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Temporal and spatial distribution of storms on January 24th and 28th, 2020 in Belo Horizonte, Minas Gerais, Brazil

Marcia Maria Guimarães

Center for Exact and Technological Sciences. State University of Montes Claros – Unimontes, Montes Claros, Minas Gerais, Brazil.
E-mail:marcia.guimaraes@unimontes.br

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***Abstract*—*The South Atlantic Convergence Zone (SACZ) is the main meteorological system responsible for the occurrence of regular rains in almost the entire central and southeastern region of Brazil in rainy season. During the January 2020 these complex system has generate severe storms especially in Minas Gerais state. These intense episodes of precipitation induced real catastrophes and numerous impacts throughout Metropolitan Region of Belo Horizonte (MRBH) like overflow of water courses and destruction of road systems with closure of major avenues, causing deaths due to flooding or landslide and very high economic losses. The Belo Horizonte City recorded the highest intensity of rain measured in one hundred and twelve years of hydro-meteorological monitoring. The aim of this paper is the analysis of temporal and spatial distribution of rainy 24 and 28 January recorded at 46 automatic weather stations (AWS). These were the worst of all storms recorded at MRBH. In the temporal analysis, were applied the regional IDF relationships, the regional annual frequency curves with dimensionless intensities, and synthetic time-distribution graphs of rainfall or hyetographs. To verify the spatial distribution of these storms some statistical tools from the QGIS software were applied with the isohyets maps drawing. These shown that at the south-central portion of the city high-value isohyets conforms approximately to the high elevations on the windward slope, thus reflecting the prevalent direction of humidity inflow and the role of regional orography in the process of intensifying short-time rains.*

I. INTRODUCTION

Designed by engineer Aarão Reis in 1897 Belo Horizonte was one of the first planned capitals in Brazil. The city started in the 1920s to channeling most of its watercourses, and with that, started its urban flooding problems. Thus, years after the channeling of the first stream, in 1929, a flood devastated the capital, showing that the rectification and fixation of the sections of the rivers and the transformation of their stretches into artificial channels did not solve the drainage issues, on contrary they accelerated and intensified their impacts. Even so, decades later, the solution found by the municipal government was to expand and deepen the Arruda's stream channel, believing that with these works they would be solving all drainage city problems. Since then flood events have been numerous.

The city of Belo Horizonte was affected in 2020 year by several storms, having recorded one of the rainiest months of January of the last one hundred and twelve years, since the beginning of its hydro-meteorological monitoring, accumulating in 2020 a total of 935.2 mm.

The second rainiest January registered 850.3 mm in 1985 and the third registered 795 mm in 2003.

The most critical precipitation occurred on January 24th and 28th, 2020 registering daily heights of 171.8 mm and 117.4 mm, respectively, with the 24th day recording the highest accumulated in the entire monitoring period, as Belo Horizonte Station data operated by the National Institute of Meteorology – INMET. However, in the south-central portion of the city, the "Leitão" automatic station registered on the 28th, in three hours, a height of 186.4 mm with an intensity of 62.13 mm/h, the greater intensity over the entire measurement period. A 30-50 mm daily precipitation accumulated is already considered high, and greater than 50 mm is extremely high. Raining 100 mm or more in one day is something special that doesn't happen very often. It is an extremely large amount of rain, with the potential to cause serious damage and flooding in urban centers [1].

The events of January 2020 were of great magnitude and exceeded the response capacity of the micro and macro drainage and flood-dampening systems in the capital and in some municipalities of the Metropolitan Region of Belo Horizonte (MRBH). Floods were recorded in several water courses in the sub-basins that drain Belo Horizonte – “Arrudas” and “do Onça” watersheds, resulting in impacts of various magnitudes, which only didn’t become a greater tragedy, due to actions of monitoring, prevention and contingency measures implemented by Belo Horizonte City Hall (PBH) by the Secretariat for Protection and Civil Defense.

This article presents a temporal and spatial analysis of the rains measured in forty-six rain gages stations (Fig. 1) on the 24th and 28th of January 2020, based on the network of automatic hydro-climatological stations of the “Hydrological Monitoring and Flood Warning Program of the Belo Horizonte municipality”, operated by Superintendence of the Development of Belo Horizonte (SUDECAP), and automatic gauges stations of INMET and National Center for Monitoring and Natural Disaster Alerts (CEMADEN) and conventional stations database provided by the Brazilian National Water and Sanitation Agency (ANA).

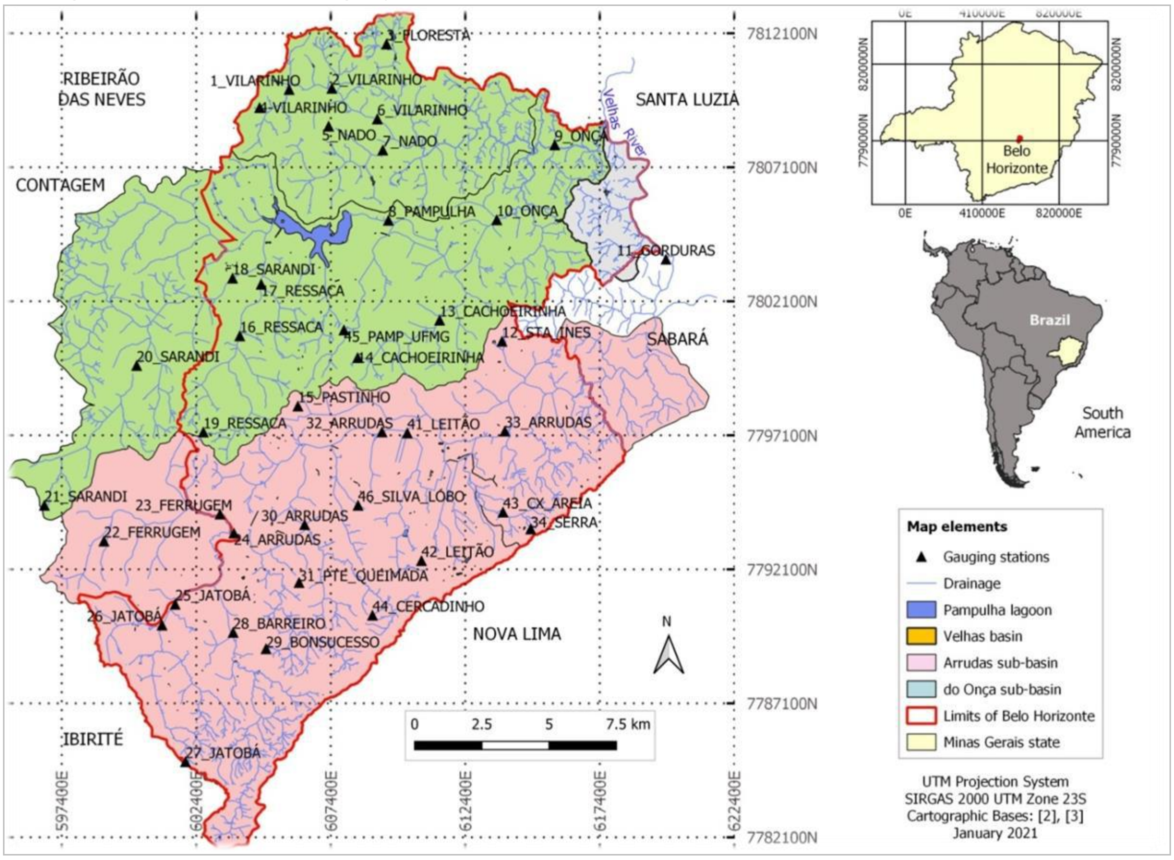


Fig. 1: Map of the study area – Belo Horizonte's rain measurement stations and sub-basins

II. METHODOLOGY

The flowchart of the presented methodology for the study of the temporal and spatial distribution of intense rainfall is illustrated in Fig. 2and the different aspects of it are explained in more detail in the following section.

