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REGULAR ARTICLE

Rainfall data adjustment to Volta Redonda macro-region

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Abstract

Most Brazilian cities do not have a proper water and soil management system due to lack of planning in this sector and of an easy-consultation local-hydrological bibliography capable of reinforcing the future creation of a hydrological modeling. Volta Redonda macro-region's case can be added to this statistics, since it accounts for several natural hazards linked to floods and inundations in some specific locations. The aims of the present study are to descriptively analyze monthly rainfall data generated by CEMADEN's rainfall gauges and to assess whether monthly rainfall in the region adapts well to probability Gamma Distribution plots. Rainfall data from four points in Volta Redonda, Barra Mansa and Pinheiral cities, recorded for 48 months, and provided by CEMADEN, were used in the study. Gamma Distribution was adjusted to monthly rainfall data. In conclusion, the probability of having a given monthly rainfall value lower than, or equal to, that recorded for the Pinheiral – Volta Redonda – Barra Mansa conurbation area can be estimated through Gamma Distribution. Values recorded for shape (γ) and scale (β) parameters of Volta Redonda macro-region's municipalities were 1.59 and 79.30, on average, respectively.

Keywords

Hydrology; rainfall; agrometeorology

Introduction

The recent intensification of flood events in some Brazilian locations is clear, either when it comes to their frequency or magnitude, since they have been exceeding the flow capacity of urban drainage systems. Assumingly, such an increase in the number of external events is the response to climate changes or to the badly planned urbanization of drainage basins (RIBEIRO et al., 2022) like São Paulo, Natal and Santos macro-regions (Marengo et al., 2022; Rodrigues et al., 2021 and Freitas et al., 2022).

Lack of urban planning leads to disorganized city growth that, in its turn, potentiates floods. It is so, because strong anthropogenic pressure and real estate speculation enable the occupation of regions accounting for high risk of floods, such as the case of permanent preservation areas and floodplains. Excessive soil sealing, and deforestation, increase surface runoff volume and, consequently, external flows, a fact that points out how drainage structures are undersized. Furthermore, lack of up-dated intense rainfall data generates doubts about calculations performed for urban drainage systems, as well as uncertainty about their results (Choi et al., 2021; Freitas et al., 2022).

In light of constant changes, either in surface occupation or in intense rainfall patterns, it is necessary adding these factors to hydrographic basin planning, mainly when it comes to macro-drainage, in order to control flood events (Roccati et al., 2020; Rodrigues et al., 2021), especially in conurbation areas.

Urbanization expansion, mainly in some metropolitan regions, increases intense rainfall frequency. This rise in extreme-rain intensity is associated with accelerated convective rain formation processes in urban zones due to likely changes in local micro-climate, which are caused by increased flow of latent heat from the surface to the atmosphere (Diaz et al., 2020; Marengo et al., 2020), such as the case of Volta Redonda macro-region.

The Volta Redonda Macro-region is located in the south of the state of Rio de Janeiro and comprises the municipalities of Volta Redonda, Barra Mansa and Pinheiral. These are located on the main road axis in Brazil, in the Middle Paraíba River watershed and in the Atlantic Forest biome, representing one of the largest conurbations in the state of Rio de Janeiro. The Volta Redonda Macro-region is part of the national history, as it was one of the largest coffee producing centers in the Empire of Brazil, and today, they are cities with high metallurgical potential in Brazil.

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The conurbation consisting of Pinheiral, Volta Redonda and Barra Mansa presents a varied geomorphology, an exponential expansion of the urban perimeter and even the use of the land without proper conservationist planning, as a result, the Volta Redonda Macro-region presents problems with natural disasters due to intense rainfall events; thus, this conurbation lacks rainfall information analyzed for assertive decision making aimed at the prevention of natural disasters (Saito et al., 2021; Santos and Duarte, 2022).

In July 2018, rain gauges from the National Center for Monitoring and Alerts for Natural Disasters (CEMADEN) were installed in the Volta Redonda Macroregion (Saito and Souza, 2013), and to date the rainfall data obtained in the Volta Redonda Macroregion have not been analyzed. In this context, the hypothesis of this studywas to check for the application of rainfall data from CEMADEN in decision making and solutions of monitored cities.

