Brazilian Journal of Cartography (2017), Nº 69/5, Special Issue GEOINFO 2017: 869-880
Brazilian Society of Cartography, Geodesy, Photgrammetry and Remote Sense
ISSN: 1808-0936

GEOINFO
Brazilian Symposium on GeoInformatics
November 27th to 30th, Campos do Jordão, SP, Brazil

ACCESSIBILITY AND FLOOD RISK SPATIAL INDICATORS AS MEASURES OF VULNERABILITY

Indicadores Espaciais de Acessibilidade e Risco de Inundação como Medidas de Vulnerabilidade

Juliana Siqueira-Gay, Mariana Abrantes Giannotti & Diego Bogado Tomasiello

Universidade de São Paulo – USP
Escola Politécnica da Universidade de São Paulo - EPUSP
Edifício de Engenharia Civil (Edif. Paula Souza) - Av. Prof. Almeida Prado, 83 - Butantã,
São Paulo - SP, 05508-070, Brasil
{siq.juliana, diegobt86}@gmail.com, mariana.giannotti@usp.br

Received on February 15, 2017/ Accepted on May 17, 2017
Recebido em 15 de Fevereiro, 2017/ Aceito em 17 de Maio, 2017

ABSTRACT

Based on the recent literature relating transport service level and social exclusion, as well as perceptions about the capacity of the population 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 indicator is 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. Those regions with low level of accessibility and close to flood prone areas are characterized by low income level as well as the low percentage of residents with sewage system.

Keywords: Vulnerability to Floods, Accessibility Measures, Spatial Inequalities.

RESUMO

Com motivação na literatura que relaciona provisão de transporte e exclusão social, além de percepções sobre a capacidade da população de lidar com a ocorrência de eventos de inundação, este trabalho identifica a padrão espacial relacionado à inundação e acessibilidade a equipamentos urbanos. Para isso, um indicador espacial composto baseado em variáveis de inundação e acessibilidade foi desenvolvido e comparado com dados socioeconômicos. A análise revela que as regiões periféricas da cidade são os locais mais vulneráveis com altos níveis de risco de inundação e baixos níveis de acessibilidade. Essas regiões são caracterizadas por baixa renda e baixa porcentagem de residências com esgotamento sanitário.

Palavras-chave: Vulnerabilidade à Inundação; Medidas de Acessibilidade; Desigualdades Espaciais.

1. INTRODUCTION

The capacity to adapt of population and systems are a relevant focus of the literature, which aim at relating the risks that occur in the urban environment (SMIT & WANDEL, 2006). To accomplish different intervenient features of environment and population, 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). In order to inform about prioritization of critical areas for implementation of adaptation and mitigation measures, vulnerability assessment represents an approach to support the decision making. In this context, the spatial analysis have been notably used to inform and communicate different stakeholders about the relation between community and the environment risks at a given scale (PRESTON *et al.*, 2011).

Different frameworks are formulated to understand the relation between systems, environment, population and risks (HOGAN, 1993; CUTTER, 1996; CUTTER *et al.*, 2003; TURNER *et al.*, 2003; ALVES, 2013; ANAZAWA *et al.*, 2013). 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 aspects, 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 and Marandola (2005) and Vignoli (2000) emphasize that these disadvantages correspond to the lack of access and capacity to deal with the availability of resources and opportunities. Therefore, the vulnerability assessment involves and integrates issues related with both, social as well as environmental dimensions.

An attribute that could affect the social exclusion/inclusion is the level of accessibility to different places and opportunities (LUCAS *et al.*, 2015). Therefore, accessibility measures are addressed to understand the social exclusion (LUCAS, 2012) and equity (NEUTENS *et al.*, 2010). In this sense, the transportation infrastructure could be understood as an instrument of integration, which connects people and opportunities throughout the territory. For Wee and Geurs (2011), indicators that include distribution effects should be explored, for instance, accessibility to reach schools and medical services. In vulnerability studies, indicators of the level of access to opportunities comprises the sensitivity and adaptive capacity indicators (MOSS *et al.*, 2001; WEIS *et al.*, 2016).

Given the consequences of floods for public health (BROUWER *et al.*, 2007), wellbeing and economic life of the citizens (HADDAD & TEIXEIRA, 2015), the assessment of affected areas is considerably important to determine the population exposure. Especially in the São Paulo municipality, floods play an important role for the population and for the dwellers security (HADDAD & TEIXEIRA, 2015).

Based on the motivation of the vulnerability mapping importance as an integrative approach, this work aims at mapping flood risk areas and accessibility to urban facilities in the city of São Paulo (Brazil) in order to determine the critical areas and identify the spatial patterns of the exposure and transport social exclusion. The main research question is: are there spatial pattern regarding accessibility conditions and flood risk areas? A flood risk indicator was calculated and compared with measures of accessibility to leisure, education and health.

