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MODELING FLOOD SUSCEPTIBILITY IN HYDROLOGICAL DATA-SCARCE STUDY AREAS

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Abstract

Hydrological information is essential for estimating the magnitude of floods, thus helping reduce losses and damage. However, when this data is scarce, it challenges flood modeling and risk assessment. In Brazil's west of Rio Grande do Sul, we used the Santa Maria hydrographic basin as a case study to estimate the river flow for different RP based on the statistical distribution of rainfall and river flow data and to simulate flood scenarios using a 2D IBER hydrological model.River flow estimates for 5, 10, 20, 30, and 50-year RP were obtained using the Giandotti equation. The results showed a high correlation between the river flows calculated from rainfall and the fluviometric data, using GEV and GumbelMax distribution. The areas susceptible to flooding are consistent with past flood events, validated with fieldwork and Sentinel imagery. River flows estimated from rainfall data can promote hydrological studies where fluviometric data is absent.

Keywords: River Flow Estimation; Generalized Extreme Values; Flood Susceptibility; Rosário Do Sul; Brazil.

Resumo / Resumen

MODELAGEM DA SUSCETIBILIDADE À INUNDAÇÕES EM ÁREAS DE ESTUDO COM ESCASSEZ DE DADOS HIDROLÓGICOS

A informação hidrológica é essencial para estimar a magnitude das inundações, ajudando assim a reduzir perdas e danos. No entanto, quando esses dados são escassos, a modelagem de inundações e a avaliação de riscos são desafiadoras. No oeste do Rio Grande do Sul, usamos a bacia hidrográfica do rio Santa Maria para estimar o fluxo do rio para diferentes tempos de retorno, com base na distribuição estatística dos dados de precipitação e vazão do rio e para simular cenários de inundação usando um modelo hidrológico IBER 2D. Os resultados mostraram uma alta correlação entre as vazões calculadas a partir da precipitação e os dados fluviométricos, usando a distribuição GEV e GumbelMax. As áreas susceptíveis de inundação são consistentes com eventos de inundação passados, validados com trabalho de campo e imagens Sentinel. Os caudais fluviais estimados a partir de dados pluviométricos podem promover estudos hidrológicos na ausência de dados fluviométricos.

Palavras-chave: Estimativa de Vazão; Generalização de Valores Extremos; Suscetibilidade à Inundação; Rosário do Sul; Brasil.

MODELIZACIÓN DE LA SUSCEPTIBILIDAD A LAS INUNDACIONES EN ZONAS DE ESTUDIO CON ESCASEZ DE DATOS HIDROLÓGICOS

La información hidrológica es esencial para estimar la magnitud de las inundaciones y contribuir así a reducir las pérdidas y los daños. Sin embargo, cuando estos datos son escasos, la modelización de inundaciones y la evaluación de riesgos se convierten en un reto. En el oeste de Rio Grande do Sul, utilizamos la cuenca del río Santa Maria para estimar el caudal del río para diferentes tiempos de retorno, basándonos en la distribución estadística de los datos de precipitación y caudal del río, y para simular escenarios de inundación utilizando un modelo hidrológico IBER 2D. Los resultados mostraron una alta correlación entre los caudales calculados a partir de la precipitación y los datos fluviométricos, utilizando la distribución GEV y GumbelMax. Las áreas susceptibles de inundación son consistentes con eventos de inundación pasados, validados con trabajo de campo e imágenes Sentinel. Los caudales fluviales estimados a partir de los datos pluviométricos pueden favorecer los estudios hidrológicos en ausencia de datos fluviométricos.

Palabras-clave: Estimación de Caudales; Generalización de Valores Extremos; Susceptibilidad a Inundaciones; Rosário do Sul; Brasil.

INTRODUCTION

Floods are seasonal processes studied by fluvial geomorphology and are associated with increased water availability in river basins and water level rise above the river channels. When related to disorderly occupation, the increase in river flow and the consequent river overflow becomes a natural disaster. Climate change has intensified extreme hydrological events' recurrence, increasing damage and loss, especially in developing countries (BRÊDA et al, 2023).

Rivers have a strong connection with the development of cities, as the construction of new territories took place through waterways. Based on the expansion of urbanized areas without planning and with processes of social segregation, where the population with lower purchasing power is pushed into floodplains or downhill slopes due to the low cost of soils, increasing the areas at risk of disasters point out that migratory movements to urban centers can result in the occupation of flood and landslide susceptible areas (DAMACENA et al, 2017).

In Brazil, from the 1960s onwards, there was an intense population movement from the countryside to the cities, increasing the country's urbanization rates; the green revolution fostered this process. When analyzing this process of migration from the countryside to the town, Teló e David (2012) described that the process of the rural exodus was linked to the Green Revolution, where small farmers and rural workers were displaced from a system that boosted large-scale agriculture, which in turn was restricted to medium and large landowners.

In Rio Grande do Sul state, this phenomenon was also observed. In the state's west, workers have seen their source of income transformed. Fields that used to be populated by cattle and sheep - which require extensive labor - have gradually been transformed into large crops, where mechanization and techniques with scarce labor prevail. This process has driven many families out of their homes and into the cities for survival. When faced with the urban reality and the search for their space, many people were driven to occupy areas less visible to the eyes of the capital (MARICATO, 1995; MATTEDI e BRIKNER, 2019; GANTUS-OLIVEIRA, 2023).

Many families living west of Rio Grande do Sul state need space to raise animals and housing. As a result, attempts are being made to reproduce the rural on the outskirts of the urban. Rosário do Sul, a city west of the state (Figure 1), is a typical example. Many of the population is exposed to hydrological dynamics associated with flooding from the Santa Maria River.

Hydrological models associated with georeferenced GIS environments have made it possible to simulate and represent flood situations based on different return periods, providing sources of information for researchers and managers (AKKAYA E DOĞAN, 2016; PRINA E TRENTIN, 2018;PEREDO et al, 2022; TUAN et al. 2024). Hydrological models are based on digital elevation models and hydrological data, such as river flow and the morphometric characteristics of the river basin.

