IJSRM
INTERNATIONAL JOURNAL OF SCIENCE AND RESEARCH METHODOLOGY
An Official Publication of Human Journals

Human Journals
Research Article
February 2021 Vol.:17, Issue:4

The Influence of ENSO in the Climate Elements of the Climate Water Balance in Lagoa Seca – Paraíba, Brasil

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Submitted: 10 January 2021
Revised: 30 January 2021
Accepted: 20 February 2021

HUMAN JOURNALS

www.ijsrm.humanjournals.com

Keywords: Climatic Variables, Anomalies, Meteorological Contributions, Water Deficiency and Surplus.

ABSTRACT

The dependence of fruit and vegetables on the climate has been going on for a long time, hence the importance of understanding the climatic elements: rains, winds, temperature, among others, the soil, and its productivity. Drought - Paraíba, using analysis on the variables: precipitation, temperature, evapotranspiration, evaporation, deficiency, and water surplus in the municipal area. A series of monthly and annual data on precipitation and average temperature for the period 1981-2019 was used; the water balance was calculated according to the methodology of Thornthwaiteand Mather, generating the variables: evapotranspiration, evaporation, deficiencies, and water surpluses. The high fluctuations in temperatures and anthropic interference contributed positively to the high rates of evapotranspiration causing water stress in fruit and vegetables where the producer had to use the irrigation system to reduce these deficiencies. The results prove that the El Niño (a) climatic phenomena do not compromise the climatic dynamics causing significant changes in the rain regime, records of increase and reduction of the rain volume in periods of El Niño and La Niña, respectively, were detected without the occurrence of major impacts. It is concluded that the climatic phenomena El Niño (a) exerted a relative and seasonal influence on the maximum daily precipitation isolated from the study area.

INTRODUCTION:

Ortolani *et al*. (1987) stated that among productive activities, agriculture stands out as being the most dependent on climatic elements and these are responsible for 70% of the final variability of agricultural production. This linkage includes the seasonal fluctuations of the climatic variables, which are determinant for the seasons, and the times of better conditions and of lower risks for the development of cultivars.

Medeiros *et al*. (2016a) analyzed the oscillations of El Niño and La Niña and their influence on the number of rainy days in the municipality of Bom Jesus do Piauí. For the Northeast, the periods of El Niño are associated with the scarcity of rain and La Niña, in general, with abundant rainfall, while in the South and Southeast regions conditions are observed with opposite events. The El Niño south oscillation (ENOS) considerably influences the climate in places where it operates, with long periods of drought and total rainfall above historical normals (Romero, 2013).

In years of the El Niño episode, 52% of the rainfall indexes in the municipality of Mossoró - RN reached below normal climatic averages. Pereira *et al*. (2011) showed a relationship with the years in which the La Niña episode occurred and observed that the rainfall rates were above average by 46%.

In the last decades, the presence of droughts and floods has been increasing, across the Globe, confirming that the interannual and decadal events that are registered on a synoptic scale, linked to climate changes, have become more frequent and intense (Marengo, *et al*., 2016).

Medeiros (2018) showed that there is a lack of studies on the correlation of rainfall with large-scale climatic phenomena, such as El Niño and La Niña. The author analyzed the influence of rainfall variability and the number of rainy days in the city of Recife - PE, and their relationship with the phenomena El Niño and La Niña. According to this author in the dry four-month period, which corresponds to October, November, December, and January, there is no interference from the El Niño and La Niña episodes in the increases and decreases in the days with rain occurrences, which are directly linked to local factors such as breeze, convective movements and line of instability. The phenomena El Niño and La Niña have little influence on the days with rain occurring in Recife - PE, because in the months with the greatest intensity of these episodes, the trend curves showed no increase or decrease. Coherent results were found in the studies by Medeiros *et al*. (2016) for the municipality of Bom Jesus do Piauí.

Duarte *et al.* (2020) in their studies identified the rainfall variability and its temporal and spatial oscillations using the quantile technique, generating water balance for different rainfall regimes (dry; very dry; rainy; very rainy; normal) for the period 1960-2018. The authors observed in the calculations of the regional water balances, the irregularities due to the absence or the aid of the factors that provoke rains in the studied periods. Most water surpluses were recorded outside the regional rainy season and were caused by extreme events with high intensity and short duration. The water deficiencies were irregular for the periods studied and are linked to the intensities of the systems that cause and/or inhibit regional rains.

Marengo (2008) stated that due to the performance of the ENOS episode, the Amazon basin registered an intense drought with rainfall peaks below 60 mm in 2005. However, in 2009, rainfall levels between 100 and 200 mm above normal were found. Santos and Ramos (2010) stated that the Southern Oscillation (IOS) and Nests Indices can contribute considerably to the prediction of extreme rain and drought events in a given region.