This paper is based on Siqueira-Gay, Giannotti and Tomasiello (2016), previously presented at GEOINFO conference (http://www.geoinfo.info/).

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, indicators development and mapping as described in this section.

2.1 Field visit

Given the hydrography of São Paulo municipality (Figure 1), an area characterized by consolidated flood risk was investigated by a field visit. The selected area is Jardim Pantanal region, close to Tietê river (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. Information of field visit is:

- 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)

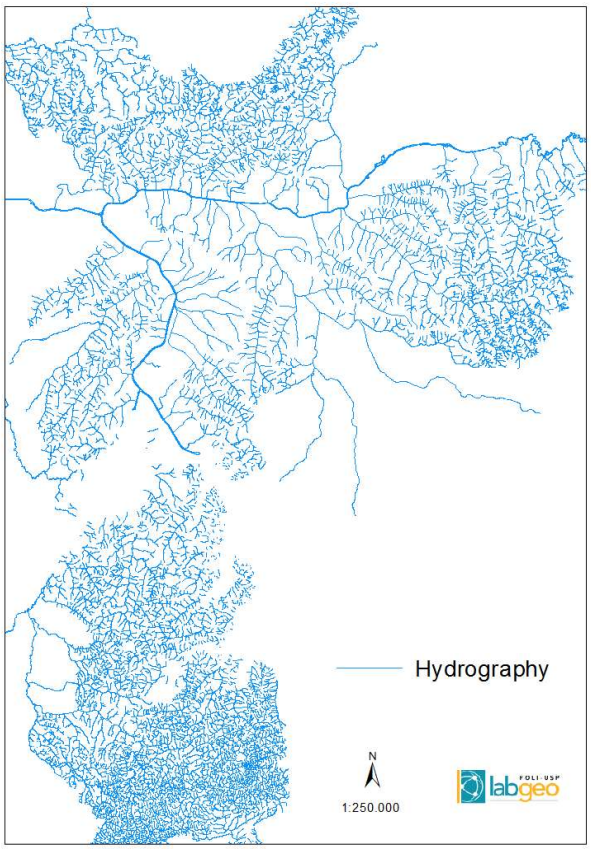

Fig. 1 – Hydrography of São Paulo municipality

This local analysis serves as experiencing the 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.

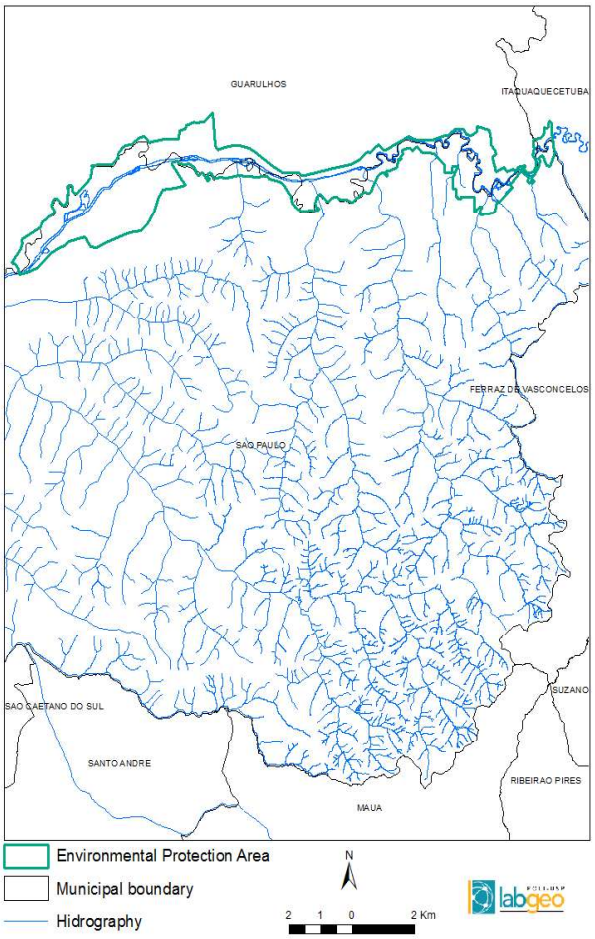

Fig. 2 - Environmental Protection Area "Várzea do Rio Tietê" in the east region of São Paulo.

2.2 Spatial data analysis

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

2.2.1 Flood risk indicators

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

$$\text{Risk} = \text{Hazard} \times \text{Exposure} \qquad (1)$$

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 are shown in Figure 3.

2.2.2 Accessibility indicators

The accessibility indicator evaluated was based on the cumulative opportunities (PÁEZ *et al.*, 2012):

$$A_{ik}^{p} = \sum_j W_{jk} I(c_{ij} \leq \gamma_i^p) \quad (2)$$

where:

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

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

γ_i^p = threshold value

The value is calculated based on the centroids of census tracts, as a proxy of travel's origin, thus it is not considering an "exact" point coordinates. 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.

