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Decadal Precipitation Analysis of The Paraíba River Upper Course, Brazil

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ABSTRACT

The municipal pluviometric information, to the man in the field, can be used by the governmental actions in the planning and improvement of the production, being of relevant importance to minimize the eventual losses. Consequently, this kind of information can help the agroclimatic zoning determining the best practices according to the mesoregion. The objective of this work is to carry out the climatological analysis of the decadal precipitation of the basin of the upper course of the Paraíba River in the state of Paraíba, Brazil, and the 12 surrounding municipalities, using a historical rainfall series between the years of 1962 to 2019. Monthly and annual precipitation data series were used, collected from Superintendência do Desenvolvimento do Nordeste (SUDENE) and provided by the Executive Water Management Agency of the State of Paraíba. Despite the variability of the observed data, the series under study between the years was unified from 1962-2019. The large-scale El Niño/La Niña phenomena for decades in the form of adverse phenomena can have had their contributions in isolated decades and can have contributed to water shortages in almost all reservoirs. Irregularity between Niño (a) active in the state of Paraíba, between decades and years, has its local and regional variations causing environmental, regional, and local disasters such as prolonged droughts and extreme rains in short intervals. Local contributions and the Intertropical Convergence Zone can act more intensely in the northern sector and cause most of the rain above normal levels in some decades.

INTRODUCTION:

Agricultural production in the Brazilian semiarid region is highly dependent on rainfall, and, therefore, its variations cause serious damage to the state's agriculture. The Paraíba State has remarkable climatic characteristics, in its temporal space irregularities affecting its rain regime. These climatic conditions directly interfere in the production of food, making it necessary to increase the production and productivity of the cultures, but for this increase, technologies already adapted for each region are indispensable, as well as, research about new technologies (Menezes *et al*., 2010; Guedes Filho *et al*.,2010). According to Pinkayan (1966) and Silva (2007) living with the semiarid requires sustainable environmental management measures. Social initiatives may result in improving the living conditions of the populations, being of vital importance for the planning and development of water resources management in this region. The identification and characterization of periods of drought and anomalous precipitation is a feasible way and identify the regional climatic nuances.

Knowledge of the climatic conditions of a given region is necessary so that strategies can be established, aimed at the most appropriate management of natural resources, thus aiming at the search for sustainable development and the implementation of viable and safe agricultural practices for the various biomes in the region (Souza *et al*., 2010). Rainfall is one of the essential elements in agricultural activities. Based on the volume of precipitated rain and its distribution, it is possible to determine the types of agricultural activities in a given location (Arrae*et al*., 2009).

In the last decades, climate change and its consequences for humanity have been one of the biggest concerns of scientists around the world, especially about the factors responsible for climatic variability, which have been increasing since the middle of the 20th century. In the view of some researchers, human activities are responsible for part of these changes. However, a possible natural climatic variability must be taken into account, since the magnitude of the signal associated with it in the existing climate records, has not yet been well determined (IPCC, 1996; IPCC, 2001).

The study of the pluviometry of a given location is generally of interest to hydrology and meteorology, but the information generated in this regard is important in many areas of Engineering such as Environmental, Forestry, Agronomy, Agricultural, Water resources, among so many applications and uses. Other expected problems are the reduction in rainfall, which may reach a range of 60% of monthly values, this the water storage reservoirs will become obsolete, further restricting drinking water for the human, animal, and plant survival, such as fauna and flora, and some species may become extinct (Marengo, 2011).

Regarding precipitation, forecasts indicate that there should be a reduction in the tropical and subtropical regions and an increase in the average of the higher latitude regions. For the cerrado region where rainfall indexes fluctuate according to the large-scale phenomena Ñino (a) the historical averages even in times of rainy season fluctuate within and below normality. The spatial and temporal variability is influenced by the meteorological systems operating in the time; its trend is that low levels of rainfall persist in future scenarios. Santana *et al*., (2007) affirm in their study in Minas Gerais, in the semiarid region, that the variability of the rainy season depends solely and exclusively on the factors that cause rain.

Medeiros *et al*., (2014) analyzed the occurrences of extreme precipitation events in Campina Grande - PB, with daily rainfall data covering the years 1970–2010. The extreme events analyzed were those with the highest intensity of daily precipitation for the years studied. The results showed that there was a change in the behavior of precipitation occurrences from the 70s in the study area. There was an intensification in maximum precipitation with a greater number of events with precipitation values greater than 80 mm. There was, in general, no direct relationship between intensification in precipitation and occurrences with ENSO (El Niño - Southern Oscillation) phenomenon events. Extreme events were evident between the months of the rainy season, with 88% of occurrences and 12% in the dry season. Medeiros (2012) analyzed the climatology of precipitation in the municipality of Bananeiras - PB, in the period 1930-2011 as a contribution to Agroindustry and found that rainfall indicators are essential to agroindustrial sustainability.

The objective of this work is to carry out a climatological analysis of the decadal precipitation of the municipalities surrounding the hydrographic basin of the upper Parnaíba River, using a historical series of rainfall from the period 1962 to 2019, which can contribute to the decisions of sectors such as socioeconomic, agriculture, irrigation, energy production, water resources, and agricultural technicians and decision-makers in case of extreme events.

METHODOLOGY:

The Alto Paraíba River Hydrographic Basin (BHRAP), with an area of 20,071.83 km^2, between latitudes 6º51'31" and 8º26'21" South and longitudes 34º48'35" and 37º 02'15" West of Greenwich, is the second-largest basin in the State of Paraíba, as it covers 38% of its territory, housing 1,828,178 inhabitants which correspond to 52% of its total population. Considered one of the most important basins in the northeastern semi-arid region, it comprises the sub-basin of the Taperoá River and the Upper Course of the Paraíba River, the Middle Course of the Paraíba River, and the Lower Course of the Paraíba River. In addition to the high population density, the basin includes the cities of João Pessoa, the state capital, and Campina Grande, its second-largest urban center (Figure 1).