In Brazil, hydrological data from fluviometric and rain gauge stations recorded in historical series can be obtained from the HidroWeb portal of the National Water Agency (ANA). River flow information is essential for monitoring river dynamics, especially in cities affected by flooding (SANTOS et al. 2019). When river flow data is not available for a hydrographic basin, its records can be estimated based on the distribution and amount of rainfall recorded in the hydrographic basin, modeling and simulating high-river flow episodes (SIMANJUNTAK et al, 2023; PONCET et al, 2024).

Using morphometric and river flow information in hydrographic basins, two-dimensional (2D) hydrological models can define areas susceptible to flooding or simulate extreme events. Fernández-Nóvoa et al. (2024) used IBER software to simulate a flood in the Tagus River Basin in 1979 to reproduce the occurrence of a significant hydrological event in a digital environment. In Bangladesh, Chowdhury et al. (2023)using a 2D model generated by HEC-RAS, delineated the areas affected by floods in the Jamuna River. In Kenya, in a river basin without a fluviometric station Houessou-Dossou et al, (2022) projected peak flows using precipitation with an EBA4SUB rainfall-runoff model. The results showed a coefficient of determination of 0.99 between peak flow modeling estimation using precipitation and flood frequency records. There are seven rain gauge stations in the Santa Maria River basin (Figure 1), and there is a daily data series of at least 30 years. In the urban area of Rosário do Sul near the bridge of the Santa Maria River, a fluviometric station can be found with a continuous daily data series since 1968. Both data sources, river flow, and rainfall data, allow statistical distribution methods to obtain different discharges for the same return periods.

The river flow estimates for different return periods are a basis for obtaining 2D hydrological models, thus contributing to predicting flooding susceptible areas. The data obtained in this test can serve as a basis for hydrological studies and for defining flood susceptibility in hydrographic basins that do not have fluviometric data. By comparing the flow data from the fluviometric station with the flow calculated from precipitation, it is possible to define the most reliable distribution method for estimating river flow in the west sector of Rio Grande do Sul in river basins without fluviometric stations or with faulty or inconsistent data series. As a result, it is possible to calculate river flows and model the effects of flooding in areas where only rainfall data is available.

In this context, the aim is to estimate river flow for different return periods, based on the statistical distribution of precipitation and river flow data, and to simulate flood scenarios for the urban area of Rosário do Sul, using a 2D hydrological model generated in IBER. The specific objectives are: i) to estimate the flow for different return periods, based on statistical distributions of precipitation and river flow data; ii) to validate the flow estimates; iii) to model the susceptibility to flooding based on different return periods, using a 2D hydrological model generated in the IBER software; iv) to compare and discuss the results of the 2D hydrological model obtained using the flow calculated from different statistical distributions.

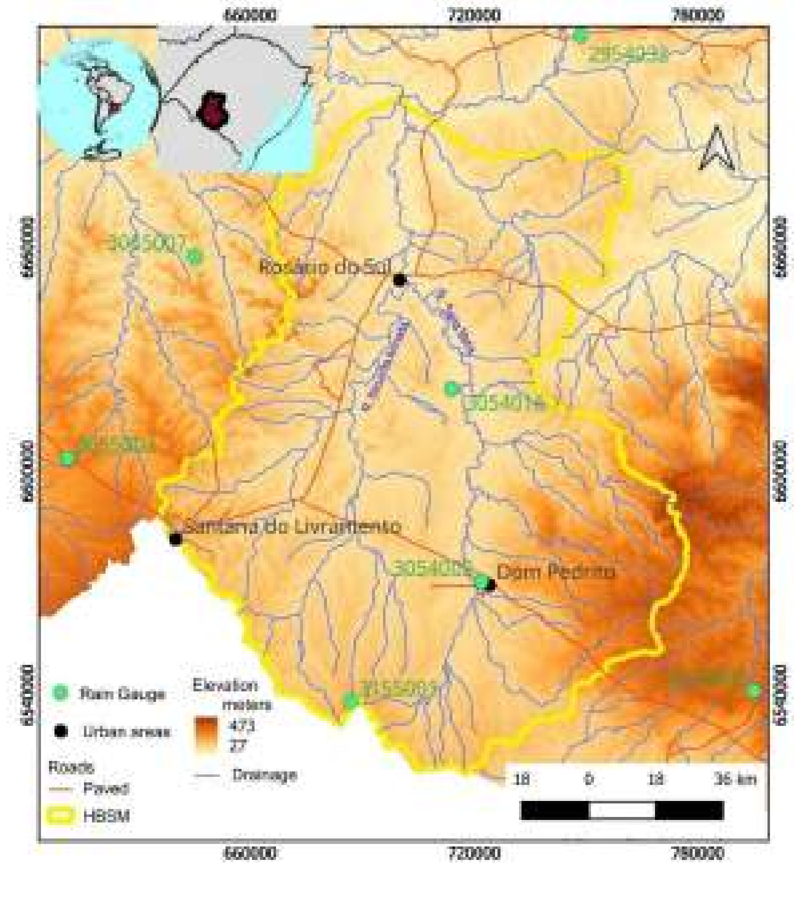

Figure 1 - Santa Maria hydrographic basin (Rio Grande do Sul state, Brazil), including elevation and location of the rain gauge and river flow stations. Source: authors.

STUDY AREA

The SMHB drains an area of 15,719.63 km, has an average altitude of 166.41 meters, an altimetric range of 405 meters and an average slope of 8%. Geologically, it is predominantly made up of clastic sedimentary rocks formed during the Paleozoic and Mesozoic periods. In the less steep areas, there are Argisols with a well-developed profile ~2.00 m deep; in the steeper areas, there are lithic neosols and rocky outcrops. In climatic terms, the SMHB is located in a subtropical climate with an average annual rainfall of around 1500 - 1700 mm (Rossato, 2011), with rainfall distributed throughout the year. In extreme conditions, the maximum daily rainfall can exceed 200 mm (Figure 2), the maximum flows are associated with intense rainfall accumulated over several days (3 to 4), while intense rainfall concentrated in a single day usually generates less severe flows.