Table 1: The spatial data used for indicators construction

x	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

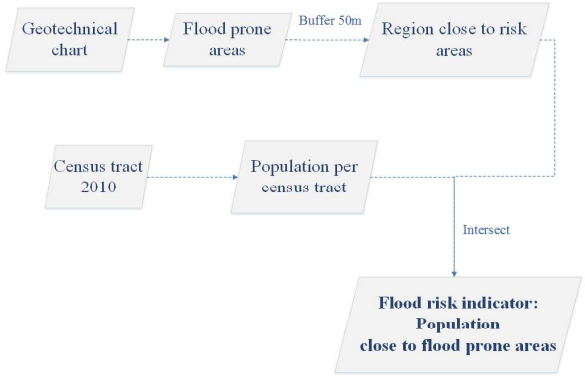

Fig. 3 - Methodology of the flood risk indicator calculation.

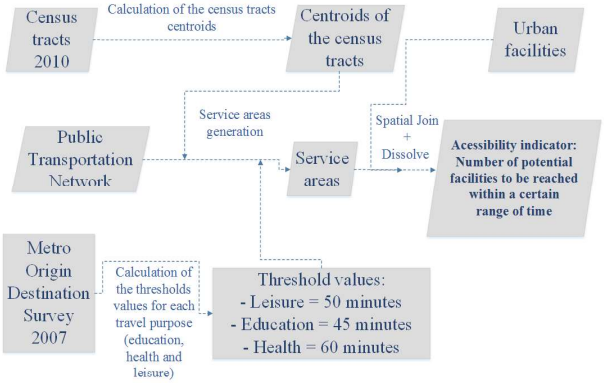

Fig. 4 - Methodology of the accessibility indicators calculation.

2.2.3 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:

$$\text{Indicator} = \frac{\text{Value(x)} - \text{ValueMin}}{\text{ValueMax} - \text{ValueMin}} \quad (3)$$

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 (HOGAN, 1993; ALVES, 2013). The sample of each indicator was reclassified and divided by the median value of the distribution. Table 2 depicts all groups composition.

Table 2: Indicators components and groups

Access 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				

High = distribution above the median
Low = distribution below the median
Without risk = outside the flood area

3. RESULTS

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.

Fig. 5 - Open sewage and unpaved street.

Fig. 6 - Accumulated garbage.

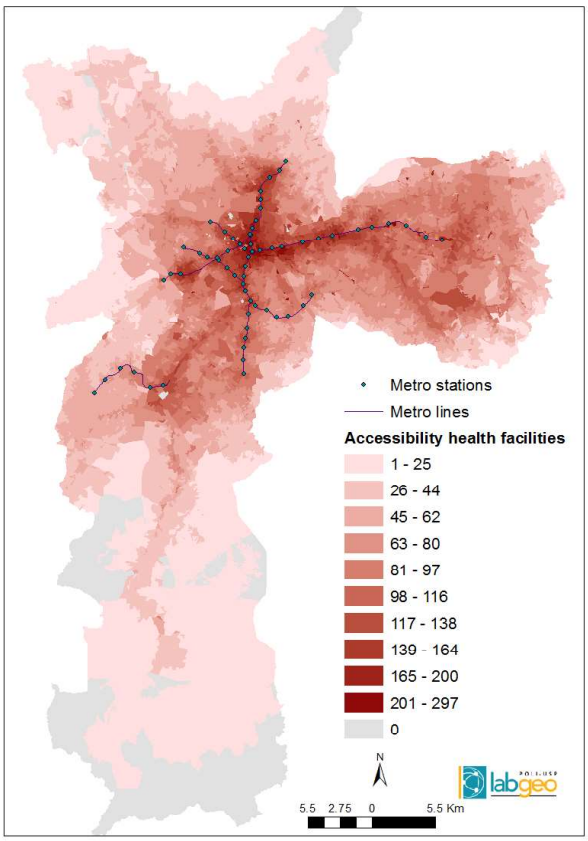

Fig. 7 - Number of health facilities to be accessed in 60 minutes with public transportation.

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 schools to be reached in 45 minutes by transit at the east zone of São Paulo (Figure 8). The map of accessibility to cultural facilities (Figure 9) displays the lack of cultural opportunities as libraries, museums, cultural centers and art galleries in the peripheral region. Although, these measures did not consider, in their formulation, the demand and quality of the urban equipment, it could be considered as an indicator that may capture the facility to reach opportunities regarding only the existence of the equipment.

In the flood risk map (Figure 10), 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, displays a population density level lower than the south of the city.

