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EXTREME EVENTS OF PRECIPITATION AND OCCURRENCES OF FLOODING, RUNOFF AND INUNDATION IN THE METROPOLITAN REGION OF CURITIBA, BRAZIL[1]

EVENTOS EXTREMOS DE PRECIPITAÇÃO E OCORRÊNCIAS DE ALAGAMENTOS, ENXURRADAS E INUNDAÇÕES NA REGIÃO METROPOLITANA DE CURITIBA, BRASIL

EVENTOS EXTREMOS DE PRECIPITACIÓN Y OCURRENCIAS DE ALUVIÓNES, DILUVIOS Y INUNDACIONES EN LA REGIÓN METROPOLITANA DE CURITIBA, BRASIL

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Abstract*:* Extreme precipitation events cause severe damage in both urban and rural areas. The objective of this work was to analyze rainfall variability, understand the dynamics of extreme precipitation events and to find out the occurrence of floods, runoff and inundation in the Metropolitan Region of Curitiba (MRC). Data from 39 rainfall stations distributed in the MRC area were used, as well as data by municipality of occurrence of flooding, runoff or inundation, from 1976 to 2018. Extreme precipitation events were identified in all months, most frequently in the summer. Totaling 48 decrees of emergency or public calamity and 397,516 people affected by one of the three socioenvironmental disasters.

Keywords: Vulnerability; Climate risk; Natural disasters.

Resumo: Os eventos extremos de precipitação causam severos danos no espaço urbano e rural. O objetivo deste trabalho foi analisar a variabilidade pluviométrica, compreender a dinâmica dos eventos extremos de precipitação e averiguar as ocorrências de alagamentos, enxurradas e inundações na Região Metropolitana de Curitiba (RMC). Utilizou-se dados de 39 estações pluviométricas distribuídas na RMC, além de dados por município de ocorrência de alagamentos, enxurradas ou inundações, de 1976 a 2018. Os eventos extremos de precipitação foram identificados em todos os meses, com maior frequência no verão. Foram 48 decretos de situação de emergência ou calamidade pública e 397.516 pessoas afetadas por um dos três desastres socioambientais.

Palavras-chave: Vulnerabilidade; Risco climático; Desastres naturais.

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Resumén: Los eventos extremos de precipitación causan severos daños en el espacio urbano y rural. El objetivo de este trabajo fue analizar la variabilidad de la lluvia, comprender la dinámica de los eventos extremos de precipitación y averiguar las ocurrencias de inundaciones, aluviónes y diluvios en la Región Metropolitana de Curitiba (RMC). Se utilizaron datos de 39 estaciones pluviométricas distribuidas en la RMC, además de datos por municipio de ocurrencia de inundaciones, aluviónes o diluvos de 1976 a 2018. Los eventos extremos de precipitación fueron identificados en todos los meses, con mayor frecuencia en el verano. Fueron 48 decretos de situación emergenciales o calamidad pública y 397. 516 personas afectadas por uno de los tres desastres socioambientales.

Palabras Clave: Vulnerabilidad; Riesgo climático; Desastres naturales.

Introduction

Natural disasters, as one of the key consequences of extreme episodes of precipitation, are defined as natural phenomena that shape and transform the landscape and geographical space (MANCILLAS et al., 2015; CARVALHO et al., 2017). If these intensify in the social environment, they can generate situations of potential harmer, causing deaths and material losses (DAMASCENA et al. 2017; MACHADO et al. 2017). The cases of floods are the main event and the most common among hydroclimatological events. Flooding represents 59 % of the cases of occurrence due to extreme weather events (MARCELINO, 2007; CALDANA et al., 2018). Such hydroclimatological events occur in more than 80% of Brazilian cities and are associated with severe atmospheric instabilities (MARCELINO, 2007). Several works around the world demonstrate the importance of understanding the rainfall regime and variability for sustainable urban development (PANDOLFO et al. 2017; PASSOS et al. 2017; DOS REIS et al. 2017; ALBUQUERQUE et al., 2018; CONCEIÇÃO et al. 2018; GELCER et al. 2018; HUANG et al., 2018; DE MATOS et al. 2018; SANTI et al., 2018; DE SOUSA e DE OLIVEIRA, 2018; DE SOUZA et al., 2018; TAYT'SOHN et al., 2018).

Extreme climatic events act in the scope of the main causes of natural catastrophes that affect man, since, the way societies organize themselves disregards the rhythm and variability of the atmospheric system (VICENTE, 2005). Every year, natural disasters result in numerous deaths, injuries, in addition, as costly economic losses (MARCELINO, 2007; HUANG et al. 2018; TSAVDAROGLOU, 2018; WOSSEN, 2018).

The spaces are affected by natural phenomena in a homogeneous way, but the socio-environmental vulnerability exposes the population to the different risks (ALCÁNTARA-AYALA, 2002). The condition of population poverty is closely linked to the condition of risk formation and socio-environmental vulnerability (MENDONÇA, 2005). The occupation of irregular areas and the risk associated with socioeconomic conditions increases the consequences of disasters and the impacts on social groups. For this context, a phenomenon can affect a region and affect the population living there differently (CIDADE et al., 2013; FREIRE et al., 2014; GRIGOLETTI et al. 2018).

