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Hydrometeorological conditions in the semiarid and east coast regions of Northeast Brazil in the 2012-2017 period

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Abstract: Various studies have identified that between 2012 and 2017, Brazil's semiarid region suffered severe drought. However, few studies have analyzed whether this drought also affected the eastern coastal region of Northeast Brazil (ENEB). Therefore, the objective of this work is to identify rainfall anomalies in these regions and verify the hydrometeorological impact on reservoirs in the 2012-2017 interval. For this purpose, we used precipitation data and atmospheric variables in the period from 1981 to 2017 to investigate the rainy season and associated dynamic patterns, as well as the consequences of these mechanisms on the variation of the water parameters of important reservoirs. The results indicated that rain events in the ENEB during 2012-2017 presented similar climatological behavior, without the characteristic of a drought event as observed in the semiarid region. The meteorological analyses showed that the combination of convergence with moisture over the Atlantic Ocean possibly favored greater frequency of shallow convective rainfall in ENEB, an important factor to explain the absence of generalized negative anomalies in the region. As a consequence, the reservoirs did not suffer from water collapse, unlike in the semiarid region.

Key words: rainy season, water vapor transport, flux divergence, water resources, drought.

INTRODUCTION

Drought is a complex natural phenomenon of lack of water caused by moisture deficiency or imbalance of the water supply and demand in a region during a determined time period (Ye et al. 2016). Droughts are normally classified in four categories: meteorological, hydrological, agricultural and socioeconomic (Heim 2002).

Meteorological drought refers to a shortage of rainfall, possibly combined with greater potential evapotranspiration, extending over a wide area for a significant time period. This combination causes lowering of the water table and reservoir levels and crop losses (Ye et al. 2016, Habibi et al. 2018, Amrit et al. 2018). Hydrological drought is associated with a reduction of the average water level of surface and underground water bodies, such as lakes, reservoirs, aquifers and streams. It can occur for a long period or only for a few days, a season or year (Ye et al. 2016, Brito et al. 2017). Agricultural drought is a deficit of moisture in the soil induced by water deficiency that impedes the growth of crops, leading to reduced biomass (Son et al. 2012). Finally, socioeconomic drought is associated with impacts on human activities, including direct and indirect impacts of agricultural production and various other economic activities (Maia et al. 2015).

Although the semiarid region of Northeast Brazil (NEB) suffers from recurrent drought episodes (Cunha et al. 2018), the last event (2012-2017) stood out as one of the region's most severe and intense in recorded history (Marengo et al. 2017, Brito et al. 2017, Barbosa et al. 2019, Cunha et al. 2019, Cabral Júnior & Lucena 2020). Several studies have shown that the economic activities in NEB were strongly affected by periods of negative precipitation anomalies, in particular farming and stock breeding (Gutiérrez et al. 2014). Other sectors, such as electricity generation, tourism and recreation and public water supply, also suffered significant losses due to this environmental problem (Wilhite et al. 2014, Getirana 2016, Medeiros et al. 2018). It is estimated that during the 2012-2016 drought, a total of R$ 104 billion in public funds was allocated to mitigate the impacts of the drought, which affected 33.4 million people (MI 2018).

As described by various authors (Rodrigues et al. 2011, Kayano et al. 2018), the rainy season in NEB is directly influenced by physical mechanisms that occur at the ocean-atmosphere interface and the associated atmospheric circulation patterns, such as the formation of Walker and Hadley cells. It is known, for example, that El Niño years are normally accompanied by a descending branch of the Walker cell over NEB, inhibiting convection movements and thus causing water deficit (Chaves & Cavalcanti 2001, Tedeschi & Collins 2016).

On the other hand, it is also known that the rainfall pattern along the east coast of Northeast Brazil (ENEB) is influenced by distinct weather systems than those observed in the semiarid region (Medeiros et al. 2017), which favors different distributions of the spatial and temporal patterns of precipitation. While in the semiarid region, the main weather system is the Intertropical Convergence Zone (ITCZ) (Uvo et al. 1998, Utida et al. 2019) – defined as a tropical belt of convective clouds –, in ENEB the Easterly Wave Disturbances (EWDs) – synoptic-scale quasi-periodic perturbation occurring within the trade wind region – act as the main rain modulation mechanism (Gomes et al. 2019).

This high spatial-temporal rainfall variability in NEB potentially affects the refilling of reservoirs in the region, and consequently the dynamics of water supply for human consumption and agricultural use. In the semiarid region, the annual variation of the storage volume of water bodies is greater than along the coast, although the latter region can face maximum or minimum storage in years of extremely heavy or sparse rainfall (Bezerra et al. 2018). In this respect, Medeiros et al. (2018) analyzing the hydrometeorological impact on the annual storage variation of the three largest reservoirs in the states of Rio Grande do Norte (RN), Paraíba (PB) and Ceará (CE) - Engenheiro Armando Ribeiro Gonçalves, Coremas and Castanhão, respectively – in years marked by extreme precipitation, found that in the wettest year (2004) there were respective increases of 37.3%, 35.09% and 61.37% in the volume stored, while in the driest year (2012) there were reductions of 33.11%, 18.01% and 29.59% in those reservoirs. Besides this, according to Medeiros et al. (2019), reservoirs with greater storage capacity are more efficient, and hence are less susceptible to droughts than smaller ones.

