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Pluvial Floatings in the State of Pernambuco – Brazil

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ABSTRACT

The objective was to characterize the climatic conditions of pluviometry in the State of Pernambuco, producing maps representative of the monthly and annual distribution by the kriging method for years between 30 and 100 years for 187 municipalities. It used the monthly totals of precipitations obtained in the pluviometric stations of the Superintendency of Development of the Northeast; Pernambuco State Agency for Water and Climate and the National Institute of Meteorology in 187 municipalities with thirty-one hundred years of observations. A spreadsheet was prepared with the data obtained and the monthly and annual averages calculated. Using the Surfer 10 software, statistics were elaborated using kriging and the production of monthly and annual maps of the averages. In the rainy months, high rainfall indices are observed, followed by short intervals of time, causing flooding, flooding, transshipment, and silting of rivers, lakes, ponds, streams, dam levels, traffic disruption, social losses, and human deaths, and animal. The rainfall trend in the entire State of Pernambuco is of extreme events with high magnitude and in a short interval of time, provoking disorder in subsistence agriculture. Three categories of climates were detected: type A with the highest prevalence, type BSh with intermediate predominance, and Am climate. Rainfall variability is irregular and with wide fluctuation throughout the year.

INTRODUCTION:

Water is an essential resource for the maintenance of life, especially to "fresh water", this factor is linked to the multiple activities developed through this resource, among them, supply for human consumption, industrial and agricultural activities, and importance for ecosystems. Rebouças (2006).

The semi-arid Northeastern region is characterized by the occurrence of scarce, irregular (spatial and temporal) rains of frequent droughts, being usually the occurrence of events of high intensity and of short duration, devoid of flow volume of rivers, this situation can be explained by the temporal variability of the precipitations and the dominant geological characteristics in addition to the meteorological systems acting according to Silva *et al,* (2013). In a climate region of contrasting neighboring areas (from one rainy side of the other semi-arid) such as the Northeast Region of Brazil (NEB) and especially the state of Pernambuco, precipitation monitoring, especially during the rainy season, is very important for making decisions that bring benefit to the population.

Climate is a set of physical, chemical and biological elements that characterize the atmosphere of a place and influence the beings that are in it according to Pereira *et al.* (2001). Therefore, it is considered one of the most important variables of the environment. However, human activities can contribute in negative ways, as they gradually change both human and animal life conditions, thus causing changes in the quality of life of society in general. The difference in thermal response between urban and rural environments is mainly marked by the development of heat islands in urban areas following Rocha (2011).

The NEB exhibits semi-arid climate with diverse spatial and temporal variability of rainfall, with high rates of evaporation according to Albuquerque et al. (2009). According to the authors Souza Filho *et al.* (2006), climate fluctuations have a significant impact on the socioeconomic sector.

Climatologically the NEB is considered semi-arid because it shows with inter-municipal irregular temporal and spatial variability and elevated temperatures throughout the year, as observed by Azevedo *et al.* (1998). According to Mendes (2015), the climatic variability of NEB is influenced by the El Niño phenomenon associated with large drought events in the region, which causes great damage to the populations of these areas.

Rainfall is a climatic variable that has a random distribution in space and time, exerting a strong influence on the environmental conditions. The equipment commonly used to measure the amount of rain that falls on a region is called pluviometers and rain gauges, and a set of these forms a network

that allows the climatological study of a given area to be a river basin or the administrative limit of A municipality per the authors Tucci (2001); Moulin (2005) and Caram (2007).

The spatial and temporal variations are characteristic of weather and climate. The temporal variation is a characteristic that must be studied with particularity and in different chronological scales. These studies will allow the knowledge of the climate in the past, present and even make predictions and diagnoses for future climatic situations from the mathematical models used (Fernando, 2008). According to Berveglieri *et al.* (2011) geostatistics, in general, develops and applies models in representations of natural phenomena whose properties vary according to the spatial position of the observed points.

Precipitation and the climatic variable with the greatest variability in time and space. For this reason, the study of extreme events of annual maximum daily precipitation is related to severe damage to human activities in almost all regions of the world, due to their potential to cause soil water saturation, runoff, and erosion by Intergovernmental Panelon Climate Change (IPCC 2007); Tammets *et al.* (.(2013).

Medeiros *et al*, (2014) It was verified that the Rainfall Anomaly Index (RAI) can be used as a tool for climatic monitoring of a locality, in this case, the Uruçuí Preto river basin, in addition to being used for regionalization, and also, through this monitoring Generate forecasts and diagnoses of local climatology. From the criteria of classifications based on the percentage deviations, the months and years of the sites that compose the river basin were classified, where extremely rainy to extremely dry oscillations were obtained.

In the semi-arid region, even with the distributions and occurrences of irregular rains, and with actions of the meteorological factors suffering blockages that impede regularities, there are sufficient and sufficient conditions of storage, not only for good planning but also for adequate monitoring of water quality according to the authors Tenenbaum *et al*, (2005).

According to Menezes *et al*. (2015) the variability of rainfall indices between the period from 1913 to 2010 for the municipality of Teresina. The precipitation variations reflect the atmospheric dynamics of the region, marked by the intense variability, where the Intertropical Convergence Zone (ZCIT) operates with its performance between January and March, this period being the rainiest. The analysis of precipitation behavior in large and medium-sized cities is extremely important for the management of water resources since these are densely urbanized areas. Often, without proper urban structuring, these cities fit perfectly in that context.

Jakob (2012) guarantees that kriging is evaluated as an interpolation methodology where tabular data and geographic disposition are used to perform the calculations. Using the principle of Tobler's First Law of Geography, which describes that the units of analysis close to each other are similarly similar to the distant units. The kriging uses mathematical functions to join larger weights at positions near the sample points and smaller weights at the distant positions, thus creating the new interpolated points based on these linear combinations of data.

The kriging method differs from other interpolation methods by the way the weights are assigned. According to Yamamoto *et al*. (2015), to understand the spatial variation of the underlying random process, one must take into account the possibility that the value of each point in space is related to values obtained at points located at a certain distance, The influence is greater the smaller the distance between the points.

Geostatistical techniques can be used to describe and model spatial patterns under study, in order to predict values in non-sampled locations and/or regions according to Andriotti (2009).

The objective of this study is to characterize the climatic conditions of rainfall in the State of Pernambuco, producing representative maps of the monthly and annual distribution by the kriging method for the period between 30 and 100 years for 187 municipalities.

MATERIALS AND METHODS:

The State of Pernambuco is located in the center east of the NEB and is bordered to the north by the state of Paraíba, to the neb, it borders with the state of Ceará, in the southeast position with the states of Alagoas and Bahia in the South and Piauí to the west, in addition to being bathed by the Atlantic Ocean in the eastern sector of the northeast. It occupies an area of 98.937.8 km ². The archipelagos of Fernando de Noronha, São Pedro and São Paulo are part of its territory.

One of the smallest states in Brazil in territorial extension, Pernambuco has a great diversity of landscapes: plateaus, mountains, swamps, semiarid and beautiful beaches. The relief is almost regular, being formed of the coastal plain about 76% of it. As we move inland, mountain peaks are exceeding 1000 meters.