2.1 Study Area and Data Collection

Located in the São Francisco river basin the limits of Belo Horizonte define a 331.4-km^2 area, between latitude 19°48'57"S and longitude 43°57'15"W, who has two sub-basins of “das Velhas” river: the “Arrudas” stream which drains the administrative regions: Barreiro, West, Northwest, Center-South and East; and the “do Onça” stream which drains the regional: Pampulha, Northeast, Venda Nova and North (Fig. 1).

Its climate is classified according to Köppen-Geiger as Cwa – tropical of altitude with dry winter and rainy summer. Throughout the year, it is under the control of the South Atlantic Subtropical Anticyclone (SASA) and, consequently, it has been subjected to large scale descending vertical movements [4].

During the spring and summer months when the South American Monsoon System is well organized, there is an expressive horizontal transport of humidity and heat from the Amazon region to Southeast Brazil. In that environment the South Atlantic Convergence Zone (SACZ) develops. This is the main large-scale system responsible for the rainfall regime over the Southeast regions of Brazil according to [5], [6], [7], [8] and [9].

The MRBH can be considered as a rainy region, presenting a basic unimodal cycle, marked by a clearly-defined wet season from October to March, followed by a dry season from April to September. Convective storms associated to frontal systems are at the origin of short-duration intense rainfall episodes over the city [4].

According to 2010 census [10] Belo Horizonte has a population of 2.5 million inhabitants. In the last decades there has been a significant increase in its urban population and that impacts the environment quality growing impermeable areas and intensifying floods.

It is observed that with the plumbing and rectification of their numerous water courses, the strangulation of the flow is notorious, causing overflows and flooding in the city. The drainage works adopted were mainly carried out with a view to solving localized problems of floods or making the implementation of “sanitary” avenues feasible. Besides, the process of uncontrolled urban growth has resulted in frequent and serious problems of urban flooding, configuring crises in drainage system.

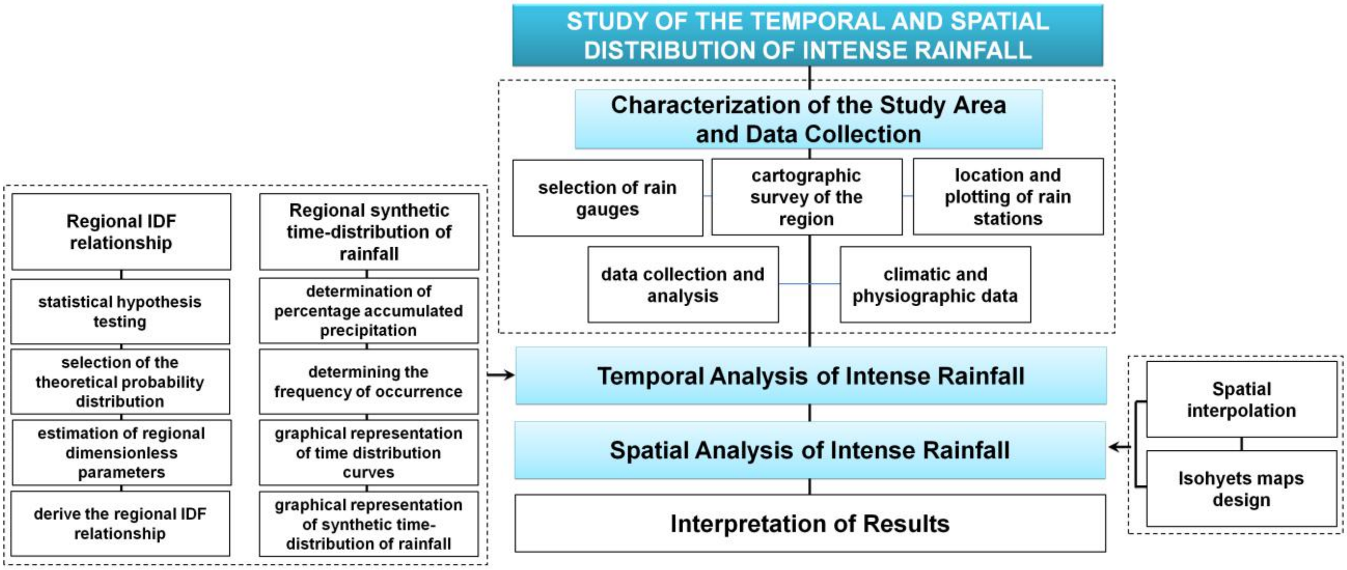


Fig.2: Overview of methodology

The regional relief is characterized by pronounced variations in altitudes, between the extremes of 650 m and 1500 m (Fig. 3), which are known to exert an important influence of intensifying condensation and consequently rainfall over the city.

In the storms of the 24th January 2020 all water courses in the city had floods, while in the 28th, the regions of Barreiro, West and South-Center were the most affected. The high altimetry levels contributed in these events with increase of the drained volume, the reduction of the time-concentration with anticipation of the peak of floods and increase of the maximum flow in the hydrographs, increasing the frequency and the magnitude of the floods.

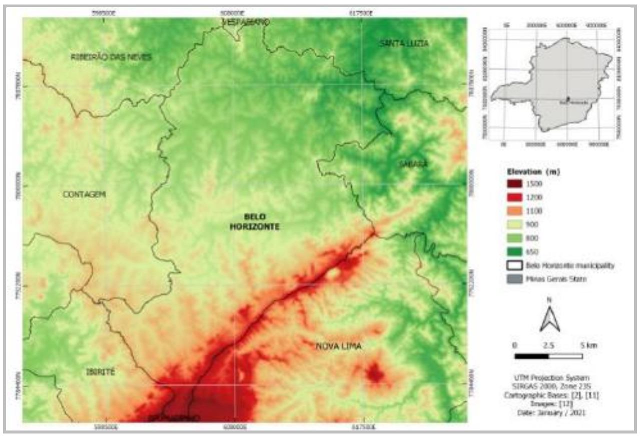


Fig. 3: Hypsometric map of Belo Horizonte

2.2 Temporal Analysis of Intense Rainfall

In many hydrological applications, interest lies in an estimation of the probability of occurrence of extreme events, as extreme rainfall intensities. These events are random variables and their probability of occurrence is represented by probability distributions.

In an extreme value analysis the determination of the most highly probable type of distribution is especially difficult. Some plausible distributions are “tied” and statistical test are performed to find the best distribution.