Figure 2 - Maximum daily rainfall (mm) for rain gauges located in the Santa Maria Hydrographic basin (upstream to downstream) and maximum daily flow rate (m3/s) for Rosário do Sul fluviometric station. Source: authors.

According to data collected from the newspapers Gazeta de Rosário, Zero Hora, and the works of Reckziegel, (2007) and Robaina et al. (2024), the city of Rosário do Sul (Figure 3) recorded 26 hydrological events with damages in 16 years between 1983 and 2023. The year 2009 recorded five flood events, followed by 2017 with three flood events and 2001, 2002, 2015, and 2022 with two flood events. The most significant numbers of affected populations were recorded in 1992, 1997, and 2001, with more than 1500 affected populations each.

Disasters can be reduced by reducing the areas affected or by reducing damage. The recurrence of extreme events has increased, requiring mitigation actions to be designed and implemented, especially in urban areas. Between 2023 and May 2024, three extreme flood events hit the municipalities of Rio Grande do Sul, with the hydrogeological events of April/May 2024 being the biggest ever recorded, with extensive damage and hundreds of fatalities (INSTITUTO NACIONAL DE METEOROLOGIA, 2024).

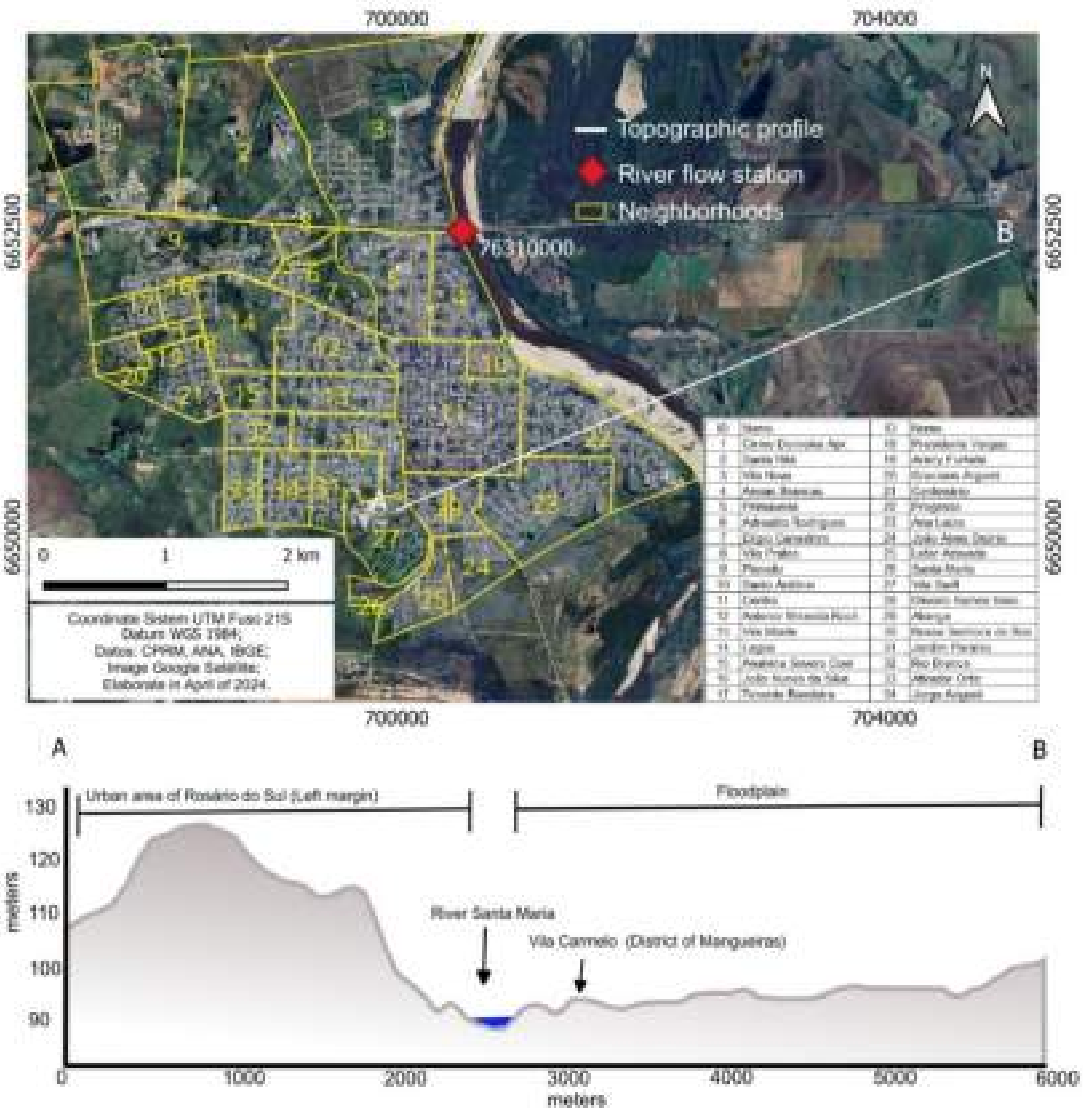

Figure 3 - Rosário do Sul urban area (Rio Grande do Sul state, Brazil) and perpendicular topographic profile in the Santa Maria valley. Source: authors.

MATERIALS AND METHODS

Our research plan included four steps: (i) data collection of daily rainfall, daily river flow data, and Digital Elevation Model (DEM); (ii) application of statistical distribution methods and calculation of the return period of extreme events based on rainfall data series and river flow estimation; (iii) computing 2D hydrological models in IBER for 5, 10, 20, 30, and 50 years return period of estimated river flow in Rosário do Sul. Figure 4 shows the methodological scheme for this work.

