VULNERABILITY TO FLOODING IN THE CITY OF SAO PAULO

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ABSTRACT:

The city of São Paulo is the largest in Brazil, covering 1,500 km², population of approximately 12 million inhabitants (IBGE , 2011) and watershed areas over than 80 % impervious. This level of soil sealing has a fundamental role in increasing the risks associated with flooding and mass movements due to increased runoff, taking the concept of risk as the product of the probability of the event, exposure, vulnerability and potential damage.

This article shows the construction of curves flooding vulnerability for different basins in the city of São Paulo, according to the probability of the rainfall event, based on the historical analysis of such incidents over 10 years of records .

Based on the data analysis of instantaneous rain records from the meteorological radar of Sao Paulo combined with 23 telemetric surface rain stations, 7 extreme rainfall events were selected and flooding incidents records were consisted by assessing those effectively linked to the rainfall event. Resulting valid data where fitted to the probability of occurrence in terms of return period and also the duration of the event, through GIS tools.

The sigmoid-type resulting functions show vulnerability to floods of each studied basin for 2, 5 and 10 year return period events, and the associated spatial distribution of this vulnerability in São Paulo. It also presents the spatial analysis of occurrences of flooding within and outside the perimeter of the so called expanded center, which coincides with the areas under the influence of the main arteries of vehicular traffic and traffic restriction polygon, adopted in the city for urban mobility improvement.

Data also point that, as in most Brazilian cities, the main road infrastructure of the city, mostly built on the floodplains of rivers and streams and often with closed sections structures, is vulnerable to events of 2 year return period.

Key Words: Flooding Risk, Urban Vulnerability, GIS

1. INTRODUCTION

São Paulo City is the largest urban area Brazil, with almost 80% of its 1,500 km² area sealed or impervious soil and approximately 12 million habitants (IBGE, 2011) . Urbanization and sealing and other factors associated empower flooding problems, due to inefficiency of storm water system, directly reflecting in urban mobility and economical losses.

Based on the analysis of rainfall data from ground stations and meteorological over 7 extreme events in the last 10 years and spatial correlations with flooded points in main streets and avenues situated in so called enlarged central area of the town, this article has as objective to present a methodology to evaluate the spatial flood vulnerability as a tool for city resilience improvement,

Assuming floods are hydrological events directly correlated to precipitation and that risk is a function of its probability, vulnerability and associated damage, the local vulnerability function become an important information for decision makers and stakeholders to assess urban interventions and public policies for land use and occupation.

As a result, vulnerability functions, combining rainfall probability and local vulnerability area presented in terms of maps for 2, 5 and 10 years of return period their spatial distribution are analyzed in terms of city occupation and growth.

2. METODOLOGY

2.1 Study area

With an area of 1,521 km² and 11.253,000 inhabitants, Sao Paulo City has a population density of 7,387 inhabitants per Km². Recent studies indicate that 85-90% of the surface area became artificially is impervious by ordinary urban land use due to population growth in the last 50 years. Situated in the upper portion of Tietê River Basin (Figure 1), the surface was initially divided into 13 sub catchments, taking in account the significant tributaries and also main traffic elements as highways and big avenues (). Another important issue considered was the traffic restriction zone existing in Sao Paulo that daily, limits the circulation 20% of the vehicles fleet.

