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Drought monitoring in the Brazilian Semiarid region

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Abstract: Drought is a natural and recurrent phenomenon. It is considered 'a natural disaster' whenever it occurs in an intensive manner in highly populated regions, resulting in significant damage (material and human) and loss (socioeconomic). This paper presents the efforts developed to monitor the impact of drought in the semiarid region of Northeast Brazil. In this scope, information from different sources is compiled to support the evaluation and identification of impacted municipalities, with the main objective of supporting emergency actions to mitigate their impact. In the semiarid region of Brazil there are frequent occurrences of dry periods during the rainy season, which, depending on the intensity and duration, can cause significant damage to family-farmed crops, with a farming system characterized by low productivity indices. However, rain-fed agriculture has great economic expression and high social importance due to the region is densely occupied, and contributes to the establishment of communities in the countryside. Specifically, in the present study, the methodology adopted to monitor the impact of agricultural droughts, including an analysis of the hydrological year 2015-2016, is presented, considering different water stress indicators for the identification of the affected municipalities and assessment of the methods and tools developed.

Key words: agriculture, drought impacts, drought monitoring, semiarid, dry farming, Northeast Brazil.

INTRODUCTION

During the past decades, droughts have increasingly drawn the attention of environmentalists, ecologists, hydrologists, meteorologists, agronomists, and decision makers. Generally, droughts are classified as either a meteorological drought (lack of precipitation over a region for a period of time), hydrological drought (deficiencies in surface and subsurface water supplies), agricultural drought (deficiency in water availability for crop or plant growth) or socioeconomic drought (failure of water resources systems to meet water demands, which impacts human activities both directly and indirectly) (Wilhite 2000, Yang 2010, Son et al. 2012, Udmale et al. 2014, Eakin et al. 2014). This natural and recurrent phenomenon is considered to be 'a natural disaster' whenever it occurs in an intensive manner in highly populated regions,

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resulting in significant damage (material and human) and loss (socioeconomic). Given the growing demand for water worldwide as a result of population growth and the expansion of the agriculture and livestock, energy and industrial sectors, this is an increasingly frequent occurrence. During periods of extreme drought, food security for the most vulnerable communities, such as those in the semiarid regions, suffers pressures with reduced subsistence production, reduced income and increased pricing of agricultural products. Food price inflation, associated with loss of income due to harvest shortfalls, loss of productivity and unemployment, results in low food security and, in extreme cases, in famine.

According to a report of the World Meteorological Organization (WMO 2015), during the period between 1970 and 2012, 8,835 natural disasters were reported that caused about 1.94 million deaths and economic losses of US$ 2.3 trillion worldwide. In 2011 alone, according to the United Nations – International Strategy for Disaster Reduction (ISDR 2012), disasters occurring that year across the entire planet ultimately resulted in record financial losses of approximately US$ 366 billion, and an estimated 201 million people were affected as a result of 302 disasters recorded. From this total number of people affected, it is estimated that 63 million are victims of drought.

In Brazil, such a phenomenon is characterized by its wide spatial coverage and is recurrent in the Brazilian semiarid region (Semiárido do Brasil - SAB), mainly due to its hydric vulnerability. Approximately 24 million people live in the SAB, which is equivalent to 12% of the national population (IBGE 2017), designating it the most densely populated dry region in the world (Ab'Saber 1985, Marengo 2008, Rêgo 2012).

The SAB is characterized by presenting irregularity in rainfall distribution, shallow and rocky soils – which gives it low water storage capacity, a small draining system, and a high evapotranspiration rate (Ab'Saber 1999). The occurrence of dry periods during the rainy season ('veranicos') is frequent and, depending on their intensity and duration, they may cause, for example, significant damage to subsistence crops (type of agricultural production predominant in the semiarid region), consequently affecting the family-run agriculture business.

