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Spatiotemporal analysis of buildings in flood hazard areas in Guarapuava, Paraná, Brazil

Análise temporoespacial de edificações em áreas de perigo de inundação em Guarapuava, Paraná, Brasil

Análisis temporo-espacial de la edificación en zonas de riesgo de inundación en Guarapuava, Paraná, Brasil

Analyse spatio-temporelle des bâtiments dans les zones inondables à Guarapuava, Paraná, Brésil

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ABSTRACT

Rapid urbanization and climate emergencies pose significant challenges to urban planning, management, monitoring, and the regulation of inadequate land occupations, particularly in flood-prone areas. This study aims to investigate the spatiotemporal dynamics of land use and occupation in critical flood hazard zones in Guarapuava (PR) from April to November 2023. The methodological approach involved visual interpretation of Google Earth imagery and orthomosaics obtained through unmanned aerial vehicles (UAVs), focusing on areas requiring public attention. The results indicate an increase in soil impermeabilization and a growing number of residential structures in

flood-hazard areas. The findings suggest that the pace of urban occupation in flood-prone zones often exceeds regulatory agencies' monitoring and enforcement capacity. Therefore, beyond implementing land use regulations in flood hazard areas, effective enforcement measures are crucial, as greater exposure to hazards heightens the risk of disasters.
KEYWORDS: disaster; mapping; impermeabilization.

RESUMO

A rápida urbanização, associada às emergências climáticas, é um desafio para o planejamento, a gestão urbana, o monitoramento e a fiscalização de ocupações inadequadas, especialmente em áreas de inundações. Objetivou-se investigar a dinâmica temporoespacial de uso e ocupação da terra em áreas críticas de perigo de inundação em Guarapuava (PR), de abril a novembro de 2023. Os procedimentos metodológicos incluíram a interpretação visual de imagens do Google Earth e ortomosaicos obtidos com um veículo aéreo não tripulado, referentes às áreas que necessitam de atenção pública. Os resultados demonstram aumento na impermeabilização do solo e no número de residências em áreas de perigo de inundação. Concluiu-se que a dinâmica de ocupação das áreas de perigo de inundação por edificações é rápida, excedendo muitas vezes a capacidade de monitoramento e fiscalização dos órgãos competentes. Portanto, além de um disciplinamento do uso e da ocupação do solo em áreas de perigo de inundação, faz-se necessária uma fiscalização eficiente, uma vez que uma maior exposição ao perigo aumenta o risco de desastres.
PALAVRAS-CHAVE: desastre; mapeamento; impermeabilização.

RESUMEN

La rápida urbanización, unida a las emergencias climáticas, supone un reto para la planificación, la gestión urbana, el seguimiento y la inspección de ocupaciones inadecuadas, especialmente en zonas inundables. El objetivo fue investigar la dinámica temporal y espacial del uso y ocupación del suelo en áreas críticas de riesgo de inundación en Guarapuava (PR), de abril a noviembre de 2023. Los procedimientos metodológicos incluyeron la interpretación visual de imágenes de Google Earth y ortomosaicos obtenidos con un vehículo aéreo no tripulado, referidos a las áreas con necesidad de atención pública. Los resultados muestran un aumento del sellado del suelo y del número de viviendas en zonas inundables. Se llegó a la conclusión de que la

dinámica de ocupación de las zonas de riesgo de inundación por los edificios es rápida, superando la capacidad de vigilancia e inspección de los órganos competentes. Por lo tanto, además de disciplinar el uso y ocupación del suelo en zonas con riesgo de inundaciones, es necesaria una supervisión eficiente, ya que una mayor exposición al peligro aumenta el riesgo de desastres.
PALABRAS CLAVE: catástrofe; mapeo; impermeabilización.

RÉSUMÉ

L'urbanisation rapide, associée aux urgences climatiques, constitue un défi pour la planification, la gestion urbaine, la surveillance et l'inspection des occupations inappropriées, en particulier dans les zones inondables. L'objectif a été d'étudier les dynamiques temporelles et spatiales de l'utilisation et de l'occupation des sols dans les zones critiques en danger d'inondation à Guarapuava (PR), d'avril à novembre de 2023. Les procédures méthodologiques comprenaient l'interprétation visuelle d'images de Google Earth et d'orthomosaïques obtenues à l'aide d'un drone, en se référant aux zones nécessitant l'attention de l'État. Les résultats montrent une augmentation de l'imperméabilisation des sols et du nombre de maisons dans les zones inondables. On a conclu que la dynamique d'occupation des zones inondables par des bâtiments est rapide, dépassant la capacité de surveillance et d'inspection des organismes compétents. On recommande de réglementer l'utilisation des terres dans les zones inondables et de mettre en place une surveillance efficace pour réduire le risque de désastre.
MOTS-CLÉS : désastre ; mapping ; imperméabilisation.

INTRODUCTION

According to the Intergovernmental Panel on Climate Change (IPCC), extreme environmental conditions, including floods, are expected to increase in both magnitude and frequency, amplifying the risk of natural disasters. In Brazil, a 1.5°C rise in temperature could lead to a 100% to 200% increase in the population affected by floods (IPCC, 2022).

In 2022 alone, the Emergency Events Database (EM-DAT, 2023a) recorded 387 natural disasters worldwide, resulting in 30,704 fatalities and affecting approximately 185 million people. The total economic losses amounted to about $223.8 billion, with flood-related disasters leading in frequency—accounting for 176 events, surpassing the annual average of 168 occurrences recorded between 2002 and 2021.

In Brazil, data from the Digital Atlas of Disasters (2023) indicate that flood-related disasters in 2021 and 2022 alone amounted to 3,660 recorded events, leading to 300 deaths and affecting 15,445,016 people. Since monitoring began in 1991, losses from these disasters have totaled R$423.05 billion. Among these events, 1,266 were hydrometeorological in nature, including heavy rainfall, floods, flash floods, and urban waterlogging. These figures underscore the urgent need for further research on disaster risk and the development of new tools and methodologies to mitigate the impacts of extreme weather events, particularly floods.

