Accessibility and flood risk spatial indicators as measures of vulnerability

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Abstract. *Based on the recent literature relating transport service level and social exclusion, as well as perceptions about the capacity to cope with the occurrence of flood events, this paper identified the spatial pattern related to flood risk and accessibility to urban facilities. For that, composite spatial indicators are developed and compared with socioeconomic data. The analysis shows the outskirts of the city with the most vulnerable places, with high levels of flood risk and low levels of accessibility. Besides that, the high-risk areas are characterized by low income level as well as the low percentage of residents with sewage system is a typical condition of regions with low level of accessibility and close to flood prone areas.*

1. Introduction

The capacity to adapt of population and systems are a relevant focus of the literature (Smit & Wandel, 2006). Vulnerability could be understood as the sensitivity or susceptibility to harm and lack of capacity to cope and adapt facing the occurrence of an extreme event (IPCC, 2014). For the discussion about adaptation measures, vulnerability assessment represents a considerable tool. In this context, the spatial analysis have been notably used to explore spatial data and maps, to inform and communicate different stakeholders about the relation between community and the environment risks at a given scale (Preston, Yuen, & Westaway, 2011).

Different frameworks are formulated to understand the relation between systems, environment, population and risks (Alves, 2013; Anazawa, Feitosa, & Monteiro, 2013; Cutter, 1996; Cutter, Boruff, & Shirley, 2003; Hogan, 1993; Turner et al., 2003). For Cutter (1996) vulnerability is defined as a coupled concept between the social vulnerability and the biophysical risk, located in a specific area. This place-based vulnerability concept involves components of risk, as the proximity to hazards, furthermore social impacts, as the infrastructure availability to support basic needs (Cutter, 1996). According to Hogan & Marandola (2005):

> "Vulnerability is associated with the social disadvantages which simultaneously produce and are reflections and products of poverty. […] Disadvantages are understood as social conditions which negatively affect people, communities or places."

Beyond that (Hogan & Marandola, 2005; Vignoli, 2000) emphasize that these disadvantages correspond to the lack of access and capacity to deal with the availability of resources and opportunities.

One dimension that could affect the social exclusion/inclusion is the level of accessibility to different places and opportunities (Lucas, van Wee, & Maat, 2015). Therefore, accessibility measures are addressed to understand the social exclusion (Lucas, 2012) and equity (Neutens, Schwanen, Witlox, & de Maeyer, 2010). For Wee & Geurs (2011), indicators that include distribution effects should be explored, for instance, accessibility to achieve schools and medical services. In vulnerability index formulation, indicators of the level of access to opportunities, sometimes are considered as components of sensitivity and adaptive capacity, (Moss, Brenkert, & Malone, 2001; Weis et al., 2016).

Based on the motivation of the vulnerability mapping importance as an integrative approach, this work aims at mapping flood risk areas and accessibility measures to urban facilities in the city of São Paulo (Brazil). The main hypothesis is: are there spatial pattern regarding accessibility conditions and flood risk areas? To answer the question, a flood risk indicator was calculated and compared with measures of accessibility to leisure, education and health.

2. Materials and Methods

Firstly, the flood risk areas in São Paulo city were identified. Then, a field work, to better understand the relations between accessibility and flood risk areas was done, as a preparation for further analysis regarding measures, indexes development and mapping as described in this section.

2.1. Field visit

An area characterized by consolidated flood risk was investigated by a field visit. The select area is Jardim Pantanal region, close to Tietê river (Figure 1 and Figure 2). The region is an Environmental Protection Area and presents a land use conflict between irregular occupation and the environment legislation. The local was visited on June, 30th, 2016.

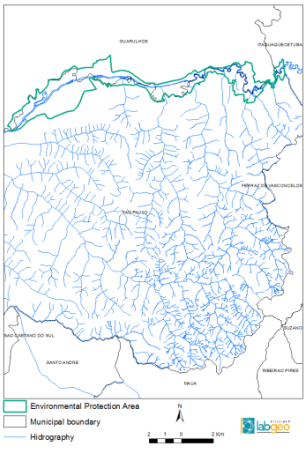

Figure 1 Environmental Protection Area "Várzea do Rio Tietê" in the east region of São Paulo

