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Pluviometry in the Serra da Caraça region and its influence on the Iron Quadrangle region, in the state of Mina Gerais, Brazil

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Pluviometry in the Serra da Caraça region and its influence in the Iron Quadrangle region, in the state of Mina Gerais, Brazil[1]

Abstract

The research focused on analyzing the pattern and distribution of rainfall in the Serra do Caraça, and the interaction with its surroundings – the Quadrilátero Ferrífero region – highlighting the function of the orography. Geographical Climatology and Spatial Analysis were used in order to develop the present investigation, with statistical techniques such as data interpretation tools, thus extracting the dynamics and climatic pattens. The results demonstrated that the mountain range, mainly on the eastern edge (Serra do Caraça), influences the dynamics of the general circulation and currents that bring disturbances in the winds (W/NW and S/SE). This contributes to precipitation, which may reach values greater than 2,500 mm. We found a variability in the distribution of rainfall within the Quadrilátero Ferrífero – N/E corners presents more substantial rainfall volumes than the W/S edges. Regarding the spatial and temporal variability: between 1984-92 the highest occurrences of rainfall were recorded; and in the years 1998-2003 and 2013-16, the lowest occurrences were recorded in the analyzed period.

Keywords: Rainfall. Iron Quadrangle. Orography. Geographical Climatology.

A pluviometria da região da Serra do Caraça e a influência no Quadrilátero Ferrífero, Minas Gerais

Resumo

A pesquisa analisa sobretudo o comportamento e a distribuição das chuvas na Serra do Caraça e a interação com seu entorno, a região do Quadrilátero Ferrífero, evidenciando o papel da orografia. Utilizou-se da climatologia geográfica e da análise espacial, com técnicas estatísticas como ferramentas de interpretação dos dados e visando extrair a dinâmica e os ritmos climáticos. Os resultados demonstraram que

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o conjunto serrano, principalmente na borda leste (Serra do Caraça), influencia a dinâmica da circulação geral e das correntes que provocam distúrbios nos ventos (W/NW e S/SE). Essas correntes concorrem com a precipitação, que pode ultrapassar os 2.500 mm. Constatou-se que há variabilidade na distribuição da chuva no interior do Quadrilátero Ferrífero (bordas N/E apresentam volumes de chuvas mais expressivos que bordas W/S). Quanto à variabilidade espacial e temporal, entre 1984-92, registraram-se as maiores ocorrências de chuva, e, nos anos de 1998-2003 e 2013-16, as menores, no arco de tempo analisado.

Palavras-chave: Pluviosidade. Quadrilátero Ferrífero. Orografia. Climatologia geográfica.

La pluviometría de la región de la Sierra del Caraça y la influencia en el Cuadrilátero de Hierro, Minas Gerais

Resumen

La investigación se centró en analizar el comportamiento y la distribución de las precipitaciones en la Sierra del Caraça y la interacción con su entorno, la región del Cuadrilátero de Hierro, destacando el papel de la orografía. Se utilizó la climatología geográfica y el análisis espacial, a través de técnicas estadística con herramientas de interpretación de datos y con el objetivo de extraer la dinámica y los ritmos climáticos. Los resultados mostraron que la cordillera, principalmente en el borde oriental (Sierra del Caraça), influye en la dinámica de circulación general y en las corrientes que traen perturbaciones en los vientos (O/NO y S/SE). Las corrientes contribuyen a la precipitación, y pueden alcanzar valores superiores a 2.500 mm. Se encontró que existe variabilidad en la distribución de la lluvia dentro del Cuadrilátero de Hierro (los bordes N/E presentan volúmenes de lluvia más expresivos en relación con los bordes O/S). En cuanto a la variabilidad espacial y temporal, entre 1984-92 se registraron las mayores ocurrencias de precipitaciones, y los años 1998-2003 y 2013-16 se registraron las menores ocurrencias en el espacio de tiempo analizado.

Palabras clave: Pluviosidad. Cuadrilátero de Hierro. Orografía. Climatología geográfica.

Introduction

The Earth's atmosphere can be considered the most latent, dynamic, and transient domain of all the natural spheres of the planet (Sant' Anna Neto, 2002). It is responsible for producing intriguing phenomena such as storms, hailstorms, tornadoes, and fogs, as well as generating natural elements: clouds of various shapes, amplitudes, and dimensions.

Climate phenomena are constituted by a set of elements of different origins that coexist, at the same time and in the same space, under a regime of reciprocal and interdependent energy exchange (Ribeiro, 1993).

Thus, a set of elements and factors in dynamic interaction merge in time and space, revealing units or types that can be measured in their size (extent) and in their rhythm (duration) – which will characterize the weather and climate conditions in a region (Ribeiro, 1993).]

Among the climatic factors, orography stands out in mountainous regions since mountains serve as anchors or barriers to moisture, creating microclimates. Jardim and Galvani (2022) recall that orographic systems increase the total rainfall, in addition to the altimetric gradient reversing temperature and altitude.