França *et al*. (2018) calculated the climatological water balance for the municipalities of São Bento do Una and Serra Talhada and investigated the influence of the phenomena El Niño (2012, 2016) and La Niña (2008, 2011) on the distribution of rainfall through analysis of the water balance extract. They found that the El Niño episode influenced the rainfall rates of the cities studied. In the La Niña episode, the distribution of these indices was irregular, reflecting on the water balance.

In the climatic regimes of a given location, it is not uncommon to see severe climatic fluctuations, which may interfere with the accredited climate model for a specific period. These oscillations originate between the elements of atmospheric circulation coming from the movements in the atmospheric pressure gradients. These gradients are responsible for the development of the winds, which transform the global circulation structure over South America, originating diverse phenomena such as the large-scale episodes El Niño and La Niña. The authors recognize that the spatial variability of rainfall is essential for monitoring water resources and their development, aiming at better urban planning (Filho *et al*, 2013).

Oliveira, *et al*, (2015) stated that the reduction in rainfall rates under the El Niño episode in Northeast Brazil (NEB) is a natural climatological phenomenon that occurs with the increase in rainfall rates in the southern regions of Brazil.

Silva *et al.* (2017) studied the rainfall fluctuations on the performance of the El Niño (a) climatic episode with the rainfall indexes in the municipality of São Bento do Una - PE, which has been facing a water crisis today. The authors verified anthropic interference in the current drought situation in the region, and further studies are needed to identify anthropic factors, and thus, solutions for drought in the municipality are proposed.

The present work aims to investigate the oscillations of the El Niño and La Niña episodes in the climate of Lagoa Seca - Paraíba, using analysis in the variables precipitation, temperature, evapotranspiration, evaporation, deficiency, and municipal water surplus.

MATERIAL AND METHODS:

Lagoa Seca is located in the Microregion of the same name and Mesoregion Agreste Paraibano. It has a territorial area of 109 km², representing 0.1937% of the State, 0.007% of the Northeast Region and 0.0013% of the Brazilian territory. The city is limited by the municipalities of Campina Grande, Massaranduba, Matinhas, São Sebastião de Lagoa de Roça, Montadas, Puxinanã and Esperança. The municipal headquarters is positioned at Latitude 07º 10 '15' 'S; Longitude 35º 51 '13' 'W, with an altitude of 634 meters (Figure 1).

Figure No. 1: Location of Lagoa Seca municipality within the state of Paraíba. Source: Medeiros (2020).

According to Köppen (1928) and Köppen and Geigen (1931), the climate is type As classified as hot and humid Rainy tropical. Studies such as that by Alvares *et al.* (2014) corroborates the type of climate for the studied area. The climatic classification of Thornthwaite (1948); Thornthwaite *et al*., (1955) is of the sub-humid, megathermic type C1ADa ', with little or no excess water and ETP with 29.66% of the potential annual evapotranspiration concentrated in the hottest quarter of the year (November, December, and January). Thermal amplitudes vary according to latitude, altitude and the degree of continentality (effects of mountains, valleys, hills, orography, among others).

The pluvial regime falls within the range of isolates (line that joins the same amount of precipitation) from 1,100 mm year1 to 1,200 mm year1. (Medeiros, 2016). The rains start in the second half of March, increasing their volume in the first days of April and extending until the first half of August, with the rainy quarter from May to July. The factors causing rain are the formation of lines of instability on the coast and transported inland by the northeast trade winds, the development of convective clusters, arising from the heat stored on the surface and transferred to the atmosphere, orography, contributions to the formation of cyclonic vortices, and having as a main system the positioning of the Intertropical Convergence Zone. Normally the rains have moderate intensity followed by irregularities due to the failures of the meteorological systems at work.

For the development of this article, monthly and annual rainfall data series were used for the observed data period (1981-2019), provided by the Executive Water Management Agency of the State of Paraíba (AFSA, 2020). The average temperature values were generated by the Estima_T software (Cavalcanti, *et al*., 1994; Cavalcanti *et al*., 2006), referring to the same rainfall period.

With the temperature and average annual precipitation data, the climatological water balance (BHC) was calculated according to the methodology of Thornthwaite (1948); Thornthwaite *et al*., (1955), to generate the variables: evapotranspiration, evaporation, water deficiencies and surpluses year by year of the series studied. The dispersion analysis to the average values was used in the evaluation of the referred elements to the phenomena E1 Niño and La Niña. The standard deviation of the mean, calculated with the complete series of data, was used for the evaluation of the extreme values and climatic anomalies, characterized as a variation greater than the standard deviation of the analyzed elements.