The vegetation cover is much diversified, with forests, mangroves, and savannahs, besides a strong presence of caatinga. The coastal vegetation predominates in areas near the ocean, is found in many coconut trees, mangroves and, in some cases, shrubs. The tropical forest is where there was originally Mata Atlântica. There were few remnants of this important Brazilian forest. Finally, in the

agreste and in the backlands of Pernambuco, what predominates is the vegetation of the caatinga. As for hydrography, there are many rivers, mainly in the Metropolitan Region of Recife, which has 14 municipalities. The main rivers of the state are Capibaribe and Beberibe, Ipojuca, Una,Pajeú, Jaboatão and the São Francisco River, the latter extremely important in the development of the sertao, since it makes possible the distribution of water to the regions affected by the drought.

Medeiros (2016) shows that the meteorological and/or rainfall systems for the state of Pernambuco that contribute moderately to weak rainfall are the vestiges of frontal systems in the southern sector of the state, Contributions from the South Atlantic Convergence Zones (ZCAS), in addition to the formations of the convective clusters and the contribution of the Bolivian High. The Intertropical Convergence Zone (ITCZ), a disturbance associated with the expansion to the southern hemisphere of the thermal equator (zone of rise of the trade by thermal convection) causes moderate to strong rains in almost all the northern area of the State, Of the contributions of the Formations of the High-Level Cyclic Vortices (VCAN), the Eastern Undulating Disturbances and the Sea and Land Breezes, the latter originating in the Atlantic Ocean; Leste waves are common in autumn/winter, aided by southeast trade winds, the waves reach the east coast of the Northeast, causing heavy rains, another rainfall inducer following Figure 1.

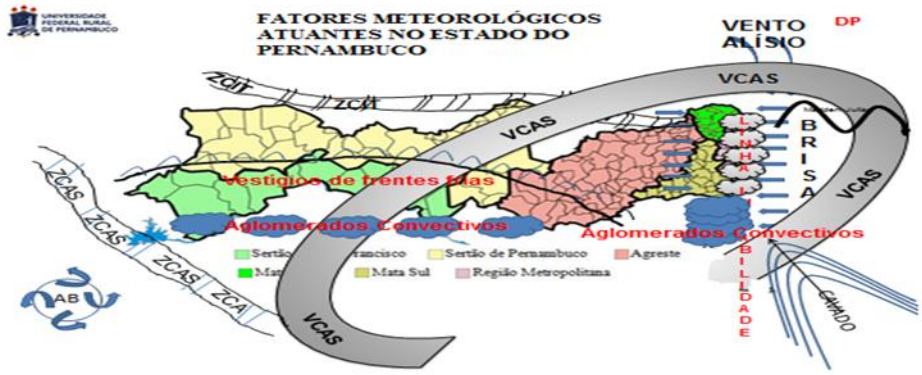

Figure No. 1: Illustrations of the meteorological factors in the state of Pernambuco.Source: Medeiros (2016).

Monthly and annual precipitation data from the National Institute of Meteorology (INMET 2015), the Northeast Development Authority (SUDENE) and the Pernambuco Water and Climate Agency (APAC) were used for 187 municipalities Compose the state, for which an analysis was made regarding its consistency, homogenization, and filling of faults in each series.

The monthly and annual rainfall values were inserted in a spreadsheet where the monthly and annual mean, the standard deviation to the mean, coefficient of variance, median, maximum, and minimum absolute value were calculated. Plotting their maps by the kriging method.

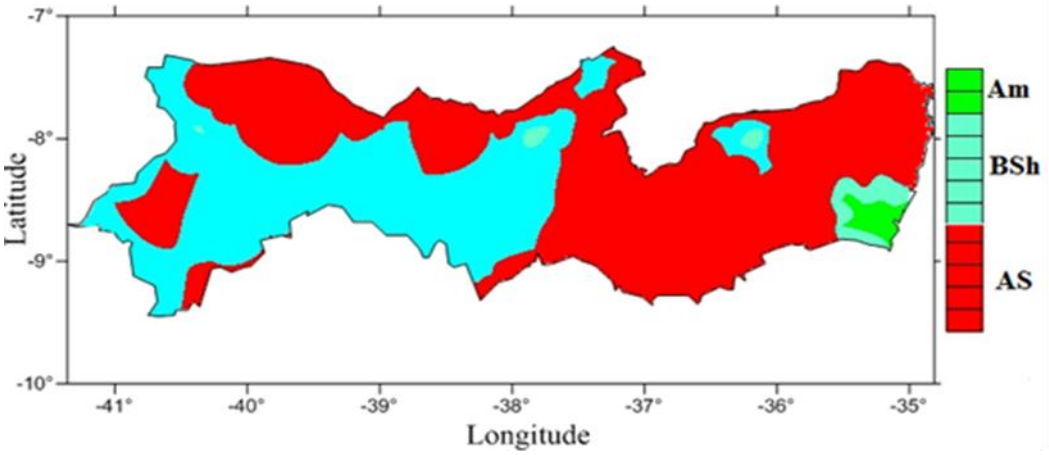

Figure No. 2: Climatic classification according to the Köppen model for the State of Pernambuco. Source: Medeiros (2016).

Similar results were found by Alvares et al. (2014) in the climatic classification for Brazil, in which the coast of Northeastern Brazil, with climate Am, in the Coastal Tablelands of João Pessoa, extends as far as the coast of Pernambuco State.

RESULTS AND DISCUSSION:

Figures 3 to 17 demonstrate the variability of monthly, annual, rainy, and dry periods of rainfall in the state of Pernambuco. It is observed that the rainfall oscillation is increasing in the west-east direction and has its irregular distribution in the five study areas (Sertão Region, Alto Sertão Region, Central Region, Zona da Mata e Litoral). These irregularities are contained in the formations and distributions of the forming elements and/or precipitation inhibitors in the study area.

Figure 3 shows the Pluvial variability (mm) of January between 30 and 100 years of observations for the state of Pernambuco. In the regions of Sertão, Alto Sertão, and western part of Central January and considered as a month of pre-season rains (rains that precede the rainy season). It is observed that in the north sector with Paraíba the high rainfall indices are recorded except between the longitudes of 35 to 37 ° W, although its irregularity isolated areas in the southern extreme north present a 100 mm area, as well as small areas of 25 mm. In the coastal region, Zona da Mata and the eastern part of the central region rainfall fluctuations range from 0 to 75 mm. These fluctuations are due to the transient meteorological systems according to Figure 1.