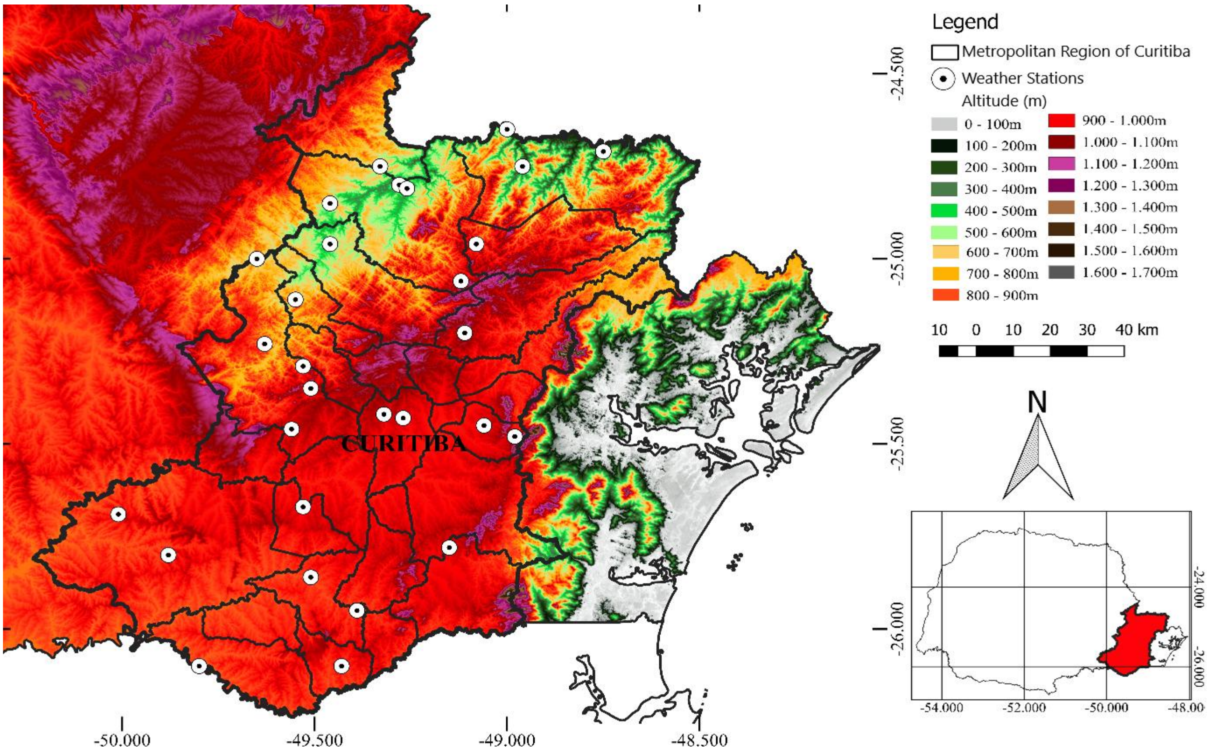
Thus, the objective of this work was to understand the rainfall variability and the dynamics of extreme precipitation events, in addition, to analyzing the occurrences of floods, inundation and runoff in the MRC - Metropolitan Region of Curitiba, Paraná State, Brazil. Therefore, were aim to analyze the rainfall of the MRC by annual and monthly variability and extreme daily events, identifying greater heights of rain concentrated in the 24-hour interval.

Material and Methods

For this, were used data from 35 weather stations, being them from the Instituto Agronômico do Paraná (IAPAR), the Instituto Nacional de Meteorologia (INMET), the Agência Nacional das Águas (ANA) and the Águas Paraná, during 1976 to 2018 (Table 01). The stations are distributed along the MRC (Metropolitan Region of Curitiba) area and in neighboring municipalities to contribute to the interpolation map in the neighboring areas (Figure 01).

Were used Box Plot to complement the analysis of rainfall variability and detection of extremes. The main resource obtained in its use is “to provide a quick view of the data distribution. If the distribution is symmetrical, the box is balanced with the median positioned in the center of the box. For asymmetric distributions, there is an imbalance in the box in relation to the median” (SILVESTRE et al., 2014, p. 27).

Figure 1 - Localization of Metropolitan Region of Curitiba (MRC) and the weather stations.



Source: IBGE (2018); Org. authors (2018).

Table 1 - Data from the Weather Stations.

Agency	Station (Municipality)	Longitude	Latitude	Altitude	Data Series
ANA	Turvo (Doutor Ulysses)	-49.33	-24.75	400m	(1976-2018)
ANA	Doutor Ulisses (Doutor Ulysses)*	-49.41	-24.56	818m	(1976-2018)
ANA	Balsa do Cerro Azul (Cerro Azul)	-49.28	-24.8	270m	(1976-2018)
ANA	Cerro Azul	-49.26	-24.81	320m	(1978-2018)
ANA	Santa Cruz - Tigre (Cerro Azul)	-49.12	-25.06	938m	(1976-2018)
ANA	Tatupeva (Adrianópolis)	-48.75	-24.71	230m	(1976-2018)
ANA	Fazenda Boa Vista (Adrianópolis)	-48.96	-24.75	227m	(1976-2018)
ANA	Capela da Ribeira (Adrianópolis)	-49	-24.65	180m	(1976-2018)
ANA	Tunas (Tunas do Paraná)	-49.08	-24.96	880m	(1976-2018)
ANA	Ervalzinho (Itaperuçu)	-49.55	-25.11	750m	(1976-2018)
IAPAR	Itaqui (Campo Largo)	-49.56	-25.46	901m	(1976-2018)
ANA	Bateias (Campo Largo)	-49.51	-25.35	890m	(1976-2018)
ANA	Pinheirinho (Campo Largo)*	-49.65	-25	517m	(1976-2018)
ANA	Três Córregos	-49.63	-25.23	800m	(1976-2018)
ANA	Curitiba	-49.26	-25.43	950m	(1976-2018)
IAPAR	Piraquara	-49.06	-25.45	900m	(1976-2018)
ANA	Fazendinha (São José dos Pinhais)	-49.08	-25.56	910m	(1976-2018)
ANA	Ilha do Rio Claro (São José dos Pinhais)*	-48.9	-25.81	237m	(1976-2018)
IAPAR	Pedra Alta (Lapa)	-49.88	-25.8	903m	(1976-2018)
ANA	Pedra Lisa (Lapa)	-50.01	-25.69	910m	(1976-2018)
ANA	Quitandinha	-49.51	-25.86	820m	(1976-2018)

ISSN 2178-0234

ANA	Rio da Várzea dos Lima (Quitandinha)	-49.39	-25.95	800m	(1976-2018)
ANA	Rincão (Tijucas do Sul)	-49.15	-25.78	913m	(1976-2018)
ANA	Rio Negro*	-49.8	-26.1	824m	(1976-2018)
IAPAR	Fragosos (Piên)	-49.38	-26.15	790m	(1976-2014)
ANA	Guaiaca (São João do Triunfo)	-50.2	-25.61	856m	(1976-2018)
ANA	Mandaçaia (Palmeira)	-50.06	-25.48	950m	(1976-2018)
ANA	Vieiras (Palmeira)	-50.29	-25.47	892m	(1976-2018)
ANA	Porto Amazonas	-49.88	-25.55	793m	(1976-2018)
ANA	Abapã (Castro)	-49.83	-24.93	1007m	(1976-2018)
ANA	Itaiacoca (Ponta Grossa)	-49.9	-25.13	975m	(1976-2018)
ANA	Morretes (IAPAR)	-48.49	-25.3	59m	(1976-2018)
ANA	Morretes (ANA)	-48.83	-25.46	8m	(1976-2018)
ANA	Antonina	-48.76	-25.43	74m	(1976-2018)

Source - ANA e IAPAR (2019); Org. authors (2019). *Weather stations used to analyses by Box Plot

Box plots represent five classifications of values. Outliers are divided into outliers (values above the maximum, but not extreme) and extremes, with any value greater than Q3 + 1.5 (Q3 - Q1) or less than Q1 - 1.5 (Q3 - Q1). The highs and lows are considered the highest values in the series, but they are not extreme or outliers. Inside the box, three quartiles are classified with 25% of the data each, in addition to the median value, equivalent to the second quartile, or 50% of the data (LEM et al., 2013; SCHNEIDER and DA SILVA, 2014).