Table No.1: Classification of the intensity of the Oceanic El Niño La Niña

Event	Index El Niño La Niña Ocean	Intensity
El Niño	0.5 to 0.9	Weak
	1.0 to 1.4	Moderate
	≥ 1.5	Strong
La Niña	-0.5 to -0.9	Weak
	-1.0 to -1.4	Moderate
	≥ -1.5	Strong

RESULTS AND DISCUSSION:

Table No. 2 shows the years of performance of the phenomena el nino and La Niña their classifications.

Table No. 2. Total annual rainfall and its classification of El Niño and La Niña events. Source: CPTEC / INPE. (2020).

Year	Total Annual	El Niño	LaNiña	Year	Total Annual	El Niño	LaNiña
1981	856,0	Weak		2001	1042,5		Moderate
1982	867,0	Strong		2002	1010,8	Moderate	
1983	1091,1	Strong		2003	998,7	Moderate	
1984	1182,2		Strong	2004	1697,7	Strong	
1985	1657,0		Strong	2005	971,5	Strong	
1986	1522,4	Moderate		2006	783,1	Weak	
1987	1236,7	Moderate		2007	844,2		Strong
1988	1251,5	Moderate		2008	1078,7		Strong
1989	928,5		Strong	2009	1256,4		Strong
1990	1088,8	Strong		2010	971,4	Weak	
1991	1078,0	Strong		2011	1797,1		Strong
1992	1433,4	Strong		2012	748,4	Moderate	
1993	607,5	Strong		2013	994,5	Moderate	
1994	1667,5	Moderate		2014	1010,6	Moderate	
1995	955,4		Weak	2015	807,1	Very Strong	
1996	1202,0		Weak	2016	809,3	Very Strong	
1997	961,1	Strong		2017	856,4		Moderate
1998	586,0		Weak	2018	938,7		Strong
1999	817,7		Weak	2019	1077,0		
2000	1584,4	Weak		2001	1042,5		

Figure 2 shows the fluctuations in annual precipitation, historical precipitation and anomalies in years of E1 Niño and La Niña in Lagoa Seca - PB. The average annual precipitation for the El Niño episode period was 1063.7 mm and for the La Niña episode, 1112.8 mm. There was a 4.61% reduction in rainfall for El Niño to the rains in the La Niña period. The highest annual rainfall magnitudes for El Niño were recorded in 1986 (1522.4 mm), 1992 (1433.4 mm), 1994 (1667.5 mm) and in 2004 with 1697.7 mm. In La Niña episodes, the highest rainfall rates were 1657.0 mm in 1985, 1584.4 mm in 2000, 1256.4 mm in 2009 and in 2011 with 1797.1 mm. Analyzing the oscillations of the El Niño and La Niña years, with the historical average of their respective elements, it is clear that their fluctuations were not between the averages. Fluctuations in rainfall anomalies for both events do not show major fluctuations. In general, they presented a balance in their anomalous indexes (Figure 2). It should be noted that the difference between the highest anomalous values from La Niña to El Niño is 5.53%, and it can be said that the rainfall indexes were among normalities. Study like Marengo, *et al*., (2011); Medeiros (2016b) corroborate the values presented in this study.

