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Geosciences

Morphometric, land cover and land use, and flow analysis of the Irani River Basin, Santa Catarina, Brazil

Aspectos morfométricos, de cobertura e uso da terra, e análise de vazões da Bacia Hidrográfica do Rio Irani, Santa Catarina, Brasil

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ABSTRACT

The Irani River Basin, located in the Hydrographic Region – RH2, in the mid-west of the state of Santa Catarina, Brazil, is an important source of water for the region. The objective of this study is to evaluate the morphometric, environmental, and land use characterization of the Irani River Basin through data from the Shuttle Radar Topography Mission (SRTM), the MapBiomas project, the Environmental Information Bank – BDia from IBGE, and the Product MERGE-INPE/CPTEC with the aid of ArcGIS Pro software. It was sought to determine the permanence flows Q98, minimum flow Q7,10, maximum flow QMAX,10, and long-term flow QMLT with data from hydroweb ANA using the SisCAH 1.0 software. The Irani River Basin is 1599.88 km², with the main river measuring 198.35 km, considered 6th order. The average altitude of the basin is 823.26 m, and approximately 91.5% of the basin has a slope lower than 45%. The basin had a drainage density of 1.77 km/km², a shape factor of 0.04 m/m, a compactness coefficient of 2.39, and a river density of 0.43, indicating that the basin has an elongated and good configuration, water drainage capacity, therefore, a basin is not subject to major floods. Land use data showed that in the last 30 years there has been a significant increase in urbanized areas as well as soybean planting, in contrast, there has been a decrease in agricultural and pasture areas. Also noteworthy is an increase of approximately 3.6% in the area of forest formation in the last 30 years. Variability in the occurrence of precipitation was observed in the basin area, with volumes varying from 2597.94 mm/year in 2015 to 869.63 mm/year in 2012, during a dry period. The flow analysis at the Barca do Irani station showed that the flow Q98 is equal to 4.3 m³/s, Q7,10 is equal to 3.4 m³/s, QMLT is equal to 50.3 m³/s and QMAX,10 is equal to 1,203.1 m³/s. This basin presents itself as a strategic region from an economic point of view for the State of Santa Catarina, with the data presented being relevant for decision-making by river basin managers.

Keywords: Water availability; Hydrological regime; Sustainable planning

RESUMO

A Bacia do Rio Irani, localizada na Região Hidrográfica – RH2, no meio oeste do estado de Santa Catarina, Brasil, é uma importante fonte de água para a região. O objetivo deste estudo é avaliar a caracterização morfométrica, ambiental e de uso do solo da Bacia do Rio Irani através de dados do *Shuttle Radar Topography Mission* (SRTM), dados do projeto MapBiomas, do Banco de Informações Ambientais – BDia do IBGE e do Produto MERGE-INPE/CPTEC, com auxílio do software ArcGIS Pro. Buscou-se determinar as vazões de permanência Q_{98}, vazão mínima $Q_{7,10}$, vazão máxima $Q_{MAX,10}$ e de longo termo Q_{MLT} com dados do hidroweb ANA, utilizando o software SisCAH 1.0. A Bacia do Rio Irani tem 1599,88 km², com o rio principal medindo 198,35 km, considerada de 6ª ordem. A altitude média da bacia é de 823,26 m, e aproximadamente 91,5% da bacia apresenta declividade menor que 45%. A bacia apresentou densidade de drenagem de 1,77 km/km², fator de forma de 0,04 m/m, coeficiente de compacidade de 2,39 e densidade de rios de 0,43, indicando que a bacia possui configuração alongada e boa capacidade de escoamento das águas, logo, uma bacia não sujeita a grandes enchentes. Os dados de uso do solo mostraram que nos últimos 30 anos houve um aumento significativo da área urbanizada, bem como do plantio de soja, em contrapartida, um decréscimo das áreas de agricultura e pastagem. Destaca-se ainda um aumento de aproximadamente 3,6% da área da formação florestal nos últimos 30 anos. Foi observada uma variabilidade na ocorrência de precipitação na área da bacia, com volumes variando de 2597,94 mm/ano em 2015, a 869.63 mm/ano em 2012, durante um período de estiagem. A análise de vazões da estação Barca do Irani mostrou que a vazão Q_{98} é igual a 4,3 m³/s, $Q_{7,10}$ é igual a 3,4 m³/s, Q_{MLT} é igual a 50,3 m³/s e $Q_{MAX,10}$ igual a 1.203,1 m³/s. Esta bacia apresenta-se como uma região estratégica do ponto de vista econômico para o Estado de Santa Catarina, sendo os dados apresentados relevantes para tomadas de decisão dos gestores da bacia hidrográfica.

Palavras-chave: Disponibilidade de água; Regime hidrológico; Planejamento sustentável

1 INTRODUCTION

It is known that water represents a valuable resource for human consumption, industrial use, agricultural and livestock production (Ana, 2024, p. 40). The growing demand for this resource worldwide, joined by the deforestation of forests and population growth, can cause a significant increase in conflicts of use (Augusto et al., 2012). The characterization of river basins is an important tool for the management of water resources.

The hydrological cycle is commonly studied in the terrestrial phase, in which the essential unit of analysis is the river basin. This geographic region is delimited by drainage divides, in which precipitation is capted and converges to a single outlet point, called a basin outlet (Tucci, 2012).

According to Tucci (2012), the analysis of morphometric parameters of watersheds contributes to decision-making related to public policies, land use, establishment of communities, as well as issues related to the quantity and quality of water, allowing an assessment of future prospects. This contribution happens when studying these parameters and taking action based on these parameters like shape factor for example. The shape factor consists in the relationship between the average width and the axial length of the basin and is an indicative index of the flood tendency of a basin. A basin with a low shape factor is less prone to flooding than another basin of the same size but with a bigger shape factor (Rocha, 2022).

In Santa Catarina, the Irani River Basin is located in the Midwest Hydrographic Region, also known as RH2, which is a comprehensive area and includes two hydrographic basins in Santa Catarina: the Chapecó River Basin and the Irani River Basin, in addition to other adjacent basins with independent drainage systems. With a total extension of approximately 10,784 km² and a perimeter of 911 km, RH2 totally or partially covers 60 municipalities in Santa Catarina, which makes it a crucial element for regional development (Plano Estadual de Recursos Hídricos, 2009).

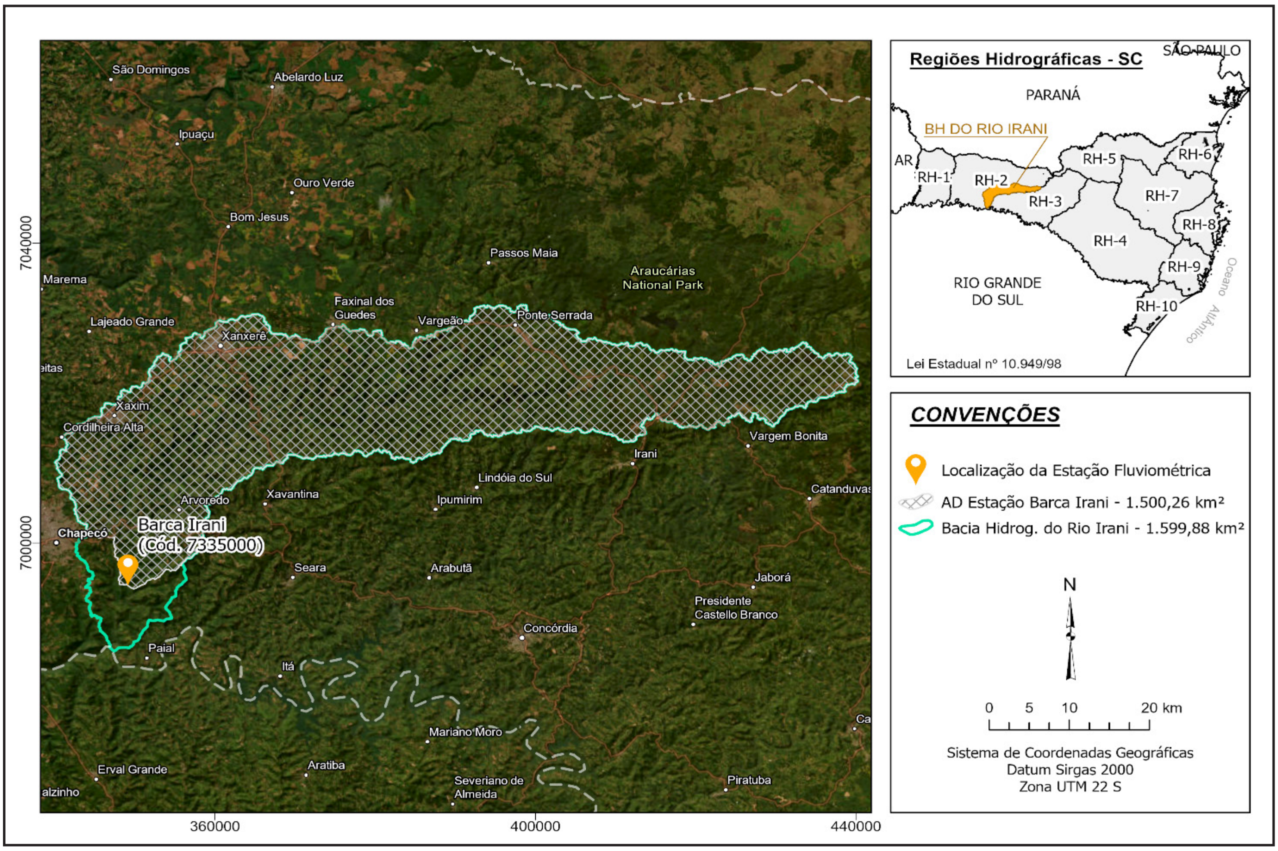
According to the study by Siviero and Rhoden (2020), the Irani River Basin, corresponding to 16% of the total area of RH2, covers 1,690 km², totally or partially involving 16 municipalities. Contiguous basins with independent drainage systems, in turn, total around 790 km², corresponding to 7% of the total area of RH2. As for altimetry, RH2 has an altimetric range of approximately 1,146 m, with altitude values ranging from 229 m to 1,375 m.

This study aims to evaluate the morphometric, environmental and land use characterization of the Irani River Basin, and analyze the flow data available in the basin. This article aims to provide contributions to managers of the RH2 Hydrographic Region and the Irani River Basin, promoting access to detailed information about the physical-geographical characteristics of the area. It is expected that these results will serve as a basis to guide future planning and territorial management guidelines. Comprehensive analysis of environmental, morphometric, land cover and land use data, together with quantitative information on surface waters, provides a deeper understanding of the water environment, contributing to sustainable and effective management of water resources in the region.

