ANALYSIS OF THE SPATIAL DISTRIBUTION OF RAIN FROM THE DOIS RIOS RIVER WATERSHED – RJ

Daiane Ferreira Campos[1], Amanda Moreira e Silva[2], Paulo Victor Campos [3], Danilo Paulúcio da Silva[4], Filippo Giovanni Ghiglieno [5]

ABSTRACT: This article investigates the annual rainfall distribution and variability in the watershed of the *Dois Rios River* in time series from 1975 to 2005 using data from 22 rainfall stations in the region, cross-checked with the annual and partial time series of maximum precipitated totals from a rain gauge installed in the basin. We evaluated from the geolocated data the area of influence by the Thiessen Polygon method. The rain indexes were spatialized by the IDW interpolation method, generating the isohyetal maps. Therefore, the Gumbel method was used to evaluate extreme events and finally, we tested the data consistency with the support of the Double Mass Curve. The pluviometric profile of the basin pointed out a strong variability in the separation indexes, ranging from 970.3 to 2061.4 mm.year^{-1}. The rain concentration clearly marks the southeast region of the hydrographic basin, in contrast, the lowest indexes follow the northwest direction.

KEYWORDS: Geostatistics, Rain Spatialization, Isohyetal Maps

ANÁLISE DA DISTRIBUIÇÃO ESPACIAL DE CHUVAS DA BACIA HIDROGRÁFICA DO RIO DOIS RIOS – RJ

RESUMO: Este artigo analisou a distribuição e a variabilidade pluviométricas anuais ocorridas na bacia hidrográfica do rio Dois Rios em uma série histórica que abrange os anos de 1975 a 2005 utilizando 22 postos pluviométricos da região, bem como analisou série anual e parcial de totais máximos precipitados de um posto pluviométrico localizado na bacia. E através do método Polígonos de Thiessen foi avaliado as áreas de influências de cada ponto de informações. Os índices pluviométricos foram espacializados pelo método de interpolação

[1] MSc. Student in Hydraulics Engineering and Sanitation, EESC / USP, CEP 13566-590, São Carlos, SP, Phone Number (77)999646632, e-mail: daianecampos.eng@gmail.com
[2] Student in Environmental Engineering, UESB, Itapetinga, BA.
[3] Student in Environmental Engineering, UESB, Itapetinga, BA.
[4] DSc. in Agricultural Engineering, DCEN / UESB, Itapetinga, BA.
[5] DSc. in Materials Science and Technology, DF / UFSCar, São Carlos, SP.

IDW (Ponderação pelo Inverso da Distância), em seguida gerado mapas de isoietas. Foi utilizado o método de Gumbel para avaliar eventos extremos e a Curva de Duplas Massas para analisar a consistência dos dados. O perfil pluviométrico da bacia apresentou grande variabilidade dos índices de separação, variando de 970,3 a 2061,4 mm.ano-^{1}. As concentrações de chuvas marcaram a região sudeste da bacia hidrográfica, em contrapartida os menores índices seguiram ao sentido noroeste.

PALAVRAS-CHAVE: Geoestatística, Espacialização de Chuvas, Isoeitas

INTRODUCTION

In hydrology, precipitation is understood to mean water from water vapor in the atmosphere deposited on the Earth's surface in any form: rain, hail, fog, snow, dew, or frost (BERTONI & TUCCI, 2001).

Precipitation indeed plays an important role in the hydrological cycle and affects the quality of the environment, together with the population's social and economic life, as well as the energy generation and the agricultural activities (DASTANE, 2004).

The factors impacting the rainfall distribution are the latitude, the distance from the sea or other humidity sources, the altitude, the slope orientation and the vegetation. Typical related data is the precipitated total, the duration, the intensity and both the spatial and temporal distribution (PINTO, 1976).