Therefore, because of the importance of rainfall and water resources to Northeast Brazil and considering that various studies have analyzed the recent drought in the semiarid region (Brito et al. 2017, Marengo et al. 2017, Cunha et al. 2018, Azevedo et al. 2018, Cunha et al. 2019, among others), while there is a lack of information about precipitation in ENEB during 2012-2017, this study examines the following two questions: Did the recent drought (2012-2017) in Brazil's semiarid region also affect the east coast of Northeast Brazil? Did the reservoirs along the east coast also face a water deficit? Therefore, the main objective of this work is to identify the rainfall anomalies and verify the hydrometeorological impact on the reservoirs of the semiarid and east coast regions of NEB in the 2012-2017 period.

MATERIALS AND METHODS

Study area

The study area mainly comprises the northern sector of the semiarid region (2.7°S – 10.0°S and 36.0°W – 42.7°W) and the east coast of Northeast Brazil (4.85°S – 10.1°S and 34.6°W – 36.0°W), covering parts of the states of Piauí (PI), Rio Grande do Norte (RN), Paraíba (PB), Pernambuco (PE) and Alagoas (AL) (Figure 1). The main characteristics of the semiarid region are

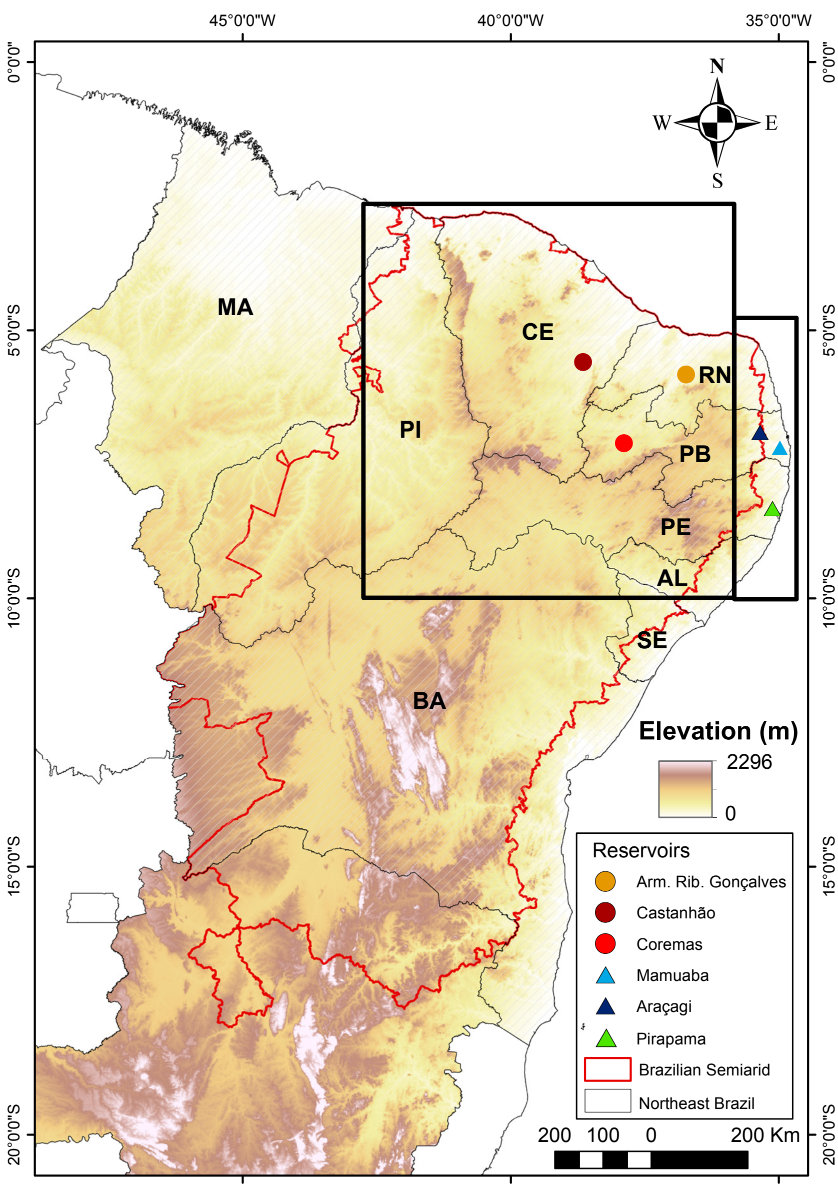

Figure 1. Delimitation of the Northeast region and limits of the semiarid region, with highlight on the reservoirs analyzed in the semiarid and east coast of Northeast Brazil.

low annual rainfall and high evaporation rates (Medeiros et al. 2017, Cabral Júnior et al. 2019).

According to the Köppen classification, the climate in the semiarid region is tropical semiarid (BSh), while that in ENEB is predominantly tropical with dry summer (As), with small portions having tropical monsoon climate (Am) (Alvares et al. 2013). The average yearly temperature in ENEB varies between 24 °C and 26°C, with annual mean precipitation ranging from 1,200 to 2,000 mm (Costa et al. 2018, Rodrigues et al. 2019).

The principal atmospheric phenomena causing precipitation in ENEB are the EWDs and convergence of moist air from onshore and offshore breezes, while in the semiarid region the ITCZ and SCM are the most frequent meteorological systems (Palharini & Vila 2017). Other weather systems such as high-level cyclonic vortices also contribute to the quantity of rainfall in ENEB and the semiarid region, depending the vortex location and its direction of movement (Kousky & Gan 1981). The main biome in the semiarid region is the Caatinga (Shrubland), and in the ENEB is the Mata Atlântica (Atlantic Forest) (Campos et al. 2019).

