INTERNATIONAL JOURNAL FOR INNOVATION EDUCATION AND RESEARCH
ISSN: 2411-2933

Journal URL: https://scholarsjournal.net/index.php/ijier

DOI: https://doi.org/10.31686/ijier.vol11.iss1.4044

Use of chirps satellite precipitation in the characterization of the franceses stream Basin, Manaus - State of Amazonas - Brazil

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Abstract

The city of Manaus has numerous waterways in its urban perimeter, and, despite this, there is a shortage of measures aimed at protecting water resources that has generated occupations very close to the riverbeds. This work aims to characterize a watershed in an urban area of Manaus and map the areas subject to flooding around the Franceses Stream. The methodology applied involved obtaining topographic and thematic information such as morphology, geographical location, elevations, extent, area, level curves (water dividers) of the basin, obtained through georeferenced satellite images in a GIS environment.In addition, monthly satellite precipitation via the CHIRPS product was used for the calculations. The physical characteristics of the basin were determined using equations employed in hydrology. The results indicated that the Franceses Stream basin is not subject to major flooding, presenting the following characteristics: compactness coefficient Kc = 5.71; form factor Kf = 0.36; circularity index Ic = 0.03; drainage density Dd = 0.94km^{-1}. It was also found that, despite the intense occupation, there is preserved vegetation within the basin. It was concluded that the precipitation estimated by CHIRPS is efficient because it has a larger coverage, and that knowing the characteristics of watersheds in urban environments is of great importance to subsidize intervention measures and planning policies that ensure the protection of water resources and minimize inconvenience to the population. It was also found that the use of GIS is an important tool for analyzing information in hydrological studies, and that it needs to become an increasingly applied tool in urban management, so that the knowledge obtained can be used to obtain better environmental and social conditions.

Keywords: hydrographic basin; urban planning; flooding.

1. Introduction

The population increase, accompanied by urban expansion, results in the need for efficient planning. However, a disorderly growth is observed in large cities, where often the issues related to water resources are not given due importance, as in suburbs and invasion areas.

Water is an element of great value and primordial to life, and it will be increasingly seen that its use is essential for the welfare and development of society. Despite this, the occupation of the surface by humanity has occurred in an unplanned way, resulting in problems such as inadequate preservation of natural resources (SANTOS, 2017).

Historically, most cities have developed along rivers, due to the need to use water for consumption, agriculture, means of transportation, and waste disposal (REIS, 2015). According to Gomes *et al*. (2019), one of the major problems that affect urban areas is the volume of water generated by rainfall and the effect of soil sealing; many cities do not have adequate components for rainwater disposal, so urban spaces suffer frequent flooding, environmental, social and economic problems.

The city of Manaus has numerous waterways in its urban perimeter, and, despite this, there is a shortage of measures aimed at protecting water resources that has generated occupations very close to the riverbeds. Cruz and Costa (2012) show that paved streets, availability of services, trade and good accessibility are privileges of those who can pay more, being the access to urban land is limited to the purchasing power, thus, clusters of people who build in hillside areas and on the banks of waterways, where the lack of infrastructure reduces the price of land.

With the economic crisis of the latex trade, Silva (2016) recalls that problems of social order, infrastructure, and unemployment emerged in the city of Manaus, and as a consequence, low-income people were building their houses in a precarious way along the waterways. From the late 1960s, Queiroz (2009) describes that with the Free Trade Zone of Manaus and the growth of industrial activity, many people from different regions were attracted to the city, causing the population to increase from 300,000 inhabitants in the 1970s to more than 1.5 million by the turn of the 21st century.

The streams were neglected in the city consolidation process, strangled and covered up to make way for the road system, converted into channels rectified by concrete, they began not only to act in the rainwater drainage, but also confused and treated as open sewers (MARTINS JÚNIOR, 2018).

As stated by Verçosa (2019), as cities develop, changes occur in land use and occupation patterns, provoking changes in hydrological processes, such as reduced water infiltration into the soil, increased surface runoff, and earlier peak flows. The researcher affirms that this process associated with the occupation of unsuitable areas, such as river floodplains, leads to flooding in the urban environment, where the damage is more expressive than in the rural environment, since the former encompasses the main socioeconomic attributes and asset bases of any population.

The growing urbanization, with the use and occupation of land without proper planning coupled with the absence of policies to monitor and preserve water resources generates a problem of great repercussion: variations in the flows in watercourses in urban centers, causing repeated flooding (APARECIDO *et al*., 2017). Silva (2016) explains that urbanization, accompanied by the removal of vegetation and soil sealing, changes the natural runoff of surface water with a reduction in the concentration time of rainwater, due to urban drainage systems, whose goal is to capture and direct the water downstream as quickly as possible, towards the watercourses, adding considerable volumes of water in rivers, which increases the potential for flooding.

The hydrological cycle is generally studied with greater focus on the terrestrial phase, where the fundamental element of analysis is the hydrographic basin. A watershed is a natural catchment area for precipitation water that converges runoff to a single point, its outlet, and is basically composed of a set of slope surfaces and a drainage network formed by watercourses that converge to result in a single bed at the outflow (TUCCI, 2001).