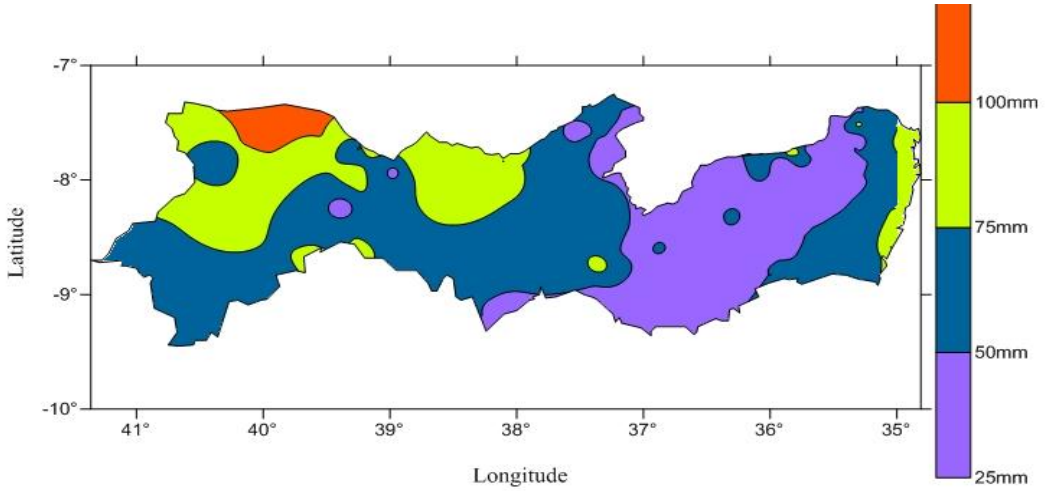

Figure No. 3: Pluviometry (mm) of the month of January between 30 and 100 years with observations for the state of Pernambuco. Source: Medeiros (2020).

The month of February with the characterization of the rainy season in the Sertão, Alto Sertão, and western part of the Central region presents with pluviometric oscillations of 40 to 140 mm. In figure 4 it is observed that in the PE / PB currency the variations are of better distributions than in the PE/AL/BA currency. In the zone of the Mata, east and coast, fluctuations occur between 40 mm and 115 mm, this area begins with pre-season rainfall from the second half of March and presents with indicated rainfall indexes for some crops.

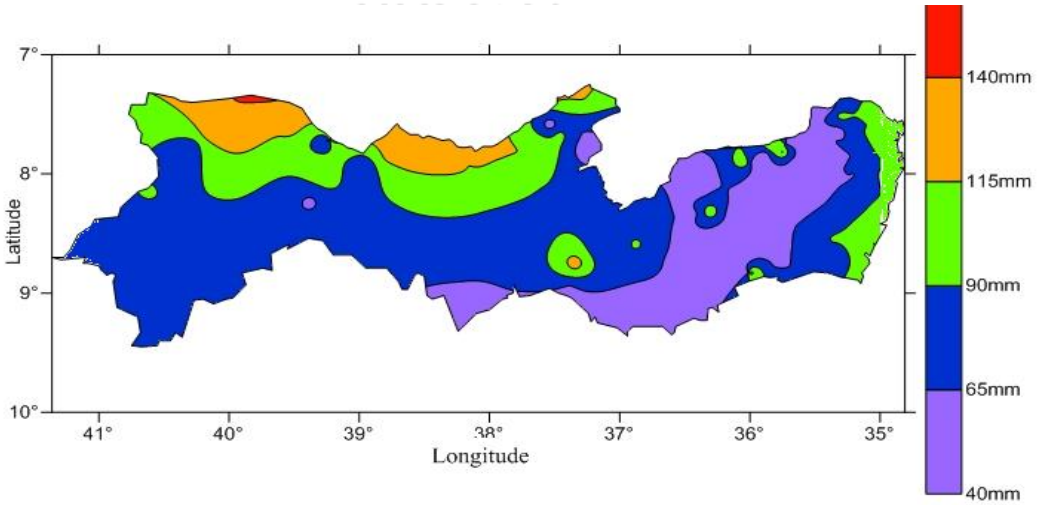

Figure No. 4: Pluviometry (mm) of the month of February between 30 and 100 years with observations for the state of Pernambuco. Source: Medeiros (2020).

Figure 5 shows the buoyancy of the rainfall (mm) of March between 30 and 100 years with observations for the state of Pernambuco.

We highlight areas with pluviometric fluctuation between the region of Mata Sul and the border with the state of Alagoas with rainfall indexes of 70 mm. On the border with the states of BA/PI/CE rainfall variability flows between 120 and 145 mm. The rainfall fluctuations occurring between the PE/PB states flow between 145 mm and 195 mm. In the littoral region rainfall of moderate magnitudes occurs and they vary between 145mm to 170mm respectively.

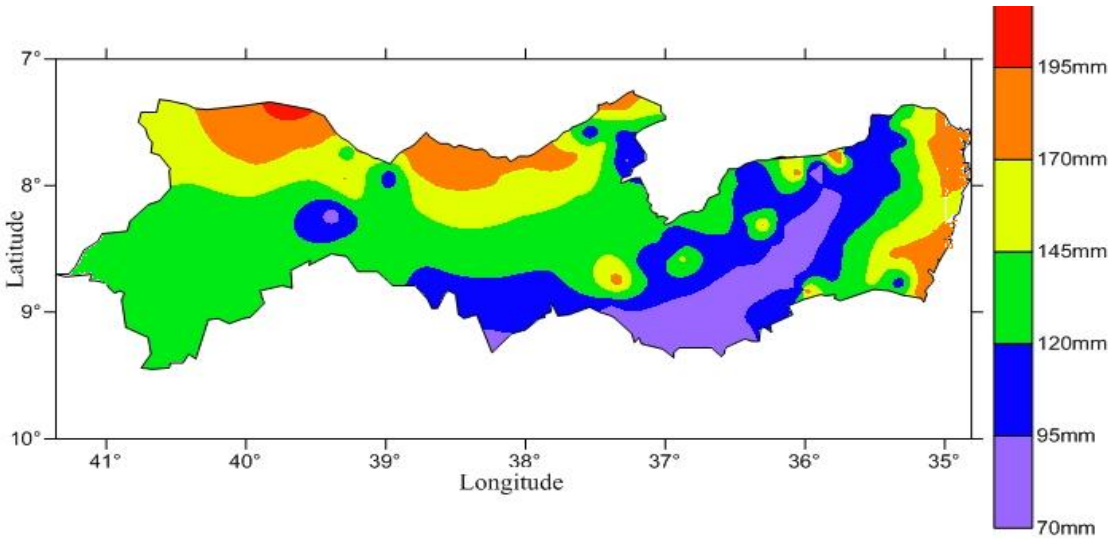

Figure No. 5: Pluviometry (mm) of March between 30 and 100 years with observations for the state of Pernambuco. Source: Medeiros (2020).

Rainfall fluctuations from April to the state of Pernambuco are shown in Figure 6. In the BA/PI/CE currency, rain reductions occurred, as in the PE/PB currency, the same reduction was detected in the central region and part of the forest. In the coastal region, there were increases in rainfall indexes according to figure 6.

