COMPARATIVE ANALYSIS OF MODELING FOR FLOOD SUSCEPTIBILITY MAPPING IN THE RIO DA PRATA DO MENDANHA AND CAMPINHO SUB-BASINS, MUNICIPALITY OF RIO DE JANEIRO

André Luiz da Silva Filho[1], Vivian Castilho da Costa[2]

1. State University of Rio de Janeiro, Rio de Janeiro, Brazil
andrefilhogeo@gmail.com
2. State University of Rio de Janeiro, Rio de Janeiro, Brazil
vivianuerj@gmail.com

Abstract
The aim of this research is to comparatively analyze GIS modeling for mapping areas susceptible to flooding in the Rio da Prata do Mendanha and Campinho sub-basins, in the municipality of Rio de Janeiro. The objectives were achieved using data from the RJ-25 Project, IBGE (2018), Data Rio and GeoINEA. To identify the areas susceptible to flooding the HAND model was used, the result of which was adjusted to the Hydrologically Consistent Digital Terrain Model. o. The results obtained when mapping the two sub-basins using the HAND model showed greater precision and accuracy compared to the mapping of areas susceptible to flooding carried out by the CPRM (2017). The results are significant in that they assess an area of study that still receives little attention from academic research and public.
Flood; HAND; Watersheds; Geographic Information System; susceptible.

1. Introduction

The UN Office for Disaster Risk Reduction (UNDRR, 2020) considers a disaster to be a serious disruption to the functioning of a society involving human, material, economic or environmental losses of great magnitude, the impacts of which exceed the ability of the affected community to cope with its own resources. The criteria adopted in the Annual Statistical Report of the Emergency Disasters Data Base - EM-DAT (UNDRR, 2020), consider the occurrence of at least one of the following criteria:
(a) 10 or more deaths;
(b) 100 or more people affected;
(c) Declaration of a state of emergency;
(d) Request for international aid.

The classification is also relevant due to the possibility of recording countless events in Brazil, thus enabling the creation of a database for the benefit of analyses and studies on the subject, as well as for planning preventive measures. Normative Instruction No. 01 (Brazil, 2012c) adopted the classification of disasters according to the International Disaster Database (EM-DAT) of the World Health Organization's Center for Research on the Epidemiology of Disasters (CRED). In this way, it established the Brazilian Classification and Codification of Disasters (COBRADE), previously classified according to the Codification of Disasters, Threats and Risks (CODAR) (Brazil, 2007), which distinguished disasters into Natural, Anthropogenic and Mixed. COBRADE distinguishes between natural and anthropogenic types. They are also classified according to intensity, periodicity and evolution.
According to UNDRR (2020), floods are the most frequent event among the various types of disasters in the world. Between 2000 and 2019 they accounted for 44% of all disasters, affecting around 1.65 billion people on the planet.

HAND modeling has published important works. Milanesi et al. (2017) used the model to recognize areas susceptible to flooding in the municipality of Porto Alegre/RS. In another study, Mengue et al. (2017) carried out an assessment using HAND in areas of urban expansion in the Metropolitan Region of Porto Alegre to identify whether urban growth in the region is occurring in flood areas. Goerl et al. (2017) carried out tests with the model at different spatial resolutions, obtaining positive results.
Also in the South, Speckhann (2018) proposed in his dissertation a mapping of flood risk areas for the Itajaí-Açu River basin using different models and in his evaluation HAND presented the best results. In the project Vulnerabilities of Brazilian Megacities to Climate Change, Nobre et al. (2010) carried out risk mapping of the Metropolitan Region of São Paulo. In the state of Rio de Janeiro, Prates and Amorim (2018) applied the model to map the lower reaches of the Muriaé River.

The aim of this research is to comparatively analyze GIS models for mapping areas susceptible to flooding in the Rio da Prata do Mendanha and Campinho sub-basins (Figure 1), which are located in Sepetiba Bay, in the western part of the city of Rio de Janeiro. The sub-basins officially occupy Planning Area V (AP5), an area that lacks both infrastructure and in-depth academic studies on the subject. Thus, the study in this area is justified by the lack of mapping of areas susceptible to flooding that integrates modeling with other techniques in order to analyze the reasons that favor such occurrences in a more fruitful way.