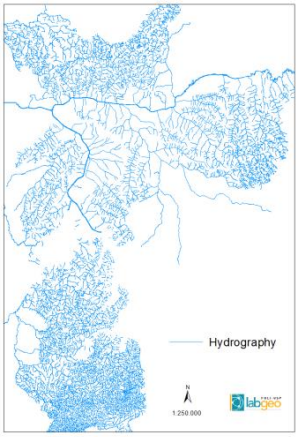

Figure 2 - Hydrography

Outward trip: Brás Metro Station– Line 12 Safira: Itaim Paulista Station. On foot until Rua Tietê (25min)

Return trip: Bus stop (25/30 min on foot) – Bus 273G-10 Metrô Arthur Alvim (50 minutes)

This local analysis serves as experiencing routine of the local population regarding the use of public transport infrastructure. The local impressions helped to confirm the hypothesis that the level of attendance of transportation infrastructure and opportunities is also an indicative of the degree of social inclusion/exclusion of the population living at risk areas.

2.2. Spatial data analysis

The procedure follows the data acquisition, indicators calculation, normalization, and composition of indicators. The analysis and maps were done using ArcGIS 10.4.1. Data used are summarized in Table 1.

Table 1 - The spatial data used for indicators construction

Category	Indicators	Data	Metadata		
			Responsible	Source	Year
Accessibility to public schools	Number of public schools to be accessed in 45 minutes by public transportation	Public schools	Municipal Secretary of Education/Municipal Secretariat of Urban Development	*Geosampa* (Prefeitura de São Paulo, 2016)	2014
		Public Transportation Network	Diego Bogado Tomasiello	(Tomasiello, 2016)	2015
		Metro Origin Destination Survey of São Paulo	São Paulo Metropolitan Company – Metro	(Companhia do Metropolitano de São Paulo, 2007)	2007
Accessibility to health facilities	Number of health facilities (hospitals and health centers) to be accessed in 60 minutes by public transportation	Health facilities (Hospitals and basic health centers)	Municipal Secretary of Health	*Geosampa* (Prefeitura de São Paulo, 2016)	2010
		Public Transportation Network	Diego Bogado Tomasiello	(Tomasiello, 2016)	2015
		Metro Origin Destination Survey of São Paulo	São Paulo Metropolitan Company – Metro	(Companhia do Metropolitano de São Paulo, 2007)	2007
Accessibility to culture facilities	Number of culture facilities to be accessed in 50 minutes by public transportation	Cultural facilities (Libraries, Museums, cultural centers, arts gallery)	Municipal Secretary of Urban Development	*Geosampa* (Prefeitura de São Paulo, 2016)	2015
		Public Transportation Network	Diego Bogado Tomasiello	(Tomasiello, 2016)	2015
		Metro Origin Destination Survey of São Paulo	São Paulo Metropolitan Company – Metro	(Companhia do Metropolitano de São Paulo, 2007)	2007
Flood risk	Population close to flood areas	Flood prone areas (Geotechnical chart)	Department of Planning, Budget and Management/Technology Research Institute (IPT)/Municipal Secretary of Public Safety/Municipal Secretary of Housing	*Geosampa* (Prefeitura de São Paulo, 2016)	1993

Flood risk indicators

The flood risk indicator was based in the general and basic definition of risk as:

$$Risk = Hazard \times Exposure$$

Hazard in the context of this work is represented by the flood risk and the exposure, by the population living in the flood prone area. The steps for the indicator construction is shown in Figure 3.