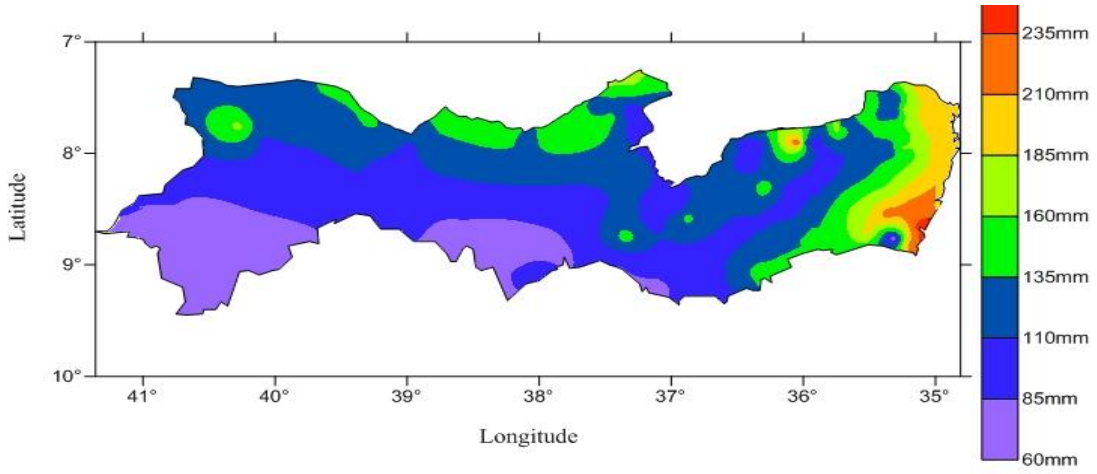

Figure No. 6: Pluviometry (mm) of April between 30 and 100 years with observations for the state of Pernambuco. Source: Medeiros (2020).

In May, the end of the rainy season for the regions of Sertão, Alto Sertão, and the western part of the Agreste region (Fig. 7), shows reductions in rainfall and PB/CE/PI/BA/AL. Rainfall above normal is observed in the East Agreste region, Mata and coastal zone with fluctuations ranging from 185 mm to 310 mm.

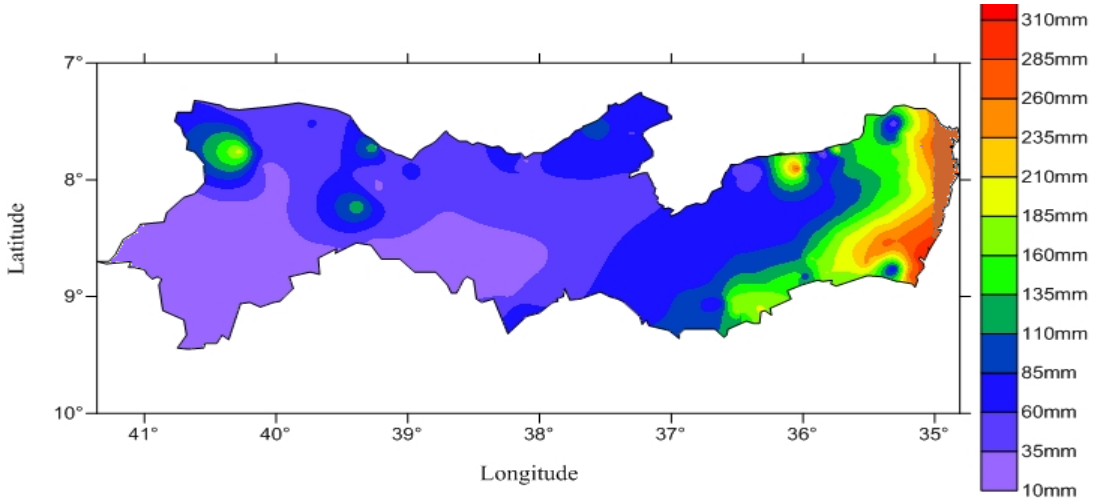

Figure No. 7: Pluviometry (mm) of May between 30 and 100 years with observations for the state of Pernambuco. Source: Medeiros (2020).

Figure 8 shows the rainfall fluctuations (mm) of June between 30 and 100 years with observations for the state of Pernambuco. In the Sertão region, Alto Sertão, the western part of the agreste region climatologically is end of rainy period with oscillations flowing between 0 to 75 mm, except the extreme upper west presenting core with precipitation of 125 to 175 mm. In the border state with Piauí/Ceará, the rainfall rates flow from 0 to 75 mm. In the division with PB the rainfall index oscillates between 0 and 250 mm. The oscillations from 0 to 250 occur between BA/AL/PE. These buoyancies are interconnected to the local, regional and orographic systems operating in the month under study.

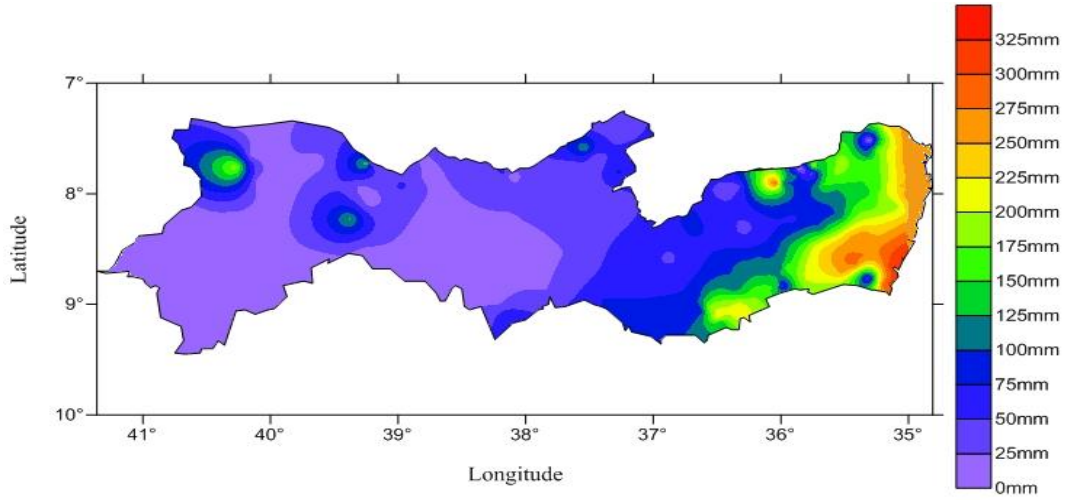

Figure No. 8: Pluviometry (mm) of June between 30 and 100 years with observations for the state of Pernambuco. Source: Medeiros (2020).

The month of July recorded irregular rainfall indices within the state of Pernambuco ranging from 25 to 325 mm. In the regions of Sertão and Alto Sertão there are isolated nuclei flowing between 50 and 175 mm. In the dry season, rainfall fluctuates between 50 and 100 mm. In the Rain Forest Zone, rainfall flows between 75 and 300 mm and tend to decline, as a variability for the dry period begins as shown in Figure 9.