Although the precipitation is something vital for sustaining life on land, its high occurrence with consecutive rainy days and heavy rains, can cause negative consequences, strongly impacting the water supply, the socioeconomic energy segments and the incidence of natural disasters , such as floods and soil erosion (BRITTO et al., 2006).

Therefore, understanding the water dynamics from the analysis of both the collected related data and the geo-characteristics of the hydrographic basins is fundamental for predicting what areas are more prone to the occurrence of major floods.

In this perspective, starting from the pluviometric data from the National Water Agency (ANA) stations, the main goal of this work was to analyze the precipitation data collected in the Dois Rios River Basin and to assess the occurrence of rainfall in the basin, adopting both the Inverse Distance Weighted (IDW) and Thiessen Polygon interpolation methods.

MATERIAL AND METHODS

The investigated geographical region

From the geographical point of view, the Dois Rios River Basin includes the municipal boundaries of Nova Friburgo, Cantagalo, Cordeiro, Duas Barras, Macuco, Bom Jardim, São Sebastião do Alto, Santa Maria Madalena, Trajano de Morais, Itaocara and São Fidelis. The area is located between the parallels -21.59 ° and -22.42 ° and between the meridians -42.73 ° and -41.77 °, in the Rio de Janeiro state (Brazil) and flows into the Paraíba do Sul River (see Figure 1).

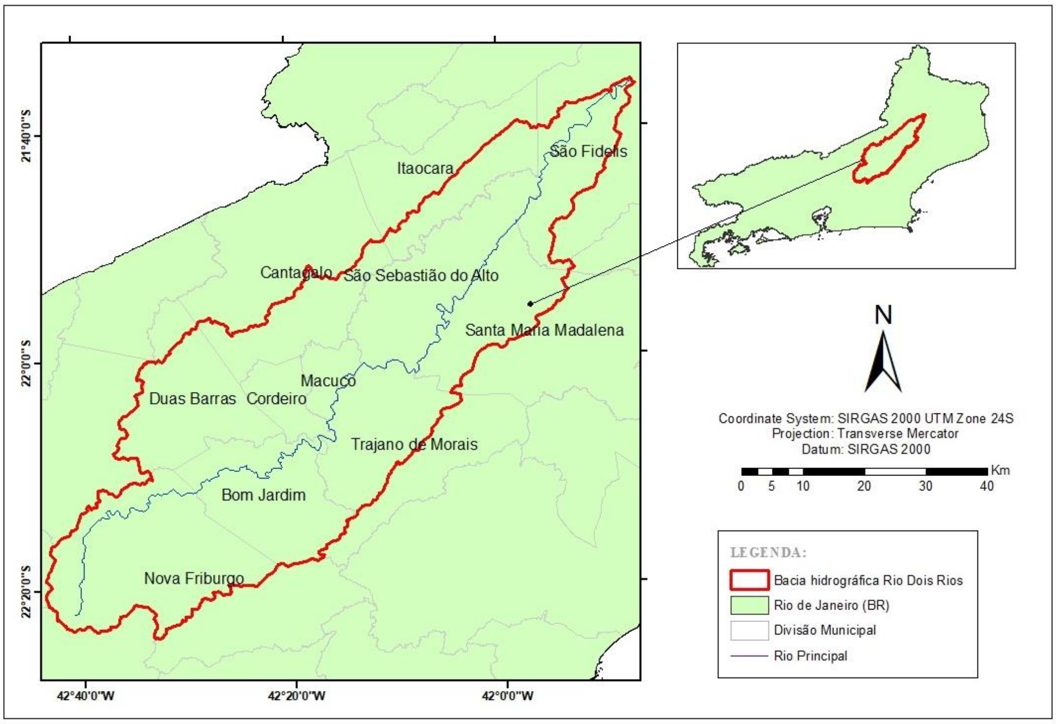


Figura 1. Figure 1: Location map. SOURCE: Authors, 2020.