Figure 1 – Sao Paulo city Area and Tietê River Basin main sub catchments

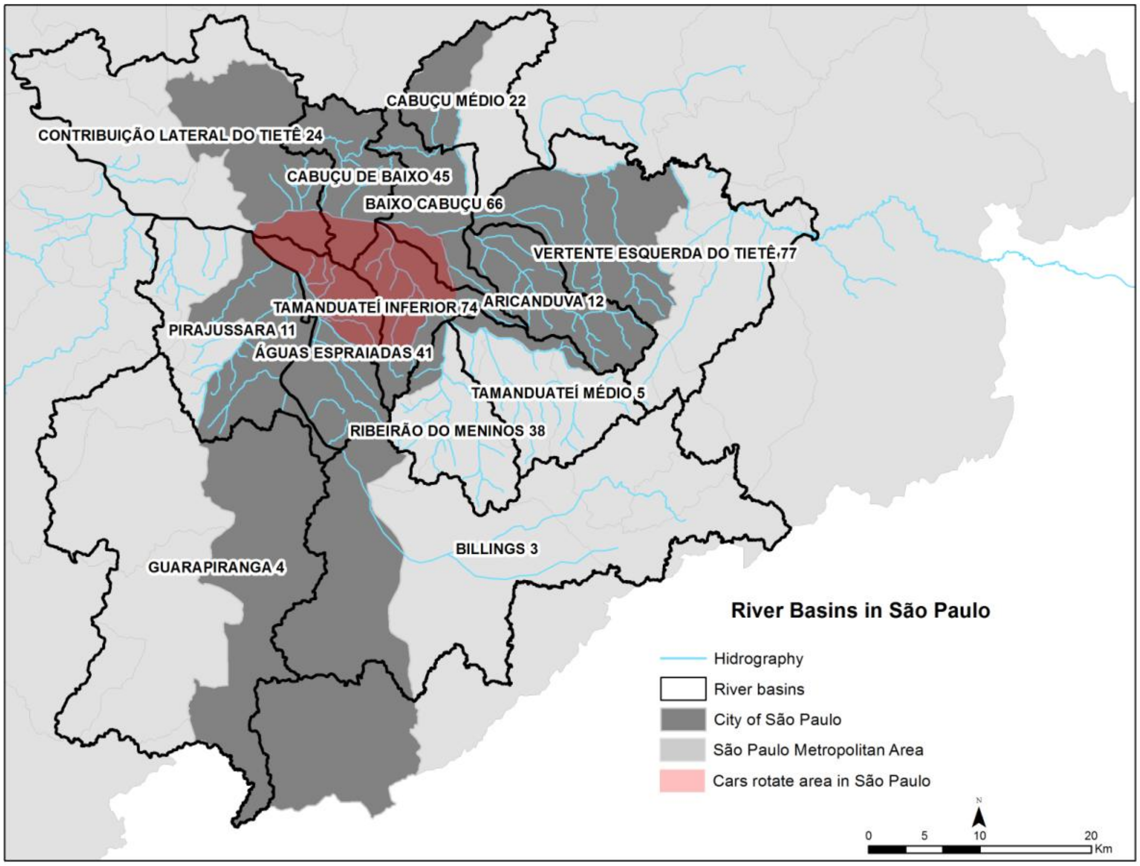


Figure 2 – Spatial Division of Sao Paulo City Area based on hydrological basins and traffic restriction zone existing in Sao Paulo Area. Source: IBGE, 2012; EMPLASA, 1974.

2.2 Extreme events

Seven extreme rainfall events were selected for vulnerability analysis, considering data from the meteorological C-band radar correlated with 23 telemetric rain stations, that provide adequate time and spatial rainfall distribution in a 10min time step. The events selected considered different durations and return periods as shown in Table 1.

Table 1- Selected Events for Vulnerability Analisys

Event	Start	End	Duration (h)	Average Return Period[1] (yr)
May2005	23/5/05 0:10	26/5/05 1:00	73	7,6
Feb2007	5/2/07 15:30	12/2/07 0:00	152	18,1
Dec2007	18/12/07 17:10	21/12/07 1:00	56	2,2
Sep2009	6/9/09 6:10	10/9/09 14:50	105	14,4
Dec2009	7/12/09 10:10	9/12/09 4:00	42	3,8
Jan2010	20/1/10 18:10	22/1/10 18:00	48	7,4
Jan2011	10/1/11 18:10	12/1/11 18:00	48	58,7

[1]Computed over 6-hour most intensive interval

The accumulated total rainfall for intervals of 6, 12, 24 and 48 hours were calculated for each event from raster files ASCII-type containing the radar images (FCTH, 2013) with the space-intensity distribution, where each pixel represents 2 x 2 km x 10 min precipitation (Figure 2) , properly consisted and correlated with ground information provided by telemetric stations (ROCHA FILHO et al., 2013). The average precipitation was calculated for each of the 13 sub catchments and the mentioned durations, as well as the flooding situations on the traffic network were collected and spatialized for the same intervals. The return period for each event were established considering Sao Paulo rainfall IDF equation (Martinez Jr. and Magni, 1999). For each duration, the number of situations in each sub catchment were normalized by the total number of occurrences and classified considering 8 precipitation categories. This procedure resulted in specific vulnerability functions that can be fitted to sigmoid curves as shown in Figure 3.

