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Papers

Bridging the Gap in Small Ungauged Basins: Integrating 2D Hydrodynamic Modeling and Social Cartography for Flood Hazard Mapping

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Abstract
The occupation of wetlands has intensified the magnitude and frequency of flood damage in Brazilian watersheds. This study validates the accuracy of 2D hydrodynamic simulations against participatory flood hazard mapping in Vila Esperança (Guarapuava, Paraná State), adopting a 10-year return period (RP) as the critical threshold for residential feasibility. The methodology integrated HEC-RAS modeling based on high-resolution LiDAR data (micro-topographic precision) with a Mental Flood Mapping derived from residents' historical reports of the study area's residents. Results demonstrate that the 10-year RP simulation identifies a chronic risk that renders residential maintenance unsustainable, affecting 10.66% of the area (93 housing units and 260 people). In contrast, the Spoken Map, anchored in the extreme 2014 event, characterizes an acute risk, covering 15.67% of the village and affecting 144 housing units and 403 people. The findings reveal that while technical modeling provides geometric flow precision, collective memory offers the "ground truth" necessary for calibrating real hazards in ungauged basins. Consequently, areas within the 10-year flood footprint must be restricted from residential use. Furthermore, risk management must evolve beyond statistical probability to include integrated disaster reduction strategies, such as resettlement and early warning systems, to address the catastrophic scenarios identified by the community.

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INTRODUCTION

Accelerated urbanization and the occupation of wetlands have intensified the magnitude and frequency of flood-related damages in Brazilian watersheds. The correlation between urbanization and flood damage is evidenced by the increase in peak flow rates, which in Brazilian urban areas can be 2 to 7 times higher than in vegetated areas (Rodrigues; Blanco, 2018). Additionally, data from the Digital Disaster Atlas (2024) confirm the increasing recurrence of hydrological events, driven by the exposure of assets and populations in floodplain areas (Brasil, 2024).

Given this growing exposure, the delimitation of hydrologically sensitive areas becomes imperative for urban planning. However, in ungauged watersheds, the accuracy of flood extents is often limited by the low resolution of global digital terrain models (Perini *et al.*, 2013). In this context, the use of LiDAR (Light Detection and Ranging) sensors represents an alternative capable of capturing micro-relief features for hydraulic simulation (Li *et al.*, 2021), allowing hydraulic models, such as HEC-RAS, to simulate complex flow dynamics in urban micro-drainage systems where traditional digital elevation models (DEM) fail to represent anthropogenic topographic changes.

The integration of physical landscape data with modeling tools enhances the diagnosis of areas susceptible to natural disasters, particularly in data-scarce regions facing systematic monitoring gaps (Soares Filho, 1998).

Beyond topographic precision, reducing uncertainties in ungauged basins depends on a consistent hydrological starting point. The use of historical precipitation series acts as necessary data to estimate design flows, allowing modeling to move beyond the purely theoretical field (Monte *et al.*, 2016). This dataset is required to calibrate the model, preventing results from overestimating or underestimating the magnitude of extreme events, as demonstrated in the decadal monitoring of large alluvial plains (Ogilvie *et al.*, 2015).

However, the effectiveness of urban planning and risk management lies not only in numerical precision but in understanding the social perception of these phenomena. As pointed out by Alves Filho *et al.* (2006), the perception of water risks evolves with events and must be compared with climatological data to improve planning and shared water management. In this sense, the use of 'mental mapping' (or 'spoken maps') emerges as a participatory cartography strategy that allows the spatialization of collective memory regarding flood events (Oliveira *et al.*, 2021). The 'mental mapping' technique functions as a qualitative calibration proxy, providing spatial constraints to validate hydraulic simulations in the absence of traditional gauge records.

Thus, constructing a resilient flood diagnosis requires a hybrid methodological approach that associates the rigor of high-resolution geotechnologies with the sensitivity of local historical records. By using LiDAR for terrain geometry refinement and 'mental mapping' for empirical validation of flood extents, an analysis protocol is established that minimizes the subjectivity of computational simulations in basins without streamflow monitoring (Krause *et al.*, 2005). Such integration not only fills physical data gaps but also legitimizes the risk management process by including community perception as a technical component of the modeling (Ben *et al.*, 2025).

The case of Entre Rios District, Guarapuava, Paraná, underscores the 'data gap' in disaster management. Despite the absence of flood records in the Civil Defense database prior to 2021, Fire Department data reveal a consistent history of events since 2008 (including 2012, 2014, 2015, 2019, 2020, 2022, 2023, and 2024), highlighting a clear recurrence that remains underestimated by official administrative records.