For analysis using Box plot, data from four weather stations were used as a parameter, one at each end of the basin. Thus, Rio Negro (South), Pinheirinho - Campo Largo (Midwest), Rio Claro Island - São José dos Pinhais (East) and Doutor Ulysses (North) were used. The identification of daily extreme events was performed using the 99% percentile of annual precipitation, using the formula:

$$Eep = \frac{P99/12}{2}$$

Eep being the extreme precipitation event;
P99, the Percentile 99 % of annual precipitation

Precipitation appears to be characterized as extreme and must have occurred within 24 hours (Table 02). The graphics were created using the Sigma Plot *software.*

Table 2 - Values used as parameter for extreme events identification.

Station	Doutor Ulysses	Rio Negro	Campo Largo	São José dos Pinhais
Precipitation	98,3	93,2	87,9	103,7

Source: Águas Paraná; ANA; IAPAR e INMET (2019); Org. authors (2019)

To identify the occurrences of floods, runoff and floods, data from the Civil Defense of Paraná were used. The Brazilian Civil Protection acts according to the need for emergency and service to be provided by assisting the affected populations. The action is immediate after the disaster, and the teams sent to the field are responsible for completing a report describing the phenomenon and the resulting damage (MARTINS et al., 2017). The Defense of Paraná State is structured by eight Regional Civil Defense Coordinators, each municipality having its Municipal Civil Defense Coordination. The data were obtained by the Report of Occurrence of flooding, runoff and flooding. The data collected were numbers of occurrences, people affected and decrees of emergency and public calamity.

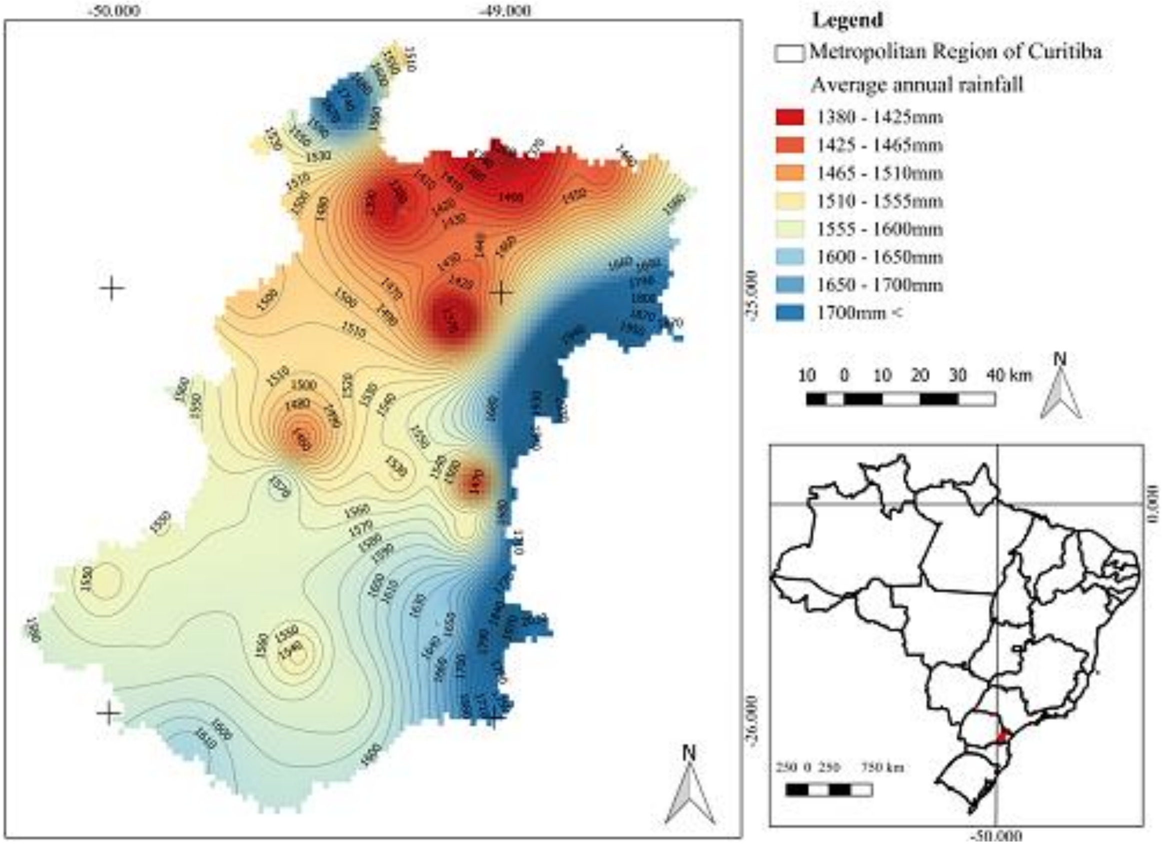
Results and Discussion

The average rainfall in the MRC (Figure 02) exhibited a significant regional difference. In the Northern central area of the MRC the minimum values are 1300 mm, while in a short distance the Eastern area is 2050mm.

This discrepancy between the average values of precipitation in the region is due to Mountain of the Sea, which covers this area of the MRC and, consequently, contribute to the difference in the topography and its altitudes (Figure 01). The highest peaks in the mountain region reach 1850 m, while in other areas of the region the average altitude is 900 m. This factor linked to maritimity, which causes orographic rains on the slopes of the mountains facing the Atlantic and makes them more humid than those facing the continent. Thus, depending on the intensity of the water steam transport, the cloud can evolve and give rise to precipitations that are wide in the windward slope and reduce the wind (VANHONI and MENDOÇA, 2008; COUTO et al. 2016; LEE et al. 2018).

ISSN 2178-0234
V.14 ♦ N. 02 ♦ 2021 pág. 143-164

Figure 2 - Average annual rainfall in the Metropolitan Region of Curitiba (1976 - 2018).



Source: Águas Paraná; ANA; IAPAR e INMET (2019); Org. authors (2019).

