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Evolution of the Flood Mark and Built-up Areas in Flooded Lands in the City of Guarapuava, Paraná

Evolução da mancha de inundação e de áreas edificadas em terrenos inundados na cidade de Guarapuava, Paraná

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Abstract: Floods are important disaster-generating events in Brazil and in the city of Guarapuava, located in the central region of the state of Paraná. With this in mind, the aim of this study was to investigate the spatial distribution of the flooded area in the city of Guarapuava in different periods, as well as to assess the infrastructures that could be affected. The methodological procedures consisted of photointerpretation from satellite images of the urban infrastructure present in 2014 and 2023 in the flooded area and geospatial comparison of the maximum flood spot mapped before and during the extreme event. The results show that more than half of Guarapuava's neighborhoods (61%) have areas susceptible to flooding and that the most impermeable neighborhoods, in terms of built-up area in the area subject to flooding, are Vila Bela, Industrial and Vila Carli. As well as an increase in urban infrastructure, in an area subject to flooding, of land built from 2014 to 2023, especially in the Morro Alto, Jardim das Américas, and São Cristóvão neighborhoods, with an increase of 2,073%, 373%, and 177%, respectively. Finally, it is concluded that actions to regulate urban land use and risk management strategies are needed to reduce disasters associated with flooding events in the city of Guarapuava.

Keywords: Disaster; Waterproofing; Urban drainage.

Resumo: Inundações são importantes eventos geradores de desastres no Brasil e na cidade de Guarapuava, região central do estado do Paraná. Nesse sentido, este trabalho teve objetivo investigar a distribuição espacial da área inundada na cidade de Guarapuava em períodos distintos, assim como avaliar as infraestruturas que seriam atingidas. Os procedimentos metodológicos consistiram em fotointerpretação a partir de imagens de satélite da infraestrutura urbana presente em 2014 e 2023 na área inundada e comparação geoespacial de mancha de inundação máxima mapeada antes e durante a ocorrência de evento extremo. Os resultados demonstram que mais da metade dos bairros de Guarapuava (61%) possuem áreas suscetíveis a inundação e que os bairros mais impermeabilizados, em termos de área construída na área sujeita a inundação, são Vila Bela, Industrial e Vila Carli. Assim como um aumento na infraestrutura urbana, em área sujeita a inundação, de terrenos construídos de 2014 a 2023, com destaque nos bairros Morro Alto, Jardim das Américas e São Cristóvão, com um aumento de 2.073%, 373% e 177%, respectivamente. Por fim, conclui-se ser emergente ações de disciplinamento do uso do solo urbano e estratégias de gestão de risco para a redução de desastres associados a eventos de inundação na cidade de Guarapuava.

Palavras-chave: Desastre; Impermeabilização; Drenagem urbana.

1. Introduction

Floods are the most common natural hazard and cause the most human losses and economic damage in the world (TEHRANY *et al.*, 2015; MIND'JE *et al.*, 2019). In 2022, the Emergency Events Database (EM-DAT) recorded 387 disasters worldwide, which caused 30,704 deaths, affected 185 million people and caused approximately US\$223.8 million in economic losses. Disasters associated with flood events predominated with 176 of these occurrences, above the average of 168 annual flood disaster occurrences recorded in the period 2001-2021 (CRED, 2022). These figures may be even higher, since not all events are recorded in the databases (presence of missing data), depending on the specificity of each region (JONES *et al.*, 2022).

In Brazil, according to EM-DAT (2022), the main disaster-generating event is floods. Between 2000 and 2018, 65 flood disasters were recorded in the country, representing around 71% of recorded disasters and causing 88% of disaster-related deaths. The disaster event with the highest incidence of deaths in Brazil during this period was a flood in 2011, with 900 deaths.

Natural disasters can be accentuated by inadequate anthropogenic action (KOBAYAMA *et al.* 2006, VESTENA, 2017), from the form of land use and occupation (STEHLI *et al.*, 2021) and the physical characteristics of the watershed (KÖENE, 2013). In this sense, the frequency of flooding changes due to changes in the watershed (KOBAYAMA *et al.*, 2006)

Flooding itself is a natural phenomenon that can be defined as an increase in the level of water in rivers beyond their normal flow, with full banks overflowing into the surrounding areas (KOBAYAMA *et al.*, 2006). However, according to Tucci (2007), the floods that occur due to urbanization are not a natural process, since the effect of man-made changes in the urban environment increases their potential, such as the sealing of surfaces, the canalization of rivers, and the obstruction of channels.