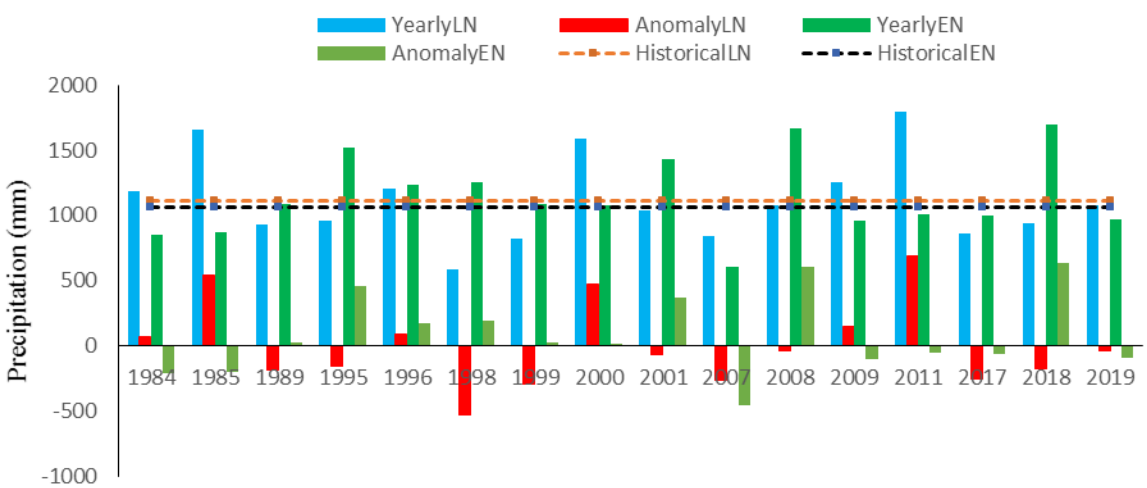

Figure No. 2: Fluctuations in annual precipitation, historical precipitation and anomalies in E1 Niño (EN) and La Niña (LN) years in Lagoa Seca - PB, for the period from 1981 to 2019. Source: Medeiros (2020).

The studies by Kayano *et al*. (1986) focus on the interannual variability of precipitation in the north and northeast regions of South America. They have associated these variabilities to the ENOS phenomenon, and positive (negative) anomalies of the sea surface temperature in the

Pacific Ocean, associated to the episodes El Niño and La Niña, producing large-scale anomalous circulations in the atmosphere, generating significant impacts on the climate of the Atlantic region and South America. In this same context, Marengo (2006) apud Gonzalez, Andreoli, *et al*., (2013) observed, for the period 1979-2000, reductions in precipitation, runoff, and moisture convergence in El Niño years, and increases in these variables in La Niña years.

Figure 3 shows the fluctuations in mean, maximum and minimum absolute rainfall values in E1 Niño and La Niña years in Lagoa Seca - PB for the period from 1981 to 2019. The maximum fluctuations in average rainfall between El episodes Niño were -5.86% below the LN rainfall index in March; In April, it rained 40.5% above El Niño indexes; in June, it dropped -26.2% of the La Niña value and in July, it precipitated 30% more than the El Niño values.

The maximum absolute values recorded in El Niño episodes were for January 2004 with 368.3 mm; June 1994 with 388.5 mm and in July 2015 with 331.4 mm. For the La Niña episode, absolute maximum values were recorded in May 2011 with 509.2 mm; June 2000 with 303.0 mm and July 2011 with 425.4 mm. With extreme events for the absolute minimum precipitation values for the El Niño episodes, they were recorded in May with 33 mm in 1987; 40.4 mm in June 2016 and 37.2 mm in July 2016. For La Niña there were minimal extreme rains in March 2017 with 41.9 mm, in June 1998 with 37, 2 mm and in 2018 in July with 53.8 mm.

According to Medeiros, *et al.*, (2013) the highest precipitation rates due to the La Niña phenomenon are due to the precipitation trends that it presents above the average, in comparison with El Niño periods that may show a reduction between 60-65 % in the rainfall index in the transition region between the cerrado, cerradão and semi-arid Piauí climate.

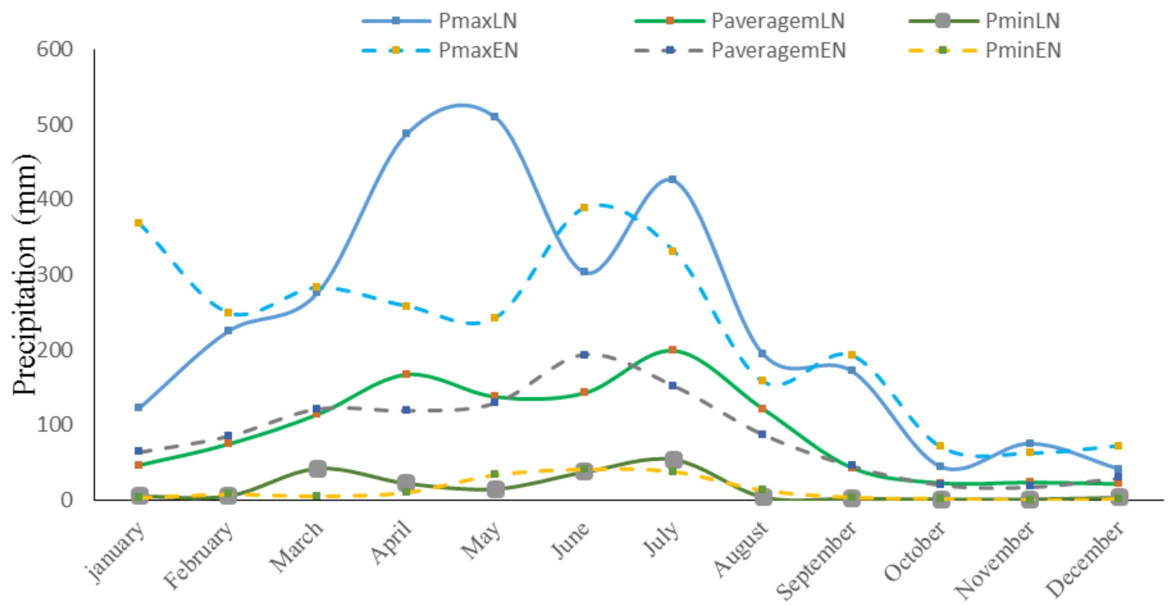

Figure No. 3: Fluctuations in mean, maximum and minimum absolute rainfall values in years of E1 Niño (EN) and La Niña (LN) in Lagoa Seca - PB, for the period from 1981 to 2019. Source: Medeiros (2020).