Data

In order to explore the circulation and the atmospheric moisture flux, we investigate the anomalous large-scale characteristic during the 2012-2017 period. For this purpose, we calculated and analyzed the monthly means of the zonal and meridional wind components, along with the specific moisture variable at the different atmospheric pressure levels (1000, 925, 850, 775, 700, 600, 500, 400 and 300 hPa) from the ERA-Interim reanalysis dataset supplied by the European Center for Medium-Range Weather Forecasting (ECMWF) (Dee et al. 2011). The period analyzed was from 1981 to 2017, in a 2.0° x 2.0° grid for the entire globe.

Monthly cumulative precipitation data from the Global Precipitation Climatology Project (GPCP) satellite (Huffman et al. 2001) for 1981-2017 were used to quantify the distribution of rainfall in the northern semiarid and east coast of NEB (Figure 1 – black boxes). This database is available in a regular grid format with horizontal resolution of 1.0° x 1.0°. The GPCP dataset was chosen to be in accordance with precipitation from weather stations, as shown by (Rao et al. 1993, Amorim et al. 2014, Pereira et al. 2014), and to be available for the entire period required (1981-2017).

The hydric situation (here considered as volume stored) of the reservoirs in the east coast of NEB during the 2012-2017 period was inferred from the monthly time series of the reservoirs Gramame/Mamuaba and Araçagi, located in the state of Paraíba (PB); and Pirapama, in the state of Pernambuco (PE) (Figure 1). To compare the variation of these reservoirs' volume stored with those in the semiarid region, we examined three other reservoirs: Engenheiro Armando Ribeiro Gonçalves, in the state of Rio Grande do Norte (RN), Castanhão, in the state of Ceará (CE), and Coremas, in the state of Paraibá (PB) (Figure 1). These reservoirs were chosen for their economic and social importance to the respective regions, and because of the existence of robust data for the period analyzed. The Gramame/Mamuaba reservoir (PB), for example, is the main source of water for 12 municipalities and more than 1 million people in the metropolitan region of João Pessoa, while the Castanhão reservoir (CE) supplies more than 4 million people in the Fortaleza metropolitan region (ANA 2018, IBGE 2018). The data for the six reservoirs were obtained from the National Water Agency (Agência Nacional de Águas, ANA) through its HidroWeb portal, and also by consulting the monthly water level records of the Environment and Water Resources Company of Rio Grande do Norte State (SEMARH-RN), the Water Management Agency of the State of Paraíba (AESA) and the Pernambuco State Water and Climate Agency (APAC) (Table I).

Methodology

Two time intervals were considered to compare the precipitation in the northern semiarid and ENEB regions. The first, denoted climatological, runs from 1981 to 2010, and the second, denoted drought event, covers 2012 to 2017. In both cases, the average rainfall was calculated considering the area of the northern semiarid and ENEB regions (Figure 1).

Based on the data from the climatological period, we constructed the histogram of monthly rainfall to identify the rainy season of the semiarid and ENEB regions. Then we obtained the time series of the precipitation anomalies to visualize the behavior of precipitation during the 2012-2017 period.

To identify the atmospheric moisture source and sink regions, we calculated the vertically integrated water vapor transport (Coutinho et al. 2015). For this calculation, we considered the pressure levels from the surface (1000 hPa) to 300 hPa, because above this level, the water vapor present in the atmosphere is small, and thus is susceptible to large instrumental measurement errors (Satyamurty et al. 2012). The vertical integration of the moisture transport is given by the following equations:

$$Q_u = \frac{1}{g}\int_{P_t}^{P_0} qu\,dp \tag{1}$$

$$Q_v = \frac{1}{g}\int_{P_t}^{P_0} qv\,dp \tag{2}$$

Where Q_u and Q_v represent the zonal and meridional moisture transport, respectively; g is the acceleration due to gravity; q is the specific moisture; u and v are the components of the zonal and meridional wind, respectively; p_o denotes the pressure in the upper part of the integration domain (300 hPa); and p_t is the

Table I. **Water capacity of the six reservoirs analyzed.**

State	Basin	Reservoir	Location	Capacity (hm^3)	Data Source
RN	Upper Piranhas	Eng. Arm. Ribeiro Gonçalves	Semiarid	2400	HidroWeb/ SEMARH
CE	Upper Jaguaribe	Castanhão	Semiarid	6700	HidroWeb
PB	Piancó	Coremas	Semiarid	1358	HidroWeb/ AESA
PB	Gramame	Gramame/ Mamuaba	ENEB	56.93	AESA
PB	Mamanguape	Araçagi	ENEB	63.28	AESA
PE	GL2	Pirapama	ENEB	58.43	APAC