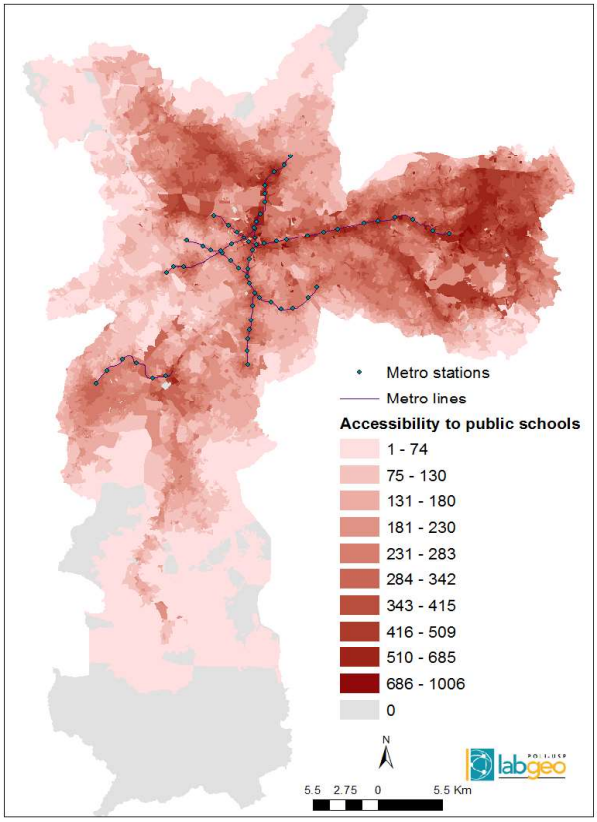

Fig. 8 - Number of public school to be accessed in 45 minutes with public transportation.

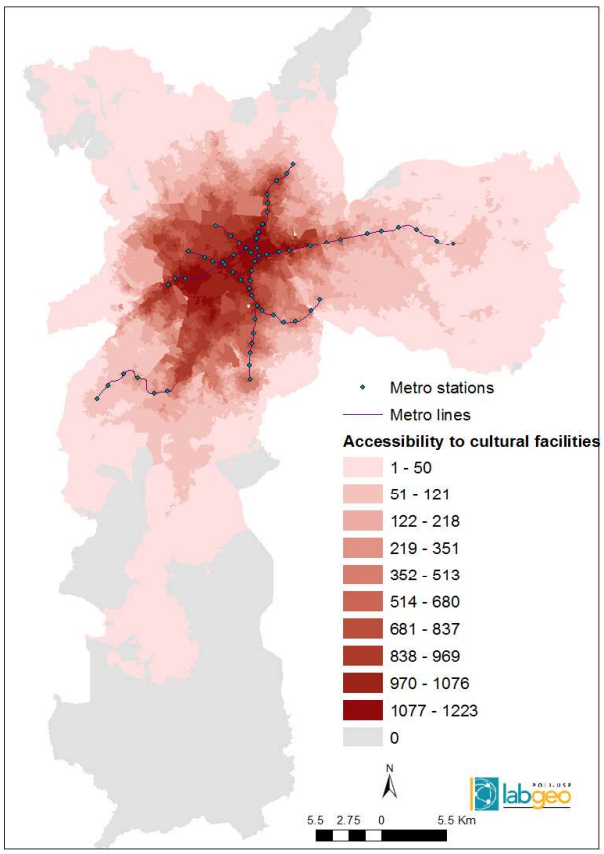

Fig. 9 - Number of cultural facilities to be accessed in 50 minutes with public transportation.

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, high and low level of flood risk, and 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.

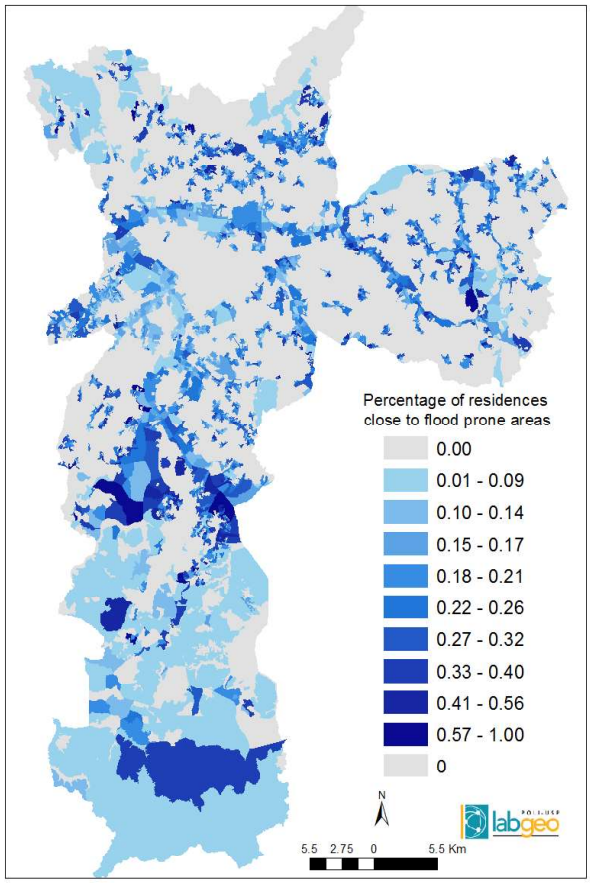

Fig.10 - Population close to flood risk areas.