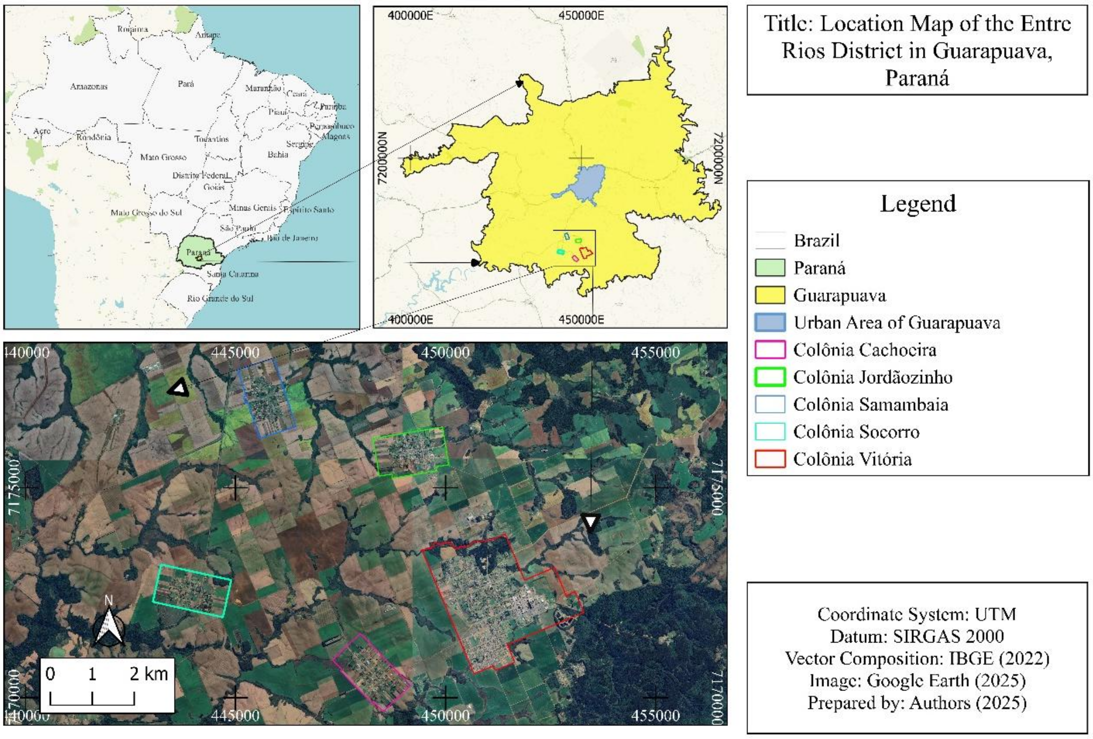
Addressing this gap, this study proposes an analysis protocol for small, high-gradient ungauged basins, common in the Brazilian Third Plateau (Paraná State), where flash floods are intensified by rapid land-use changes. The present work aims to map the flood extent in an ungauged watershed in the Entre Rios District, in Guarapuava (Paraná State), using the integration of high-resolution modeling (LiDAR) and participatory cartography. It seeks to validate the accuracy of computational simulations for a 10-year return period, identified as the critical threshold for housing unfeasibility (Tucci, 1993), by comparing technical results with the local population's collective memory systematized through mental flood mapping.

MATERIALS AND METHODS

Study Area Characterization

The Entre Rios District is located in the southern portion of the municipality of Guarapuava, Paraná State, approximately 30 kilometers from the municipal seat. Administratively, the District comprises five main established colonies: Samambaia, Jordãozinho, Vitória, Cachoeira, and Socorro. These colonies are interconnected by the PR-170 highway, forming an urbanized area of approximately 41.84 km², with an estimated population of 8,962 inhabitants (Guarapuava, 2022) (Figure 1).

Figure 1 – Location of the Entre Rios District in the municipality of Guarapuava, Paraná State



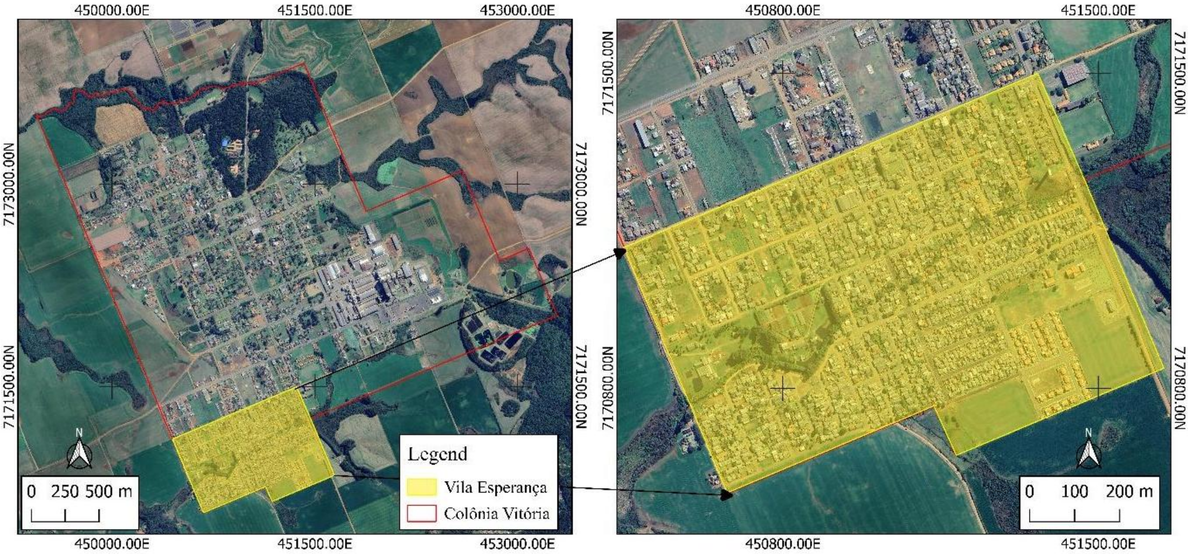
Source: The authors (2025).