According to Leal and Tonello (2016), physical characteristics, particularly those associated with relief, shape, and drainage network, are highly related to the time and speed of water runoff, which incurs in greater or lesser infiltration of water into the soil. The authors state that according to the physical description of the basin it is possible to know its susceptibility to flood risk, surface runoff and erosive processes, giving an indication of how the basin should be managed so that it can provide greater infiltration of water into the soil.

In this context, it is evident that it is of utmost importance for managers and researchers to develop studies and research that aim to characterize hydrographic basins to subsidize, with information and data, integrated management programs of these areas, with diagnosis, evaluation and planning of the use of natural resources (NOBRE *et al*., 2020).

Conforming to Mendes and Cirilo (2001, *apud* ALVES, 2017), environmental studies, such as those related to water resources, face major challenges in the execution of experiments that provide highly accurate results; subsist the complexity of carrying out field measurements for large areas associated with the difficulties of representing the different physical parameters of the environment. Thus, remote sensing and geoprocessing techniques are being disseminated and applied in the area of water resources through the use of space satellites, aerophotogrammetric sensors installed in aircraft, radars and laser profiling techniques.

Geography is concerned with representing physical space as accurately as possible, and with the development of cartography, maps have become the main source of spatial information. Technological advances and computer development led to the emergence, in the 1960s, of Geographic Information Systems (GIS) (BATISTA, 2019). GIS are systems aimed at the acquisition, analysis, storage, manipulation, and presentation of spatial information (BRASIL, 2007). The large amount of basin data to be used has made the employment of GIS and Remote Sensing an important part of the input structure of some models (DIAS, 2015).

Santos (2015) points out that remote sensing is part of the geoprocessing system and can be defined as the manipulation of georeferenced spatial data within a computer system. The author mentions that remote sensing is a tool for data acquisition without much need for field work and geoprocessing associated with appropriate methodologies can be a good tool for planning and decision making.

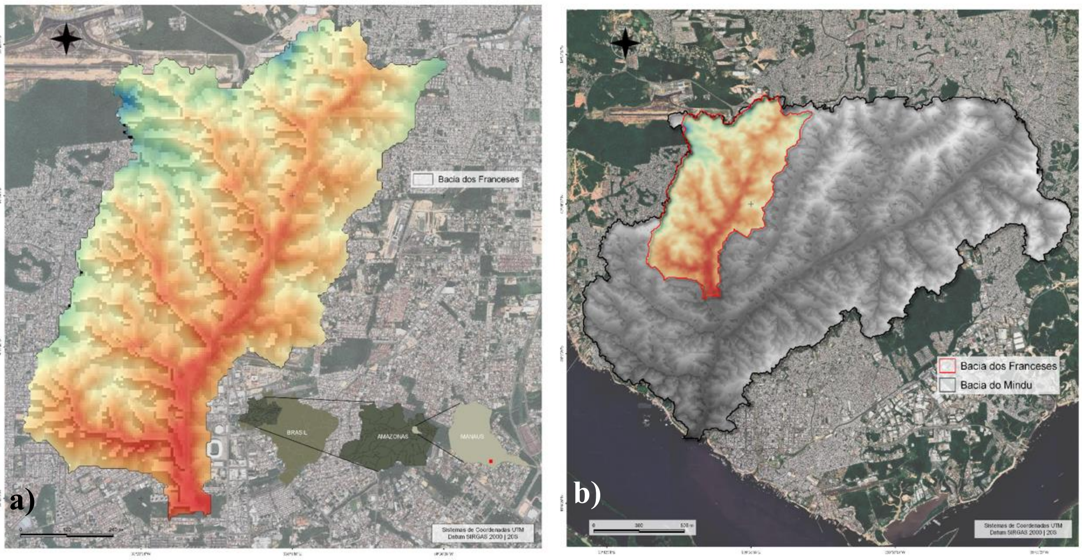
In view of the above, this work aims to characterize a watershed in an urban area of Manaus and map the areas subject to flooding around the Franceses Stream using satellite images. It is justified by the importance of knowing the peculiarities of the water courses for a better urban planning.

2. Materials and Methods

2.1 Study Area

The Franceses Stream is located in a central area of the urban perimeter of the city of Manaus, Amazonas (Figure 1a), has a drainage area of 17.45 Km² and a perimeter of 85.22 Km. The basin's outflow is located at coordinates 60° 1′ 45.336″ W longitude and 3° 5′ 26.952″ S latitude, while its source is at 60° 0′ 44.928″ W longitude and 3° 2′ 26.124″ S latitude. Its outlet is at an elevation of 28.07 m and its source is at 42.77 meters. The width of its wet area varies during its extension from 5.53 to 17.80 meters. The Stream is inserted in the Mindu Basin, and its source is close to the mouth of the Bindá Stream Basin (Figure 1b).