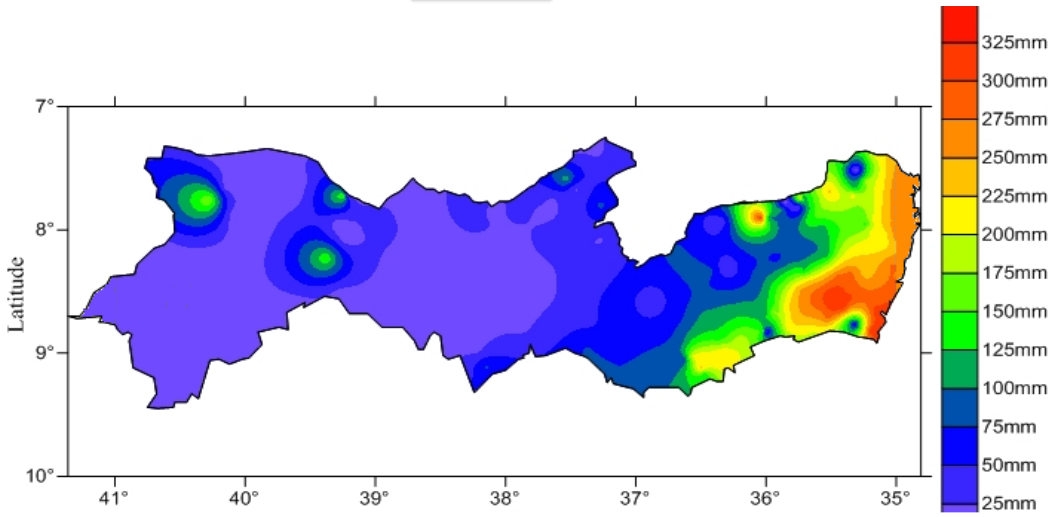

Figure No. 9: Pluviometry (mm) of July between 30 and 100 years with observations for the state of Pernambuco. Source: Medeiros (2020).

In August, the areas of the sertão, high sertao and part of the central region are highlighted, with rain pluviometrical ranging from 0 to 25 mm, except for some localities. In the regions of the coast and Zona da Mata stand out the irregularities pluvial with fluctuations between 50 to 175 mm. The rains

that occurred in the study month according to figure 10 are caused by the local contributions and regions and occur in a short interval of time.

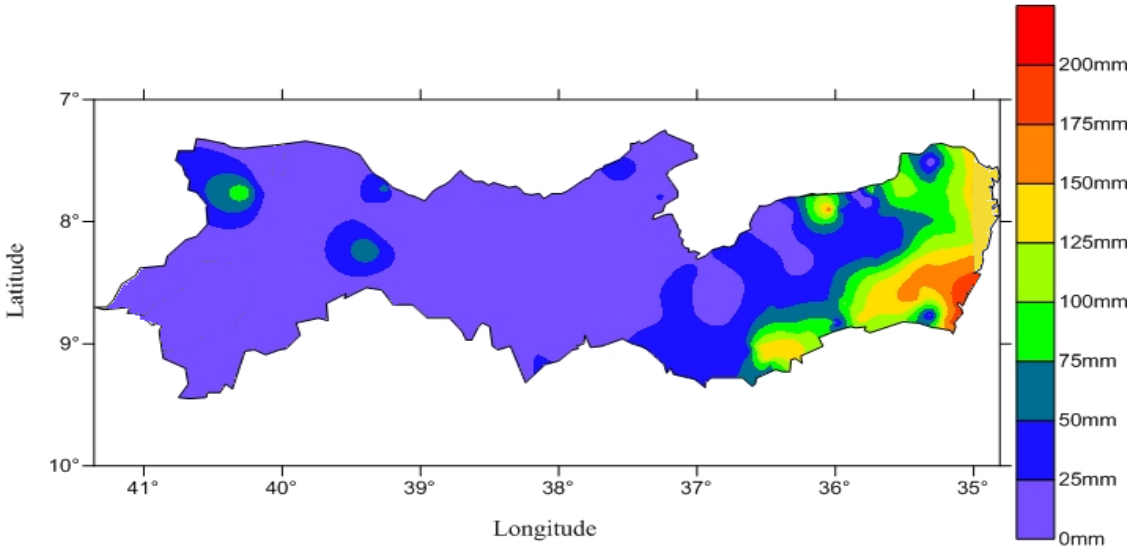

Figure No. 10: Pluviometry (mm) of August between 30 and 100 years with observations for the state of Pernambuco. Source: Medeiros (2020).

Figure 11 spatial distribution of rainfall indexes for September. In the Litoral and Zona da Mata regions, there are high recorded rainfall values. In the regions: central, sertao and high sertao, low rainfall intensities are recorded, except in the border with Ceará in a small isolated area with rainfall between 50 and 75 mm. These low rates are related to the high intensity of solar radiation, low relative humidity, and cloud cover.

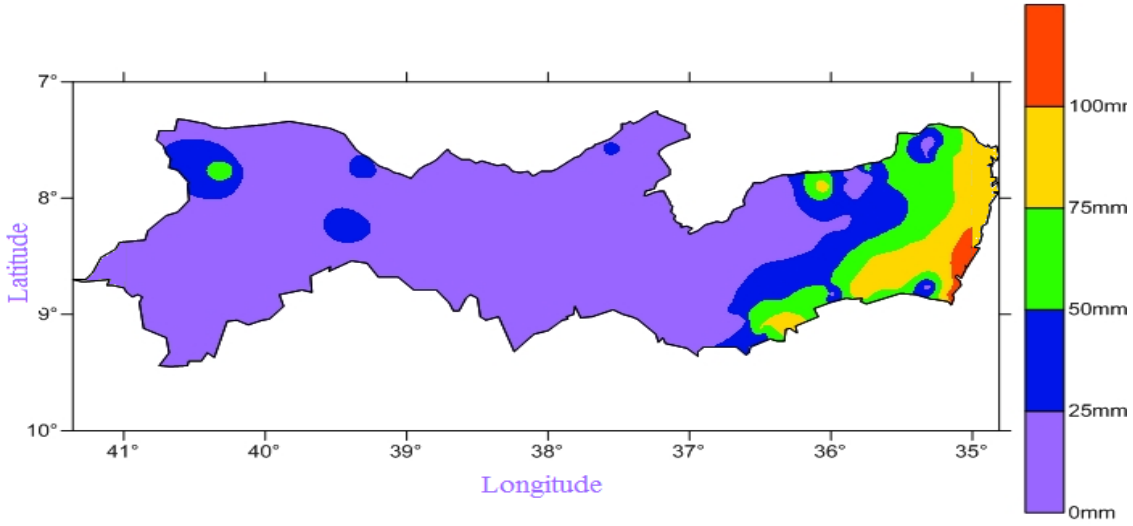

Figure No. 11: Pluviometry (mm) of September between 30 and 100 years with observations for the state of Pernambuco. Source: Medeiros (2020).

The month of October is characterized by low pluviometric indices throughout the State of Pernambuco according to Figure 12. In the Littoral, Zona da Mata and in small isolated areas rainfall is occasional and of low magnitude. In the Sertão, high Sertão and central regions there are no rainfall events. These variabilities are related to low cloud cover, high incidence of solar radiation, the relative humidity of the air below normal standards, weak wind intensity in addition to the contribution of the high-pressure center contributing to the subsidence movements (air downward from top to bottom) . On the coast and the Zona da Mata rainfall events were mostly caused by local effects and the sea breeze.

