Cadastral Survey of Urban Areas Susceptible to Flooding Using Remotely Piloted Aircraft (RPA) for Hydrological Risk Classification: Case Study Santa Luzia Island, Mossoró, Rio Grande do Norte, Brazil

*******************(for review, names must be rendered anonymous)

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Abstract

This paper addresses the significant impact of extreme hydrometeorological events on Brazil, exacerbated by its tropical location. Flooding, driven by urbanization and inadequate planning, is a major concern, particularly in states like Pernambuco, Alagoas, São Paulo, and Rio Grande do Sul. Geoprocessing and photogrammetry techniques using Remotely Piloted Aircraft (RPA) are essential for mapping flood-prone areas and improving disaster management. The study focuses on Ilha de Santa Luzia in Rio Grande do Norte, vulnerable to flooding during heavy rainfall. It demonstrates the effectiveness of RPAs in generating precise cadastral survey data, adhering to national standards. Methodologies include photogrammetric surveys using a DJI Phantom 4 Advanced RPA, data processing in Agisoft Metashape, and validation against Cartographic Accuracy Standards. Results include detailed mappings aiding flood risk analysis and urban planning, crucial for mitigating flood impacts on local communities. The findings underscore the utility of RPAs in acquiring high-precision geospatial data swiftly and cost-effectively, essential for monitoring and managing flood-prone urban areas.

1. Introduction

In Brazil, the most harmful disasters are related to extreme weather events of a hydrometeorological nature, due to the country's location in tropical areas. These events result in significant precipitation during the rainy season and a high potential for evapotranspiration in semi-arid regions (Marengo, 2007). The combination of natural soil geodynamics, extensive anthropization of risk areas, and deficiencies in urban planning exacerbates the impacts of these events (BRASIL, 2012; TOMINAGA et al., 2009; CARMO, 2014; COUTINHO, 2019).

One of the primary causes of flooding is soil impermeabilization, which reduces water infiltration and increases surface runoff in urbanized areas (COBRAPE, 2018; PEREIRA et al., 2019). Urbanization in Brazil, which intensified in the second half of the 20th century, has altered the natural conditions of watersheds (Nascimento and Matias, 2011; Poleto and Tassi, 2012).

Flooding has significant environmental and socioeconomic impacts and is recurrent in various Brazilian states, such as Pernambuco, Alagoas, São Paulo, and Rio Grande do Sul, in different years. The need for studies to monitor and assist in flood prevention has made geoprocessing and photogrammetry techniques using Remotely Piloted Aircraft (RPA) indispensable for mapping risk areas, providing consistent data for planning and management (Santos et al., 2016).

RPAs have proven to be effective tools in collecting high-precision geospatial data, offering advantages such as the speed of information acquisition, the ability to access difficult areas, and reduced operational costs. This technology is applied to the cadastral surveying of urban areas, adhering to Cadastral Cartography standards NBR 14.166/1998 and NBR 13.133/2021.

This paper aims to demonstrate the applicability and efficiency of RPAs in generating cadastral survey data, highlighting methodological procedures, challenges faced, and results obtained for flood risk analysis in a GIS environment. Ilha de Santa Luzia, in the semi-arid region of Rio Grande do Norte, Brazil, was chosen due to its vulnerability to flooding during periods of intense rainfall. The detailed survey of the area will contribute to the development of mitigation strategies and urban planning, aiming to minimize the impacts of flooding on the local community.

1.1 Climatic Scenario in Mossoró

In Mossoró, a semi-arid region of Rio Grande do Norte, the climate is characterized by sparse precipitation throughout the year. According to the Köppen-Geiger classification, the prevailing climatic conditions are categorized as BSh. Historical meteorological data spanning 30 years indicate an average annual temperature of 27.8°C.

Examining the distribution of rainy days per month, April stands out as the only month over the past three decades to record an average of at least one day of rainfall between 20mm and 50mm. March typically sees around one day with rainfall between 10mm and 20mm.