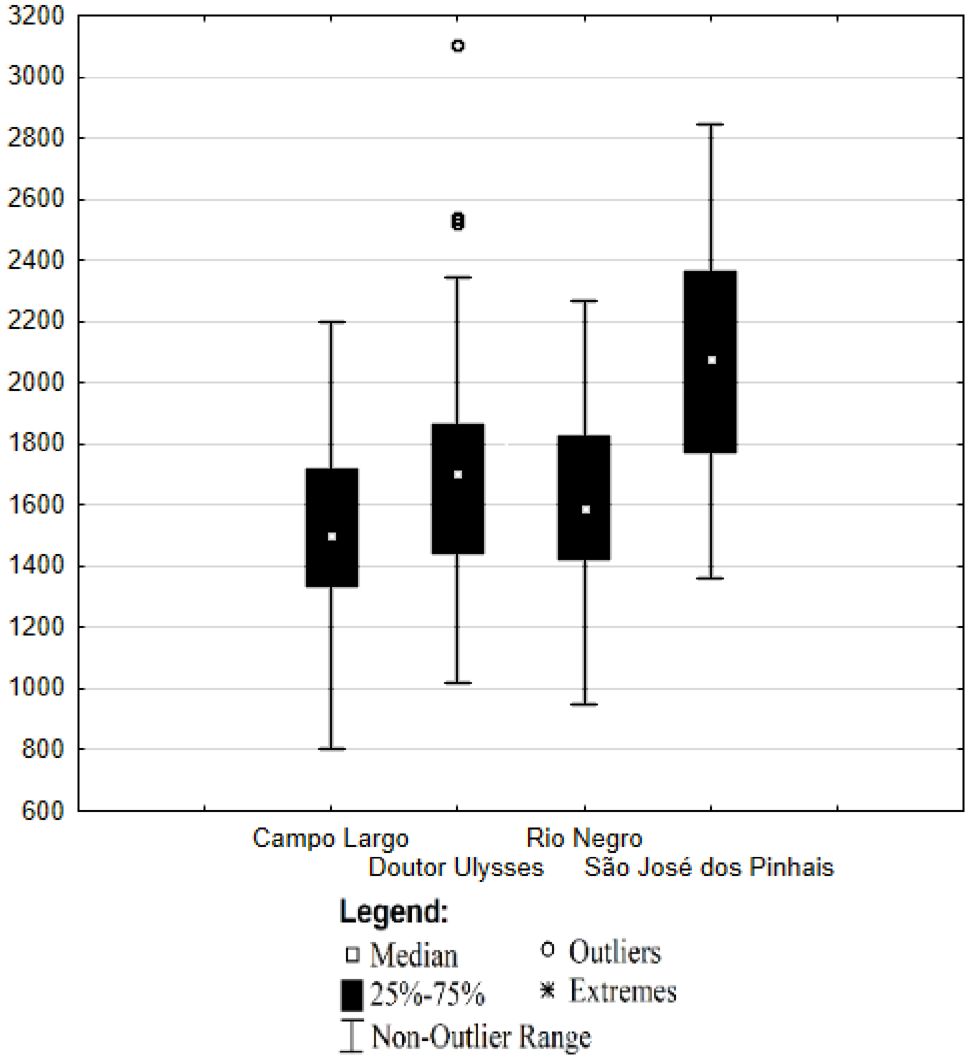
Latitude also proved to be a determining factor in the precipitation of the region, since the Southern region, close to the Iguaçu River channel showed average values from 1500 to 1600 mm, while the Northern area exhibited values from 1300 to 1400 mm.

In order to improve and complement the analysis of rainfall variability, a Box Plot graph was created to identify the variation in annual precipitation in the MRC (Figure 03). It was possible to verify a great discrepancy between the pluviometric heights in the station of the mountainous area (São José dos Pinhais) for the others. In this station, a maximum value of 2820 mm was observed, not being considered a discrepant value. While the lowest observed value was 1380 mm, being extremely higher than other stations.

The variation of the box in the ranges of 25 % to 75 % was from 1790 mm to 2380 mm, respectively.

ISSN 2178-0234

Figure 3 - Box plot of annual precipitation (mm) of the Metropolitan Region of Curitiba (1976 - 2018)**.**



Source: Águas Paraná; ANA; IAPAR e INMET (2019); Org. authors (2019).

The other three stations do not exhibit significant differences in annual rainfall variability. It is should be noted that at the Doutor Ulysses station there were four discrepancies, higher than 3,000 mm. The discrepancies did not affect the median value of this station, being 1,650 mm, with little difference for the other two stations.

The highest annual rainfall recorded in the four stations, including the one above 3,000 mm, occurred in 1983, with the magnitude of this year average rainfall in the Paraná State being highlighted in several studies (MINUZZI e CARAMORI, 2015; NASCIMENTO JUNIOR and SANT'ANNA NETO, 2016; CALDANA et al., 2018; CALDANA et al., 2019).

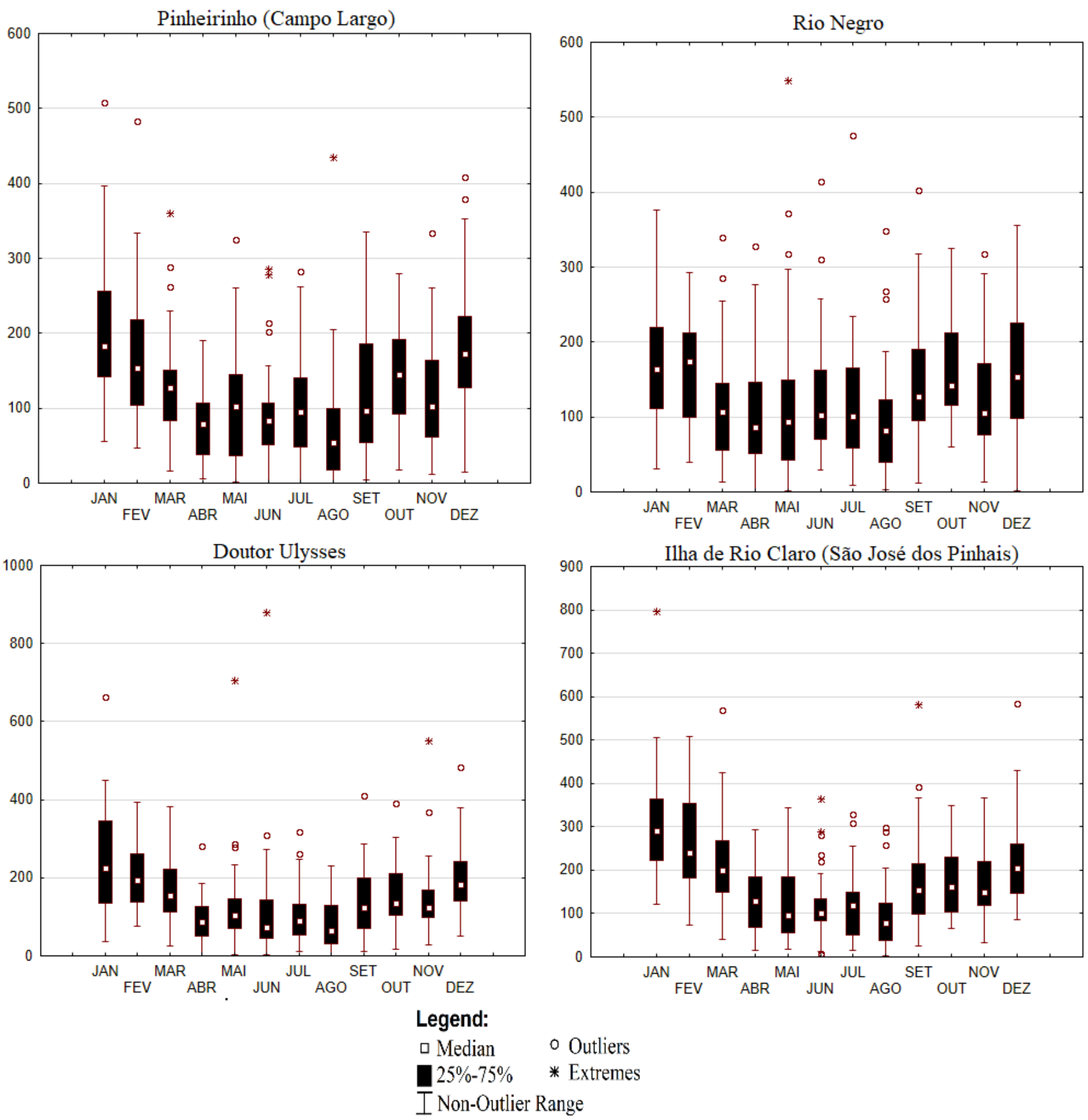
The Campo Largo station, located in the Central-Western area of the MRC was identified as the driest, with a median of 1,450 mm. The station had no discrepancy and showed 25 % and 75 % quartile variation from 1,380 mm to 1,710 mm. The lowest annual