Figure 1: a) Delimitation of the Franceses basin; b) Franceses Basin inserted in the Mindu Basin.



Source: Authors (2022)

2.2 Materials

Basically, a first set was used, composed of the STRM - *Shuttle Radar Topography Mission* satellite images, used to determine the hydrological profile of the creek basin (Digital Elevation Model - DEM) for the day 07/18/2021, where there was low cloud cover at the study site. These images are for public use and obtained from the geomorphometric database of INPE (National Institute for Space Research) through the TOPODATA project, with a spectral resolution of up to 60 m.

The second set are the images for the analysis of the vegetation in the study area. For this, the Normalized Difference Vegetation Index (NDVI) was used, indicated to assess the conditions and quantity of vegetation remotely. The intervals chosen in the image have a basis in the literature where Gomes *et al*., (2019) and Rosendo (2005) adopt values in the images ranging from -1 to 1, which values close to 1 indicate denser vegetation, while those closer to 0, indicate an unvegetated surface.

To characterize the rainfall regime in the city of Manaus, and in particular in the study region, and thus calculate the overflow curve, data from CHIRPS (Funk *et al*., 2015) were obtained (Precipitation Estimates from Pluviometer and Satellite Observations - https://www.chc.ucsb.edu/data/chirps). The CHIRPS product has been in operation since 1999, created in collaboration with scientists at the USGS Center's Earth Resources Observation and Science (EROS) to provide complete, reliable and up-to-date datasets for a range of early warning purposes, such as trend analysis and seasonal drought monitoring. The precipitation extracted from CHIRPS is based on NASA and NOAA grid satellites, were leveraged to construct precipitation climatologies with spatial resolution of the pixel size of 0.1° x 0.1°.

2.3 Methods

To obtain the overflow curve of the Franceses Basin it was necessary to calculate some parameters of the topography, morphology, geographic location, elevations, extension, area, level curves (water dividers) of the basin. This information was obtained through georeferenced satellite images, using the QGIS program, and analyzed in a GIS environment. From the georeferenced information it was possible to calculate some physical parameters of the basin, presented sequentially in Board 1.

To determine the rainfall intensity, it is necessary to formulate the rainfall equation (IDF curve) in the study region. Based on the CHIRPS precipitation data, were constructed a series of probable annual maximum heights and respective Recurrence Time (Tr) and associated probability, resulting in the maximum probable heights for return periods of 10 to 100 years. Also, the research must be considered as macro drainage, so the return period of 10 and 50 years will be adopted. The design rainfall intensity for Tr = 2 to 100 (equation 5).

To calculate the parameters K, m, t_o and n the Solver tool of the Excel spreadsheet was used, using parameters such as a maximum time of 100 seconds; interaction equal to 100; precision of 0.000001; with a tolerance of 5%; and convergence of 0.0001. Subsequently, with the results obtained, the IDF curve for the study region was formulated, given by Equation 5.

For the design of drainage structures, where the flows are determined by the rational method, the duration time of the rainfall is equal to the time of concentration, which can be determined with *Kirpch's* formula (published in California Culverts Practice - 1956), valid for basins with drainage areas of up to 100 ha, with *tc* in minutes (equation 6). For the basin under study, these values are diverse because it is a matter of sub-basins delimited along the study area, from which it is determined that the average *tc* is 190.62 min (Equation 6).

The recurrence time or return period was adopted to determine the design flow and helps in the sizing of drainage devices for definitions in macro drainage and micro drainage. Thus, macro drainage was adopted in this study for a return period of 25 years, i.e., through the equation the design rainfall intensity for Tr = 25 is given by Equation 5.

Board 1: Main physical parameters calculated for the Franceses Basin.

PARAMETER	EQUATION	VARIABLES
Coefficient of compactness (equation 1)	$Kc = 0,28xP/\sqrt{A}$	Kc – coeficiente of compactness P - perimeter A – drainage area
Form factor	$F = A/L^2$	F – form factor

(equation 2)		A - drainage area L - length of the basin axis
Circularity index (equation 3)	$IC = 12,57 \times A/P^2$	IC - circularity index A - drainage area P – perimeter
Drainage Density (equation 4)	$Dd = L_t/A$	Dd - drainage Density L_t - sum of the lengths of watercourses A – basin area
Probable maximum intensity (equation 5)	$i = \frac{7,91512 \, . Tr^{0,15792}}{(t + 9,11857)^{0,70462}}$	*i* - probable maximum intensity, in mm/min *Tr* – return period, in years *t* – precipitation time, in minutes
Time of concentration (equation 6)	$tc = 57(\frac{L^3}{H})^{0,385}$	*Tc – time of concentration* *L* - watercourse length, in kilometers *H* - difference between the headwaters of the main watercourse to the outlet, in meters.