As highlighted by Bezerra (2016), production in the semiarid region is generally characterized by extensive livestock farming and subsistence agriculture with low technological investment and low productivity (Nascimento 2006, Marengo 2008), which, owing to the absence of alternative strategies, forces the producers to use the natural resources in an intensive and abusive manner (Sá et al. 2010, Pantalena 2012). This contributes to worsened soil degradation in this region, mainly because of the degradation of the areas used for grazing (Parente and Parente 2010), and the low productivity of dry farming, which is affected by the high intra-seasonal and inter-annual rainfall variability that characterizes the Brazilian semiarid region. Since the crops are used for the subsistence of small farmers' families and for animal feeding, there is a strong relationship between agricultural productivity and food security in rural regions. According to the Brazilian Institute of Geography and Statistics (IBGE 2014), the Northeast region presents the most critical situation within the country in regard to food security, and 38% of the population presents signs of food restrictions in their daily diet.

For more than a century, efforts have been made to support the formulation of strategies for the prevention and mitigation of the effects of droughts (Gutierrez et al. 2014). More recently, in 2013 the National Integration Ministry (*Ministério de Integração Nacional − MI*) established partnerships with National Water Agency (*Agência Nacional de* Águas − *ANA*) and with the Ceará Foundation for Meteorology and Water Resources (*Fundação*

Cearense de Meteorologia e Recursos Hídricos − Funceme), in addition to other institutions, to implement a model of drought monitoring, based on the methodology of the United States Drought Monitor, developed at the University of Nebraska. The project receives technical and financial support from the World Bank and other international partners such as the United States National Drought Mitigation Center (Martins et al. 2015).

Considering the drought that has been affecting the Brazilian semiarid region for the past 6 years, the federal government has requested information for the identification of the municipalities affected by the phenomenon with the main objective of supporting emergency impact mitigation measures. In this context, the National Center for Monitoring and Early Warning of Natural Disasters (*Centro Nacional de Monitoramento e Alertas de Desastres Naturais − CEMADEN*) has been monitoring, since 2012, the drought situation in the semiarid region and its impact, which information is available in monthly bulletins from September 2015 onwards (http://www.cemaden.gov.br/situacao-atual-da-seca-no-semiarido-e-impactos-fevereiro-de-2017/). It should be noted that the seasonal and sub-seasonal climatic forecasts are also presented in monthly bulletins. In the short term (up to 10 days), Eta numerical model forecasts (Mesinger et al. 1988) from the Center for Weather Forecasting and Climatic Studies (*Centro de Previsão de Tempo e Estudos Climáticos – CPTEC*) of National Institute for Space Research (INPE) are used. For a period of two weeks, a similar methodology is employed, but using the global model of CPTEC/INPE (Cunningham et al. 2014) and the Global Forecast System (GFS) of the National Centers for Environmental Prediction in the United States (Kalnay et al. 1990). In addition, such information supports emergency drought impact mitigation measures under the MI (Resolution Nº 13, May 22, 2014).

Specifically, regarding the impact of agricultural droughts in municipalities in the SAB, CEMADEN provides municipal databases containing remote-sensing-based drought indices and other hydrometeorological data for the identification of municipalities affected by droughts. Such an initiative aims to meet the provisions established in Presidential Decree Nº 8,472, June 22, 2015, in the context of the *Garantia Safra* Program of the Ministry of Agrarian Development (*Ministério do Desenvolvimento Agrário − MDA*). The *Garantia Safra* Program is operated by the SAF/MDA since 2002. It aims to guarantee minimum conditions of survival of the rural family farmers affected systematically by drought or excess rainfall. The family farmers may receive a benefit on the occurrence of drought or excess rainfall, which causes at least 50% of loss on productions of beans, corn, rice, cassava or cotton crops. The *Garantia Safra* covers the family farmers in the Northeast, in the Mucuri and Jequitinhonha valleys, the north of the state of Minas Gerais, and in the north of the state of Espírito Santo (predominantly semiarid).

In the scope of the above, the methodology used for monitoring the impact of agricultural droughts in the SAB is presented in this study, including an analysis of the hydrological year 2015−2016, considering different water stress indexes for the identification of the municipalities affected and the assessment of the methods and tools used.