2 MATERIAL AND METHOD

The study area comprises the river basin of the Irani River which is located in the south of Brazil, in the west of Santa Catarina, but specifically in the RH2 Middle West Hydrographic Region (Santa Catarina, 1998), which integrates the River Basin Uruguay. Its area is located between the geographic coordinates 52°36'43.6" to 51°36'6.61" West longitude and 26°49'56.04" to 27°14'39.56" South latitude, as shown in Figure 1.

Figure 1 – Location map of the Irani River Basin and the Barca do Irani fluviometric station, Hydrographic Region – RH2 Midwest, SC



Source: Authors (2023)

The environmental characterization of the watershed was conducted using vector data from the Environmental Database and Information System (BDIA) of the Brazilian Institute of Geography and Statistics (IBGE), available at https://bdiaweb.ibge.gov.br/#/home (BDIA IBGE, 2023). Additionally, raster and statistical data from the MapBiomas program were used. The vegetation cover database of the biomes in Brazil used in this study corresponds to the statistics Collection 7.1. These area data are generated by algorithms that classify land use and land cover using pixels from Landsat image series through the Google Earth Engine platform (Mapbiomas, 2023). The data can be obtained at https://mapbiomas.org/estatisticas.

The morphometric characterization of the watershed was performed using Digital Elevation Models (DEM) of the study area. The DEM images were obtained from the website of the U.S. Geological Survey (USGS) and are products of the Shuttle Radar Topography Mission – SRTM (USGS, 2023).

The watershed was automatically delineated using the Strahler method (1964) in the ArcGIS Pro software. The tools used are found in ArcToolbox > Spatial Analyst Tools > Hydrology, including the Flow Direction, Flow Accumulation, Con, Stream to Feature and Watershed functions. It is important to highlight that the raster data underwent data filling pre-processing using the Fill function, also found in spatial analysis tools.

The drainage area of the watershed is defined as the flat area in square kilometres (km^2) that lies between the ridges or topographic dividers (Villela & Mattos, 1980). The calculation of the drainage area was performed using ArcGIS Pro software, employing the Calculate Geometry function after projecting the watershed polygon to the projected coordinate system, Datum SIRGAS 2000, zone 22 South.

River ordering is a classification system that allows rivers to be ranked based on their position in relation to other rivers within the watershed. This system is based on the concept of river order, which is determined by the watercourse's position in relation to its confluence with other watercourses. A first-order river is one that has no tributaries, while a second-order river is formed by the confluence of two first-order rivers. A third-order river is formed by the confluence of two second-order rivers, and so on. The river order was determined by following the upstream watercourse and identifying the order of its tributaries (Villela & Mattos, 1980). The Strahler method was used to classify the river order using the ArcGIS Pro software and the tools in ArcToolbox > Spatial Analyst Tools > Hydrology, including the functions Fill, Flow Direction, Flow Accumulation, Con, and Stream to Order.

The form factor (Kf) is an index that relates to the time it takes for water to travel the distance from the boundaries of the watershed to the outlet or pour point. This index is calculated from the ratio of the average width to the axial length of the watershed using the following formula (Villela & Mattos, 1980):

$$Kf = \frac{A}{L^2} \tag{1}$$

Where Kf represents the form factor (dimensionless), A represents the watershed area in square kilometres (km²), and L represents the axial length of the watershed in kilometres (km)

The compactness index (Kc) is a measure that relates the perimeter of the watershed to the circumference of a circle with the same area as the watershed. This index is obtained using the following formula (Villela & Mattos, 1980):

$$Kc = 0{,}28 * \frac{P}{\sqrt{A}} \tag{2}$$

Where Kc represents the compactness index (dimensionless), A represents the watershed area in square kilometres (km²), and P represents the perimeter of the watershed in kilometres (km)

According to Villela and Mattos (1980), drainage density can be used as a measure of the efficiency of the drainage system in a watershed. Watersheds with high drainage density tend to have faster runoff, which can lead to floods and soil erosion. On the other hand, watersheds with low drainage density tend to have slower runoff, favoring water infiltration into the soil and aquifer recharge. To calculate the drainage density

(Dd), the Stream to Feature output shapefile, which had previously been clipped and delimited by the watershed, was used in ArcGIS Pro. The dissolve tool was applied to the shapefile based on the GRIDCODE attribute to calculate the total length of rivers present in the watershed. The drainage density (Dd) was then calculated using the following formula:

$$Dd = \frac{\sum L}{A} \tag{3}$$

Where Dd represents the drainage density, L represents the total length of rivers, and A represents the area of the watershed

According to Horton (1945), river density is a measure of the intensity of river development in a watershed. It is defined as the ratio of the total number of first-order or headwater streams to the watershed area (Horton, 1945).. The formula proposed by Horton for calculating river density is:

$$Dr = \frac{\sum N}{A} \tag{4}$$

Where Dr represents the river density, N represents the total number of first-order or headwater streams, and A represents the drainage area of the watershed

When executing the formula for calculating river density, only the first-order channels are considered. River density is an important aspect to consider as it reflects the hydrographic behaviour of an area and its capacity to generate new drainage channels (Christofoletti, 1980).

The hypsometric curve was obtained from the digital elevation model (DEM). Subsequently, a reclassification was performed, defining altitude intervals of 100 meters. The resulting raster was converted to a polygon vector format, allowing quantification of the areas corresponding to each altitude interval, as well as the cumulative area and total area as a percentage.

For the longitudinal profile curve of the main river and the slope of the main river, the values were obtained through interpolation of the shapefiles of the main river and the DEM, which had been previously clipped by the watershed, using the 3D Analyst > Function Surface > Interpolation Shape tool in ArcGIS Pro.

Then in Excel, the curve with the river profile was plotted, and the total slope (DT) of the river in meters per meter was determined using the following equation:

$$Dt = \frac{(Upstram\ Elevation - Downstram\ Elevation)}{River\ Length} \tag{5}$$

For the analysis of accumulated precipitation in the Irani River watershed, the values of the MERGE/INPE-CPTEC product by Rozante et al. (2010) were extracted and processed in ArcGIS PRO. These data were evaluated on a monthly, seasonal and annual basis over the period 2001 to 2020, allowing a comprehensive understanding of rainfall patterns over time. This temporal analysis approach gives insights into the monthly, seasonal and annual variability of precipitation in the region.

2.1 Flow Analysis of the River Irani Basin Hydrometric Station

Water availability was obtained by considering the flows of permanence and drought. As specified in Article 2 of Ordinance SDS nº 043/2010, when evaluating the water availability for withdrawals from watercourses in Santa Catarina, the reference flow Q98 is utilized. The grantable flow is determined as 50% of the reference flow at all control sections in the basin, in conformity with the lack of conflicts. The third paragraph stipulates that individual consumptive usage cannot surpass 20% of the conceivable flow in each river segment, though for human use it can extend up to 80%, with rational criteria (Portaria SDS 043/2010, of 08/13/2010). While the ordinance doesn't specify whether the permanence flow – Q98 should be calculated from daily or monthly flow data, it is advisable during conflicts to rely on Q95 derived from daily flows, much more stringent than Q98 based on monthly flows.

The flow of permanence was analyzed through the frequency of flow occurrences at the river section of the watershed, with the 98% flow of permanence being used, which represents the average flow exceeded or equaled 98% of the time. The drought or minimum flow used was the Q7,10, which corresponds to the minimum flow of 7 consecutive days with a return period of 10 years. The calculations were performed using the *Sistema Computacional para Análises Hidrológicas – SisCAH 1.0 software*.

The SisCAH 1.0 is a computer system designed to work on Windows, allowing to import data from files obtained from the ANA's website, and from these obtain information such as maximum, minimum and average flows, for example (Souza et al., 2009). SisCAH 1.0 was developed for the treatment of historical series of hydrological data (Souza et al., 2009).

The flow data was obtained from Hidroweb, a platform provided by the National Water Agency (ANA, 2022). The selected station is called Barca Irani and is located on the Irani River, Sub-Basin 73 – Uruguai, Chapecó, and Others, Basin 7 – Rio Uruguai. Table 1 presents the remaining data for the mentioned station.

Table 1 – Data from the ANA's river monitoring station, Barca do Irani, located on the Irani River, in the city of Chapecó, Santa Catarina, Brazil

Parameter	Information
River gauging station code	7335000
Station name	Barca Irani
State	Santa Catarina
Municipality	Chapecó
Hydrographic basin	7 – Rio Uruguai
Sub-basin	73 – Rios Uruguai, Chapecó e outros
Drainage area (km^2)	1500
River name	Rio Irani
Responsible Entity	ANA
Operator	CPRM
Latitude	-27,1656
Longitude	-52,5228
Elevation (m)	280
Drainage area (km^2)	1500

Source: National Water Agency – ANA (2022)

The choice of this river monitoring station is justified by the data series that begins from 1969, and by the fact that the other upstream river monitoring stations have a poorly representative sample series. Figure 1 shows the location of the Barca Irani River Monitoring Station and its respective drainage area. The time frame of the analyzed data ranges from 1969 to 2014. Years with data failures exceeding 5% were excluded.

3 RESULTS AND DISCUSSION

The characteristics of the river basin have diverse impacts on the local community, biodiversity and regional planning. The basin's topography influences the distribution and intensity of floods, directly affecting riverside communities and local economic activities, such as agriculture and fishing. Furthermore, the vegetation present in the basin plays a crucial role in conserving biodiversity, regulating the hydrological cycle and protecting against soil erosion. Land use in the basin, including activities such as deforestation and urbanization, can result in negative impacts on water quality, soil erosion and loss of natural habitats, thus affecting biodiversity. In regional planning, the characteristics of the basin, such as its water storage capacity and hydroelectric potential, are considered in the management of water resources, in territorial planning and in the development of infrastructures, such as dams and water supply systems.

3.1 Morphometric Characterization of the Irani River Basin

The Irani River Basin, located in the RH2 Midwest Hydrographic Region, is responsible for draining its waters into the Uruguay River. The morphometric characteristics of this basin are described by the parameters in Table 2. The Irani River watershed has a considerable area of 1,599.88 km^2, being classified as large. The form factor – Kf equal to 0.04 is less than 0.5 and the compactness coefficient – Kc above 1.5 indicate that the basin is not subject to occurrences of large floods and inundations. This suggests a more elongated configuration of the basin, which favours a more efficient flow of water. A river density (Dr) of 0.43 points to a moderate proportion of watercourses in relation to the basin area, indicating a relatively low drainage network. In addition, the drainage density (Dd-h) of 1.77 km/km² shows a good flow capacity and fast flow of water within the watershed.