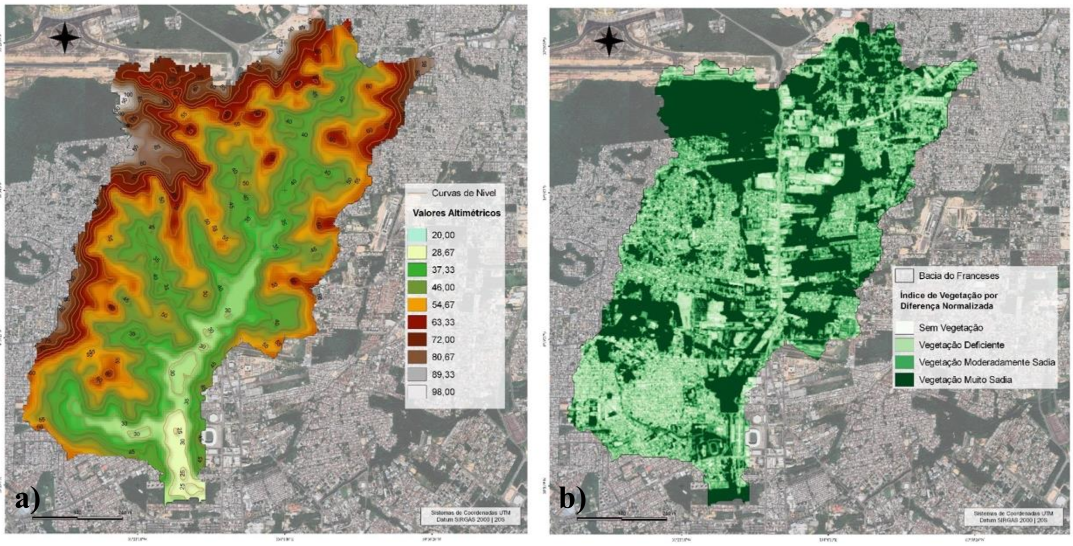
3. Results and Discussions

Uses of the Franceses Stream Basin

The Franceses Stream basin is located in a predominantly urban area, with its banks cleared for residential occupation and sewage discharge into its bed, as routinely occurs in urban waterways. The occupation of the banks of the waterways of Manaus continues at a rapid pace, causing urban water resources and their surroundings to present an advanced state of environmental degradation, requiring the implementation of measures to mitigate the impacts arising from these occupations, through public policies of sanitation and environmental management (MARTINS JÚNIOR, 2018).

Analyzing Figure 2a, it is possible to identify that the basin has a vast population density in its surroundings, being inserted in an urban area, leaving isolated fragments of healthy vegetation, it is also noted that there is mostly an abundance of moderately healthy and deficient vegetation.

Figure 2: a) Altimetric profile of the basin, b) NDVI; obtained by satellite.



Source: Authors (2022)

The characteristics of the Franceses Stream basin, obtained through QGIS and using the equations presented in the methodology, are presented in Table 1. The coefficient of compactness (Kc) shows the relationship of the basin shape to a circle, which can determine how fast the basin can overflow. A Kc equal to 1 represents a perfectly circular and more compact basin. The lower the Kc, the more circular is the basin, having a shorter concentration time and a greater tendency to flood peaks. When we analyze the Kc for the Franceses Basin (Kc = 5.71) we notice that it is not a basin subject to large floods. When we analyze the shape factor (Kf = 0.36), it is verified that this is a more elongated basin, less subject to flood peaks. The tendency of the basin not to have flood peaks can be also verified by the circularity index (Ic=0.03), suggesting that the basin tends to be elongated, not favoring floods.

In addition to the morphological characteristics presented above, the drainage density of the Franceses Stream basin was 0.94 km/km², which corresponds to a regularly drained basin. This characteristic indicates the quantity of water courses that supply the basin, showing that because it does not have many contributors, the tendency to fill quickly is low.

Regarding the environmental characterization of the study area, information was collected about the Normalized Difference Vegetation Index – NDVI, as shown in Figure 2b.

Table 1 – Morphological characteristics of the Franceses Stream basin.

Characteristics	Result
Area (A)	17.45 km²
Perimeter (P)	85.22 km
Coefficient of compactness (kc)	5.71
Form fator (Kf)	0.36

Drainage Density (Dd)	0.94
Circularity index (Ic)	0.03
Highest elevation	42.77 m
Outflow elevation	28,07 m
Total length of the watercourses	16.41 km
Main stream lenght	6.97 km
Average slope	0.0068 m/m

Source: Authors (2022)

Rainfall-runoff Model of Franceses Basin

The parameters to calculate the flows in the Franceses basin were those presented in Table 2. It was verified that the Franceses basin registered a maximum flow of 2.12 m³/s, while in the month of August, the period when precipitation is minimum in the region, the flow reached values around 0.72 m³/s, while the average flow was 1.25 m³/s, as shown in Table 2.