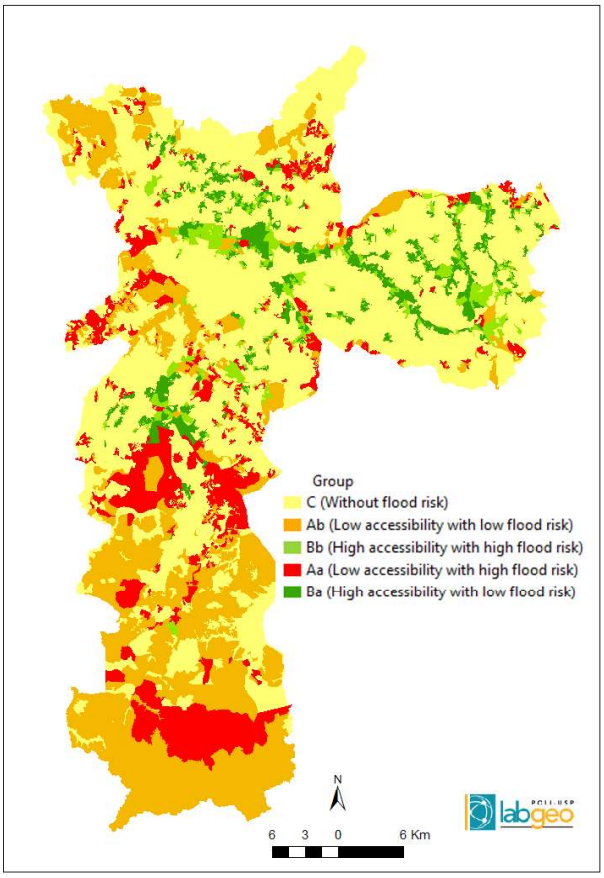

Fig. 11 - Accessibility to public schools and flood risk area.