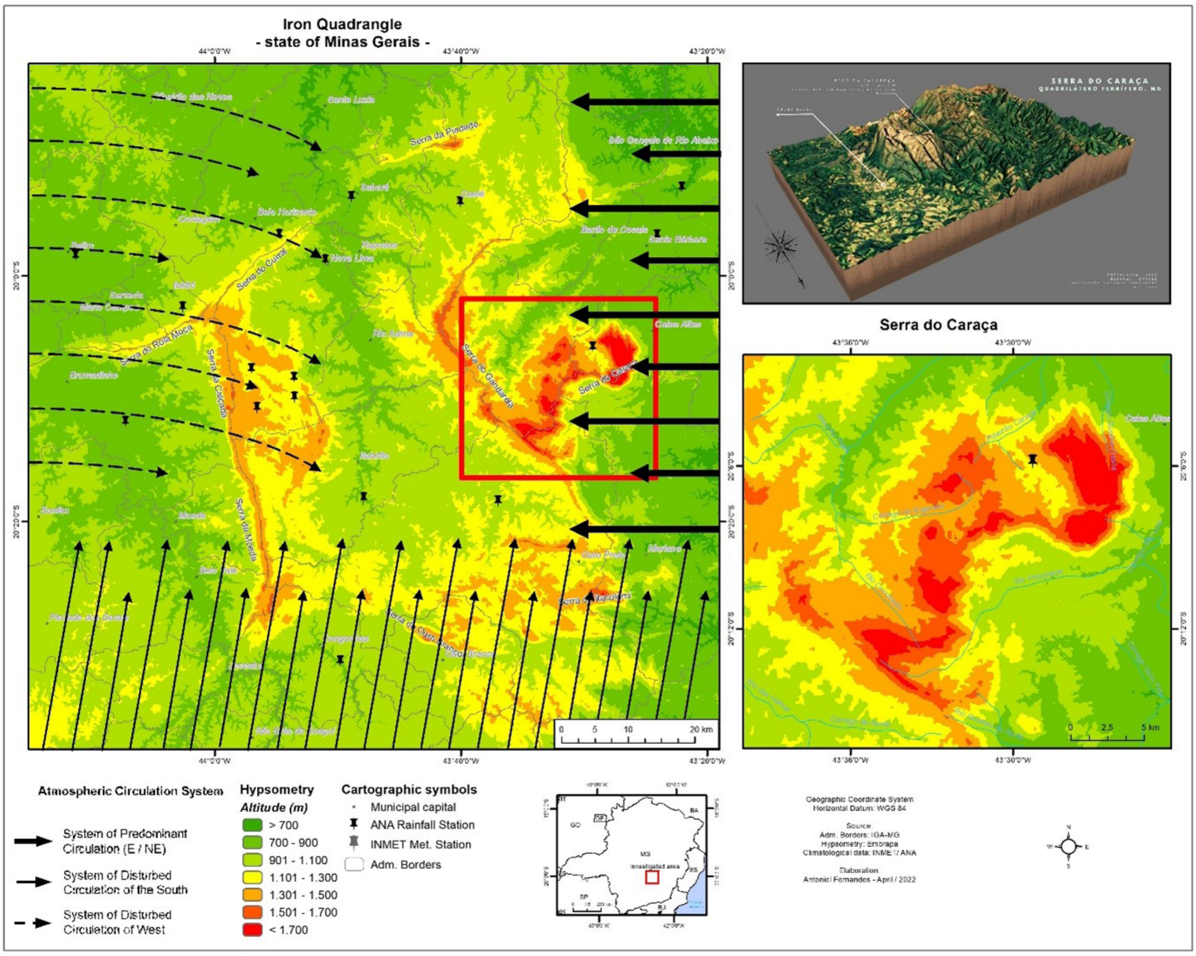
In their research on the effect of Serra do Curral orography on the rainfall regime of the city of Belo Horizonte, in the state of Minas Gerais, Moreira, J. and Abreu (2002) found that in April and September the topographic factor is the main cause of the rains concentration to the south of the municipality. In October (beginning of the rainy season), however, the rains are predominantly due to the areas of higher topographies allied to the rise in temperatures, correlated with the migration of the equatorial air mass towards the southeast of Brazil that gives rise to the formation of instability lines.

The authors also verified that, in November, December, and January, Serra do Curral acts as an inducer of the highest rates of rainfall – which reaffirms its role of setting the frontal and convective processes, as well as its interactions with the zones of moisture convergences that occur in the region during this period (Moreira, J.; Abreu, 2002).

The south region of Belo Horizonte has a quadrangular-shaped mountain complex that was named the Iron Quadrangle (*Quadrilátero Ferrífero*) by geologist Luis Felippe Gonzaga de Campo due to its lithological structure when he was producing maps and information about the region at the request of the Geological and Mineralogical Service of Brazil at the beginning of the 20th century (Souza, 2021). The expression was first published in the works by Dorr II (Souza, 2021), in the 1950s, and has been consolidated as a denomination of this region.

Within the Iron Quadrangle (IQ), the Serra do Caraça stands out. Located on the eastern edge, it presents the highest altimetric values of the central region of the state of Minas Gerais (Moreira, A.; Pereira, 2004), with peaks higher than 2,000 m (*Pico do Inficionado*, with 2,068 m, and *Pico do Sol*, with 2,070 m). Thus, the Serra do Caraça is configured as an orographic barrier, retaining part of the moisture transported by the predominant circulation of winds (E-NE) and the disturbed currents (W and S) in this region (Figure 1).

Figure 1 – Location of the Serra do Caraça in the Iron Quadrangle, in the state of Minas Gerais



source: Map adapted from Nimer (1972).

In addition to the high concentration of hematite and itabirite, which has been exploited as iron ore, the quadrilateral has great species richness and endemism (Rego; Franceschinelli; Zappi, 2012; Carmo, Mount Carmel, Mount Carmel, Jacobi, 2013; Fernandes, 2013), besides the expressive volume of another mineral resource essential to life: water, both on surface and sub-surface.

The waters in this region supply the public water system of much of the Metropolitan Region of Belo Horizonte. A single extraction point in Das Velhas River, in the interior of IQ, is responsible for providing approximately 6,600.00 l/s of water for human consumption (Belo Horizonte, 2016), which supplies about 1.8 million people (Lemos; Magellan Junior, 2019).

As Souza (2021) recalls, within the IQ, the waters must be recognized as an essential element in the relationships happening in this space, which influences the conditions of life of the Metropolitan Region of Belo Horizonte. Also according to this author, the territory should be recognized as an Aquifer Quadrangle and not as Iron Quadrilateral, since characterizing this territory as an iron-rich region reinforces the bias towards mining exploration of the region. Thus, the expression Water Quadrangle (*Quadrilátero das Águas*) is suggested since much of this water resource is under the surface.

This article aims to identify the particularities of rainfall in Serra do Caraça, as well as its contrasts with the Iron Quadrangle, in the state of Minas Gerais.

Methodological procedure

In this study, descriptive statistics were used based on data extracted from meteorological and rainfall stations of the National Institute of Meteorology (INMET, 2022) and the National Water and Sanitation Agency (ANA, 2021), respectively. Means, maximum, and minimums values per hour, day, and month, amplitude, medians, and quartiles were used.

Data contained in the Provisional Climate Normals of 1981-2010 were used from the Forest, Ibirité, Belo Horizonte, João Monlevade, Viçosa, Barbacena, and São João del-Rei stations – all from the state of Minas Gerais. These stations were chosen due to their availability and proximity to the Iron Quadrangle and by the formation of a polygon that involved the area under study.

In addition to these stations, a set of rainfall stations managed by ANA was used, located inside the Iron Quadrangle and in its immediate surroundings. The selection of the set of rainfall stations was due to the availability of a common time arc and the longest timeframe of data possible, the consistency of historical records, and the geographical location that allows framing the study area and obtaining transects to better understand the meteorological and climatic conditions of the region.

The information was obtained via descriptive statistical analysis to identify the central trends, frequencies, correlations, amplitudes, and variability of climatic elements. To such end, extracting the dynamics and climatic rhythms of the area under study was necessary, besides assisting in the definition of "exceptional standard years," as proposed by Monteiro, C. (1971), and in the identification of singularities in the region under study.

To assign class intervals to rainfall data, the method proposed by Sturges (Equation 1) was adopted, which relates the size of the class intervals to the extent of the data.

$$K = 1 + 3{,}322\ (\log n) \tag{1}$$

In which: K is the number of classes; n is the universe of the sample.

Quartiles were used to identify exceptional rainfall periods (as there are significantly disparate values in the samples). The quartile orders used in this study were $Q_{(0.25)}$ and $Q_{(0.75)}$, defined in descriptive statistics as lower quartile and upper quartile, or even first and third quartiles – which, in this research, can be understood as the threshold of exceptionally dry or rainy periods.