The formation of the Entre Rios District is marked by the migratory process of German communities, known as Danube Swabians (*Donauschwaben*), who sought refuge in Austria after World War II and settled in Brazil starting in the 1950s (Elfes, 1971). The arrival of these groups and the subsequent demand for services attracted Luso-Brazilian populations to the colonies, particularly to Colônia Vitória. This colony hosts the Agrária Agroindustrial Cooperative, comprising approximately 640 members and a workforce of over 1,500 direct employees. The cooperative's industrial complex houses the largest malting plant in Latin America. This facility is strategic for the supply security of the national beverage sector, accounting for approximately 30% of the total malt consumed in the Brazilian market. The vertical integration of production, ranging from barley seed genetic research to final industrial processing, grants the region a unique socioeconomic relevance and status as a benchmark in the brewing industry.

This dynamic resulted in a distinct socio-spatial organization within Colônia Vitória. The main area, inhabited by German descendants, is characterized by urban planning and consolidated infrastructure (classified as the Historical Residential Zone - ZRH) (Figure 1). In contrast, the Vila Esperança ('Vila dos Brasileiros') emerged as a more recent settlement, frequently characterized by precarious urban infrastructure and distinct socio-cultural dynamics of Luso-Brazilian origin (Stefenon; Silva, 2005) (Figure 2).

The study area delineated for this research comprises Vila Esperança (Figure 2), located in Colônia Vitória. The selection of this spatial focus is justified by the recurrence of hydrological events, with floods of the Pioko River recorded by the Fire Department on nine occasions between 2008 and 2024. Regarding demographics, Vila Esperança concentrates approximately 50.8% of the population of Colônia Vitória, housing 2,990 of the locality's 5,884 inhabitants (IBGE, 2022).

Figure 2 – Location of Vila Esperança, in the southern region of Colônia Vitória



Source: The authors (2026).

Database

Topographic Data

Topographic information was derived from Light Detection and Ranging (LiDAR) data, with a spatial resolution of 1 meter and an altimetric precision of 10 centimeters. Initially, the raw Digital Terrain Model (DTM) underwent pre-processing in a Geographic Information System (GIS) environment, using a depression filling algorithm (fill) according to the methodology of Jenson and Domingue (1988). This stage ensures the hydrological consistency of the model by eliminating topographic imperfections and artificial depressions that could interrupt the continuity of surface flow in subsequent simulations.

With the hydrologically adjusted DTM, flow direction was determined using the D8 (Deterministic 8-Neighbor) algorithm, which directs runoff to the neighboring cell with the steepest slope (Tarboton, 1997). From the resulting flow accumulation map, the drainage network was delineated by applying a threshold of 25,000 cells, equivalent to a contribution area of 0.025 km². This value was selected based on its optimal fit to the actual watercourses; it was further validated through visual inspection and comparison with the high-resolution UAV (Unmanned Aerial Vehicle) orthomosaic, ensuring that the generated network accurately aligns with the ephemeral and perennial channels identified in the urban landscape.

Precipitation Data

Precipitation data were obtained from the historical series of the Colônia Vitória Meteorological Station, located in the district of Entre Rios, municipality of Guarapuava–PR, at coordinates 25°33'00" S latitude and 51°28'59" W longitude, identified by code 02551008. The rainfall records were accessed through the Meteorological Database for Teaching and Research (BDMEP, 2025), maintained by the National Institute of Meteorology (INMET, 2025), and consist of daily accumulated precipitation data.

The rainfall database covered a 56-year interval (1964-2020), delimited by the installation and decommissioning periods of the monitoring station (Table 1). Design rainfall was estimated using the Gumbel distribution, with a 10-year return period adopted as the boundary condition for the hydrodynamic simulations.

Table 1 – Meteorological Station Information: Colônia Vitória

Station	Latitude	Longitude	Elevation	Station Code	Start Date	End Date
Colônia Vitória	25°33'00"S	51°28'59" O	1000 m	02551008	07/17/1964	12/31/2020

Source: The authors (2026).

Hydrological Modeling

Hydrological modeling was structured using the Hydrologic Modeling System (HEC-HMS) software, with the primary objective of generating flow hydrographs for the analyzed scenarios. The model is based on the physical representation of the basin through a diagram of interconnected elements (sub-basins, junctions, and reaches), where each component simulates a specific stage of the transformation of precipitation into surface runoff (Hydrologic Engineering Center, 2021a).