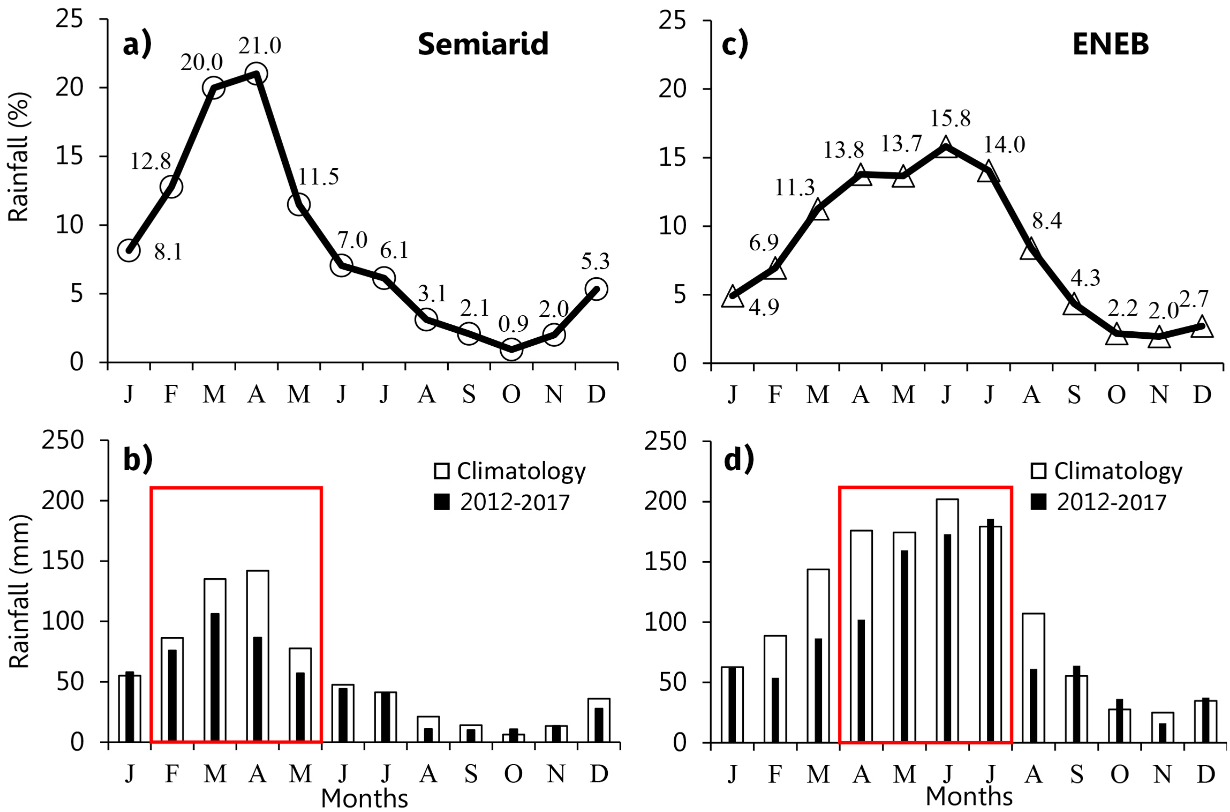

Figure 2. Monthly concentration of precipitation extracted from the GPCP satellite database in the climatological period (1981-2010) in the northern semiarid region a and east coast of Northeast Brazil b; and comparison between average monthly rainfall in the 1981-2010 and 2012-2017 periods (mm), with highlight on the rainy seasons of the northern semiarid region (FMAM) c and east coast of Northeast Brazil (AMJJ) d.

surface pressure (hPa). The unit of these flows is kg s^{-1}.

We also analyzed current lines of the anomalous circulation at low levels (850 hPa) and the quantity of moisture available through the anomalous spatial distribution of specific moisture in the period from 2012 to 2017. Finally, to verify the hydrometeorological impact on the reservoirs located in the semiarid and ENEB regions, we subjectively evaluated the variation of the water in these reservoirs through the time series of the volume stored in the period from January 2012 to December 2017.

Linear trend: Mann-Kendall test

The nonparametric test for linear trend in time series proposed by Mann-Kendall (MK) (Mann 1945, Kendall 1975) was applied to detect tendencies in the volume stored time series of the six reservoirs analyzed here. The method compares each value of the time series with the remaining subsequent values in sequential order, considering how many times the remaining values are higher or lower than the value being currently analyzed. The MK test is considered one of the most adequate to analyze trends in climate variables, and it has been used in several studies in Northeast Brazil (Oliveira et al. 2016, Bezerra et al. 2018, Cabral Junior et al. 2019). The null hypothesis of the MK test is that there is no trend of the calculated time series, while the alternative hypothesis says there is trend (positive or negative). Based on a bilateral test, the significance level was determined both for 5% ($p<0.05$) and 1% ($p<0.01$). The null hypothesis should be rejected if the p-value is less than the significance level.

RESULTS AND DISCUSSION

Analysis of the monthly concentration of precipitation in relation to the cumulative yearly average (675.8 mm) in the northern semiarid region revealed that the wettest months were concentrated from February to March (65.3%), while the dry season ran from August to November (8.1%) (Figure 2a). The months of December and January represented the pre-rainy season, accounting for 13.4% of the yearly total, while June and July were the transition from the wet to the dry season. Likewise, for ENEB (Figure 2c), the wettest months were April to July (57.3%), while the dry season went from October to December (6.9%). The seasonal transitions occurred in August (wet to dry) and January (dry to wet). This distribution of rainfall in these two regions is well known and discussed in various works (Oliveira et al. 2016, Marengo et al. 2017, Gomes et al. 2019). Figure 2 also reveals that although the precipitation is heavier in the semiarid region during the wettest months (Figures 2a, c), the annual accumulation of rainfall in the ENEB region is clearly higher (Figures 2b, d).