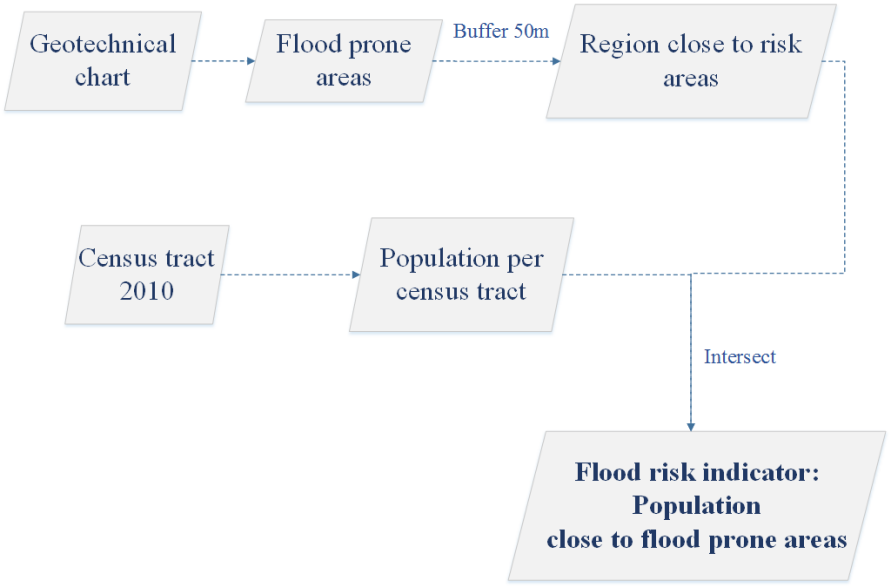

Figure 3 - Methodology of the flood risk indicator calculation

Accessibility indicators

The accessibility indicator evaluated was based on the cumulative opportunities (Páez, Scott, & Morency, 2012):

$$A_{ik}^{p} = \sum_{j} W_{jk} I(c_{ij} \leq \gamma_i^p)$$

Where:

W_{jk} = facility of type k at location j

c_{ij}= cost of travel, here is considered the travel time measured in the public transportation network

γ_i^p= threshold value

The value is calculated based on the centroids of census tracts, as a proxy from the origin and destination location, thus not considering an "exact" point coordinate. This approximation was necessary to make the process effort reasonable for this large volume of data. The threshold value is calculated based on the guideline of the Department for Transport Business Plan (2012) from UK and represents the median of the all travel with public transportation with specific reason: education for accessibility to public schools, health to accessibility to hospitals and health centers and leisure for cultural facilities. The steps for the indicator construction are summarized in Figure 4.

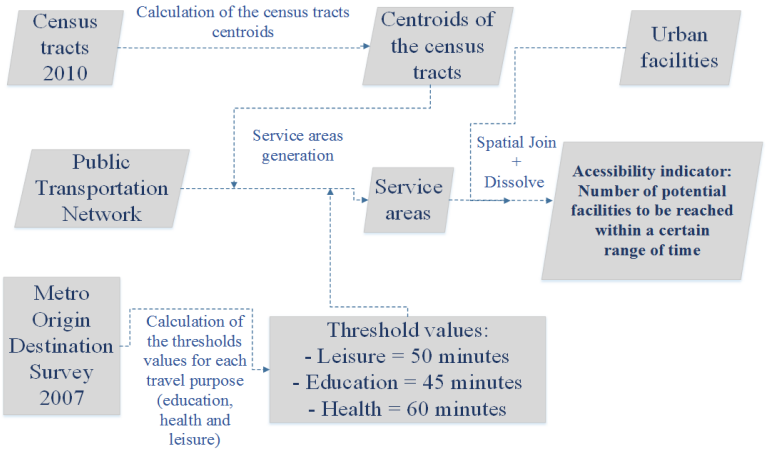

Figure 4 - Methodology of the accessibility indicators calculation

Indicator composition

All the components were calculated and aggregated in the census tract area. They were normalized to a scale from 0 to 1, according to the formula:

$$\text{Indicator} = \frac{\text{Value(x)} - \text{ValueMin}}{\text{ValueMax} - \text{ValueMin}}$$

Where:

Value (x) = value of the indicator in the referenced census tract

ValueMin = minimum value of the distribution of all the category

ValueMax = maximum value of the distribution of all category

The composition follows the methodology of works already developed in the field of environmental risk (Alves, 2013; Hogan, 1993). The sample of each indicator was reclassified and divided by the median value of the distribution.

High = distribution above the median

Low = distribution below the median

Without risk = outside the flood area

Table 2 - Indicators components and groups

Accessibility to facilities	Flood risk	Group		
Low	High	Aa	A	Low accessibility with the flood risk (high and low)
	Low	Ab		
High	High	Ba	B	High accessibility with the flood risk (high and low)
	Low	Bb		
High	Without risk	C		Without flood risk
Low				

3. Results and Discussions

The outcomes of the field visit are the perceptions about the transit system and the population at risk condition. The residents at Jardim Pantanal area live at border of the transit system. Besides that, they suffer with low level of attendance of sewage treatment system coverage (Figure 5) and accumulated garbage on the streets (Figure 6), causing a considerable harm to the public health. The high travel time to reach the place (more than one hour from metro station) shows that to achieve facilities and even go to work is a costly task for the population living there.