MATERIALS AND METHODS

DELIMITATION OF THE MONITORED AREA

The monitored area (Figure 1) is located in the equatorial zone (1–21° S, 32–49° W) and covers an area of 1,800,555 km^2, which represents approximately 20% of Brazil's territory. The limits of the monitored area were defined by SUDENE, that include 1,989 municipalities, all monitored by CEMADEN for the impact of drought. Most of the study area is covered by mixed grasslands−

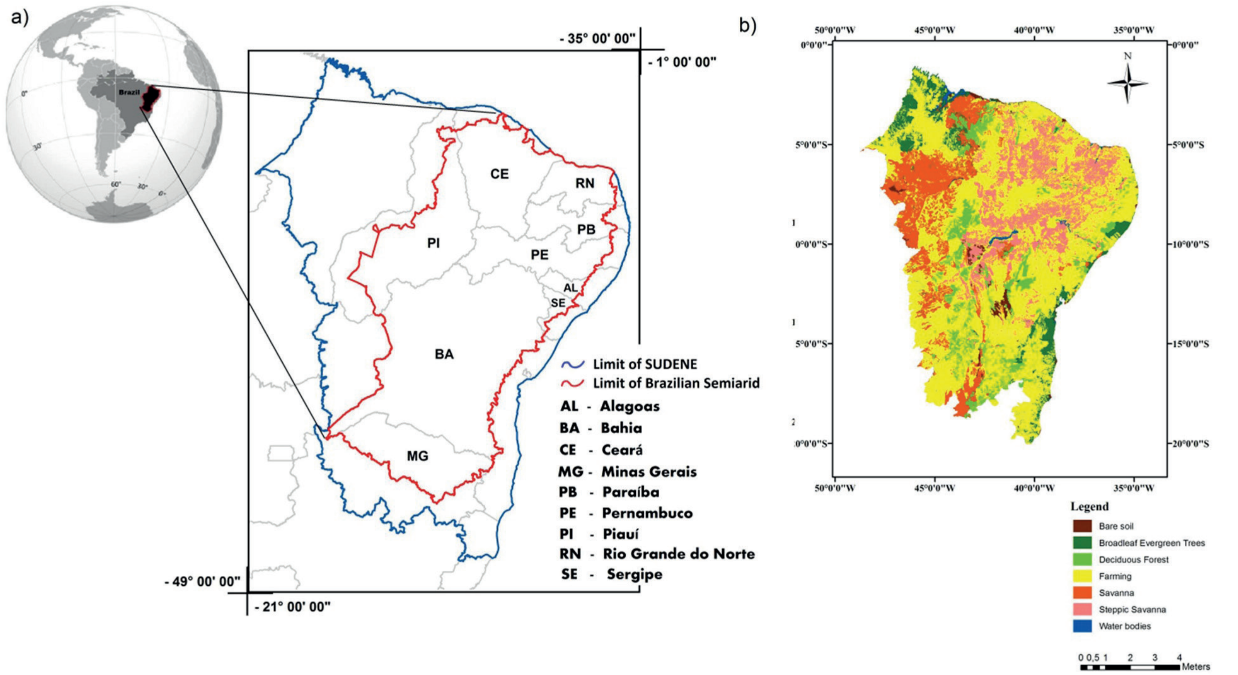

Figure 1 - Geographic limits of the monitored area (SUDENE's acting area - blue line; limits of the Brazilian semiarid region - red line) (**a**); and land use and land cover map of the Brazilian Northeast (Source: Adapted from Vieira et al. 2013) (**b**).

croplands. Other land types covered are 'caatinga' (closed and open shrublands) and savanna (Figure 1). In 2010, the total area for pasture and agricultural activities was 1,024,621 km^2, which represents 57% of the Northeast of Brazil (Vieira et al. 2013).

The Brazilian semiarid region is included in the acting area of SUDENE, covering an area of 980,323 km^2 and including 1,136 municipalities (Figure 1).

METHODOLOGY FOR MONITORING DROUGHT

The quantification of drought is usually determined by remotely sensed spectral indices and water balance simulations. A number of drought indices, including meteorological (Wilhite and Glantz 1985), remote sensed, hydrological and other indicators, have been used to measure drought impacts (Palmer 1965, 1968, Kogan 1990, 2002, McKee et al. 1993, Keyantash and Dracup 2004, Bhuiyan et al. 2006, Yagci et al. 2011, Zhou et al. 2012, Du et al. 2013, Yang et al. 2013, Abbas et al. 2014, Cunha et al. 2015). Traditional methods of drought assessment and monitoring rely on rainfall data (e.g., Precipitation Percentile). However, in a region where the density of meteorological stations as well as the temporal scale of the data are insufficient, it is impossible to monitor drought using indices that are based on rainfall data. In contrast, satellite-sensor data are consistently available and can be used to detect the onset of drought, its duration and magnitude across large areas (Thiruvengadachari and Gopalkrishna 1993). A large number of drought indices are based on the Land Surface Temperature – Normalized Difference Vegetation (LST-NDVI) space such as Vegetation Health Index (VHI, Kogan 1990, 1997), Temperature-Vegetation Drought Index (TVDI, Sandholt et al. 2002), Vegetation Supply