Changes in land use and urban growth, such as rapid urbanization, contribute to flood risks, since urban growth alters the natural system and hydrological dynamics, producing effects on the water system, the climate, the water balance of the urban watershed, erosion and sedimentation in the watershed and riverbed, water quality, biodiversity, and the population occupying danger areas (TUCCI, 2007).

Urbanization increases the impermeable surface area, which generally reduces the hydrological response time and therefore increases the risk of flooding, i.e. soil sealing creates higher runoff rates and lower infiltration rates, as well as reducing the time needed to reach the peak flow of the channel (FENG *et al.*, 2021). Especially when conduits and channels are built that increase the speed of runoff (TUCCI, 2007) and consequently expand the flood areas or marks.

According to Tucci (2007), it is estimated that the average person seals an area of 50m², which has a significant impact on urban hydrological dynamics. In addition, floods resulting from urbanization can increase maximum flows by up to 7 times, as well as increasing their frequency due to the increase in runoff capacity through conduits and channels and the sealing of surfaces (TUCCI and BERTONI, 2003).

In addition to urbanization and changes in land use, there are other factors that can influence flooding, but these can vary from region to region. These factors can be divided into four main groups: topographical, climatic, hydrological, and human activities. Topographical factors include elevation, terrain slope, curvature and slope orientation (GHOSH, *et al.*, 2022). Climatic and hydrological factors include precipitation and drainage (CHEN *et al.*, 2022). Human activities include changes in land use and land cover (TUCCI, 2007), distance from urban settlements, and distance to streets (VU *et al.*, 2023).

As in most Brazilian cities, the city of Guarapuava has already experienced adverse events with intense rainfall generating floods, especially in the floodplain of the Cascavel River, as pointed out by Binda and Bertotti (2008), Dias-Oliveira and Vestena (2013), Vestena *et al.* (2014), Dias-Oliveira and Vestena (2017), and Vestena *et al.* (2020). This problem has intensified as a result of soil sealing and irregular occupation along the floodplain of the Cascavel River (AMARAL and THOMAZ 2008; VESTENA and SCHMIDT, 2009; GOMES, 2012).

Based on the above, this paper presents the results of a study that aimed to investigate the spatial distribution of the floodplain in the city of Guarapuava in different periods, before and after the disaster event associated with the maximum flood, recorded in 2014; as well as to identify and evaluate the infrastructures present in the flood area in 2014 and in 2023 with the potential to be affected. This work is justified since the city of Guarapuava is one of the medium-sized cities and regional hubs in the state of Paraná with the most damage from flood-related disasters.

2. Methodology

2.1 Study area

The study area is located between parallels 25° 26' 57" and 25° 18' 25" South latitude and meridians 51° 35' 23" and 51° 22' 36" West longitude. The urban area of Guarapuava (Figure 1) is located on the Cascavel river basin and comprises 75.2% (60.55 km²) of the hydrographic basin area.

According to demographic census data from IBGE - Brazilian Institute of Geography and Statistics (2022), 182,093 inhabitants live in Guarapuava. According to data from the UNDP - United Nations Development Program (2010), Guarapuava has a MHDI - Municipal Human Development Index - of 0.731, classified as high.

According to Silva (1995), the expansion of Guarapuava's urban area was accelerated and disorganized, as in most Brazilian cities. According to Gomes and Vestena (2018), the territorial expansion basically had three distinct phases: i) until the 1960s, when the majority (83.12%) of the municipality's inhabitants lived in the countryside and the facilities and services were concentrated in the central area of the city; ii) from 1970 to 1990, with horizontal expansion and urbanization, with the 1970s being the period in which there was the greatest increase in Guarapuava's urban area; iii) after 1990, there was a densification of the urban area through the occupation of areas already provided with infrastructure. Guarapuava has an urbanization rate of approximately 91% (GOMES and VESTENA, 2018). According to Dias-Oliveira and Vestena (2017), the urban expansion of Guarapuava occurred until 2010 basically in areas drained by the Cascavel River.