In the state of Rio de Janeiro, the tropical climate is predominant with significant rainfall during the most of the months. According to Koppen (1948), the climate of this region is classified as a Moçonic climate (Am), strictly related to the circulation of the monsoons, which refer to seasonal changes in the direction of the wind, with an average temperature of 23.2 ° C.

The database

The Hydrological Information System (HidroWEB) of the National Water Agency (ANA) collects the pluviometric information from pluviometric stations. In our study, we selected the data from 22 pluviometric stations. Our database consists of a spatial and temporal series along with 30-years from 1975 to 2005. To optimize our analysis, data comes from 8 pluviometric posts across the drainage area in the Dois Rios River basin and 14 pluviometric posts located within a radius of 30 km from the borders of the hydrographic basin, according to Figure 2.

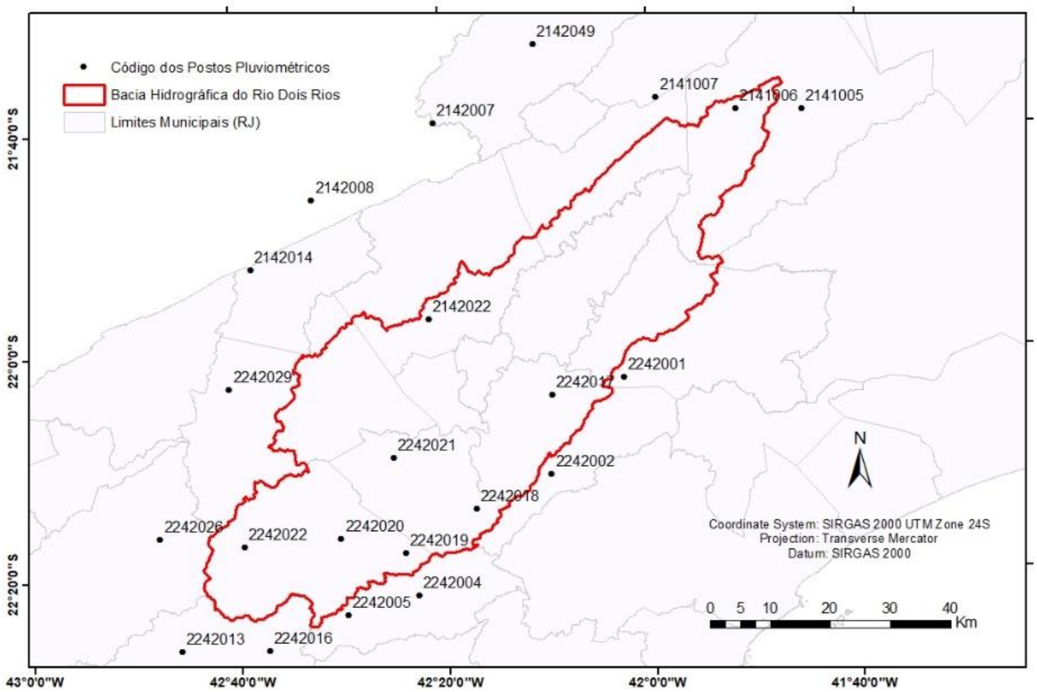


Figura 2: Location of rainfall stations. SOURCE: Authors, 2020.

Data spatialization

The method used to spatialize the average annual total precipitation data was the IDW (Inverse Distance Weighting) using the ArcGIS 10.5 software (ENSRI), by the geostatistical extension Analist. Subsequently, the isohyetal map was elaborated by the *3D Analyses Raster Surface tool*. We briefly resume below the two adopted methods in this task.

• *Distance Inverse Weighting (IDW) interpolation*:

The Inverse Distance Weighted (IDW) method predicts a value for some unmeasured location starting from the values sampled around it. Starting from a value, each value around it has a different weight depending on the distance, that is, each point has an influence on the new point, which decreases as the distance increases. The IDW system can be characterized as a smoothing as well as exact interpolator, on a global basis, reasonably faithful to the sampled data, with fast processing speed. It is important to underline that: the algorithm does not estimate values of the sampled neighbouring point greater or less than the maximum and minimum quantitative data reported. (LANDIM, 2000).