Figure No. 1: Location of the hydrographic basin of the Alto Paraíba River. Source: Medeiros (2020).

The basin is made up of regions afflicted by local, regional, and large-scale synoptic events causing rain, such as the Intertropical Convergence Zone (ITCZ) and the contributions of the Upper-Level Cyclonic Vortex systems (ULCVs) when in activity on Northeast Brazil (NEB). In addition, there are the effects of the northeast trade winds in conjunction with the effects of sea breeze, aided by the formation of the South Atlantic Cyclonic Vortices (SACV) and the formation of the instability lines (LI), the Dipole Pattern (PD) in the Ocean Tropical Atlantic and wave disturbances in the field of trade winds, providing events for droughts, floods, overflow of rivers, dams, muds, ponds, lakes, and streams. The flow of rivers at the headwaters is temporary, due to poor rainfall distribution. In the region of Paraíba, the rainy season with the increase in rainfall levels causes a significant increase in runoff in which the majority are dammed in large and medium dams and their excesso, after the damming flows, goes slowly into the ocean due to the relief and its basic courses of waters (Medeiros, 2019).

Floods have already caused damage and removals to several villages and towns. Historically the greatest floods occurred between the middle, low and high Paraíba stretches, being the occurrence of floods almost periodic, depending on the quality and quantity of the rainy season. It is known that in this area there are no flood containment systems and their flow rates are random, aided by relief (SUDENE, 1999).

The relief is generally quite diversified, consisting of different forms of relief worked and by different processes, acting under different climates and on rocks that are little or very different. Regarding geomorphology, there are three groups formed by the most significant climatic types: humid, sub-humid, and semi-arid. Current use and vegetation cover are characterized by forest formations defined as open tree shrubbery, closed tree shrubbery, closed treehouse, coastal board, mangroves, humid forest, semi-deciduous forest, Mata Atlântica (Atlantic forest), and sandbank.

It is noteworthy that in basins and water sources, there are impacts and degradation by pollution, through sewage networks and dumps near its banks and/or even thrown by riverside populations or transported by water currents after strong events of precipitations. The intense amounts of pesticides that have been used improperly in the agricultural sector, affect directly the areas of the basin, reservoirs, lagoon, lake, streams, and in the subsoil waters, contaminating them and directly affecting the human, animal, and plant (Maruyama *et al*., 2005).

The series of monthly and annual precipitation data collected by the Superintendência do Desenvolvimento do Nordeste (SUDENE, 1990) and provided by the Executive Water Management Agency of the State of Paraíba (AESA, 2020), were used. Despite the variability of the observed data, the series under study were unified between 1962-2019, making statistical calculations for the study area to have more information and unify the data to better simulate and obtain accurate information about the area of study. The decade-long variability was studied between municipalities to understand its oscillations and variability, thus taking into account the variability of rainfall dynamics in the study area (Table 1). It is assumed that for periods of less than 10 years, these fluctuations must be more intense.

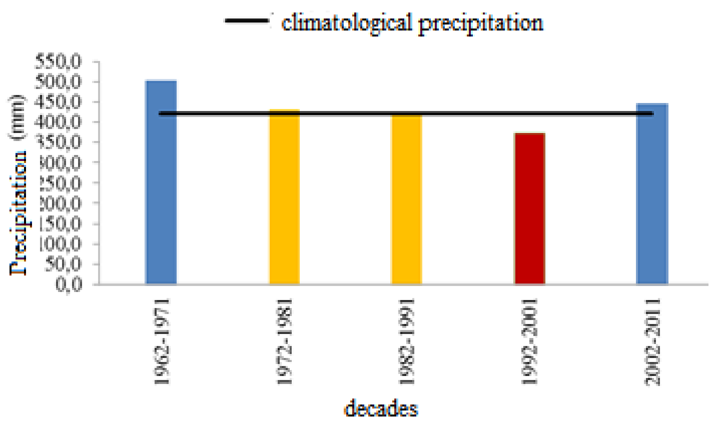
Table No. 1: Location of the municipalities and their geographic coordinates (latitude, longitude, and altitude) followed by the observation period of monthly and annual rainfall.Source: Medeiros (2021).

Municipalities/months	Latitude	Longitude	Altitude	Period
Barra de São Miguel	-7,45	-36,19	520	1962-2019
Cabaceiras	-7,29	-36,17	338	1926-2019
Camalaú	-7,53	-36,49	565	1962-2019
Caraúbas	-7,43	-36,29	460	1962-2019
Congo	-7,47	-36,39	500	1962-2019
Coxixola	-7,37	-36,36	465	1962-2019
Monteiro	-7,53	-37,07	590	1962-2019
Prata	-7,41	-37,04	600	1962-2019
São João do Tigre	-8,04	-36,5	616	1962-2019
São José dos Cordeiros	-7,23	-36,48	600	1962-2019
São Sebastião do Umbuzeiro	-8,09	-37,00	600	1962-2019
Serra Branca	-7,28	-36,39	450	1962-2019

RESULTS AND DISCUSSIONS:

The decadal distributions of the 12 municipalities that surround the basin of the upper course of the Parnaíba river are illustrated in Figures 2 to 13 below.