To determine the quartiles, Equation 2 was applied, as proposed by Monteiro, J. and Zanella (2014).

$$Q(P) = y_i + \{[P-P_i] / [P_{i+1} - P_i]\} * [y_{i+1} - y_i] \tag{2}$$

In which: Q(P) is the quartile used, which corresponds to the quartile order; P = 0.25 or 0.75; i is the order number of each value (in ascending order); y corresponds to each order number i (total rainfall in mm); Pi is the quantile order (Pi = i/(N + 1)); and N is the number of elements in the series.

For this study, the quartiles technique was adopted for the accumulated rainfall totals at monthly and annual intervals. For more details of the technique of quartiles applied to climatology, see: Xavier and Xavier (1999); Zavattini and Boin (2013); Monteiro, J. and Zanella (2014); Silva, M., Moura e Jardim (2017); and Gouvea et al. (2018).

Interquartile interval were based on the determination of the lower and upper quartiles, which is given by Equation 3 – in order to obtain the degree of dispersion around the centrality measure, as well as to elaborate box plots that demonstrate the variability of precipitation.

$$IIQ = Q_3 - Q_1 \qquad (3)$$

The data obtained were organized in maps, tables, and graphs in the ArcView GIS 10.5 (Esri) and Microsoft Excel 2016 software, and in the statistical Minitab software, version 17.

Rainfall maps were elaborated using isohyet tracing, obtained by the mathematical interpolation topo to raster, according to tests performed with different interpolation raster of the ArcView GIS 10.5 program. Tests found the interpolator that presented greater smoothness among the isohyetal lines and better coincidence with the altimetric characteristics of the region, corroborating the results found by Marcuzzo, Andrade and Melo (2011).

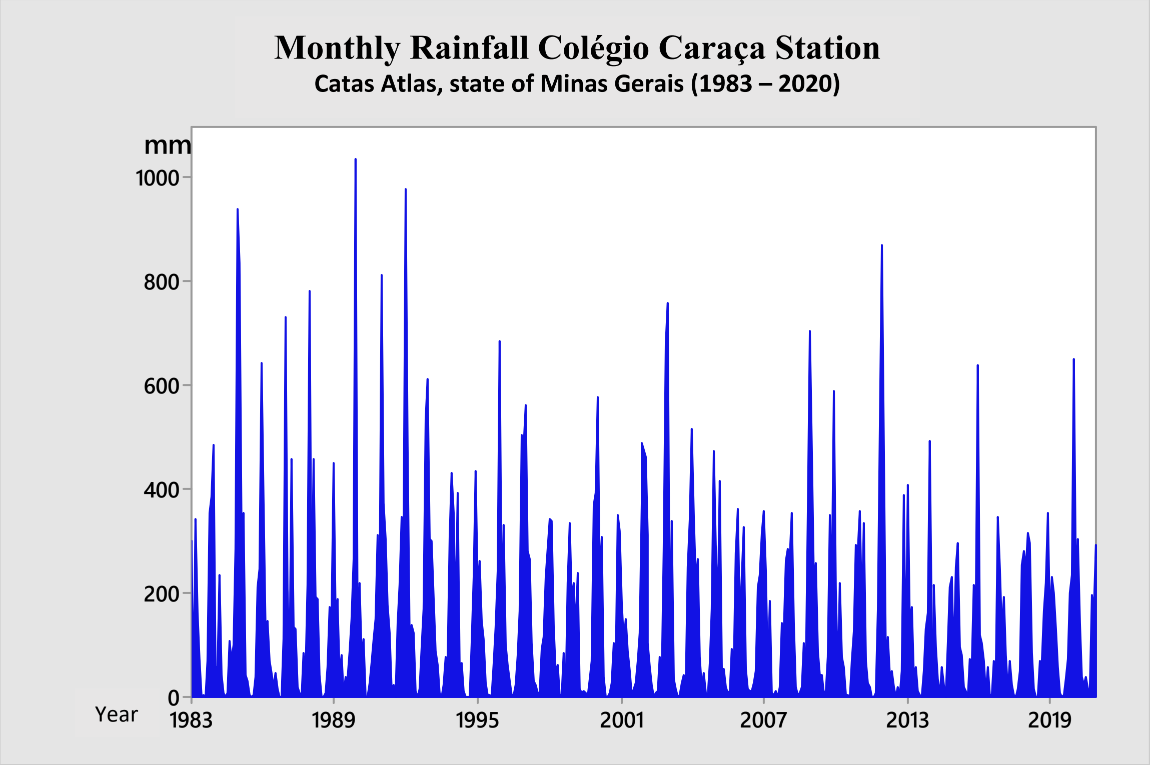
For the interpolation, annual and seasonal precipitation data from up to 31 rainfall stations managed by ANA and located in the Iron Quadrangle and surroundings were used. The years 1992, 2005, and 2017 were chosen considering their rain (1992) and drought (2017) extremes, in addition to the typical standard year (2005), identified by the lower and upper quartiles of the data obtained for the Colégio Caraça Rainfall Station (Estação 2043059, ANA, 2021). Data from rainfall stations that were not recorded for at least one month of the analyzed years were ignored.

Particularities of rainfall in Serra do Caraça

The highest monthly rainfall indexes recorded in Serra do Caraça are close to 1,000 mm, according to the data collected in the rainfall station installed in the region with a time range from 1983 to 2020 (Graph 1), were: in December 1984 (939.7 mm); January 1985 (837.3 mm); December 1989 (1,035.5 mm); January 1992 (980 mm); December 2011 (871.9 mm).

Analyzing the behavior of rainfall over the last 37 years of measurements, we noticed that during the 1980s (until 1992) there was a cycle of higher amount of rainfall. From 1993 to 2010, the records were close to the climatology of the region. In turn, 2011 was marked by positive rainfall anomalies; in the subsequent years, negative rainfall anomalies were observed. The cause of this behavior may be related to several factors of interannual variability, such as the occurrence of Enos in their negative and positive phases. Nevertheless, the analysis of interannual variability is not the objective of this research.

Graph 1 – Monthly rainfall at Colégio Caraça Station – Catas Altas, MG



source: Total monthly precipitation. Station 2043059 – Colégio Caraça – 1983-2020 (ANA, 2021).