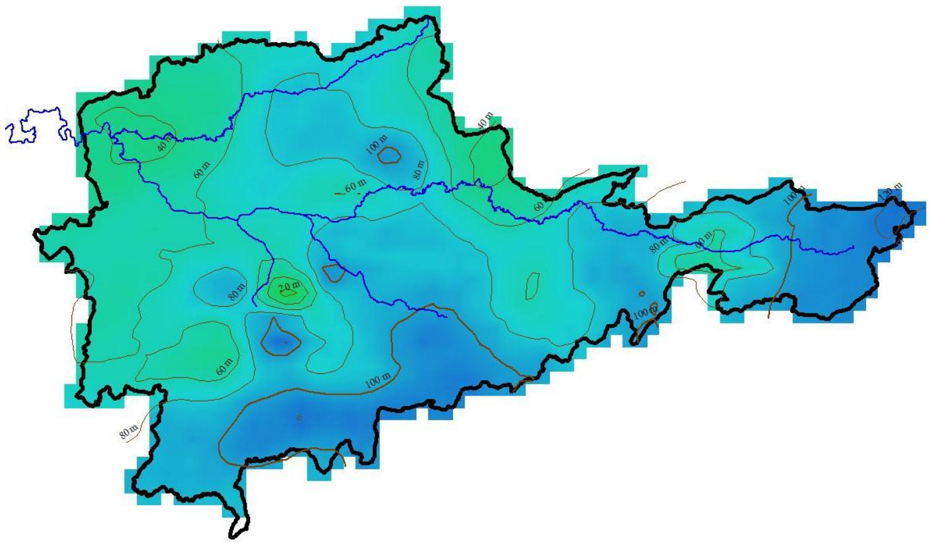
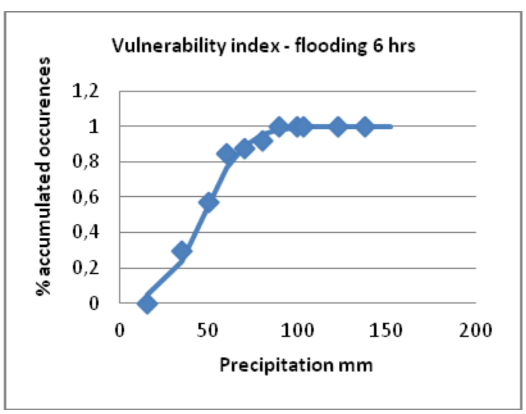
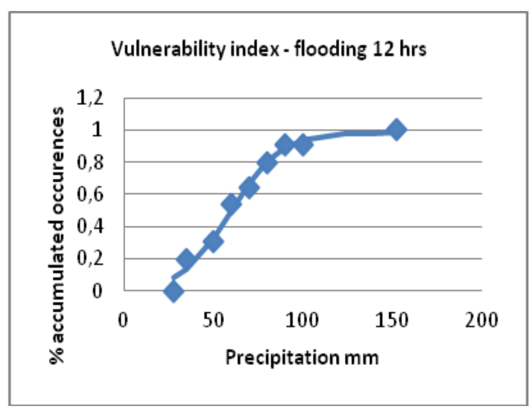