In order to identify the possible areas of influence for each rainfall station in the proximity of the watershed considered in our analysis, the Thiessen Polygon method was applied using the Analysis Tools Proximity tool, also by ArcGIS 10.5 (ENSRI).

• *Thiessen polygon*:

The method generates a weighted average of the heights recorded by the rain gauges, which is directly proportional to the basin's area of influence. It considers the non-uniformity of the spatial distribution of the stations, and it does not take into account the relief of the basin (TUCCI, 1997).

This method consists on joining the stations by straight lines, drawing lines perpendicular to the rectilinear stretches on the mediator of the line connecting the stations and extending the perpendicular lines until finding another mediator (BARRY & CHORLEY, 2010).

Data Analysis

We performed with Microsoft Office tools the analyses of the average monthly precipitation, the annual series and the partial series for the maximum precipitated totals, as well as the estimates of precipitation events with different return periods and analyses of the Double Mass curve. We briefly resume below the two adopted methods in this task.

• *Gumbel method*:

The Gumbel method is also known as the extreme event method, which is widely used in various areas of knowledge in order to model the maximum values of occurrence of a given phenomenon of interest. The issue in using this method is related to estimate distribution parameters based on some statistical methodology (COTTA, et al., 2016).

The method uses data already known to estimate events that have not yet happened, and these can be estimated for different periods of return.

• *Double Mass Curve*:

The double mass curve method aims to analyse the consistency of data in a regional scope, testing the degree of homogeneity of the data available for a station and relating these to the observations recorded in support stations. Applying this methodology, the station of interest and the stations next to it are selected, with the intention of evaluating the consistency of the accumulated total annual data. These data are tabulated and plotted on a graph (CARVALHO & RUIZ, 2016).

In this method, the result of the plotted data is expected to be a straight line, thus proving its proportionality. If a sudden change appears in the direction of the line, that indicates there was an abnormality in the analysed stations. This requires a data correction procedure for the current conditions.

RESULTS AND DISCUSSION

The average annual total precipitation of the 22 stations analysed in the period from 1975 to 2005 is shown in Table 1.

Table 1. Average annual total rainfall. SOURCE: Research data.

Station Code	City	FU	Responsible	Annual Average Precipitation (mm.-¹)
2141005	São Fidélis	RJ	ANA	928,7
2141006	São Fidélis	RJ	ANA	1016,6
2141007	Cambuci	RJ	ANA	1056,5
2142007	Pirapetinga	MG	ANA	1198,9
2142008	Volta Grande	MG	ANA	1278,2
2142014	Carmo	RJ	ANA	849,02
2142022	Cantagalo	RJ	ANA	1247,7
2242001	Santo Antônio de Pádua	RJ	INMET	1560,6
2242002	Trajano de Morais	RJ	ANA	1642,6
2242004	Trajano de Morais	RJ	ANA	1954,7
2242005	Nova Friburgo	RJ	ANA	2158,6
2242013	Nova Friburgo	RJ	ANA	2108,07
2242016	Cachoeiras de Macacu	RJ	ANA	2489,85
2242017	Cachoeiras de Macacu	RJ	ANA	1236,6
2242018	Trajano de Morais	RJ	ANA	1324,7
2242019	Bom Jardim	RJ	ANA	1580,4
2242020	Bom Jardim	RJ	ANA	1433,5
2242021	Nova Friburgo	RJ	ANA	1390,3
2242022	Bom Jardim	RJ	ANA	1538,36
2242026	Nova Friburgo	RJ	ANA	1306,7
2242029	Teresópolis	RJ	ANA	1384,08
2142049	Sumidouro	RJ	ANA	1044,3