By having all the aforementioned aspects in mind, the aims of the current study were (i) to make the descriptive analysis of rainfall data recorded for Volta Redonda macro-region, (ii) to assess whether Gamma Distribution adapts well to these data's description, in order to help planning or organizing the urban expansion vector in Volta Redonda, Pinheiral and Barra Mansa cities, (iii) to contribute to the elaboration of propositions and of structural and non-structural actions to control floods and to help promoting safety for both the population and the urban infrastructure installed in Volta Redonda macro-region.

Materials and methods

Rainfall data recorded for Barra Mansa, Volta Redonda and Pinheiral cities were collected by automatic rainfall gauges installed in these municipalities, in July 2018, by the National Center for Natural Hazardous Monitoring and Warning, also known as CEMADEN.

Initially, rainfall data from each municipality were screened to qualify intense rainfall events. Rainfall events whose intensity was higher than 30 mm h^{-1} were considered intense based on the limit adopted by CPTEC/INPE for intense rainfall warning.

Subsequently, data were organized per month; then, descriptive statistical analysis was applied to all monthly rainfall data recorded for the herein assessed conurbation area; in other words, rainfall data from July 2018 to May 2022. It was done to get measures of central tendency and dispersion of the rainfall series (Assis et al., 1996; Assis et al, 2016).

Monthly rainfall data recorded for the aforementioned conurbation area were descriptively analyzed to define the coefficient of asymmetry (A), shape (γ) and scale (β) parameters (Assis et al., 1996) (Equations 1, 2 and 3) – which, to this point, remained unknown for Volta Redonda, Barra Mansa and Pinheiral conurbation areas.

$$A = \ln \bar{x} - \frac{1}{n} \sum_{i=1}^{n} \ln x_j$$

(1)

Wherein,

A – dimensionless coefficient of asymmetry;

x_j – monthly rainfall height, mm; and

x – mean monthly rainfall height, mm.

$$\gamma = \frac{1 + \sqrt{1 + \frac{4A}{3}}}{4A}$$

(2)

Wherein,

γ – dimensionless shape parameter; and

A – dimensionless coefficient of asymmetry.

$$\beta = \frac{\bar{x}}{\gamma}$$

(3)

Wherein,

β – scale parameter, mm;

x – mean monthly rainfall height, mm; and

γ – dimensionless shape parameter.

Subsequently, monthly rainfall data were adjusted to Gamma Distribution by using the Taylor series in order to estimate the probability of having intense rainfall events in the assessed conurbation area. Therefore, these cities would have an accurate hydrological tool to help developing preventive actions against floods and landslides (Equations 4 and 5) (Assis et al., 1996; Botelho and Morais, 1999).

$$F(x) = \frac{1}{\beta^{\gamma} \Gamma(\gamma)} \int_0^x u^{(\gamma-1)} e^{(-u/\beta)} du$$

(4)

Wherein,

$F(x)$ – dimensionless probability equal to, or lower than, x rainfall;

$\Gamma(\gamma)$ – incomplete gamma function;

γ – dimensionless shape parameter;

β – scale parameter, mm;

e - base of the Neperian logarithm (2.718); and

x – rainfall volume, mm.

$$F(t) = \frac{t^{\gamma}}{\gamma\Gamma(\gamma)e^{\gamma}}\left(1 + \frac{t}{\gamma+1} + \frac{t^2}{(\gamma+1)(\gamma+2)} + \ldots\right) \quad (5)$$

$$t = \frac{x}{\beta}$$

Wherein,

F(t) – dimensionless probability of having rainfall equal to, or lower than, *t*;

t – dimensionless independent variable of the Taylor series;

x – rainfall volume, mm; and

β – scale parameter, mm.

Data estimated through Gamma Distribution, and those deriving from CEMADEN's rainfall gauges installed in the assessed conurbation area, were assessed through Kolmogorov-Smirnov adherence test, at 1% significance level (Birnbaum, 1952).

Results and discussion

It was possible observing that intense rainfall events take place in Volta Redonda macro-region and that they are mostly observed in different neighborhoods and dates, in the assessed municipalities (Table 1). Thus, it is necessary installing other CEMADEN rainfall gauges in different neighborhoods in Volta Redonda macro-region to achieve accurate prevention and detailed attention warning for intense rainfall events.