Flooding can lead to disasters depending on its magnitude and the extent of human presence in affected areas. According to EM-DAT (2023b), an event is classified as a disaster when human and/or economic losses meet at least one of the following criteria: (i) 10 or more fatalities; (ii) at least 100 affected individuals; (iii) a declared state of emergency; or (iv) an international request for assistance.

As noted by Vestena (2017), most disasters result from adverse natural phenomena and are directly linked to both environmental characteristics and human activities—particularly patterns of land use and occupation. In other words, disasters are closely tied to human encroachment into hazard-prone areas, such as floodplains, and the structural quality and resilience of built environments.

So-called "natural" disasters are classified based on the nature of the triggering event (hazard) (Marcelino, 2008), yet their impacts manifest within a social system (which is inherently vulnerable) through human, material, and environmental losses (Vestena, 2017; Castro, 1996).

Flood hazard zones are defined as areas with a probability of experiencing damage or disasters. Hazards may pose significant risks over a specific time frame and within a defined geographic space (Castro, 1996; Assefa, 2018). Therefore, exposure to hazard zones inherently means increased vulnerability and a heightened likelihood of loss or damage (Robaina & Oliveira, 2013).

Floods are natural events characterized by a rise in river levels beyond their normal capacity, leading to water overflow into adjacent areas (Kobiyama *et al*., 2006). However, their severity is often exacerbated by urbanization-driven increases in impermeable surfaces (Tucci, 2007; Zhang *et al*., 2018; Xu *et al*., 2023), a common trend in most Brazilian cities.

Both climate change and urbanization significantly impact hydrological systems. On one hand, climate change increases the frequency and intensity of extreme weather events (Sandink, 2009; *Yang et al.*, 2021; IPCC, 2022; Ng *et al.*, 2024), such as intense rainfall over short periods, which heighten flood risks. On the other hand, urban areas experience widespread conversion of natural land into impermeable surfaces, inhibiting water infiltration (Feng, Zhang & Bourke, 2021). As Tucci (2007) highlights, this transformation accelerates runoff velocity and expands flood-prone areas.

Brazil's first legal framework for disaster management was introduced through Provisional Measure No. 547 on October 11, 2011. This measure required municipalities experiencing urban expansion to develop growth plans, including the "delineation of areas with urbanization restrictions and zones subject to special control due to natural disaster risks" (Brasil, 2011).

This provision was later incorporated into Federal Law No. 12,608 of April 10, 2012, which established the National Policy for Civil Protection and Defense. This law aimed to reduce disaster risks by mandating municipalities to map areas susceptible to floods and other natural disasters (Brasil, 2012a). Consequently, municipal master plans must integrate disaster risk areas into urban planning. To meet these requirements, local governments must maintain up-to-date databases, conduct continuous mapping of flood-prone regions, carry out in-depth studies to identify high-risk areas, and implement proactive measures for disaster risk reduction.

In the city of Guarapuava (PR), data from Paraná's Civil Defense (2023) indicate that between 1992 and 2023, 31 flood-related disaster events were recorded, affecting a total of 175,792 people. According to Vestena, Almeida, and Geffer (2020), the most affected neighborhoods include Primavera, Industrial, Vila Carli, Jardim das Américas, Cascavel, and Vila Bela, primarily due to settlements along riparian zones in the floodplains of the Cascavel River, which are highly susceptible to flooding.

Given the urgent need for a deeper understanding of flood-related disaster risks, this study focused on two areas in Guarapuava that require special attention. The spatial dynamics of land use and occupation in these regions were analyzed to provide data-driven insights for municipal management, particularly for land-use regulation and enforcement.

Although Guarapuava has a Municipal Drainage Plan (PMG, 2021) and urban zoning laws, these regulatory instruments are limited and have proven insufficient in curbing the rapid and unregulated urban expansion into flood-prone areas. This expansion frequently outpaced the monitoring and enforcement capacities of relevant agencies, as evidenced by the growing number of residential constructions in environmentally sensitive zones that should be designated as Permanent Preservation Areas (PPA).

The city also exhibits a pattern of informal settlement in so-called "urban voids"—underutilized spaces near riverbanks. As unplanned urban growth continues and new subdivisions emerge, the existing drainage system faces demands beyond its original design capacity, exacerbating challenges in urban planning and disaster risk management in Guarapuava, Paraná.

This study seeks to address the existing gaps in land-use mapping and monitoring while proposing methodological alternatives that can be applied to other communities for assessing land cover changes.

Characterizing flood-related disaster risk is a critical step in managing such events, as identifying socio-environmental characteristics provides essential inputs for planning. As Smith (2018, p. 45) emphasizes, "the early identification of risk-prone areas is crucial for implementing preventive measures and ensuring community safety".

Freely available satellite imagery is a valuable resource for identifying land cover and infrastructure within hazard-prone or restricted-use areas. However, due to the rapid pace of land occupation and change, satellite-based monitoring has inherent limitations. In contrast, the use of unmanned aerial vehicles (UAVs), commonly known as drones, allows for the generation of high-resolution land-cover maps and real-time monitoring of environmental changes over short time intervals. This capability enables regulatory agencies to make more agile and effective decisions. UAV technology has thus emerged as a highly efficient tool for identifying and analyzing disaster risks in areas vulnerable to flash floods, urban waterlogging, and riverine flooding.

Decision-makers can leverage these tools to map hazard-prone areas and assess disaster risks, as integrating data from multiple sources, including UAVs and satellite imagery, is crucial for a comprehensive understanding of environmental conditions (Smith, 2018, p. 67). Comparative studies of temporal and spatial flood hazard dynamics further enhance this understanding.

