Simplified Flood Risk Index Applied to the Duque de Caxias Municipality in the Metropolitan Region of Rio de Janeiro

Indice de risque d'inondation simplifié appliqué à la municipalité de Duque de Caxias dans la région métropolitaine de Rio de Janeiro

Francis Martins Miranda[1]; Matheus Martins de Sousa[2]; Osvaldo Moura Rezende[3]; Ana Caroline Pitzer Jacob[4], Marcelo Gomes Miguez[5] & Assed Naked Haddad[6].

[1]PEA, Federal University of Rio de Janeiro (francis@coc.ufrj.br); [2]PEA, Federal University of Rio de Janeiro (matheus@hidro.ufrj.br); [3]PEA, Federal University of Rio de Janeiro (omrezende@coc.ufrj.br); [4]AquaFluxus Environmental Consulting in Water Resources (caroline@aquafluxus.com.br); [5]PEA/POLI, Federal University of Rio de Janeiro (marcelomiguez@poli.ufrj.br); [6]PEA/POLI, Federal University of Rio de Janeiro (assed@poli.ufrj.br)

RÉSUMÉ

Selon la méthodologie adoptée par la Banque Mondiale, l'évaluation du risque d'inondation peut être définie comme un processus continu d'analyse, d'ajustement et d'adaptation des politiques et des mesures visant à réduire les risques d'inondation. Cependant, il s'agit d'une approche complexe comportant un grand nombre de variables possibles, des difficultés inhérentes à leur application et par conséquent rarement introduites dans les pays en développement. De cette manière, cette étude présente le processus méthodologique et l'application d'un indice de risque d'inondation simplifié (SFRI). Le SFRI est composé de deux sous-index représentant l'aléa et ses conséquences pour le système socioéconomique. Les indicateurs IRS sont le référent des hauteurs d'inondation (IP), de l'exposition (IE), de la susceptibilité physique aux inondations (IPSF) et de la vulnérabilité socio-économique (ISS). L'étude de cas a été adoptée dans la municipalité de Duque de Caxias, région métropolitaine de Rio de Janeiro, au Brésil. En conséquence, l'indice peut servir de guide pour la planification urbaine.

ABSTRACT

According to the methodology adopted by the World Bank, the Flood Risk Assessment can be defined as a continuous process of analysis, adjustment and adaptation of policies and measures to reduce flood risks. However, its a complex approach with a large number of possible variables, difficulties inherent to their application and consequently rarely introduced in developing countries. In this way, this study presents the methodological process and application of a Simplified Flood Risk Index (SFRI).The SFRI is composed of two subindexes representing the hazard and its consequences reaching socioeconomical system. The IRS indicators are referent of flood heights (IP), exposure (IE), physical susceptibility to flood (IPSF) and socioeconomic susceptibility (ISS). The case study was adopted in the municipality of Duque de Caxias, Metropolitan Region of Rio de Janeiro, Brazil. As result, the index can be used as guideline for urban planning.

KEYWORDS

Duque de Caxias, Flood index, Flood risk management, Multicriteria analysis, Urban floods

1 INTRODUCTION

According to UNESCO's definition, Flood Risk Management (FRM) is a continuous process of analysis, adjustment and adaptation of policies and measures to reduce flood risks (UNESCO, 2013). The approach involves data acquisition and information processes, risk analysis and assessment, evaluation of options for building, implementing and reviewing decisions to reduce, control, accept or redistribute flood risks. The classic definition of risk is given by the combination of hazard and its associated consequences. In FRM, the term "Hazard" represents the probability of occurrence or materialization of a flood event over the basin, while "Consequence" is associated with the effects of the hazard when accessing the socioeconomic system. Thus, regions that even have high depth flooding areas unoccupied do not present Flood Fisk, once there are no exposure of properties or persons (Miguez, Veról, De Sousa, & Rezende, 2015). Thereby, the present study presents the application of a Simplified Flood Risk Index (SFRI) for the municipality of Duque de Caxias, localized in Rio de Janeiro Metropolitan Area (RJMA), Brazil, as an integral part of the Basic Sanitation Plan developed for the municipality in 2017 (SERPEN/COBA/UFRJ, 2017). The main objective is to provide a fast and easy way to mapping and classify flooding areas over municipality territory.