According to the Inverse Distance Weighting (IDW) interpolation method, the average precipitation in the Dois Rios River Basin was 1417 mm.year-¹. However, it presented great rainfall variation along the basin, with indexes spreading from 970.3 to 2061.4 mm.year-¹. Our study shows that the highest indexes mark the eastern border of the basin in the mountainous region in the state, mainly pointing in towards the southeast, closer to the Atlantic Ocean and they have a possible influence of coastal rains. On the other hand, we find the lowest rainfall indexes in the northwest of the state, covering part of the political regions in the north and northwest of Rio de Janeiro. In Figure 3 the municipality of São Fidélis is listed as the least rainy in the hydrographic basin and for that the most vulnerable to shortage of water (see Figure 3).

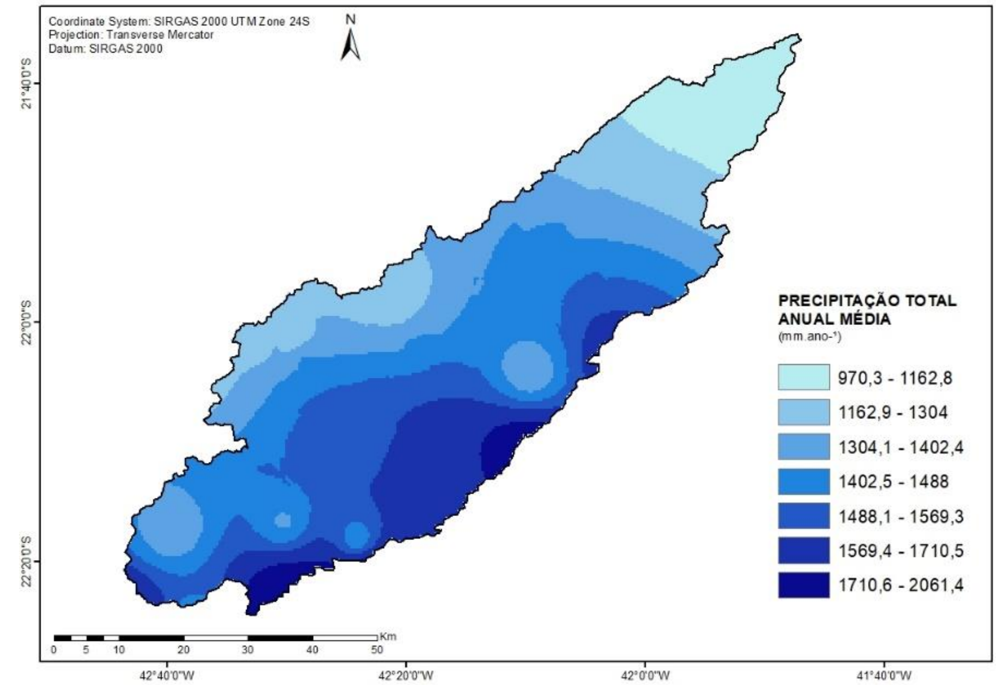


Figure 3. Precipitation map of the Dois Rios River Watershed. SOURCE: Authors, 2020.

Figure 4 was generated from hydrological profile applying the IDW interpolation method. It shows the isohyetal map in the Dois Rios River hydrographic basin, easily identifying the pluviometric indexes.