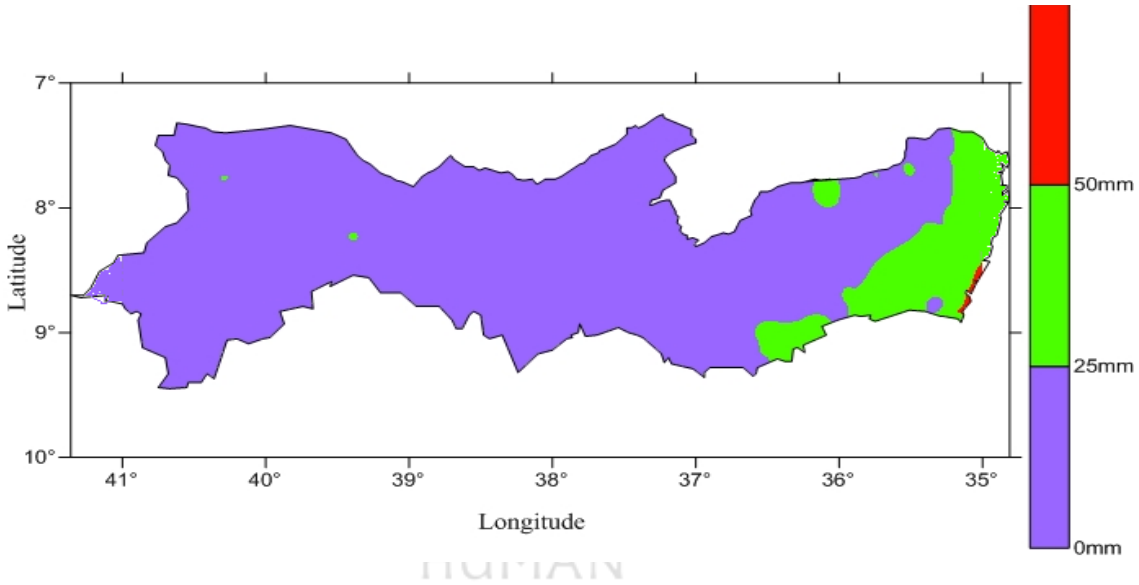

Figure No. 12: Pluviometry (mm) of October between 30 and 100 years with observations for the state of Pernambuco. Source: Medeiros (2020).

Figure 13 shows the rainfall variability (mm) of November, the irregularities recorded in the rainfall indexes between 0 and 75 mm are due to local and regional effects. Two small areas of maximum pluvial incidence on the coast and in the extreme west stand out.

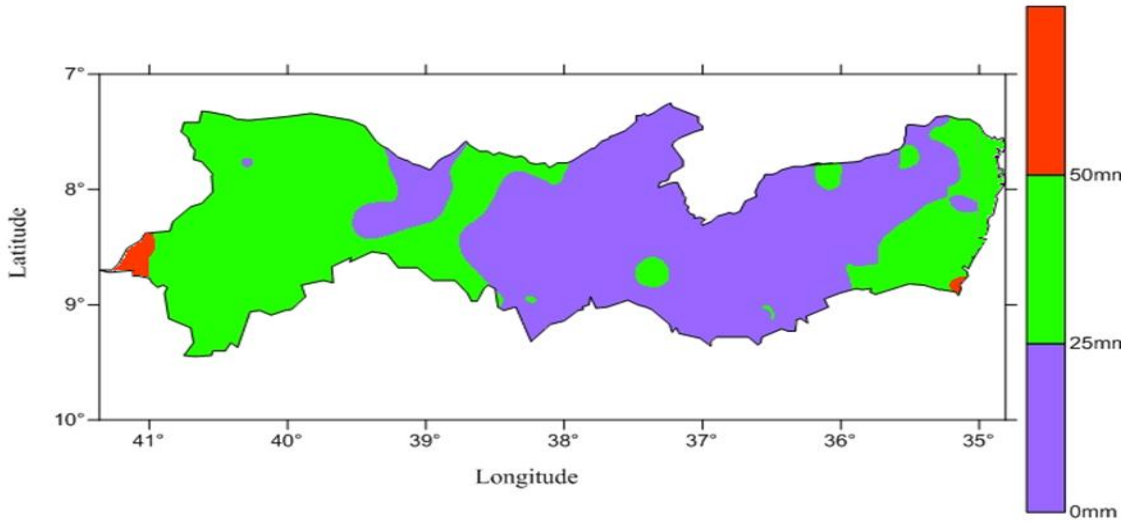

Figure No. 13: Pluviometry (mm) of November between 30 and 100 years with observations for the state of Pernambuco. Source: Medeiros (2020).

Figure 14 shows the rainfall variability (mm) of December between 30 and 100 years for the state of Pernambuco. It is observed in the region of the sertão and high sertaopluviometric indices flowing in isolated areas of 25 and 75 mm, and in its totality, the rainfall index is inferior to 25 mm. In the central region of the forest and coastal areas rainfall ranges from 25 mm to 75 mm.

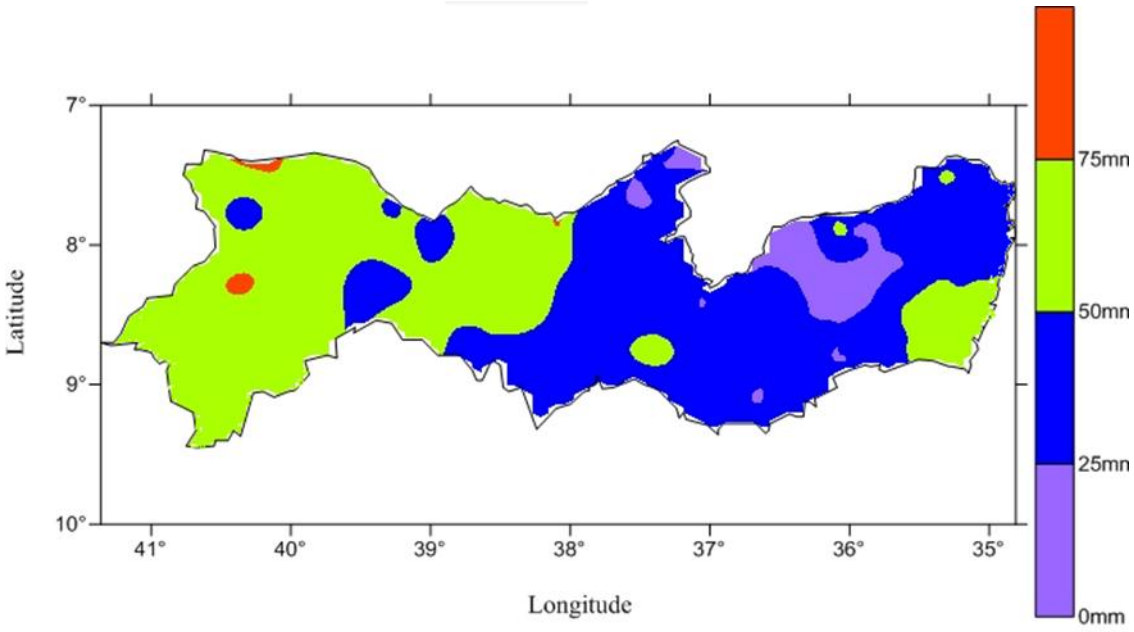

Figure No. 14: Pluviometry (mm) of December between 30 and 100 years with observations for the state of Pernambuco. Source: Medeiros (2020).