ISSN 2178-0234

rainfall recorded at the station was 805 mm, the lowest in the series analyzed for all weather stations.

Monthly (figure 04) the weather stations exhibited a similar distribution, during the months of the Spring and Summer and for the months of Fall and Winter, drier. The station with the highest rainfall was São José dos Pinhais. Four extreme values were identified, during January, June and September, and eleven discrepancies, one in the lower area of the box plot, in June. There were two months without precipitation in the analyzed series, both occurrences were in August.

Figure 4 - Box plot of monthly precipitation in the Metropolitan Region of Curitiba (1976 - 2018).



Source: Águas Paraná; ANA; IAPAR e INMET (2019); Org. authors (2019).

ISSN 2178-0234

For the Campo Largo station, four extreme values were observed in the months of March, June and August, in addition to eleven discrepancies. In addition, it was identified that in the months of April, May, June, July and August there were months without precipitation. The month of December showed the greatest precipitation monthly variation, ranging from 20 to 400 mm.

The analysis of data from the Rio Negro station showed only one extreme value in May, in addition to thirteen discrepancies. The highest monthly variation was observed in December, with oscillations from 0 to 360 mm. The months of April, May, August and December showed monthly occurrence without precipitation.

For the Doutor Ulysses station, the highest monthly precipitation height was identified, with 860 mm in June, in addition to two other discrepancies in the months of May and November. Altogether it was eleven months with discrepancies.

Were verified significant precipitations heights concentrated in 24 hours, with a greater number of occurrences in all the locations analyzed. Were observed with great frequency of high daily rainfall, which can become extreme precipitation events in the region. Thus, we used as a parameter the occurrences of half of the monthly average precipitation in the 24-hour interval (Figure 05).

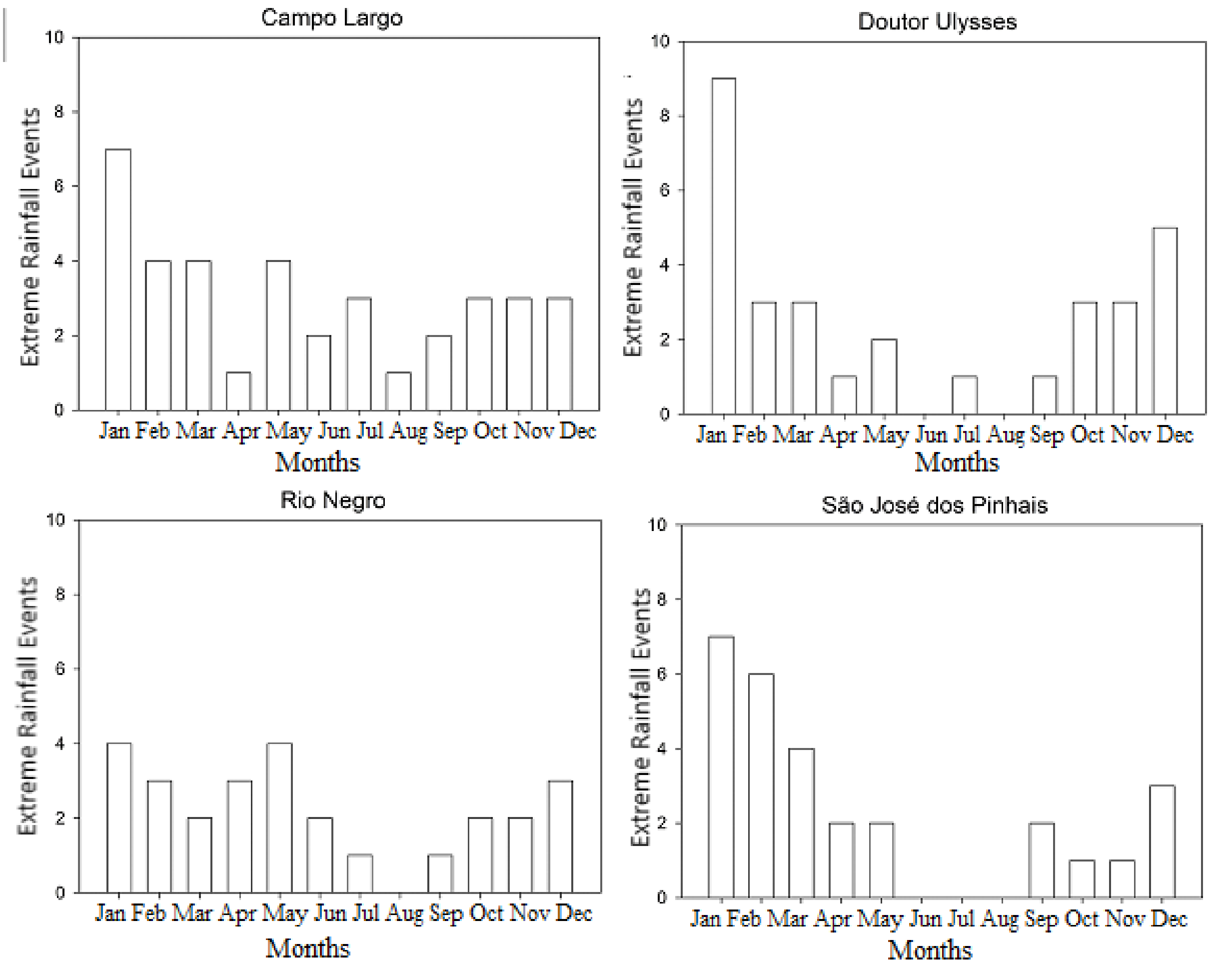
For the Campo Largo Station was observed 37 extreme daily precipitation events were observed at Campo Largo station, mainly concentrated during the Summer, with an emphasis on January, with seven occurrences. In the region covered by this station, the formation of Convective Systems and Mesoscale Convective Complexes - MCC (CALDANA et al., 2018; CALDANA et al., 2019).