2 MATERIALS AND METHODS

In the present work, the hazard is represented by the flood height resulting from the occurrence of a storm event with 50 years of recurrence time. The portion referring to the consequence covers aspects of vulnerability and exposure of the urban system to the potential damages of the event. Therefore, it was elaborated indicators to evaluate these two aspects of flood risk. The hazard was evaluated by computational modelling, using MODCEL (Mascarenhas & Miguez, 2002; Miguez et al., 2017) as supporting tool to perform hydrologic and hydrodynamic simulation. The vulnerability analyse was conducted through secondary data evaluation, using census information (IBGE, 2010) and local physical characteristics. All worked data was evaluated in a geographic information system basis, within the concept of multicriteria evaluation.

2.1 Computational modelling system

In order to obtain information on flood patterns in different scenarios, hydrological and hydrodynamic modelling tools are used to support predictions using different rainfall design events for a set of varied return periods, involving the estimation of representative points in the proper probabilistic curve. In this case, this information was obtained by using the Urban Flow Cell Model – MODCEL (Miguez et al., 2017). This model was based on the original work of Zanobetti and Lorgeré (1968) and assumes that the watershed can be subdivided into various types of flow-cells, which interact with each other through 1D flow equations, representing the watershed surface and its flow pattern. MODCEL can be described as an urban flow cell model, which integrates hydrological processes observed in each cell into a looped hydrodynamic model, creating a spatial representation that interconnects surface flow, channel flows and storm drains. Therefore, a dual drainage approach supports this model, so the flow can occur simultaneously on both layers – surface and underground (Silva et al., 2017). This feature allows the assessment of both phenomenon, the river flooding and the drainage network failing. MODCEL can be classified as a multilevel quasi-2D model.

2.2 Simplified Flood Risk Index (SFRI)

The risk mapping considers a Hazard Indicator, based on water depth, and three vulnerability indicators, covering exposure and susceptibility. The exposure is represented by population density and susceptibility by socioeconomic data and physical environment characteristics. Applying these considerations to the classical Risk definition, the Simplified Flood Risk Index (SFRI) formulation, based on a multicriteria methodology, is given by Equation 1. All indices and indicators are normalized, with values between 0 and 1, representing lower and higher risk, respectively. Each indicator is presented in the following.

$$SFRI = [I_H]^A \cdot \left[(I_E)^{i_1} \cdot (IPSF \cdot c_1 + SSI \ \cdot c_2)^{i_2}\right]^B \qquad (1)$$

- ✓ A, B, i_1, i_2, c_1 and c_2 are the heights of the indicators

I_H – Hazard Indicator

This indicator is represented by the maximum flood depth and indicates the potential damage of a given flood event. I_H is also normalized by a reference depth, adopted in this study as the value of 1.00 m, from which a maximum potential damage is considered, according to the methodology described in

(Rezende, 2018). Floods heights less than 0.05 m are considered to have no potential to cause significant damage, resulting in a null value for the indicator. In the interval between these extreme values, maximum damage and insignificant damage, an exponential curve is normalized, representing the increasing potential damage of flood as water depths get closer to the maximum damage level.

***I_E* – Exposure Indicator**

The Exposure Indicator considers the inhabitants' density, indirectly indicating the number of people potentially exposed to flooding. The density estimation was performed by dividing the number of people domiciled in each grid of the official statistical mesh of Brazil (IBGE, 2016) by the total grid area, in hectares. For the composition of the indicator, the population density was normalized, with values between 0 and 1, being greater the more people are exposed. For the normalization of the indicator, it is considered that the maximum exposure happens in the value of density referring to the third quartile of the whole sample, in order to reduce possible "flattening" of the evaluation scale, due to the presence of extreme values.