These results found in the study under discussion differ from the results found by the authors Fontona *et al*, (1997) for the Rio Grande do Sul region, Por Cunha (1999) for the Southeast region and by Mello (1999) for the municipality of Campinas - SP . Regarding the effects on agriculture, Rizzi, *et al*., (2003) pointed out that during the El Niño episode there was an increase in the rainfall index leading to an increase in the productivity of the soybean crop, north of Rio Grande do Sul. The result of this article has similarity with the studies by Marengo *et al.*, (2008); Marengo, *et al*., (2011), Gonzalez, *et al*., (2013).

Figure 4 shows the oscillations of the mean, maximum and minimum evapotranspiration indices in years of events of the phenomena El Niño (EN) and La Niña (LN) in Lagoa Seca - PB, between 1981 to 2019.

The average evapotranspiration (ETP) from January to early June and from September to December, in the episode of La Niña, exceeds the values of ETP compared to El Niño. Between the beginning of June and the beginning of September, the values of ETP were equalized. The absolute maximum values predominated due to the El Niño phenomenon from April to December and in the months from January to March the absolute maximum values were predominant in La Niña. The fluctuations in ETP to the absolute minimum predominated above in the condition of El Niño in the months from January to April. Between May and June the evapotrapirative indexes were equal and between July and December the evapotranspiration power was greater in episodes of El Niño. The ETP peaks were recorded in the months of March, October, November and December and the minimum peaks in the months of February and July. Work such as Sentelha, *et al*.,(2008), Varejão-Silva (2006); Camargo (1971) corroborate the results presented.

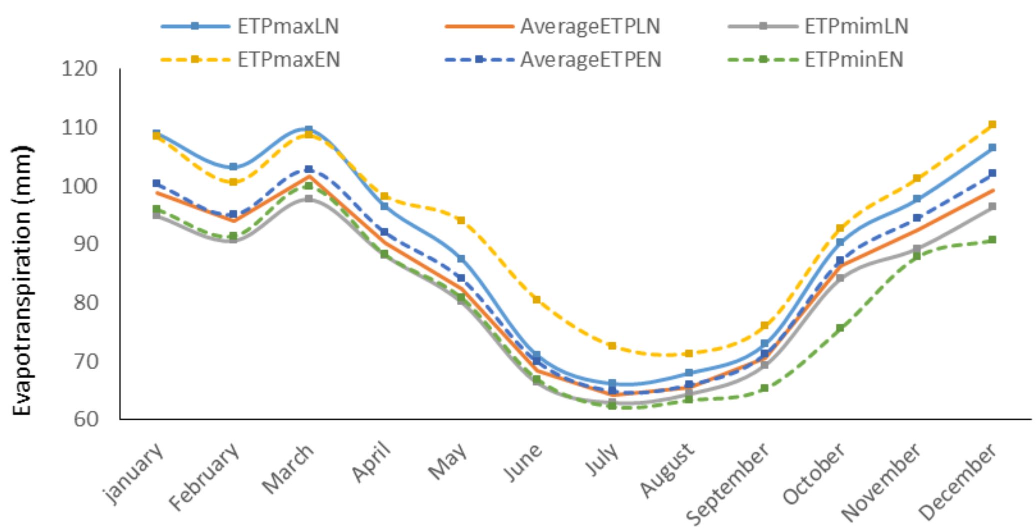

Figure No. 4: Oscillations of the maximum, average and absolute minimum evapotranspirative indices in years of events of the El Niño (EN) and La Niña (LN) phenomena in Lagoa Seca - PB, between 1981 to 2019. Source: Medeiros (2020).

Figure 5 shows the mean evaporation oscillations (EVR), maximum and minimum absolute in episodes of the EN and LN phenomena in Lagoa Seca - PB, between 1981 and 2019. The mean EVR variability registered greater fluctuations between the months of December to May, on the conditions of EN the evaporative indices were greater, the oscillations between June to November were close to the episodes of EN, LN. With annual evaporation of 730.7 mm, it evaporated 40.96% below the rainfall index.