Water Index (VSWI, Carlson et al. 1990, 1994), and Drought Severity Index (DSI, Mu et al. 2013, Cunha et al. 2015). So, considering the spatial dimension of the monitored area, as well as the available in situ data, in the present study the indicators adopted were based on remote sensed data and rainfall measurements.

Meteorological Drought

a) Precipitation Observational Data – Integrated Network

The rainfall data necessary for the monitoring implemented by CEMADEN derive from the rain gauge station data from different sources (INPE, CEMADEN, National Meteorology Institute [*Instituto Nacional de Meteorologia – INME*T], and the State Meteorology Centers) for the period 1999-2017. The data are interpolated in a regular grid of 5 km of spatial resolution, using the ordinary kriging technique (Matheron 1969). The Kriging method is considered the best linear unbiased estimator because its estimates are weighted linear combinations of the data and deviations between value and estimated value are null. The same interpolated data was used in the water balance model developed by PROCLIMA/INPE (Souza et al. 2001), to estimate soil moisture and the days of soil moisture deficit.

b) Evaluation of Cumulative Rainfall Percentiles in the Hydrological Years

The percentile is used as a way to classify the status of each municipality according to the amount of precipitation received, as explained below:

- Very Dry (precipitation below or equal percentile 15);
- Dry (precipitation between percentiles 15 and 35, where 35 is included);
- Normal (precipitation between percentiles 35 and 65, where 65 is included).

The thresholds adopted were also used by Xavier and Xavier (1999) to assessment of dry and wet periods in Ceará State, localized in semiarid region. The meteorological drought monitoring is based on percentiles considering the frequency distribution of precipitation divided into three parts. For the calculation of the percentiles of cumulative rainfall, a historical precipitation database is used, starting in 1999, which is updated in monthly bulletins. The historical cumulative data are organized in ascending order and all of them represent the total of the series, i.e. 100% of the data. For example, percentile 15 is the amount of (historical) precipitation that separates 15% of the lowest values in the series from the remaining 85%. Therefore, if at a certain period of time a region was classified as 'Very Dry', this means that the cumulative rainfall of this region was classified among the 15% lowest values in the series. The category 'Dry' includes regions that present precipitation between 15% and 35% of the lowest values in the series, and so on.

Agricultural Drought

a) Vegetation Supply Water Index (VSWI)

The VSWI derives from the Normalized Difference Vegetation Index (NDVI) and canopy temperature data, generated by the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor aboard the AQUA and TERRA satellites, with a resolution of 1 km (composition performed in order to obtain data with higher temporal resolution). The data used comprises the period 2003-2016.

The index indicates a drought condition when the NDVI (vegetation index) is low (indicating low photosynthesis activity) and the vegetation temperature is high (indicating water stress). Therefore, the index is inversely proportional to the moisture content of the soil and provides indirect information about the water supply to the vegetation (Cunha et al. 2015). The relationship between canopy temperature and the NDVI has been used at large drought monitoring centers in different countries, such as the United States (National Oceanic and Atmospheric Administration, NOAA) and China.

One of the adaptations conducted for the application of the VSWI as an indicator of drought impact involved calculating the index only over pasture and agricultural lands, thus excluding urban areas, water bodies and natural vegetation (Cunha et al. 2015). The spatial limit of the areas used for pasture and agricultural lands was extracted from the Land Cover Land Use map of the study area (Vieira et al. 2013). This map was derived from a Landsat 7 equipped with Enhanced Thematic Mapper Plus (15 m) and Landsat 5 Thematic Mapper (30 and 60 m) mosaic (Vieira et al. 2013). The map presents the location and distribution of major vegetation types and non-vegetated land surface formations for the Northeast Brazil Region, which includes the semiarid region (Figure 1).