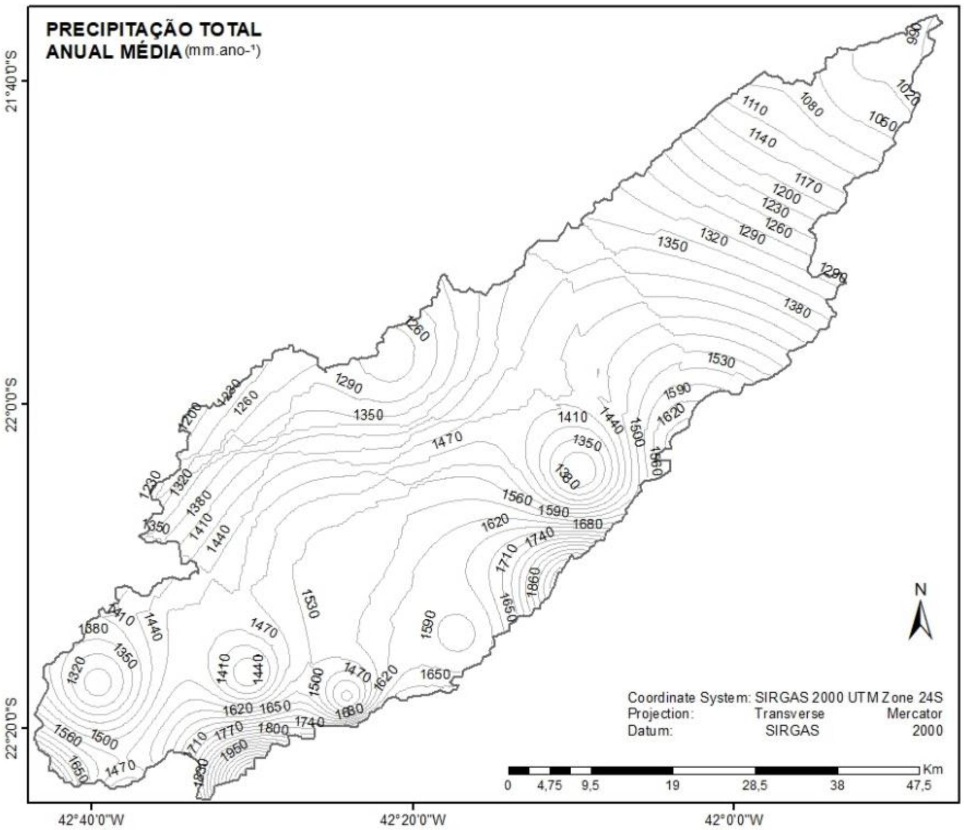


Figure 4. the Dois Rios River Basin isohyetal map. SOURCE: Authors, 2019.

The method investigating the influence area for each station, called the Thiessen Polygon method, gives an estimation of 1447.68 mm.year-¹ for the average rainfall in the hydrographic basin, spreading from 849.02 to 2489.85 mm.year-¹. The diagram according to the Thiessen Polygon method indicated that of all the 22 pluviometric stations, only 19 have any influence within the area of the watershed of the Dois Rios River, underlying the importance of this approach. Figure 5 shows the areas of influence for each the pluviometric station and minimum and maximum values for precipitation indexes.