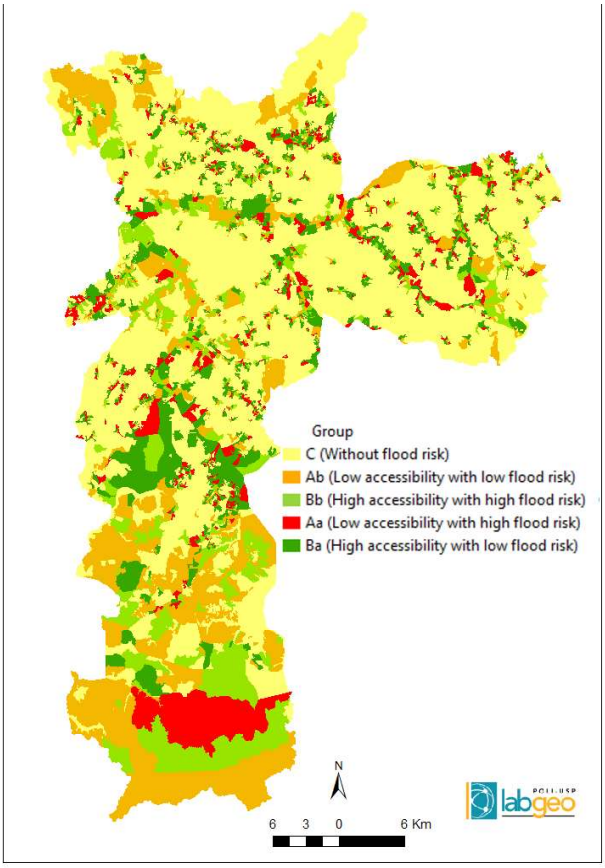

Fig. 12 - Accessibility to cultural facilities and flood risk areas

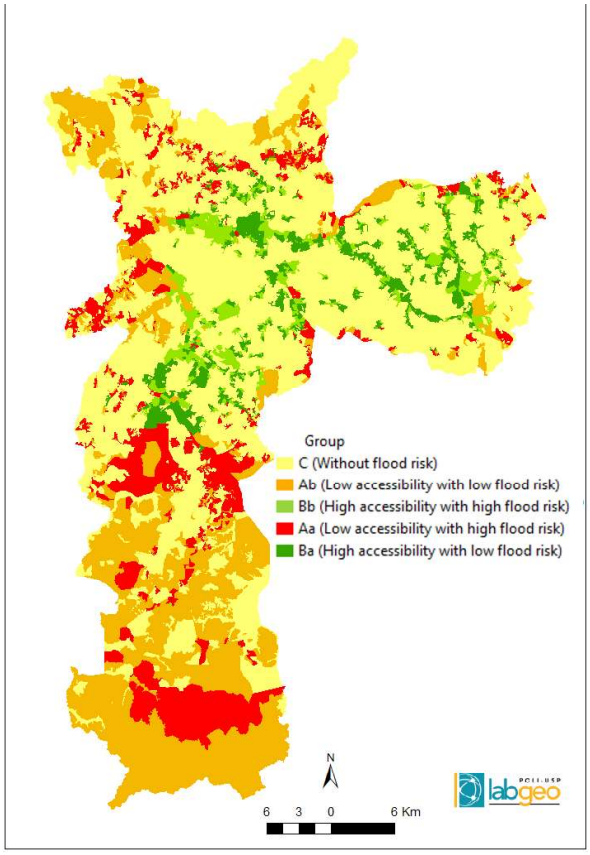

Fig. 13 - Accessibility to health facilities and flood risk areas.

4. DISCUSSIONS

The analysis of the results of Census 2010 (Table 3) aims to show the differences between the already defined groups concerning the variables of socioeconomic, households, skin color and vulnerable groups. The proportion of the population in each group (Figure 14) shows that around 18% of the São Paulo municipality population are living at flood risk areas. It is equivalent to two million inhabitants. Of these, 10% presents low accessibility to health facilities, 10% to public schools and 6% cultural facilities. Therefore, more than a half of population that are living in flood prone areas are feature by low accessibility to health facilities and public schools.

The socioeconomic variable of average income of the group with high flood risk and low accessibility has lower values than the other groups (Figure 15). The most critical group of low accessibility and high flood risk presents the lowest income average value. Different from the population analysis, this analysis does not present distinguished tendency regarding the type of urban facility. Thus, there is no pattern relating risk, income and accessibility.

In the household attributes analysis, the variables water supply, garbage and energy system did not present a clear pattern of correlation. Although, in the analysis of 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).

It is not possible to confirm some correlation between risk and 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 (HOGAN, 1993; ALVES, 2013) 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 skin color 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 skin color, 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				Skin color				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 skin color
8. Proportion of residents from black skin color
9. Proportion of residents from yellow skin color
10. Proportion of residents from pardo skin color
11. Proportion of population less than 11 years
12. Proportion of population 65 years or older
13. Proportion of residences headed by a female

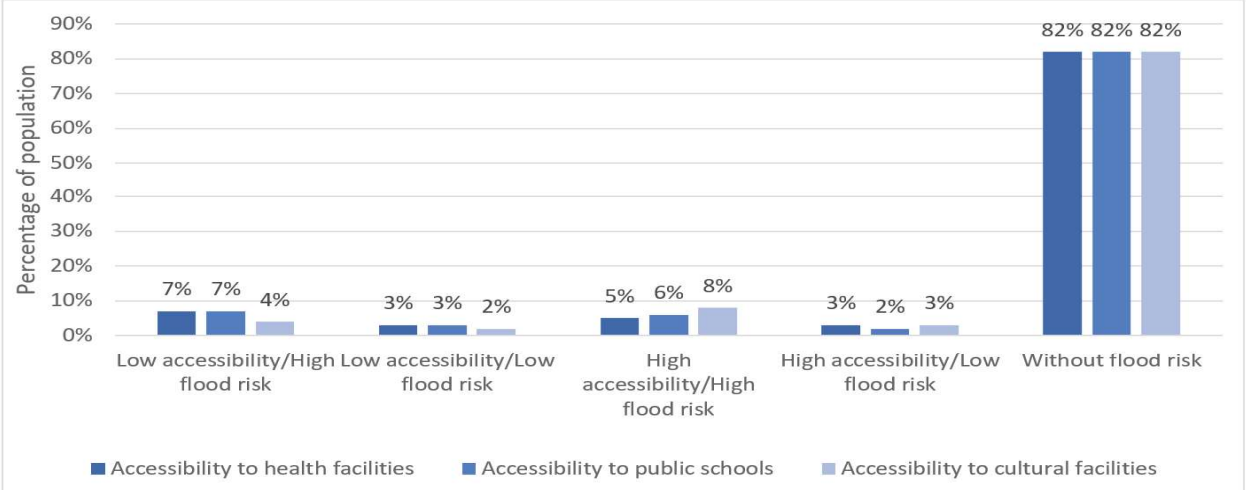

Fig. 14 - Proportion of population in each group.