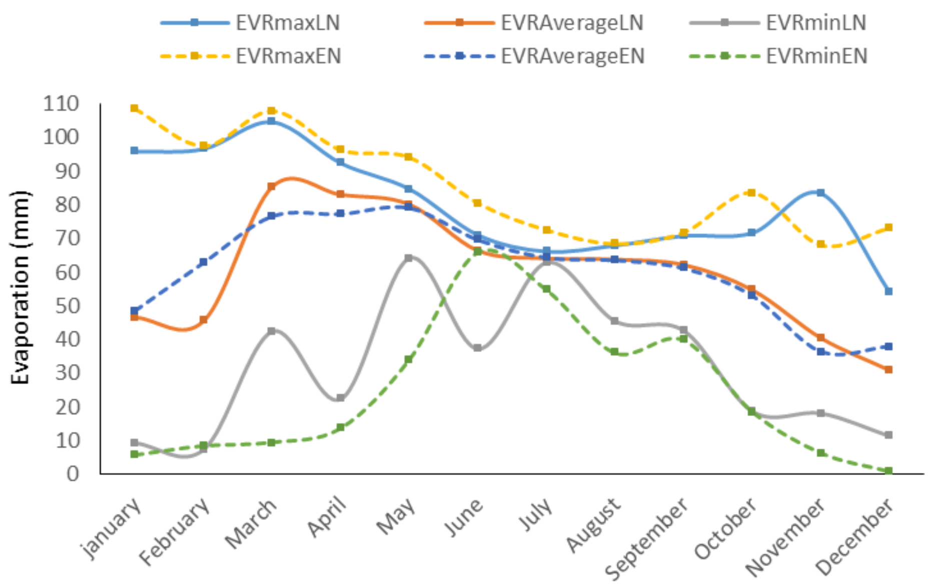

Figure No. 5: Fluctuation of mean evaporation, maximum and minimum absolute in years of episodes of the phenomena El Niño (EN) and La Niña (LN) in Lagoa Seca - PB, between 1981 to 2019. Source: Medeiros (2020).

The maximum rates evaporated in the EN episode were recorded in January 2016 with 108.3 mm; in February with 97.3 mm in 2003 and in March 2016 with 107.7 mm. The minimum evaporative rates occurred in January with 5.7 in (1991), February with 8.4 mm in 1993 and in November with 6.3 mm (2016). Studies such as that of França, *et al*., (2017); Costa, *et al*., (2015) corroborates the results discussed.

Fluctuations of average, maximum and minimum absolute water deficiencies in years of episodes of the El Niño (EN) and La Niña (LN) phenomena in Lagoa Seca - PB, between 1981 to 2019 (Figure 6).

With annual water deficiency of 295.5 mm in EN periods and its average fluctuations flowing from 0.2 mm in June to 60.1 mm in December. In December to March, the greatest water deficiencies were registered, ranging from 85.8 mm (February) to 94.5 mm in January. With an annual average of 290.5 mm for LN episodes. The maximum water deficiencies in times of LN occurred in December, January, February and April with 95.1 mm; 88.4 mm; 95.8 mm and 74.0 mm respectively.

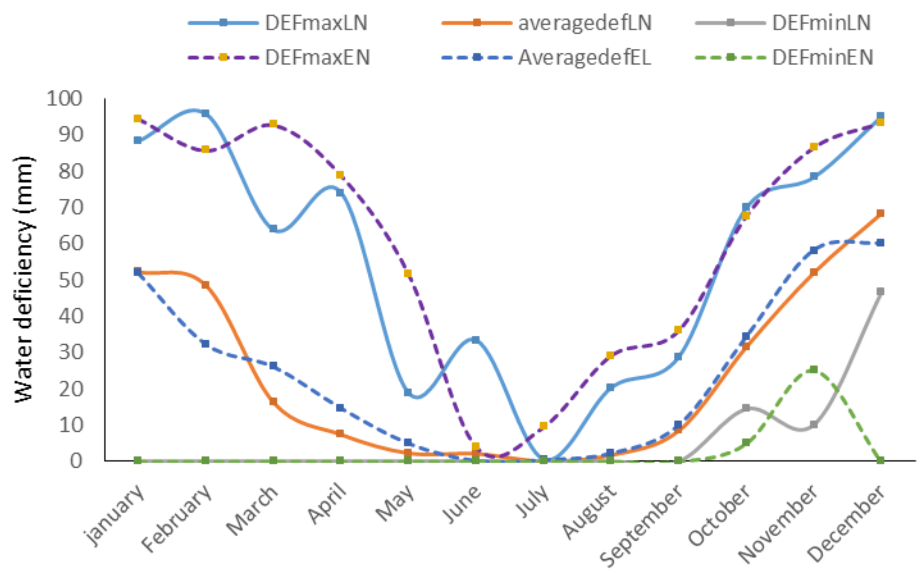

Figure No. 6: Fluctuation of mean, maximum and minimum absolute water deficiencies in years of episodes of the El Niño (EN) and La Niña (LN) phenomena in Lagoa Seca - PB, between 1981 to 2019. Source: Medeiros (2020).