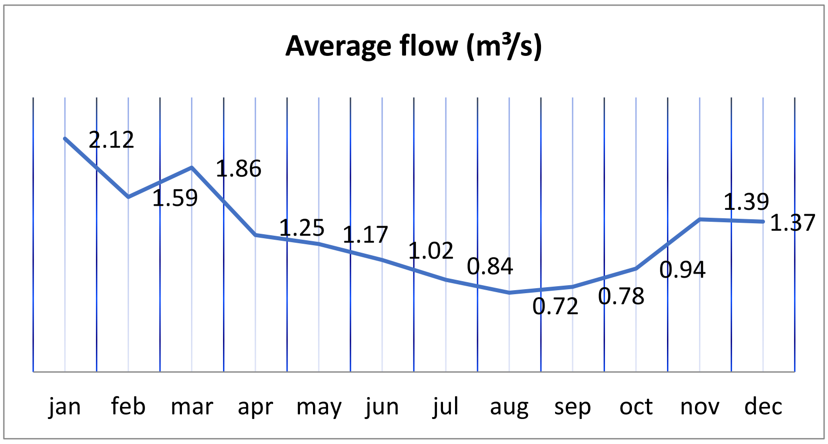
Table 2 – Flow for the Franceses Basin.

Month	Rain (mm)	m³/s	m³/h
jan	420.94	2.12	7649.699
feb	315.88	1.59	5740.337
mar	368.90	1.86	6703.896
apr	247.13	1.25	4491.052
may	230.97	1.17	4197.329
jun	202.18	1.02	3674.093
jul	166.51	0.84	3026.012
aug	143.03	0.72	2599.314
sep	153.67	0.78	2792.629
oct	186.47	0.94	3388.597
nov	275.29	1.39	5002.824
dec	271.26	1.37	4929.606
Average flow (m³/s)		1.25	4516.28

Source: Authors (2022)

The flow hydrograph presented in Figure 3 shows that the average flows from the outlet of the Franceses basin present an annual cycle with a 2-month lag in relation to the diurnal cycle of precipitation in the Amazon region. Indicating that after the wettest months in the region is when the floods may occur in the urban area around the stream.

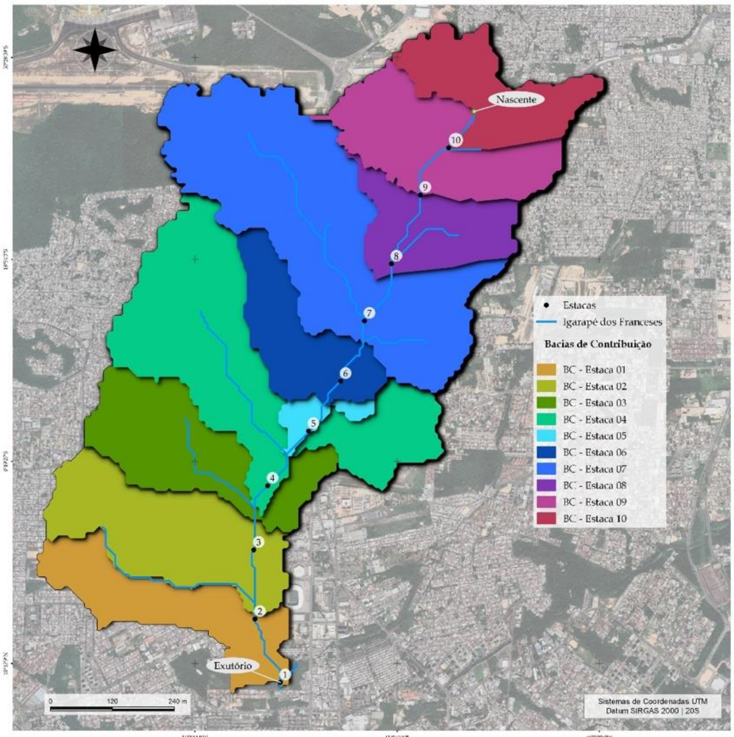
Figure 3: Average flow hydrograph for the Franceses Basin.



Source: Authors (2022)

By obtaining the topographic curves and precipitation on the perimeter of the basin area, it was possible to characterize the watercourse in an extension of approximately 14 km, comprised between the geographic coordinates 60° 1′ 45.336″ W to 60° 0′ 44.928″ W, within the perimeter of the 10 de Novembro Parque Neighborhood, as illustrated in Figure 4. At the same time, other information such as points and watercourse information were performed using georeferenced satellite images and topographic information of the watershed thalweg, with data collection at the staking points of the basic project, measured from 5 in 5 km, totaling 10 points, from downstream to upstream of the stream. Figure 4 shows the marker points in the basin, showing the southernmost position in the basin being the first marker point to point number 10, located at the northernmost position.

Figure 4: Basin Stakes.



Source: Authors (2022)

Because the basin is inserted in the same urban ecosystem of the city of Manaus, it has the same characteristics that define the climate in the city. However, the rainfall regime of the region influences the process of flood and ebb of the stream presented in the study, only with a lag of a few months, i.e. the floods happen around 2 months after the maximum rainfall in the region (as shown in Table 2).