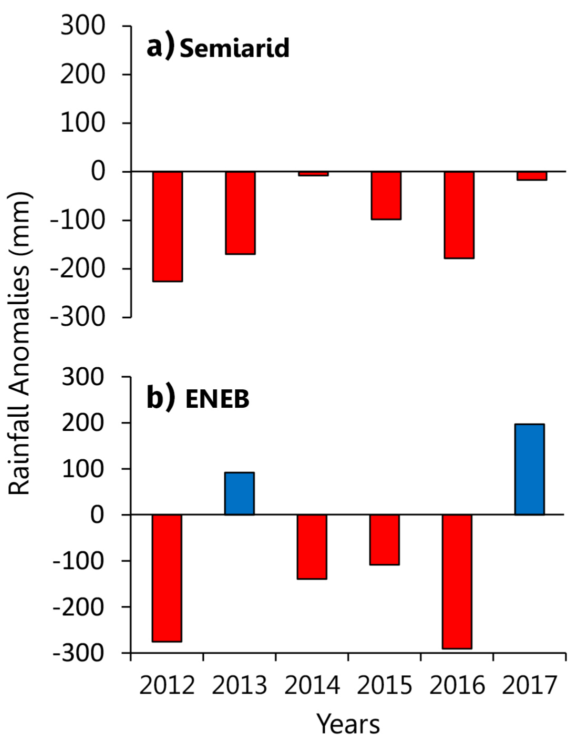

Figure 3. **Time series of precipitation anomalies accumulated during the rainy seasons of the a northern semiarid region (FMAM) and b east coast of Northeast Brazil (AMJJ) extracted from GPCP satellite data during the 2012-2017 period. The anomalies were calculated based on the climatological average for 1981-2010.**

Comparison of the precipitation in the rainy season (FMAM) during the climatological cycle and during the 2012-2017 in the semiarid region (Figure 2c) reveals that in all months of that period the rainfall was lower than in the climatological period, by 10.4, 28.8, 55.4 and 20.5 mm, respectively. In the ENEB region, in May-June-July (MJJ) both periods presented similar values (Figure 2d). In the climatological period, the precipitation values in May and June were 14.7 and 29.1 mm higher, respectively, than in the period from 2012 to 2017, while in July the average precipitation in 2012-2017 was 6.4 mm greater than in the climatological period. On the other hand, in April there was an average water deficit of 73.8 mm in relation to the climatological period (Figure 2d). Proportionally the rain reduction in the northern semiarid region was 25.74%, while in the ENEB it was 12.03% during the 2012-2017 period. Medeiros et al. (2020) analyzing the wet season (March-April-May) of the northern sector of Northeast Brazil (NNEB), found that climatological rainfall in the region was 742.2 mm, but during the 2012-2016