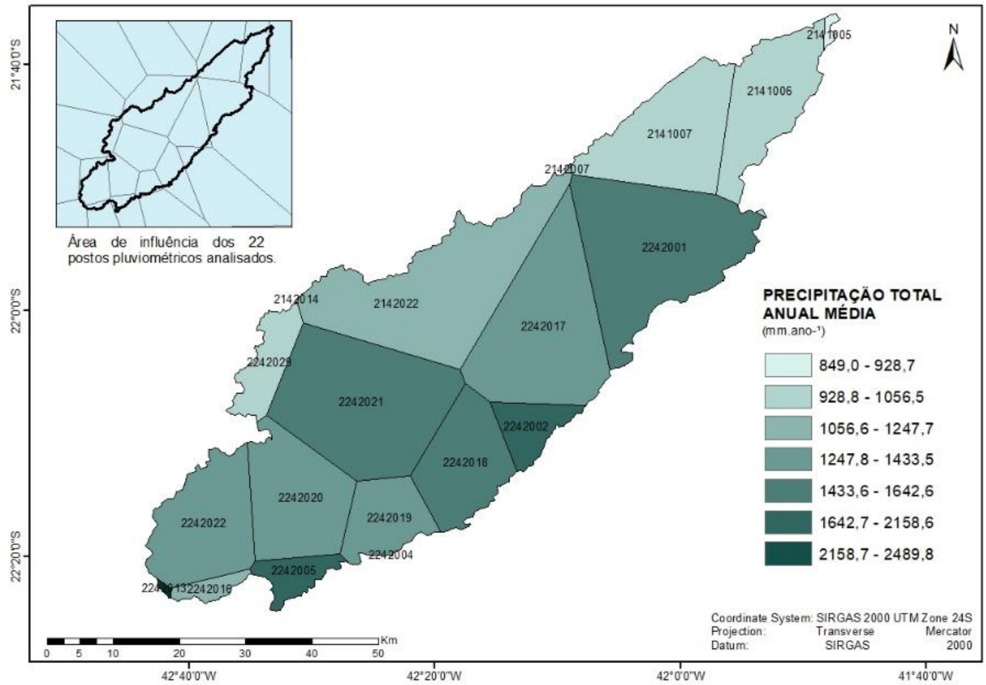


Figure 5. Precipitation map based on Thiessen polygon. SOURCE: Authors, 2020.

To understand the hydrological profile of the Dois Rios River basin in a seasonal perspective, we focused on the average monthly rainfall coming from the pluviometric station located in the municipality of Cachoeiras de Macacu – RJ. The station (code 2242016) is under the responsibility of the National Water Agency (ANA) and it is installed less than 6 km from the limit of the basin to the southwest of the state and inserted in the mountainous region, so this analysis is shown in Table 2.

Table 2: Average monthly rainfall in mm.year-¹.

Avarage Monthly Rainfall			
January	342,3	July	96,65
February	234,2	August	96,9
March	255,6	September	171,1
April	201,3	October	171,11
May	149,08	November	325,7
June	90,36	December	355,4

SOURCE: Research data.

The average monthly precipitation allows to identify the rainfall behaviour for the temperate climate characterized by intense rains in summer and drought in winter. As shown in Table 2, the highest precipitation rates start in November and extend until March, with June being the month of greatest drought.

The annual series of maximum totals precipitated in 24 hours allows to identify the peaks of the pluviometric indexes of each year, however the partial series of maximum totals precipitated in 24 hours identifies the highest precipitation indexes of the series in a genuine way with no restrictions in the time period. Both series from the rain gauge identified with the code 2242016 are shown in Table 3.

Table 3: Annual Precipitated Maximum Totals Series (APMTS) and Precipitated Maximum Totals Partial Series (PMTPS). SOURCE: Research data.

	APMTS mm.ano-¹		PMTPS mm.ano-¹		APMTS mm.ano-¹		PMTPS mm.ano-¹
1975	82,0	01/11/2004	190,9	1990	141,2	01/12/2005	120,4
1976	93,6	01/01/1998	148,2	1991	143,1	01/02/2005	111,8
1977	125,0	01/01/1991	143,1	1992	60,9	01/11/1998	108,6
1978	125,0	01/11/1990	141,2	1993	61,2	01/02/1979	100,6
1979	100,6	01/12/1989	140,0	1994	72,6	01/05/1979	100,4
1980	70,4	01/01/2004	136,5	1995	36,1	01/04/1977	100,0
1981	60,2	01/11/2003	132,1	1996	96,1	01/03/1979	100,0
1982	60,6	01/11/1978	132,0	1997	87,9	01/03/1999	99,6
1983	80,4	01/02/1998	130,6	1998	148,2	01/03/2005	98,5
1984	51,4	01/01/2005	126,3	1999	99,6	01/12/1998	98,3
1985	62,4	01/01/1977	125,0	2001	90,8	01/11/1977	98,0
1986	71,4	01/04/1978	125,0	2002	76,2	01/12/2003	96,4
1987	38,6	01/02/1991	121,7	2003	132,1	01/12/1996	96,1
1988	46,4	01/04/1991	121,4	2004	190,9	01/02/1976	93,6
1989	140,0	01/11/2005	120,8	2005	126,3	01/10/1976	92,0

Based on the series above, we show in Table 4 the results for the calculations of return periods in pluviometric events using the Gumbel method on the annual and partial series.