A methodology has been worked out by [13] that used the theory of probability weighted moments (PWM), introduced by [14], to define quantities known as L-moments. The L moments of order r, denoted by λ, can be written as linear combinations of the corresponding PWMs, these denoted by β, and defined as the following mathematical expression:

$$\beta_r = E\{X[F(X)]^r\} \tag{1}$$

The estimators for the first four L-moments can be calculated in terms of the PWM estimators from

$$\begin{aligned} \hat{\lambda}_1 &= \hat{\beta}_0 \\ \hat{\lambda}_2 &= 2\hat{\beta}_1 - \hat{\beta}_0 \\ \hat{\lambda}_3 &= 6\hat{\beta}_2 - 6\hat{\beta}_1 + \hat{\beta}_0 \\ \hat{\lambda}_4 &= 20\hat{\beta}_3 - 30\hat{\beta}_2 + 12\hat{\beta}_1 - \hat{\beta}_0 \end{aligned} \tag{2}$$

where $\hat{\beta}_r$ represent the unbiased PWM estimators for a given ordered sample $\{X_n \le X_{n-1} \le \cdots \le X_1\}$ of size n.

Formally,

$$\hat{\beta}_r = \frac{1}{r+1}\sum_{j=1}^{n-r}\frac{\binom{n-j}{r}}{\binom{n}{r+1}} r \le n-1 \tag{3}$$

As compared to conventional moments, L-moments generally yield more robust and accurate estimates of distribution parameters and quartiles of a random variable. L-moments and L-moments ratios can be interpreted as measures of distributional shape. For instance, λ1 is a measure of locations, λ2 is a measure of scale, the ratio L-cv = λ2/λ1 is analogous to the conventional coefficient of variation, the rations τ3 = λ3/λ2 and τ4 = λ4/λ2 represents measures of skewness and kurtosis, respectively.

2.2.1 Regional IDF relationship

Specific applications and illustrations of the theory for regional frequency analysis has been applied by many authors like [4][15], [16] and[17], and others that as [18], [19], [20]and [21] used “index-flood”-type procedures along with L-moments and L-moments ratios averaged over a number of sites within a region, to propose a set of statistics which provide objective backing to the typical stages involved in regional frequency analysis, such as data consistency, identification of homogeneous regions and choice of frequency distribution and estimation of its parameters.

These statistics are: the discordancy measure (Di) for screening discrepant data at site I, the heterogeneity measure (H) for identifying homogeneous regions, and the goods-of-fit measure Z for selecting the appropriate regional probability distribution.

These techniques have been used to define the regional IDF relationship valid for the MRBH, by combining regression models with the dimensionless regional frequency curves that results to be,

$$\hat{\imath}_{T,d,j} = 0{,}76542\ d^{-0{,}7059} P_j^{0{,}5360} \mu_{T,d} \tag{4}$$

where $\hat{\imath}_{T,d,j}$ is the storm rainfall intensity of duration d associated to return period T, at site j inside the MRBH (mm/h); d is the rainfall duration (h); Pj is the mean annual precipitation (mm) at site j, from the isohyets map and $\mu_{T,d}$ is the regional dimensionless quartile. These quartiles refer to the ratios $\frac{i_{T,d}}{\bar{\imath}_d}$, where $i_{T,d}$ represents the intensity of rain (mm/h) for a return period T and $\bar{\imath}_d$the average intensity of the maximum events of precipitation at a given location within the MRBH, both for the duration d according to [4], [15] and[17].

It is observed in equation (4), that the annual precipitation is a variable independent of the regional IDF relationship for the MRBH. The inclusion of annual precipitation in this equation synthesizes the influence of two factors on the maximum intensities of precipitation. The first one refers to the spatial differences in available humidity for the origin and continuity of the occurrences of intense rainfall, indirectly quantified by the variation of the annual rainfall totals in the MRBH. The second, inherent to the layout and spatial conformation of the isohyets map, reflects the orography influences on the intensification of precipitation events [4].

This pioneering work provided better estimates of quartiles and regional synthetic time-distribution precipitation, leading, in turn, to the assertiveness of the estimates of the characteristic variables of urban drainage systems projects, as found by [22] who verified the effectiveness of this equation in the dimensioning of drainage systems for the present day, not having found significant differences between the results obtained in their study and with the application of Equation (4).

After estimating the dimensionless quantiles for all the studied durations was prepared regional annual frequency curves for dimensionless intensities on extreme I-Gumbel type paper [4]. These curves were used to estimate the frequency of precipitation that occurred in the city of Belo Horizonte in January 2020.

2.2.2 Regional synthetic time-distribution of rainfall

The methods for creating reference hyetographs are described in the literature. The division of these methods has been described in many works, including [23], [24] and [25] as based on IDF/DDF curves, historical rainfall data, and stochastic methods.

According to [25] the best known with widespread use to analyze the variability of precipitations over time is the method proposed by [26]. Huff' curves are, therefore, a probabilistic representation of the ratio of cumulative precipitation heights.In this method, the temporal distribution of the storm is obtained by the relationship between the percentiles of the total precipitation and the percentiles of the total duration. The storms are grouped according to the occurrence of their maximum intensities in the 1st, 2nd, 3rd or 4th quartile of the temporal distribution of the total height of precipitation. For each quartile, dimensionless mass curves are associated with probabilities ofexceedance, selected to construct synthetic time-distribution of precipitation relative to different probabilities of exceedance and duration of precipitation in a region.

In order to determine the temporal distribution of precipitation, established design hyetograps for the MRBH based on Huff's methodology and on information compatible with the hydro-climatological conditions of the region. The great advantage of this method is the establishment of regional hyetograps, provided that regional homogeneity has been previously defined. These are used in the analysis of the most critical condition of rainfall in January 2020. With these studies, it is possible to construct the hyetographs of MRBH projects for different intervals of precipitation duration and probabilities of exceeding 10% to 90% ([4],[15], [17).

2.3 Spatial Analysis of Intense Rainfall

2.3.1 Spatial interpolation

The analysis of the spatial evolution of rainy events isbased on event data collected at various points in the study area. These data are selected for different durations.

Then, the spatial analysis of the data is made through interpolations of these and the tracing of isohyets. Spatial interpolation is a process used to estimate unknown values of a function from known values of the same function. In this sense, several interpolators can be used, such as Kriging, Minimum Curvature, Nearest Neighbor, Radial Base Function, Moving Average, Local and Inverse Polynomial of Distance Power, or Inverse of Distance to a Power, or even, Inverse Distance Weighting (IDW) ([27]).

Interpolation results can vary significantly based on the method and parameters you choose. For modelling spatial distribution of rain using one spatial interpolation methods applying the software QGIS that is a free and open source GIS application enabling the user to visualize, manage, edit, analysedata, and compose printable maps. QGIS interpolation supports Triagulated Irregular Network (TIN) and Inverse Distance Weighting (IDW) methods for interpolation. TIN method is commonly used for elevation data whereas IDW method is used for interpolating other types of data such as punctual rainfall measures.

In the IDW interpolation method, point samples are "weighed" during interpolation according to how the influence of one point relative to another declines with the distance from an unknown point that you want to create. This method is widely used in the interpolation of rainfall data, as the study for Brazilian Goiás State [28]. These authors varied the power parameter to be equal to 2, 3, 4 and 5 and concluded that β = 2 produces more accurate results than the others,

$$\hat{Z}_j = \frac{\sum_{i=1}^{n}\left(\frac{Z_i}{h_{ij}^{\beta}}\right)}{\sum_{i=1}^{n}\left(\frac{1}{h_{ij}^{\beta}}\right)} \quad (5)$$

$$h_{ij} = \sqrt{d_{ij}^2 + \delta^2} \quad (6)$$

where, $\hat{Z}_j$ is the interpolated value of grid node j; h_{ij} is the effective separation distance between grid node j and neighboring point i; Z_i are neighboring points; β is the weighting power (power parameter); d_{ij}^2 is the distance between grid node j and neighboring point$i$; $\delta^2$is the smoothing parameter.