Design Rainfall Intensity – IDF Curve

One of the problems encountered when using this method is the weak precipitation monitoring network in the region and in the country. Thinking about this problem, it was decided to innovate by using the precipitation product made available through the CHIRPS satellite images, thus, it was possible to obtain a uniform time series. To determine the rainfall intensity, it was necessary to formulate the rainfall equation (IDF curve) in the study region. To obtain the hydrological data for the studied basin, it was sought in the database obtained by satellite images that represent the occurrence and behavior of rainfall in the study region, which are shown in Table 2.

Table 2: Precipitation from the CHIRPS satellite.

Year	Maximum [mm]	Year	Maximum [mm]	Year	Maximum [mm]	Year	Maximum [mm]
1981	58.36	1991	49.86	2001	35.09	2011	57.41
1982	52.41	1992	53.01	2002	54.75	2012	50.45
1983	99.08	1993	47.62	2003	43.19	2013	62.43
1984	37.88	1994	52.69	2004	41.19	2014	108.20
1985	72.40	1995	51.91	2005	54.53	2015	53.45
1986	53.05	1996	60.32	2006	41.81	2016	62.27
1987	66.76	1997	72.47	2007	40.60	2017	62.67
1988	88.52	1998	50.87	2008	56.00	2018	42.77
1989	63.07	1999	48.12	2009	42.81	2019	62.23
1990	43.49	2000	53.38	2010	41.23	2020	46.96

Source: CHIRPS satellite

From the precipitation it was possible to build a set of time series of probable maximum annual heights and respective Recurrence Time (Tr) and probability associated, as presented in Table 4.

Table 4: Series of Maximum Annual Heights, Tr and Probability.

Height [mm]	Tr [years]	Probability	Height [mm]	Tr [years]	Probability
108.20	42.00	0.024	53.01	1.91	0.524
99.08	21.00	0.048	52.69	1.83	0.548
88.52	14.00	0.071	52.41	1.75	0.571
72.47	10.50	0.095	51.91	1.68	0.595
72.40	8.40	0.119	50.87	1.62	0.619
66.76	7.00	0.143	50.45	1.56	0.643
63.07	6.00	0.167	49.86	1.50	0.667
62.67	5.25	0.190	48.12	1.45	0.690
62.43	4.67	0.214	47.62	1.40	0.714
62.27	4.20	0.238	46.96	1.35	0.738
62.23	3.82	0.262	43.49	1.31	0.762
60.32	3.50	0.286	43.19	1.27	0.786
58.36	3.23	0.310	42.81	1.24	0.810
57.41	3.00	0.333	42.77	1.20	0.833
56.00	2.80	0.357	41.81	1.17	0.857
54.75	2.63	0.381	41.23	1.14	0.881
54.53	2.47	0.405	41.19	1.11	0.905
53.45	2.33	0.429	40.60	1.08	0.929
53.38	2.21	0.452	37.88	1.05	0.952
53.37	2.10	0.476	35.09	1.02	0.976
53.05	2.00	0.500			

Source: CHIRPS satellite

In parallel, data were adjusted to the Normal Distribution, and the series was later submitted to the Kolmogorov-Smirnov (KS) test in order to compare the precipitation obtained by CHIRPS with the values of the normal distribution, finding values around 5%. Once the test provided Dmax ≤ Dlim it was admitted that the series of observations fits the Gaus Probability Distribution (Normal Distribution). Applying the Normal distribution, the maximum probable heights of 1 day (h) were obtained for return periods (Tr) of 2, 5, 10, 20, 50 and 100 years. Using the constant ratios between maximum annual precipitation of one day (rain gauge data) and precipitation of 24 hours and other durations (rain gauge data), proposed by Antônio Coimbra in "*Drenagem de Várzeas da Amazônia Ocidental*", the maximum probable heights (h) were estimated for durations (t) of 5, 10, 15, 20, 25 and 30 minutes and also for 1, 6, 8, 10, 12 and 24 hours. Table 5 shows the Maximum Probable Heights as a function of duration and return period.

Table 5: Probable Maximum Height

Duration	Tr (years)					
(min)	2	5	10	20	50	100
5	6.424	8.042	9.113	10.140	11.470	12.466
10	10.203	12.772	14.473	16.105	18.217	19.799
15	13.226	16.556	18.761	20.876	23.614	25.666
20	15.304	19.158	21.709	24.157	27.325	29.699
25	17.194	21.523	24.390	27.139	30.698	33.365
30	18.894	23.652	26.802	29.823	33.735	36.665
60	25.532	31.962	36.219	40.302	45.587	49.548
360	43.770	54.792	62.089	69.089	78.149	84.939
480	47.417	59.358	67.263	74.846	84.662	92.017
600	49.849	62.402	70.713	78.685	89.004	96.736
720	51.673	64.685	73.300	81.563	92.260	100.275
1440	60.792	76.100	86.235	95.957	108.541	117.971

Source: Authors (2022)

With the maximum probable heights (h) for durations (t) of 5, 10, 15, 20, 25 and 30 minutes and 1, 6, 8, 10, 12 and 24 hours, the maximum probable intensities (i) were calculated, for the same durations (t) of 5, 10, 15, 20, 25 and 30 minutes and 1, 6, 8, 10, 12 and 24 hours, shown in Table 6, and given by i [mm/min] = h [mm] / duration [min]. It can be seen that the maximum intensity increases as the return time also increases, i.e., among the 6 periods analyzed the Tr of 100 years presented the highest values of maximum rainfall intensity in all calculated time intervals (in minutes).