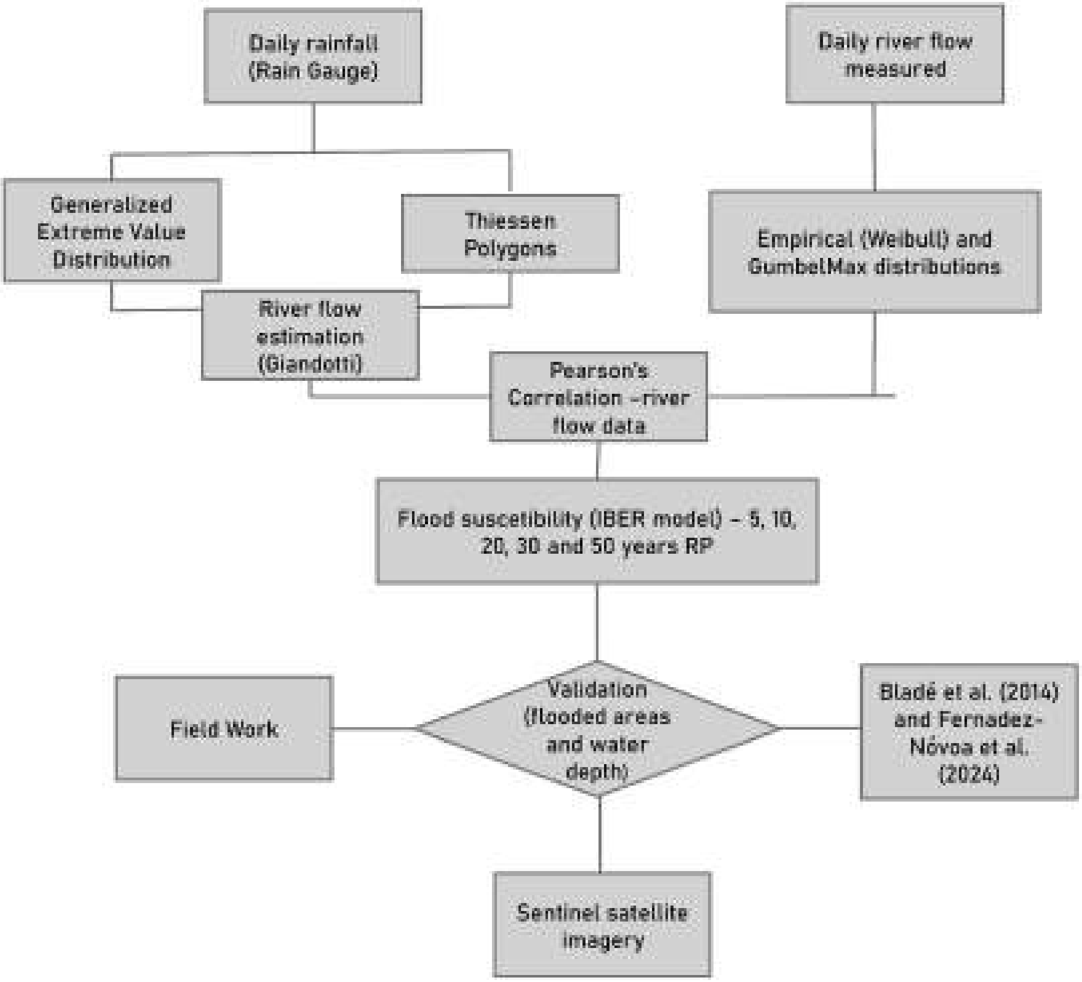

Figure 4 - Methodological scheme used to obtain the data, process the model, and validate the results.
Source: authors.

DAILY RAINFALL, DAILY RIVER FLOW, AND CARTOGRAPHIC DATASETS DATA COLLECTION

The National Water Agency (ANA), https://www.snirh.gov.br/hidroweb/download, provides the daily rain, river flow data series, and DEM, with 30 meters of spatial resolution. After identifying the rainfall and river flow stations in and around the hydrographic basin of Santa Maria, we selected the stations with at least 30 years of continuous matching data series (1991-2021). Inside the hydrographic basin, from upstream to downstream, we used the rain gauge stations of Três Vendas (3155001), Dom Pedrito (3054002), and Granja Umbu (3054016). Outside the hydrographic basin, we used the rain gauge stations Ponte Toropi II (2954032), Fazenda Encerra (3055003), São Carlos (3055007), and Paraíso (3153003). The fluviometric station used was Rosário do Sul (76310000), installed on the bridge over the River Santa Maria, close to the urban area of Rosário do Sul. The river flow has been continuously measured daily since 1968 (54 years with records).

For the calculations of concentration time, flow rate, and return period, some morphometric data of the watershed is required, such as the delimitation of the drainage area, average altitude, length of the main channel, and average slope of the channel (upstream of the urban area), for which SRTM data was used, available in the USGS database (https://earthexplorer.usgs.gov/) with a spatial resolution of 30 meters. This DEM automatically defined the Santa Maria and Ibicuí da Armada River basins in Qgis 3.28 to calculate morphometric variables with area basins, average elevation, and slope of the main river. The information obtained was used to define the concentration time and calculate the flow rate;

more details are in the next section.

RETURN PERIOD OF EXTREME EVENTS AND RIVER FLOW ESTIMATION

River flow data obtained from the Rosário do Sul fluviometric station was used to compute the flow rates for 5, 10, 20, 30, and 50-year return periods (Table 1) using an empirical distribution method, where data series are in decreasing order. The Weibull equation computed the position (Tavares e Santos, 2022). The river flow data was also used to test the best statistical distribution method to estimate the river flow from the rainfall and river data.

Return Period (years)	Date	River flow (m^3/s)	Maximum registered level (m)
5	14/02/1973	2,849.45	7.90
10	23/11/2009	3,785.37	8.86
20	06/09/2001	4,203.00	9.47
30	30/12/1997	4,367.91	9.54
50	15/04/1992	4,693.50	9.65

Table 1 - Hydrological data from the Rosário do Sul River flow station. Source: National Agency of Waters. Source: authors.

Other statistical distribution methods were tested to analyze the best-fit distribution of the fluviometric data and the rainfall data in the EasyFit software: Gumbel Max, LogPearson, and LogNormal. After estimating the distribution for all the return periods, it was found that the GumbelMax distribution had the highest correlation with the empirical distribution. Pearson's correlation was applied to check which distribution was closest to the empirical one. The calculations were made in Excel, and the equations' parameters were obtained in EasyFit.