Figure 5 - Open sewage and unpaved street

Figure 6 - Accumulated garbage

In the spatial analysis, each component has been calculated and grouped by the census tract. The map of accessibility to health facilities (Figure 7) shows a clear pattern related to the transit system. The facilities are concentrated close to the metro lines. The maps of accessibility to public schools reveal the plenty distribution of school at the east zone of São Paulo (Figure 8). Although, these measures did not consider, in their formulation, the vacancies and quality of the schools. The map of accessibility to cultural facilities displays the lack of cultural opportunities as libraries, museums, cultural centers and art galleries in the peripheral region.

In the flood risk map, the high concentration of population and the proximity of the Billings and Guarapiranga reservoirs, present a critical region in the watershed area. Other areas, as the Pinheiros river, which represents an economic development hub, however displays a population density level lower than the south of the city.

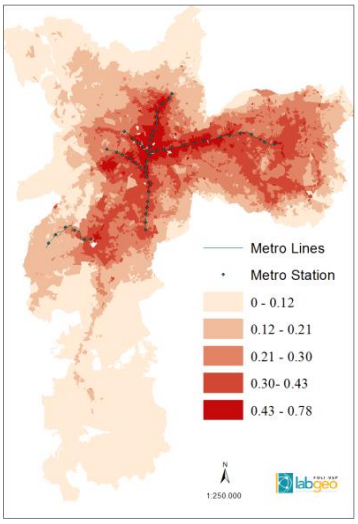

Figure 7 - Number of health facilities to be accessed in 60 minutes with public transportation (normalized)

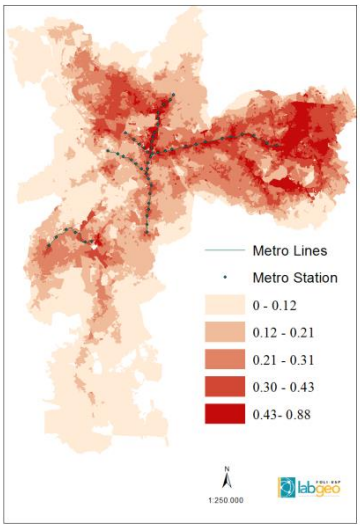

Figure 8 - Number of public school to be accessed in 45 minutes with public transportation (normalized)

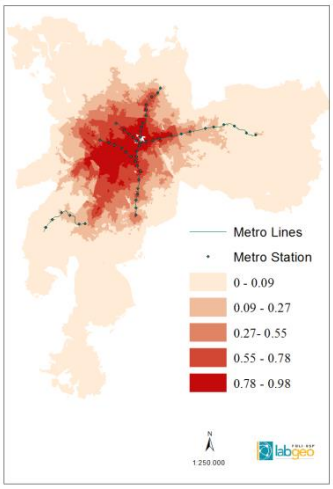

Figure 9 - Number of cultural facilities to be accessed in 50 minutes with public transportation (normalized)

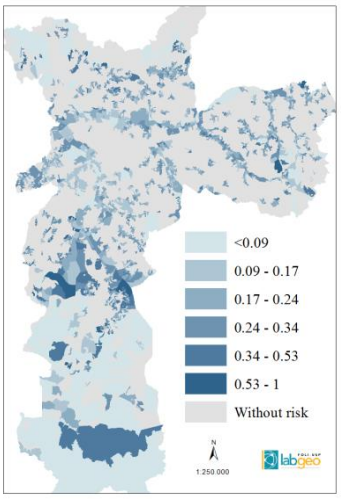

Figure 10 - Population close to flood risk areas

The indicators have been combined and 5 groups have been mapped. It is possible to note the difference between critical areas of accessibility to schools and health facilities compared to the cultural facilities.

In Figure 11 and Figure 13, which present the map of accessibility indicators for public schools and hospitals, the south region presents both, the high and low level of flood risk, and the low level of accessibility. In contrast, in Figure 12, the census tracts very close to the watershed, present high level of accessibility to cultural facilities.

Considering the center and the east zone of the city, the composite indicator for accessibility to cultural facilities (Figure 12) presents some tracts with high level of flood risk, especially along the Aricanduva river, unlike the pattern presented in the other maps.

In general, the risk areas follow the pattern of the hydrographic network of the city, although the outskirts concentrate the tracts classified in the group 1, namely the regions with low accessibility and risk areas.