Table 6: Probable Maximum Intensity

Duration	Return Period (years)					
(min)	2	5	10	20	50	100
5	1.285	1.608	1.823	2.028	2.294	2.493
10	1.020	1.277	1.447	1.610	1.822	1.980
15	0.882	1.104	1.251	1.392	1.574	1.711
20	0.765	0.958	1.085	1.208	1.366	1.485
25	0.688	0.861	0.976	1.086	1.228	1.335
30	0.630	0.788	0.893	0.994	1.124	1.222
60	0.426	0.533	0.604	0.672	0.760	0.826
360	0.122	0.152	0.172	0.192	0.217	0.236
480	0.099	0.124	0.140	0.156	0.176	0.192
600	0.083	0.104	0.118	0.131	0.148	0.161

720	0.072	0.090	0.102	0.113	0.128	0.139
1440	0.042	0.053	0.060	0.067	0.075	0.082

Source: Authors (2022)

Design Flows

Finally, the summary of the calculation of the design flows for the channel in the project area is presented in Table 7.

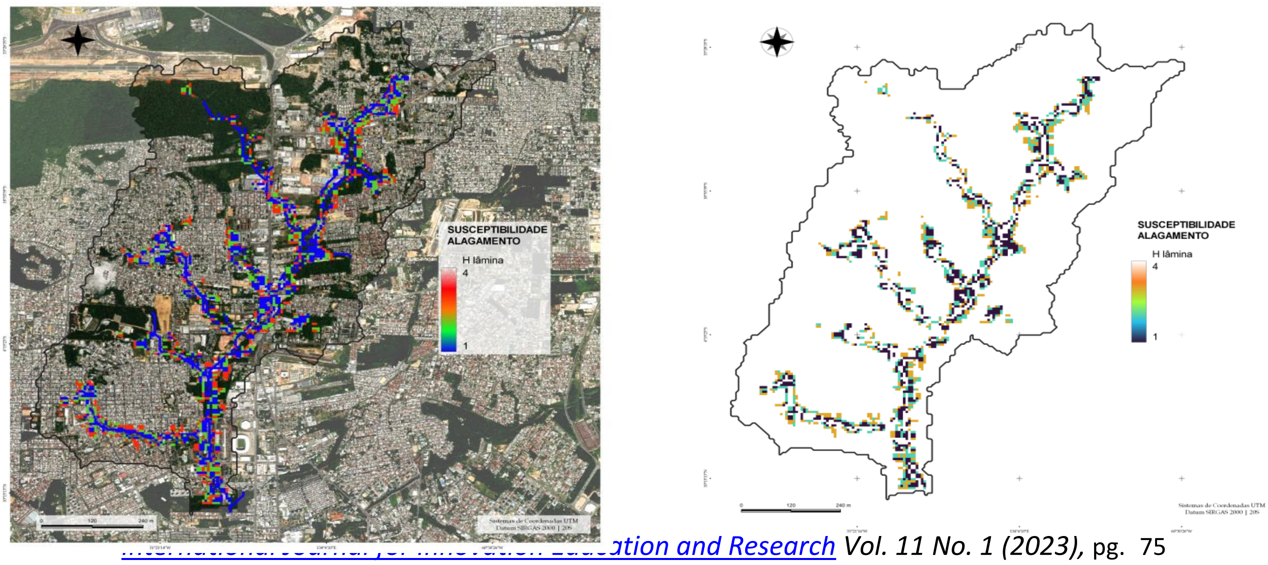
Tabela 9: Design Flows (Q)

STK	Point	Bi	H	H water depth (10 years rain)	H water depth (50 years rain)	Q PROJ (10 years)	Q PROJ (50 years)
0	1	13,22	2,81	10,52	13,57	151,87	195,82
0+5	2	12,67	2,82	10,20	13,15	139,84	180,31
0+10	3	17,80	3,16	5,46	7,04	123,05	158,65
0+15	4	15,86	3,16	5,60	7,22	108,60	140,02
0+20	5	13,44	3,29	5,08	6,55	80,27	103,50
0+25	6	11,02	3,30	6,48	8,36	78,38	101,06
0+30	7	12,32	3,56	4,73	6,10	68,38	88,17
0+35	8	6,40	4,07	5,85	7,54	33,32	42,97
0+40	9	10,96	4,26	1,89	2,44	24,03	30,99
0+45	10	5,53	4,27	2,16	2,79	10,05	12,96

Source: Authors (2022).

Using QGis it was possible to georeference the information presented in Table 7, such as the susceptibility of the Franceses Stream basin to flooding in the next 10 and 50 years (Figures 6a and 6b). In order to understand the role of urban settlements near the creek and the behavior of precipitation intensities estimated by the overflow curve model, it is important to check the behavior of the current water levels, presented in Figure 5.