Convective Systems and MCCs operate along the year in the Southern region of Brazil but predominantly in the spring and summer seasons (BALDO et al., 2017; CALDANA et al., 2018; CALDANA et al., 2019), MCCs are identified in satellite images by their approximately circular shape and by a wide area of storm coverage. They are defined as a cluster of cumulunimbus covered by a dense cirrus layer, still being convective cloud systems, with rapid vertical and horizontal growth in a time interval of 6 to 12 hours (HOLLEMAN, 2001; KUNZ et al., 2009). Depending on their intensity, they can create several nuclei with the formation of storms and the incidence of hail. Their displacement along the Paraná State is normally in the Western - Eastern direction, coming from Paraguay (DAFIS et al., 2017; PUNGE et al., 2017; TREFAULT et al., 2018; CALDANA et al., 2018; CALDANA et al., 2019). It is should be noted that the altitudes of the region increase, in the

Western-Eastern direction, which may contribute to the friction of the system with the topography, mainly in the region of Campo Largo (Figure 01).

Convective systems, on the other hand, are differentiated by the smaller spatial scope, formed by the process of heat transfer by conduction that occurs in intense vertical movements, leading to the rapid condensation process and the formation of Cumulunimbus (CALDANA et al., 2018; CALDANA et al., 2019). In both cases, precipitation is generally short-lived and of high intensity (SCAGLIONI and SARAIVA, 2004; DAFIS et al., 2017; TREFAULT et al., 2018). Therefore, the occurrence of extreme events per month in 4 weather stations was analyzed, namely Campo Largo, Doutor Ulysses, Rio Negro and São José dos Pinhais.

Figure 5 - Number of Occurrences of Extreme Rainfall Events in the Metropolitan Region of Curitiba (1976 - 2018).



Source: Águas Paraná; ANA; IAPAR e INMET (2019); Org. authors (2019).

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At Doutor Ulysses station, 31 extreme events were detected and their distribution was similar to that of Campo Largo, with a predominance of events during the Summer. The highest incidence was also in January, with nine occurrences. There were few extreme events between June and November.

The Rio Negro station showed slightly different incidences from the others, with emphasis on the number of occurrences in the Fall and Winter months, concentrated mainly in the month of May.

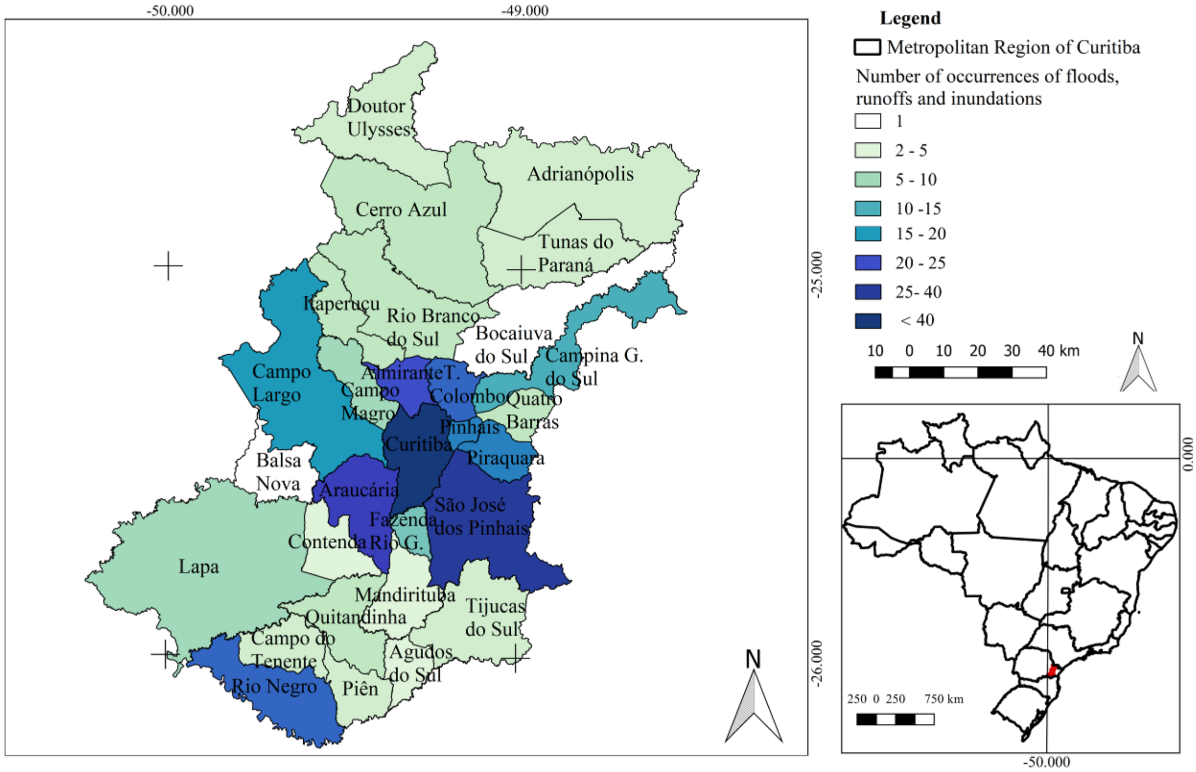
For these weather stations, a large part of the rainfall of this region is formed by the entry of Polar Air Masses that collide with the hot continental air, generating cold fronts and strong atmospheric instability, which can lead to the formation of cumulunimbus and lead to the formation of strong storms and hail formation. In these cases, precipitation is normally longer and less intense than in the formation of Convective Systems and MCC formed in the Spring and Summer months (BEREZAUK and SANT'ANNA NETO, 2006; PUNGE and KUNZ, 2016; BEREZUK, 2017; CALDANA et al., 2018). Thus, it is possible to justify the volumes of rainfall concentrated in the winter months throughout the region.

The formation of active systems and the identification of extreme precipitation events were important to analyze and identify that greater rainfall heights in a short period of time occur frequently in the MRC and thus investigate some of the impacts of rain in the region. For this context, were used data on the occurrence of flooding, runoff or inundation in the municipalities (Figure 06). It was observed that all municipalities had at least one occurrence of the socio-environmental disasters from 1990 to 2018. There were 368 occurrences, with predominance in the central axis of the region, mainly in the municipalities around Curitiba. It is possible to identify that the occurrences are in places where there is a greater concentration of rainfall (Figure 02), mainly in São José dos Pinhais.