Data recorded by the rainfall gauges showed that the highest rainfall event intensities in the assessed conurbation area were observed in Retiro neighborhood, Volta Redonda City, and downtown Pinheiral City (Table 1). A likely explanation for such a finding lies on the fact that these neighborhoods are placed on locations surrounded by hills and waterbodies, such as water reservoirs and Paraíba do Sul River; in other words, assumingly, rainfall events in Retiro neighborhood and downtown Pinheiral have significant orographic component since their terrain favors water vapor accumulation and ascension to the atmosphere (Santos and Garcia, 2016).

Table 1. Intense rainfall events in the Pinheiral – Volta Redonda – Barra Mansa conurbation area (from 2018 to 2022).

City	Neighborhood	Year	Month	Day	Rainfall (mm)	Intensity (mm h^{-1})
Pinheiral	Downtown area	2019	January	15th	36.4	31.2
		2021	February	1st	29.0	43.5
				20th	95.8	52.3
			March	16th	44.0	33.0
			December	22nd	29.8	59.6
Volta Redonda	Retiro	2019	April	7th	164.6	61.7
		2020	November	16th	27.0	32.4
			December	16th	27.6	55.2
		2021	March	14th	60.0	40.0
		2022	March	13th	55.6	37.1
	Santa Cruz	2018	December	23rd	62.6	31.3
				28th	21.8	32.7
		2019	February	3rd	46.6	31.1
		2020	January	1st	19.2	38.4
				10th	62.8	34.3
			November	16th	55.0	55.0
		2021	December	29th	51.0	61.2
Barra Mansa	Vila Maria	2019	April	5th	68.8	59.0
			December	22nd	66.4	30.6
		2020	January	2nd	26.0	31.2
			November	16th	15.6	31.2
	Vila Orlandélia	2018	December	20th	52.2	34.8
		2019	February	22nd	62.4	31.2
			April	5th	74.6	74.6
		2020	January	1st	5.4	32.4
				12th	102.0	43.7
		2021	January	9th	21.2	31.8
			February	2nd	62.8	31.4
		2022	February	14th	29.8	44.7
				22nd	29.0	34.8
Total					1,532.4	

The most significant monthly rainfall events in Volta Redonda macro-region were observed in Santa Cruz neighborhood, Volta Redonda City (Table 2). Municipal Natural Park Santa Cecília do Ingá, which is one of the largest forest conservation areas in Southern Rio de Janeiro State, is located in this neighborhood. It was possible observing one of the lowest variation coefficients recorded for monthly rainfall events of this macro-region in this location. Thus, assumingly, the forest is helping rain formation in Santa Cruz neighborhood due to its contribution to the formation of water vapor in the atmosphere because of forest evapotranspiration (Keys and Erlandsson, 2018).

Table 2. Descriptive statistics of monthly rainfall between 2018 and 2022 in the Pinheiral – Volta Redonda – Barra Mansa conurbation area.

Monthly rainfall (mm)	Pinheiral	Volta Redonda		Barra Mansa	
	Downtown	Santa Cruz	Retiro	Vila Maria	Vila Orlandélia
Maximum	306.8	482.0	447.2	452.8	471.4
Minimum	3.6	6.6	1.4	1.6	1.0
Mean	113.8	138.0	129.1	120.3	131.0
Median	89.6	96.6	101.4	89.2	94.0
Standard deviation	90.5	114.1	108.7	101.9	108.6
Variation coefficient (%)	79.5	82.7	84.2	84.7	82.9

Murta et al. (2005) and Silva et al. (2007) analyzed rainfall events observed in Southwestern Bahia State and in Santa Maria City (RS); they found that Gamma Distribution allowed better understanding rainfall height probabilities in the assessed locations. It was also possible observing that the herein expected monthly rainfall data calculated through Gamma Distribution adhered ($p<0.01$) to monthly rainfall data recorded for the assessed conurbation area (Figure 1), i.e., it is possible estimating the probability of monthly rain in Volta Redonda macro-region based on Gamma Distribution (Dourado Neto et al., 2005; Coan, et al., 2015).