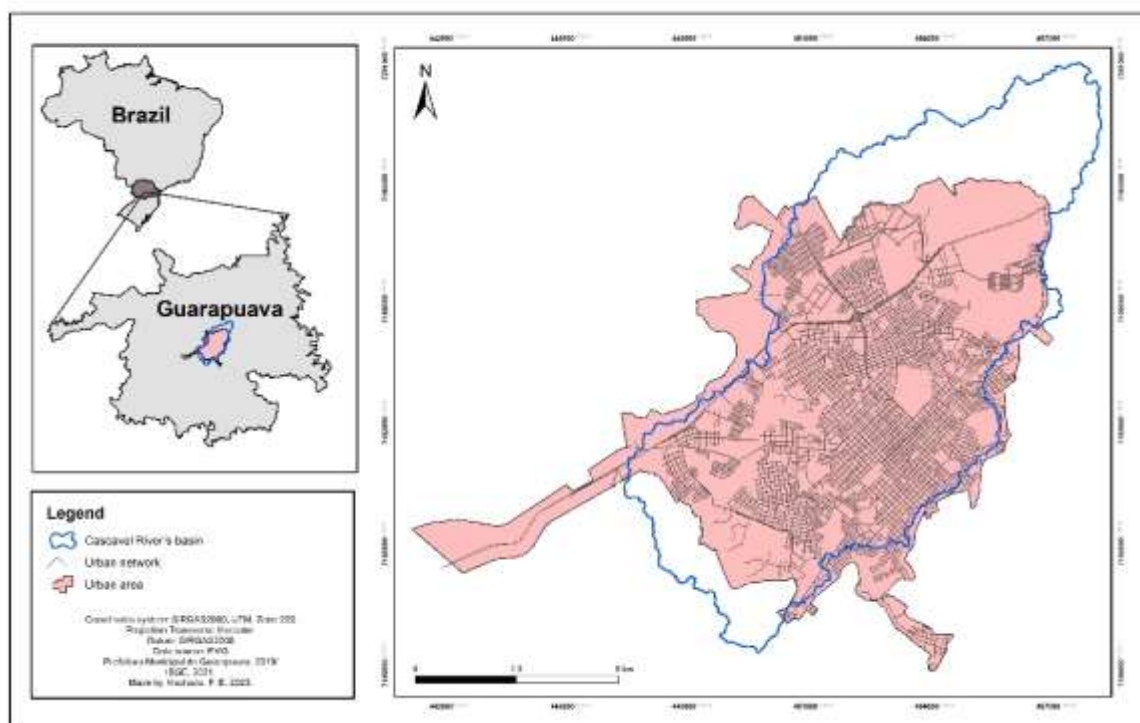


Figure 1 – Location of the study area.

Source: Authors (2023).

Considering the Köppen-Geiger climate classification, the region is under the influence of the Cfb-Temperate Climate type climate, with averages of 18°C in the coldest month and 22°C in the hottest month, representing cool summers and no defined dry season. (CAVIGLIONE *et al.*, 2000; IAPAR, 2019). Thomaz and Vestena (2003) define the region's climate as subtropical, mesothermal, humid, with no dry season, cool summers and mild winters and an average annual rainfall of 1,960.93 mm. In the Cascavel River basin, there is a decrease in rainfall in the months of July and August (STEHLI *et al.*, 2021).

2. 2 Materials and methods

This work briefly followed three stages: data and information gathering, analysis and synthesis. Table 1 shows the data used and their respective sources.

Table 1 – List of data/information and their sources.

Data	Description	Source
Flood spot - 2014 event	Effectively flooded areas mapped.	Guarapuava City Hall (PMG) (2016)
Flood spot - before the 2014 event	Flooded areas mapped on the basis of maximum elevations surveyed by local residents.	Geffer and Vestena (2014)
Photo interpretation year 2023 (image date: 22/04/2023)	Areas with urban infrastructure	Satellite image - Qgis Plugin "HCMGIS-Google Satellite" (2023)
Photo interpretation year 2014 (image date: 04/12/2014)	Areas with urban infrastructure	Google Earth satellite image of the historical series (2014)

Source: Authors (2023).

The methodological procedures were structured as follows:

1. Photo interpretation: QGIS software version 3.28.8 was used to identify the buildings¹ within the flood zone, using the HCMGIS add-on. Using this software, it was possible to identify and specialize the constructions on the earth's surface, as it allows high-resolution satellite images to be inserted into the project's background. Photo interpretation was carried out in the same way for the satellite image dated 2014 from the Google Earth historical series. The photo interpretation was based on the authors' experience and previous knowledge of the area, using visual photo interpretation. After this procedure, the areas for each polygon were calculated.

The buildings on the earth's surface were identified through visual interpretation by detecting roofs and buildings on the satellite image. The information identified was later validated through fieldwork. The types of buildings found were homes, storage sheds, commercial stores, schools and industries. It should be noted that urban infrastructure such as streets and sidewalks were not mapped.

2. Drawing up a comparative graph: Excel spreadsheets from Microsoft Office software were used to tabulate the area data and draw up the comparative graph.