The most affected municipality was Curitiba with 46 occurrences in the analyzed period, with more than two occurrences per year. It should be noted that for the Civil Defense to provide assistance, it demonstrates that this occurrence has brought damage to society and / or the environment, and also that these events can occur more frequently, since not all incidences of one of the three phenomena may have had assistance from the Civil Defense.

South of Curitiba stand out the municipalities bordering São José dos Pinhais and Araucária, with 35 and 28 occurrences, respectively. In the North, Colombo and Almirante Tamandaré stand out with 23 and 25 occurrences, respectively. It is noteworthy that all of these registered more than one occurrence per year, demonstrating the socio-environmental vulnerability in Curitiba and its neighboring municipalities.

Figure 6 - Number of occurrences of floods, runoffs and inundations in the Metropolitan Region of Curitiba (1990 - 2018).

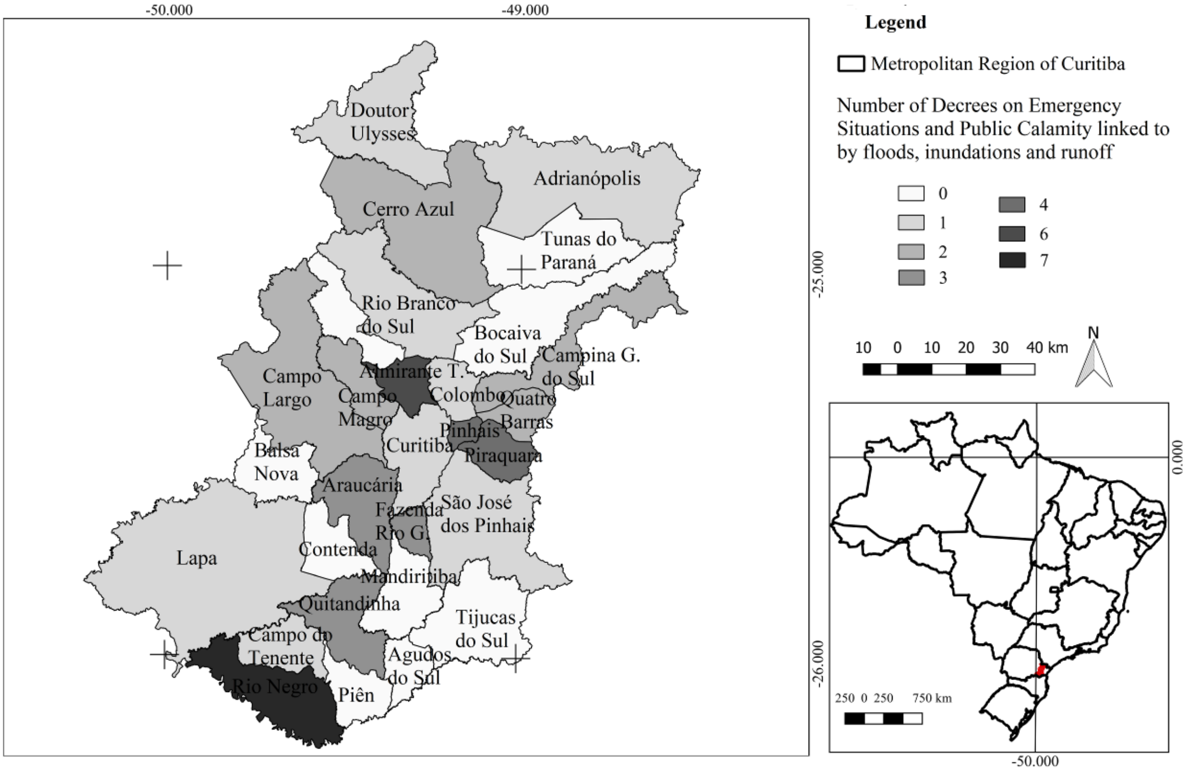


Source: Paraná State Civil Protection and Defense Coordination (2018); Org. authors (2019).

Of these events, some can be so disastrous that the municipalities declare an Emergency Situation or Public Disaster (Figure 07), showing the legal recognition by the municipality affected of an abnormal situation caused by disasters. The emergency situation is characterized by the fact that it is bearable and surmountable damage by the affected community, while in Public Calamity the damage is not only social but also brings high risk to life. Its damages are difficult to repair, only being overcome with the help of governments and external bodies (CASTRO, 1998). Altogether there were 48 decrees in the region, one of which was a public calamity.

Only 9 of the 29 municipalities did not declare an emergency or public calamity in the region, from 1990 to 2018. The municipality with the highest number of decrees was Rio Negro with seven, the only one to declare a state of Public Calamity on June 9, 2014, in a flood-related event.

Figure 7 - Number of Decrees on Emergency Situations and Public Calamity linked to by floods, inundations and runoff in the Metropolitan Region of Curitiba (1990 - 2018).



Source: Paraná State Civil Protection and Defense Coordination (2018); Org. authors (2019).

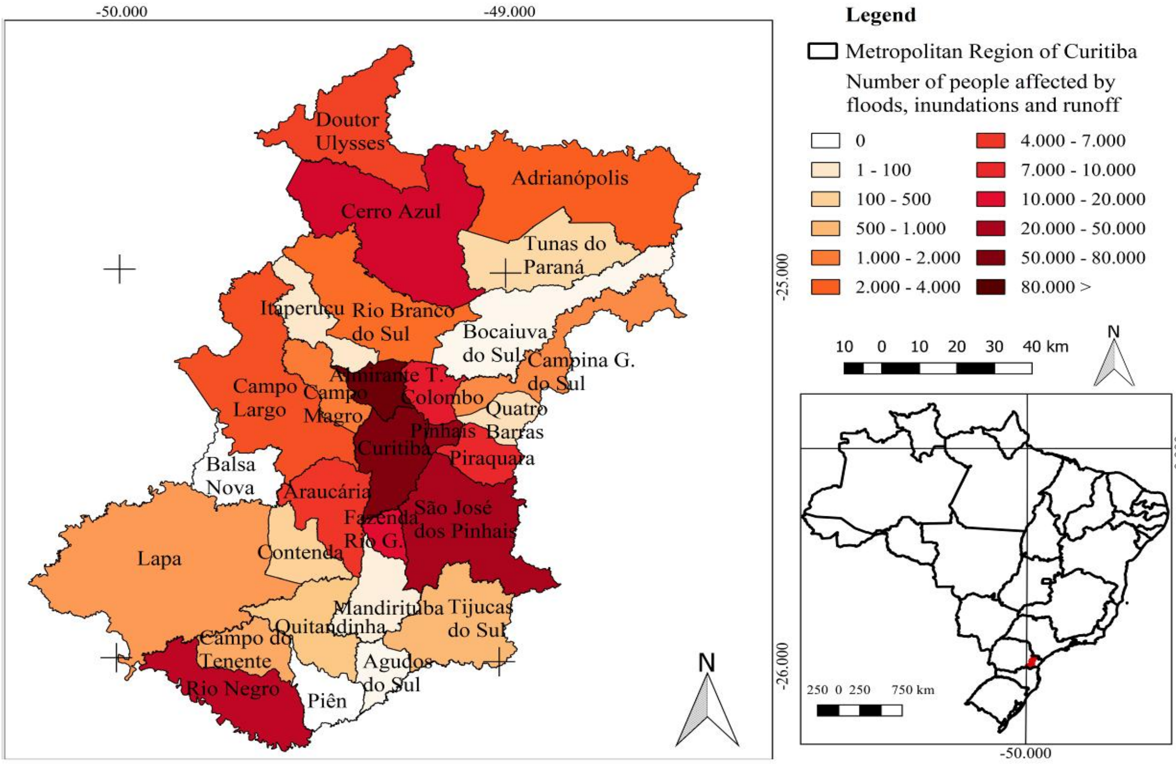
Then, the municipality of Almirante Tamandaré appears with six decrees of emergency situation, followed by Pinhais and Piraquara with four decrees each. Curitiba showed only an emergency situation decree on June 20, 2013, linked to flooding.