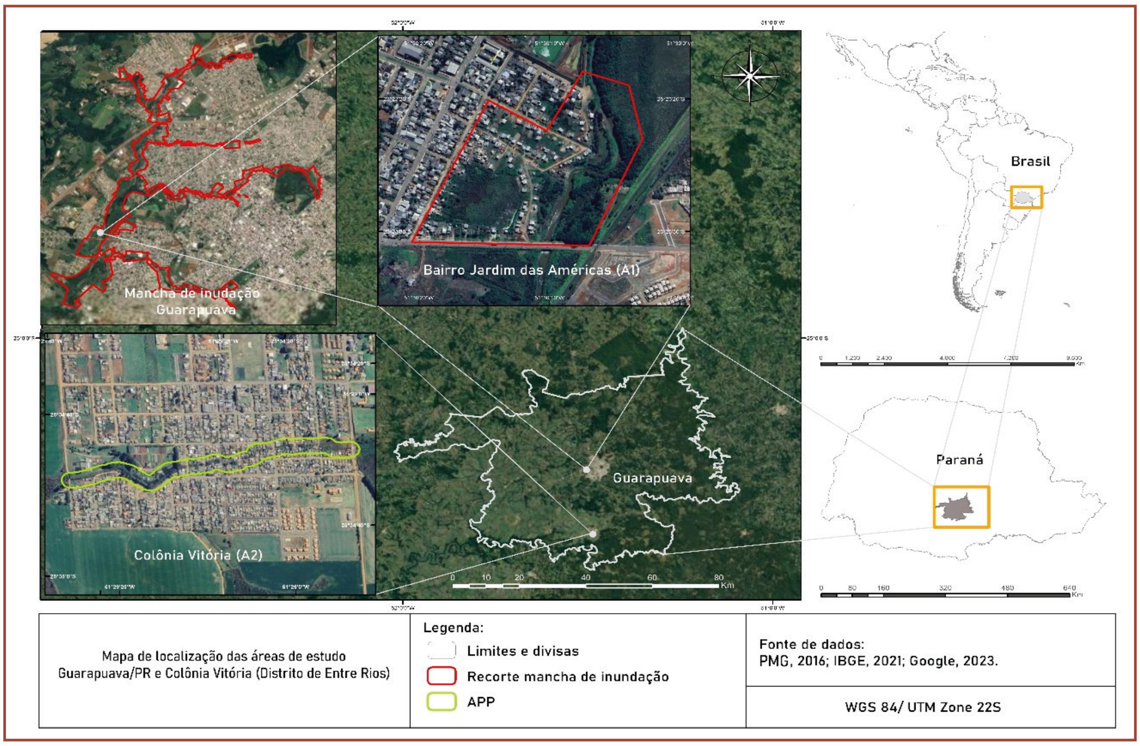
In this context, this study presents findings on the spatiotemporal dynamics of land use in critical flood hazard zones in Guarapuava (PR), analyzing data from April and November 2023 using satellite imagery from Google Earth and high-resolution aerial surveys conducted with UAVs.

MATERIAL AND METHODS

Study areas

This study was conducted in the city of Guarapuava (PR), focusing on two areas of concern regarding flood-related disasters. The first area (A1) is a 12.32-hectare floodplain located in the Jardim das Américas neighborhood, within the Cascavel River's flood zone (Figure 1). The second area (A2) is in Colônia Vitória, within the district of Entre Rios, designated as a Permanent Preservation Area (PPA), spanning 6.53 hectares and associated with the Pioko River, a tributary of the Jordão River Basin (Figure 1).

Figure 1 – Location map of the study areas



Source: Adapted from PMG (2016), IBGE (2022), and Google Earth (2023a, 2023b).

Guarapuava is situated in the south-central region of Paraná and has a population of 190,342, with a demographic density of 57.48 inhabitants per km² (IBGE, 2022).

The spatial distribution of poverty in Guarapuava reflects broader patterns typical of urbanization in developing countries, where a significant portion of the low-income population is concentrated in peripheral areas (Lima, 2013). Jardim das Américas, located in the western portion of the city's urban area, and the "Vila dos Brasileiros" in the district of Entre Rios exemplify this dynamic, as they are predominantly inhabited by low-income residents with limited purchasing power.

According to Gomes (2010), Jardim das Américas (A1) is home to many people in poverty, characterized by low educational attainment and employment in informal or precarious jobs, often in waste collection and recycling, with wages significantly below the municipal average. As Lima (2013) notes, the lower land prices in this peripheral area compared to other neighborhoods have been the primary factor driving settlement. Additionally, the region features wetlands, hydromorphic soils, and peat deposits, which pose significant challenges for urban planning and flood risk management, as these hydrologically sensitive areas influence local hydrodynamics and increase vulnerability to flooding.

The second area (A2) is in Colônia Vitória, within the district of Entre Rios, and is occupied partially by low-income wage earners from the Cooperativa Agrária Agroindustrial and primarily by impoverished populations. The Entre Rios district consists of five urban settlements, historically inhabited by descendants of Danube Swabians, a German-speaking community that sought refuge in Austria following World War II before migrating to Brazil (Elfes, 1971). In Colônia Vitória, there is a clear distinction between the area inhabited by German descendants, known as the "Vila dos Alemães", and the "Vila dos Brasileiros", which is predominantly occupied by Brazilian residents (Stefenon & Silva, 2005). The study area was delineated based on the PPA designation along the Pioko River.

The occupation of these areas exposes their populations to significant socio-environmental vulnerability, where residents not only contribute directly and indirectly to environmental degradation but also face precarious living conditions and heightened exposure to extreme hydrometeorological events. This reality results in a diminished capacity for resilience against flood-related adversities.