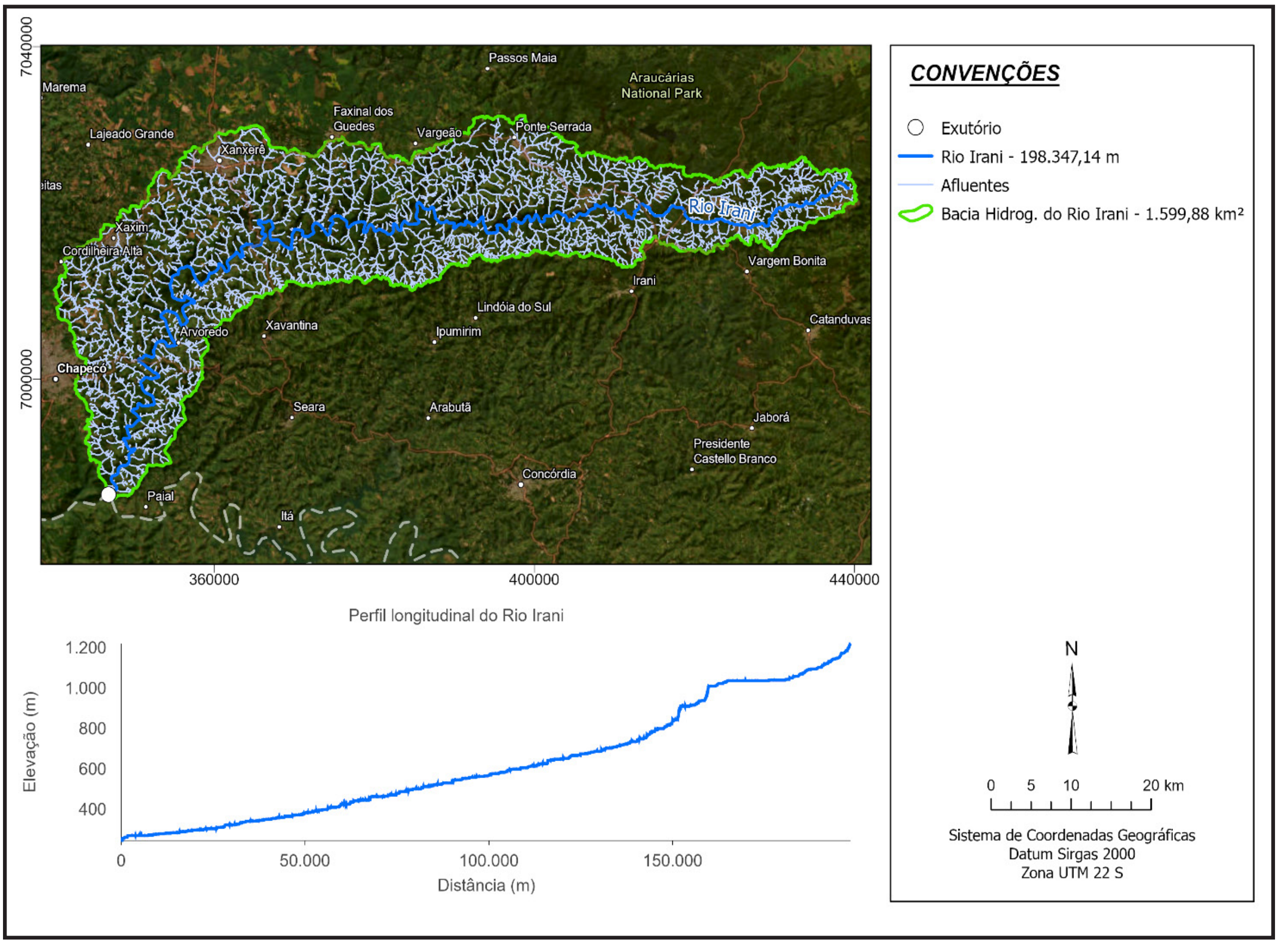
Table 2 – Morphometric characteristics of the Irani River watershed – SC

Morphometric Parameters	Results
Area (km²)	1.599,88
Perimeter (km)	341,12
Average width of the basin (km)	8,07
Amount quota (m)	1.221,00
Downstream Quota (m)	245,00
Slope (m/m)	0,005
Length of the Main River (m)	198.347,14
Length of the Main River (km)	198,35
Σ Length of rivers (m)	2.836.807,20
Nº of 1st Order Rivers	683
Compactness Coefficient - Kc	2,39
Form Factor - Kf	0,04
Density of Rivers - Dr	0,43
Drainage Density - Dd-h (km/km²)	1,77

Source: Organized by the authors (2023)

Figure 2 presents the longitudinal profile of the main river in the Irani River Basin, together with the hydrographic network. This information provides a more comprehensive view of the structure and functioning of the basin, being of great importance for the planning and management of water resources in the region. Given that in higher altitude areas, where there are springs and aquifer recharge areas, there is potential for capturing and storing quality water. The basin's drainage network is essential for understanding water flow, allowing land use planning, and influencing the distribution of natural resources. Furthermore, the topography and drainage network help identify areas at risk of landslides, floods, and other disasters.

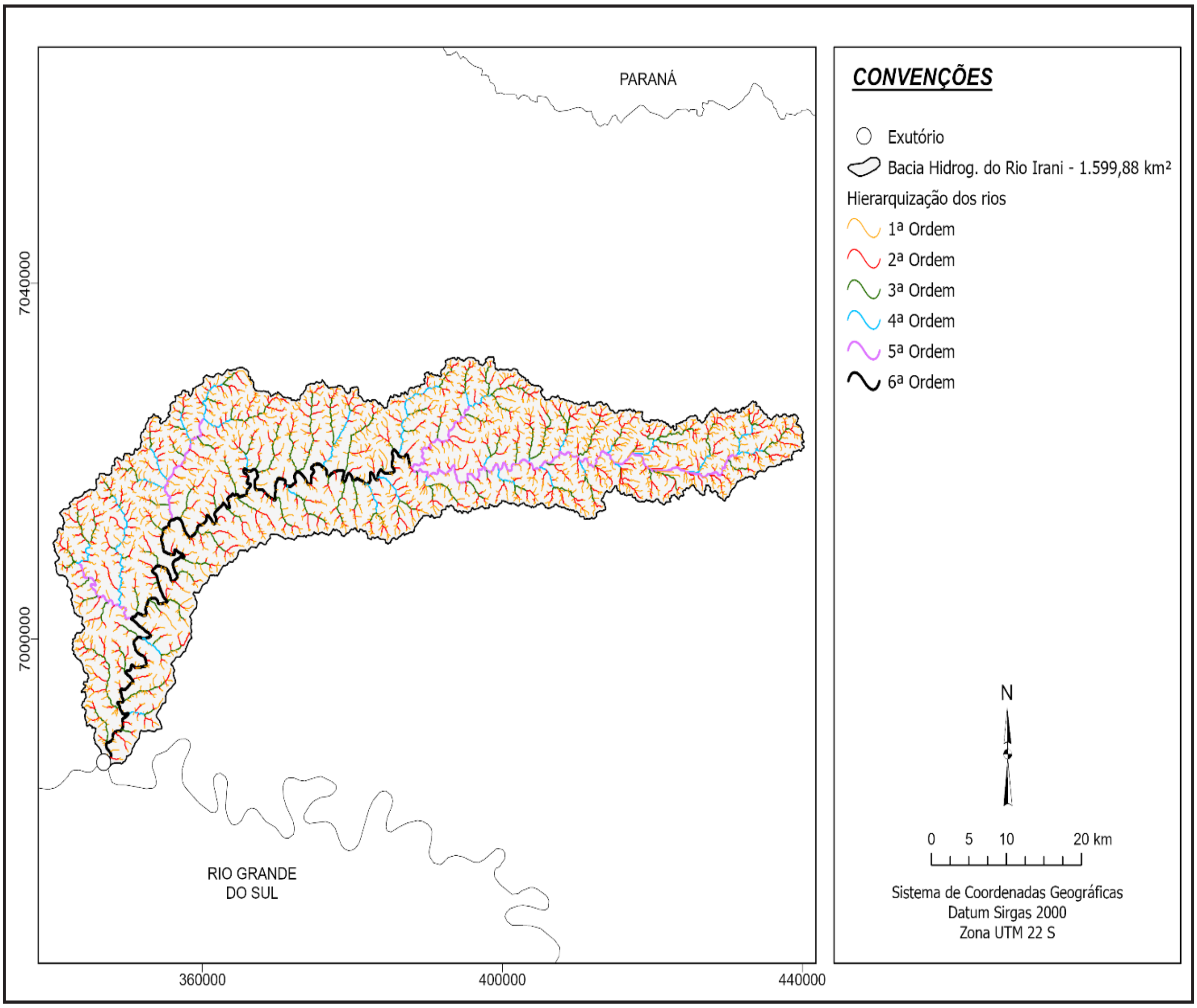
Figure 2 – Hydrography and longitudinal profile of the Irani River Basin – SC



Source: Authors (2023)

The Irani River watershed presents the Irani River as a 6th order river. This classification indicates that the Irani River plays a key role in catching and transporting water in the basin. The hierarchy of the rivers is important to understand the hydrological dynamics of the region, since the higher order rivers have a larger catchment area, receiving contributions from an extensive territorial area. Figure 3 shows the map with the fluvial hierarchization of the Irani River.

Figure 3 – Fluvial hierarchy of the Irani River Basin – SC



Source: Authors (2023)

The Irani River Basin presents a significant altimetric variation, with altitudes ranging from a minimum altitude of 245 meters to a maximum altitude of 1294 meters. The average altitude of the basin is 823.26 meters, while the median altitude is 833.53 meters. These altimetric values indicate an area with varied relief and a large altimetric amplitude. Table 3 below shows the altitude classes as well as the corresponding elevations and areas.