2.3.2 Isohyets maps design

Isohyets are used to represent the rainfall values measured across the study area. The construction of this map is proceeded by an interpolation performed in a discrete way between successive points. Among the interpolation methods, the IDP stands out for being a method that seeks the minimum variance with a low density and irregularly spaced data network [29].

III. RESULTS AND DISCUSSION

3.1 Location of Monitoring Stations

Forty six rain gauges were selected and information was collected from institutions that operate the hydro-meteorological gauging stations in Belo Horizonte, as well as results of studies developed by ([4],[15] and [17]).The physiographic aspects of the region also were used as a basis for analyzes.

The precipitations that occurred on 24 and 28 January 2020 in 10-minute intervals were accumulated in intervals of 1, 2, 3 and 4-hours for the entire automatic network operated by SUDECAP, INMET and CEMADEN and conventional station database provided by ANA in the city of Belo Horizonte.

3.2 Meteorology of January 2020 events

Raining heavily in January is quite common over Brazil. In a normal situation, the country already has a high availability of humidity and hot air, basic ingredients for the formation of large clouds that cause storms. In addition, it is a month in which the South Atlantic Convergence Zone (SACZ) events and the areas of instability in the Inter-tropical Convergence Zone (ITCZ) which cause heavy and voluminous rain also begin to act on the country. In January 2020, the meteorological systems were operating in Brazil, and described below.

The South Atlantic Convergence Zone (SACZ) is the most important phenomenon on the inter-seasonal scale that occurs during the summer over Brazil, resulting from the interaction of the wind circulation of several meteorological systems that act at the same time ([5],[6],[7],[8], [9]). The Bolivian High (BH), which is a large system of high atmospheric pressure is an anti-cyclonic circulation, counterclockwise which develops during the summer over the Bolivian Altiplano, a high plateau region of the Central Andes ([30], [31]).

Inter-tropical Convergence Zone (ITCZ) is an system of low pressure in which the circulation presents the colder center than your periphery and occur more frequently in January. A warmer air rises on the periphery, where there is formation of cloudiness [32]. Cold Front on the Southeast Coast (CFSC) is the presence of an atmospheric trough (waving in the clockwise movement of winds) at medium levels of the atmosphere [1]. The most intense period of rain that occurred on January 24th was between 19:30h and 22: 30h, while on 28th was between 20:20h and 23:20h.

3.3 Temporal Analysis of January 2020 rainfalls

The rainfall on 24 and 28 January 2020 with durationsof 1, 2, 3 and 4 hours, were dimensionless by the regional average and represented in graphs of the MRBH annual regional curvesobserved (Fig. 4). It was observed that in the January 24th storm, all monitoring points registered rainfall with return periods below 100 years. However, the January 28 storm was much more severe in terms of short duration, since in some points return periods of around 1000 years were observed, as is the case with stations 30-Bonsucesso, 43-Caixa de Areia and 44-Cercadinho, while at station 42-Leitão outliers of the time series were. According to WMO (2009), the presence of these values in historical series can influence the values of the series mean and standard deviation, and, consequently, the frequency analysis, suggesting evaluations of PMP - maximum probable short-term precipitation for the MRBH.

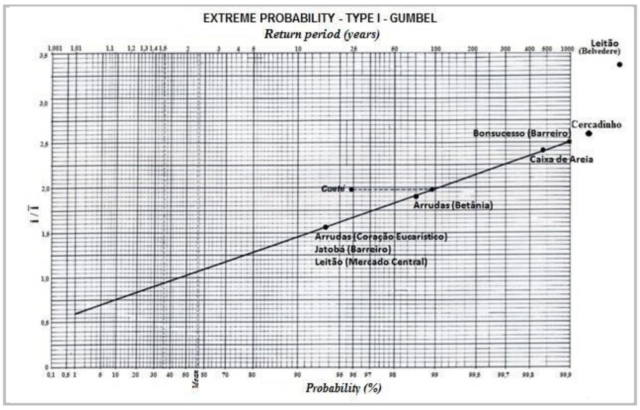


Fig. 4: Regional annual frequency curve for dimensionless intensities. Precipitation duration = 3 hours

As it is the largest storm in the Belo Horizonte region with maximum intensity at the first three hours Fig.5 to 7show the temporal distribution of the January 28 rainfall occurring in the "Leitão" stream (Central-South Region) for different exceedance probabilities, were built according to [4]. This author has demonstrated that this analysis is essential to obtain reliable results on the effects of floods in urban basins.

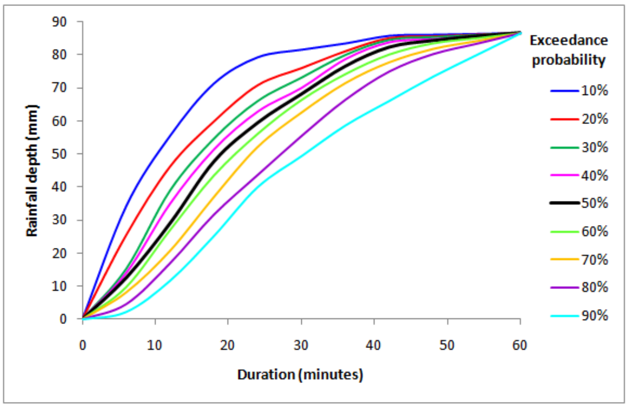


Fig.5: Temporal distribution of precipitation for different probabilities of exceedance and duration < 1 h

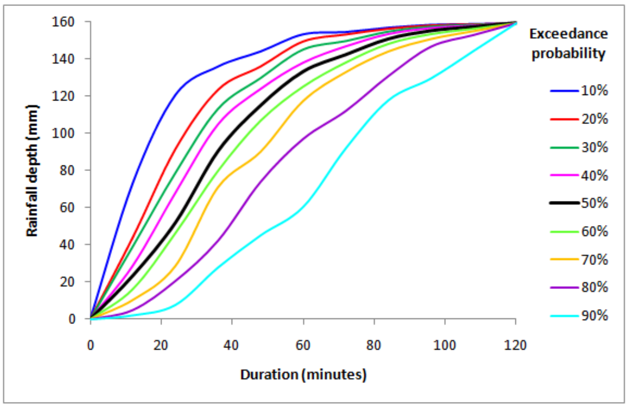


Fig. 6: Temporal distribution of precipitation for different probabilities of exceedance and 1h < duration < 2 h

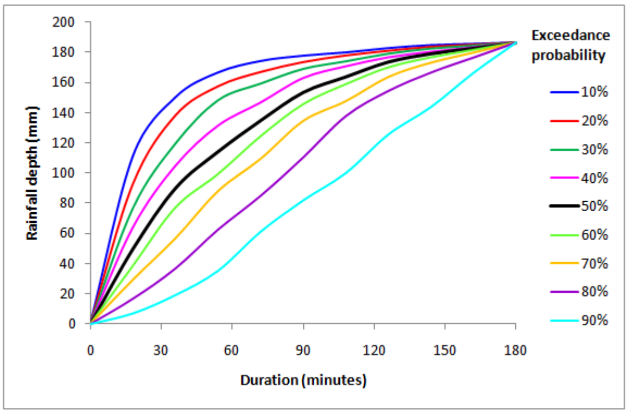


Fig. 7: Temporal distribution of precipitation for different probabilities of exceedance and 2h < duration < 3 h

According to [34] the median curve (50% probability of exceedance) is the most representative although the others allow determining the flow relationships for various types of distributions that occur in nature with each one of the four basic types of storm (quartile groups). This author suggests that the 10% and 90% curves are useful for estimating runoff in the most extreme types of temporal distributions. However, he also claims that the median curve is the most stable curve in all quartiles compared to the 10% and 90% curves.