3. Comparison between two flood spots: the effective flood spot was acquired from Guarapuava City Hall - PMG (2016), which was mapped after the extreme flood event in June 2014. The "spoken" floodplain was collected by the authors Geffer and Vestena (2014) through fieldwork, by collecting flood boundary points with GPS (Global Positioning System) and spatializing the floodplain, based on the experience of residents along the course of the Cascavel River. The information was gathered from interviews with residents who have lived there for at least ten years. The authors mapped the flooded area before the extreme event of June 2014.

The stages of comparing the flood spots in terms of their area, by plotting the information acquired, were carried out using ArcGis software version 10.5. This software was also used to lay out the cartographic products.

3. Results and discussion

Figure 2 shows the area effectively flooded, mapped by Guarapuava City Hall during the extreme flood event recorded in the city in June 2014, with the buildings within its boundaries, mapped in 2014 and 2023.

¹ The buildings identified by photo interpretation were not classified in this study as to their type of use.

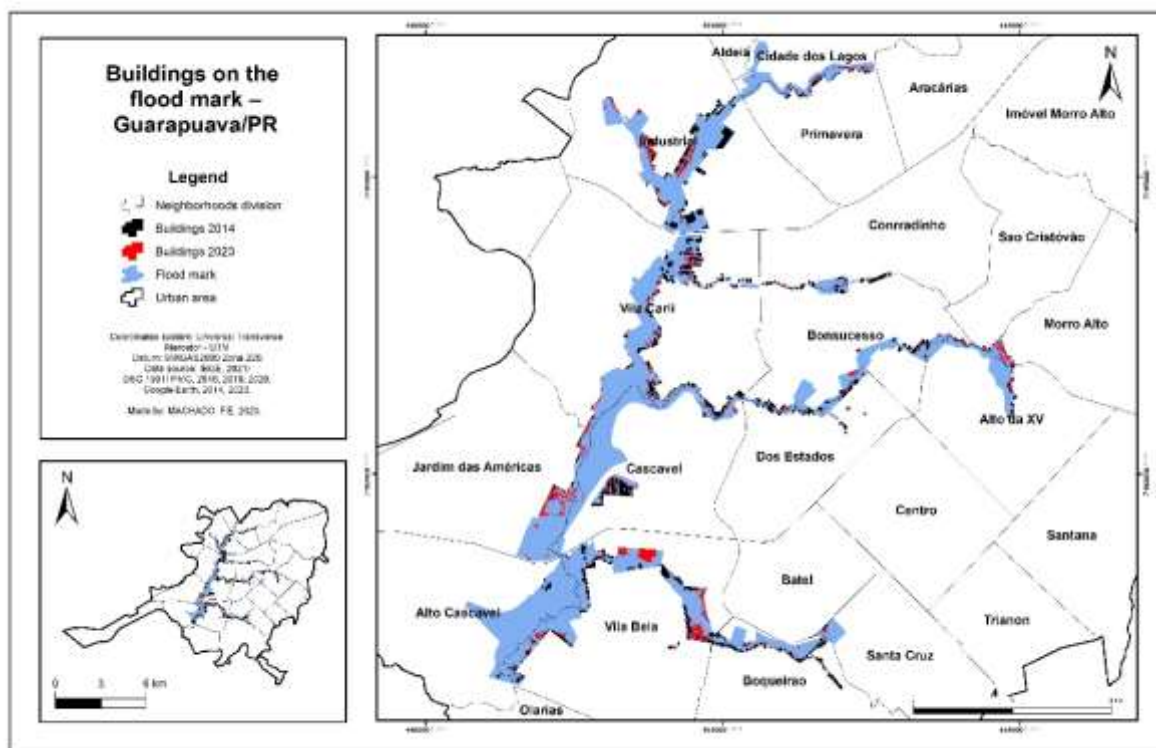


Figure 2 – Floodplain and buildings present in the area in 2014 and 2013.
Source: Authors (2023).

Photo interpretation of satellite images from 2014 identified 1,234 objects of various sizes (Figure 2). The total sum of the area of these objects corresponded to an area of 210,360 m², representing 5.4% of the total area flooded in the extreme event. In the 2023 mapping, 2,179 objects of various sizes were identified, corresponding to an area of 310,512 m², representing 8% of the total area of the flood zone. This represents an increase of 100,152 m² in the built-up area between the years 2014 and 2023 on the area flooded in 2014. Figure 2 shows that the growth in construction during the period was differentiated, i.e. at specific points, such as in the south, north and east of the flooded area.