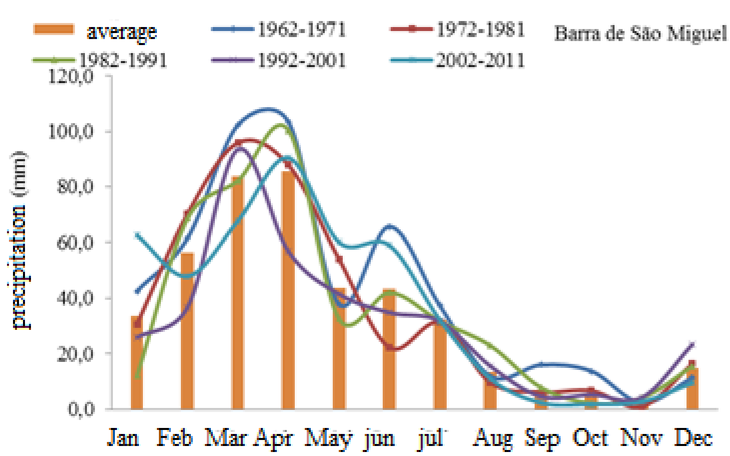
The annual distribution of precipitation for the municipality of Barra de São Miguel is shown in Figure 2a. The decade of 1992-2001 exhibit rains below the climatological stands out, the decades of 1962-1971 and 2002-2011 exhibit rains above the climatological one, and the decades of 1972-1981 and 1982-1991 exhibit rains within the normality.



a

Figure No. 2a: Climatic precipitation in 5 decades in the municipality of Barra de São Miguel. Source: Medeiros (2021).

Figure 2b shows the fluctuations of the monthly rainfall for the municipality of Barra de São Miguel. The months of December to June show significant irregularities in the rainfall indexes, ranging from 15 to 110 mm. In March and April, the greatest intensities of rain are concentrated, with fluctuations between 60 and 110 mm. These irregular fluctuations are correlated to the local and regional effects followed by the variability in the performance of large-scale phenomena acting like El Niño (a). Similar results were detected by Marengo *et al.*, (2015) and by Medeiros *et al.*, (2012).

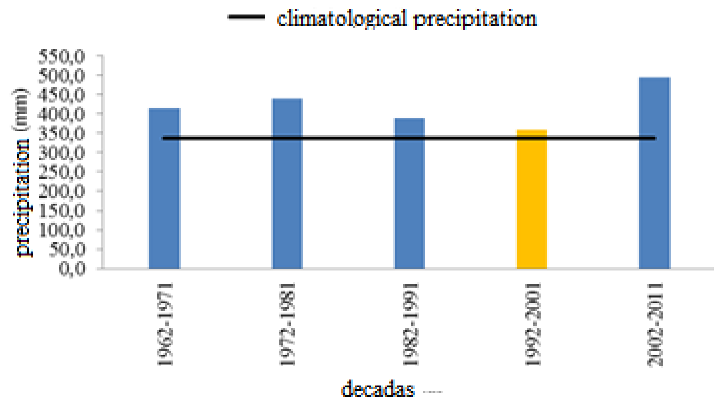


b

Figure No. 2b: Monthly rainfall in the five decades studied for the municipality of Barra de São Miguel. Source: Medeiros (2021).

In the months from August to November, there is a reduction in the precipitated indexes and their fluctuation occurs in the range of 0 to 15 mm, except for the decade of 1962 to 1971, which presented values higher than the other decades in September and October.

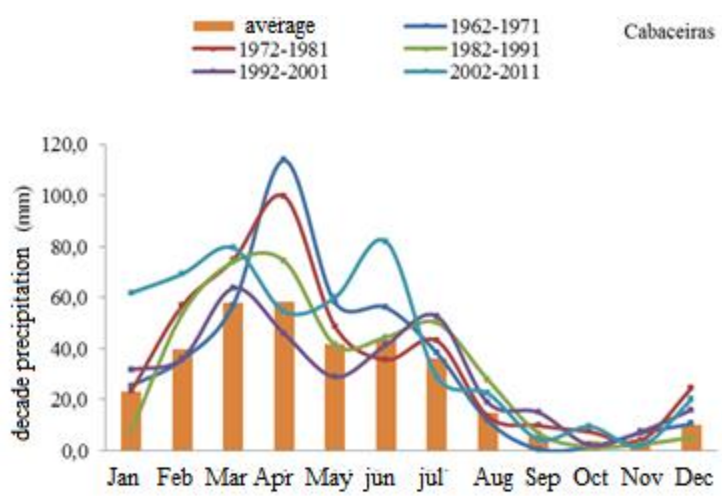
Figure 3a represents the annual totals of the decades and the climatological precipitation for the municipality of Cabaceiras. In the 1992-2001 decade, there were rains between climatological normality and in the other decades, rains were above climatological.



a

Figure No. 3a: Climatic precipitation in 5 decades in the municipality of Cabaceiras. Source: Medeiros (2021).

Figure 3b demonstrates the rainfall variability that occurred between February to May presented with rainfall rates above normal in the decades of 1962-1971, 1972-1981, and 2002-2011. Between August to November, practically every decade kept above the climatological.



b

Figure No. 3b: Monthly rainfall in the five decades studied for the municipality of Cabaceiras. Source: Medeiros (2021).

Figures 4a and 4b show the annual, monthly oscillations and climatology of the decade's understudy for the municipality of Camalaú. In figure 4a the annual totals of the decade of 1982-1991 form the climatological precipitation. In the decades of 1992-2001 and 2002-2011, the referred annual totals were below the average. In the decade of 1982-1991, the rains oscillated between the climatological normal, and in the decades of 1962-1971 and 1972-1981 the registered rains were above normal.