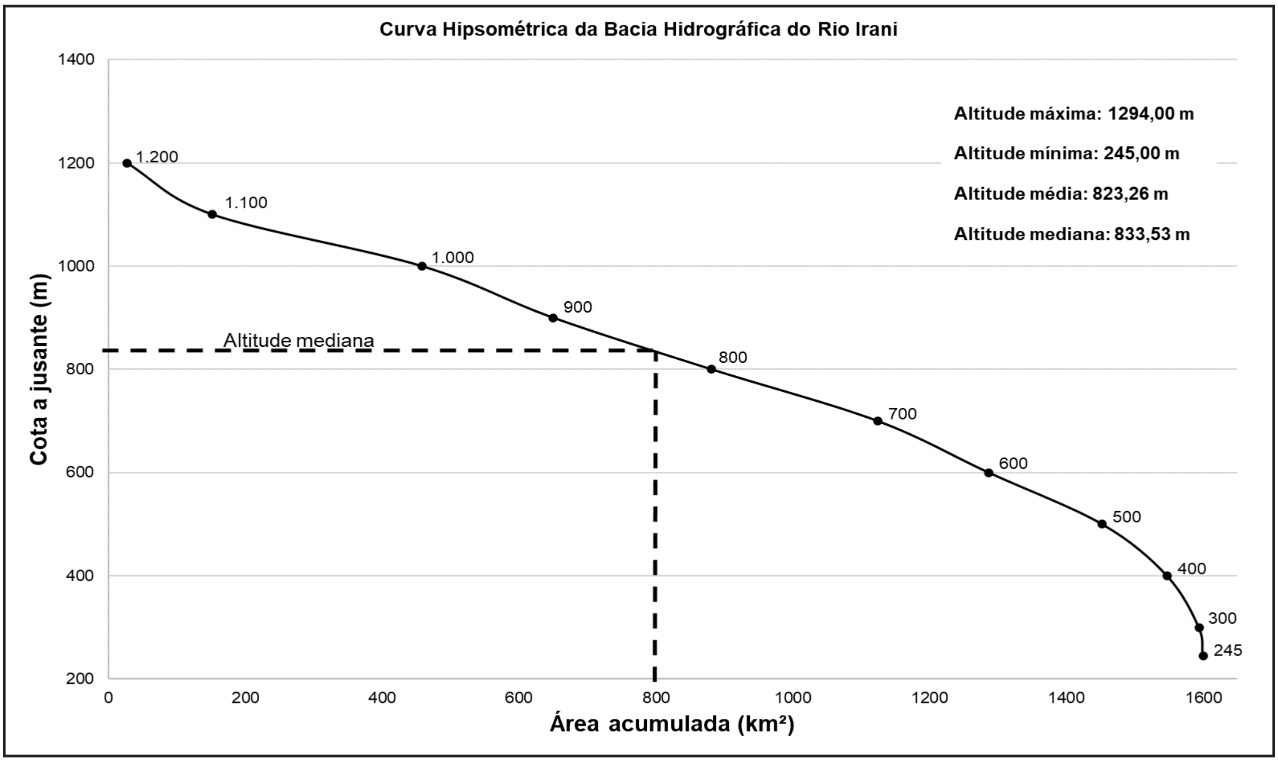
Table 3 – Altitude classes and corresponding areas of the Irani River Basin

Altitude Classes (m)	Upstream Elevation (m)	Downstream Elevation (m)	Mean Elevation (m)	Relative Elevation (m)	Surface Area (km²)	Accumulated Area (km²)	Relative Area (%)
(1200 - 1294)	1294	1200	1247	1,00	26,47	26,47	1,65%
(1100 - 1200)	1200	1100	1150	0,92	125,41	151,88	9,49%
(1000 - 1100)	1100	1000	1050	0,84	306,01	457,89	28,62%
(900 - 1000)	1000	900	950	0,76	191,93	649,82	40,62%
(800 - 900)	900	800	850	0,68	231,45	881,28	55,08%
(700 - 800)	800	700	750	0,60	242,60	1123,88	70,25%
(600 - 700)	700	600	650	0,52	162,42	1286,30	80,40%
(500 - 600)	600	500	550	0,44	165,98	1452,29	90,77%
(400 - 500)	500	400	450	0,36	94,97	1547,25	96,71%
(300 - 400)	400	300	350	0,28	46,67	1593,92	99,63%
(245 - 300)	300	245	272,5	0,22	5,96	1599,88	100,00%

Source: Organized by the authors (2023)

By analyzing the hypsometric curve of the Irani River Basin, it's possible to observe the distribution of altitudes along the study area (Figure 4). The hypsometric curve shows that the main river can present a certain erosive potential, it also shows different altitude classes, each one of them representing a specific altimetric range. It is observed that the area with higher altitudes is between 1200 and 1294 meters and covers an area of 26.47 km², representing 1.65% of the total area of the basin. It can observed that as altitude decreases, area increases, indicating a greater extent of land at lower altitudes.

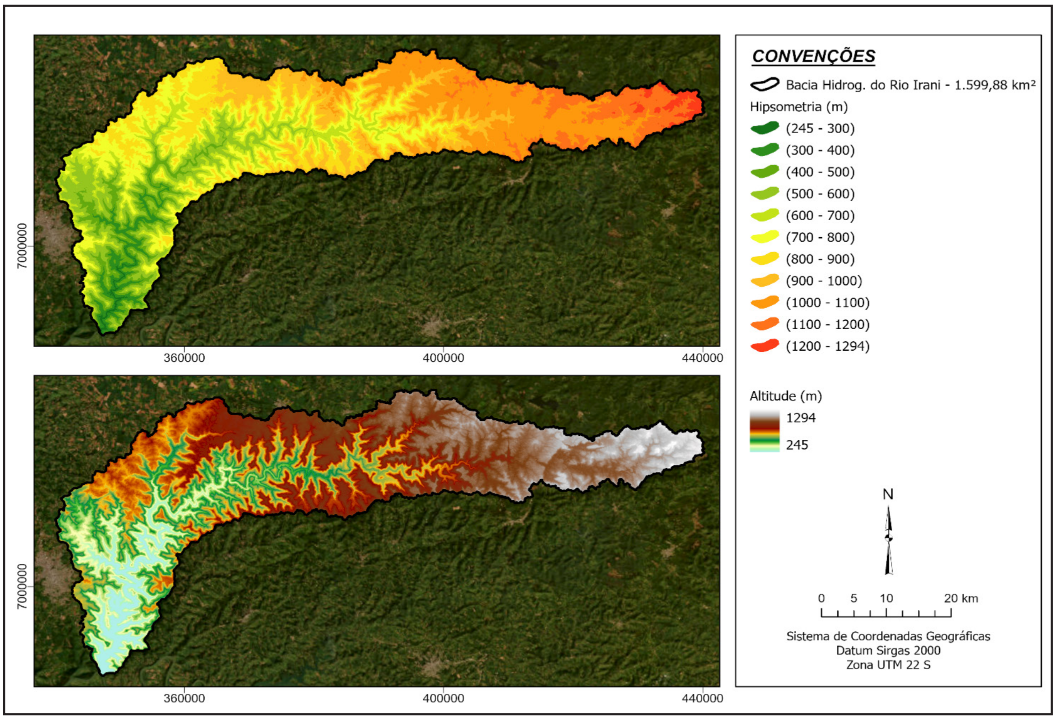
Figure 4 – Hypsometric curve of the Irani River Basin – SC



Source: Authors (2023)

The hypsometric curve also demonstrates that the largest area of the Irani River Basin is concentrated at altitudes between 1000 and 1100 meters, covering an area of 306.01 km², which corresponds to 28.62% of the relative area of the basin. It can see that as the altitude continues to decrease, the area gradually increases, showing a progressive distribution at lower altitudes. The area with altitudes between 400 and 500 meters, for example, has a surface area of 94.97 km², representing 5.94% of the total area of the basin. Figure 5 shows the hypsometry and altitude of the basin.

Figure 5 – Hypsometric and Elevation Maps of the Irani River Basin – SC



Source: Authors (2023)

The watershed of the Irani River has a variety of slopes along its relief. The analysis of the distribution of slope classes, according to the criteria established by Embrapa (1979), reveals the characteristics of this distribution in the basin, as shown in Table 4.

Table 4 – Relief and slope classes of the Irani River Basin – SC

Relief	Slope Class (%)	Area (km²)	Area (%)
Flat	0 - 3%	49,93	3,12%
Soft wavy	3 - 8%	268,63	16,79%
Wavy	8 - 20%	539,34	33,71%
Strong wavy	20 - 45%	605,35	37,84%
Mountainous	45 - 75%	133,55	8,35%
Steep	> 75%	3,09	0,19%
Total	-	1599,88	100,00%

Source: Organized by the authors (2023)

A small portion of the basin area, corresponding to 3.12% and covering an area of 49.63 km², is classified as flat, with slopes between 0 and 3%. These flat areas are associated with wide valleys and valley bottoms, where water flow occurs more slowly.

The next grade of slope is called smooth undulating, with grades ranging from 3% to 8%. This class covers an area of 267.04 km², corresponding to 16.79% of the total area of the basin. The gently undulating relief is characterized by hills and small elevations, providing an efficient flow of water.

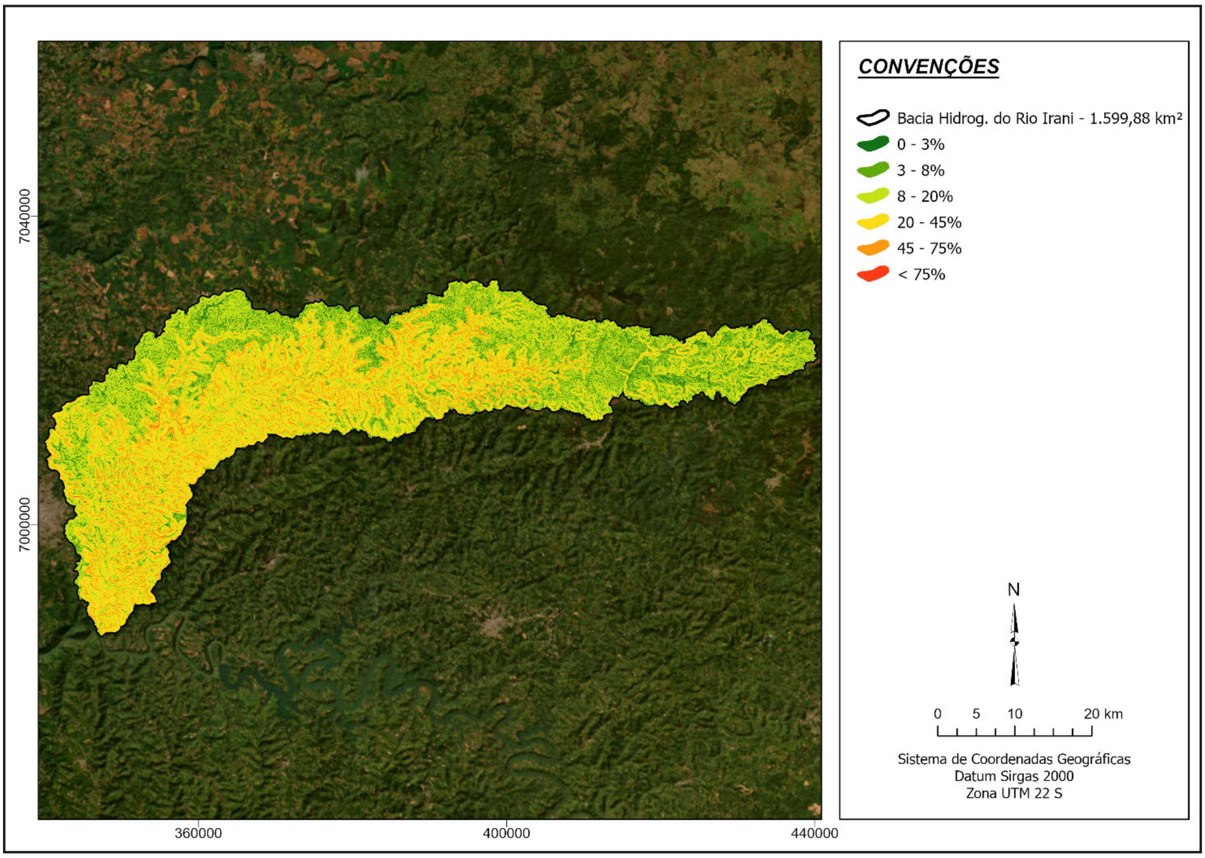
The undulating slope class, with slopes between 8% and 20%, represents a significant area of 536.15 km², corresponding to 33.71% of the basin area. In this type of relief, there are more pronounced hills and areas with a greater potential for erosion.