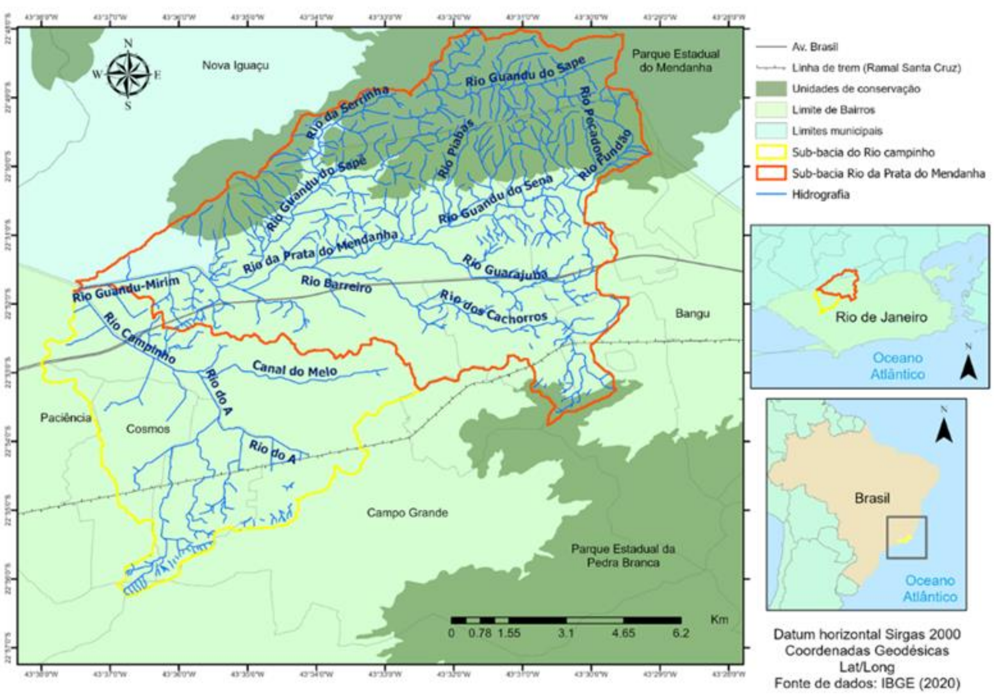

Fig. 1 Location of the study area

2. Methods or Materials

The Height Above the Nearest Drainage (HAND) model developed by the National Institute for Space Research (INPE) is used for modeling areas susceptible to flooding, land zoning and natural disasters, biogeochemistry, pedology, landscape ecophilosophy, among others (NOBRE et al., 2011a). For application in modeling areas susceptible to flooding, HAND converts the MDT-HC in order to discover the difference in altitude of the terrain and the altitude of the drainage network closest to each pixel.

According to INPE (2012), the model's differential lies in its ability to calculate terrain gradients on larger geographic scales, since other hydrodynamic models are capable of predicting flood areas, but their complexity in terms of

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parameterization and use restricts them from being applied on smaller, localized geographic scales, and the values calculated by HAND are also related to the depth of the water table.