The VSWI anomalies percentage (difference between the average VSWI and the VSWI value) were calculated to evaluate changes in the index relative to normal conditions. A positive anomaly percentage indicates different levels of vegetation stress, and a negative anomaly percentage means a favorable condition for vegetation (Cunha et al. in press). From the VSWI anomalies percentage it is possible to estimate the percentage of the area used for agricultural and livestock activities that has been affected by the drought.

RESULTS

ANALYSIS OF THE HYDROLOGICAL YEAR 2015-2016

A first characterization of the meteorological drought was conducted taking into account information from rain gauges obtained from the integrated network of precipitation data collected in the last six hydrological years (from the start of the rainy period until the end of the dry period). The concept of a hydrological year is used to enable an assessment of drought conditions considering the region's hydrological cycle (DNAEE 1976), i.e. considering that it starts in October and ends in September. The last hydrological years were marked by precipitation levels below the climatological average for SAB, as shown in Figure 2. According to Marengo et al. (in press) in a companion paper, since 2011 the semiarid region of NEB has been experiencing one of the 147 longest and most intense droughts in decades. Meteorological conditions associated with the temperatures of the Atlantic and Pacific oceans, including the presence of an intense El Niño event in 2015−2016, as well as large-scale disturbances, resulted in a shift of the intertropical convergence zone to the North of its climatological position, contributing to the worsening and persistence of drought conditions. In terms of annual accumulated precipitation, the hydrological year 2015−2016 was identified as the second-driest period after 2012−2013 (Figure 2), in agreement with Marengo et al. (in press).

Figure 3a shows the classification of drought condition according percentile precipitation for hydrological year 2015-2016 for each municipality in the monitored area. In addition, Figures 3b, 3c and 3d show the accumulated precipitation corresponding to the 15% (very dry), 30% (dry) and 65% (normal) percentiles. For most of the semi-arid region, the cumulative annual precipitation below 600 mm corresponds to the very dry condition, while in the interior of semi-arid region the same drought classification corresponds to precipitation below 300 mm (Figure 3b). In order to discuss the affected sub-regions, the results were analyzed considering all the states in the SUDENE's acting area. According to the percentile precipitation, aw the most affected areas (precipitation deficit) are those identified as "Very Dry", mainly localized in the states of Maranhão, Piauí, southern Ceará, Alagoas, Sergipe, east and south of the state of Bahia, some parts of northern Minas Gerais and

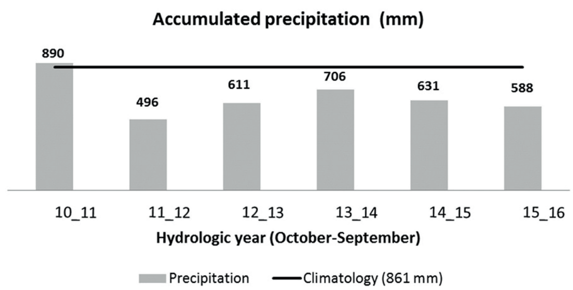

Figure 2 - Accumulated precipitation for the period from October 2015 to September 2016.

northern Espírito Santo states (Figure 3a). The total municipalities identified with very dry and dry conditions were 652 and 490, respectively. The State of Bahia, according to the percentile, was the one that presented the largest number of municipalities under dry conditions (276 municipalities).

Figure 4 shows a time series of accumulated annual precipitation of a box including a region in very dry condition (southeast of Bahia state). This figure illustrates the temporal evolution of dry condition in this specific region. As can be noted in the time series from 1999 to 2016 (seventeen years), only in the hydrological year 2002-2003, as well as in 2015-2016, this specific region experienced the very dry condition, emphasizing that in the last year the condition is even worse than the 2002-2003 one´s.