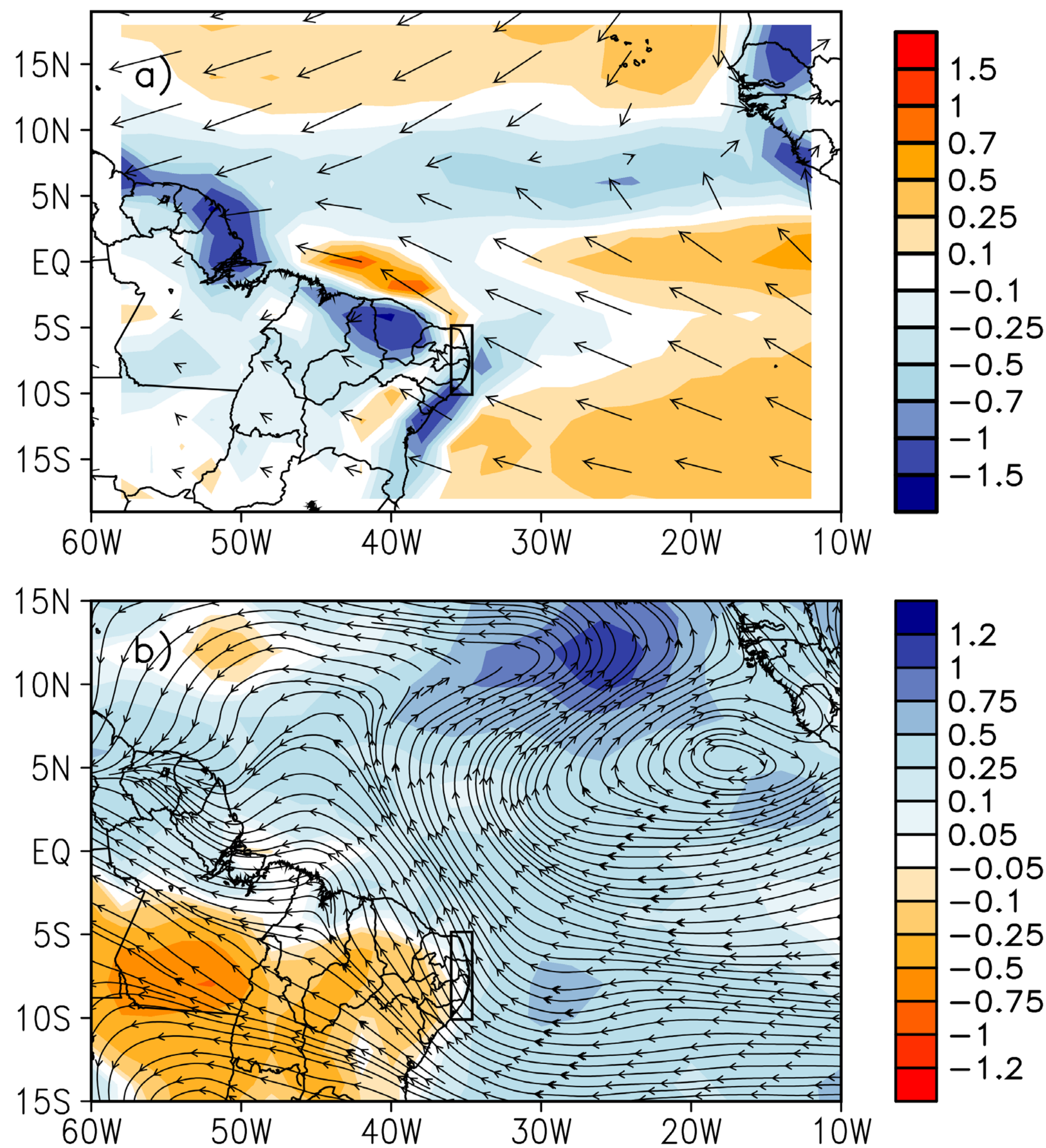

Figure 4. a Average anomalous vertically integrated water vapor transport (1000-300 hPa) (vectors, kg m^{-1} s^{-1}) and its divergence (colors, 10^{-5} x kg m^{-2} s^{-1}); b Specific moisture (colors, g kg^{-1}) and anomalous circulation current lines at 850 hPa during May the July in the period from 2012 to 2017. The anomalies were calculated based on the climatological average for 1981-2010.

period, the average precipitation in MAM was 462.2 mm, representing a water deficit of 37.8%, mainly caused by the anomalous position to the north of the ITCZ.

Examination of the time series of the precipitation anomalies in the rainy season of the northern semiarid region (FMAM) (Figure 3a) and ENEB (AMJJ) (Figure 3b) reveals that in all years in the semiarid region, negative rainfall anomalies occurred (-696.5 mm), with highlight on 2012, 2013, 2015 and 2016, which presented the greatest rainfall shortages (-225.9, -169.7, -98.1 and -178.1 mm, respectively). In ENEB, on the other hand, four rainy seasons were detected with negative precipitation anomalies (2012, 2014, 2015 and 2016) and two with positive anomalies (2013 and 2017) (Figure 3b). Indeed, from 2012 to 2017 precipitation was 525.1 mm below the average, with AMJJ in 2012 and 2016 being the rainy seasons with the largest negative precipitation anomalies, respectively 37.9% and 40.0% below the climatological average of the region from 1981 to 2010 (727.4 mm). In 2013 and 2017, the precipitation was 288.8 mm higher than the climatological average, denoting wetter than average rainy seasons.

The results depicted in Figure 3 indicate that unlike observed in the semiarid region, in which all the anomalies were negative during the interval from 2012 to 2017, as reported previously by Marengo et al. (2017) and Brito et al. (2017), the distribution of rainfall in ENEB did not have a generalized water deficit, so this pattern can be attributed to the natural climatic variability of the region.

Figure 4a, referring to the integrated water vapor transport and the convergence/divergence pattern of the winds in MJJ, the months when the EWDs are active, shows that the convergence areas (blue shades) were located in the convergence zone of the trade winds from the southeast and northeast over the Atlantic Ocean, along the coastline and a large portion of the NEB region. According to Figure 4a it can be seen that the Atlantic Ocean near the ENEB acts as a source of moisture while the onshore regions are receivers, i.e., in these areas, convergence of the moisture mass and flow occurs, which is an indicative of the associated convective activity. Figure 4b shows the specific moisture (in colors) and the anomalous circulation (current lines) at 850 hPa. The circulation pattern over the Atlantic Ocean is predominantly from the east and southeast, positively favoring the advection of moisture from the ocean to the east coast of NEB.