Estimating the river flow from rainfall data involves a more significant number of procedures. The first step is to assess the area covered by each rainfall station. To do this, the Thiessen polygons generated from the location of the rainfall stations were calculated. In the next step, the maximum daily rainfall values were estimated for all the stations with 5, 10, 20, 30, and 50-year return periods. The distribution method that showed the most significant adherence (verified in EasyFit considering Kolmogorov-Smirnov) to the rainfall data was the GEV (Generalized Extreme Value) method. The flow rates were calculated after defining the maximum daily rainfall for the established return period and testing the Dooge, Johnstone Corps of Engineers, Kirpich, Ven te Chow, and Giandotti methods (Patricio et al. 2021; Lencastre & Franco, 2003). The Giandotti method showed the best correlation and was closest to the data obtained with the Empirical and GumbelMax distributions, considering the 24-hour concentration time for the BHRSM (MARCUZZO e PINTO, 2022).

DHYDROLOGICAL MODELS TO DEFINE FLOOD SUSCEPTIBILITY

FIRST, the flow rate estimation for the established return period (Table 2) was used to compute the hydrological models in the IBER software. The mesh used in IBER as a basis for elevation comes from data extracted from Alos/Palsar images with a spatial resolution of 12.5 meters from the Alaska Satellite Facility (https://asf.alaska.edu/). The image was transformed from *. geotiff into *.txt. The time of concentration used in the hydrograph was 86,400 seconds.

Return Period (years)	GEV (m^3/s)	Gumbel Max (m^3/s)	Empirical (m^3/s)	Difference GEV-Empirical (%)	Difference Gumbel-Empirical (%)
5	2563.61	2711.23	2764.44	-7.26	-1.92
10	3019.34	3359.24	3717.73	-18.79	-9.64
20	3532.55	3980.82	4202.96	-15.95	-5.29
30	3794.22	4338.41	4367.91	-13.13	-0.68
50	4175.97	4785.40	4693.50	-11.03	1.96

Table 2 - Flow rate estimation (m3/s) using GEV, GumbelMax, and Empirical distribution. Source: authors.

Secondly, the roughness data (Manning) was obtained from MapBiomas based on the 2022 collection(SOUZA et al., 2020). Once the data was in a matrix model, the classes were organized into six types: River, Agriculture, Forest, Sand/Clay, Residential, and Unclassified. Once organized, the data was transformed from *geotiff into *.txt. Further information on data manipulation and the generation of 2D hydrological models in IBER can be found in Bladé et al. (2014), Camargo et al. (2012), Quijano et al. (2018), and https://www.iberaula.es/.

After generating the 2D hydrological models for all return periods, the files were converted into a raster for ArcGIS PRO® and Qgis 3.28. The areas susceptible to flooding were calculated in Qgis 3.28 using the r.report tool. The raster was converted into points, and the depth information was extracted. From this data, graphs were constructed in SPSS® to show and compare the depth and flooded area.

The flooded areas overlapping, the relationship between the modeled surfaces, and the comparison between the maximum depths based on the return periods were analyzed. The model was validated according to Bladé et al, (2014) and Fernández-Nóvoa et al, (2024), where the results were compared with the river flow records from the fluviometric station, fieldwork data collection and Sentinel 2B satellite images from November 7, 2019, where it was possible to see flooded areas.

RESULTS

The statistical determination of the flow rates made it possible to check the correlation between the data (Figures 5A, 5B and 5C). The data showed a high correlation, R^2 greater than 0.90, which indicates that there is statistical reliability for the use of the distribution methods, as well as the flow values found. Although the correlation is slightly lower, the result is statistically acceptable.

When comparing the flood depths simulated based on the flow data, it was found that the lowest values are linked to the data calculated from the rainfall data, which was to be expected as the flow rates are lower. The purpose of applying the model is to spatialize the calculated flow data. When analyzing the data, it is possible to see that the depths are consistent. However, they are lower than those measured at the fluviometric station, which we considered the DEM's resolution causes.

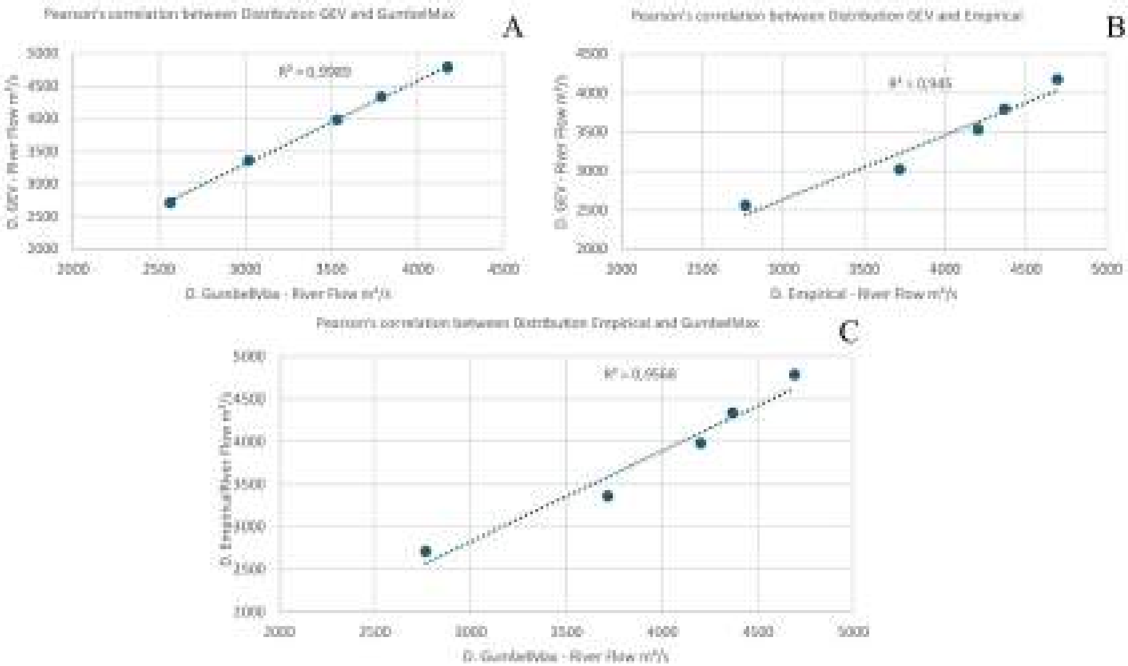

Figure 5 - Pearson's correlation of the river flow data between the flow rate obtained by the Generalized Extreme Value (GEV) and GumbelMax distributions (A), between GEV and Empirical distributions (B), and between Empirical and GumbelMax distributions. Source: authors.

