the analyzed days, the two days with higher return period T are 15/03/2012 and 23/11/2015. The rains of the seventh critical days presented in Tables 3 and 4 were intense and with short duration but in the precedent days there was no major precipitation volume. (Tables 3 and 4).

Table 2: Table with the number of occurrence per day from 2005 to 2015.

Day	Number of Damage	Day	Number of Damage
20/01/2005	4	14/02/2012	2
25/02/2005	5	15/03/2012	5
16/03/2005	7	04/06/2012	4
08/01/2006	13	23/10/2012	1
15/02/2006	5	13/11/2012	2
06/03/2006	3	24/11/2012	1
20/11/2006	1	04/01/2013	3
13/01/2007	7	12/03/2013	1
28/01/2007	5	15/03/2013	5
11/03/2007	1	27/05/2013	2
16/07/2007	1	21/07/2013	4
23/07/2007	2	04/11/2013	2
25/07/2007	2	21/11/2013	4
27/07/2007	2	30/11/2013	4
06/11/2007	1	05/12/2013	1
12/12/2007	1	23/01/2014	8
04/01/2008	2	20/03/2014	1
29/10/2008	1	02/09/2014	1
10/11/2008	2	24/09/2014	1
02/01/2009	2	26/09/2014	2
14/01/2009	5	05/01/2015	5
12/02/2009	4	07/01/2015	1
03/09/2009	1	14/01/2015	3
23/09/2009	2	21/01/2015	2
28/11/2009	4	09/02/2015	5
02/12/2009	1	07/03/2015	1
07/10/2010	3	21/04/2015	1
30/11/2010	8	10/05/2015	1
08/01/2011	6	25/09/2015	1
13/01/2011	1	17/11/2015	1
25/01/2011	3	23/11/2015	1
16/02/2011	1	24/11/2015	1
28/02/2011	1	10/12/2015	1
15/10/2011	2	25/12/2015	1
22/11/2011	1	28/12/2015	1
08/12/2011	1		

Days with T > 2 years
Local occurrence ≥ 6

Tables 5 and 6 shows the days with number of occurrences greater than 6 and the respective return period (T). Note that despite the return periods are less than 2 years, damage has occurred in different parts of the city on the same day. 8th January 2006 was the day with the highest number of records, with a large amount of rain in a short time and no rain on the precedent day. In contrast, on 08/01/2011 occurred a continuous rain over six days (total of 134.12mm).

Table 3: Result of the critical days from 2005 to 2015, considering the return period greater than 2 years.

Date	Pluviometer IPMet (mm)-accumulated in the period	Duration (min.)	Return Period T (years)
25/02/05	61.98	160	3.04
15/02/06	56.90	145	2.5
06/11/07	79.5	470	3.56
28/11/09	44.7	50	3.12
15/03/12	71.12	160	5.07
07/03/15	54.09	125	2.38
23/11/15	40.6	24	9.19

Table 4. Result of the critical days from 2005 to 2015, with damage

Date	N° previous days with rain	Rain on the previous day (mm)	Damage/ Occurrences
25/02/05	0	0	Flood, Overflow
15/02/06	0	0	Overflow
06/11/07	0	0	Flood, Overflow
28/11/09	1	0.51	Flood, River full
15/03/12	1	1.52	Overflowing rivers, Flood, Overflow, Person dragged by flood
07/03/15	1	3.56	Overflowing rivers, Flood, Overflow
23/11/15	0	0	Flood, River fulls, Overflow, Person dragged by flood

According Nakazawa et al (1994), Bauru has high susceptibility to erosion induced by runoff. However, by the analyses of the geotechnical map, there is no evidence that the physical environment leads to the incidence of floods. So, the inefficiency of the drainage system may be major cause of such disasters.