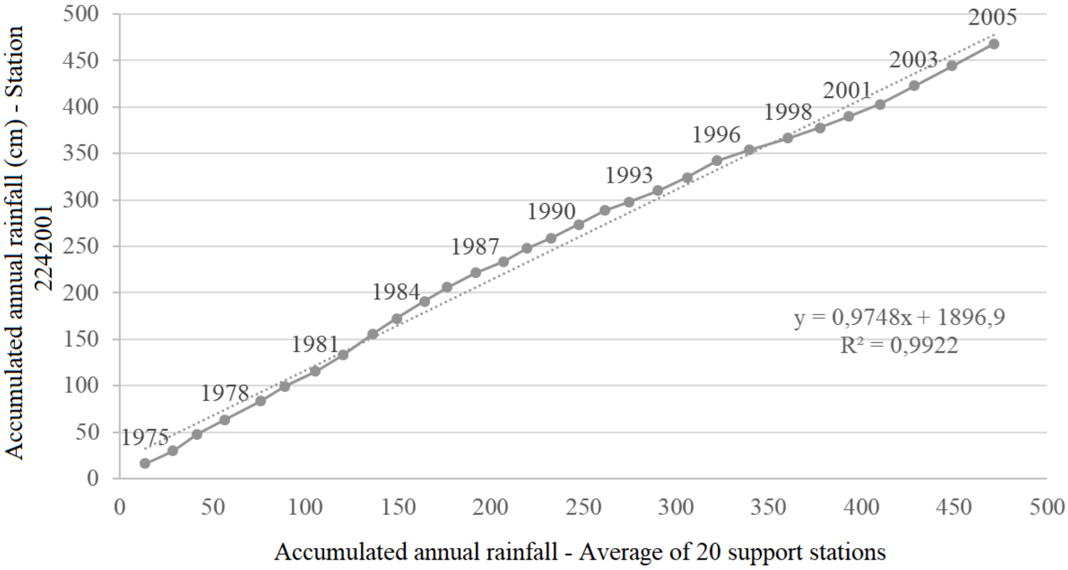
Table 3. Precipitation events based on the annual series.

Return Period with Gumbel Method		
T(anos)	Annual Series	Partial Series
	P(mm)	P(mm)
10	153,1737	151,6945
50	208,6931	183,8696
100	232,1643	197,4718
500	286,4025	228,9044
1000	309,7203	242,4177

SOURCE: Authors, 2020.

Applying the Double Mass Curve method, we tested the homogeneity on data for the series of all annual precipitation. To plot this curve, we chose the station identified with the code 2242001 and we compared with the averages of the other support stations, summing up 20 stations.

Through this methodology, we analysed the consistency of the data, in order to prove the its degree of homogeneity for the chosen station, starting from the relationship with the other data recorded in neighbouring stations. The curve in the Graphic 1 shows our result.



Graphic 1: Plot of the Double Mass Curve. SOURCE: Authors, 2020.

As there was no sudden change in the direction of the line, we can conclude that there is no abnormalities in selected time window and the data shows good consistency and homogeneity.

CONCLUSIONS

In this work, the GIS tools applied to climatological analysis show off positive results and a significant contribution to our scientific research. According to the IDW method, in the Dois Rios River Watershed we estimated the average precipitation in 1417 $mm.year^{-1}$, while using the Thiessen Polygon method in 1447.68 $mm.year^{-1}$, slightly higher value. The pluviometric profile makes evident the higher rates on the eastern border of the basin in the areas of the mountainous region.

The average monthly precipitation easily allows us to identify the rainfall behavior of temperate climate characterized by intense rains in summer and drought in winter. Therefore, this as well as the other parameters provide a better understanding of climatological factors in the region.

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