This built-up part of the land raises two main problems. The first of these is soil sealing within the flood area, since buildings consequently affect the infiltration of water during rainfall events and lead to higher maximum flows and, consequently, an expansion of the flood zone. In addition, the built-up area may be even larger, since this research did not take into account the basic infrastructure built along the affected area, such as streets and roads, for example. The second obstacle is the potential for damage during and after a possible extreme event. The current 8% of built area indicates that this space is used in some way, representing that the buildings and people using these spaces are potentially susceptible to danger and damage when a flood event occurs, that is, they are at risk of disaster.

Guarapuava's urban area is made up of 26 neighborhoods. Of all the neighborhoods, 16 are in the flood zone mapped by Guarapuava City Hall in 2014: São Cristóvão, Morro Alto, Conradinho, Santa Cruz, Primavera, Dos Estados, Cidade dos Lagos, Alto da XV, Boqueirão, Bonsucesso, Jardim das Américas, Alto Cascavel, Cascavel, Industrial, Vila Bela and Vila Carli.

The neighborhoods in the flooded area with the largest areas with buildings are Vila Bela, Industrial, and Vila Carli, both in 2014 and 2023. There was an increase in 2023 in the areas with construction and sealing in all neighborhoods when compared to the 2014 data. The Vila Bela neighborhood had its built area increased from 37,984.57 m² in 2014 to 74,992.58 m² in 2023, representing an increase of 37,008.01 m², making this the neighborhood with the largest number of buildings in an area that floods.

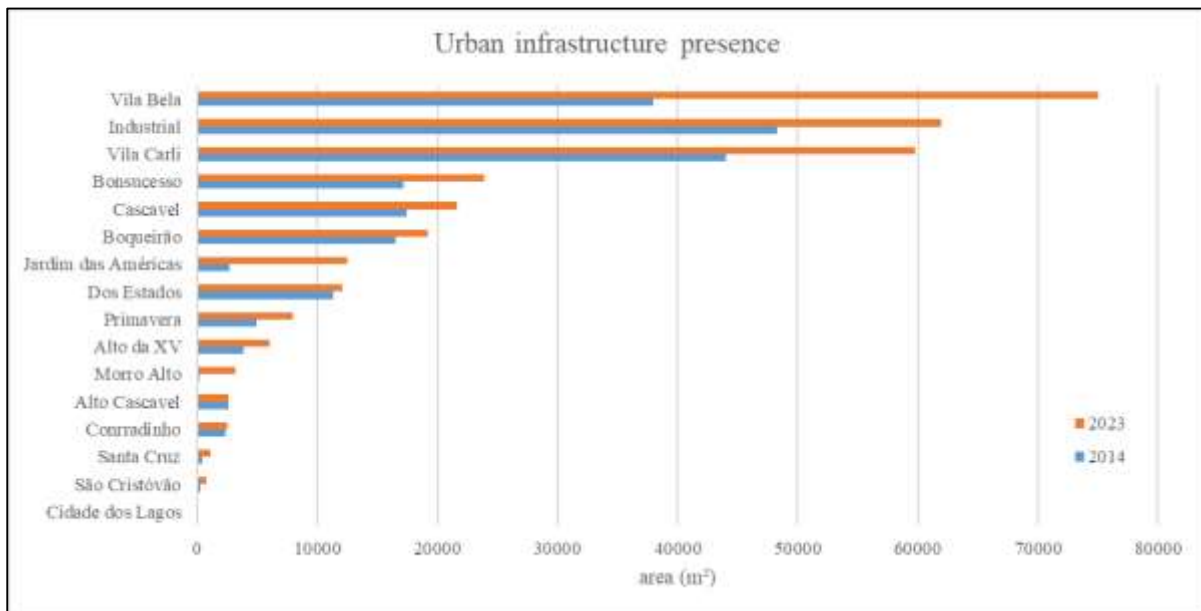


Figure 3 – Presence of urban infrastructure by affected neighborhood, in the BRC flood zone.
Source: Authors (2023).

Regarding the variation in the area with urban infrastructure, the neighborhood with the greatest increase in construction in the floodplain was the Morro Alto neighborhood, with a 2,073% increase in built-up area, followed by the Jardim das Américas, São Cristóvão and Santa Cruz neighborhoods (Table 2). The Alto Cascavel neighborhood had no variation in its built area during the period, with a predominance of vegetated areas.