2. Methodological Procedures

2.1 Photogrammetric Survey and Cadastre

Initially, the planning of the photogrammetric survey was conducted to ensure accuracy in accordance with standards NBR 13133 and NBR 14166, following the outlined steps below:

- ✓ Flight planning using DroneDeploy software, considering both lateral and longitudinal overlap for cartographic accuracy;
- ✓ Installation of 2 geodetic markers with GNSS CHCI73+ NONE, tracking for three hours, following the methodology recommended by IBGE for Precise Positioning Points (PPP) and in compliance with NBR 13.133/2021;
- ✓ Surveying of 11 control points and 2 check points. The transformation from ellipsoidal to orthometric height utilized the IBGE topographic model hgeoHNOR2020;
- ✓ Photogrammetric flight using a DJI Phantom 4 Advanced Remotely Piloted Aircraft (RPA) equipped with a 1-inch camera;
- ✓ Processing and validation of the acquired data in Agisoft Metashape software to generate products (Digital Surface Model (DSM), Digital Terrain Model (DTM), Orthophoto) with parameters as presented in Figure 1;

- ✓ Validation and classification according to the Cartographic Accuracy Standard for Digital Cartographic Products (PEC-PCD) (Brazil, 1998);
- ✓ Photogrammetric restitution for cadastre purposes and extraction of 0.10m contour lines.

Number of images:	337	Camera stations:	336
Flying altitude:	88.7 m	Tie points:	290,331
Ground resolution:	2.61 cm/pix	Projections:	1,182,587
Coverage area:	0.338 km^2	Reprojection error:	1.44 pix

Figura 1. Parametres calibrate camera, *Agisoft Metashape*

It is worth noting that the registration of existing buildings on the island, on the day of the orthophoto acquisition (October 2023), involved registering buildings where geometrical definition was unclear according to the guidelines of Ordinance 511/2009, addressing parcel delineation by considering territorial objects.

Finally, a layout was developed with all mapped elements for the cadastre, identifying buildings, curbs, roads (paved and unpaved), pathways, walls, bridges, watercourses, and 0.10m contour lines.

2.2 Classification of Flood-Prone Areas

A survey of 7 cross-sectional profiles across the watercourses surrounding the island was conducted, using a geodetic base starting from one of the geodetic markers installed at the study lot site. The GNSS equipment CHCI73+ NONE was used, employing the Precise Positioning Point (PPP) method with 15-minute precision as recommended by IBGE, 2009. Planimetric elevations were obtained at each point along the transverse profile of the riverbed, on both the left and right margins.

Using the DTM in ArcGIS PRO 3.2 software, simulations were performed considering progressive river increases of 1m, 2m, 3m, 5m, and 7m. Within a Geographic Information System (GIS) environment, flood susceptibility areas were identified in High, Medium, and Low classes. The susceptibility model employed the HAND (Height Above the Nearest Drainage) modeling technique in a GIS environment.

Subsequently, through spatial analysis conducted in ArcGIS PRO, buildings located in susceptible areas were identified, thereby classifying the risk associated with each construction.

GIS overlay was employed to integrate susceptibility classification data from the Ministry of Cities and IPT (2004), modified by SGB-CPRM (2023). The HAND model, which normalizes the Digital Terrain Model (DTM) relative to vertical distance from watercourses (Nobre et al., 2011), was utilized to analyze flood-prone areas. Results from the HAND model classified flood susceptibility according to thresholds defined by Nobre et al. (2011)1:

- ✓ Baixio: HAND 0 to 5.3m (High)
- ✓ Ecotone: HAND 5.4 to 6m (Medium)
- ✓ Ecotone: HAND > 6m (Low)

2.3 Flood Risk Classification Based on Cadastre

In a Geographic Information System (GIS) environment, spatial analysis was conducted by overlaying susceptibility data with building cadastre information in the area. According to Santos (2013), adopting parcels as the cadastre unit is a cornerstone of a multifunctional territorial cadastre. This approach represents an effective alternative for registering buildings in disaster-prone areas within urban communities, aiming at risk management and reduction of disasters, particularly in areas historically neglected by multifunctional cadastres

3. Results and Discussion

The region of Santa Luzia Island exhibits a generally flat slope (0 to 7º). The highest altimetric elevation mapped was at Profile 4 of the river, measuring 5.93 m, while Geodetic Marker M2 located within the island's occupied area registered 8.12m.

3.1 Planialtimetric Data Analysis

The geodetic markers installed in the area served for planialtimetric adjustments of the surveys conducted, presenting the following altimetric elevations for Geodetic Markers Elevations (m), M1=8.64 and M2=8.12.

The data processing yielded precise XYZ coordinates as reported by Geodetic Markers M1 and M2, adhering to IBGE standards. Both geodetic markers maintained an altimetric accuracy of 0.005m, contributing to a precise subsequent analysis of flood susceptibility.