The methodological processing followed four fundamental parameterization steps: 1. Delineation and Spatial Discretization: The basin and its drainage network were automatically delineated using geospatial processing tools integrated into the software. Utilizing the Digital Terrain Model (DTM), the study area was subdivided into elements that ensure accurate calculation of water travel time according to terrain morphology. 2. Loss Method: To estimate effective precipitation the portion of rainfall that generates runoff the SCS Curve Number (CN) method was adopted. The infiltration potential parameterization was based on the GCN250 global dataset (Jaafar *et al.*, 2019). However, to account for the high level of spatial detail required, these parameters were cross-referenced and refined using the 22 cm resolution UAV orthomosaic. This integration allowed for a precise classification of impervious surfaces, such as roofs and paved roads, versus pervious residential backyards, resulting in a locally adjusted CN that more accurately reflects the urban hydrological response. Rainfall-Runoff Transformation (Transform Method): The conversion of effective rainfall volume into flow over time was performed using the SCS Unit Hydrograph method. This method uses lag time to distribute the runoff, resulting in the output hydrograph for each sub-basin. 3. Flow Routing and Consolidation: The transport and attenuation of the flood wave through the main channels were simulated using the Muskingum method. At the end of the processing, the model consolidated contributions from all sub-basins to generate the design flow hydrograph, which describes the flow behavior at the cross-section of interest for a 10-year return period.

The output of this stage, the flow hydrograph, constitutes the input data for the subsequent hydraulic simulation stage, allowing the flood propagation to be analyzed dynamically in both space and time.

Hydraulic Modeling

The hydraulic simulation was conducted using the HEC-RAS software, employing a two-dimensional (2D) modeling approach to represent the flood wave propagation in detail. This technique allows the shallow water equations to be solved within a computational mesh, capturing velocity and depth variations throughout the floodplain (Hydrologic Engineering Center, 2021b).

The development of the hydraulic model was based on the following parameters: 1 - Geometry and Computational Mesh: The study area was discretized into a two-dimensional computational mesh overlaid on the LiDAR-derived Digital Terrain Model (DTM). The mesh refinement enhanced spatial resolution, allowing the micro-relief to dictate flow directionality. This ensured that specific urban features and topographic variations were accurately integrated into the flood extent delineation. 2 - Roughness Coefficients: Flow resistance was parameterized using Manning's roughness coefficient (n), with values assigned according to channel typologies and land cover (Chow, 1959), following the technical recommendations from Porto (2006). 3 - Flow Regime and Boundary Conditions: The simulation was performed under an unsteady flow regime, allowing for the analysis of the flood's temporal variation.

To enable the simulation, the following boundary conditions were established: Upstream - The flow hydrograph previously generated in the HEC-HMS model for the 10-year return period was inserted. Downstream - The normal depth of the reach was adopted, allowing for the free flow of water out of the model domain.

Mental Mapping (Spoken Maps)

The construction of the "Flood Mental Map" was based on the systematization of local hydrological memory for the empirical comparison of mathematical models. The methodological procedure was divided into three stages: 1 - Field Survey and Community Memory: Technical visits and informal interviews were conducted with residents of areas near the river who have lived there for more than 10 years. The focus of these approaches was the identification of physical marks and historical landmarks of extreme events, allowing for the spatialization of the maximum water reach according to the inhabitants' perception. 2 - Georeferencing of Control Points: The exact locations indicated by residents as flood boundaries were georeferenced in the field using a Garmin eTrex 20 GPS receiver. As a single-frequency navigation receiver was used, the recorded points initially exhibited limited positional accuracy. Nevertheless, this coordinate registration enabled the integration of oral accounts into a geoprocessing environment, allowing these points to be overlaid onto the Digital Terrain Model (DTM) and high-resolution UAV imagery. While handheld GPS receivers are often scrutinized in strictly engineering contexts due to limited standalone accuracy, in the framework of participatory mapping, this technological constraint was actively neutralized. Any potential positional drift was corrected through a participatory fine-tuning process: residents visually verified and adjusted each point over a high-resolution (22 cm) UAV-derived orthomosaic. Therefore, this spatial validation combines quantitative positioning with qualitative community consensus, yielding a highly reliable 'ground truth' that respects both the social reality and the geographic scale of the study area. 3 - Processing and Spatial Interpolation: To convert the georeferenced points into a continuous flood extent, the maximum elevations (stage) recorded at each control point were extracted from the LiDAR-derived DTM. A contour-based interpolation (altimetric slicing) was then performed in QGIS (Qgis Development Team, 2020), connecting these flood-crest elevations to delineate a flood footprint that reflects the hydrological dynamics observed by the community.

The 'Spoken Map' was developed with 30 long-term residents (over 15 years of residency), primarily aged 45–70. This demographic ensured a reliable historical record of the extreme event of 2014 and subsequent land-use changes. Spatial data was gathered by mapping flood boundaries directly onto high-resolution orthophotomosaics during interviews, later converted into vector layers for model comparison.