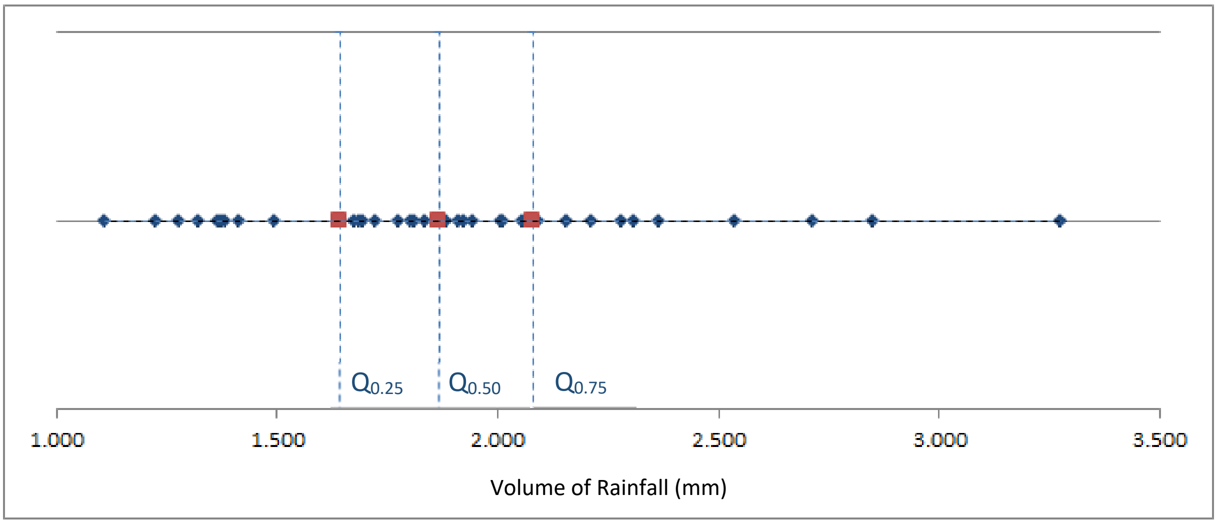
The absence of precipitation on monthly bases was verified in June, July, August, and September. Even so, the relative frequency in August was 20%, in July it was 14%, and in June and in September, 9%. In other words, only about 20% of August had no rain – this analysis can be replicated for the other months. The explanation of the observed behavior is the positioning of the South Atlantic High (SAH) during the winter months, closer to the South American coast. This conditions strong subsidence and atmospheric stabilization.

Regarding the annual rainfall in Serra do Caraça, the highest rainfall records were greater than 2,500 mm: with 2,711 mm in 1985; 2,847.8 mm in 1991; 3,274.4 mm in 1992; and 2,533.9 mm in 2011. The lowest annual rainfall records were no less than 1,000 mm: with 1,281.6 mm in 2010; 1,277.8 mm in 2012; 1,222 mm in 2014; and 1,109.1 mm in 2017 (Graph 2).

When applying the Sturges equation, we found that the highest frequencies were concentrated in the class intervals of 1,829-2,189 mm (modal class), which hold 34% of the total annual rainfall. About 24% of the total annual rainfall values occurred in the range of 1,469-1,829 mm; and 21% in the range of 1,109-1,469 mm. The modal class, obtained by the Sturges method, suggests the typical rainfall interval in the Serra do Caraça region.

This time series presents a total amplitude of variation (TAV) of 2,165.3, with a frequency of variation equal to 1 (Graph 2), due to the differences between the extreme values of the series, in addition to low frequency of these values (maximum and minimum) (Table 1).

Graph 2 – Volume of annual rainfall (mm) – Colégio Caraça Rainfall Station



note: $Q_{0.25}$ – 1st quartile; $Q_{0.50}$ – median; $Q_{0.75}$ – 3rd quartile.
source: Prepared by Antoniel Silva Fernandes with data extracted from the total monthly rainfall. Station 2043059 – Colégio Caraça – 1983-2020 (ANA, 2021).

The analysis of the measures of central trend and the values obtained by the calculation of the standard deviation, correlated with the mean values in the annual analysis, showed significant seasonality or greater dispersion between the months of higher rainfall intensities (November, December, and January) and those of lower intensities (June, July, and August), data confirmed by the cash diagram (Graph 3) elaborated with variability measurements.

Considering the measures of central trend, the low total monthly averages of precipitation indicate that the months of June, July, and August presented the highest coefficients of variation and the lowest standard deviations (Table 1). However, since the statistical universe presents significantly disparate values, the central trend measures are not recommended in this case. Alternatively, the measures of variability should be considered, and in this research we opted for the interquartile interval associated with the median (Graph 3). Causal factors for low seasonal winter rainfall in the region have already been mentioned and refer to the strong atmospheric stabilization due to the positioning of the SAH.

Graph 3 shows the noticeable variability of rainfall, especially in the months of greatest rainfall (December and January), and in the months of greater amplitude (relationship between the minimum and monthly maximums). We can also notice the differentiated behavior of precipitation in the month of February – with a period of drought amid the rainy season (called *veranicos*). Causal factors of the strong rainfall concentration in the rainy semesters and rainy trimester are the passage of systems of extratropical origin, the management of Amazonian humidity by the configuration of the South Atlantic Convergence Zone, the passage of instability lines and the strong continental warming during the summer (Moreira, J.; Abreu, 2002; Assisi, 2010; Silva, E.; Reboita, 2013), among other possibilities. Studies on atmospheric dynamics may better elucidate the causative factors for the *veranicos* frequently observed in this region in February.

Table 1 – Monthly and annual rainfalls recorded at Colégio Caraça Rainfall Station (mm)