The portion of the basin classified as strongly undulating, with slopes between 20% and 45%, covers an area of 601.77 km², corresponding to 37.84% of the total area. This class is characterized by steep hills and steep slopes, presenting a higher risk of erosion and faster runoff. The mountainous class encompasses slopes between 45% and 75%, representing an area of 132.76 km², corresponding to 8.35% of the total area. In this type of relief, there are mountainous areas and very steep slopes, which directly influence the speed of surface runoff and the occurrence of more intense erosion processes. Figure 6 shows the slope map of the basin.

Topography, basin shape, drainage network and land use directly influence processes such as water runoff, aquifer recharge, soil erosion and the basin's response to climate change. Basins with mountainous relief tend to have faster runoff and more pronounced flood peaks, while flat areas accumulate more water and have slower runoff. Land use distribution and vegetation affect soil water infiltration and erosion, with implications for water quality and soil stability.

The morphometric characteristics of a river basin influence both land use patterns and water availability. Areas with mountainous relief tend to have a greater slope, which can limit land use for agricultural and urban purposes and increase the potential for soil erosion. Furthermore, the shape of the basin as well as the type of vegetation affects the distribution of precipitation and water runoff, influencing the availability of water in different parts of the basin. The drainage network also plays an important role in water availability, determining how water is collected and transported throughout the basin.

Figure 6 – Slope of the Irani River Hydrographic Basin – SC.



Source: Authors (2023)

3.2 Environmental Characterization of the Irani River Basin

The Irani River watershed presents a variety of vegetation types, which are classified according to the Phytoecological Regions or Predominant Vegetation Types (IBGE, 2012). The Seasonal Deciduous Forest occupies an area of 123.11 km², corresponding to 7.69% of the total basin. This vegetation is characterized by losing its leaves during the dry season, adapting to the seasonal conditions of the region's climate (IBGE, 2009).

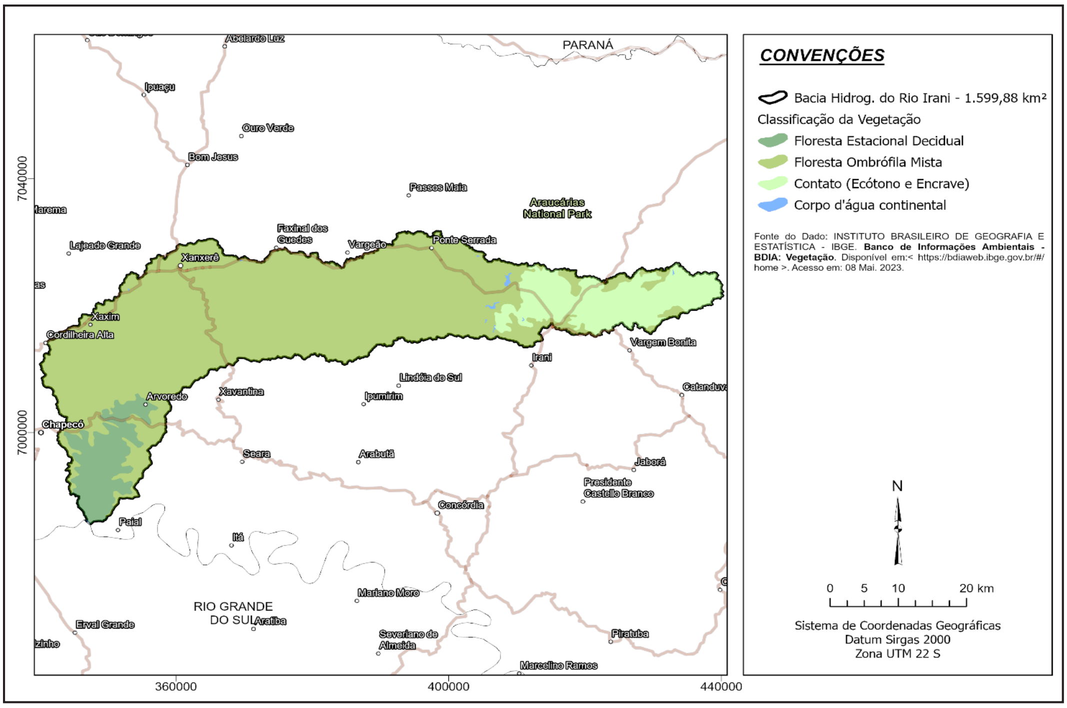
The Mixed Ombrophylous Forest is predominant in the basin, covering an extensive area of 1,265.60 km², which corresponds to approximately 79.11% of the total surface. This type of vegetation is characterized by the presence of tree species that adapt both to conditions of high rainfall and seasonal variations in climate, presenting a rich biodiversity (IBGE, 2009).

In addition, there are contact areas, also known as ecotones and enclaves, which total 208.51 km², representing 13.03% of the basin. These regions are characterized by the transition between different types of vegetation, forming an interface between ecosystems and favoring species diversity (IBGE, 2009).

The presence of continental water bodies, such as rivers, lakes and ponds, is also relevant in the basin, occupying an area of 2.66 km², corresponding to 0.17% of the total. These areas play a key role in the region's ecological balance, providing habitat for a variety of aquatic species and influencing the availability of water resources.

Taken together, these different vegetation types contribute to the ecological richness of the Irani River Basin, playing important roles in biodiversity conservation, water regulation and provision of ecosystem services to the region. Figure 7 below shows the vegetation map of the Irani River Basin.

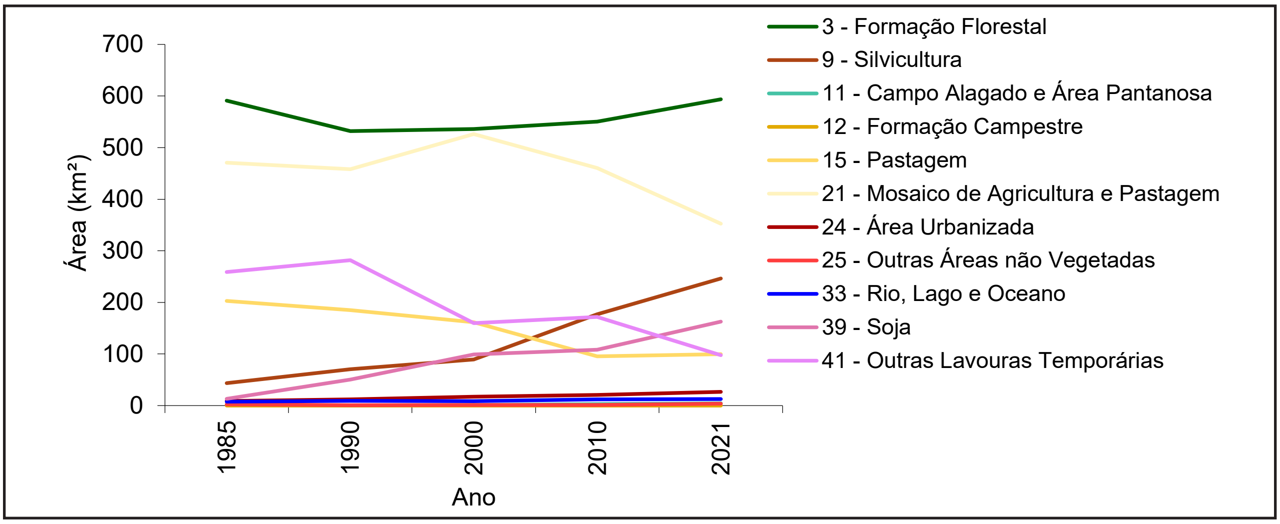
Figure 7 – Vegetation types of the Irani River Basin – SC



Source: Authors (2023)

Based on data extracted from the Project MapBiomas collection 7.1, changes in land use area in the years 1985, 1990, 2000, 2010 and 2021 in the Irani River watershed were analyzed (Figure 8).

Figure 8 – Area variation of land use and occupation during the years 1985, 1990, 2000, 2010 and 2021 in the Irani River Basin – SC, data from the 7.1 collection of the MapBiomas Project



Source: Organized by the authors (2023)

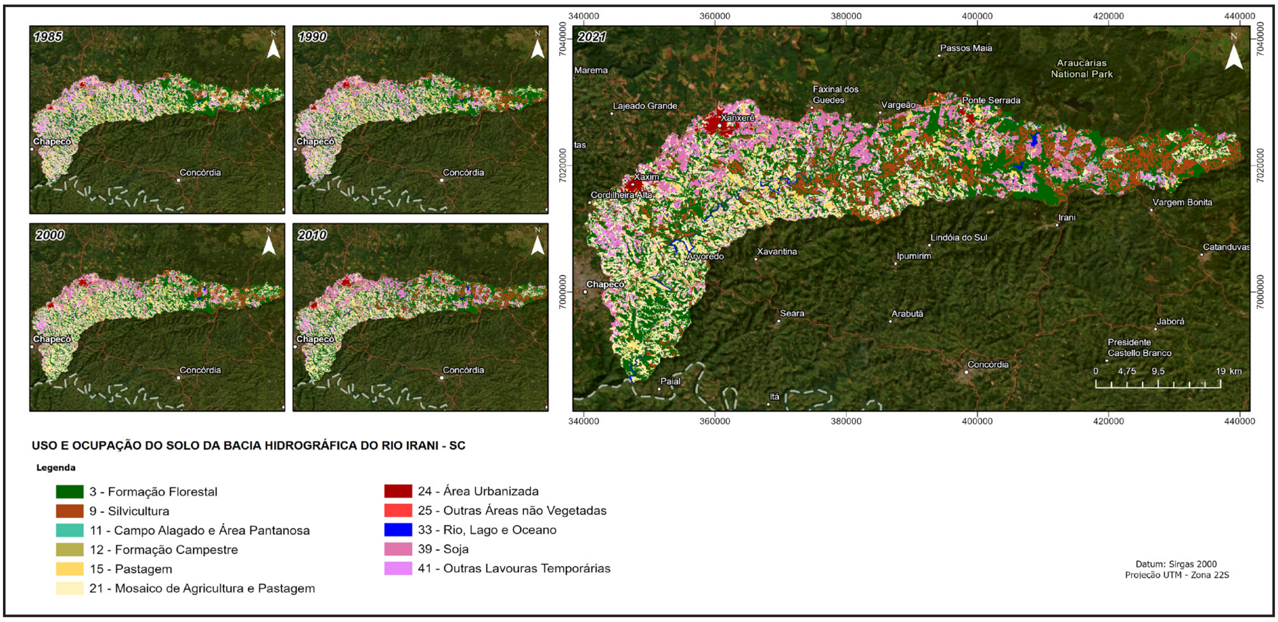
The Forest Formation – Category 3 plays a crucial role in the preservation of water resources and biodiversity. During the analyzed period, the area of forest formation remained relatively stable, increasing from 590.85 km² in 1985 to 593.58 km² in 2021. This consistency underscores the importance given to the conservation of these areas.