***ISS* – Indicator of Socioeconomic Susceptibility**

One of the variables used in the risk assessment methodologies is the value of exposed properties, tending to prioritize richer regions instead of areas with high social vulnerability. In order to avoid this distortion in decision making, it was considered an indicator that gives greater criticality to regions with high social vulnerability, adding the relative value exposed and not the total value. This indicator considers the social classification according to Brazilian Criterion socioeconomic classification (ABEP, 2014), as shown in Table 1.

Table 1. Socioeconomic classification according to Brazilian Criterion (ABEP, 2014)

Class	A	B1	B2	C1	C2	DE
Income (US$*)	7,696.50	3,301.78	1,680.85	914.58	549.07	242.89

***** currency values of 2015

***IPSF* – Index of Physical Environment Susceptibility to Flooding**

The IPSF aims to map and classify areas prone to flooding in a qualitative way, in function of the combination of its natural and built environment (Miranda, 2016). In the SFRI composition, IPSF represents environmental aspects in risk assessment. Also based on a multicriteria methodology, the index is composed of four indicators based on physiographic characteristics of the terrain as briefly described in Table 2.

Table 2. Indicators components of IPSF (Miranda, 2016)

Indicator of Slope for Drainage (ISD)	Low slope regions presents difficulties in natural drainage due to inefficiency to conduct flows downstream. Studies as Therany et al. (2014) and Kazakis et al. (2015) consider slope as the most important physical parameter in the definition of floodplains or flooded areas.
Indicator of Soil Imperviuousness (ISI)	This indicator hierarchizes areas with different kinds of land-use in regarding the soil sealing degree. It indicates which regions have greater potential for generation and accumulation of runoff.
Indicator of Proximity to Drainage Network (IPROX)	The IPROX considers the average slope of the surrounding areas towards the watercourse and its respective distance. It represents the characteristics of the thalweg, as well as the access of the fluvial flooding to the adjacent plains.
Indicator of Absolute Altimetric Land Level (IAE)	In IEA the territory is classified regarding its altimetric quota in relation to the average sea level. Their application is related to vulnerable areas subject to tide variations, which can present low efficiency of discharge capacity during high tides. The chosen criteria are based in results of hydrodynamic modelling of catchments along the study area.

3 RESULTS

In this study it was adopted values of 0.5 to all indicators weight, in order to not favour any of the parcels before an effective sensitivity test. Figure 1 presentes the spatilization of IPSF clipped to the municipality of Duque de Caxias with the division of the local neighbourhoods for planning purposes.

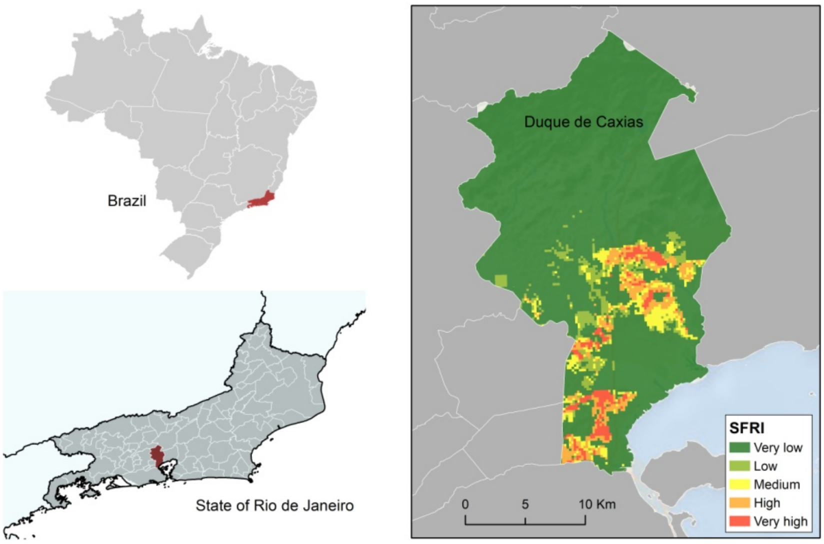

Figure 1. Flood Risk mapping in Duque de Caxias city, using the Simplified Flood Risk Index - SFRI.