Cartographic data

The cartographic data used in this study included *shapefiles* representing the extreme flood-prone area of Guarapuava (within the Jardim das Américas neighborhood, A1) and a 30-meter *buffer zone* delineating the PPA along the Pioko River in Colônia Vitória (A2). These datasets were created and provided by the Municipal Government of Guarapuava (PMG, 2016, 2021). Additional territorial boundary datasets (Latin America, Brazil, Paraná state, and the municipality of Guarapuava) were obtained as *shapefiles* from the updated 2021 mapping database of the Brazilian Institute of Geography and Statistics (IBGE).

To visually identify buildings, two different types of imagery were analyzed. First, publicly available satellite images from Google Earth were used, with a resolution of 12 meters. At the time of data acquisition, the most recent images were dated April 2023. Additionally, an orthomosaic was generated with a resolution of 22 centimeters using an aerial photogrammetric survey conducted with an unmanned aerial vehicle (UAV) in November 2023, captured from an altitude of 80 meters over both study areas.

Digital Terrain Models (DTMs) from the ALOS PALSAR satellite, with a resolution of 12.5 meters, were also utilized in TIFF format to delineate contributing drainage areas.

Methodological Procedures

The methodological procedures involved mapping land use and land cover at two distinct time periods—April and November 2023—followed by cartographic overlay analysis using QGIS *software*.

The mapping process was carried out through visual interpretation of images obtained from the Google Earth platform (April 2023) and aerial surveys conducted with UAVs (November 2023). This mapping involved the manual generation of *shapefile* datasets for two land cover classes: “buildings” and “road networks”. Table 1 presents a comparative analysis of the methodological aspects of UAV-acquired imagery versus Google Earth satellite imagery for building identification, highlighting key characteristics of each data source.

Table 1 – Key Characteristics of UAV-Acquired and Google Earth Satellite Imagery

Criteria	UAV-Acquired Imagery	Google Earth Imagery
Spatial resolution	22cm	12 m
Image update frequency	Can be scheduled based on favorable weather conditions	Variable; depends on location and type of data collection (platform updates may involve images taken over days or months)

Criteria	UAV-Acquired Imagery	Google Earth Imagery
Cost	Requires equipment, operational expenses, and data processing	Free or low-cost, widely accessible
Need for specialized personnel	Requires trained personnel for operation and data interpretation	User-friendly; no advanced technical skills required
Coverage area	Limited, may require multiple flights	Global coverage, spanning diverse regions
Suitability for high-precision applications	High accuracy for detailed analyses	Limited resolution for applications requiring fine details
Availability	Dependent on flight planning and field visits	Immediate and unrestricted access

Source: Compiled by the authors.

The primary limitation of mapping using Google Earth imagery was its spatial resolution, which made it difficult to distinguish rooftops of closely spaced residences, leading to polygon groupings that occasionally encompassed multiple buildings (Figures 2 and 3).

Despite these limitations, Google Earth imagery was employed primarily to highlight the addition and/or removal of buildings. This underscores the potential of using these images to detect spatiotemporal changes in urban occupation within flood-prone areas.

Figure 2 – UAV-Acquired Image

Source: UAV (2023a).

Figure 3 – Google Earth Imagery

Source: Google Earth (2023a).

Thus, to spatially identify built-up areas that were either removed or added over the study period, overlay analyses were conducted using the mapped data from the two different timeframes. A hatching pattern was used to represent the built-up areas as of April 2023, while a solid color indicated areas added by November 2023. To quantify landscape changes, the total area occupied by buildings and roadways was calculated for each period, allowing for an estimation of the extent of impervious surface expansion.

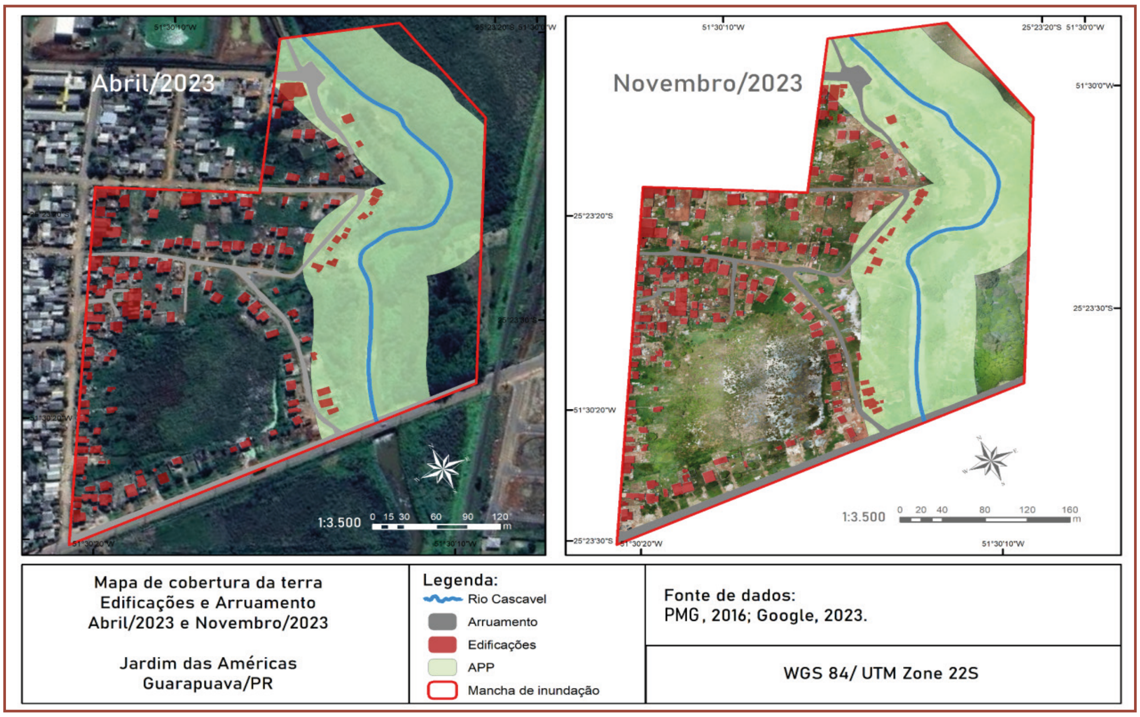
The delineation of contributing areas within the study sites was carried out using Digital Terrain Model (DTM) data from the ALOS PALSAR satellite. Geographic Information System (GIS) modeling was employed to identify and demarcate zones that influence water runoff patterns in the investigated regions.