Figure 2 – Accumulated Precipitation plot – Dec 2009





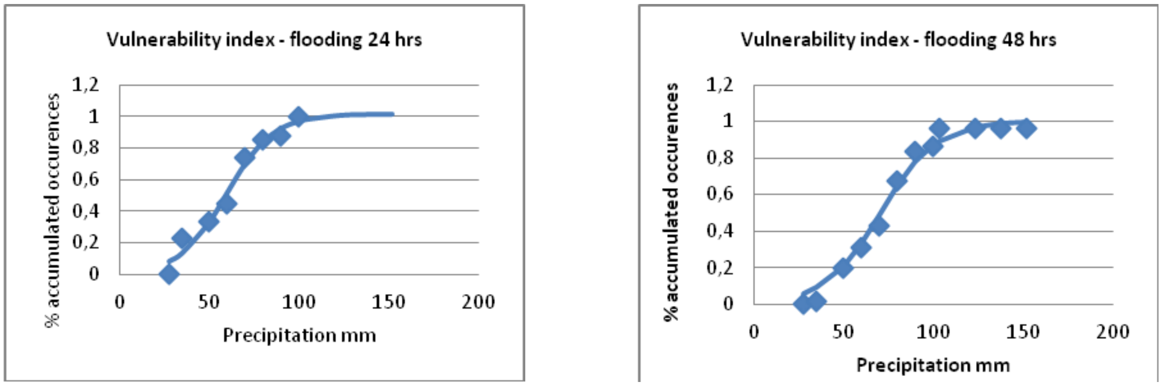


Figure 3 – Vulnerability Function to Flooding

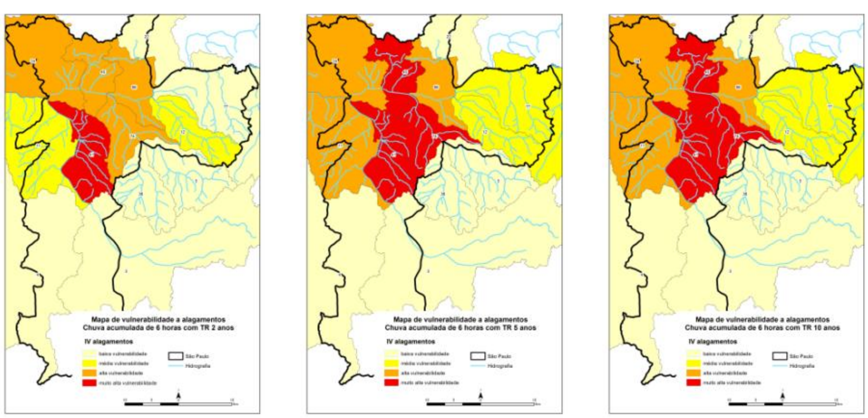
2.3 Classification of urban vulnerability

Four vulnerability categories were proposed: low vulnerability; medium vulnerability; high vulnerability and very high vulnerability. River basins with low vulnerability were considered when number of occurrences for a period of rain accumulated and TR lesser than 10 % of total occurrences. The remaining 90% were divided into three linear classes following Table 2. Maps of flooding vulnerability can now be constructed considering the vulnerability functions and return period, in order to display spatial susceptibility to flooding along main regions in the city.

Table 2: Vulnerability Categories

Flooding occurrences	Vulnerability
0 to 10	low vulnerability
10 to 30	medium vulnerability
30 to 65	high vulnerability
> 65	very high vulnerability

Figure 4 shows vulnerability maps for 6, 12, 24 and 48 h and return period from 2 to 10 years. It is interesting to verify that very high vulnerability is present in even for high frequency events (2-yr return period), which denotes the unappropriated performance of the urban drainage system on those sub catchments. Considering flood occurrences in the polygon that circumscribe the vehicle circulation area, it can be seen that 55% of that situations are concentrated within this area(Figure 5).