Table 2 shows that the Cidade dos Lagos neighborhood did not have any built-up area in 2014 since it is a planned neighborhood that emerged recently; in 2014, the corresponding area was rural, without any buildings. This neighborhood is located in the northern part of the urban area, which was previously used only for planting agricultural crops. As the city expanded in this direction, there was a rapid increase in urbanization, resulting mainly in soil sealing. Consequently, during rainfall events, the maximum flow peaks in the watershed can become faster, increasing the potential for flooding events in the plains of the Cascavel River.

Table 2 – Variation in the percentage of buildings in the flood zone, by neighborhood, from 2014 to 2023.


Neighborhood	Area (m ²) 2014	Area (m ²) 2023	Variation (%)
Morro Alto	148.34	3,223.71	2,073
Jardim das Américas	2,645.23	12,519.30	373
São Cristóvão	280.58	777.73	177
Santa Cruz	411.89	1,112.00	170
Cidade dos Lagos	0.00	126.72	100
Vila Bela	37,984.57	74,992.58	97
Primavera	4,986.42	7,975.68	60
Alto da XV	3,869.80	6,013.87	55
Bonsucesso	17,151.60	23,859.27	39
Vila Carli	43,979.79	59,784.43	36
Industrial	48,303.69	61,973.75	28
Cascavel	17,423.97	21,608.06	24

Boqueirão	16,509.16	19,208.06	16
Conradinho	2,342.01	2,505.69	7
Dos Estados	11,343.34	12,087.69	7
Alto Cascavel	2,570.30	2,570.30	0

Source: Authors (2023).

Table 3 shows the satellite images of the floodplain for the years 2014 and 2023 in the three neighborhoods with the greatest increase in buildings in the period. This growth is most evident in the Jardim das Américas neighborhood. It had an expansion and densification of buildings in some parts of the flooded area. In addition to the problem of soil sealing in these areas, there is also the issue of population growth, which means that, during an extreme event, more people would be exposed to danger and, consequently, more people would be affected.

Table 3 – Satellite image of the neighborhoods with the greatest increase in buildings, from 2014 to 2023.

Neighborhood	Year 2014	Year 2023
Morro Alto		
Jardim das Américas		



Source: Google Earth, 2014 and 2023; Authors (2023).

According to data from GCH (2016), in the city of Guarapuava, there are three flood elevations along the Cascavel River, 1,013m, 1,014m, and 1,016m, which are arranged in this way due to dykes that hinder the flow of water in rainy periods. An analysis of the mapping data showed that 40% of the buildings in the flood zone are between the altimetric levels of 1,007m and 1,016m (Figure 4), i.e., on land with altitudes lower than the maximum flood levels, which represents a danger of disaster due to periodic flooding.