Additionally, field surveys were conducted during both study periods to collect socio-environmental data and to observe natural processes and human activities in the selected areas. These surveys also included photographic documentation, which served as a key component in characterizing the study sites.

RESULTS AND DISCUSSION

In the first study area (A1), 148 buildings were identified in April 2023, increasing to 176 in November 2023, reflecting a net gain of 28 structures over a six-month period. Figure 4 presents the mapped buildings in A1, located in the Jardim das Américas neighborhood, where 38.18% of the total area—approximately 4.70 ha—falls within the PPA of the Cascavel River.

Figure 4 – Mapping of buildings and roadways in April 2023 and November 2023 within the A1 study area



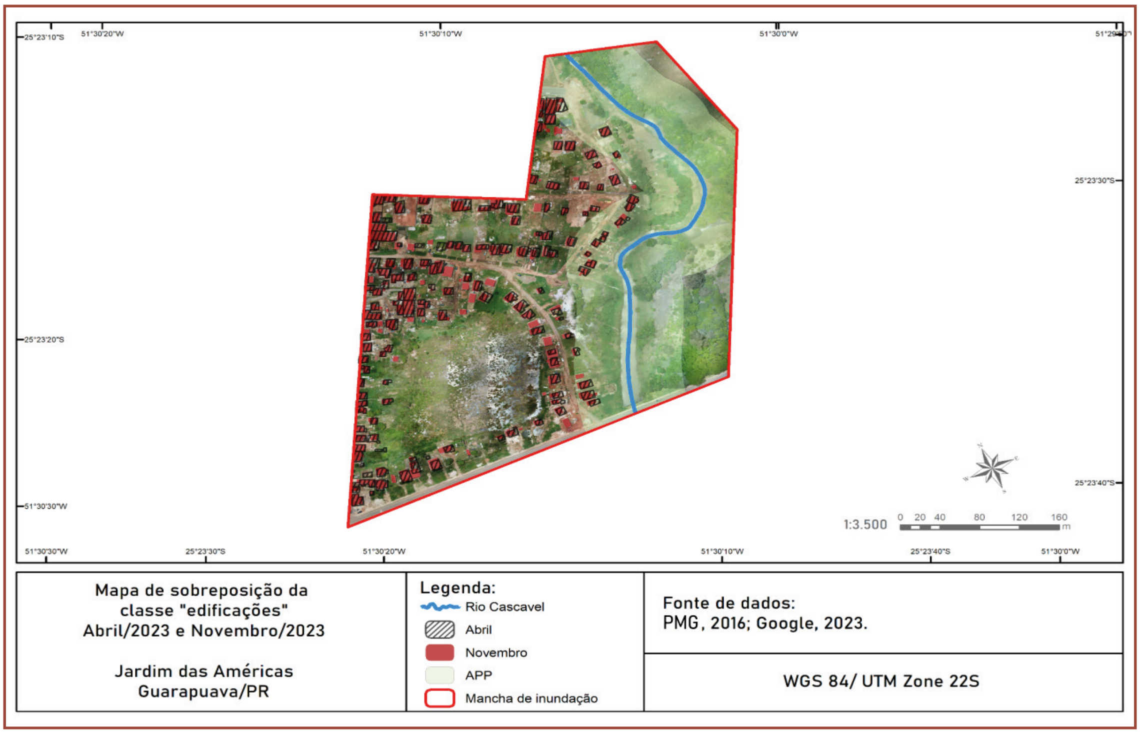
Source: Adapted from PMG (2016) and Google Earth (2023a, 2023b).

Regarding the total built-up area, the April mapping identified 0.96 ha, while the November survey recorded 0.95 ha. Despite the increase in the number of mapped buildings, the total built area slightly decreased. This discrepancy may be attributed to differences in spatial resolution between imagery sources. The UAV-derived images from November provide higher spatial resolution than those from Google Earth in April. Since greater spatial resolution allows for more precise mapping, variations in image quality likely influenced the results.

The combined area of buildings and roadways in A1 was 1.55 ha in April and 1.60 ha in November, marking a 3.23% increase—equivalent to 0.05 ha (403.81 m²). Mapping data further indicated that as of November, 13% of A1's total area was covered by impervious surfaces, including buildings and roadways.

Figure 5 highlights the expansion of residential structures in November 2023 compared to April, pointing to ongoing urban intensification. Additionally, the UAV-based mapping conducted in November, with its superior precision and resolution, likely enhanced the identification of structures. Despite these methodological differences, the results indicate specific areas where new buildings have emerged, underscoring the need for heightened municipal oversight.

Figure 5 – Overlay map of the "Buildings" land-use category in April 2023 and November 2023 within the A1 study area



Source: Adapted from PMG (2016) and Google Earth (2023a, 2023b).

Most residences in A1 are built with wood or on stilts (palafitas) (Figures 6 and 7). The use of stilts is a strategic adaptation to frequent flooding events in the area. Figure 7 shows land filled with construction debris, a common practice among residents in A1. This filling technique raises the ground level to mitigate water saturation, enabling construction in an area otherwise unsuitable for development. According to the city's Master Plan (PMG, 2016), this region is classified as inappropriate for urbanization and construction due to its permanently saturated peat soils.