In addition to drought intensity, the extension of its impact in areas covered by pasture and agricultural lands was also evaluated by using the VSWI anomalies percentage. It is highlighted that this analysis was performed only for lands that were covered by pastures and/or crops; thus, natural vegetation, urban areas and water bodies were excluded from the analysis. These areas were excluded because their inclusion could interfere with the meteorological and hydrological conditions and maintain normal vegetation health in spite of poor rainfall or water-stress, which can cause a large response delay. Figure 5 presents the intensity of drought impact to the hydrological year 2015−2016, which dark red shades are associated with more intense impact. . In general, the below normal precipitation condition observed during 2014-15 (as indicated by the percentile, Figure 3a) induced the low vegetation productivity as indicated by the VSWI anomalies. Even as indicated by the percentile, the VSWI anomalies maps shows that all the states included in the acting area of SUDENE presented vegetative drought conditions. The highest drought intensity was mainly observed in the south part of the region (including the states of Espírito Santo, Minas Gerais and Bahia), and also in the central part of the semiarid region (mainly some parts of Pernambuco State). As it can be observed, the impact of drought on the vegetation was not restricted only to the limits of the semiarid area, i.e. parts of the states of Maranhão and Espírito Santo were also affected. In particular, regarding the drought impacts in the State of Maranhão, considering the last 6 hydrological years the 2015-2016 was the ones that presented the most significant impacts, as also highlighted by Marengo et al. (in press).

Figure 6 presents the municipality area percentage used for agriculture and livestock farming affected by the drought. Just in the hydrological year 2015−2016, 923 municipalities had at least 50% of their area affected, which represents about 50% of the municipalities in the SUDENE coverage area. The State of Bahia was the ones that presented the largest impacted area, followed by the State of Ceará. The total affected areas by the drought add to approximately 53 million hectares (Table I).

DROUGHT IMPACT FOR THE HYDROLOGICAL YEAR 2015−2016

Damages due to droughts are related to decreased agricultural production, and effects on livestock farming, water supply and the economy, which requires the availability of financial resources from the Federal Government to the municipalities affected.

As noted by Marengo et al. (2016), according to the MI the losses caused by the effects of drought on the agriculture sector in the Northeast of Brazil in 2010−2015 were US$6 billion. According to data from the Integrated Disaster Information System − S2ID, developed by the National Secretariat for Civil Protection and Defense (*Secretaria Nacional de Proteção e Defesa Civil – SEDEC*), only in 2016 did the Federal Government recognize the emergency situation in 1,270 municipalities as a result of the drought. Such recognition allows the municipalities to request the support of the Federal Government for emergency measures to face the water scarcity period. In addition to enabling access to treated water supply programs, such as the *Carro-Pipa* Federal Operation, this recognition also allows municipalities to be entitled to other benefits. Among them, the debt renegotiation in the agriculture sector and acquisition of basic food baskets to assist in the economic recovery of the regions affected.

Figure 7 presents the number of municipalities affected by the drought in the past hydrological year of 2015−2016; these were identified through the VSWI, the precipitation percentile, as well as the number of municipalities affected by the drought and recognized by the MI and the Secretariat of Family Farming of the MDA (SAF/MDA). For the evaluation of losses, in addition to information associated with CEMADEN indexes (VSWI and precipitation data), the SAF/MDA uses meteorological analyses provided by the INMET, based on their own data or on data provided by other institutions in the country or abroad; crop estimates provided by the IBGE; and information on constant losses of technical reports, in the form defined in decree by the MDA.

From Figure 7, and comparing the municipalities impacted by the drought and dry season recognized by the MI, it is observed that the indexes (VSWI and precipitation percentile) underestimated the number of municipalities affected in the states of Espírito Santo, Paraíba and Pernambuco, and overestimated the number of municipalities affected in the states of Ceará, Maranhão and Rio Grande do Norte. In the states of Alagoas and Bahia, the indexes diverged, i.e. when an index underestimates the other overestimates. Best estimates were obtained for the states of Minas Gerais and Espírito Santo. Comparing the municipalities that joined the Crop Guarantee Program, the indexes (VSWI and precipitation percentile) overestimated the number

TABLE I
Impacts of drought in the municipalities related with SUDENE's acting area from 2015 to 2016.