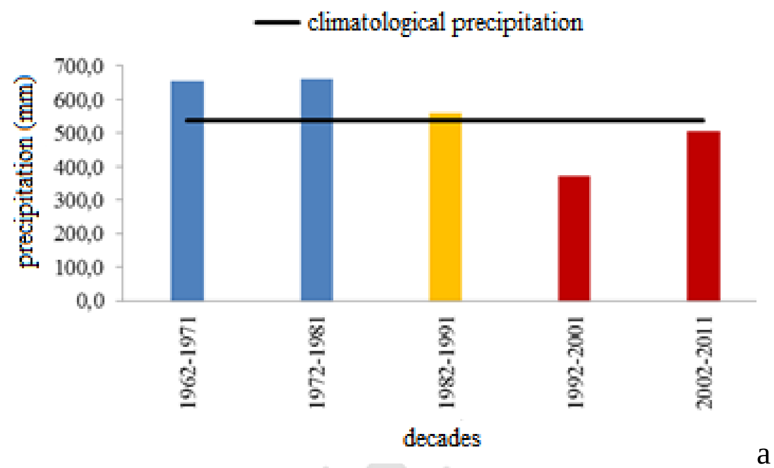
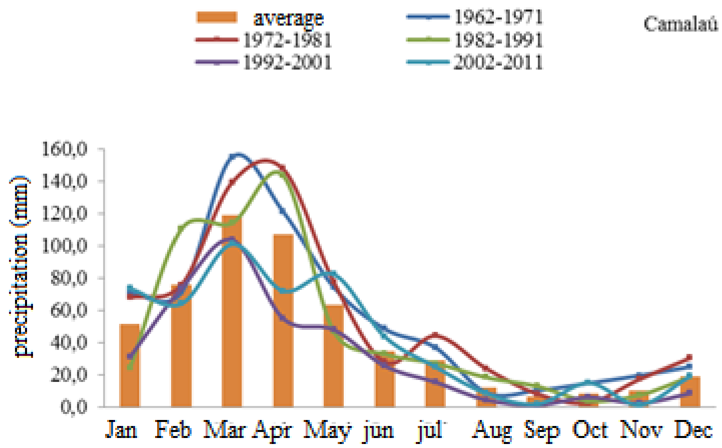


Figure No. 4a: Climatic precipitation in 5 decades in the municipality of Camalaú. Source: Medeiros (2021).

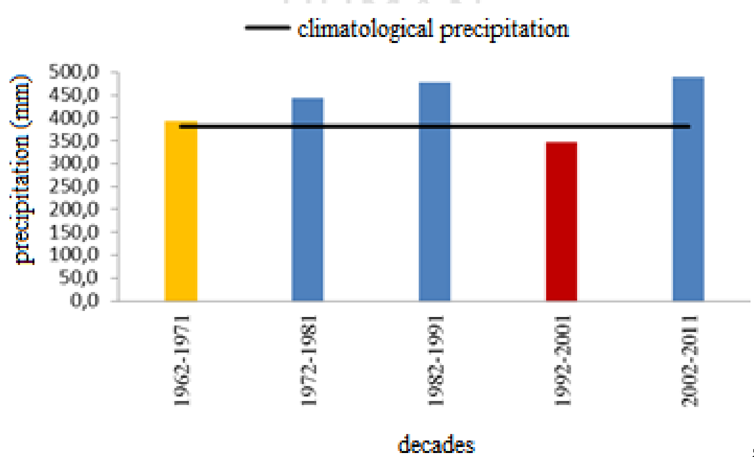
Figure 4b shows the variability of precipitation over the decades in the municipality of Camaláu. It is observed that in the months from January to May for the decades of 1962-1971, 1922-1931, and 1972-1981 the rains were above climatology and for the decade of 1982-1991, the rains were above climatology in February to May. From June to November, the climatology exhibits reductions in its indexes and any anomalous rain covers its expected values.



b

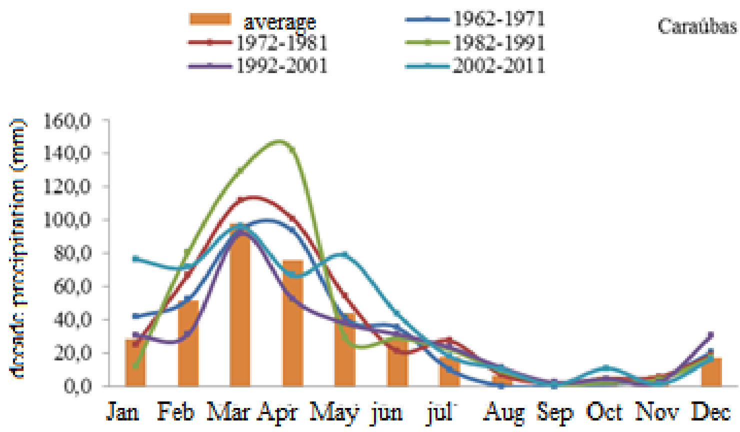
Figure No. 4b: Monthly rainfall in the five decades studied for the municipality of Camalaú. Source: Medeiros (2021).

The rainfall fluctuations between the decades 1962 to 2011 for the municipality of Caraúbas are shown in Figures 5a and 5b. In the five decades studied, one had rain close to climatology, three decades with rainfall above normal climatology, and one decade with rain below normal. Studies such as those by Marengo *et al.*, (2015) and by Medeiros *et al*., (2012) corroborate the results discussed.



a

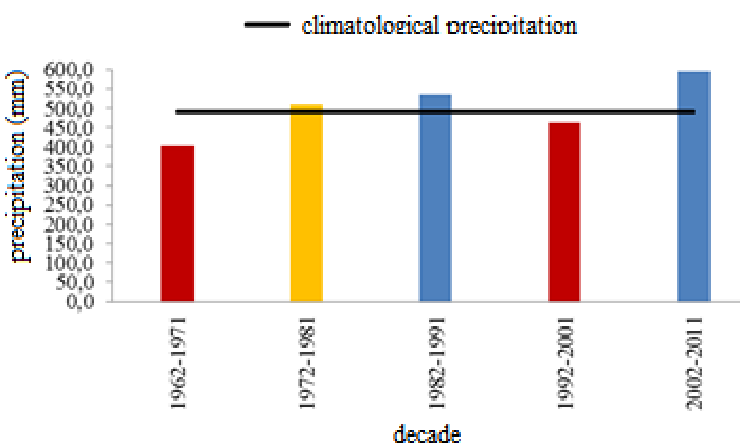
Figure No. 5a: Climatic precipitation in 5 decades in the municipality of Caraúbas. Source: Medeiros (2021).