Table 3 shows the maximum flood depths obtained with the 2D model compared to those recorded at the Rosário do Sul fluviometric station. The depths obtained in the return period of 5 years are the closest to the values recorded at the fluviometric station, with the GEV distribution being the nearest.

Return Period (years)	GEV (m)	Gumbel Max (m)	Empirical (m)	Observed River height (m)
5	8.00	8.05	8.08	7.90
10	8.30	8.39	8.56	8.86
20	8.44	8.60	8.69	9.47
30	8.54	8.76	8.69	9.54
50	8.64	8.81	8.67	9.65

Table 3 - Maximum flood depth (m) using GEV, GumbelMax, Empirical distribution estimations, and observed river height for different return periods. Source: authors.

At the other return periods, the depths projected using the hydrological model with different distributions were below the values observed at the fluviometric station. The GumbelMax distribution for 10, 20, 30, and 50-year return periods was the one that obtained the depths closest to the measured values. (Druzian et al. (2023), when projecting flow rates using the GR4J model based on CHIRPS data for the Ibirapuitã River basin (RS), observed an overestimation of base flows and an underestimation of peak flows. However, the authors comment that the model presented satisfactory results and can be used as an alternative for locations with rainfall and rain gauge data restrictions.

Following the recommendations of Bladé et al. (2014) for the validation process of models based on depth, it proved to be satisfactory, especially for shorter return periods, as can be seen in 5 years return periods, where the values were very close, with an average oscillation of approximately 0.10 meters. However, what should be considered is the coherence of the depth values, which followed an increasing logic according to the river flow data. As the return periods were extended, the depths obtained in the 2D model proved to be underestimated compared to those measured at the fluviometric station, reaching a maximum range of 1.1 meters when analyzing the model based on the GEV distribution with a 50-year return period. The DEM is not high resolution and shows some differences in altitude in the lower bed of the Santa Maria River (Figure 6).

Figure 6 - Flood height (m) in the Santa Maria Valley, Rosário do Sul urban area (Rio Grande do Sul state, Brazil). Source: authors.

Figure 7 shows the box plot for the flood depth distributions obtained by the hydrological models using GEV, Empirical, and GumbelMax functions for 5, 10, 20, 30, and 50-year return periods. When analyzing the trios by return time, there is a slight variation between the quartiles and in the median oscillation, which does not exceed 0.5 meters, indicating that the flood depths show a reduced range, even using different distribution methods used to estimate the flood rate. The Q1, Median, and Q3 values are very close between the various distributions for the different return periods.

The best result was observed for the 5-year return period, which had already been diagnosed at the maximum depths. The range between the quartiles for 20 years return periods onwards, where the first and second quartiles of the GEV distribution show lower depth values than the others. The extreme flood depth values have been represented as outliers and have, therefore, been removed from the graph.

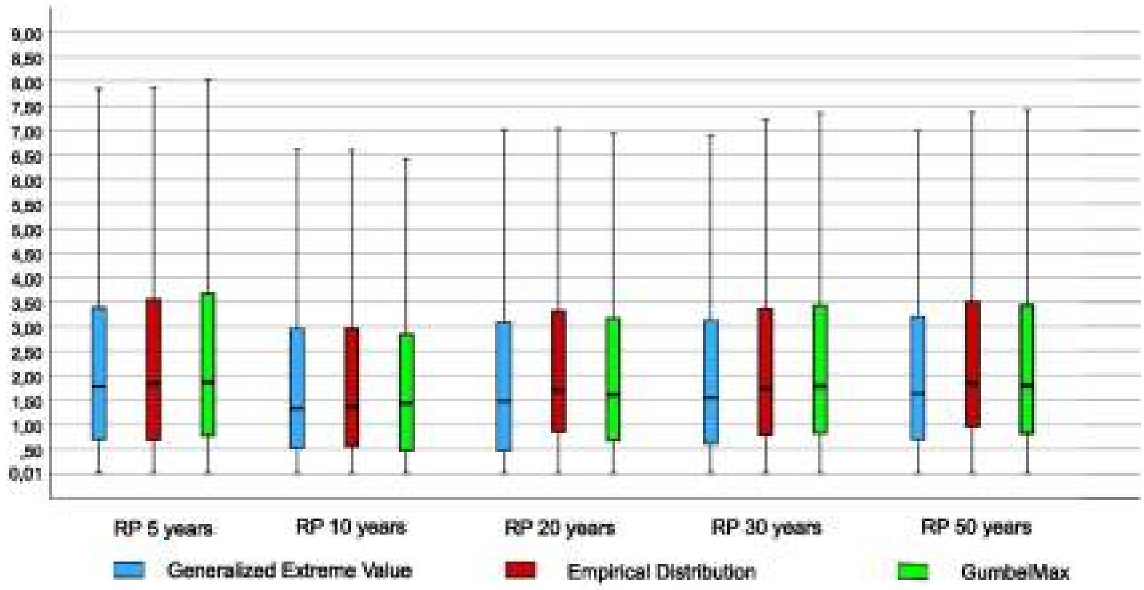

Figure 7 - Flood depth (m) estimations boxplot for 5, 10, 20, 30, and 50 years return period using GEV, GumbelMax, and Empirical distributions. Source: authors.