The absolute minimum water deficiencies oscillate between 0.0 mm to 49.7 mm in the periods of EN and in the LN period their absolute minimum oscillations were recorded in October to December with oscillations flowing between 0.3 to 29.7 mm. Collaborating with the studies by Medeiros (2016b); Marengo, *et al*., (2015); Santos, *et al*., (2017), Costa *et al*., (2017), Menezes et al. (2008), Silva, *et al*., (2017).

Figure 7 shows the fluctuations in mean, maximum and minimum absolute water surpluses in years of episodes of the El Niño (EN) and La Niña (LN) phenomena in Lagoa Seca - PB, between 1981 to 2019.

In the LN episodes for October, November, December and January there were no water surpluses (EXC). Between February and September, EXCs flowed between 0.6 mm to 132.1 mm with an annual total of 359.7 mm. The highest annual EXC occurred in 2011 (1013.5 mm); 2009 (507.9 mm); 2000 (693.4 mm) and the years 1984 and 1985 with 486.4 mm respectively. The lowest EXC was registered in 1998 (53.9 mm) and 1999 (56.1 mm). The absolute minimum values were 0.0 mm in all LN episodes; absolute maximums occurred in May 2011 with 427.4 mm; June 2000 (235.6 mm) and July 2011 (361.4 mm). This buoyancy is following the studies by Marengo

(2006); Marengo, *et al*., (2011). The study by Santo, *et al*., (2010) corroborates the results discussed in the study.

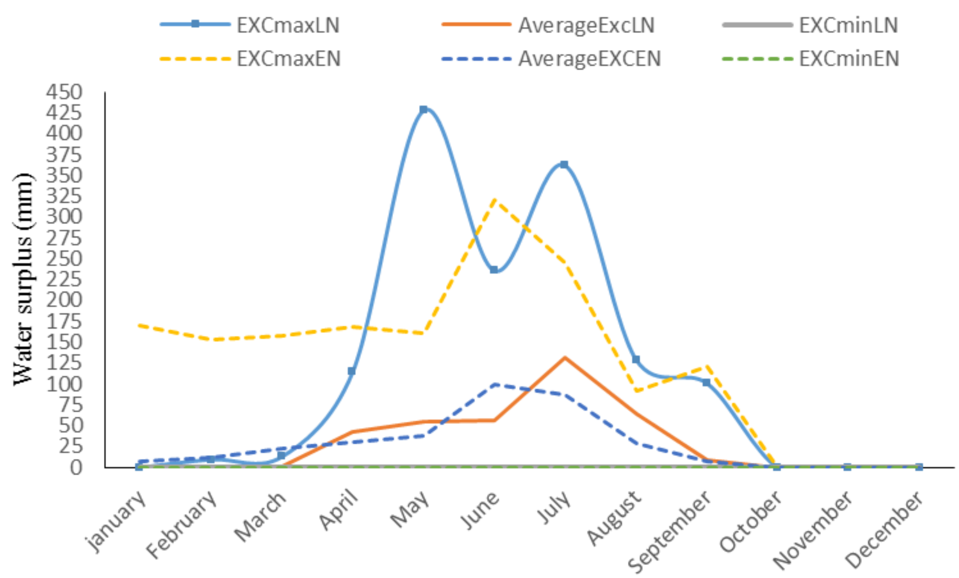

Figure No. 7: Fluctuation of the average water surplus, maximum and minimum absolute in years of episodes of the phenomena El Niño (EN) and La Niña (LN) in Lagoa Seca - PB, between 1981 to 2019. Source: Medeiros (2020).

The variability of mean, maximum and minimum absolute temperatures in years of episodes of EN and LN in Lagoa Seca - PB, between 1981 to 2019 (Figure 8).

The average annual temperature for the EN episode was 21.8 ºC and its oscillations fluctuated between 19.6 ºC in July and 23.3 ºC in February. The absolute maximum values fluctuated between 20.2 ºC in August 2015 to 23.9 ºC in the months of January and February 2016. The absolute minimum temperatures fluctuated between 19.2 ºC in July and August of the years 1998 and 1981 at 22.9 ºC in February 2016.