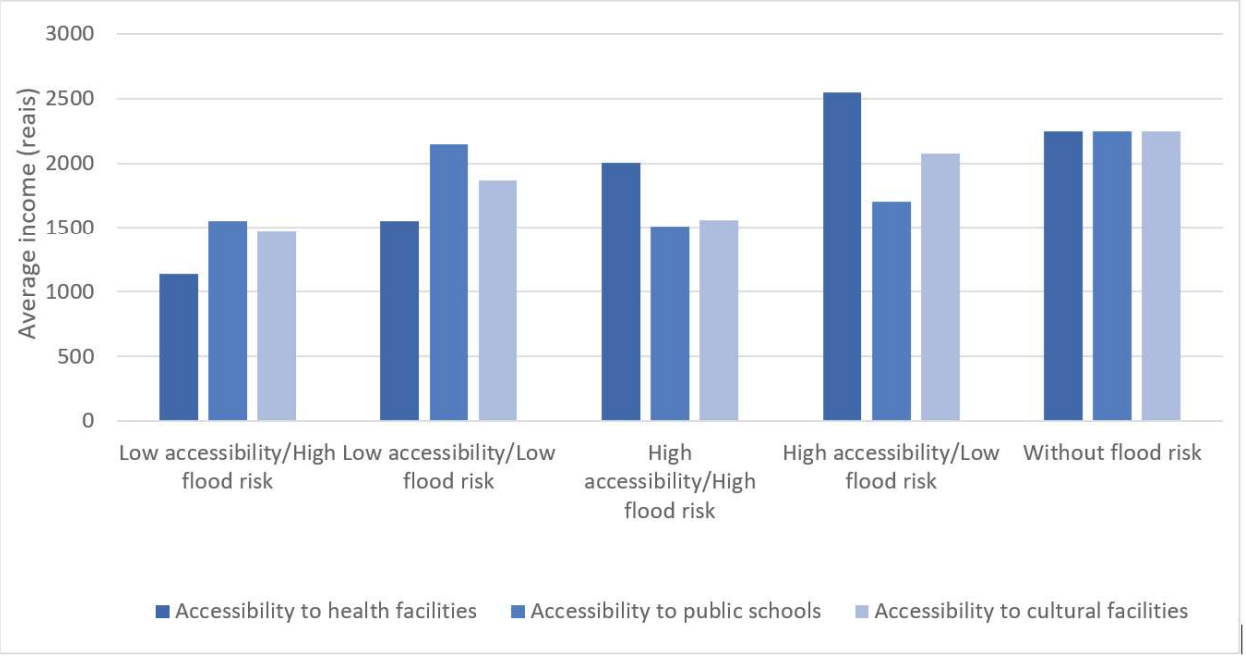

Fig. 15 – Average income of each group.

5. CONCLUSION

This work analyzes 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 by flood risks, is presented supported by a motivation to 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 high level of accessibility to cultural facilities.

Some results of Census 2010, as socioeconomic, households, skin color 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 by a high percentage of children and people from pardo skin color and low percentage 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, other risks and equity values could be tested. 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 *et al.*, 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

ACKNOWLEDGEMENTS

The authors acknowledge the Coordination for the Improvement of Higher Education Personnel (CAPES) for graduate scholarships financial support. The second author thanks to FAPESP (15/50127-2).

REFERENCES

ALVES, H. P. D. F. Análise da vulnerabilidade socioambiental em Cubatão-SP por meio da integração de dados sociodemográficos e ambientais em escala intraurbana. **Revista Brasileira de Estudos de População**, v. 30, n. 2, p. 349–366, 2013.

ANAZAWA, T. M.; FEITOSA, F. da F.; MONTEIRO, A. M. V. Vulnerabilidade socioecológica no litoral norte de São Paulo: medidas, superfícies e perfis de ativos. **Geografia**, v. 38, n. 1, p. 189–208, 2013.

APEL, H.; ARONICA, G. T.; KREIBICH, H.; THIEKEN, A. H. Flood risk analyses - How detailed do we need to be? **Natural Hazards**, v. 49, n. 1, p. 79–98, 2009.

BECCARI, B. A Comparative Analysis of Disaster Risk, Vulnerability and Resilience Composite Indicators. **PLoS Currents Disasters**, v. 14, n. 1, 2016.

BROUWER, R.; AKTER, S.; BRANDER, L.; HAQUE, E. Socioeconomic vulnerability and adaptation to environmental risk: A case study of climate change and flooding in Bangladesh. **Risk Analysis**, v. 27, n. 2, p. 313–326, 2007.

COMPANHIA DO METROPOLITANO DE SÃO PAULO. **Pesquisa Origem Destino**. Disponível em: <http://ww

.metro.sp.gov.br/>.

CUTTER, S. L. Vulnerability to environmental hazards**. Progress in Human Geography**, 10,4 (1996), p. 529-539, 1996.