b

Figure No. 5b: Monthly rainfall in the five decades studied for the municipality of Caraúbas. **Source: Medeiros (2021).**

Figure 6 shows the annual rainfall (a) by decade and climatological and (b) monthly oscillations for the municipality of Coxixola. In Figure 6a for the decades of 1962-1971 and 1992-2001, rainfall rates were recorded below the historical average. In the decade of 1972-1981 the rainfall occurred was equal to the average, and for the decades of 1982-1991 and 2002-2011, the rainfall rates exceeded the historical average. Such variability in irregularities is following studies by Marengo *et al*., (2004).



a

Figure No. 6a: Climatic precipitation in 5 decades in the municipality of Coxixola. **Source: Medeiros (2021).**

Decadal variability of rainfall for Coxixola is shown in Figure 6b. In both decades between August and December, the rainfall rates were practically the same, except for the decade of 2002-2011 for October, and for the decade of 1992-2001 comprised between August and September that surpassed the climatology. In February and March, the decades 1992-2001 stand out. In the 2002-2011, 1972-1981, and 1982-1991 decades the rainfall rates appear above climatology. A study by Holanda *et al*.,(2016) corroborates the results discussed here.

In studies by Barbieri (2007) and Sachs (2015), four decades ago, these authors realized that the finitude of natural resources accompanied by the fragility of the planet's ecosystems would not support the pace of socioeconomic increase imposed by humanity. This statement corroborates the results discussed in this article.

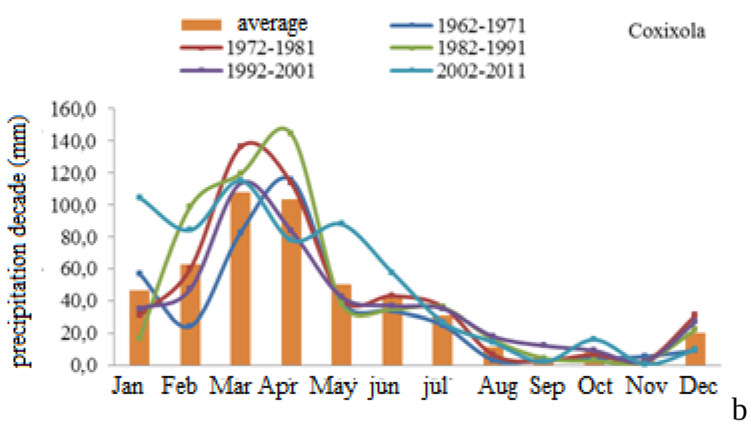
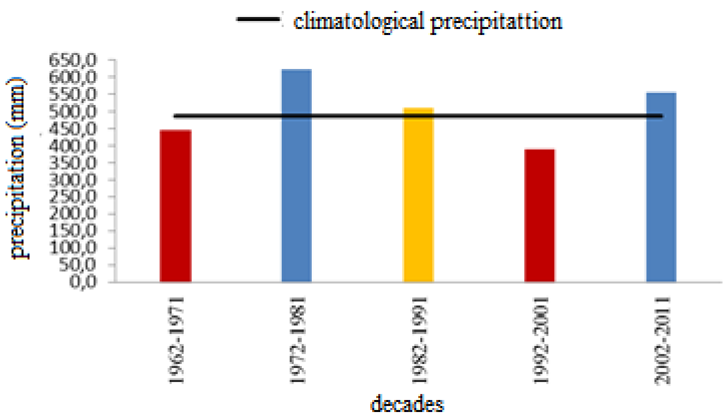


Figure No. 6b: Monthly rainfall in the five decades studied for the municipality of Coxixola. Source: Medeiros (2021).

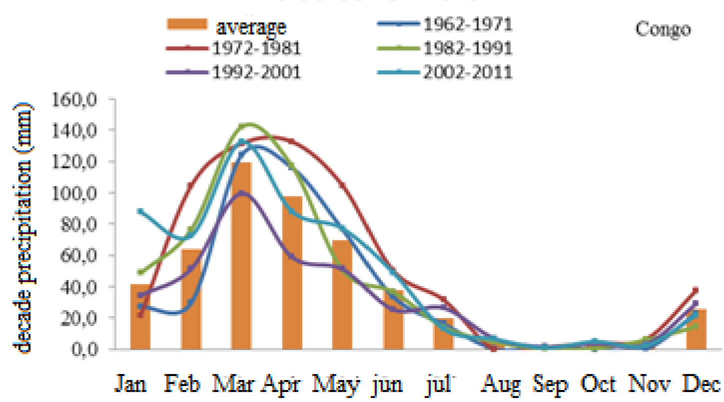
Decadal oscillations for the municipality of Congo are shown in Figures 7a and 7b. In Figure 7a, the decades of 1962-1971 and 1992-2001 occurred precipitations below the normal. In the other decades, the rains were above normal. These results corroborate the study by Nunes (2016).



a

Figure No. 7a: Climatic precipitation in 5 decades in the municipality of Congo. Source: Medeiros (2021).

In Figure 7b, between August and November, the rainfall rates were equalized. In the months from February to April, there were irregularities in the rainfall rates in the municipality of Congo, and the decades 1992-2001 and 2002-2011 presented as the lowest rainfall rates. These irregularities are following the studies by Medeiros, *et al*., (2016), (IPCC, 2014), and Medeiros (2018).