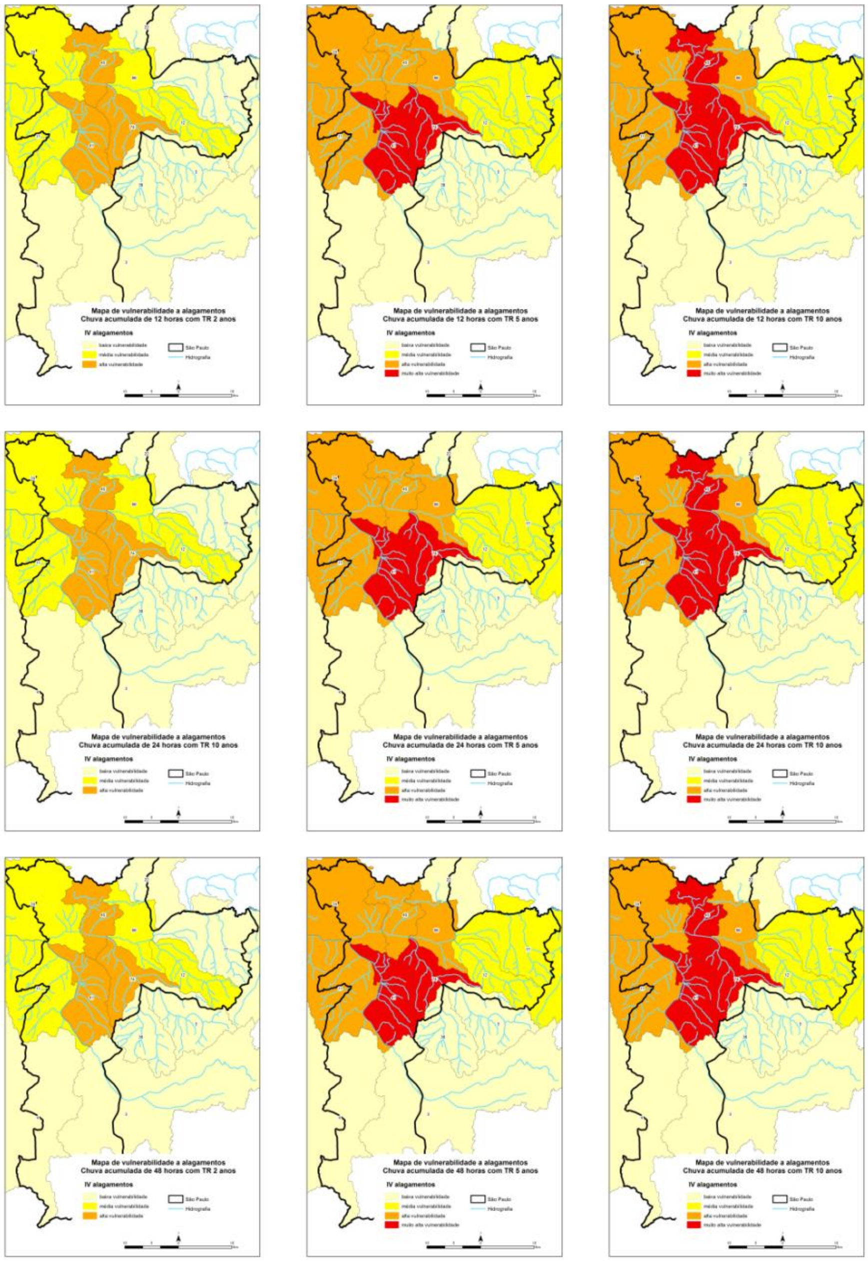


Figure 4 - Urban vulnerability to flooding for different duration and return period