Fig.8 to 10 show the rainfall design hyetographs for the probability of exceedance = 50%, rain durations = 1, 2 and 3 hours. It is observed that 60% of the rain occurs in the first hour of the event. These should be used in a typical rainfall-runoff hydrologic model.

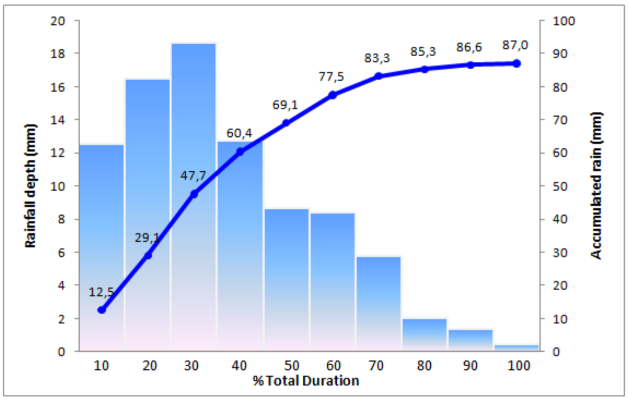


Fig. 8: Time distribution of rainfall for duration < 1 h and probability of exceedance = 50%

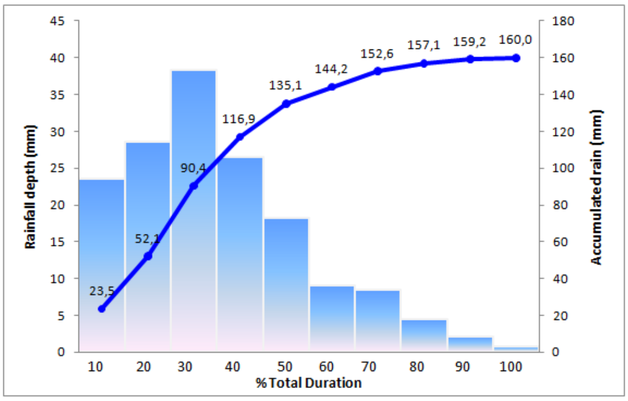


Fig. 9: Time distribution of rainfall for 1h < duration < 2 h and probability of exceedance = 50%

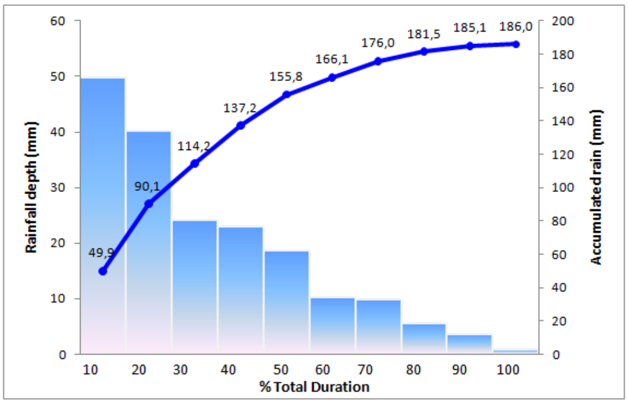


Fig. 10: Time distribution of rainfall for 2h < duration < 3 h and probability of exceedance = 50%

3.4 Spatial Analysis of January 2020 rainfalls

In order to represent the rainfall values in the entire study area, it was necessary to apply an interpolation for spatial analysis using the QGIS software. As a product ofthe interpolation map, the extraction of isohyets can be performed. The analysis showed that the Inverse of Distanceto a Power (IDP) type was the most representative, generating isohyets at 10 mm intervals.

Fig. 11 and 12 illustrate the products of the analyze were empirical evidence of the influence exerted by the relief of city on the intensity of precipitation in the interior of the region can be observed. This orographic influence on rainfall can be visualized on these figures. At the south-central part of the region, high-value isohyets conform approximately to the high elevations on the windward slope, thus reflecting the prevalent direction of humidity inflow into the area. These characteristics are expected to explain part of the spatial variability of short-duration rainfall over the region.

It can be seen in the maps in Fig. 11 that the event on the 24th was of great magnitude and covered the entire municipality, having surpassed the response capacity of the drainage and flood dampening system implemented in the city. According to the Civil Defense at 7:41 pm it was raining extremely hard in the Pampulha, Barreiro, Center-South, Northwest and East regions having accumulated in 24 hours 180.8 mm, 179.0 mm, 174.4 mm, 170.0 mm and 169.8 mm, respectively. In the Northeast, Venda Nova, and West regions, the rain was heavy, registering 159.4 mm, 154.4 mm and 151.8 mm, respectively. In the Northern region of the capital, it rained moderately, accumulating 118.8 mm. Streams overflowed, avenues were flooded and people were stranded. The Bernardo Vasconcelos Avenue in the Northeast region was flooded after the Cachoeirinha stream which cuts this avenue did not support the volume of water and overflowed. The Cristiano Machado Avenue one of the most important in the city was flooded in São Gabriel Station'.

Fig. 12 shows that the event on the 28th was also of great magnitude, being more intense mainly in the regions of Barreiro, Center-South and West. In the Center-South region, a height of 183.4 mm was recorded, corresponding to 55.7% of the expected value for the entire month of January. Rain was also critical in the Barreiro and West regions, having accumulated 136.6 mm and 103.6 mm in 24 hours. On the other hand, in the North it rained 4.2 mm and in Venda Nova it only rained 0.4 mm. Several regions of the city were flooded such as Prudente de Morais avenue in the Center-south region (Leitão stream), Tereza Cristina avenue in Barreiro region (Ferrugem stream), and West region (Arrudas stream).