Regarding the delimitation of flood areas, the model generally showed similar values in the flooded areas (in km²) for all the considered return periods and distribution methods, as seen in Table 4. The data based on the return periods of 5, 30, and 50 years remained very close, with variations of less than one km². The flooded areas quantified for the ten and 20-year return periods showed a more significant difference, around three km². However, when comparing the results, the flow rate and flood depth show consistency in the flooded areas.

Return Period (years)	GEV (km^2)	Gumbel Max (km^2)	Empirical (km^2)
5	10.29	10.37	11.05
10	14.37	15.81	17.91
20	16.7	19.54	20.32
30	19.19	20.4	20.37
50	19.58	20.44	20.89

Table 4 - Flooded area (km2) using GEV, GumbelMax, and Empirical distributions. Source: authors.

Regarding the flooded areas modeled for each return period, it is clear that the models met expectations when compared with the data observed during fieldwork in the urban area of Rosário do Sul. The 2D model generated in IBER can be considered a tool with potential for use, especially at an early stage of analysis, as it indicated areas that are historically affected by the waters of the Santa Maria River in flood events, mainly in the Santo Antônio and Progresso neighborhoods (Figure 8).

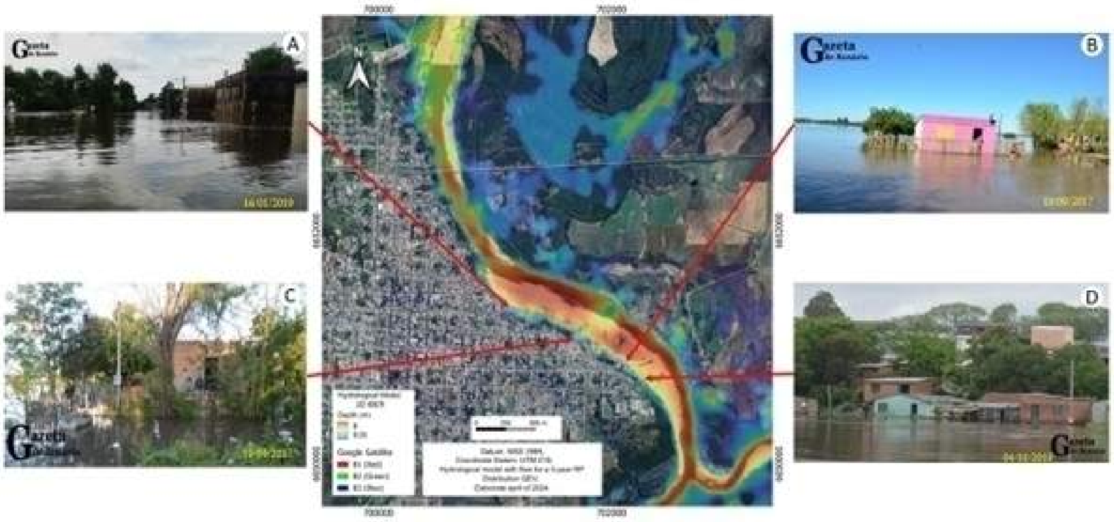

Figure 8 - Photographs of flood events in Rosário do Sul and the 2D hydrological model with flow rate for a 5-year RP. A - Branca's neighborhood; B, C, and D - houses affected in the Progresso neighborhood in the September 2017 and November 2019 flood events. The photos are from the local newspaper Gazeta de Rosario. Source: authors; Gazeta de Rosário.

Flooding in Rosário do Sul does not cause even more severe damage, as the floodplain on the right bank is wider than 3 km long. Additionally, the urban area is on a hill, so the flooded regions are smaller on the left bank of the Santa Maria River. This does not exclude the need for flood management and mitigation actions, especially to avoid further losses and damage. The work by Dias (2017) presents a geo-environmental mapping of the municipality, where it is possible to see the characteristics of the physical environment in more detail, including the dimensions of the flood plains. On the left margin, the models had very similar responses, indicating the flooded portions, especially in the Progresso and Ana Luiza neighborhoods. For this scale of work, the floodable areas were undersized in the Vila Nova neighborhood in all the models.

Figure 9 shows the estimated flooded areas for different return periods, emphasizing the urban area. When comparing the images, it is possible to see that up to 20 years of RP, the enlargement of the flood area is more prominent. From 30 years of RP onwards, the most significant changes are linked to the increase in the flood depth, and the advance of the flooded area is only more noticeable in the southern part of the urban area, in the Ana Luiza neighborhood.