Spatial Overlap Analysis and Socio-Environmental Impact Assessment

The validation process was conducted through the spatial overlap of the 10-year return period (RP) flood hazard map and the 'spoken map' derived from residents' collective memory. This comparative analysis identified convergences and discrepancies between technical simulations and empirical records. Subsequently, the intersecting areas were used to quantify the affected infrastructure and population; this was achieved by overlaying the resulting flood footprints onto high-resolution cadastral data, allowing for an accurate estimate of the number of residential units and inhabitants situated within the high-risk zones.

The identification of exposed buildings and residents was conducted through visual interpretation using high-resolution UAV (Unmanned Aerial Vehicle) orthomosaics, integrated with field-validated data. Estimation of direct economic damages followed the spatial analysis between flood footprints and the urban multipurpose technical cadastre, following the framework by Sousa and Goerl (2018). Property valuation was based on alphanumeric data from the GeoGuarapuava (Guarapuava, 2025) platform, utilizing the total Market Value (Valor Venal), which integrates land and built-up area values. To determine the value of the exposed asset, a Correction Factor (Fc) was applied to the market value, reflecting the structural typology and physical condition of the property. Finally, the number of affected people was projected by crossing the number of impacted households with the average inhabitants per household, according to the 2022 IBGE Demographic Census.

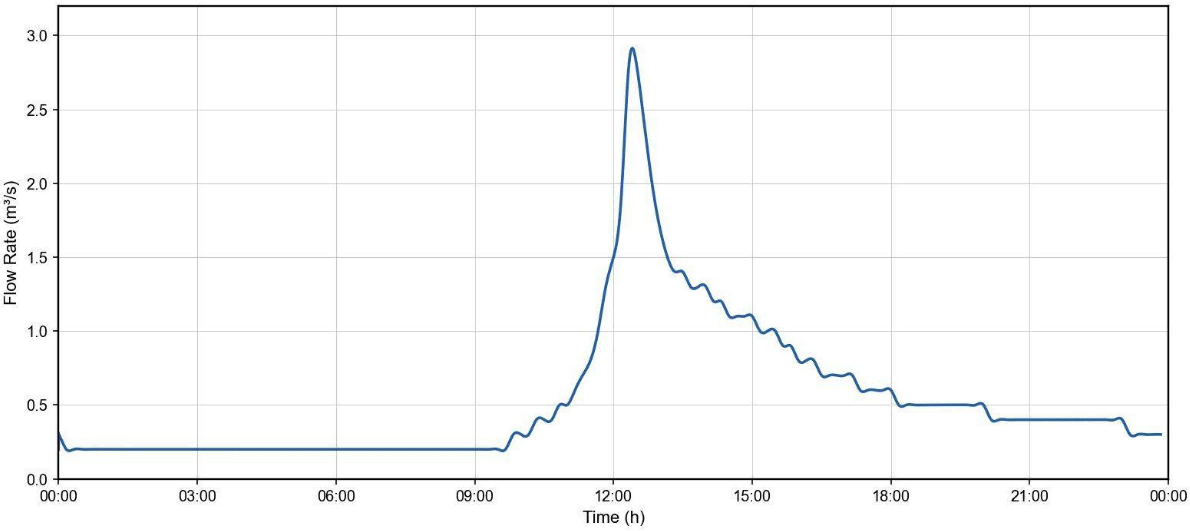
RESULTS AND DISCUSSION

HEC-HMS and HEC-RAS Model Simulations

The application of the Gumbel distribution to the 56-year historical series resulted in a design precipitation of 132.32 mm for a 10-year return period. Based on this rainfall event, the hydrological modeling estimated a peak flow of 2.8 m³/s, a parameter that served as the boundary condition for the flood extent simulations.

The hydrological behavior for the 10-year return period (RP) design event is characterized by a well-defined rising limb and a calculated peak flow of 2.8 m³/s (Figure 3). This output served as the boundary condition (or data input) for the subsequent hydrodynamic simulation.

Figure 3 – Simulated hydrograph for the 10-year return period (RP) event



Source: The authors (2026).

Analyzing the statistical estimate for the 10-year return period (132.32 mm) against historical records, it is observed that rainfall events of similar magnitude produced distinct hydrological responses. On 12/02/1974 (132.2 mm) and 10/13/2004 (132.7 mm), the estimated flows were 4.2 m³/s and 3.8 m³/s, respectively. This variation, even with nearly identical precipitation volumes, highlights the influence of antecedent moisture conditions and the temporal distribution of rainfall on the rainfall-runoff conversion performed by the hydrological modeling (HEC-HMS). Table 2 presents the hydrological variability of the basin, showing that events of similar magnitudes can generate different responses due to the antecedent moisture conditions.

Table 2 – Hydrometeorological parameters and simulated peak flows for the major daily precipitation events (1964–2020)

Rank	Daily Precipitation (mm)	Maximum Simulated Flow (m³/s)	Peak Flow Date	Event Total Accumulated Rainfall (mm)	Event Duration (days)
1	232.4	6.9	05/29/1992	335.5	6
2	164.4	4.9	06/15/1984	251.7	4
3	132.7	3.8	10/13/2004	134.1	2
4	132.2	4.2	12/02/1974	199.7	3
5	127.8	4.0	07/08/1995	187.1	4

Source: The authors (2026).