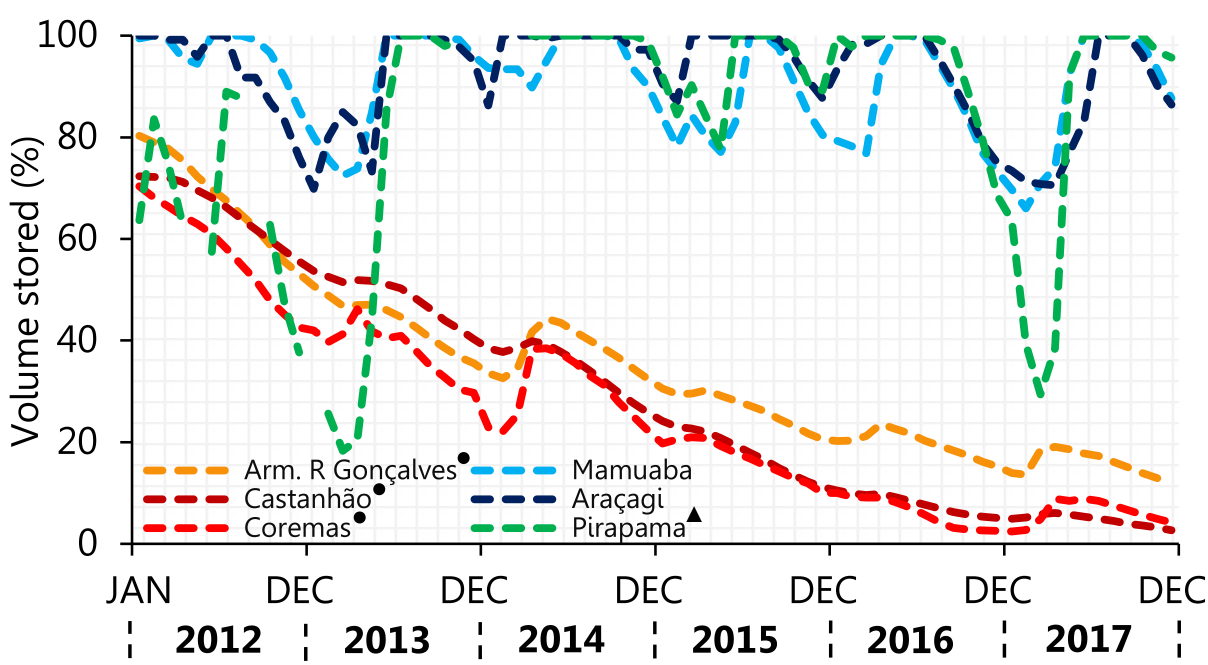

Figure 5. Variation of volume stored of three reservoirs in the semiarid region (Eng. Armando Ribeiro Gonçalves, Castanhão and Coremas) and three in the east coast of Northeast Brazil region (Mamuaba, Araçagi and Pirapama) in the 2012-2017 period. The circles represent negative trend with statistical significance at p=0.01; the triangle represents positive trends with statistical significance at p=0.05.

Further according to Figures 4a, b, the surrounding regions of NEB during the months of MJJ from 2012 to 2017 were marked, in average terms, by a reasonable concentration of available moisture, which possibly contributed to the greater occurrence of warm clouds, and consequently a greater frequency of shallow convective rains, typical of ENEB (Palharini & Vila 2017, Rodrigues et al. 2019), explaining the behavior near the climatological average during these three months (Figure 2d).

The patterns of the vertically integrated water vapor transport (Figure 4a) and specific moisture (Figure 4b) help explain why the ocean-atmosphere mechanism that controls rainfall in ENEB is different than that detected in the semiarid region. While in the semiarid region, the zonal and meridional tropical circulation cells (Walker and Hadley cells, respectively) are important to modulate the occurrence of rain (Moura & Shukla 1981, Rodrigues & McPhaden 2014, Tedeschi & Collins 2016), the moisture coming from the Atlantic Ocean is the main dynamic force responsible for the atmospheric instabilities associated with the Easterly Wave Disturbances, which form the main system causing rain in the MJJ period in ENEB (Torres & Ferreira 2011, Gomes et al. 2019).

These atmospheric characteristics influence the geographic surface, such as the variations of water reserves, whose reservoirs are the main source of supply to the population. Analyzing the variation in the volume stored of important reservoirs inserted in the semiarid and ENEB regions in the 2012-2017 period (Figure 5), it can be seen that five of the six reservoirs analyzed here (the exception being Pirapama, located in eastern Pernambuco) presented decreased volume stored from January 2012 to December 2017. The volume reductions in the reservoirs located in the semiarid region were clearly, in average terms, gradual and more pronounced (statistically significant negative trend at 1% level). In January 2012, Engenheiro Armando Ribeiro Gonçalves reservoir (the largest in the semiarid region of Rio Grande do Norte) held 80.29% of its maximum capacity, while at the end of December 2017 its volume was only 11.93% of capacity, a variation of 68.36%, which means losses equal to 1640.6 hm^3. The Castanhão (CE) and Coremas reservoirs (the second the largest in the semiarid region of Paraíba) also suffered reductions of the volume stored similar to that of Engenheiro Armando Ribeiro Gonçalves (69.65% and 66.14%), representing losses of 4,666.5 hm^3 and 898.2 hm^3, respectively.

These low water volumes in the reservoirs in the semiarid region due to the prolonged drought caused many impacts on the municipalities of the region, such as severe electricity shortage (Miranda 2013, Getirana 2016), losses to farmers and stock breeders (Zeri et al. 2018, Cunha et al. 2019), and implementation of rotating tank truck water supply in many small and midsize municipalities (Alvalá et al. 2017).

On the other hand, associated with the more regular distribution of rainfall in ENEB, the variation of the volume stored in its reservoirs was less variable, for the most part above 80% of capacity, with brief alternating periods of loss and recharge, except for the Pirapama reservoir, which between mid-July 2012 and April 2013, and from October 2016 to April 2017, showed sharp variations of 68.5% and 50.4% in its volume, respectively. This greater variation in the Pirapama reservoir in 2013 and 2017 was probably due to the small contribution from the affluent rivers, since the cumulative precipitation observed in the rain gauges of the reservoirs of the ENEB analyzed (data from APAC and AESA) indicated it rained more in the Pirapama reservoir than in the others during the months of the dry season and the transition from the dry to rainy season (not shown). In the

Mamuaba reservoir (PB), in 62.5% of the months in the 2012-2017 period the volume was greater than 90%, while for the Araçagi reservoir (PB) the figure was 70.8%. Despite the greater variation of the Pirapama reservoir (PE) (statistically significant positive trend at the 5% level), in the three ENEB reservoirs the lowest volumes stored occurred in the first months of 2013 and 2017 due to the more intense negative rainfall anomalies recorded in 2012 and 2016 (Figure 3). Therefore, the alternation of rainfall values below and above the average in ENEB between 2012 and 2017 meant that the region's reservoirs did not face the critical situation that occurred in all the reservoirs in the semiarid region.