Altogether there were 17 deaths caused by one of the three socio-environmental disasters, with the municipalities with the highest number of deaths, Fazenda Rio Grande, Rio Negro and São José dos Pinhais, with 3 each.

People are the ones who suffer most from the disasters caused by the rains, which suffer the impacts directly and indirectly. In this sense, the number of people affected by floods, runoff or floods (Figure 08), was 397,516, from 1990 to 2018 in the MRC. The most affected municipality was Curitiba, with 87,507 people affected. The high numbers of the capital of Paraná are due to the fact that it is the most populous, and therefore those who are at greater risk and vulnerable to impacts, within the municipalities analyzed. Curitiba has 1,917,185 inhabitants (IBGE, 2018). Then, Almirante Tamandaré appears with 86,005 inhabitants who suffered some damage from one of the three events, counting a population of 117,168 (IBGE, 2018). In the central area of the region, Pinhais also stands out with 79,598 affected people and a population of 129,445 inhabitants (IBGE, 2018).

ISSN 2178-0234

Figure 8 - Number of people affected by floods, inundations and runoff in the Metropolitan Region of Curitiba (1990 - 2018).



Source: Paraná State Civil Protection and Defense Coordination (2019); Org. authors (2019).

Less developed and less demographic cities also registered decrees due to disasters. It is worth mentioning that the size of the municipalities and the number of people residing there does not rule out the possibility of a disaster occurring due to extreme precipitation events. Among the small towns in the region, Rio Negro stands out with 25,043 affected people and a population of 31,261 inhabitants and Cerro Azul with 20,626 affected people and a population of 16,948 inhabitants (IBGE, 2018). The latter, proportionally being the municipality most affected in the MRC, and also demonstrating that part of the population was affected more than once by any of the episodes in the municipality.

In the Metropolitan Region of Curitiba, as in most Brazilian metropolises, the risks in the urban space associated with climatic events are often linked to the rapid process of urbanization and civil construction. Curitiba, mainly, after the 1970s, had its population increased abruptly and received a range of migrants, in many cases, "bearers of low technical and educational preparation and less financially well-off", being subjected by the city's real estate market to a proliferation from peripheral neighborhoods, often in irregular occupations and in dwellings with little preparation for the climatic adversities that occur in the city, such as floods, runoff, inundation, gales and hail. Thus, this portion of the population started to live with several types of environmental impacts and risks, characterized as "socio-environmental vulnerability" (MENDONÇA, 2005, p. 143; CIDADE, 2013; MENDONÇA et al., 2016; WILK et al., 2018).

Problems with floods, inundation and runoff are frequent throughout the world, and as mentioned, representing at least 80 % of Brazilian cities. In recent decades, these events have gained public attention and investments in infrastructure, concentrated mainly in large cities (MARCELINO, 2007 CHEN, et al. 2018). At the MRC the problems caused are notorious and alarming, they were present in at least 90 % of the municipalities. The planning of this region must always be carried out with measures aimed at improving urban drainage, thus mitigating this type of occurrence, and consequently improving environmental and water quality.

Construction and housing sites may be linked to the number of people affected and the types of damage caused. The exposure of part of the regional population to the damage caused by these phenomena can be reduced, aiming mainly at improving the housing location in areas where the occurrence of floods, runoff and inundation are frequent.

Future work is necessary, focusing on the areas of Meteorology, Climatology, Hydrology and Urban Planning, mainly on the local scale, to identify in a morphometric analysis the most propitious places in these municipalities for this type of occurrence, thus assisting urban planning in this region. In addition, further studies that identify rainfall trends and extreme climatic events in the region would enable large-scale time planning.

And such studies gain greater magnitude in climate change scenarios. Urban centers should look for strategies and technologies to minimize impacts, whether social or environmental. And cities with reduced development size should focus on seeking to increase the resilience of the population to overcome these adversities.

Final Considerations

Precipitation in the Metropolitan Region of Curitiba proved to be well distributed regionally, but with greater heights in the mountain range. It was identified that extreme rain events, by the two methods of analysis, are striking during all months. In the Campo Largo, Doutor Ulysses and São José dos Pinhais stations, the occurrence of extreme events in the

Summer months predominated, while in the Rio Negro station, located far Southern in the region, events formed in the Fall and Winter months predominated. Events of months without precipitation are concentrated during the Fall and Winter.

The responses of these extreme precipitation events on the surface are noticeable through floods, runoffs and inundation. In total there were 368 occurrences, 48 decrees and 397 thousand people affected by at least one of the three disasters. Curitiba was the most affected municipality with 46 occurrences, followed by Araucária and São José dos Pinhais. Rio Negro was the only municipality to register a state of public calamity due to a flood event, in which the municipality was unable to repair the damage caused by the extreme event. Curitiba, having due the higher population when compared to the others, was the one that had the most people who suffered damage from the events, with 87,507 people affected. However, proportionally, the municipality most affected was Cerro Azul with 20,626 affected people and a population of 16,948 inhabitants, demonstrating that the event reached more than once the same person in 28 years of analysis. The vulnerability and risks of natural disasters caused in the urban space are alarming and should assist in planning and decision-making in the MRC, aiming mainly at improvements in urban drainage and housing.

Disasters notably occur due to urban planning, which often does not have mechanisms to reduce the impacts of extreme rainfall. Depending on the intensity of rainfall, disasters are inevitable, however, most cases can be remedied with effective and robust urban planning, especially in urban areas that are highly vulnerable. It stands out here, the role of the civil defense in providing quick assistance in order to minimize the impacts.

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