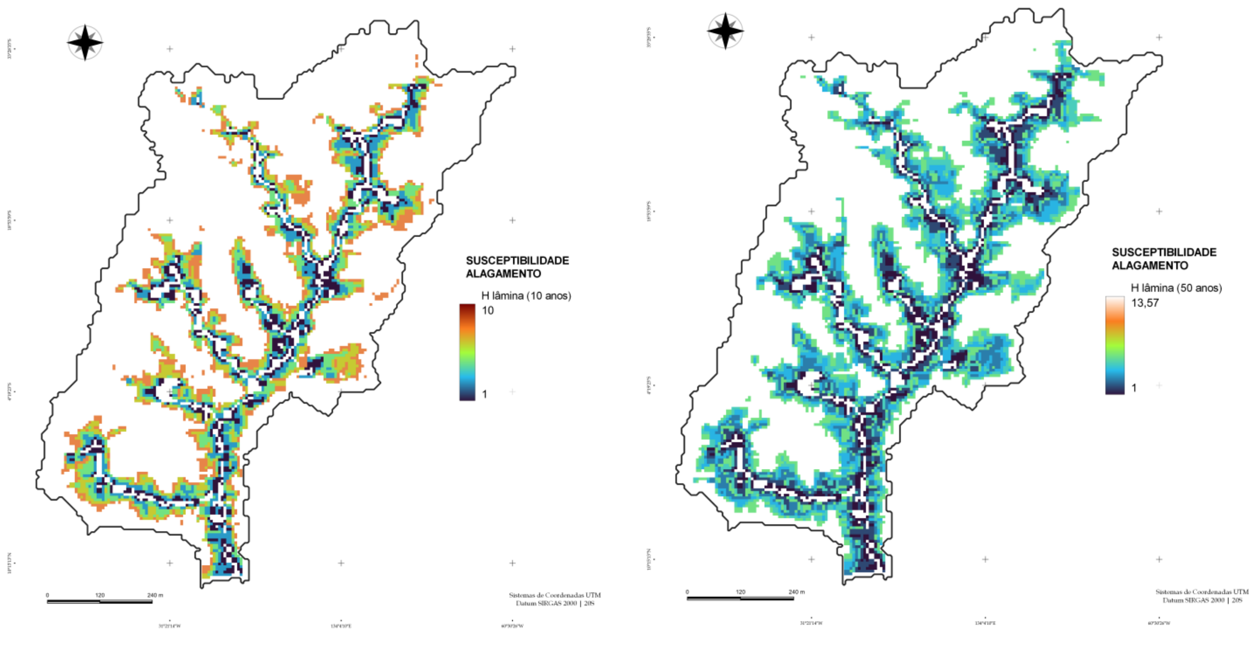
Figure 5: Overflow curve of the Franceses Stream for initial water depths.



Source: Authors (2022).

When comparing the behavior of the water depths in the initial period (Figure 5) and the curves estimated by the overflow curve model, it is noted that in 10 years there is a probability of an increase of 6 m in the water depth, allowing the water to enter the areas near the stream, as shown in Figure 6a. However, when analyzed for the 50-year period (Figure 6b) it appears that the increase in the water level is even greater, showing an increase of about 10 m in relation to the current situation, and almost 4 m in relation to Tr = 10 years, showing that there is a probability of flooding in areas very close to the banks of the creek, which will cause a great inconvenience to the population, considering that the area is basically composed of irregular occupations.

Figure 6: Overflow Map for a Rainfall; a) Tr =10 years; b) Tr = 50 years.



Source: Authors (2022).

4. Final Considerations

Knowing the characteristics of watersheds in urban environments is of utmost importance to support intervention measures and planning policies that ensure the protection of water resources and minimize disorder to the population. This study presented information about the Franceses Stream watershed, demonstrating that it is not subject to major flooding. It was also possible to verify that there are areas of preserved vegetation within the basin despite the intense occupation.

Although the chosen method is widely used in the literature, it becomes innovative because it uses precipitation data provided by the CHIRPS satellite product, which increased the accuracy of the calculations, since we had a larger area of rainfall measurement points. The physical coefficients of the studied basin indicate a good drainage capacity, but subject to flow peaks due to intense precipitation because of its low concentration time. The overflows of the gutters, caused by excessive sealing of the soil, generate high coefficients of water flow return to the channels of the streams, which cannot support the flow. A possible solution would be the widening and deepening of these channels, generating flow areas for peak flows.

Furthermore, a significant increase in the flood area was verified only with the change of the rainfall recurrence time. It is observed that for a normal rainfall, with Tr=10 years, the stream channel does not suffer major overflow, as opposed to Tr=50 years, impacting a larger number of dwellings, especially at the 0+45 stake. Finally, the work shows that GIS is a very valuable tool in the analysis and studies in hydrology, and it is necessary that it becomes an increasingly applied tool in urban management, so that the knowledge obtained is used to obtain better environmental and social conditions.

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