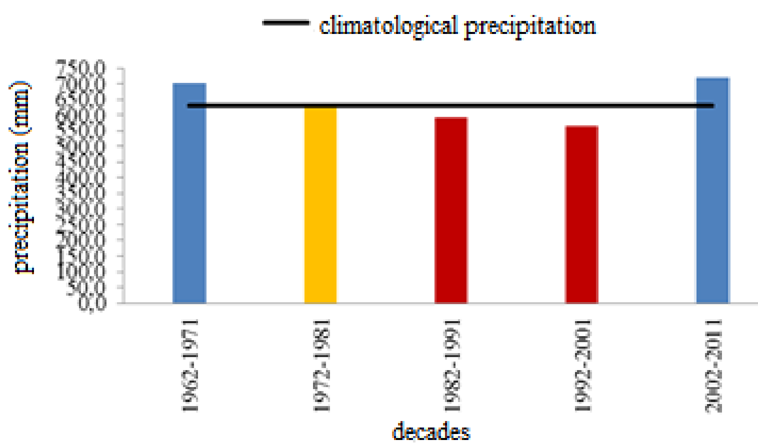
b

Figure No. 7b: Monthly rainfall in the five decades studied for the municipality of Congo. Source: Medeiros (2021).

Figure 8 shows the rainfall fluctuations for a decade and climatological (a) and monthly (b) for the municipality of Monteiro. Can be observed two decades above and two decades below the historical average and one decade between normality (Figure 8a).

The rainfall irregularities recorded in Figure 8a, with emphasis on the decades 1992-2001 and 1962-1971, show that their decadal rainfall rates were below normal.

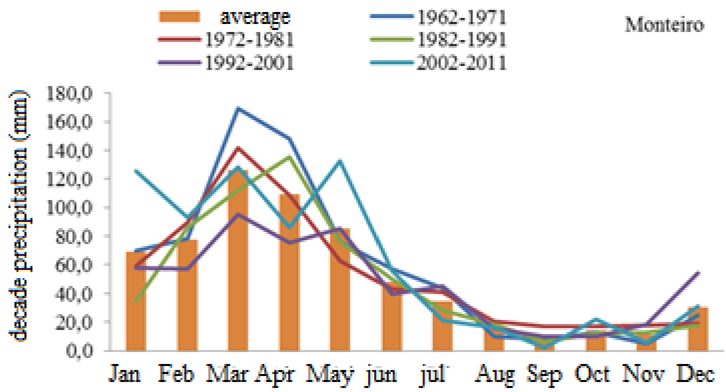
The rainfall irregularities caused by El Niño (a) were not the cause of the variability in Monteiro. Studies like that by Medeiros (2018), França, Ferraz, Medeiros, Holanda & Rolim Neto (2018) corroborate the discussions presented here. These irregularities are linked to the rain-causing systems in the study area, followed by local and regional contributions that cause irregular and moderate intensities of rainfall (Figures 8a and 8b). Figure 8 a appear three decades with rainfall above climatology and two decades with rainfall levels below normal.



a

Figure No. 8a: Climatic precipitation in 5 decades in the municipality of Monteiro. **Source: Medeiros (2021).**

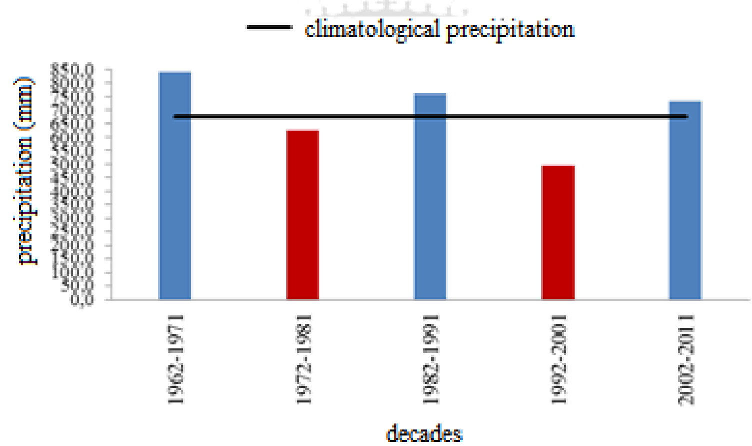
Figure 8b shows the decadal irregular for the municipality of Monteiros. The 1972-1981 decades stand out; 1992-2001; with rainfall index higher than historical averages for March and April and averages equal to decades for the other decades.



b

Figure No. 8b Monthly rainfall in the five decades studied for the municipality of Monteiro. Source: Medeiros (2021).

Figure 9 shows rainfall fluctuations for a decade and climatological (a) and monthly (b) for the municipality of Prata. There are two decades above and two below the historical average and one decade between normality (Figure 9a).



a

Figure No. 9a: Climatic precipitation in 5 decades in the municipality of Prata. Source: Medeiros (2021).

There are irregularities observed in Figure 9b with emphasis on the1992-2001, 2002-2001, and 1972-1981 decades, which registered rainfall levels below the historical average.

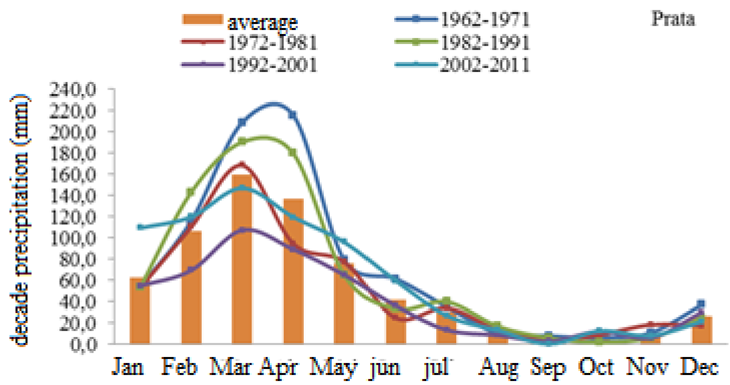


Figure No. 9b. Monthly rainfall in the five decades studied for the municipality of Prata. Source: Medeiros (2021).