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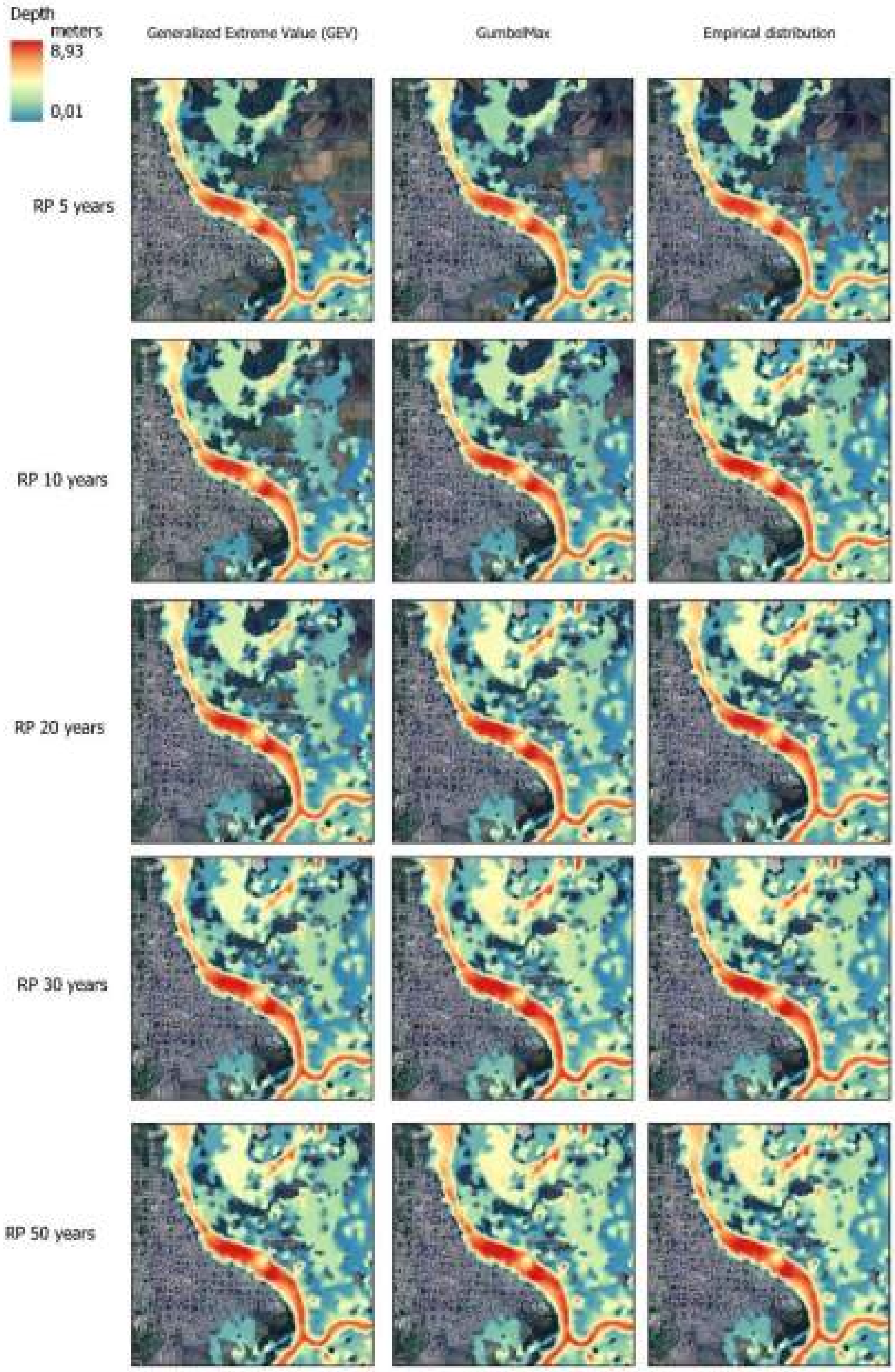

Figure 9 - Flooded areas and flood depth (m) using GEV, GumbelMax, and Empirical distribution to 5, 10, 20, 30, and 50 RP used in the 2D hydrological model. Source: authors.

DISCUSSION

The study and definition of areas susceptible to flooding help to reduce damage and losses in urban areas. Geoprocessing is proving to be a low-cost and efficient alternative for studies on this subject, given that free software and cartographic data are available (Moreira e Santos, 2020).

The tests proved promising in obtaining the flow rate data from the statistical distribution between rainfall and flow rate for known areas, which can be applied in study areas with similar geomorphological and hydrological conditions but with incomplete or without measured flow rate data series. Using EasyFit to test the distribution methods was efficient and made it possible to verify the adherence of the data. Regarding the use of the GEV distribution, Mamoon e Rahman (2017) tested the best method to analyze the frequency of extreme rainfall in Qatar; the authors concluded that the GEV distribution was the most suitable and that the most effective adherence tests were Kolmogorov-Smirnov, Anderson-Darling, and Chi-square.

Based on the Weibull formula, the empirical distribution proved suitable for sorting the historical series of river flow data in Rosário do Sul. This result corroborates the findings obtained by Tavares e Santos (2022), where they used the Weibull distribution together with GEV to analyze the return period of extreme rainfall events in Rio de Janeiro/Brazil.

A DEM with more detailed information could present results closer to those of the fluviometric station, considering that the calculated river flow values are highly correlated. Fernández-Nóvoa et al, (2024) used IBER to compare the simulated results to historical flooding events on the River Tejo. The authors tested three digital elevation models (DEMs) and concluded that Copernicus DEM was the most suitable and had the most significant detail.

The hydrological models generated in IBER based on fluviometric and rainfall data have proved to be a reliable alternative for defining flood areas and estimating flood depths, considering the scale of the information. This data, added to the inventories and information collected in the field, can help municipal and civil defense managers plan mitigation actions based on the frequency and severity of events. Cea et al, (2024) reproduced the floods in Maputo Province in 2023; the authors comment that the 2D model generated, even with restricted spatial data, is an essential planning tool and helps reduce damage.

As the RPs were extended, the depths obtained in the 2D model proved to be underestimated compared to those measured at the fluviometric station, reaching a maximum range of 1.1 meters when analyzing the model based on the GEV distribution with 50-year RP. The difference between simulated and measured data does not eliminate the merit of the results found. Le e Pricope (2017)comment that simulation information is an essential alternative for planning and management in some regions where fluviometric data is scarce.

The differences observed in-depth and flooded areas may be linked to the variation in altitude observed in the digital elevation model. The difference in altitudes in DEMs from remote sensing is an expected characteristic since there may be a mixture of information with objects on the surface or even the scale of the image itself (NEVES et al, 2021).

CONCLUSIONS

The results obtained with the 2D model using the software Iber showed that it is possible to use flow rate estimated from rainfall data to model flooded areas and flood depth with acceptable results. The flow rate values tend to be undersized when compared to those obtained from fluviometric stations, but in statistical terms, there is a strong correlation, as was proven in this work.

The areas susceptible to flooding and the depths defined in the 2D model were consistent, as the responses followed a continuous elevation pattern as the flow rate increased. Running the model for different return periods and basing the results on information collected in the field and remote sensing products when available is recommended to diagnose discrepancies.

The data on susceptible areas and depth found for Rosário do Sul should not be used as a basis for structural actions, as the digital elevation model used is considered medium scale. The purpose of this article is to present a methodological possibility for which the Alos/Palsar image perfectly meets the need. To use the data from the 2D hydrological model for operational and structural purposes, it is recommended that the work be done by neighborhood and that the digital elevation model be based on high-resolution data.

The objectives proposed for this article are fully met, and the procedures adopted can be easily replicated in other areas or with more detailed data. For future work, we plan to generate new hydrological models by neighborhood based on high-resolution data about the terrain and households.

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