Forestry Plantation – Category 9, which represents areas intended for planting and forest management for commercial purposes, recorded significant growth over time. The area destined for forestry increased from 43.51 km² in 1985 to 246.29 km² in 2021. This increase reflects the demand for wood resources and the development of forestry activities in the region. On the other hand, the Pasture – Category 15, showed a gradual reduction over the years, going from 202.83 km² in 1985 to 99.69 km² in 2021. This decrease may indicate changes in the pattern of land use, such as the substitution of pasture for other types of occupation or the intensification of agricultural production in smaller areas.

There is a significant increase in the Urbanized Area – Category 24, reflecting the process of urbanization and urban growth in the region. The urbanized area increased from 8.80 km² in 1985 to 26.61 km² in 2021. This phenomenon is associated with economic development and population concentration in the urban areas of the watershed.

Also noteworthy is the significant growth in the area destined for Soybean – Category 39, which increased from 13.10 km² in 1985 to 162.70 km² in 2021. This increase reflects the expansion of commercial agriculture and the economic relevance of this crop in the region. Figure 9 – shows the land use and land cover in the Irani River Basin – SC.

Figure 9 – Land use and land cover in the Irani River Basin – SC. Information from the 7.1 collection of the MapBiomas project



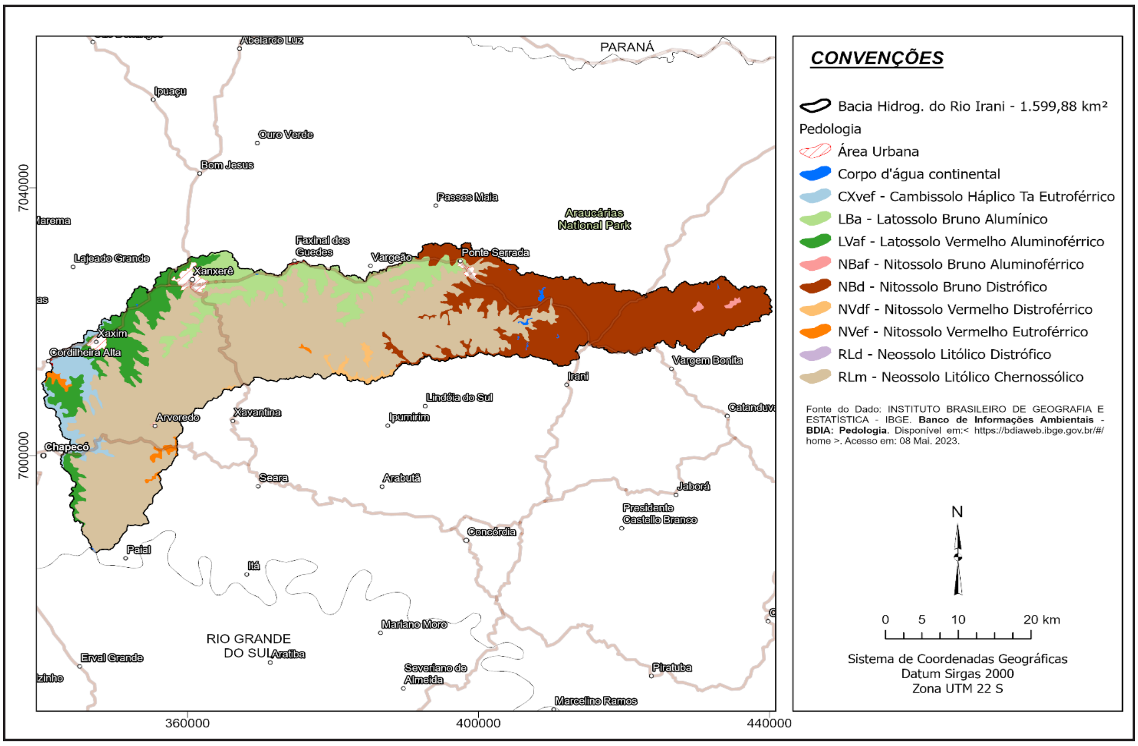
Source: Authors (2023)

Regarding Geology, the Irani River watershed is inserted in the structural subprovince of Serra Geral, covering an area of 1597.22 km², which corresponds to 99.83% of the total area of the basin (Table 5). Serra Geral is a geological unit that extends through several regions of Brazil, characterized by basaltic rocks formed during the Mesozoic period. These rocks are the result of volcanic lava flow and have a stratified arrangement, forming extensive areas of plateau (Silva, 2015).

The pedology of the basin reveals the presence of different types of soils that play an important role in the characterization and use of land in the region. Among the main types of soil identified, the following must be highlighted: the Cambisol Haplic Ta Eutroférrico (CXvef) – 3.08%, the Latosol Bruno Alumínico (LBa) – 8.50%, the Latosol Vermelho Aluminoférrico (LVaf) – 7.20%, the Nitosol Bruno Aluminoférrico (NBaf) – 0,19%, the Nitosol Bruno Distrófico (NBd) – 23.99%, the Dystroferric Red Nitosol (NVdf) – 0.67%, the Eutroferric Red Nitosol (NVef) – 0,63%, the Dystrophic Litholic Neosol (RLd) – 0,01% and the Chernosolic Litholic Neosol (RLm) – 54.33%, with 1.4% of the basin area corresponding to urbanized areas and bodies of water.

This diversity of soils reflects the variability of edaphic factors, such as texture, structure, fertility and mineralogy, which influence the characteristics and potential use of land in the watershed. These soils play different roles in agricultural production, water absorption and retention, nutrient cycling and the sustainability of the ecosystems present in the region. Figure 10 shows the soil types of the Irani River Basin.

Figure 10 – Soil types of the Irani River Basin – SC



Source: Authors (2023)

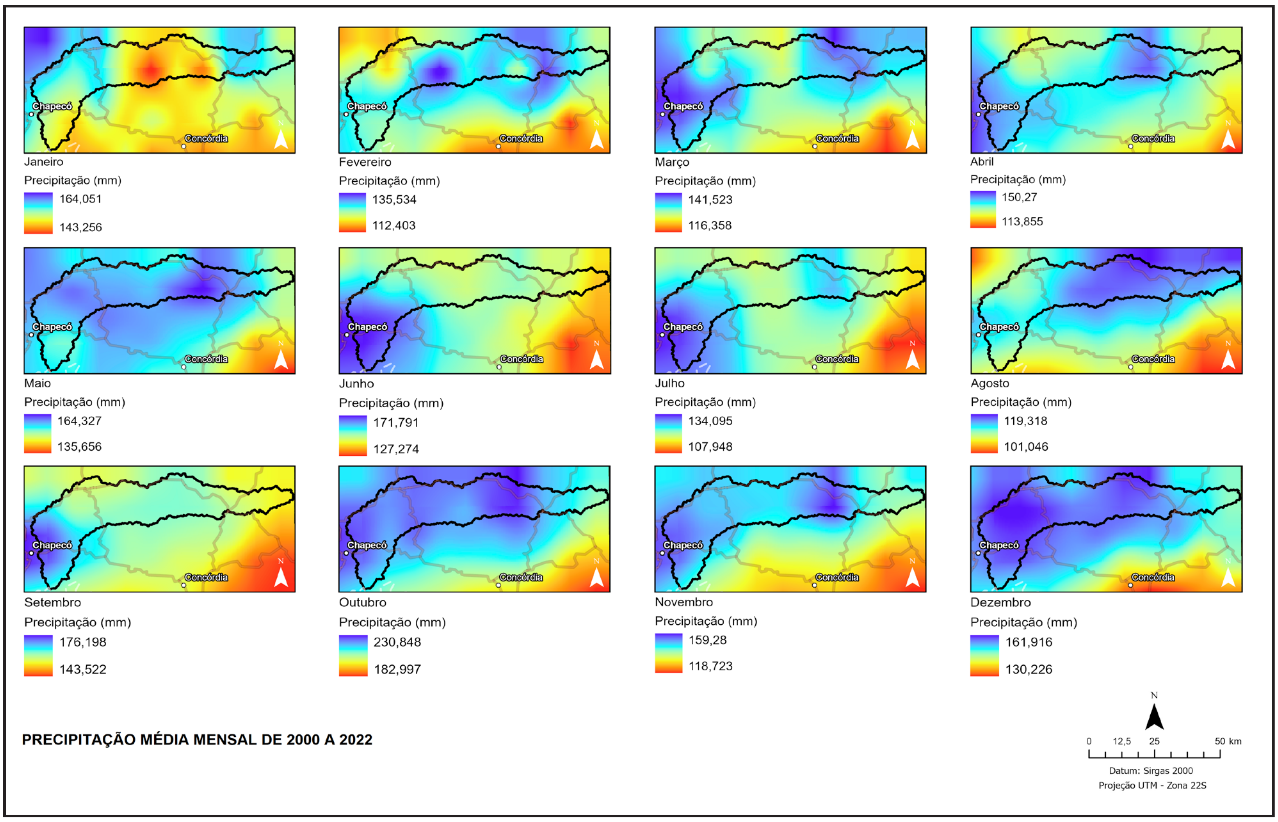
3.3 Precipitation in the Irani River Hydrographic

The Irani River Basin presents a significant variation in precipitation throughout the year, with monthly averages that vary according to the seasons and an annual average that reflects the amount of rainfall received in the region. The sample period of analysis ranged from June 2000 to December 2022.

When considering the seasonal average, it is possible to notice that spring has the highest average monthly rainfall, reaching 182.7 mm, indicating a rainy period. Summer and winter, in turn, registered a maximum average of 143.3 mm and 141.8 mm of precipitation respectively in the study area, showing the seasons with less precipitation in the basin. The seasons with the highest precipitation were autumn (mean of 159.9 mm) and spring. The months from April to June were categorized as autumn, July to September as winter, October to December as spring, and January to March as summer.

When analyzing the average monthly precipitation in the Irani River Basin, it was observed that the maximum values occur in the months of September – 176.198 mm and October – 230.848 mm, indicating a period of greater rainfall (Figure 11). On the other hand, the months of July – 134.095 mm and August – 119.318 mm register the minimum precipitation values, characterizing a drier season. The maps have different scales to assess the variation in precipitation in the region of the Irani River watershed. The first cycle occurs from February to June, a period in which it is possible to observe an increase in rainfall. In these months, the rains become more intense and frequent, contributing to an increase in the volume of water in the basin.