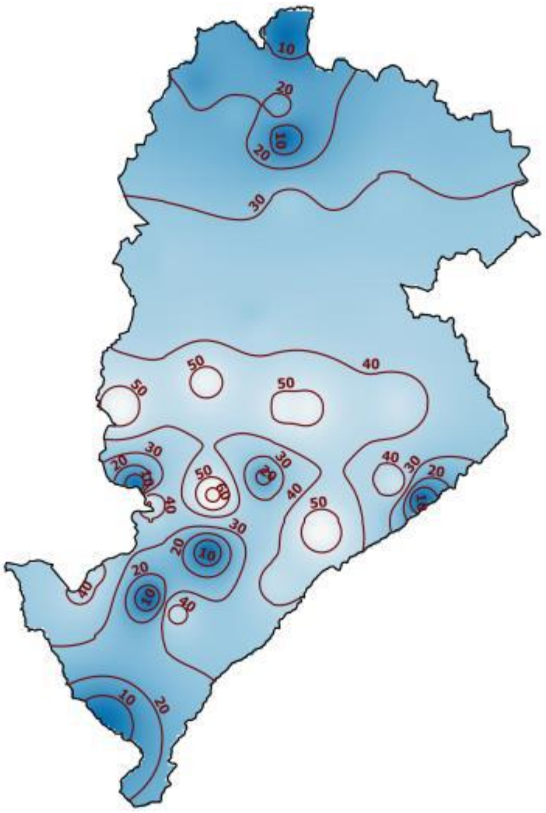
IV. CONCLUSIONS

The results obtained with the application of the methodology make it possible to validate the application of the MRBH IDF equation and the respective annual regional frequency curves for dimensionless intensities, as well as the design hyetographsforthe different precipitation duration intervals and probabilities exceedance.These studies are of technical and scientific importance, represented by the knowledge of the pluviometric regime, in view of its use in the design of hydraulic structures. If compared to the punctual studies existing in the region, developed with short historical series, their results are more reliable, because, in addition to being based on a much larger number of pluviograph posts, with more representative historical series, they were of a regional character.

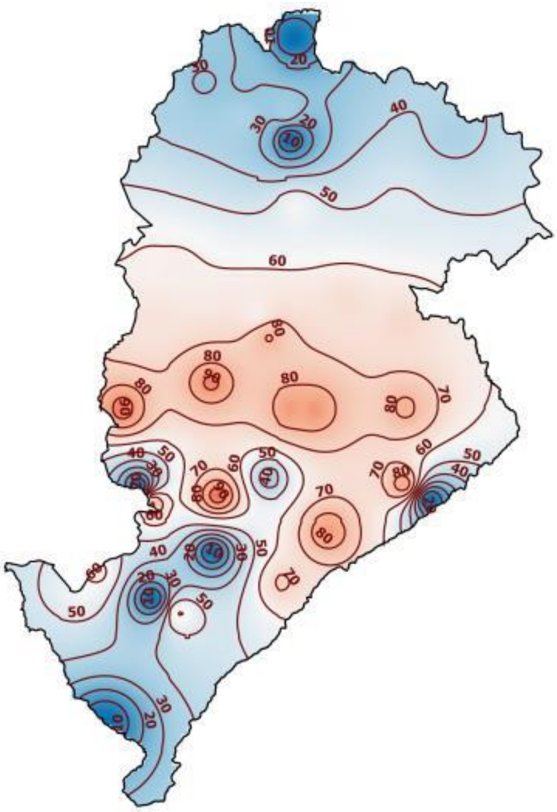
The high spatial resolution of the data showed regional seasonality satisfactorily, with high rainfall in the south-southeast portion, following the high topography of the Curral mountains and reflecting the orographic influence in the intensification of precipitation events.

At the time of the 24th all monitoring points recorded rainfall with return periods of less than 100 years. On the 28th, the eventwasmoresevere, reaching periods of return ofaround 1000years; the Leitãostation recorded outliers of the time series.It is concluded that these studies can be used in planning the occupation of the flood plains of Belo Horizonte, as well as in proposing structural and non-structural measures to mitigate damage caused byextreme hydrological events suggesting, however, new assessments of the PMP - maximum probable short-term precipitation for the RMBH, in view of the event recorded mainly in the Leitão stream.

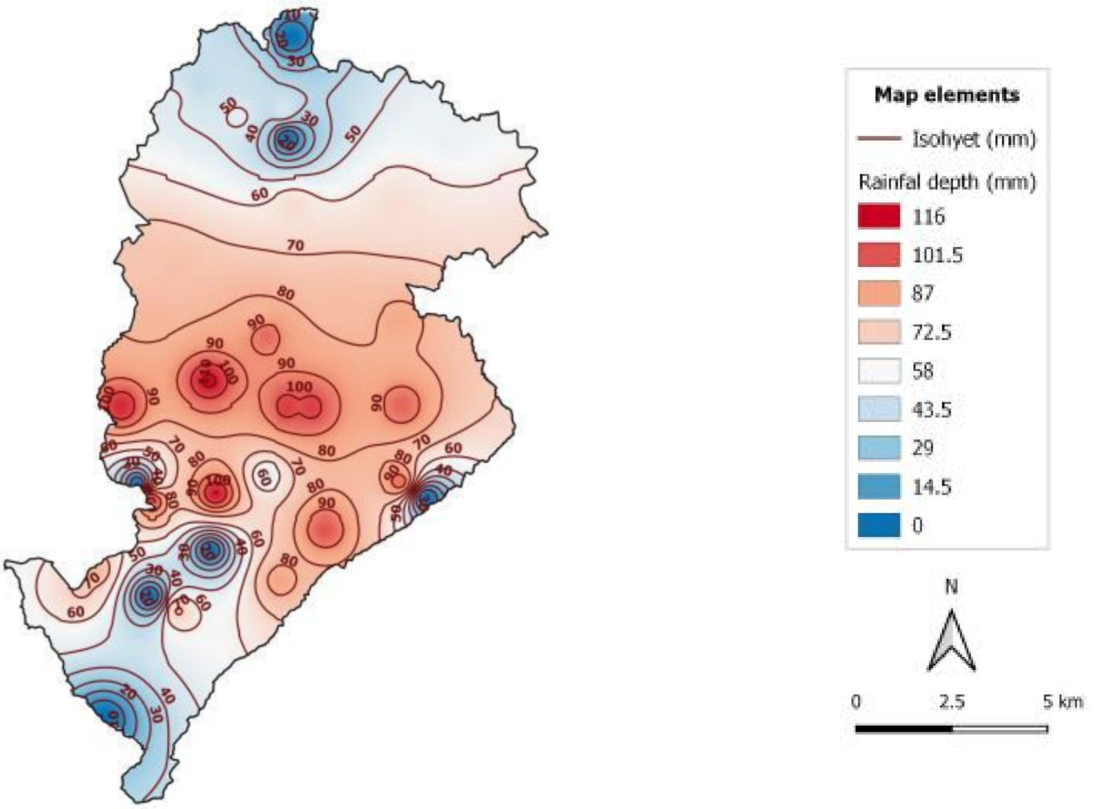
The results observed in the present work can be used as a reference for site suitability analysis of watersheds infrastructure. The parameters can be integrated with other hydrological information in GIS domain for decision making regarding water conservation structures by local government authorities related to water management projects.