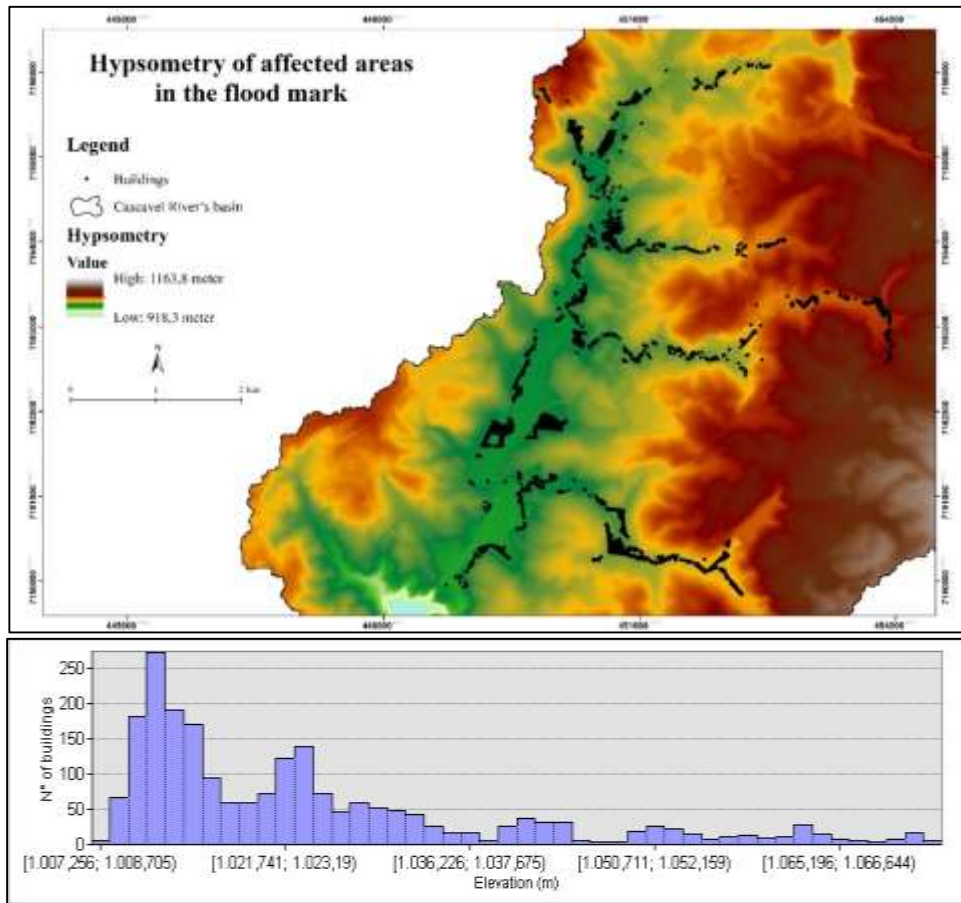


Figure 4 – Spatial arrangement of buildings and distribution frequency histogram in relation to altitude.
Source: Authors (2023).

The mapping in this study presented that the altimetric level with the highest number of buildings is the 1,013m level, with a frequency of 272, representing approximately 12% of the total number of buildings mapped, followed by the 1,014 and 1,011 levels with 191 and 181 buildings, respectively (Table 4). There is a greater frequency of buildings at lower levels than the maximum flood levels defined by the GCH (2016).34

Table 4 – Number of buildings per elevation, most representative data.

Quota (m)	No. of buildings	%*
1,013	272	12
1,014	191	8.7
1,011	181	8.3
1,015	170	7.8
1,024	139	6.3

Source: Authors (2023). *Of the total number of buildings.

Figure 4 also shows that the buildings are almost entirely in valley bottoms corresponding, in this case, to the floodplain of the Cascavel River and its tributaries, which, according to Vestena *et al.* (2020), provide a special situation for the accumulation of water during precipitation events. This condition occurs due to topographical factors, such as relief, and according to Costa and Miyazaki (2016), due to geomorphological compartmentalization, where plains undergo natural flooding processes.

In the flood area, the spaces were used in a wide variety of ways, and different forms of buildings were found. There were both public facilities, such as a state school (Figure 5), and private facilities (Figures 6, 7 and 8). Regarding the types of buildings, there were wooden, masonry, stilt, and prefabricated houses on the field.



Figure 5 – State school.
Photo: Fabiula Eurich Machado (2023).



Figure 6 – Area for storing recycled material.
Photo: Fabiula Eurich Machado (2023).