Table 5. Results to days with greater than 6 damages and return period

Date	Pluviometer IPMet (mm)-accumulated in the period	Duration (min.)	Return Period T (years)
08/01/06	40.89	105	1.41
13/01/07	28	80	1.06
30/11/10	27.17	75	1.05
08/01/11	38.61	65	1.6
23/01/14	23.11	55	1.03

Table 6. Results to days with greater than 6 damages and the damage respective damage.

Date	N° previous days with rain	Rain on the previous day (mm)	Damage/Occurrences
08/01/06	0	0	Flood, Overflow
13/01/07	1	2.79	Flood, Overflow
30/11/10	1	1.02	Overflow, Person dragged by flood
08/01/11	6	134.12	Overflowing rivers, Fiver Full, Overflow
23/01/14	1	4.06	Overflowing rivers, River full, Overflow

4.1 Climatological Analysis

The rainfall pattern in São Paulo state is strongly influenced by the presence of SACZ - South Atlantic Convergence Zone, which promotes moisture transfer from the north to the southeast region of Brazil. As in 2015 the highest rainfall rates and temperatures were recorded, here is presented a synoptic description of weather condition of the months where the worst events were recorded.

By the end of December 2014 an atmospheric blockade that persisted until January 2015 acted, preventing the SACZ formation and therefore low rainfall occurred in the period. This situation changed in late January and February with an increase of rainfall; making the rainfall more regular in the state of São Paulo. In March 2015, the total precipitation height were higher than the monthly rainfall totals average of long period. The temperatures for this month were normal. Winter 2015 ended with great irregularity in the spatial and temporal distribution of precipitation, especially the excessive rainfall in July and shortages in the months of June and August. The little frontal activity increased mean temperatures in August and decreased in July due to strong frontal activity.

In much of the central region of São Paulo, which includes the city of Bauru, the monthly cumulative rainfall in the month of September 2015 was 224% above the historical average, due to the passage of cold fronts that reinforced instability areas. Note that on 25th September, IPMet weather station recorded daily 74.2 mm, while the average climatological for the month is 68 mm.

Spring had temperatures above the climatological average in most of Brazil, according to CPTEC (2016) - Center for Weather Forecasting and Climatic Studies, which was confirmed by the weather station IPMet

During November, the rainfall surplus condition persisted in São Paulo state. IPMet weather station recorded an increase of 74% above the climatological average for the month of November. That can be explained by the instability of areas associated with low pressure systems and the passage of two cold fronts.

In December, it was noted an increase in precipitation in IPMet records, with the performance of cold fronts, warm and moist air masses and areas of instability due to the action of a low steady pressure system.

5 CONCLUSION

The year 2015 was considered the hottest year recorded with various drought events in worldwide (ONU, 2016). In addition the higher return period was registered for the studied period. IPMet station also recorded the highest annual average temperature (29,6ºC) within the range of 15 years of data in Bauru.

Considering the analyzed period of ten years, an event with return period of 9.19 years occurred, indicating a consistent result considering the IDF equation.

The drainage designs done in past decades failed to predict the growth of cities and the increase in impermeable areas. Damages are recorded to rain with return period of 1 year. A rain of 5 years of return period caused an event of “person dragged by flood”. Urban managers have a huge challenge: the implementation of public policies that that ensure water retention on the property. These polices may reduce the demand of major engineer drainage projects to avoid flooding points in ordinary events (with a return period of less than 2 years). The maintenance of drainage infrastructure is also relevant because is recurrent the registration of culverts clogged with garbage soil. For floods the existence of rain in precedent days does not seem to worsen the damage recorded.

Since there were only one pluviometer available in that period, this study used only punctual data. Higher rainfall volume may have occurred in others points of the city. Future studies aim to link the spatial precipitation variability with the risk of occurrences. This includes the merge of rainfall measurements with local radar and satellite information. Now, from 2015, Civil Defense installed five pluviometer spread on Bauru urban area.This will improve the analysis of the prevailing phenomena acting in the region, helping the implementation of warning systems to prevent these occurrences.

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