(a) Duration = 1 hour

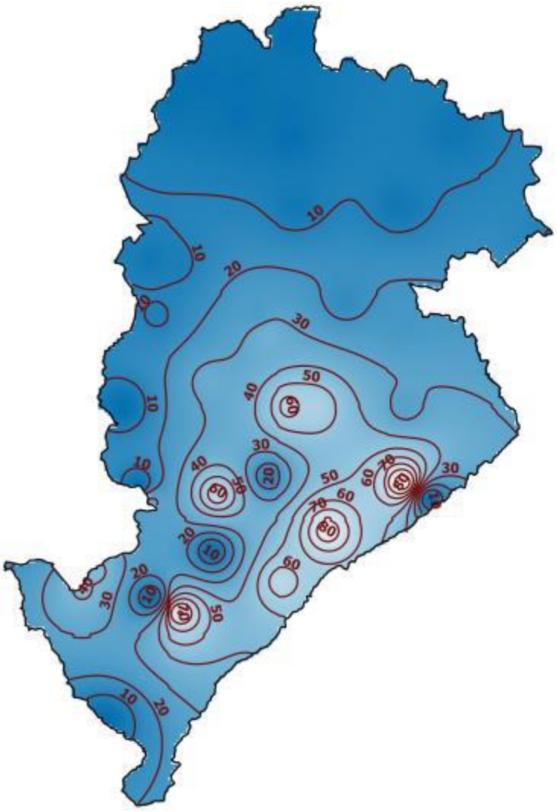


(b) Duration= 2 hours

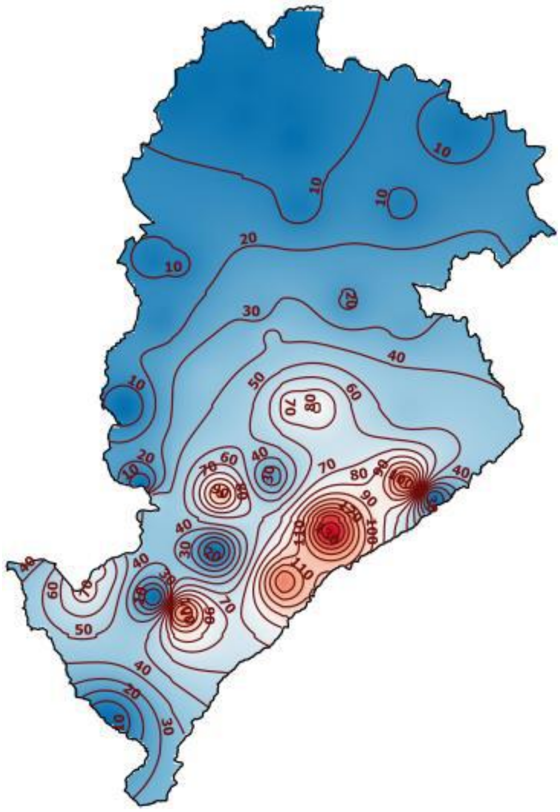


(c) Duration= 3 hours

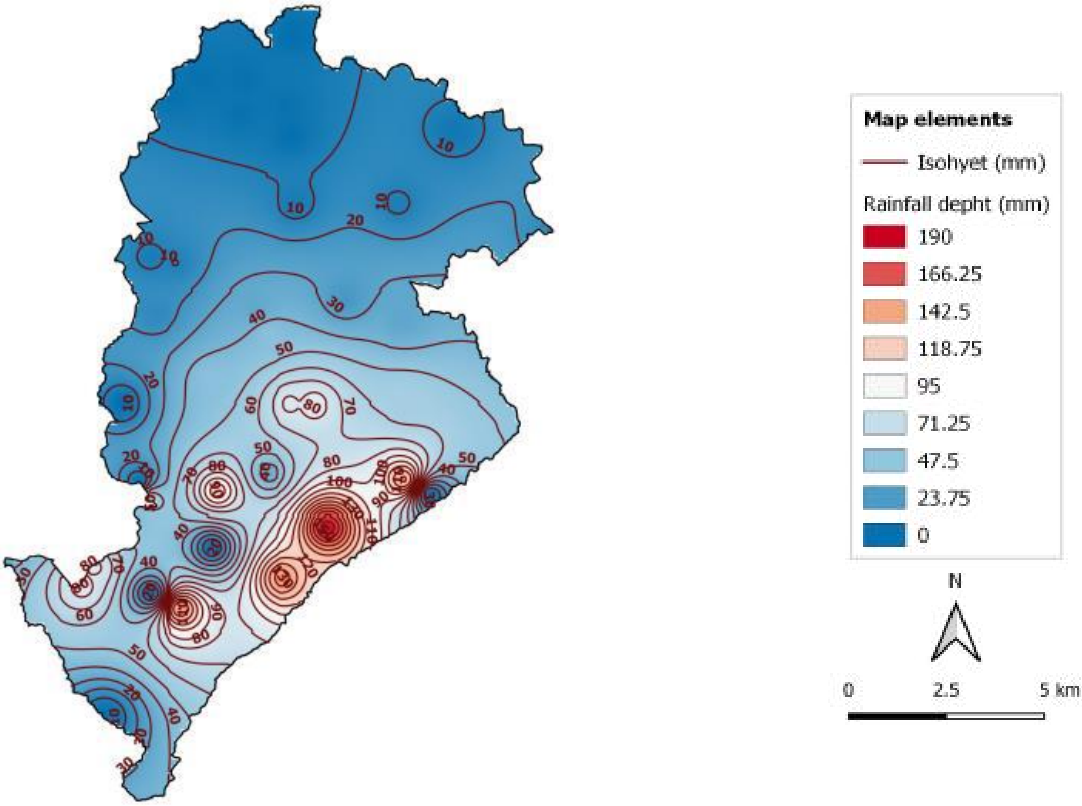
Fig. 11: Maps of isohyets of precipitations in 24 January 2020.



(a) Duration = 1 hour



(b) Duration = 2 hours



(c) Duration = 3 hours

Fig. 12: Maps of isohyets of precipitations in 28 January 2020.

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REFERENCES

[1] CLIMATEMPO (2020).*Tempestades de janeiro de 2020*. Availablefromhttps://www.climatempo. com.br/noticia/2020/01/24/tempestades-de-janeiro-de-2020-1500. Access onJanuary 30, 2020.

[2] IBGE-Instituto Brasileiro de Geografia e Estatística (2017). *Bases Cartográficas Contínuas*. Availablefromhttps://www.ibge.gov.br/ geociencias/downloads-geociencias.htmlAccess on July 06, 2020.

[3] PBH-PRODABEL-Prefeitura de Belo Horizonte-Empresa de Informática e Informação de Belo Horizonte S/A (2020). *Mapas para download.*Available from http://bhmap.pbh.gov.br/v2/mapa/ idebhgeo#zoom=4&lat=7796893.0925&lon=609250.9075 &baselayer=base Access on March 07, 2020.

[4] PINHEIRO, M.M.G. (1997). Estudo de chuvas intensas na Região Metropolitana de Belo Horizonte-RMBH (*Dissertação de mestrado*). EE-UFMG, 216p.

[5] AMBRIZZI, T. & FERRAZ, S.E.T. (2015). An objective criterion for determining the South Atlantic Convergence Zone. *Frontiers in Environmental Science* 3, 23. Available from https://doi.org/10.3389/fenvs. 2015.00023. Access on March 15, 2020.

[6] ROSA, E.B.; PEZZI, L.P.; QUADRO, M.F.L.; BRUNSELL, N. (2020). Automated Detection Algorithm for SACZ, Oceanic SACZ and their Climatological Features. *Frontiers in Environmental Science* 8, 18. Available from https://doi.org/10.3389/fenvs.2020. 00018 Access on April 04, 2020.

[7] SANTOS, V.J. & FIALHO, E.S. (2016). South Atlantic Convergence Zone (SACZ) and Intense Rainfall Impacts: The case of the City of Ubá/MG. *BrazilianJournalofClimatology*, v.19,-218-238.