The annual distribution (figure 15) shows high spatial variability with fluctuations ranging from 400 to 2100 mm. In the coastal region, high rainfall rates are recorded, in high sertao and sertao rains occur in isolated areas of up to 1100 mm as well as variations of 400 to 900 mm in the border with the states of Alagoas, Bahia and Piauí. On the border with Paraíba rainfall indexes ranging from 400 to 1100 mm and small area 1900 mm are recorded, in the central region rainfall variability is 400 to 1100 mm. These variabilities are due to atmospheric factors such as low solar intensity, high cloud cover, fluctuations in relative humidity, and atmospheric pressure oscillation.

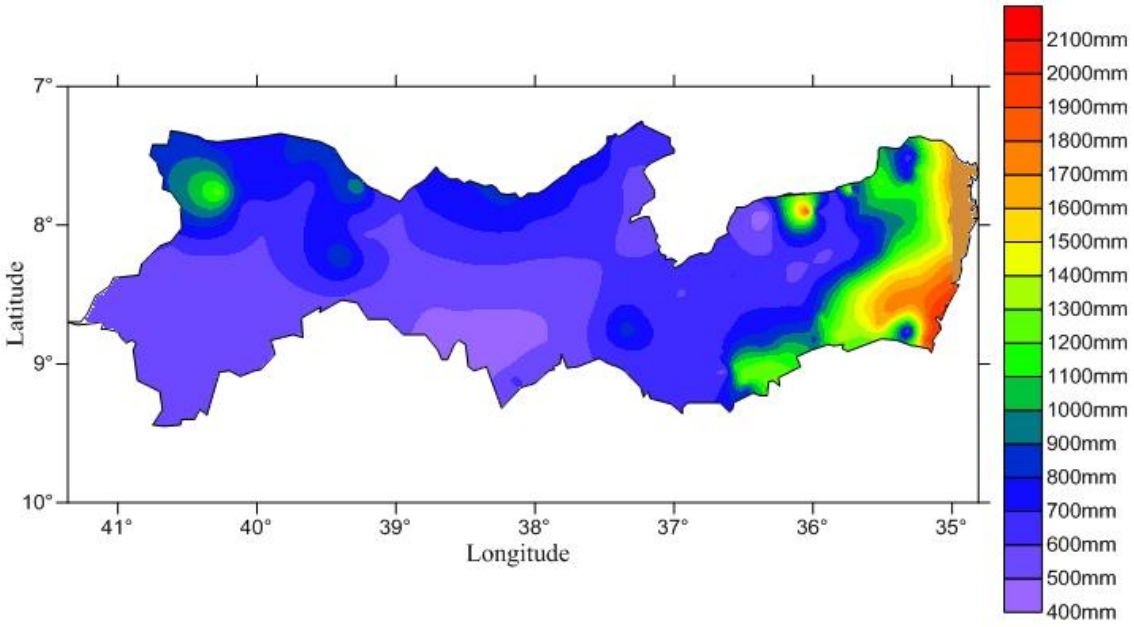

Figure No. 15: Annual pluviometry (mm) of the period between 30 and 100 years with observations for the state of Pernambuco. Source: Medeiros (2020).

Figure 16 represents the distribution of the five rainy months (March, April, May, June and July) of the State of Pernambuco. Distribution in the five study areas (Region of Sertão, Region of Alto Sertão, Central Region, Zona da Mata and Litoral). The rainfall ranges from 121.3 to 135.5 mm, totaling 66% of the annual rainfall value. In the border with Paraíba, the buoyancy of the indexes oscillate between 40 to 230 mm. In the coastal region, Zona da Mata and part of the central region, its oscillations occur between 90 and 250 mm. In the western sector the rainfall distribution is between 40 and 160 mm. On the border with Bahia and Alagoas.

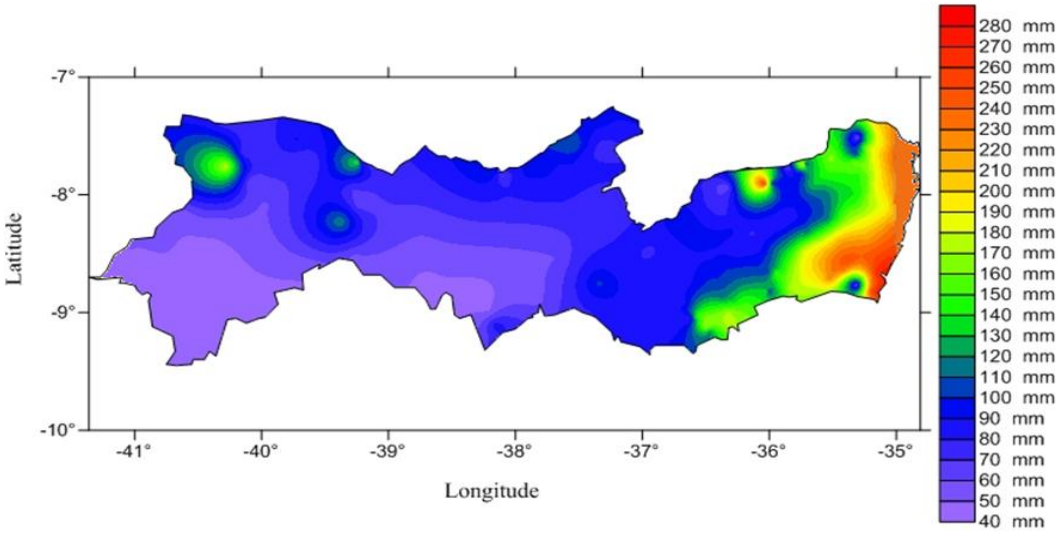

Figure No. 16: Pluviometry (mm) of the rainy months (March, April, May, June and July) for the state of Pernambuco. Source: Medeiros (2020).

Figure 17 shows the distribution of the dry period (September, October, November, December, and January) of the State of Pernambuco. In the upper extreme west and in isolated areas between the north of the Sertão region and the west of the high sertao region it is observed a nucleus of maximum precipitation oscillating between 15 a 45 mm in the other areas of this region prevails raindrops indices equal or inferior 20 mm. In the coastal region, Zona da Mata and the northern part of the central region fluctuations between 5 and 95 mm are recorded. These rainfall irregularities are caused by atmospheric instability and local and regional contributions.