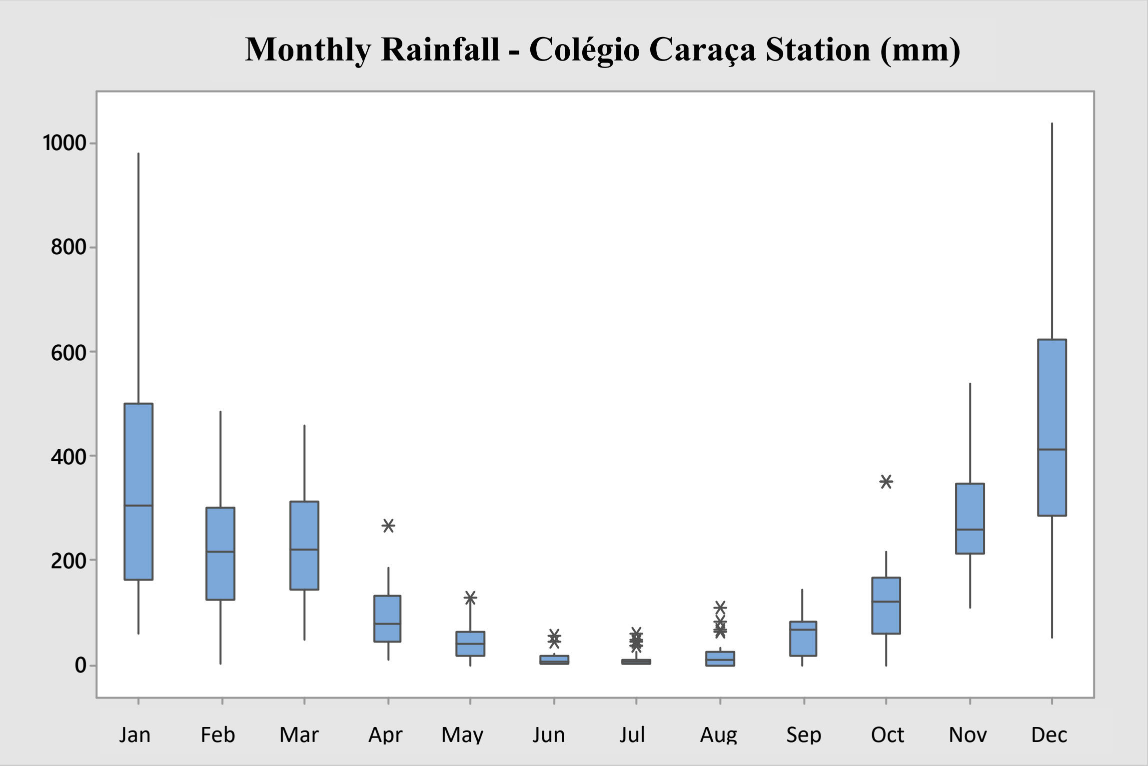
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Out	Nov	Dec	Annual Total
1983	–	3,8	342,1	162	72	1,5	3	**0**	68,2	353	385,5	484,5	1875,6
1984	59	57	234	42	8,2	**0**	8	108,4	69,2	98,5	284	939,7	1908
1985	837,3	301,5	352,8	43,8	30,7	2,5	**0**	3,2	37,4	211,3	248,1	642,4	2711
1986	381,9	124,7	145,2	67,8	48	19	48	16	**0**	1	111,5	730,1	1693,2
1987	209	60	459,9	135,5	130,2	18,2	8	**0**	84,5	50	215,5	782	2152,8
1988	155,5	459,5	192	187,5	42	1,6	**0**	6,5	57	174,5	152	449	1877,1
1989	166	190	178	46	82	5	39	35	87,5	151,6	264	1035,5	2279,6
1990	107	221	76	113	0	0,3	26	66	112	150,2	311	190	1372,5
1991	811	375	306	179	125	16	24,5	**0**	143,3	214	348	306	2847,8
1992	980	484	105	139	124	10	**0**	16,5	96,9	168	537	614	3274,4
1993	306	299	187	88	61	8	**0**	24	77,5	67	307,9	433	1858,4
1994	355,3	145,7	392,8	60,3	64	13	**0**	**0**	**0**	101,9	230,4	436,9	1800,3
1995	203,2	260,8	146	111,4	27,5	2,1	4,2	1,1	65,6	134,9	241,6	684,6	1883
1996	161,2	330	99,4	60,2	32	2,4	2,5	21,4	81	164,6	503,8	482,6	1941,1
1997	561,4	282	265,9	102,9	31,3	23,2	6,6	8,7	91,1	116,4	231,5	285,8	2006,8
1998	344,2	339,8	136,4	44,4	62,2	5,4	3,6	85,2	8,6	218,5	336,7	187,9	1772,9
1999	219,9	125,9	238,8	14,6	7,4	9,8	6	0,1	35,8	68,4	370,3	393,9	1490,9
2000	578,8	222,2	307	39,7	0,4	1,4	8,1	25,6	103,5	52,3	351,1	319,8	2009,9
2001	182,9	109,2	151,2	90,1	48,8	3,1	14,1	27,7	70,3	123,4	373,8	489	1683,6
2002	463	313,6	103,1	55,9	22,2	**0**	6,3	9,8	78,3	36,8	285,6	680	2054,6
2003	757,8	78,7	337,8	36,2	16,8	**0**	4,9	25,9	42,7	28,8	250,5	342,2	1922,3
2004	516,5	346,8	223,7	265,5	77,8	15,2	44,9	9,6	**0**	66,6	169,4	472,8	2208,8
2005	291	167,3	415,8	52	54,3	20,7	6,6	12,2	90,8	62,7	276,6	360,3	1810,3
2006	143	235,2	326,3	55,4	14,3	10,2	12,1	28,5	50,8	210,7	233,4	315,3	1635,2
2007	359,2	243,1	48,8	186	8,9	5,7	11,7	1,9	19,3	140,8	121,9	263,5	1410,8

Table 1 – Cont.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Out	Nov	Dec	Annual Total
2008	285,5	274,5	352,6	140,3	18,5	4,5	8,2	18,7	104,2	50,4	345,9	703,2	2306,5
2009	476,8	214,3	256,6	87,4	40,7	43,4	7,5	11,7	78,4	351	205,1	591,1	2364
2010	207,3	38,2	217,8	75,3	57,6	3	5,1	**0**	70	127,1	293,7	286,5	1381,6
2011	357,6	161,4	334,9	69,2	26,2	17,7	0,3	1	8,9	170,8	514	871,9	2533,9
2012	482,8	54,1	116,2	39,3	51	20,1	0,9	18	2,3	50,6	388	54,5	1277,8
2013	409,9	139,3	173,1	43,4	59	11,4	2,8	**0**	50,5	129,4	163	491,1	1672,9
2014	114,9	129	215,6	95,5	32,8	4,9	58,7	21,6	1,5	105,3	210,5	231,7	1222
2015	65,1	252,1	297,7	96,3	81,2	19	11,9	0,6	72,4	66,1	217,4	185,3	1365,1
2016	640,6	118,3	105,5	68,8	9,5	56,3	2,1	4,2	67,9	54,4	346,3	245,5	1719,4
2017	126,4	193,1	82,1	10,8	70,3	23,6	4	**0**	13,5	49,7	252,7	282,9	1109,1
2018	246,8	317,1	296,3	84,4	16,6	**0**	**0**	68,7	67,3	164	218,2	353,2	1832,6
2019	146,8	230,6	198,4	130,9	57,2	8,3	**0**	3,4	35,4	73	202	233,2	1319,2
2020	649,1	213,9	303,5	142,4	39,6	23,9	38,3	16,1	11	195,1	163,8	292,9	2089,6
Sum	13359,7	8111,7	8721,3	3462,2	1751,2	430,4	427,9	697,3	2154,6	4752,8	10661,7	17143,8	71674,6
Mean	361,1	213,5	229,5	91,1	46,1	11,3	11,3	18,4	56,7	125,1	280,6	451,2	1886,2
Standard Deviation	236,1	114,1	105,5	55,3	33,3	12,1	15,1	24,9	37,1	80,1	101,8	229,0	463,4
Coefficient of variation	65,4	53,5	46,0	60,7	72,3	107,0	134,1	135,9	65,5	64,0	36,3	50,8	24,6
Median	306	217,65	220,75	79,85	41,35	8,15	6,15	10,75	67,6	119,9	258,35	413,45	1867
Lower Quartile	166,0	126,7	145,4	47,5	19,4	2,4	2,2	1,0	23,3	63,6	216,0	286,0	1644,6
Upper Quartile	482,8	294,8	306,8	126,4	61,9	18,1	11,9	23,4	80,4	167,2	346,2	608,3	2080,9
Maximum	980	484	459,9	265,5	130,2	56,3	58,7	108,4	143,3	353	537	1035,5	3274,4
Minimum	59	3,8	48,8	10,8	0	0	0	0	0	1	111,5	54,5	1109,1
Mode	–	–	–	–	–	0	0	0	0	–	–	–	–

source: Prepared by Antoniel Silva Fernandes with data extracted from the total monthly rainfall. Station 2043059 – Colégio Caraça – 1983-2020 (ANA, 2021).