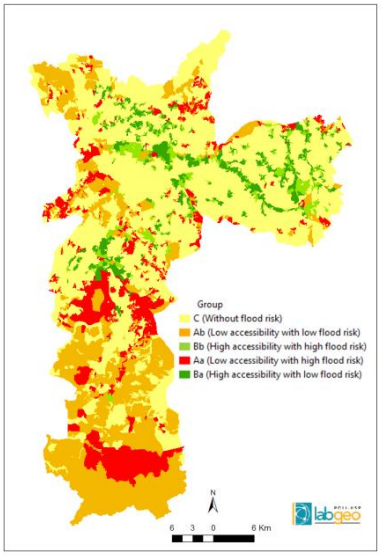

Figure 11 - Accessibility to public schools and flood risk area

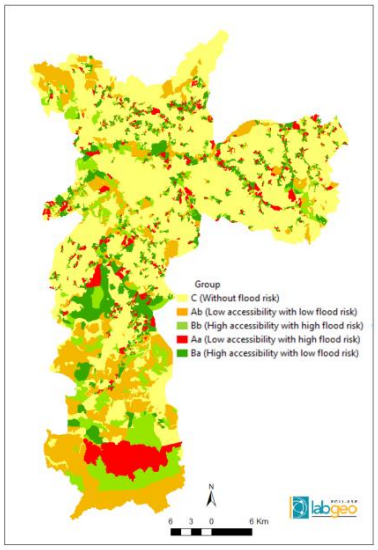

Figure 12 - Accessibility to cultural facilities and flood risk areas

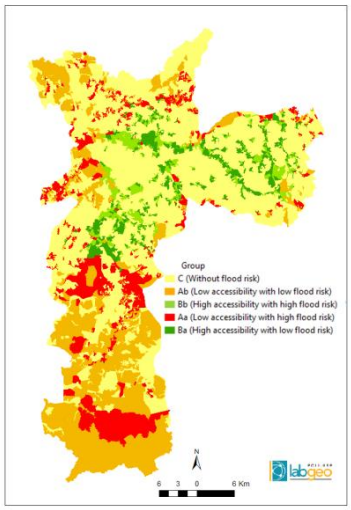

Figure 13 - Accessibility to health facilities and flood risk areas

The analysis with the results Census 2010 (Table 3) aims to show the differences between the already defined groups (Table 2) concerning the variables of socioeconomic, households, race and vulnerable groups.

The proportion of the population in each group shows that around 10% are living in areas with low accessibility to health facilities and public schools and are living close to flood prone area. Of these, 7% are located in regions with high level of flood risk. The socioeconomic variable of average income of the group with high flood risk (Aa and Ba) is lower than values of the groups with low and without risk (Aa, Bb, C). The difference between groups with high (Aa and Ab) and low accessibility (Ba and Bb) is considerable only in the accessibility to health facilities analysis. These differences demonstrate that the poverty dimension is more coincident to risk pattern than to accessibility levels of public schools and cultural facilities.

In the households' attributes analysis, the variables of water supply, garbage and energy system did not present a clear pattern of correlation. Although, in the analysis of the private bathroom and sewage system, the group with low accessibility (A) shows a median lower than the group located at areas with low accessibility (B) and without risk (C). Is not possible to confirm some correlation between risk or accessibility, however it is clear the characterization of the most vulnerable regions (A) as precarious with respect to the sewage infrastructure. Other remarkable works in the vulnerability assessments in Brazil (Alves, 2013; Hogan, 1993) present similar analysis focused on the income variable, relating environmental risk and poverty. According to Alves (2013), in Cubatão city it is possible to say that the level of attendance of sewage treatment systems is very different between groups and strongly related to environmental risk.

About the race variables, it is possible to conclude that, for all accessibilities measures, the percentage of white people is lower than pardo people percentage in the most vulnerable group (A). From this analysis, there is no evidence of correlation between high risk level in these variables, meanwhile, for the black race, the percentage is higher or equal between the groups with high flood risk (Aa and Ba).

The consolidated literature about vulnerability, shows as critical groups the families headed by a female, children and elderly. Among these groups, children are the most related with risk and low accessibility and also this is the most susceptible group to waterborne diseases (Alves, 2013).