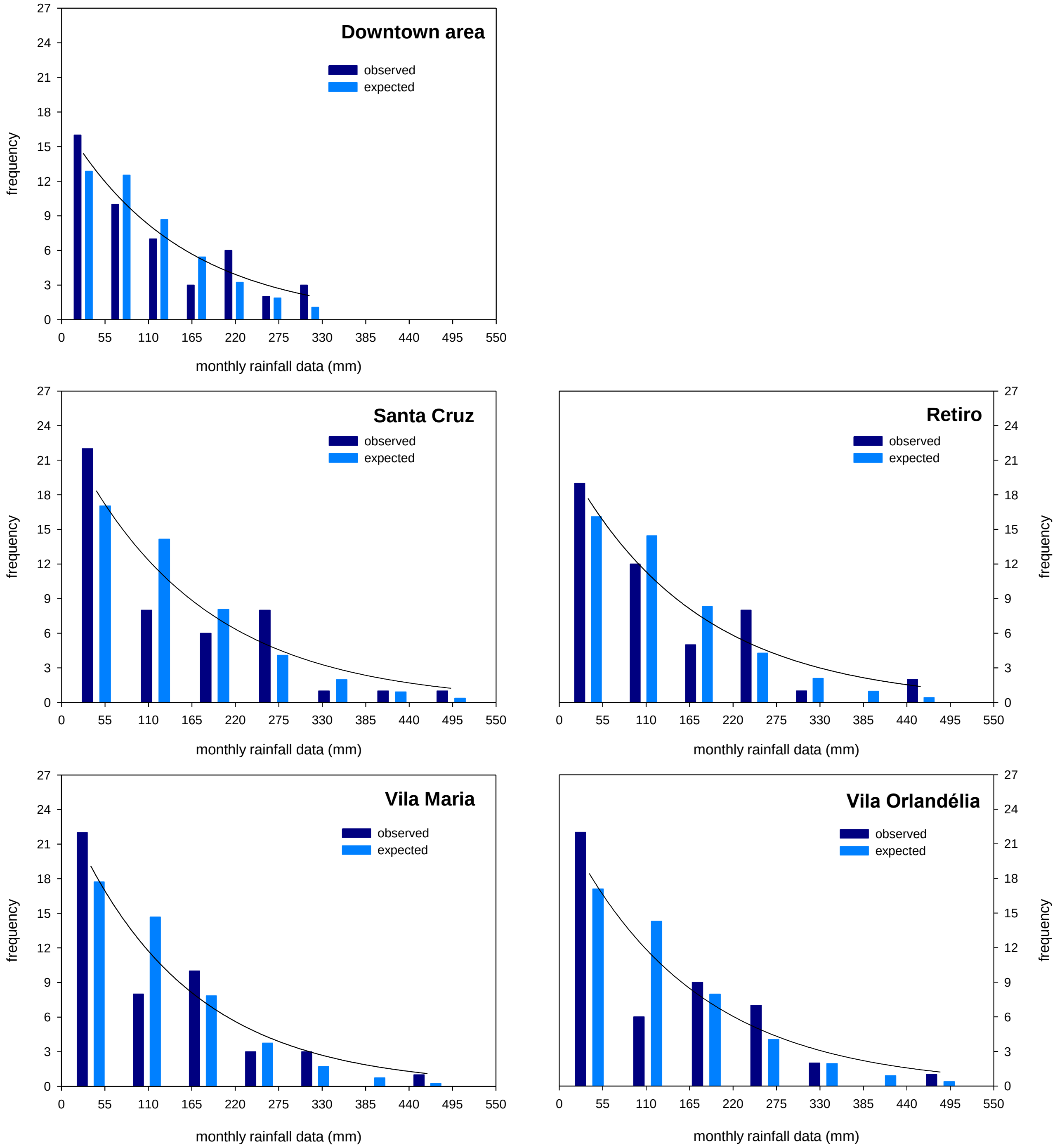

Figure 1. Gamma distribution plotted for monthly rainfall events in Pinheiral (Downtown), Volta Redonda (Santa Cruz and Retiro) and Barra Mansa (Vila Maria and Vila Orlandélia) (from 2018 to 2022).