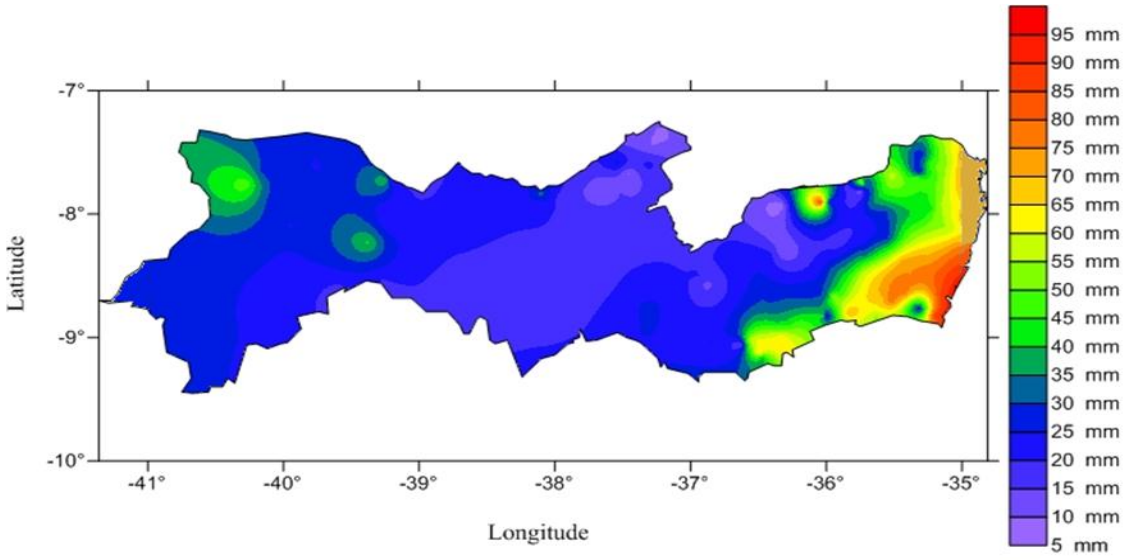

Figure No. 17: Pluviometry (mm) of the dry months (September, October, November, December, and January) for the state of Pernambuco. Source: Medeiros (2020).

Figure 18 shows the orographic distribution of the state and the altitudes located in the central region and part of the Zona da Mata and the upper extreme west show rainfall contributions by the windward contribution.

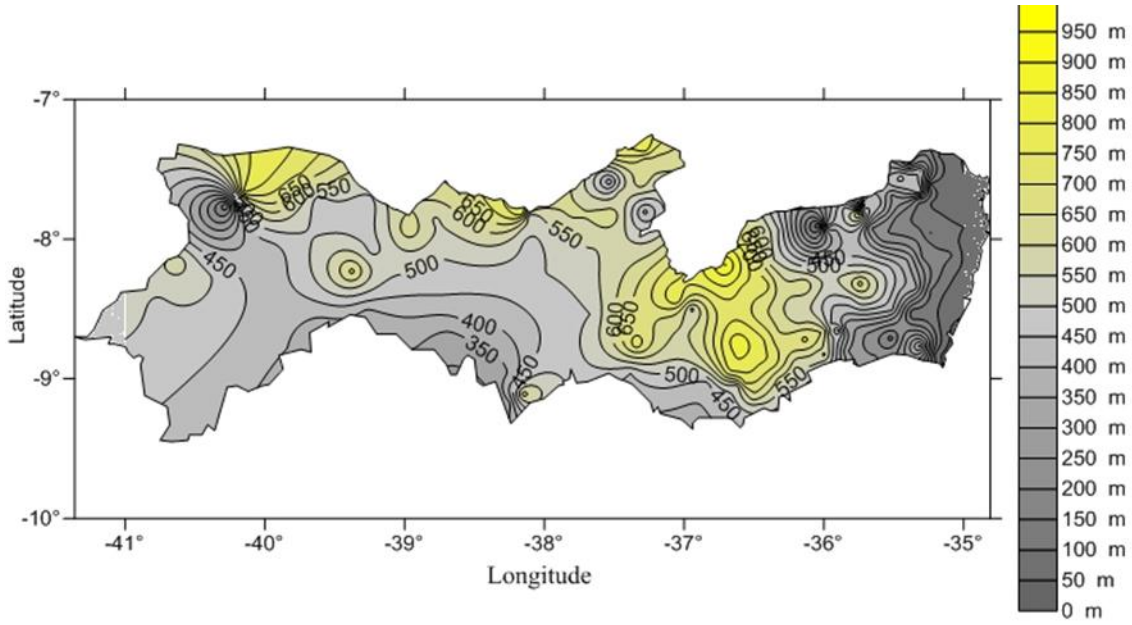

Figure No. 18: Altimetry chart of the state of Pernambuco.Source: Medeiros (2020).

Table No.1. shows the statistical variability of the parameters: maximum, minimum, mean, median, standard deviation and coefficient of variance of the precipitation for the study area.

Table No. 1: Precipitation: maximum, minimum, mean, median, standard deviation and coefficient of variance for the 187 municipalities of the state of Pernambuco. Source: Medeiros (2020).

Month	Maximum	Minimum	Average	Mean	Standard Deviation	Coefficient Variance
January	107.7	25.5	56.7	43.0	19.0	0.335
February	134.7	46.0	77.2	54.5	24.1	0.312
March	210.3	73.5	132.5	106.6	34.8	0.263
April	238.5	63.1	135.5	126.1	40.1	0.296
May	328.6	14.6	121.4	133.3	78.0	0.643
June	320.2	6.6	121.3	169.2	89.2	0.735
July	324.1	2.0	124.9	161.9	96.6	0.773
August	215.8	1.0	63.3	74.9	55.7	0.880
September	111.5	2.8	40.7	49.7	32.5	0.798
October	51.5	2.9	21.1	21.6	12.1	0.574
November	54.4	3.4	23.8	22.4	11.1	0.466
December	87.4	10.4	41.6	34.5	15.3	0.368
Yearly	2063.5	428.2	959.9	997.7	419.8	0.437

Statistical analyzes confirm an annual rainfall index of 959.9 mm presenting spatiotemporal irregularities in all areas. The maximum recorded rainfall occurred in the Island of Itamaracá with 2063.5 mm, with monthly maximum fluctuations ranging from 51.5 mm in October to 328.6 mm in May. The minimum annual precipitation was registered in the municipality of Santa Cruz do Capibaribe with 428.2 mm. The most probable precipitation values are shown in the median column.

CONCLUSION:

Rainfall variability is irregular and with wide fluctuation throughout the year and rainfall variability increases from the west to the east during the rainy season, which comprises the months of March, April, May, June and July corresponding to 66% of the annual index. In September, October, November, December and January corresponding to the dry months has an annual rainfall contribution of 18%.

During the dry months, the occurrence of isolated and low magnitude rainfall, these occurrences are related to the high evaporative power of the remaining forest shadows, local heat exchange and regional effects.

In the rainy months, high rainfall indices are observed, followed by short intervals of time, causing flooding, flooding, transshipment and silting of rivers, lakes, ponds, streams, dam levels, traffic disruption, social losses, and human deaths, and animal.

The rainfall trend in the entire State of Pernambuco is of extreme events with high magnitude and in a short interval of time, provoking disorder in subsistence agriculture.

Three categories of climates were detected: type A with the highest prevalence, BSh type with intermediate predominance and Am climate.

The altitude influences the rainfall indices of the Central, Zona da Mata and the extreme upper west due to the windward contribution.

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