Table 3 - The summary of the Census 2010 indicators according accessibility measure and flood risk group

Group		Socioeconomic		Households				Race				Vulnerable groups		
		1	2	3	4	5	6	7	8	9	10	11	12	13
Accessibility to health facilities	Aa	**7%**	**1134**	0,97	**0,79**	1,00	1,00	**0,51**	**0,08**	0,01	**0,40**	**0,20**	0,06	0,43
	Ab	**3%**	1554	0,81	**0,65**	0,92	0,94	**0,53**	0,06	0,02	**0,33**	**0,18**	0,07	0,41
	Ba	5%	**2007**	0,99	0,94	1,00	1,00	0,66	**0,06**	0,03	0,26	0,16	0,10	0,44
	Bb	3%	2551	0,98	0,89	0,99	0,99	0,67	0,05	0,03	0,24	0,15	0,11	0,44
	C	82%	2249	0,95	**0,88**	0,95	0,96	**0,60**	0,06	0,02	**0,27**	**0,16**	0,08	0,43
Accessibility to public schools	Aa	**7%**	**1552**	0,97	**0,81**	1,00	1,00	**0,54**	**0,07**	0,01	**0,37**	**0,20**	0,07	0,42
	Ab	**3%**	2148	0,82	**0,69**	0,93	0,94	**0,57**	0,06	0,02	**0,29**	**0,17**	0,08	0,41
	Ba	6%	**1509**	0,99	0,91	1,00	1,00	**0,61**	**0,07**	0,02	0,30	0,17	0,09	0,44
	Bb	2%	1703	0,98	0,86	0,98	0,99	0,61	0,06	0,02	0,29	0,17	0,09	0,44
	C	82%	2249	0,95	**0,88**	0,95	0,96	**0,60**	0,06	0,02	**0,27**	**0,16**	0,08	0,43
Accessibility to cultural facilities	Aa	**4%**	**1472**	0,99	**0,86**	1,00	1,00	**0,57**	**0,07**	0,02	**0,34**	**0,18**	0,08	0,42
	Ab	**2%**	1871	0,82	**0,67**	0,91	0,93	**0,56**	0,06	0,02	**0,29**	**0,17**	0,08	0,41
	Ba	8%	**1558**	0,98	0,86	1,00	1,00	**0,58**	**0,07**	0,02	0,33	0,18	0,08	0,43
	Bb	3%	2076	0,94	0,83	0,98	0,99	0,61	0,06	0,02	0,29	0,17	0,09	0,43
	C	82%	2249	0,95	**0,88**	0,95	0,96	**0,61**	0,06	0,02	**0,27**	**0,16**	0,08	0,43

1. Proportion of population
2. Average income
3. Proportion of residences with water supply system
4. Proportion of residences with private bathroom and sewage system
5. Proportion of residences with garbage system
6. Proportion of residences with energy system
7. Proportion of residents from white race
8. Proportion of residents from black race
9. Proportion of residents from yellow race
10. Proportion of residents from pardo race
11. Proportion of population less than 11 years
12. Proportion of population 65 years or older
13. Proportion of residences headed by a female

4. Conclusion

This work is an exploratory analysis of the relation between risk and accessibility as a measure of social exclusion in the context of the vulnerability assessment. Some initial perception about the relation between transportation service level and the disadvantage by the lack of access and flood risks, helped to stablish the hypothesis and basic motivation for the spatial analysis.

The indicators of accessibility to urban facilities and flood risk are combined to compose groups with high and low level of attendance at flooded and non-flooded areas. It is possible to conclude that areas with low accessibility and risk are located in the outskirts of São Paulo city and present a different pattern according to the type of the facilities. The south region presents low and high levels of flood risk combined with low level of accessibility to public schools and health centers. In the east and central regions, mainly along Aricanduva river, there are some areas with high level of flood risk and also high level of accessibility to cultural facilities.

Some results of Census 2010, as socioeconomic, households, race variables and vulnerable groups are brought for discussion of the differences between groups. The accessibility to public schools and health facilities presents, in general, more discrepancy between the groups, while the accessibility to cultural facilities, presents more homogenous values. Besides that, the high-risk areas are characterized by low income level. The low percentage of residents with private bathroom and sewage system is typical of areas with low level accessibility and close to flood prone areas. Such areas are also characterized for higher percentages of children and people from pardo race and lower percentages of white people.

It is important to remark that these relations are only valid for accessibility considering the public transportation and flooding risk, therefore, it is not enough for evaluating all the vulnerability relations. For further developments, it could be tested others risks and equity values. Also improvements in the flood risk indicators could be made, for instance, considering the return period and the respective variation of the flooded areas, as well as interpolation of water surfaces and intersection with digital elevation model (Apel, Aronica, Kreibich, & Thieken, 2009). Regarding the accessibility and its relation with equity (Neutens et al., 2010), it would be interesting to consider the competition and more sophisticated measures. The formulation of vulnerability index with different technics as Principal Component Analysis and other weighting methods (Beccari, 2016) are further methods to be explored.

5. Acknowledgements

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