In Figure, 10a appear five decades of rainfall are recorded in the municipality of São João do Tigre, with rainfall above the climatological normal, in four of them. In Figure 10b, the decades of 1962-1971 stand out. In the 1972-1981 decade, from February to May, occurred rain above normal. In the decade of 1982-1991 in February, April and May, the remaining decades see the temporal space irregularities with indexes below the average. This variability is following the studies of IPCC (2014) and IPCC (2007).

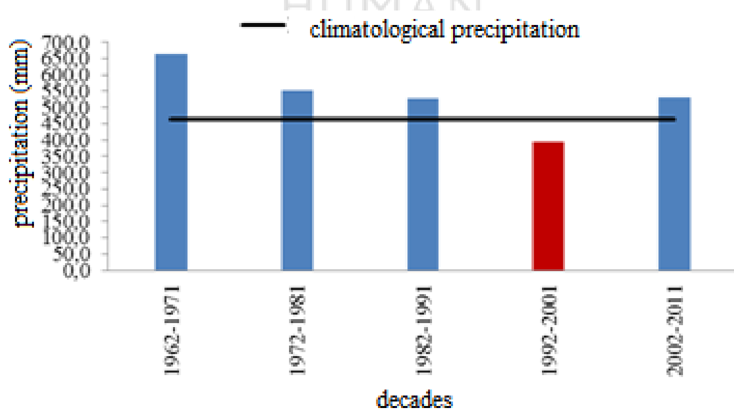
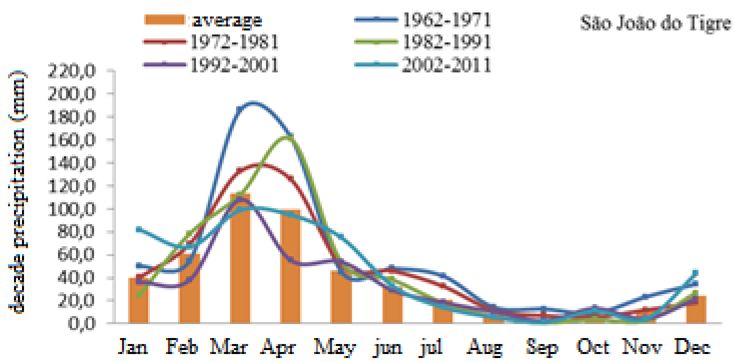


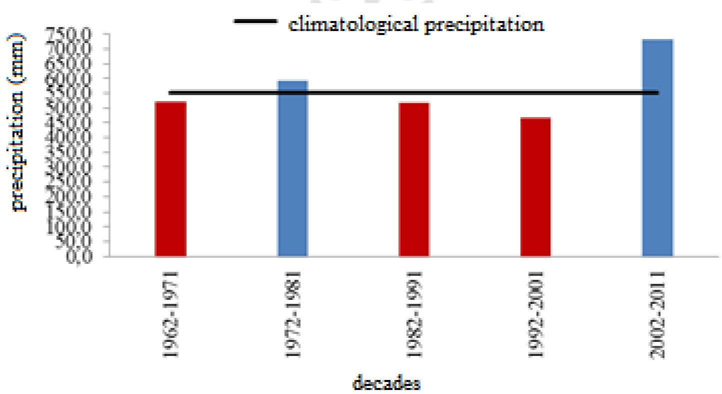
Figure No. 10a: Climatic precipitation in 5 decades in the municipality of São João do Tigre. Source: Medeiros (2021).



b

Figure No. 10b: Monthly rainfall in the five decades studied for the municipality of São João do Tigre. Source: Medeiros (2021).

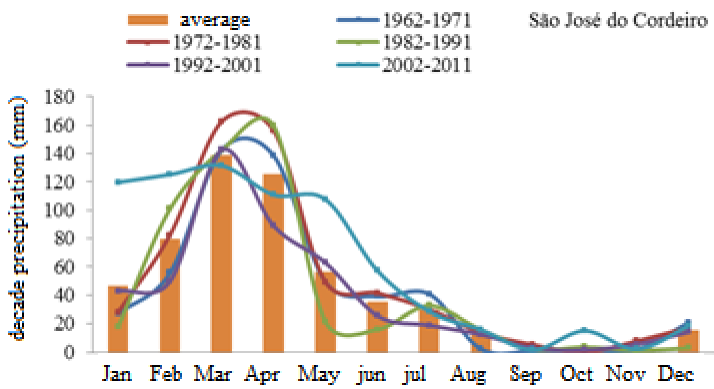
In Figure 11,annual precipitation per decade and climatological (a) and monthly (b) for the municipality of São José dos Cordeiros. In the decades 1962-1971, 1982-1991, and 1992-2001 the rainfall rates were below normal. In the 1972-1981 and 2002-2011 decades the rainfall rates surpassed climatology (Figure 11a).



a

Figure No. 11a: Climatic precipitation in 5 decades in the municipality of São José dos Cordeiros. Source: Medeiros (2021).

Figure 11b shows rainfall fluctuations above the historical, between February and April, except for the decade 2002-2011. Between July and December, the rainfall indexes were the same, except for the decade of 2002-2011 for October.