Figure 11 – Average monthly precipitation from 2000 to 2022 in the Irani River Basin – SC, data from the MERGE/INPE – CPTEC product (color scale each month is variable)



Source: Authors (2023)

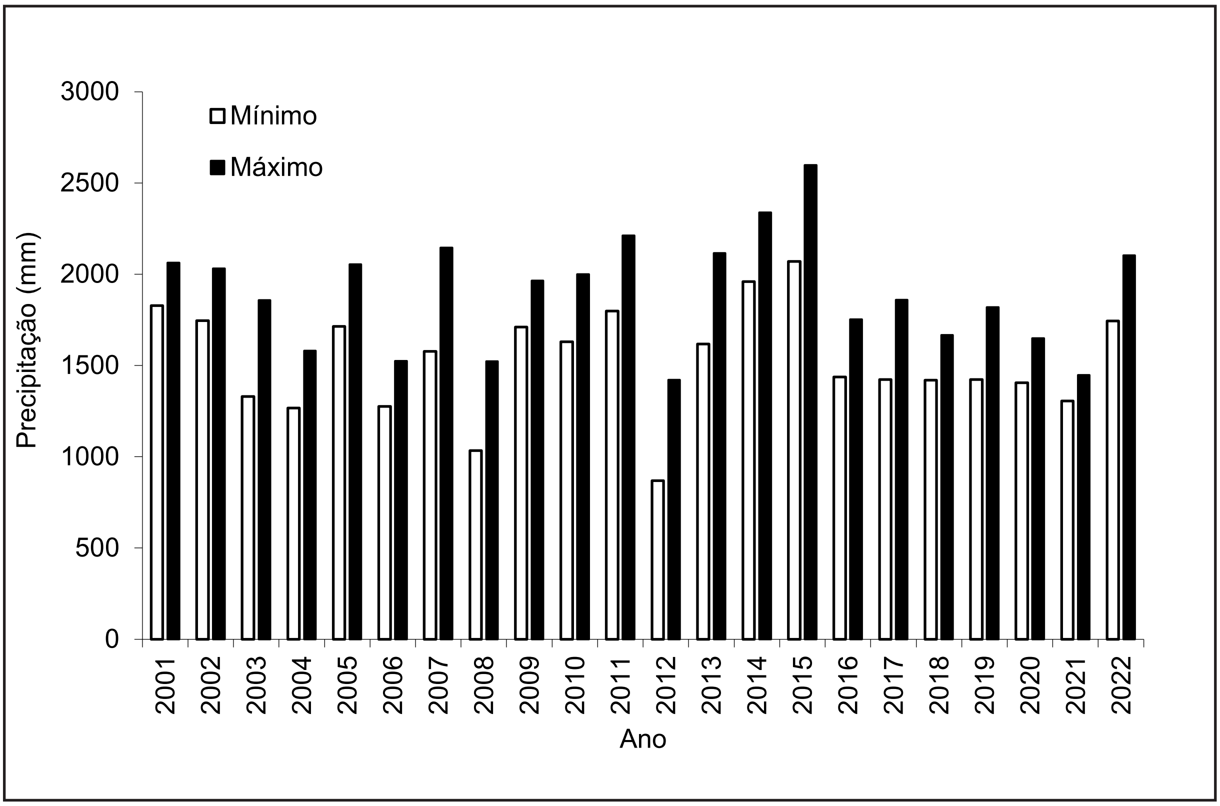
Then there is a second cycle, which extends from July to August, characterized by a drop in rainfall. These months represent a drier season in the region, with reduced rainfall compared to previous months. This decrease in rainfall can affect river water levels and the availability of water resources in the basin.

Subsequently, from September, the third cycle begins, in which precipitation rises again until October. During these months, there is a gradual increase in rainfall, which contributes to the recovery of water levels in the watershed.

Now, from October to February, there is the fourth cycle, characterized by a new drop in rainfall. These months represent a drier season, with less frequent rainfall and reduced volumes, which may affect the availability of water in the watershed. It is notable that the month of October stands out as the one with the highest precipitation rate.

With regard to the annual average precipitation, the data reveals a variation over the years. The year 2015 recorded the highest volume of precipitation, with 2,597.94 mm, while the year 2012 recorded the lowest volumes, with precipitation varying from 869.63 mm to 1,420.94 mm, throughout the basin area. These variations indicate that the Irani River basin may go through periods of greater or lesser water availability, which directly affects water resources, and the dynamics of the ecosystems present in the region. Figure 12 presents the graph of the average annual precipitation values from the MERGE/INPE – CPTEC product data, the maximum and minimum values indicate the variation in precipitation in the territory of the river basin.

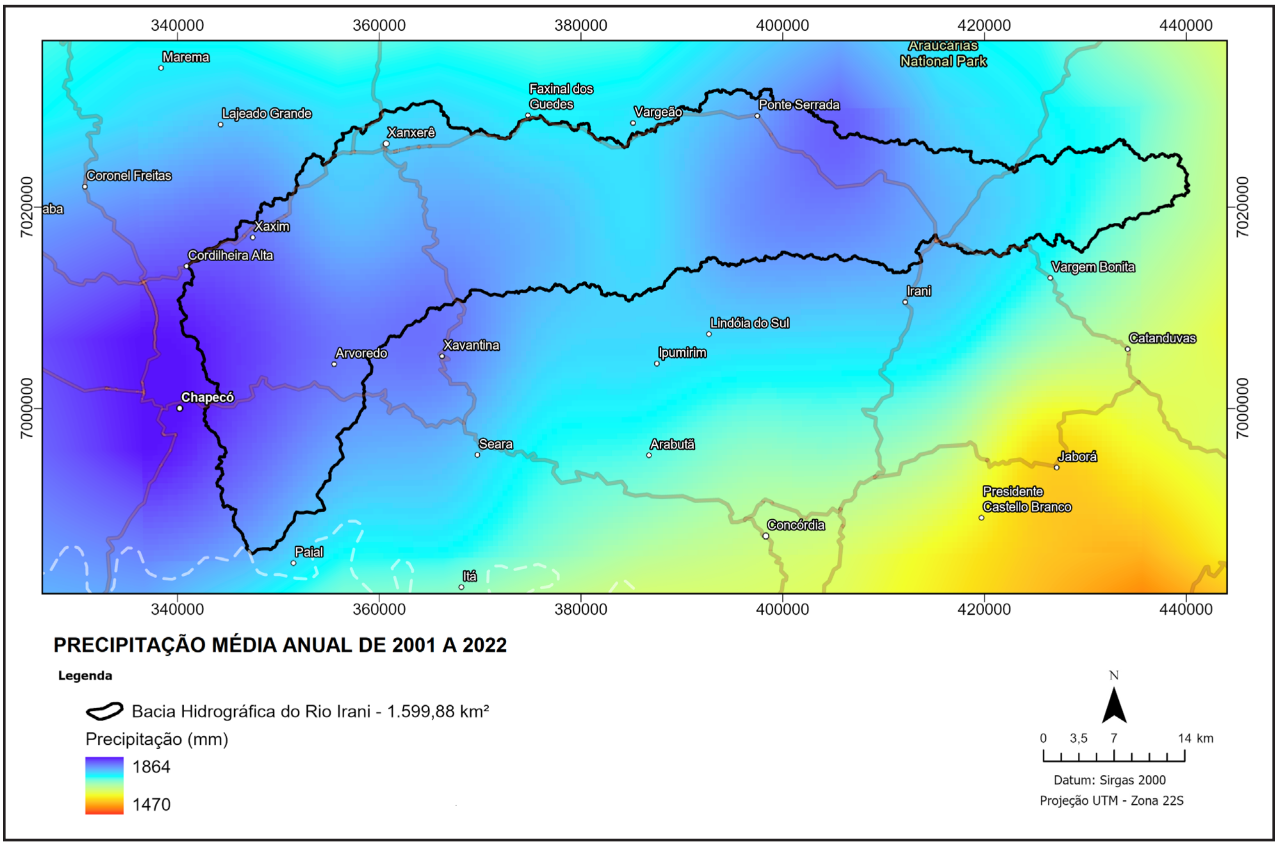
Figure 12 – Annual precipitation from 2001 to 2022 in the study area. Information extracted from pixels in the study area of the MERGE/INPE-CPTEC product



Source: Organized by the authors (2023)

In total annual precipitation, there are two clusters of higher precipitation, one upstream and the other downstream from Irani River (Figure 13).

Figure 13 – Average annual precipitation from 2000 to 2022 in the Irani River Basin – SC, data from the MERGE/INPE – CPTEC product



Source: Authors (2023)

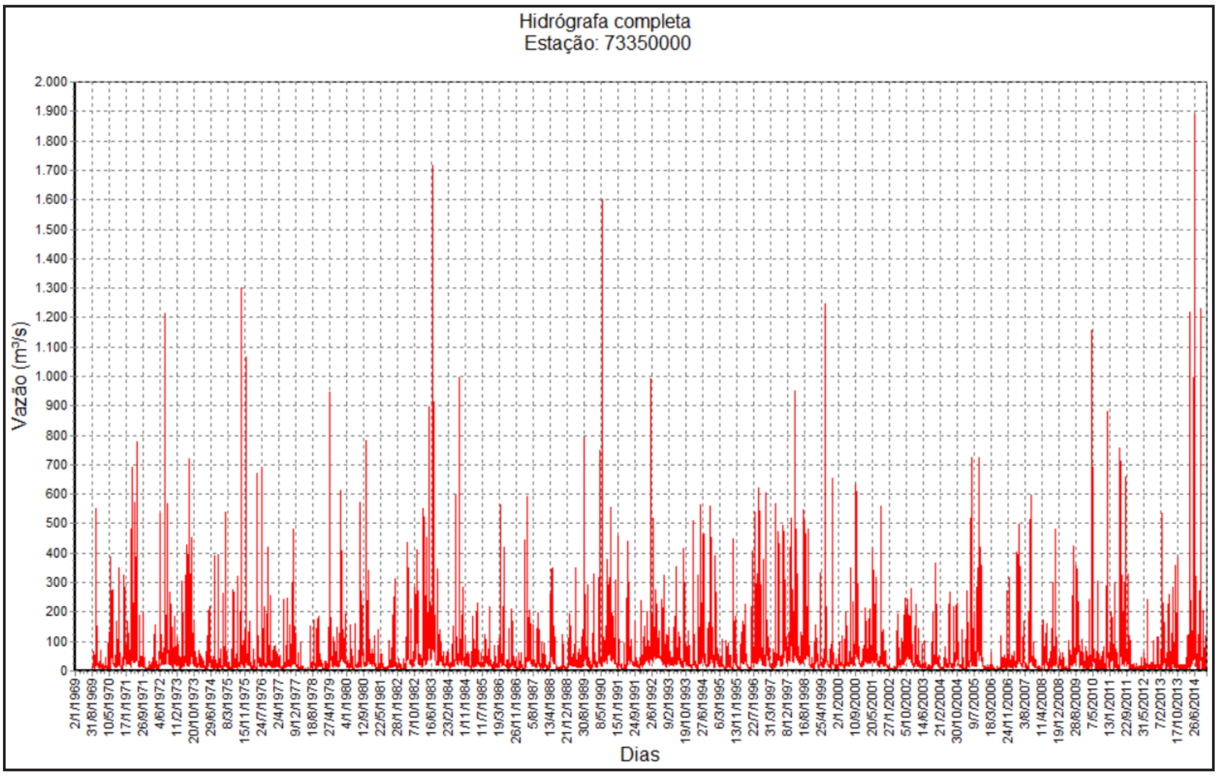
The variation in precipitation throughout the year has a significant impact on the dynamics of the river basin. Seasonal fluctuations in the amount and distribution of precipitation directly influence the flow regime of rivers, aquifer recharge, soil erosion and the availability of water for various uses, such as public supply, agricultural irrigation and hydroelectric power generation. Periods of intense rain can result in flooding and soil erosion, while dry periods can lead to reduced river flows and water shortages. Therefore, understanding seasonal variation in precipitation is essential for effective management of water resources and for mitigating impacts associated with extreme hydrological events.