Graph 3 – Temporal distribution of rainfall (mm) – Colégio Caraça Rainfall Station



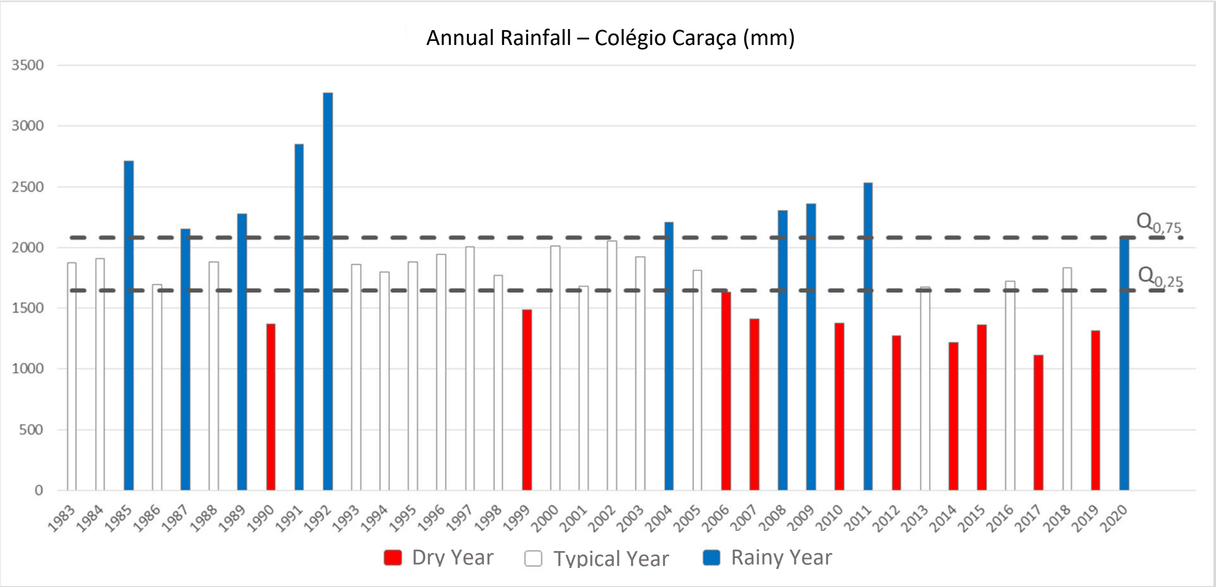
source: Prepared by Antoniel Silva Fernandes with data extracted from the total monthly rainfall. Station 2043059 – Colégio Caraça – 1983-2020 (ANA, 2021).

In addition, the occurrence of extremes, or outliers, are noticeable in the months that mark the transition from the rainy season to the dry season (October and April), as well as the irregularity of the rains in the months of prolonged drought (June, July, and August). However, as shown in the graph above, these months show low precipitation variability. The occurrence of these outliers is related to the longer or shorter delay of the configuration of the rainy/dry season, as well as to the low mean reference values in the winter period.

By the interquartile amplitude method (Zavattini; Boin, 2013), the typical standard years would be within the rainfall values of 1,654 mm and 2,103 mm, i.e., a dispersion of 450 mm (see quartiles results in Table 1). Values lower or higher than this interval are characterized, respectively, as exceptionally dry (or prolonged drought) or exceptionally rainy.

Graph 4 corroborates the analysis of Graph 1, in which the cyclicality of rainfall is observed in the studied area. Between 1993 and 2005, the predominance of normal or typical standard years of precipitation was observed – total annual volumes between 1,654 mm and 2,103 mm. Rainfall above the usual standards was concentrated in the first decade of the series until 1992, with a maximum annual value of 3,284 mm. The values below the cutoff line (1st quartile, represented in the graph as $Q_{0.25}$), were concentrated in the 2010s, with the lowest record registered in 2017 (1,109 mm) (Graph 4 and Figure 2).

Graph 4 – Standard and exceptional values of annual rainfall by the interquartile amplitude (mm) method – Colégio Caraça Station



source: Prepared by Antoniel Silva Fernandes with data extracted from the total monthly rainfall. Station 2043059 – Colégio Caraça – 1983-2020 (ANA, 2021).

Rainfall contrasts between Serra do Caraça and Iron Quadrangle

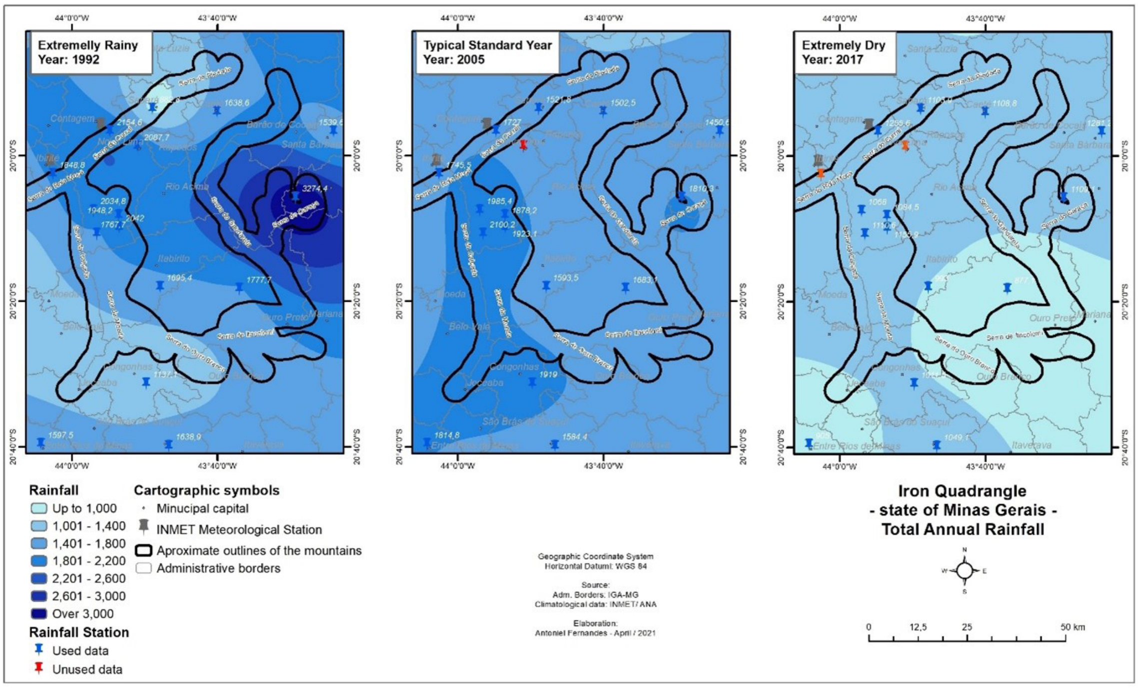
The distribution of rainfall in the Iron Quadrangle was interpolated based on the definition of the standard years (rainy, normal or typical, and dry or prolonged drought) (Figure 2 and Graph 5). Notably, in the extreme rainy year (1992), the highest volumes of precipitation were concentrated in the region of Serra do Caraça (eastern part of the IQ); and the smallest records occurred in the far west (western front of the Serras da Moeda and Calçada), which evidences the role of humidity management that Serra do Caraça plays at regional level.