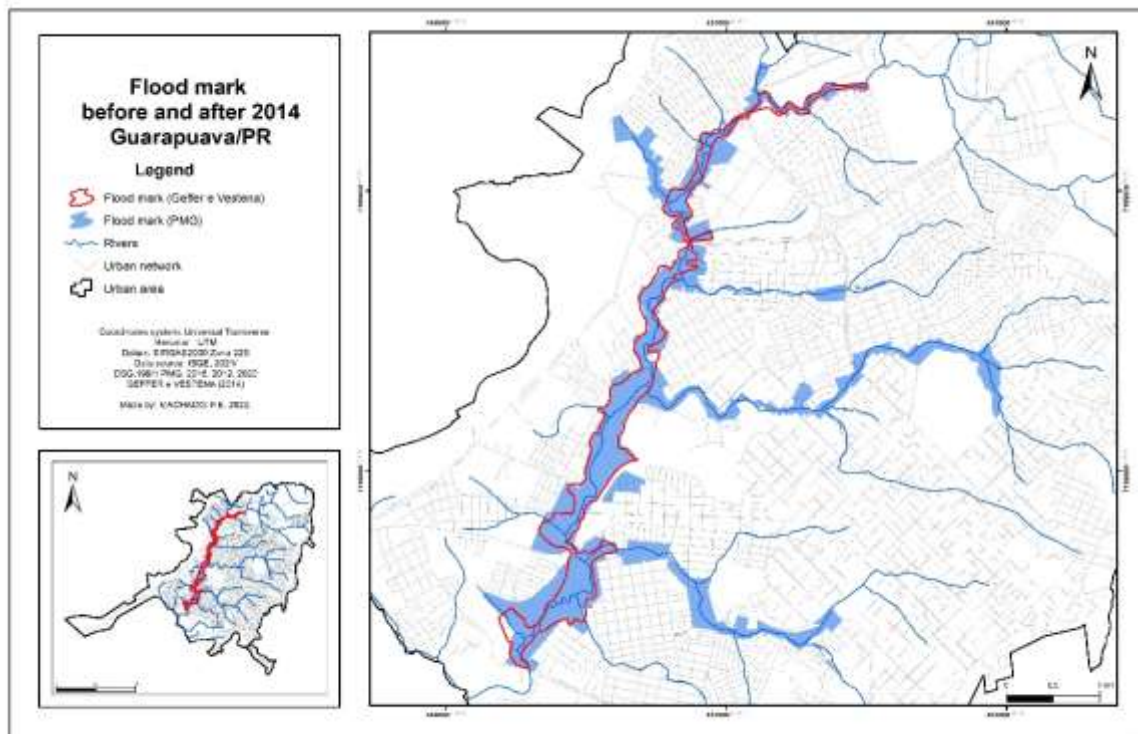


*Figure 7 - Wooden house.
Photo: Fabiula Eurich Machado (2023).*



*Figure 8 – Two-storey masonry house.
Photo: Fabiula Eurich Machado (2023).*

The official flood area mapped by the GCH is 3.84 km². Figure 9 shows that the floodplain mapped by Geffer and Vestena (2014) has smaller boundaries when compared to the area mapped by GCH. The total area of the floodplain mapped by the authors is 1.55 km², representing an area of 2.29 km² smaller than the area flooded in 2014. It should be noted that the authors mapped the floodplain only in the areas close to the Cascavel River.



*Figure 9 – Floodplain before and after the 2014 event.
Source: Authors (2023).*

Also, in a comparison between the city's floodplains, figure 9 shows that soil sealing caused by urban dynamics may have increased the flooded area in the vicinity of the Cascavel River since sealing can increase maximum flows during

rainfall events. However, some places mapped as flooded before 2014 do not appear in the floodplain made after the 2014 event, such as small portions to the south, center, and north in figure 9.

The rainfall event in June 2014 was the largest extreme disaster event recorded in the Guarapuava Civil Defense database since the monitoring began (DEFESA CIVIL PARANÁ, 2023). The heavy rains on June 6, 7, 8, and 9, 2014, had significant accumulations and affected at least 167,562 people (Figures 10 and 11), resulting in three deaths (DEFESA CIVIL PARANÁ, 2023).



*Figure 10 – 2014 flood, Guarapuava-PR.
Photo: Leandro Redin Vestena (2014).*



*Figure 11 - Rescue operation during the 2014 flood.
Photo: Leandro Redin Vestena (2014).*

The municipality declared a State of Emergency due to the damage that occurred in the city in June 2014. According to Castro (1998), an emergency situation is recognized by the government as being caused by disasters, which cause damage and losses, resulting in partial impairment of the government's ability to respond. In the case of Guarapuava, in addition to those affected in the flooded areas, the water supply system was compromised since the water collection station was flooded, and the collection had to be interrupted (SANEPAR, 2014). The production of drinking water only resumed two days after the end of the event (DEFESA CIVIL PARANÁ, 2014).

4. Final considerations

Soil sealing is an important factor when discussing changes in the watershed and, consequently, the increase in the number of people affected during and after extreme events associated with flooding. This study showed that more than half of Guarapuava's neighborhoods (61%) have areas that flood.

The area of the effective floodplain from the extreme event in 2014, mapped by the Guarapuava City Hall, has a flood hazard recognition parameter, which means that it is not advisable to build in this space. Although this parameter is significant for urban planning, 8% of this area has buildings of varying sizes. People who use these areas are vulnerable to flooding events. In addition, the increase in soil sealing area in the watershed increases the potential for flooding.

The neighborhoods with the most impermeable surfaces, in terms of built-up area in the flood area, are Vila Bela, Industrial, and Vila Carli, both in 2014 and 2023. However, the neighborhoods with the greatest variation in built-up area from 2014 to 2023 were Morro Alto, with an increase of 2,073%, Jardim das Américas, with an increase of 373%, and São Cristóvão, with an increase of 177%. These neighborhoods already had problems during heavy rainfall events that caused flooding, which indicates that this problem is likely to worsen as soil sealing in these areas has increased.

The evolution of the floodplain in the comparison between the two mappings carried out by GCH and Geffer and Vestena (2014) showed a difference in the flooded areas around the Cascavel River. This indicates that the urban soil sealing may have increased flooding during the 2014 extreme event. The floodplain mapped by Geffer and Vestena (2014) is naturally smaller than the one mapped by GCH (2014) since the mapping carried out by the authors was restricted only to the areas bordering the Cascavel River.

Concluding, actions to regulate urban land use and risk management strategies for disasters associated with flooding events in the city of Guarapuava are urgently needed.

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