The wide climatic variability in the NEB rainfall regime may be influenced by anomalies in sea surface temperature, such as: El Niño, La Niña, North Atlantic and South Atlantic temperatures, as well as regional atmospheric circulation and other phenomena synoptic scale (Ferreira & Hermenes 2017). Similar results were found by Romero (2013); Vicent, *et al*., (2005); IPCC (2014); Medeiros (2016b); Medeiros *et al*. (2015).

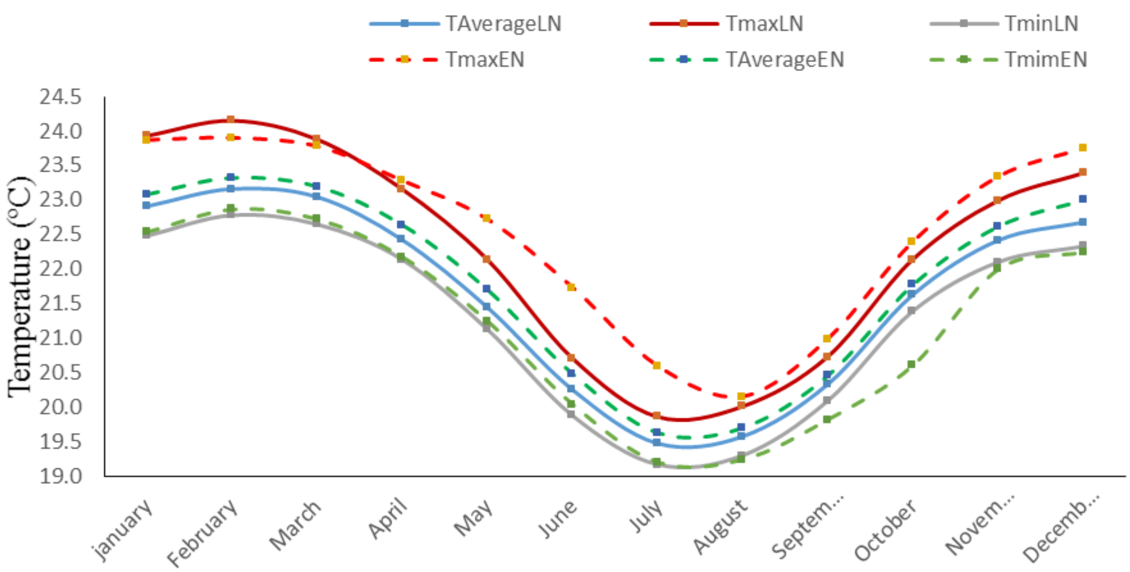

Figure No. 8: Average temperature variability, maximum and absolute minimum in years of episodes of the El Niño (EN) and La Niña (LN) phenomena in Lagoa Seca - PB, between 1981 to 2019. Source: Medeiros (2020).

In La Niña episodes, the average temperature was 21.6 ºC, ranging from 19.5 ºC in July to 23.2 ºC in February. The maximum absolute temperatures occurred in February dem2019 with 24.2 ºC and the absolute minimum with 19.2 ºC in July 1984.

Studies on extreme events carried out in South America through the analysis of temperature trends (Vincent, *et al*., 2005) observed an increase in minimum temperature and hot nights, a reduction in cold nights is becoming scarce and an increase in thermal amplitude, this confirmation was reported by Berlato *et al*. (2010).

Costa, *et al.*, (2015) Calculated the average monthly and annual temperature for the municipality of Matinhas and performed their analysis. The results confirmed that elevation and latitude are the physiographic variables that better explain the fluctuations in the temperature of the studied area, their oscillations derive from the synoptic systems active during the rainy and dry period, but large scale systems also had a high degree contribution to the thermal variability of the area in years in which extreme episodes intensely acted, this study corroborates the results presented.

CONCLUSION:

The rainfall indexes showed a better temporal distribution of rainfall as opposed to the period that rains above the historical average, with the rainfall index more grouped over time. The performance of El Niño episodes (a) is not related to increases and/or decreases in rainfall.

The high fluctuations in temperatures and anthropic interference contributed positively to the high rates of evapotranspiration, causing water stress in fruit and vegetables where the producer had to use the irrigation system to reduce these deficiencies.

The results prove that the El Niño (a) climatic phenomena do not compromise the climatic dynamics causing significant changes in the rain regime, records of increase and reduction of the rain volume in periods of El Niño and La Niña, respectively, were detected without the occurrence of major impacts. It is concluded that the climatic phenomena El Niño (a) exerted a relative and seasonal influence on the maximum daily precipitation isolated from the study area.

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