Although monthly rainfall data presented high variation coefficient values (Table 2), the scale parameter of Gamma Distribution also showed high values (Table 3). Thus, it is possible confirming that there is great monthly rainfall data dispersion in Volta Redonda macro-region (MURTA et al., 2005). Assumingly, this finding can be explained by time variation in rainfall over the year, because the most significant rainfall events were observed from October to March; thus, if there were similar monthly rainfall values every year, the scale parameter and the coefficients of variation recorded for monthly rainfall events would be lower (Assis et al., 2006; Silva et al., 2007; Coan et al., 2015).

The scale parameter values of Gamma Distribution observed in data of Volta Redonda macro-region are lower than 100 (Table 3); thus, it is feasible using Gamma Distribution to estimate the probability of rainfall heights in Volta Redonda macro-region (Thom, 1958).

Table 3. Gamma Distribution parameters for monthly rainfall in Pinheiral – Volta Redonda – Barra Mansa conurbation area (from 2018 to 2022).

Parameter	Pinheiral	Volta Redonda		Barra Mansa	
	Downtown	Santa Cruz	Retiro	Vila Maria	Vila Orlandélia
shape (γ)	1.577	1.651	1.611	1.600	1.533
scale (β)	72.159	83.569	80.113	75.187	85.491
p-value	0.0003	0.0002	0.0003	0.002	0.0008
Coefficient of asymmetry (A)	0.351	0.333	0.342	0.345	0.362

Gamma Distribution allowed observing that the probability to have monthly rainfall lower than, or equal to, 125 mm ranges from 55% to 65% in Volta Redonda macro-region (Table 4). Thus, it is not recommended to use mean rainfall data (Table 2) to make decisions about water and soil use and management in this macro-region's municipalities. This statement is justified by the low value recorded for the probability of having monthly rainfall equal to, or lower than, 125 mm in it (Table 4), and by the low frequency of this rainfall height in the assessed conurbation area (Figure 1) (Morais et al., 2001; Paiva Sobrinho et al., 2014; Coan et al., 2015).

Table 4. Probability (%) of having monthly rainfall equal to, or lower than, that observed for the Pinheiral – Volta Redonda – Barra Mansa conurbation area (from 2018 to 2022).

Monthly rainfall (mm)	Pinheiral	Volta Redonda		Barra Mansa	
	Downtown	Santa Cruz	Retiro	Vila Maria	Vila Orlandélia
25	10.9	7.6	8.8	9.8	9.4
50	26.5	20.1	22.4	24.6	22.9
100	54.4	45.0	48.4	51.7	48.3
125	65.0	55.5	58.9	62.3	58.5
150	73.4	64.4	67.6	70.9	67.0
200	85.0	77.7	80.4	83.1	79.6

Paiva Sobrinho et al. (2014) assessed rainfall events in Mato Grosso State and observed that Gamma Distribution parameters were different within the State and that it is recommended using Rainfall Gamma Distribution to plan agriculture in this State. Morais et al. (2001), by analyzing rainfall events in Lavras City, pointed out that using mean rainfall values can undersize water and soil engineering projects in this municipality; they recommended using Gama Distribution to do so, since it allows better understanding likely rainfall heights in this city. Dourado et al. (2005) analyzed rainfall events in Piracicaba City through Gamma Distribution and recommended using it to understand rainfall events in this municipality, as well as to make it possible reaching a more accurate rainwater-use planning.

Based on the herein recorded results, it is possible stating that Gamma Distribution allows better understanding monthly rainfall events in Volta Redonda macro-region, besides providing rainfall data based on statistics to plan rain drainage sites and soil conservation sites for agricultural activities in Pinheiral, Volta Redonda and Barra Mansa conurbation area.

Conclusions

Our findings contain rainfall information for use by the technical and scientific community of the Volta Redonda Macroregion to support land use planning and the prevention of natural disasters.

The probability of having a given monthly rainfall value in Pinheiral – Volta Redonda – Barra Mansa conurbation area can be estimated through Gamma Distribution.

It was possible estimating the Gamma Distribution parameters, at good adherence, for cities in Southern Rio de Janeiro State conurbation area.

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