Figure 6 – Building within the flood hazard zone (Jardim das Américas neighborhood)

Source: Authors' collection (2023).

Figure 7 – Landfilling for construction in a flood hazard area

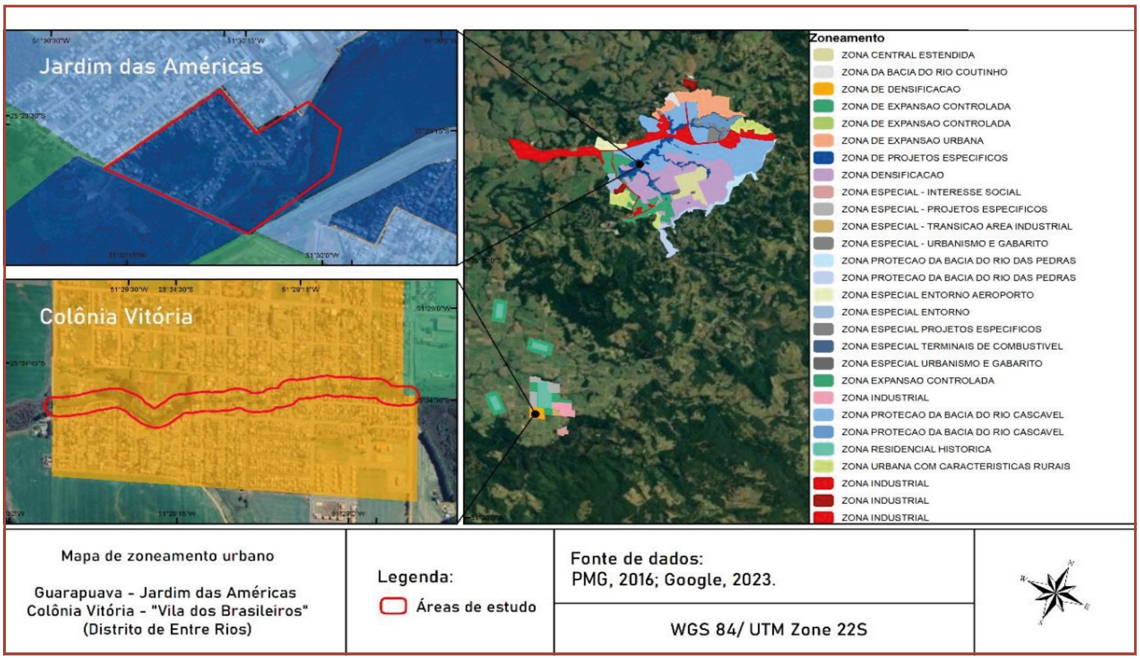
Source: Authors' collection (2023).

Field observations confirmed that, due to legal restrictions on construction in these areas, residents often resort to unsafe methods to access water and electricity, including unauthorized wiring ("gatos"). These informal connections not only pose electrocution risks but also exacerbate health hazards due to inadequate sanitation infrastructure.

Beyond the structural inadequacies of informal housing, the lack of basic sanitation further amplifies the vulnerability of residents to disasters. Basic sanitation includes essential services such as water supply, sewage management, urban cleaning, solid waste disposal, and stormwater drainage—all of which are virtually absent in these areas. The absence of these urban infrastructures leads to soil and water pollution, as seen in the improper storage of recyclable materials near residences, litter accumulation along riverbanks, and direct sewage discharge into watercourses. These conditions exacerbate flood risks by obstructing natural drainage pathways.

This area is officially designated by the Guarapuava municipal government as being within the flood-prone zone of the Cascavel River. It is also classified as a Zona Especial - Projetos Específicos (Special Zone for Specific Projects) under Complementary Law No. 69/2016 (GUARAPUAVA, 2016). This zoning regulation mandates the establishment of linear parks in flood-prone areas, aligning with the guidelines of Guarapuava's Master Plan Council (Concidade).