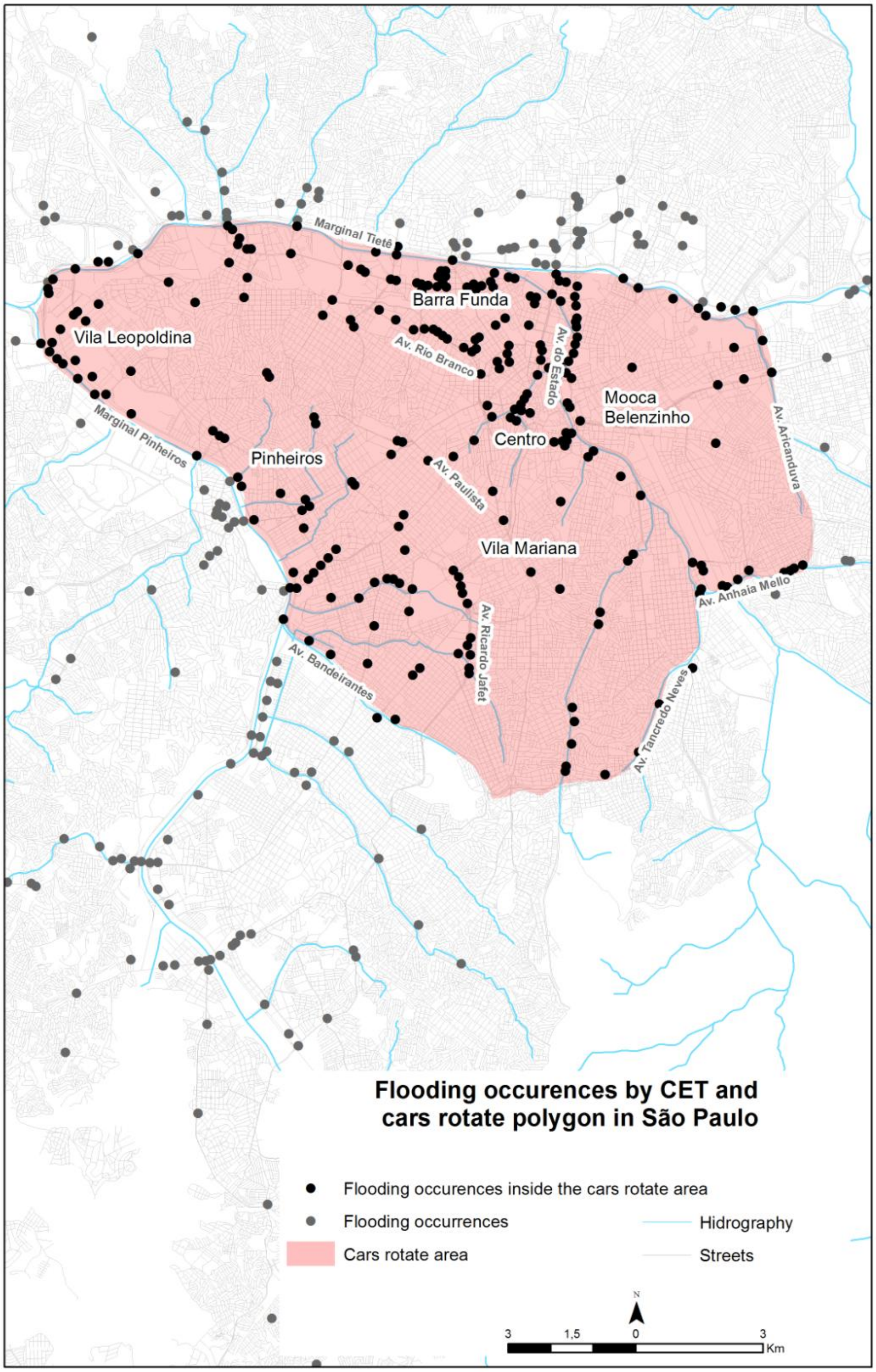


Figure 5 - Cars rotate polygon and flooding. Source: CET, 2012. Created by Perez, 2013.

3. DISCUSSITON

The spatial analysis of the occurrences of floods show that the most affected districts are the central districts, where are concentrate most of the services in São Paulo, such as Santana , important axis in the north of the city , Pinheiros , Água Branca, Barra Funda , Santo Amaro and Vila Mariana , important neighborhoods in service availability, beyond the downtown , which continues to be a financial hub , hub services , and large flow of people and vehicles . The percentage of 55% the occurrence of flooding, 100 meters distant from each other, within the area of vehicle circulation restriction, shows that there are 253 points subject to flooding within a perimeter that contains the main traffic arteries of the city .

The construction of the vulnerability index shows that "common" events is highly correlated with the flooding occurrences in Sao Paulo . The maps of urban vulnerability shows:

- The most vulnerable river basins are Água Espraiada, Cabuçu de Baixo, Baixo Cabuçu, Tamanduateí Inferior, Contribuição Lateral do Tietê, and the most important areas of the road system affected by flooading in São Paulo are in downtown , near the Avenida dos Estados , and Vale do Anhangabau , causing damage to the entire system traffic in the city.

- The most vulnerable river basins are inisde the perimeter of cars rotation in Sao Paulo .

Using the latest technology, such as images generated from data from telemetric network of surface rain gauges and radar images , GIS techniques , programming , and statistical analysis, is possible created an index of urban vulnerability to flood risk.

The functions presented in the results, and especially the vulnerability maps of river basins , proves that it was possible to build an efficient instrument .This instrument , which is the index of vulnerability itself, make possible the classification of river basins by vulnerability and the construction of the maps.

Even with urban infrastructure planning for higher return periods, the occupancy of floodplain water bodies by high ways and avenues are not a apropriate solution.

4. REFERENCES

CET < www.cetsp.com.br > acesso em maio, 2103.

DAEE. **Relatórios do Plano Diretor de Macrodrenagem do Alto Tietê** (PDMAT 3), São Paulo, 2012.

EMPLASA – **Mapeamento GEGRAM**. 1974.

FCTH, F.C.T.d.H. SAISP, Sistema de Alerta â Inundações de São Paulo, São Paulo, 2013.

IBGE. **Download de Dados**. Disponível em: < www.ibge.gov.br > Acesso em agosto de 2012.

Martinez Jr., F. and N.L.G Magni. Equações de Chuvas Intensas do Estado de São Paulo. DAEE, São Paulo, 1999.

Perez, L.P. – Índice de vulnerabilidade urbana a alagamentos e deslizamentos de terra, em função de eventos extremos de clima, na Região Metropolitana de São Paulo: uma proposta de método. Tese de doutorado. FFLCH – USP. São Paulo, 2013.

ROCHA FILHO, K.; CONDE, F.; ANDRIOLI, C.P. Correção em tempo real da precipitação estimada por um radar meteorológico com uma rede de superfície. XX SIMPÓSIO BRASILEIRO DE RECURSOS HÍDRICOS, Bento Gonçalves, Brasil. Nov 2013.