CUTTER, S. L.; BORUFF, B. J.; SHIRLEY, W. L. Social Vulnerability to Environmental Hazards. **Social Science Quarterly**, v. 84, n. 2, p. 242–261, 2003.

HADDAD, E. A.; TEIXEIRA, E. Economic impacts of natural disasters in megacities: The case of floods in São Paulo, Brazil. **Habitat International**, v. 45, n. P2, p. 106–113, 2015.

HOGAN, D. J. População, pobreza e poluição em Cubatão, São Paulo. In: MARTINE, G. (ORG) (Ed.). **População, meio ambiente e desenvolvimento**. Campinas: Editora Unicamp, 1993. p. 101–131.

HOGAN, D. J.; MARANDOLA, E. Towards an interdisciplinary conceptualisation of vulnerability. **Population, Space and Place**, v. 11, n. 6, p. 455–471, 2005.

IPCC. **Climate change 2014: impacts, adaptation, and vulnerability. part b: regional aspects. contribution of working group ii to the fifth assessment report of the intergovernmental panel on climate change**. United Kingdom and New York, NY, USA: Cambridge University Press, 2014, 1150 p.

KOWARICK, L. Viver em risco: sobre a vulnerabilidade no Brasil urbano. **Novos Estudos**, n. 63, p. 9–30, 2002.

LUCAS, K. Transport and social exclusion: Where are we now? **Transport Policy**, v. 20, p. 105–113, 2012.

LUCAS, K.; VAN WEE, B.; MAAT, K. A method to evaluate equitable accessibility: combining ethical theories and accessibility-based approaches. v. 43, p. 473-490. **Transportation**, 2015.

MOSS, R. H.; BRENKERT, a L.; MALONE, E. L. Vulnerability to climate change: a quantitative approach. **U.S. Department of Energy, Oak Ridge, TN**, n. September, p. 1–88, 2001.

NEUTENS, T.; SCHWANEN, T.; WITLOX, F.; DE MAEYER, P. Equity of urban service delivery: A comparison of different accessibility measures. **Environment and Planning A**, v. 42, n. 7, p. 1613–1635, 2010.

PÁEZ, A.; SCOTT, D. M.; MORENCY, C. Measuring accessibility: Positive and normative implementations of various accessibility indicators. **Journal of Transport Geography**, v. 25, p. 141–153, 2012.

PREFEITURA DE SÃO PAULO. **Geosampa**. Disponível em: <http://geosampa.prefeitura.sp.gov.br/>.

PRESTON, B. L.; YUEN, E. J.; WESTAWAY,

R. M. Putting vulnerability to climate change on the map: A review of approaches, benefits, and risks. **Sustainability Science**, v. 6, n. 2, p. 177–202, 2011.

SIQUEIRA-GAY, J.; GIANNOTTI, M. A.; TOMASIELLO, D. B. Accessibility and flood risk spatial indicators as measures of vulnerability. In: SIMPÓSIO BRASILEIRO DE GEOINFORMÁTICA, 17. (GEOINFO), 2016, Campos do Jordão. **Anais...** São José dos Campos: INPE, 2016.

SMIT, B.; WANDEL, J. Adaptation, adaptive capacity and vulnerability. **Global Environmental Change**, v. 16, n. 3, p. 282–292, 2006.

TOMASIELLO, D. B. **Modelos de rede de transporte público e individual para estudos de acessibilidade em são paulo**. 2016. Universidade de São Paulo, 2016, p. 94.

TURNER, B. L.; KASPERSON, R. E.; MATSON, P. A.; MCCARTHY, J. J.; CORELL, R. W.; CHRISTENSEN, L.; ECKLEY, N.; KASPERSON, J. X.; LUERS, A.; MARTELLO, M. L.; POLSKY, C.; PULSIPHER, A.; SCHILLER, A. A framework for vulnerability analysis in sustainability science. **Proceedings of the National Academy of Sciences of the United States of America**, v. 100, n. 14, p. 8074–8079, 2003.

VIGNOLI, J. R. **Vulnerabilidad demografica: una faceta de las desventajas sociales**. Proyecto Regional de Población CELADE-FNUAP-CELADE. 2000, p.79.

WEE, B.; GEURS, K. Discussing equity and social exclusion in acessibility evaluations. **European Journal of Transport and Infrastructure Research**, v. 11, n. 4, p. 350–367, 2011.

WEIS, S. W. M.; AGOSTINI, V. N.; ROTH, L. M.; GILMER, B.; SCHILL, S. R.; KNOWLES, J. E.; BLYTHER, R. Assessing vulnerability: an integrated approach for mapping adaptive capacity, sensitivity, and exposure. **Climatic Change**, v. 136, n. 3–4, p. 615–629, 15 jun. 2016.