Figure 8 – Urban zoning map of Guarapuava

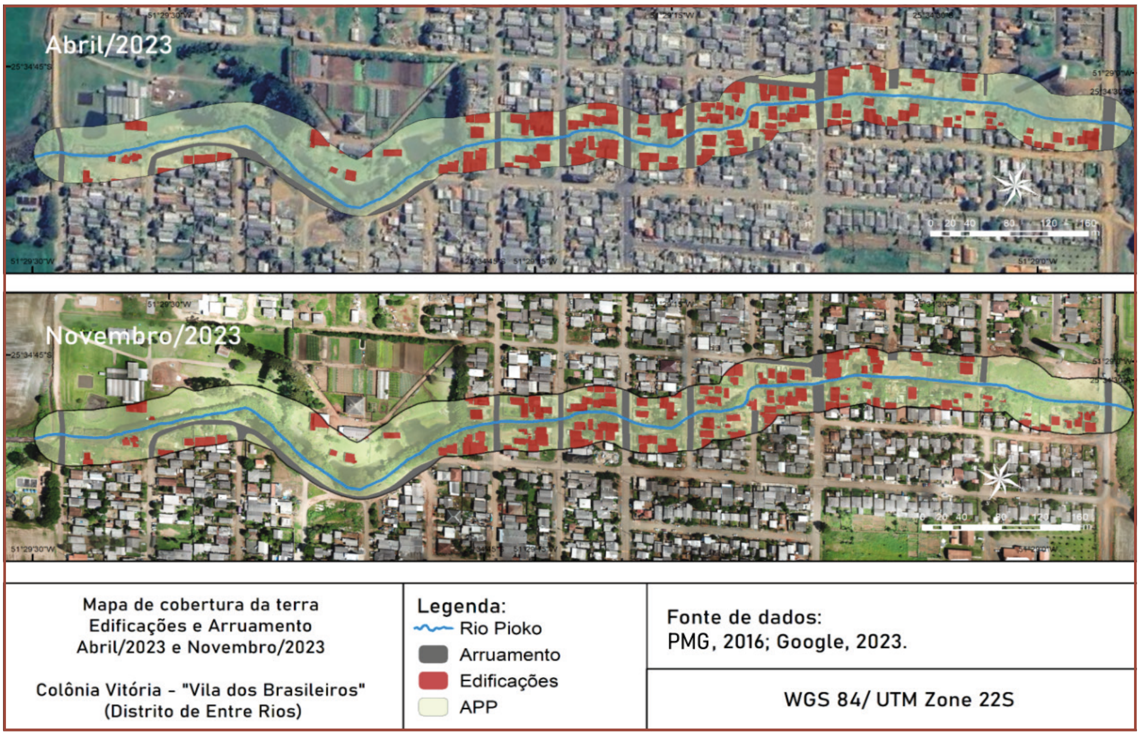


Source: Adapted from PMG (2016) and Google Earth (2023a, 2023b).

Land use regulation and spatial planning in A1 are essential to mitigate potential flood-related damages. The proposed implementation of a linear park and the relocation of current residents from this high-risk zone could enhance community safety by addressing the existing hazard and vulnerability conditions.

In the second study area (A2), 111 buildings were identified in April 2023, increasing to 122 in November, marking a net gain of 11 structures (Figure 9). This rise in construction amplifies disaster risk, as more individuals are exposed to hazardous conditions. The findings underscore the inadequacy of current regulatory actions in reversing this trend, highlighting the urgent need for more comprehensive and effective interventions by relevant authorities to reduce, rather than increase, the number of people living in high-risk areas.

Figure 9 – Mapping of buildings and roadways in April 2023 and November 2023 in A2



Source: Adapted from PMG (2016) and Google Earth (2023a, 2023b).

Regarding the total built-up area, the April mapping recorded 1.28 ha, whereas the November mapping showed 1.06 ha. Like A1, A2 experienced a decrease in built-up area, which, as previously mentioned, may be attributed to differences in the resolution and scale of the images used. As previously mentioned, UAV-derived imagery provides higher accuracy than Google Earth satellite imagery, which should be used primarily as an indicative tool.

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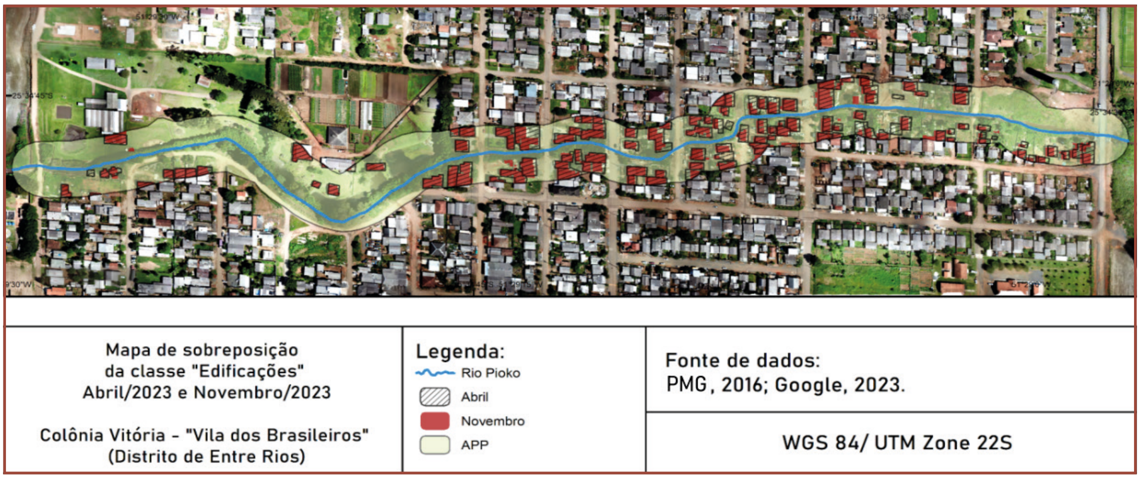
In April, the total area covered by buildings and roadways was 1.78 ha, whereas in November, it decreased to 1.65 ha, marking a reduction of 0.13 ha (1,358 m²). The second survey revealed that approximately 25% of the APP in A2 had been impervious due to construction and road development, despite this area being designated for preservation. Figure 10 illustrates the overlay of mapped buildings for both periods, showing an increase in the number of structures.

Figure 10 – Overlay map of the “Buildings” land-use category in April 2023 and November 2023 in A2



Source: Adapted from PMG (2016) and Google Earth (2023a, 2023b).

Field observations in A2 revealed the construction of a provisional wooden bridge (Figure 11) by residents to facilitate pedestrian crossings after a previous bridge was destroyed by flooding. Additionally, many buildings were found near the river channel, increasing their exposure to flood events.

Landfilling was also observed as a widespread practice in A2, with residents using soil and construction debris to raise the ground level for housing and road construction. Basic drainage infrastructure, such as culverts (Figure 12), was also present in some locations, along with bridges and stormwater drains along roadways. However, these structures may contribute to localized flooding by obstructing water flow during peak discharge events.

The Guarapuava Complementary Law No. 69/2016, which governs zoning, land use, and urban occupation (as depicted in Figure 8), establishes that the area corresponding to Vila dos Brasileiros falls within the Densification Zone, defined as follows:

> Art. 17 - The Densification Zone encompasses areas where the physical environment, infrastructure availability or proximity, and the need for diversified and intensified land use allow for greater density than in other zones (GUARAPUAVA, 2014).

Figure 11 – Pedestrian bridge over the Pioko River (Vila dos Brasileiros)

Source: Authors' collection (2023).

Figure 12 – Drainage culvert in a Permanent Preservation Area (Vila dos Brasileiros)

Source: Authors' collection (2023).