Step 1: Hydrologically-consistent Digital Terrain Model (HC-DTM): A Digital Terrain Model (DTM) is a computer representation of a spatial phenomenon in a region of the earth's surface, allowing calculations, description and analysis to be carried out. For hydrological analysis, the Hydrologically Consistent Digital Model (HC-DTM) is the best application, as it contains information on contour lines, elevation points, hydrography and the boundary of the study area, building a model with smoothing through water bodies (CAMARA; FELGUEIRAS, 2005; MOORE et al., 1991). For the preparation of the HC-DTM, all the data acquired was from the RJ25 Project (IBGE, 2018), in vector format, developed on a scale of 1:25,000 in 2018. Hydrography data, elevation points and contour lines were used from this database. Every database used in this work follows the standardization of Presidential Resolution No. 1 (IBGE, 2005) in which geodetic data must be associated with the SIRGAS 2000 Reference System (horizontal datum), specifically in the case of this work the vertical datum is EGM96 and the projection system is UTM, spindle 23 - South. Using the ArcGIS Geographic Information System, topological errors were corrected to avoid flaws in the altimetry and the overlapping of contour lines, as well as inversions direction of flow of the hydrography. 469 errors were found and corrected using the Merge/ArcGIS, Explode/ArcGIS and Snap/ArcGIS tools. The tool used to generate the MDT-HC was Topo to Raster/ArcGIS. This tool used a geodatabase to insert, respectively, elevation points, contour lines, hydrography (RJ-25/IBGE, 2018) and the boundaries of Planning Area V and neighborhoods in the municipality of Rio de Janeiro and the municipality of Nova Iguaçu (bases available from the Data.rio and GeoINEA geoservices). In order for the tool to work correctly, it is necessary to define the cell resolution, in Output cell size, so, respecting the resolution defined by IBGE (2018), a resolution of 20 meters was used, compatible with the cartographic scale of the data

Stage 2: Modeling with HAND: For application in modeling areas susceptible to flooding, HAND converts the HC-DTM in order to discover the difference in terrain elevation and the elevation of the drainage network closest to each pixel. The TerraView 4.2.2 Geographic Information System, a free software developed by the National Institute for Space Research (INPE), which has HAND as one of its functions, was used for the modeling. In order to generate the flood areas, it is necessary to define the direction of flow, called Extraction Flow, and also to correct possible sinks (depressions) in the HC-DTM, using the Fixed DEM tool. The next step is to generate the contributing area, i.e. the area where the flows accumulate, called Contributing Area, and the Cells option is selected in the Unit field. The drainage is extracted using the Drainage Extraction tool. The value set for Threshold was 1738, which is the tool's default value. Through various tests, it was found that lower values could underestimate the extraction and higher values could overestimate it.

3. Results

The use of HAND proved to be positive and promising, but with some points for attention. The HAND results were compared with the data from the CPRM flood susceptibility maps (2017) for the area of each of the two sub-basins under analysis (Figures 2 and 3). For the study area, the CPRM only defines the classification of high susceptibility for up to 15m. Overlaying the data showed that the areas susceptible to flooding were mapped correctly, as most of them are within each other, with some differences.

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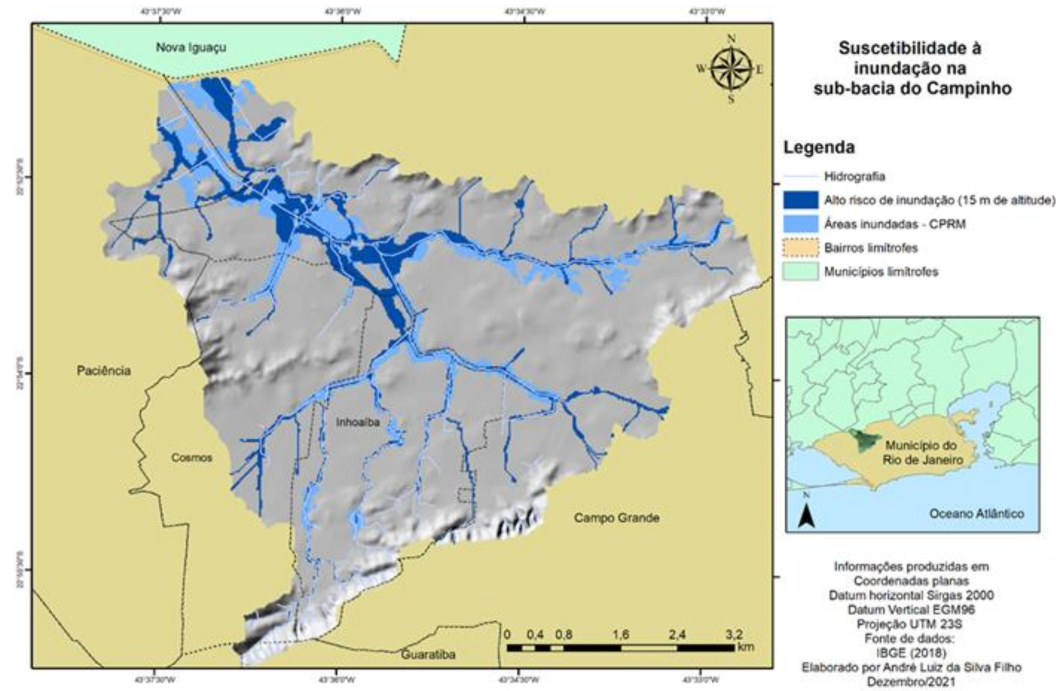