The camera calibration process was conducted internally during data processing; prior to the insertion of support points for exterior orientation, the XYZ errors were 4.40753, 2.63983, and 16.2163, respectively.

Upon adding 11 support points for aerial photograph orientation distributed across the area of interest to ensure cartographic precision, they achieved an average error (RMSE) of X=1.70726cm; Y=0.919958; and Z=1.7015.

The XYZ RMSE result for each support point and the 3 check points individually. The Cartographic Accuracy Standard for Digital Cartographic Products (PEC-PCD) obtained was classified for a 1:1000 scale, where planimetric PEC-PCD was 0.28m (PEC) and 0.17m (EP), and altimetric PEC-PCD for surveyed points, DTM, and DSM was 0.27m (PEC) and 0.17m (EP), as stipulated by Decree 89.817, June 20, 1984. Hence, XYZ accuracy reached Class A, with RMSE XYZ of 1.71cm, 0.92cm, and 14.34cm, respectively, for the 11 support points, and for the 3 check points, RMSE XYZ was 9.03cm, 5.21cm, and 14.34cm. Thus, with products achieving PEC-PCD Class A, they are suitable for building cadastres and flood risk mapping.

The orthophoto shows the nearest watercourse to Avenida Presidente Dutra, the urban expansion area of the island, approximately 60m away, a second-order tributary of the Apodi-Mossoró River. The built-up areas have a flat slope, with a west-east decline directing drainage towards the watercourse to the north (Figure 2, left). The area is utilized for commerce and services, with access roads having drainage infrastructure (lacking effective maintenance observed on-site).

The Digital Surface Model (DSM) presents terrain elevation and natural and constructed elements of the areas. In the topographic profile drawn in the terrain area, the topographic variation is evident, necessitating area leveling considering urban drainage and the final destination of surface runoff to prevent potential contributions to flooding during periods of high rainfall (Figure 2).

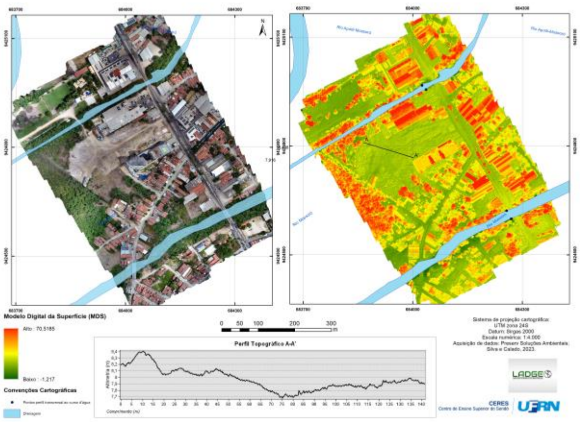

Figure 2. Ortophoto and DTM

3.1.1 Planialtimetric Cadastre

The cadastre of the area utilized the orthophoto depicting the current occupancy status, identifying all existing buildings. Given the dynamic nature of occupancy areas, which tends to be rapid without proper oversight from competent authorities, monitoring the area is crucial to prevent irregular constructions.

The cadastre survey registered a total of residential units on Avenida Presidente Dutra, the urban expansion area of the island.

3.2 Flood Susceptibility Data Analysis

The cross-sectional profiles drawn along the watercourses bordering the island presented the following elevations, with river depths estimated based on local community input. Elevations on the banks of the watercourses surrounding the island range from a minimum of 1.92m to a maximum of 5.93m above sea level.

The area's susceptibility analysis indicates predominantly medium and low susceptibility classes. Simulating a hypothetical river level increase up to 7m, most inundated buildings would. The Risk Analysis will be presented on a map with buildings classified according to susceptibility analysis simulations.

3.3 Conclusions

Geodetic markers M1 and M2 provided precise results for leveling in engineering projects and served as the basis for planialtimetric adjustments of river cross-sectional profiles and support and check points of photogrammetric surveys with RPA. Therefore, the use of precise geodetic data is recommended for leveling in engineering project execution.

Therefore, flood risk increases with new urban uses and occupations; the use of photogrammetry with RPA presents itself as a low-cost and easily manageable alternative for monitoring disorderly occupations in risk areas. Mitigating measures, such as structural works and maintenance of existing urban drainage systems, are essential to prevent the area from being affected by flooding during periods of high rainfall.

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