This area is also designated as part of the Special Zone surrounding Colônia Vitória Airport (GUARAPUAVA, 2014). Land use regulations in this zone permit single-family residences and the construction of water reservoirs, cemeteries, plazas, parks, green areas, and sports fields. Certain uses—such as collective housing, commercial, industrial, educational, religious, and healthcare facilities—may be authorized by Concidade upon prior approval, provided they do not interfere with airport operations or aircraft navigation.

According to the New Forest Code, municipal environmental councils must define buffer zones where occupation is prohibited due to disaster risks for PPAs in consolidated urban areas. Land use in these areas is restricted to public interest projects, low-impact activities, or essential infrastructure (BRASIL, 2012b). Therefore, given its high flood disaster risk, Guarapuava's municipal legislation (Complementary Law No. 69/2016) should establish stricter zoning parameters for land use in this region.

In A1, the hydrological contribution area spans 5,468.06 ha, with predominantly urbanized land cover and extensive impervious surfaces. Imperviousness is a major factor influencing hydrological response, as it increases surface runoff, intensifies peak discharge, and reduces water infiltration.

These conditions are particularly critical during intense rainfall events, leading to sudden increases in runoff and exacerbating peak discharge rates. On average, peak discharge in A1 is estimated to be twice as high as in rural areas within Guarapuava (OLIVEIRA, 2011; GOMES, 2014). This phenomenon directly correlates with the recurrence of urban flooding (TUCCI, 2005).

Field surveys in A1 revealed the presence of a railway line in direct proximity to the river. Among other factors, this infrastructure may impede water flow during heavy rainfall, effectively acting as a barrier that could exacerbate overflow events along the margins of the Cascavel River.

In A2, the hydrological contribution area spans 369.32 ha of the Colônia Vitória territory, upstream of the Pioko River. Given its semi-rural context, land use in this region is divided between urbanized zones and areas dedicated to intensive agriculture. Unlike urbanized landscapes, where impermeabilization accelerates runoff, the predominance of agricultural land in A2 leads to a slower hydrological response in river flow regulation. However, intensive land use for agriculture, particularly through heavy machinery, can compact the soil, reducing its water absorption capacity and increasing surface runoff (ALMEIDA *et al.*, 2016; QUIJANO; KUHN; NAVAS, 2020).

These land use and land cover dynamics have the potential to disrupt the region's natural hydrological cycle, increasing flood hazard susceptibility by reducing the soil's ability to store and absorb water. Therefore, these areas require strategic land-use planning measures to prevent further impermeabilization, which would heighten disaster risks associated with flooding.

FINAL REMARKS

The occupation of flood hazard areas increases disaster risk, while soil impermeabilization in contributing areas further exacerbates this threat.

The two regions examined in Guarapuava, identified as particularly vulnerable to flood-related disasters, exhibited significant impervious surfaces due to buildings and roadways. These areas should be preserved, as they are hydrologically sensitive zones, subject to recurring floods, and designated as Permanent Preservation Areas (PPA) along the Cascavel and Pioko rivers. In both locations, structures were found in close proximity to river channels, exposing residents to heightened socio-environmental vulnerability. In addition to being at risk of extreme hydrological events, these areas lack basic sanitation infrastructure, further worsening living conditions and contributing directly and indirectly to environmental degradation, particularly of soil and water resources.

Given this context, land-use regulation and enforcement, particularly in risk-prone areas and urban voids, are essential to curb environmental degradation and preventing vulnerable populations from being further exposed to disasters.

It is imperative that municipal authorities implement both structural and non-structural measures in these areas, integrating technical, environmental, social, and economic considerations. Key actions include enforcing land-use regulations in hydrologically sensitive zones; adopting stricter legal parameters for land occupation, aligned with the Master Plan and Drainage Plan; enhancing municipal oversight through rigorous enforcement; and establishing linear parks, flood retention reservoirs, and buffer lakes. These actions prioritize PPA preservation and the maintenance of green spaces in contributing areas.

While technically viable and essential, such measures pose complex social challenges, particularly regarding the prevention of irregular settlements in flood-prone regions and the potential need for relocation of existing populations. Any resettlement initiative must guarantee quality of life and mitigate disaster risks, ensuring socially just and environmentally sustainable solutions.

The implementation of these strategies requires qualified technical personnel, political commitment, and financial resources, often making the process challenging and time-consuming. Given climate change and the increasing frequency of extreme weather events, municipal authorities must strengthen flood monitoring and early warning systems while progressively advancing socio-environmental conflict resolution efforts.

The goal is to enhance public safety, improve well-being, and ensure environmental protection.

Analysis of spatiotemporal land-use changes revealed a decrease in total impervious surfaces, largely attributed to higher spatial resolution of UAV-generated imagery in the second dataset, which significantly improved mapping accuracy. The initial April dataset, derived from Google Earth imagery, underestimated the number of individual residences while overestimating total built-up areas—a discrepancy likely due to limited spatial resolution, which hindered the differentiation of adjacent rooftops and led to generalization in land classification.

In conclusion, mapping and monitoring the spatiotemporal dynamics of land use and cover can contribute to the development and refinement of planning and management strategies for these risk-prone areas. These approaches not only enhance the effectiveness of land-use enforcement in restricted zones but also generate crucial knowledge for informed decision-making, ultimately reducing vulnerability, limiting exposure, and mitigating disaster-related damage. ●

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Leandro Redin Vestena: Conceptualization and overall structuring of the article; definition of materials and methods; revision and refinement of the manuscript.

Rebeka Aparecida Almeida dos Santos: Writing of the materials and methods section; development of maps and cartographic products; analysis of results and discussion; writing of the conclusions.

Fabiula Eurich Machado: Writing of the introduction; contribution to materials and methods; development of part of the results and discussion; partial writing of the discussion and conclusions.

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