Fig. 2 Areas susceptible to flooding by HAND in the Campinho sub-basin superimposed on CPRM mapping areas

It was first decided to analyze the sub-basins in which the HAND results show that the areas susceptible to flooding in the two sub-basins represent 7.33 km^2, 3.88 km^2 for the Mendanha sub-basin and 3.45 km^2 for the Campinho sub-basin.

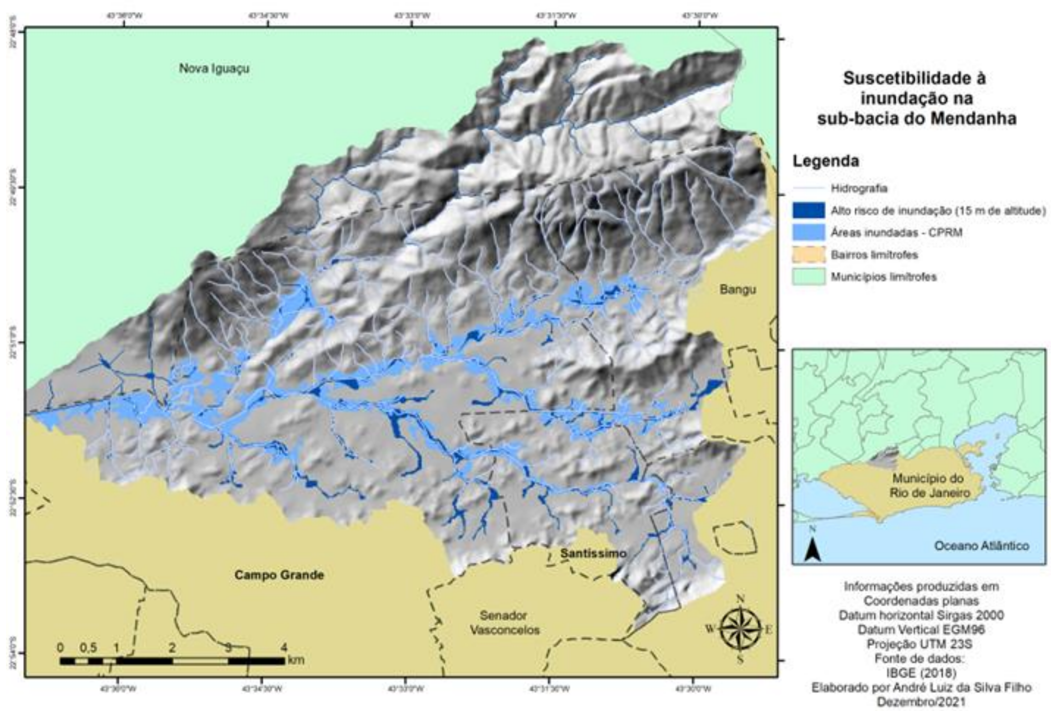

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Fig. 3 Areas susceptible to flooding by HAND in the Campinho sub-basin superimposed on CPRM mapping areas

The CPRM data show that the areas susceptible to flooding in the two sub-basins represent 10.05 km^2, with 6.20 km^2 for the Mendanha sub-basin and 3.85 km^2 for the Campinho sub-basin