4 CONCLUSIONS

The combination of data of different natures from a multi-criterion methodology and, consequently, the elaboration of an index has as main advantages the capacity to transform a large group of data into relevant information, reducing the complexity and bringing clarity to the decision process. In addition, indexes enable the densification of complex information in a usable form for public policy.

The application of the SFRI results in the spatialization of risk over the territory of Duque de Caxias municipallty and enables criteria definition for resources allocation and investments in strategic interventions for risk reduction. The results of the index can subsidize other municipal sectoral plans, such as the urban master plan, mobility planning, storm water management and risk management, among others. In this context, urban drainage can be seen as a structuring axis in the planning process of the territory, since its failure interferes with or even disrupts other urban systems.

LIST OF REFERENCES

ABEP. (2014). *Alterações na aplicação do Critério Brasil de Classificaçao Econômica*. Retrieved from http://www.abep.org/criterio-brasil

IBGE. (2010). Censo 2010. Retrieved December 7, 2018, from https://censo2010.ibge.gov.br/

IBGE. (2016). *Grade Estatística*.

Merz, B., Hall, J., Disse, M., & Schumann, A. (2010). Fluvial flood risk management in a changing world-Merz.pdf, 509–527.

Miguez, M. G., Battemarco, B. P., De Sousa, M. M., Rezende, O. M., Veról, A. P., & Gusmaroli, G. (2017). Urban flood simulation using MODCEL-an alternative quasi-2D conceptual model. *Water (Switzerland)*, *9*(6). https://doi.org/10.3390/w9060445

Miguez, M. G., Veról, A. P., De Sousa, M. M., & Rezende, O. M. (2015). Urban floods in lowlands-levee systems, unplanned urban growth and river restoration alternative: A case study in Brazil. *Sustainability (Switzerland)*, *7*(8), 11068–11097. https://doi.org/10.3390/su70811068

Miranda, F. M. (2016). *Physical environment's susceptibility flood index as a tool for urban planning*. Federal University of Rio de Janeiro.

Rezende, O. M. (2018). *Quantitative analysis of flood resilience for urban planning: case of the canal do Mangue in-Rio de Janeiro*. Universidade Federal do Rio de Janeiro. Retrieved from http://www.coc.ufrj.br/pt/teses-de-doutorado/603-2018/9043-osvaldo-moura-rezende

SERPEN/COBA/UFRJ. (2017). *Plano Municipal de Saneamento Básico - Relatório Final Consolidado*. Duque de Caxias.

Silva, B. M. G., Sousa, M. M. De, Rezende, O. M., Pitzer, A. C. J., De França, L. B. R., Miguez, M. G., & Arrais, C. M. (2017). Use of multilevel model for urban flood evaluation. In *XXII Simpósio Brasileiro de Recursos Hídricos* (pp. 1–8). Florianópolis: ABRHidro. Retrieved from http://evolvedoc.com.br/xxiisbrh/detalhes-1039_uso-de-modelo-multicamadas-para-avaliacao-de-cheias-urbanas

UNESCO. (2013). *Flood Risk Management: A Strategic Approach*. *Water and Sewerage Journal*. https://doi.org/10.1016/j.jacc.2006.07.056

Zanobetti, D., & Lorgeré, H. (1968). Le modèle mathématique du Delta du Mékong. *La Houille Blanche*, (1), 17–30. https://doi.org/10.1051/lhb/1968002