In this case, as Moreira, J. and Abreu (2002) found, the orography constitutes an atmospheric force by clouding the overlying airflow. This vortex, in turn, potentiates precipitation; the more stable the atmosphere the more important it is, such as at the beginning of the rainy season.

The rainfall pattern within the IQ in an extremely dry year (2017) shows to be of more homogeneous distribution and of greater scarcity in the southern part, possibly generated by the greater performance of the SAH and, consequently, of the Atlantic tropical mass (mT). These may lead to a longer period of stability in the weather conditions, since they prevent the penetration of the disturbed currents of West and especially South – responsible for producing conditions of instability and, therefore, favoring precipitation. The role of orography is evident; however, especially in the Serras do Caraça and Calçada/Moeda, due to the vertical undulating effect of moisture when it passes through these two lines of mountains.

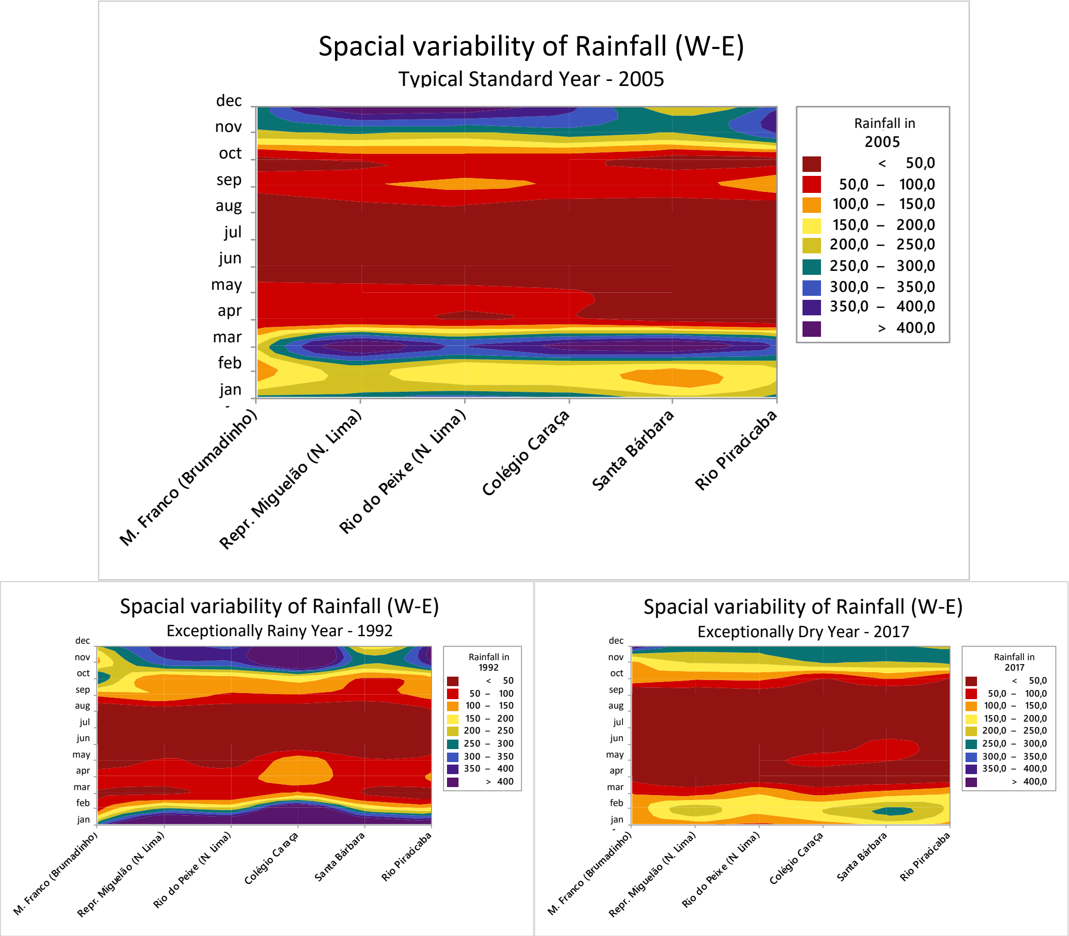
In the typical or normal distribution of rainfall (2005), the mountains in the north-south direction (Serras da Moeda and Calçada) and mainly by the Serra do Caraça influence the organization of humidity and produce higher rainfall volumes than in the immediate surroundings. Notably, the Serra do Caraça is the highest point of this region, with more than 2,000 m of altitude, and is located at the eastern end of the IQ, thus configuring an orographic barrier.

Figure 2 – Standard years (rainy, normal, and dry) in IQ



source: Prepared by Antoniel Silva Fernandes, 2021.