It is important to mention that the working scale of the CPRM data is the same as the current dissertation: 1:25,000, however factors such as the quality of the Digital Terrain Model, the delimitation of river basins, as well as the correction of topological errors, not mentioned in the methodology by CPRM (2017), in addition to the lack of verification of faults in the drainage network or crossing of contour lines, hinder modeling with HAND, as they can lead to an underestimated or overestimated result. Faria (2021) demonstrates in his work how computational and physical differences in basins, such as biomes, can alter the results of delimitations, so CPRM data prepared for the entire state of Rio de Janeiro should be used with care on a local scale, with the analyst having knowledge of the characteristics of their study area in order to avoid failures and generalizations. All these steps were taken into account in the methodology of this dissertation.
In addition to providing results for the sub-basins, it was possible to further detail this research and show which neighborhoods are most susceptible to flooding. Since the Mendanha sub-basin is the one with the largest susceptible area, it became clear that the neighborhoods occupying this area would present corresponding results (Table 1).

Table 1: Total areas susceptible to flooding in the neighborhoods.

Districts	*HAND*	CPRM	Intersection
Bangu	0,60 km^2	0,65 km^2	0,18 km^2
Campo Grande	4,54 km^2	7,11 km^2	2 km^2
Cosmos	0,27 km^2	0,20 km^2	0,05 km^2
Inhoaíba	0,51 km^2	0,56 km^2	0,17 km^2
Paciência	0,33 km^2	0,45 km^2	0,11 km^2
Santíssimo	0,40 km^2	0,56 km^2	0,16 km^2
Senador Camará	0,18 km^2	0,09 km^2	0,03 km^2
Km 32 (Nova Iguaçu)	0,50 km^2	0,43 km^2	0,04 km^2
Total	7,33 km^2	10,05 km^2	2,74 km^2

The Campo Grande district had the largest area susceptible to flooding, at 4.54 km^2, corresponding to 62% of the district's total area. The CPRM data shows a larger area of susceptibility with 7.11 km^2. One justification for HAND showing a smaller area is that the model is more refined, showing in greater detail the areas that are most susceptible. In relation to the 2 km^2 intersection, around 62% of the area resulting from HAND was in the same location as the CPRM data.

This research achieved the proposed objectives by qualitatively and quantitatively analyzing the different natural and anthropogenic factors in the sub-basins, erosion processes, precipitation and, through modeling, was able to locate susceptible areas, showing, for example, which neighborhoods on the borders of the sub-basins are more or less subject to flooding.
Throughout the research, various difficulties were encountered, for example with the modeling, where it was necessary to learn the best way to use the model by carrying out various tests with different parameters so that we could arrive at a result.

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4. Conclusions

The modeling results cannot be used separately from the rest of the variables presented in this research. Its ability to point out areas susceptible to flooding is notorious, however, by using only the altimetry parameter, it makes it explicit that analysis in the study area must be accompanied by other factors such as land use and cover, soil types, slope, precipitation, current state of the hydrography, among others.
In some stretches, the modeling shows inconsistent results, for example in hillside areas, as shown in the Mendanha sub-basin. In these areas, with the high flow velocity due to the slope, flooding would hardly occur, but the HAND model uses the height closest to the drainage, taking into account the drainage as zero altimetry, which can lead to errors in sloping areas. Evaluation using only numerical results is not correct and should not be used without other parameters. Therefore, the analysis needs to be very careful, with as much field work as possible to have real contact with the conditions of the drainage and its surroundings, so that the researcher is not misled.

Finally, even though the HAND model needs attention in its results, it is a good option for studies on the subject, as it has already been used and tested in different studies with satisfactory results. Its graphical interface is user-friendly and users of Geographic Information Systems can recognize its tools. No knowledge of programming languages is required to use it, which often puts researchers off other models because they don't have a command of the subject.
I would like to thank the Rio de Janeiro State Research Foundation (FAPERJ) for the grant (Master's Degree Note 10) awarded for this research.

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