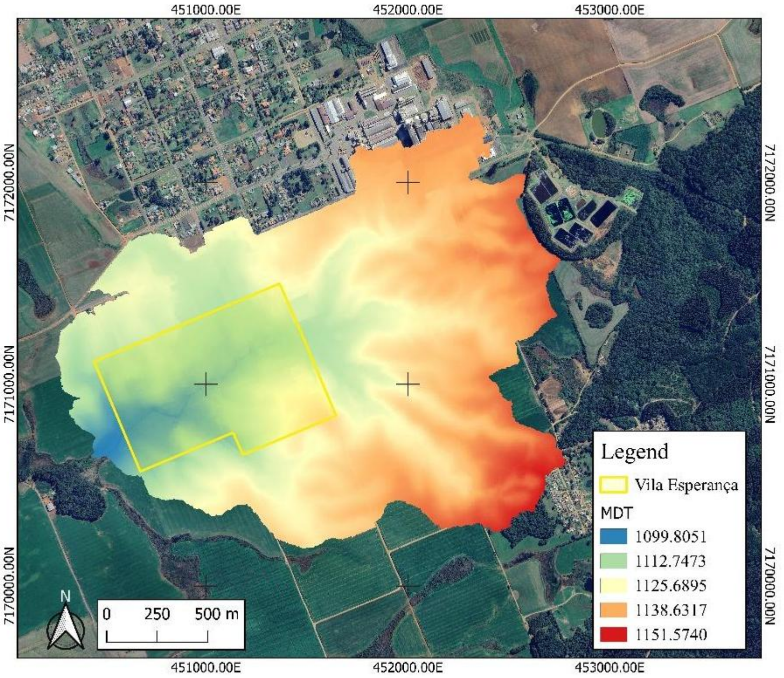
Evaluation of these data reveals a complex hydrological response that depends not exclusively on daily rainfall magnitude, but substantially on its temporal distribution and the cumulative volume. The comparison between the 1974 and 2004 events is emblematic: despite virtually identical daily precipitation, the 1974 peak flow was approximately 10.5% higher. This behavior is driven by the larger cumulative volume in 1974 (199.7 mm over 3 days), which implies a significantly higher antecedent soil moisture state than in 2004.

This discrepancy demonstrates that cumulative rainfall and event persistence are determining factors for hydrological stress. Continuous precipitation promotes the progressive saturation of topsoil horizons, thereby reducing infiltration capacity and increasing the runoff coefficient (C). Consequently, HEC-HMS modeling highlights that long-duration events (even with moderate daily intensities) can generate more severe hazard scenarios than isolated rainfall pulses due to the synergistic effect between antecedent soil moisture and catchment hydraulic connectivity.

However, it is noteworthy that due to the absence of fluviometric data for direct calibration, the simulated flows may have a conservative character. In the absence of direct flow measurements (staff gauges or current meters), the hydrological model parameterization was based on theoretical estimates of loss and infiltration that prioritize structural safety and statistical consistency. This approach may result in a more contained hydrological response compared to the exceptional magnitude of historical events, such as the peaks observed in 1974 and 2004 (Tucci, 2005).

Based on these parameters, flood wave propagation was simulated using the high-resolution terrain geometry provided by the Digital Terrain Model (DTM) (Figure 4).

Figure 4 – Digital Terrain Model (DTM) of the study area derived from high-resolution geospatial data



Source: The authors (2026).

The hydraulic simulation indicates extensive overbank flow, with surface runoff exceeding the main channel's discharge capacity and spreading across the floodplain topography. The spatial distribution of this simulated flood extent for the 10-year Return Period (RP), integrated with empirical field validation data, is presented in Figure 5.

Based on this high-resolution spatialization (Figure 5), an inventory of exposed structures was conducted via visual interpretation of Unmanned Aerial Vehicle (UAV) orthomosaics. A total of 93 housing units were identified within the 10-year RP flood hazard zone. Assuming an average household size of 2.8 inhabitants per unit (IBGE, 2022), approximately 260 people are directly exposed to the flood hazard. This corresponds to 8.70% of the total population of Vila Esperança, underscoring a significant socioeconomic vulnerability to medium-recurrence hydrological events.

Flood Mental Map

The construction of the flood mental map relied on the collaboration of approximately 30 residents, distributed across both banks of the Pioko River. This bilateral sampling was essential to capture the overflow dynamics on both floodplains, ensuring that the relief of both margins was represented in the social perception.

During the fieldwork, the interviewees indicated 22 control points marking the maximum historical flood limit. These points were georeferenced and served as the basis for generating the mental flood footprint. The interpolation of these points resulted in a theoretical water surface, based on the assumption of hydrological continuity between the observed landmarks.

This approach enabled the transformation of empirical oral narratives into a structured vector dataset. Integrated within the geospatial analysis in Figure 5, the spatialization of this qualitative data, alongside the 22 field-validated GPS points, delineates the historical flood footprint in Vila Esperança as preserved by local community knowledge.