Graph 5 – Rainfall variability (rainy, normal, and dry years) in IQ

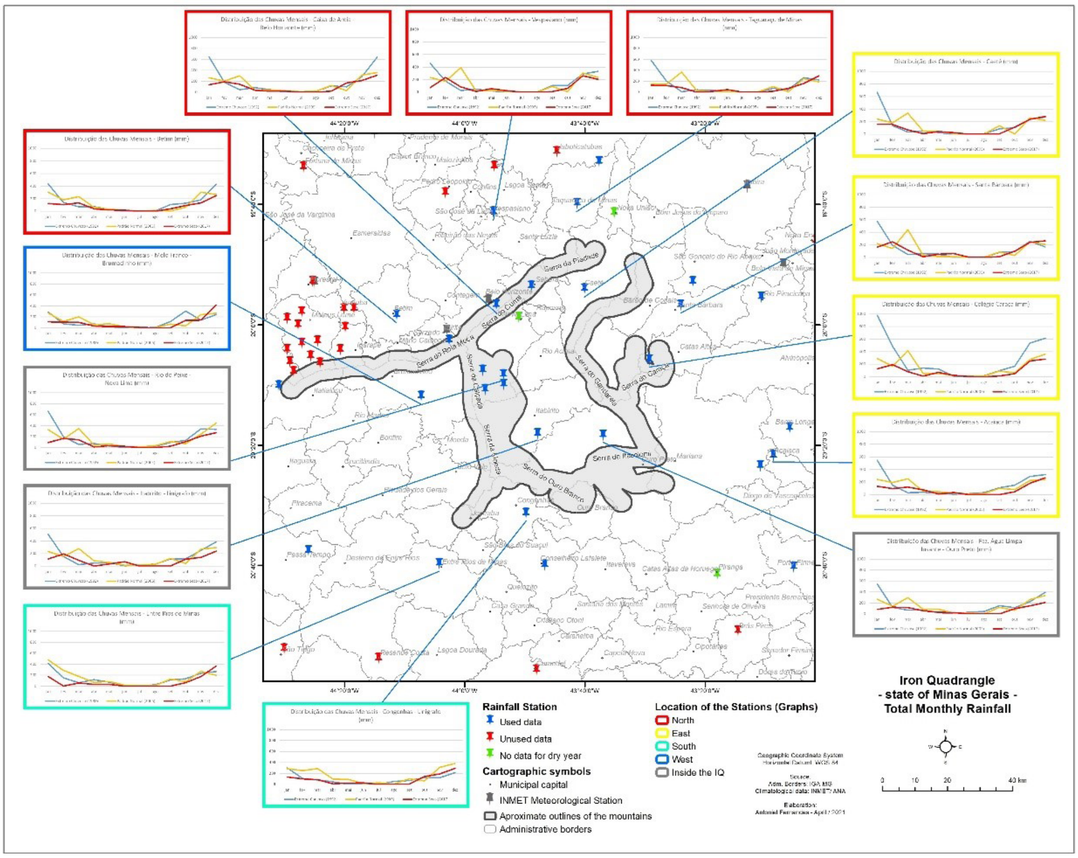


source: Total monthly precipitations in the years 1992, 2005, and 2017.
Stations 2044008, 2043004, 1943007, 2043059, and 1943001 (ANA, 2021).

Moreover, the S-shaped morphology of Serra do Caraça can contribute to the swirling of the air and channel the moisture that precipitates in the region. Besides, it is worth noting once again the vertical wave effect that lifts the air at this point and creates the subsidence of the still humid air over the region of Serra da Calçada, promoting the increase in precipitation.

To analyze the monthly rainfall pattern in the station and in the context of the Iron Quadrangle, the graphs in Figure 3 for the reference years were produced: typical/normal (2005), extreme rainy (1992), and dry (2017).

Figure 3 – Distribution of monthly rainfall in standard years (rainy, normal, or dry) in IQ



source: Prepared by Antoniel Silva Fernandes, 2021.

Considering the extremely rainy year of 1992, the results illustrated in the graphs corroborate the previous analysis, which shows that rainfall volumes are higher in the eastern and northern areas of the IQ than in the western and southern areas.

The analysis of rainfall pattern in January showed a precipitation of approximately 600 mm in the inner and in northern and eastern edges of the IQ. On the western and southern edges, a reduction of 300 mm was observed during the same period – which may indicate the influence of topography and relief conformation for the studied area. This pattern is also perceived in the other months of the rainy season.

Another spatial pattern observed is the behavior of precipitation in the stations installed closer to the IQ mountains, where the rainfall is higher than in the others. In January 1992, rainfall volumes close to 1,000 mm were recorded in Serra do Caraça. This value did not repeat in the other stations of the IQ or in its surroundings. In the Caixa de Areia Station, located in the Serra do Curral, and Rio do Peixe Station, installed in the Moeda syncline, the precipitations exceed 600 mm. In the stations of Congonhas (south of Serra do Ouro Branco), Entre Rios de Minas, and Melo Franco (in Brumadinho) – the last two being west of the Serras da Calçada and Moeda – the records were close to 400 mm for the same analyzed period (January 1992).

The analysis of the records of the Itabirito and Fazenda Água Limpa stations, both in the interior of the IQ and north of Serra do Ouro Branco, showed an increase in precipitation (close to 500 mm) when compared with the records of the stations south of this mountain range. This evidences the behavior of moisture and the role of the mountains and IQ configuration in the distribution of rainfall in this region.

In the analysis of the normal/usual standard year (2005), the distribution of rainfall is more homogeneous both inside the IQ and in its surroundings. A short dry period that occurs during the rainy season (February) is noticeable. With the resumption of the rains in March, a slightly higher precipitated volume is seen around the Serra do Caraça when compared with the surroundings. This fact may be related to altitude (higher altimetric dimensions in the IQ), position (east of the IQ), and morphology (S-shaped mountains), which may favor precipitation in the region, as explained before. It is also possible to note that the records of precipitation volumes – at the east edge stations (Colégio Caraça and Santa Bárbara) in March – exceed by up to 200 mm the stations of the west (Melo Franco – Brumadinho station) and south (Entre Rios de Minas and Congonhas station).

As for the extremely dry year (2017), the highest monthly volumes were close to 400 mm; however, for most of the period the records were below 200 mm, even during the rainy season. Still, the behavior of rainfall distribution differs between the east and north edges (larger monthly records) and the west and south edges (smaller monthly records). Inside the IQ, the behavior resembles those detected at the stations of the east and north edges.

Final considerations

The Serra do Caraça is certainly the region of the Iron Quadrangle that has the highest volumes of precipitation. Its orography and position (eastern edge of the IQ) allows for annual rainfall volumes greater than 2,500 mm, which occurred in the years 1985, 1991, 1992, and 2011. On the other hand, the lowest annual rainfall records (in 2010, 2012, 2014 and 2017) were no less than 1,000 mm; as for monthly occurrences, the records are close to 1,000 m (in the years 1984, 1985, 1989, 1992, and 2011). Thus, both annual and monthly records show the rainfall amplitude of Serra do Caraça and demonstrate the interannual behavior.

Notably, in the Serra do Caraça and its surroundings, the typical standard years occur when rainfall is between 1,654 mm and 2,103 mm (interquartile amplitude method). In evaluating the historical series, we found that, between 1993 and 2005, the usual standard years of precipitation predominated. Rainfall above the usual standards was mostly from the first decade of the series until 1992; conversely, rainfall below the usual standard years occurred mainly in the 2010s.

We also noticed the probable vertical wave effect of Serra do Caraça with the predominant currents of East-Northeast air, which cause heavy rainfall when humid, and with the subsidence over the region of Serras da Calçada and Moeda, which contributes to increase the precipitation in this region as well.

Moreover, we also identified the variability between the years with the delimitation of a typical or normal standard years (in other words, within an acceptable cutout for the climatology of the region). While also observing exceptional years, that is, when there were anomalies (years of drought or excessive rain) in the Region of the Iron Quadrangle – which helps to understand the rainfall regime in order to promote more assertive actions in the management and use of water resources. It is worth noting that the average rainfall around the IQ is 1,450 mm annually, extracted from the Provisional Climatological Normal of 1981-2010 (INMET, 2022).

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Authors' Contribution

Antoniel Silva Fernandes: Conception of the study, data collection, data analysis, preparation and writing of the text, and review and approval of the final version.

Alecir Antonio Maciel Moreira: Study orientation, data analysis, and review and approval of the final version.

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