[8] SILVA, J.P.R., REBOITA, M.S., ESCOBAR, G.C.J. (2019). Caracterização da Zona de Convergência do Atlântico Sul em Campos Atmosféricos recentes. *Revista Brasileira de Climatologia* 25, 355-377. Availablefromhttp://dx.doi.org/10.5380/abclima.v25i0.64 101 Access onMarch 16, 2020.

[9] SILVA, P.N.; ESCOBAR, G.C.J.; REBOITA, M.S. (2020). Eventos extremos de precipitação no Estado de Minas Gerais associados com a ocorrência de episódios de Zona de Convergência do Atlântico Sul. *Revista Brasileira de Geografia Física* v.13, n.3, 1013-1023, 2020. Availablefromhttps://periodicos.ufpe.br/revistas/rbgfe Access on July 15, 2020.

[10] IBGE-Instituto Brasileiro de Geografia e Estatística (2010). *Censosdemográficos. 2010*. Available from https://censo2010.ibge.gov.br/ sinopse/index.php?dados= Access on March 07, 2020.

[11] METROPOLITAN PLAN-MRBH (2020). *Bases Cartográficas*.2020. Available from http://www.rmbh.org.br/central-cartog.php Access on July 06, 2020.

[12] NASA Shuttle Radar Topography Mission (SRTM). *USGS Science for a changing world* (2020). Available from https://earthexplorer. usgs.gov/ Access on September 18, 2020.

[13] HOSKING, J. R. M. (1986). The theory of probability weighted moments. *Research Report RC12210*, IBM Research Division, Yorktown Heights, N.Y.

[14] GREENWOOD, J.A.; LANDWEHR, J.M.; MATALAS, N.C.; WALLIS, J.R. (1979). Probability weighted moments: definitions and relation to parameters of several distributions expressable in inverse form. *Water Resources Research*, New York, American Geoph.Union, v.15, n.5, p.1049-1054.

[15] GUIMARÃES-PINHEIRO, M & NAGHETTINI, M. (1998). Frequency and time distribution of rainfall in heavy storms over the metropolitan region of Belo Horizonte, Brazil. *Proceedings of the British Hyd.Soc.Int. Conf.*, Exeter, July. John Wiley & Sons Ltd., p.297-306.

[16] KHAN, S.A.; HUSSAIN, I; HUSSAIN, T.; FAISAL, M. SHAD, Y.; SHOUKRY, A.M. (2017). Regional Frequency Analysis of Extremes Precipitation Using L-Moments and Partial L-Moments. *Hindawi Advances in Meteorology*, Volume 2017, Article ID 6954902, 20 p., Available from https://doi.org/10.1155/2017/ 6954902 Access on February 20, 2020.

[17] PINHEIRO, M.M.G. & NAGHETTINI, M. (1998). Análise regional de freqüência e distribuição temporal das tempestades na Região Metropolitana de Belo Horizonte – RMBH. Revista Brasileira de Recursos Hídricos. v.3, n.4, p.73-88. Availablefromhttps://doi.org/10.21168/ rbrh.v3n4.p73-88Access onMarch 16, 2020.

[18] HOSKING, J.R.M. & WALLIS, J.R. (1993). Some statistics useful in regional frequency analysis. *Water Resources Research*, v.29, n.1., p.271-281.

[19] HOSKING, J.R.M. & WALLIS, J.R. (1995). Correction to "some statistics useful in regional frequency analysis". *Water Resources Research*, v.31, n.1., p.251.

[20] HOSKING, J.R.M. & WALLIS, J.R. (1997). Regional frequency analysis. In: An approach based on L-moments. *Cambridge Univ. Press*, Cambridge, New York, Melbourne, 224 pp.

[21] HOSKING, J.R.M. & WALLIS, J.R. (2005). Regional frequency analysis: an approach based on L-Moments. *Cambridge Univ. Press*, 244 pp.

[22] NASCIMENTO, A.S.; NUNES, A.A.; ABADE, D.S.O.; CASTRO, G.A.; OLIVEIRA, J.G.; CASTRO, K.D.R. (2020). Análise de chuvas intensas para o município de Belo Horizonte. *Braz. Journal of Develop*., Curitiba, v. 6,

n.5, p.32184-32218. ISSN 2525-8761. Available from https://doi.org/10.34117/bjdv6n5-605. Access on September 20, 2020.

[23] CHOW, V.T.; MAIDMENT, D.R.; MAYS, L.W. (1988). *Applied Hydrology*. McGraw-Hill: New York, NY, USA.

[24] LIN, G.F.; CHEN, L.H.; KAO, S.C. (2005). Development of regional design hyetographs. *Hydrol. Process*., 19, p.937–946.

[25] WARTALSKA, K. ZMIERCZAK, B.K.; NOWAKOWSKA, M. KOTOWSKI, A. (2020). Analysis of Hyetographs for Drainage System Modeling. *Water 2020*, 12(1), 149. Available from https://doi.org/10.3390/w12010149. Access on March 16, 2020.

[26] HUFF, F.A. (1967). Time distribution of rainfall in heavy storms. *WaterResourcesResearch*, v.3, n.4, p.1007-1019.

[27] SILVA, C.R.; QUINTAS, M.C.L.; CENTENO, J.A.S. (2007). Estudo do método de interpolação do inverso da distância a uma potência. II Simpósio Brasileiro de Geomática, *V Colóquio Bras. de Ciências Geodésicas*. Pres. Prudente-SP, ISSN 1981-6251, p.057-062.

[28] REIS, M. H.; GRIEBELER, N. P.; SARMENTO, P. H. L.; OLIVEIRA, L. F. C.; OLIVEIRA, J. M. (2005). Espacialização de dados de precipitação e avaliação de interpoladores para projetos de drenagem agrícola no estado de Goiás e Distrito Federal. Anais XII *Simpósio Brasileiro de Sens. Remoto*, Goiânia-GO. INPE, p.229-236.

[29] LUO, W.; TAYLOR, M. C.; PARKER, S. R. (2007). A comparison of spatial interpolation methods to estimate continuous wind speed surfaces using irregularly distributed data from England and Wales. International *Journal of Climatology*, v.28, n.7, p. 947-959.

[30] LENTERS, J. D.& COOK, K. H. (1997). On the Origin of the Bolivian High and Related Circulation Features of the South American Climate. *Journal of the Atmospheric Sciences*, 54 (5): 656–678. Available from https://doi.org/10.1175/1520-0469(1997)054<0656:OTOOTB>2.0.CO;2. Access on March 07, 2020.

[31] REBOITA, M.S.; GAN, M.A.; ROCHA, R.P.: AMBRIZZI, T. (2010). Regimes de precipitação na América do Sul: uma revisão bibliográfica. Rev. Bras. Meteorol. v.25 n.2. Available from https://doi.org/10.1590/S0102-77862010000200004.Access on March 16, 2020.

[32] MORAIS, .D.C.; OLIVEIRA, F.P.; COUTINHO, M.D.L. (2015). One case of simulation of upper tropospheric cyclonic vortex in the Brazil Northeast – impact in the convection paramet. *Journal of Hyperspectral Rem. Sensing* 01, 27-44.

[33] WMO-World Meteorological Organization (2009). *Manual on estimation of Probable Maximum Precipitation – PMP*. Geneva: 2009. 291 p.

[34] HUFF, F.A. (1990). Time distributions of heavy rainstorms in Illinois. Illinois State Water Survey, *Circular 173*. Champaign, Ill.