Based on this spatialization, 144 housing units were identified within the mental flood extent. Considering an average household size of 2.8 inhabitants per household (IBGE, 2022), it is estimated that approximately 403 people are affected by flooding in this scenario. This contingent represents 13.48% of the total population of Vila Esperança and 6.85% of the inhabitants of Colônia Vitória.

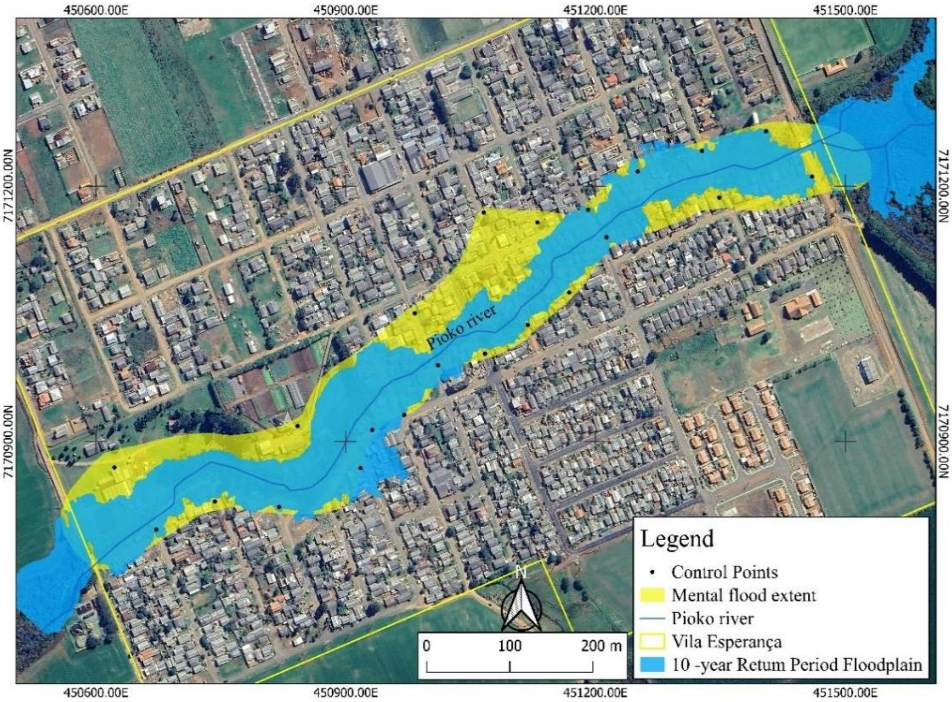
While spatialization established clear flood boundaries, most residents could not precisely recall the specific dates or years of the events associated with the observed marks. Nevertheless, a significant convergence of memory emerged regarding the 2014 event, which was cited by the majority of interviewees.

The magnitude of this event is corroborated by records from the Diário de Guarapuava (2014) newspaper, which at the time reported an accumulated rainfall of 466 mm in just four days for the city of Guarapuava. The report highlights the severity of the scenario in Entre Rios, stating that more than 100 people were left homeless in the district, in addition to recording widespread flooding that resulted in the displacement of approximately 900 residents and two deaths in Guarapuava. These journalistic data validate the mental flood footprint, linking the community's perception to one of the most severe climatic events in the region's recent history.

Flood Dynamics and Exposed Population: Integrating Hydrodynamic Modeling and Participatory Cartography

The comparison between the flood extent generated by the HEC-RAS hydrodynamic modeling and the extent obtained through Mental Flood Mapping (Spoken Maps) reveals significant spatial convergence, although both products possess distinct methodological natures and purposes. While the computational model offers a simulation based on physical and probabilistic parameters, the Mental Map acts as a historical-empirical record of the lived reality. The overlay of these two cartographic layers, including the GPS control points, is presented in figure 5, demonstrates that although the numerical model presents a more conservative character by identifying 93 affected housing units, the Mental Map expands this perception to 144 residences, capturing the magnitude of critical events that exceed theoretical recurrence.

Figure 5 – Integrated flood analysis: comparison among the 10-year TR flood extent, the mental flood map (Social Cartography), and georeferenced GPS landmarks



Source: The authors (2026).

From an urban planning perspective, the technical delineation for the 10-year Return Period (TR) already places Vila Esperança in an imminent hazard zone, affecting 10.66% of the village's total area. As Tucci (1993) points out, a 10-year TR represents an excessive frequency of occurrence for housing maintenance, making the area economically and socially unsustainable for residential use. While a 10-year TR was used for risk assessment, increasing precipitation extremes in Southern Brazil suggest this footprint may occur more frequently in the future. The 2014 'Spoken Map' serves as a benchmark for this 'new climatic normal,' indicating that urban planning must shift from static historical averages toward safety margins that reflect growing hydro-climatological variability. The recurrence of structural damage and the risk to life at such short intervals hinder safe urban consolidation, transforming the locality into a scenario of permanent danger. This situation, already critical in the decennial modeling, worsens exponentially during extreme events, as observed in the mental map extent, which compromises up to 15.67% of the village area.