3.4 Flow Analysis of the Barca Irani fluviometric station

It was noted the absence of data in the years 1969, 2007, 2012, 2013 and 2014 for the Barca Irani station. However, only in 1969 was the filling rate of the daily discharge data lower than 80%, since the initial station records only started in September of that year. Therefore, the sample period analyzed covered more than 40 years.

The hydrograph shown in Figure 14 shows all the average daily flow data for the analyzed sample period. The resulting hydrograph shows the flow variation over the analyzed period, allowing to identify periods of drought, floods and flow peaks.

Figure 14 – Complete hydrograph of the Barca Irani station, containing average daily flow data for the period between 02/01/1969 and 08/31/2014



Source: Authors (2023)

Based on data on average daily flows, available at the fluviometric station Barca Irani, code 73350000 of the National Water Agency – ANA, the values of the referred flows were processed (Table 5). It is worth mentioning the flow called Q98, which represents that in 98% of the times the flow of the river where the station is located is equal to or greater than 4,321 m³/s.

Table 5 – Average daily permanence flows of the Barca Irani Fluviometric Station, code: 7335000

Probability of flow being equaled or exceeded (%)	Flow (m³/s)
98	4,321
95	6,329
90	9,035
85	11,094
80	12,993
75	14,749
70	16,601
65	18,548
60	20,589
55	23,270
50	26,083

Source: Organized by the authors (2023)

According to article 2 of Ordinance SDS nº 043/2010, to analyze the water availability in abstractions from watercourses in Santa Catarina, the reference flow Q98 is adopted, which represents the flow exceeded by 98% of the time. The grantable flow is defined as 50% of the reference flow in all control sections in the basin, in accordance with the absence of conflicts. The third paragraph establishes that the individual consumptive use cannot exceed 20% of the conceivable flow in each stretch of the river, which may reach 80% for human use, with rational criteria (Portaria SDS 043/2010, of 08/13/2010). Although the ordinance does not specify whether the permanence flow – Q98 should be calculated from daily or monthly flow data, it is recommended, in conflicts, to use the Q95 based on daily flows, many times more restrictive than the Q98 based on monthly flows.

Regarding the analysis of the minimum flow Q7,10 calculated by different distributions (Table 6). The Pearson 3 Log distribution was the one that presented the best statistical result, with a confidence interval greater than 95%, it is assumed that the minimum flow of 7 consecutive days and with a return period of 10 years – Q7,10 was of 3,405 m³/s at the Barca Irani fluviometric station, code 7335000.

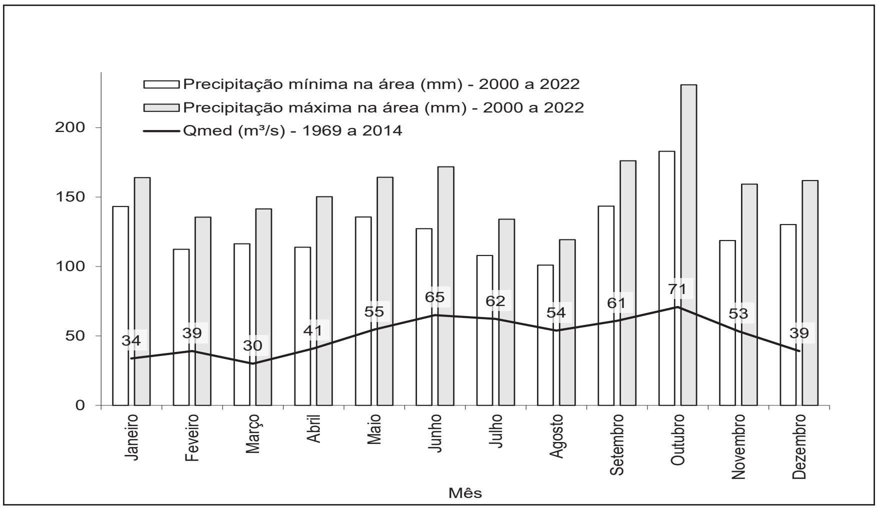
Table 6 – Calculation of the Q7,10 flow by different distributions and statistical results, for the fluviometric station Barca Irani, code 7335000

Distribution	Interv. conf. sup. (95%)	Event (m³/s)	Interv. conf. inf. (95%)	Standard Error	Mean	Variance	Skewness	Standard Deviation	Confidence Interval Width
Weibull	4,366	3,396	2,426	0,495	7,366	14,392	1,316	3,794	1,940
Pearson 3	4,810	3,553	2,296	0,641	7,366	14,712	1,613	3,836	2,514
Logpearson 3	4,029	3,405	2,780	0,319	1,870	0,265	0,238	0,514	1,250
Lognormal 2	4,707	3,487	2,267	0,623	7,366	14,712	1,274	3,836	2,440
Lognormal 3	4,369	3,217	2,065	0,588	7,366	14,712	1,274	3,836	2,304

Source: Organized by the authors (2023)

The Long Term Average Flow or duration was obtained from the average monthly flows of the entire analyzed period. Regarding the average monthly long-term flows, October was the month with the highest Qmed value = 70.840 m³/s and March the lowest Qmed value = 30.021 m³/s. For the Barca Irani fluviometric station, code 7335000, the long-term average flow is QMLT = 50.329 m³/s. Long-term average monthly flow data are shown in Figure 15.

Figure 15 – Average monthly precipitation in the Irani River Basin between the years 2000 and 2022 and long-term average monthly flows from the Barca Irani fluviometric station, code 7335000, between the years 1969 and 2014



Source: Authors (2023)

The maximum flow values for a return period of 10 years – QMAX,10 were obtained through different distributions. The results indicate that the Log Normal 3 distribution had the best statistical performance, with a confidence interval greater than 98%. Based on this information, it appears that the maximum flow for a return period of 10 years at the fluviometric station Barca Irani, code 7335000, was 1203.094 m³/s (Table 8).

Table 8 – Calculation of the QMAX,10 flow by different distributions and statistical results, for the fluviometric station Barca Irani, code 7335000

Distribution	Interv. conf. sup. (95%)	Event (m³/s)	Interv. conf. inf. (95%)	Standard Error	Mean
Gumbel	1529,758	1271,437	1013,116	131,796	685,880
Pearson 3	1466,035	1207,721	949,406	131,793	685,880
Logpearson 3	1611,085	1269,006	926,928	174,530	685,368
Lognormal 2	1485,746	1181,838	877,931	155,055	685,880
Lognormal 3	1436,660	1203,094	969,528	119,166	685,880

Distribution	Variance	Skewness	Standard Deviation	Confidence Interval Width
Gumbel	157259,179	1,248	396,559	516,642
Pearson 3	157259,179	1,580	396,559	516,629
Logpearson 3	0,350	0,388	0,591	684,157
Lognormal 2	157259,179	1,248	396,559	607,815
Lognormal 3	157259,179	1,248	396,559	467,131

Source: Organized by the authors (2023

Table 9 shows the constant specific discharge values for the fluviometric station Barca Irani.

Table 9 – Constant specific discharge for the calculated flows of the fluviometric station Barca Irani, code 7335000

Flow Type	Riverometric Station Barca Irani – Cód. 7335000 (m³/s)	Riverometric Station Barca Irani – Cód. 7335000 (L/s)	Drainage Area (Km²)	Constant Specific Discharge (L/s.km²)
Permanência Q90	9,035	9.035	1.500,92	6,020
Permanência Q95	6,329	6.329	1.500,92	4,217
Permanência Q98	4,321	4.321	1.500,92	2,879
Mínima – Q7,10	3,405	3.405	1.500,92	2,269
Média de Longo Termo – QMLT	50,329	50.329	1.500,92	33,532
Máxima – Qmax,10	1.203,094	1.203.094	1.500,92	801,571

Source: Organized by the authors (2023)

4 CONCLUSIONS

The flow analysis of the Barca Irani Fluviometric Station has provided insights into water availability over the years 1969 to 2014. This analysis takes into account factors such as permanence, drought, and long-term flows. The results of specific flows are promising for application in studies and projects in the river basin region.

The morphometric characteristics of the Irani River watershed, including the drainage area, shape factor, and compactness coefficient, indicate that the basin has an elongated configuration, facilitating efficient water flow. River density and drainage density suggest a moderate number of watercourses relative to the size of the basin, indicating good runoff capacity and rapid water flow.

The integration of data from the MapBiomas Project allowed a broader understanding of land use patterns in the different periods analyzed. The analysis of land use and occupation revealed changes that occurred over the years. A significant increase in the urbanized area was observed, resulting from the urbanization process, as well as a significant increase in soybean cultivation, on the other hand a decrease in the areas allocated for agriculture and pasture. An increase in forest area has also been observed over the last 30 years.

These changes are the result of processes of agricultural expansion, reforestation and urbanization, which directly influenced the landscape and environmental dynamics of the region. Increased urbanization tends to increase soil sealing, reducing infiltration capacity and increasing surface runoff, which can lead to increased flood peaks and soil erosion. Furthermore, changes in vegetation cover, such as an increase in forest area, influence evapotranspiration and rain interception, affecting precipitation patterns and water availability in watercourses. Reducing the pasture area can also have effects, such as reducing the load of sediments and nutrients transported to rivers, impacting water quality.

Regarding precipitation, the data reveal temporal patterns in the Irani River Basin, as well as the occurrence of a precipitation gradient in the basin area. These patterns were evaluated on different time scales, providing information on seasonal and annual precipitation variability. The results indicate that the most significant precipitation in the basin occurs during spring, with a peak in October (approximately 231 mm).

Data from sources such as BDIA-IBGE, ANA, MAPBIOMAS and MERGE/INPE-CPTEC proved to be effective in providing a comprehensive characterization of the Irani River Basin. The use of these databases allowed precise analyzes of the environmental and morphometric characteristics of the basin. This multidisciplinary approach, combined with data from diverse sources, significantly increases ability to assess the complex hydrological processes and interactions that shape the watershed. It represents a promising approach to the analysis of environmental systems.

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