However, it should be noted that although the situation of severe deficit was not observed in the same proportion in the reservoirs in the ENEB region, this does not mean all of them were free of water problems. Some ENEB reservoirs did face problems, such as Pirapama (PE), which established rationing due to the low water level in March 2013.

The water deficits recorded in the Armando Ribeiro Gonçalves (RN), Castanhão (CE) and Coremas (PB) reservoirs (statistically significant negative trend at the 1% level) (Figure 5) also occurred in various other large and small reservoirs in the semiarid region, as described by Martins et al. (2017) for the São Francisco Basisn, Azevedo et al. (2018) for the Sobradinho reservoir, and Medeiros et al. (2019) for the Cruzeta weir (RN). These results corroborate the importance of annual rainfall variation to the water resources in NEB, making it important to continually monitor the hydrometeorological conditions and seasonal climate forecasts in the region. Besides this, our results show that even the largest reservoirs in the semiarid region are unable to withstand several consecutive years of water deficits, indicating the need for infrastructure works, such as transposition of the São Francisco River (Stolf et al. 2012) to supply water for human consumption, farming and stock breeding.

CONCLUSIONS

This study analyzed the difference in precipitation in the rainy season between the climatological period (1981-2010) and the interval from 2012 to 2017 in the semiarid and east coast of Northeast Brazil regions, as well as investigating the association between the distribution of rainfall in these regions and the water level situation of some reservoirs in the regions in the latter period.

The distribution of monthly average precipitation revealed that both in the climatological period and the 2012-2017 period, the rainfall in the wet season of ENEB presented similar behavior, unlike observed in the northern part of the semiarid region, where in all months the rainfall was lower than in the climatological period. The analysis of the vertically integrated water vapor transport and the anomalous circulation at 850 hPa indicated that advection of atmospheric moisture from the Atlantic Ocean adjacent to ENEB in MJJ probably intensified the convective movements associated with the Easterly Wave Disturbances, which form the main dynamic system responsible for ENEB rainfall.

In general, the analyses carried out indicated that despite the predominantly negative precipitation in the ENEB – an average of 66.7% between 2012-2017 (compared with the climatological data) – these anomalies (12.03% below average) were not sufficient to culminate in hydrological drought, i.e, this behavior of precipitation around the climatological average in the ENEB enable the region's reservoirs to avoid water deficit, unlike those in the semiarid region, which due to persistent and severity of negative precipitation anomalies reached critical situation.

In percentage terms, in the Mamuaba (PB) and Araçagi (PB) reservoirs, located in ENEB, the variations of the volume stored between January 2012 and December 2017 were 11.76% and 13.59%, respectively, while the smallest volumes recorded in these reservoirs were 66.01% and 69.85% (without positive or negative trend). The Pirapama reservoir (PE), on the other hand, presented a variation of 68.5% between July 2012 and April 2013. Nevertheless, unlike observed in the semiarid zone reservoirs, it presented excellent water recharge in the ensuing months, so that critical water problems did not occur in the 2012-2017 period. In the Engenheiro Armando Ribeiro Gonçalves (RN), Castanhão (CE) and Coremas (PB) reservoirs, on the other hand, the rainfall deficit recorded in the semiarid region in all years from 2012 to 2017 caused a steady decline of the volume stored, with an average variation of about 70% in those six years in the three reservoirs (statistically significant at the 1% level). Besides this, we found that the Castanhão (CE) and Coremas (PB) reservoirs presented volume under 10% starting in February 2016, explaining the various requests for declaration of public calamity by municipalities located in the semiarid region due to the drought in NEB (Brito et al. 2017).

The results presented in this study indicate that even the largest reservoirs in the semiarid region are unable to withstand several consecutive years of below average rainfall, which highlight the need for water infrastructure works to assure the water security of the population of the semiarid region of Northeast Brazil. Examples such as the construction of the Oiticica dam in the municipality of Jucurutu (RN), whose maximum capacity will be 556 hm³, and the Seridó project, conducted by SEMARH-RN, to build pipelines in the next 50 years to guarantee water to some 500 thousand people in the Seridó region of RN, where desertification is intense (Mutti et al. 2020), should be expanded to other states in the Northeast to combat the effects of drought. The results presented here can also be used by water policymakers and managers, by indicating how the reservoirs in the semiarid and ENEB regions respond to the distribution of precipitation.

Furthermore, these results can help support decisions in various areas of knowledge, since the irregularity and persistence of anomalies involving the distribution of rainfall, besides affecting the availability of water in the reservoirs, also affects livestock and crop production (especially from dryland farming), and consequently the local economy. It should also be noted that unlike in the ENEB, in the watersheds of the semiarid region, temporary or ephemeral watercourses prevail, so during long dry periods, the access to water by the people is even more difficult, compromising the satisfaction of basic needs due to shortage. This problem falls most heavily on people with lower incomes, who cannot purchase water from tank trucks and hence need the support of public policies. Therefore, the planning by managers should be a priority so that in the occurrence of unfavorable hydrometeorological conditions, they can establish strategies to mitigate the effects of prolonged drought, as the one that afflicted the semiarid region between 2012 and 2017.

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