The quantitative divergence between the models is technically justified by the difference between the input data and collective memory. The hydraulic modeling was calibrated by a statistical precipitation event of 132.32 mm, while the socially constructed extent reflects the experience of severe events, such as the one in 2014, when the accumulated rainfall reached 466 mm (Diário De Guarapuava, 2014). Therefore, the Mental Map not only validates the simulated drainage channels but also fills the gap left by the absence of fluviometric data, allowing for a risk calibration based on the territory. As indicated by Tucci (2005), uncertainty in ungauged basins is mitigated by local accounts that offer social accuracy.

The gap between the technical flood area and the perceived area highlights risk as a socio-spatial construction. While HEC-RAS 2D provides geometric precision, social memory captures infrastructure failures, like clogged culverts, missed by numerical models. This synergy demonstrates that effective disaster management in Vila Esperança requires transitioning from traditional 'control engineering' to a model of integrated 'risk governance'.

The observed discrepancy between the simulated flood footprint for a 10-year return period (10.66% of the area) and the area delineated by the 'Spoken Map' (15.67%) reflects the distinction between chronic recurrence and acute historical extremes, such as the 2014 event; nonetheless, this divergence validates the effectiveness of social cartography as a 'ground truth' for calibrating models in ungauged basins and reinforces the objective of restricting residential use in areas prone to recurrent inundation.

The integration of these results indicates that while technical modeling provides the geometric precision of the flow, participatory cartography confers historical legitimacy to the diagnosis. The identification that 13.48% of the population of Vila Esperança is within the mental extent, compared to 8.70% in the 10-year TR extent, reinforces that civil defense policies must consider both mathematical probability and the real critical scenario. This hybrid approach consolidates a cartographic product that is simultaneously technical and socially representative, providing support for damage mitigation in areas where housing maintenance challenges the limits of hydrological safety.

The data presented in Table 3 shows that the mental flood footprint covers an area 47% larger than the 10-year technical simulation. This increase directly impacts the socio-economic assessment: the number of affected households rises from 93 to 144, exposing an additional 121 residents to risk.

Table 3 – Comparative metrics of flood impact: Technical Model vs. Mental Map

Metric	Technical Model (10-year RP)	Mental Map (Social Perception)	Discrepancy (%)
Total Flood Area (%)	10.66%	15.67%	+ 47%
Affected Households (Units)	93	144	+ 55%
Exposed Population (Inhabitants)	260	403	+ 55%

Note: Estimated based on spatial intersection with the cadastral database.

Source: The authors (2025).

This difference underscores the 'data gap' discussed previously; social memory preserves the flood footprint of severe historical events, such as those recorded by the Fire Department in 2014 or 2023, which represent return periods significantly higher than the 10-year parameters used in the HEC-HMS/HEC-RAS modeling. Therefore, the integration of these methods provides a diagnostic tool for civil defense, bridging the gap between statistical probability and the lived reality of vulnerable communities.

FINAL CONSIDERATIONS

The absence of historical fluviometric data constitutes a recurring challenge in Brazilian hydrology; however, the results obtained demonstrate that the integration of high precision geotechnologies can partially bridge this informational gap. The use of LiDAR data allowed for a high-quality representation of the relief, a determining factor for the hydrodynamic modeling to achieve a realistic representation of local hazards. Even when operating under conservative theoretical parameters, the simulation was able to delineate the main overflow channels and hazard areas in Vila Esperança, proving that micro-topographic precision detailing is essential for the reliability of models in ungauged basins.

In parallel, the Spoken Map methodology proved to be a powerful instrument for validating simulated scenarios. By converting social perception and collective memory into geographic data, this approach allowed for the confrontation of mathematical estimates with the historical reality of the residents. Participatory cartography offered the necessary 'ground truth' to legitimize the results, demonstrating that systematized popular knowledge functions as a human sensor for understanding extreme hydrological phenomena that elude official records.

This study highlights the need for further research focused on modeling in data-scarce basins, especially considering the increasing frequency of extreme climatic events. In contexts where technologies such as LiDAR are limited, strengthening hybrid methods that integrate social cartography becomes a viable and low-cost alternative.

In conclusion, the findings demonstrate that hydrodynamic modeling for the 10-year RP identifies chronic risk, whose frequency of occurrence makes the maintenance of housing situated in the highest-hazard areas of Vila Esperança unsustainable. Conversely, the Participatory Map characterizes acute risk, based on historical extreme events that exceed decadal technical limits. It is recommended that areas within the 10-year flood extent be prioritized for non-structural control measures, such as the implementation of early warning systems and restrictive zoning, while reserving resettlement as a definitive solution for housing in situations of irreversible structural vulnerability.

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Bruno dos Santos Lemes: Conceptualization, Data curation, Investigation, Software and Writing - original draft. Leandro Redin Vestena: Conceptualization, Methodology, Supervision and Writing - review & editing.

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