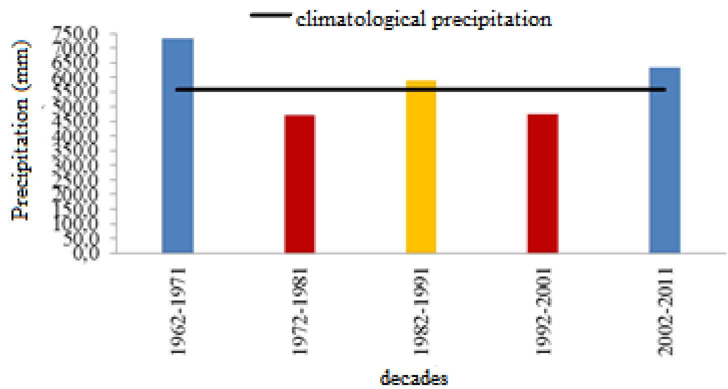


b

Figure No. 11b: Monthly rainfall in the five decades studied for the municipality of São José dos Cordeiros. Source: Medeiros (2021).

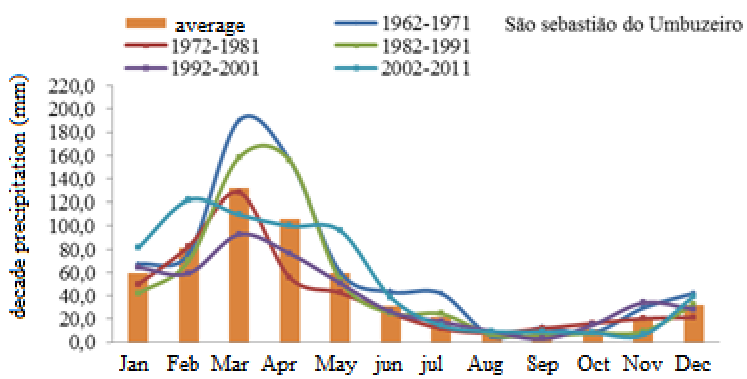
Studies by Medeiros *et al*., (2016), and França*et al*., (2018) corroborate the results in the discussions of the present work.

Figures 12a and 12b show annual rainfall fluctuations (a) per decade and climatological and (b) monthly for the municipality of São Sebastião do Umbuzeiro. Figure 12a shows the decadal rainfall fluctuations and their irregularities. In the decades 1972-1981 and 1992-2001 the rainfall indexes flowed below climatology; the decades 1962-1971 and 2002-2011 registered rainfall indexes higher than climatology; in the decade 1982-1991, the rainfall indexes were equal to climatic intensities. The rainfall variability recorded in March and April for the studied area shows irregularities for both decades. Between July and December, the rainfall rates were practically equal (Figure 12b). The rainfall irregularities caused by El Niño (a) were not the cause of their variability. Studies like that by Medeiros (2018) andFrança*et al*., (2018) corroborate the discussions presented here.



a

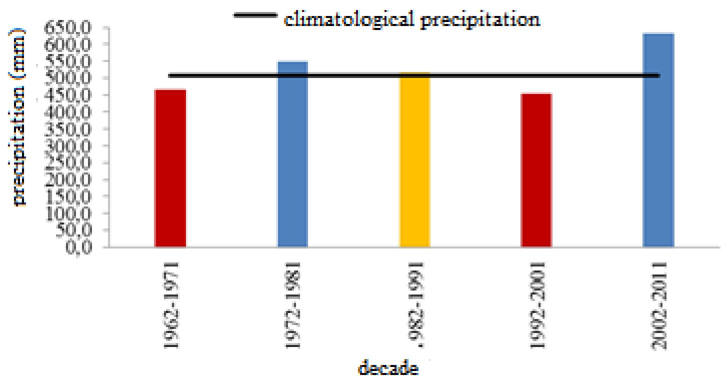
Figure No. 12a: Climatic precipitation in 5 decades in the municipality of Umbuzeiro. Source: Medeiros (2021).



b

Figure No. 12b: Monthly rainfall in the five decades studied for the municipality of São Sebastião do Umbuzeiro. Source: Medeiros (2021).

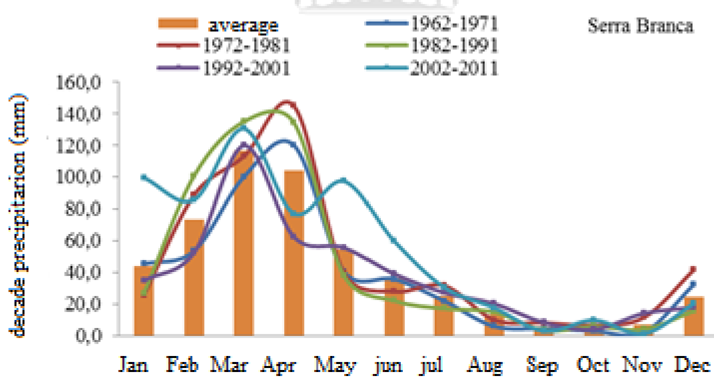
The decade's understudy for the municipality of Serra Branca shows two decades with rainfall below normal, two decades with rainfall above the historical average, and the decade of 1982-1991 with rainfall between normal (Figure 13a).



a

Figure No. 13a: Climatic precipitation in 5 decades in the municipality of Serra Branca. Source: Medeiros (2021).

Figure 13b shows the inter-irregular irregularities that occurred in the municipality of Serra Branca. From May to January the decade precipitation flowed close to or below the climatological average, except the decade of 1962-1971. The decades 1982-1991 and 2002-2011 present rains above normal. These variabilities are linked to large-scale phenomena, local effects, and heat exchange.



b

Figure No. 13b: Monthly rainfall in the five decades studied for the municipality of Serra Branca. Source: Medeiros (2021).

CONCLUSIONS:

The large-scale El Niño/La Niña phenomena for decades in the form of adverse phenomena can have had their contributions in isolated decades and can have contributed to water shortages in almost all reservoirs.

The irregularity between Niño (a) active in the state of Paraíba, between decades and years, has its local and regional variations causing environmental, regional, and local disasters such as prolonged droughts and extreme rains in short intervals.

Local contributions and the Intertropical Convergence Zone can act more intensely in the northern sector and cause most of the rain above normal levels in some decades.

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