State	Municipalities	Municipalities with more than 50% of affected area	Affected areas (ha)	Estimation of family farming establishments susceptible to drought impact
BA	417	194	15,867,556.68	333,640
CE	184	86	4,331,446.80	151,048
PI	224	115	7,548,151.92	106,879
PB	223	105	2,111,169.13	64,925
AL	102	39	895,407.80	69,372
RN	167	79	1,731,129.62	37,382
MA	217	48	3,719,232.72	36,072
SE	75	34	921,318.92	42,470
ES	28	27	1,950,260.16	25,171
PE	184	76	3,584,318.06	141,143
MG	168	120	10,004,976.17	99,017
TOTAL	1989	923	52,664,967.98	1,107,119

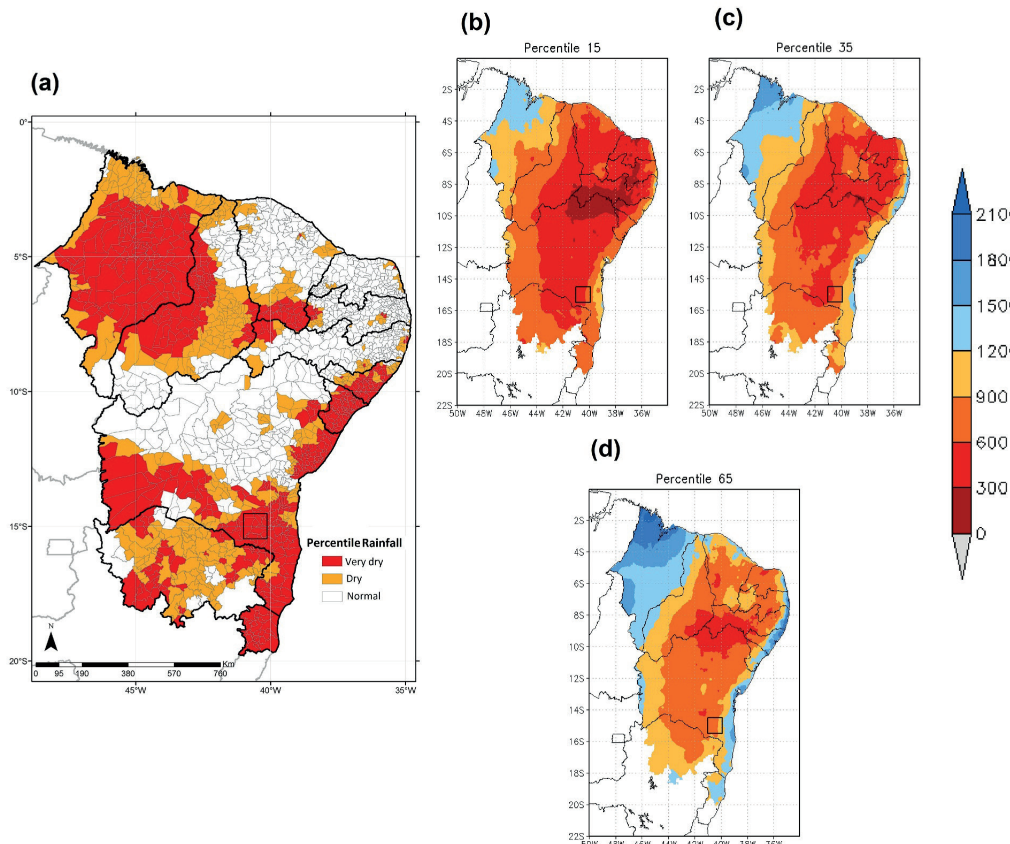

Figure 3 - Classification of the drought condition according to the percentile of precipitation from October 2015 to September 2016: (**a**) and accumulated rainfall (mm) for thresholds Percentile 15% (**b**) Percentile 35% (**c**) and Percentile 65% (**d**).

of municipalities in the states of Ceará, Paraíba, Pernambuco, Piauí and Rio Grande do Norte, whereas they underestimated these for the states of Alagoas, Maranhão, Minas Gerais and Sergipe. The only divergence observed was for the state of Bahia, i.e. the VSWI underestimated the number of municipalities and the percentile overestimated them. Best estimates obtained were for the states of Bahia and Minas Gerais. It is observed that the estimate of municipalities affected by drought obtained with the VSWI is in agreement with the number of municipalities recognized by the MI in the states of Bahia and Espírito Santo. It is highlighted that the number of the municipalities affected by drought underestimated through the indexes (VSWI and percentile) is associated with the fact that the methodology contemplates the evaluation of all the municipalities included in the SUDENE acting area, without repressing those that are not part of the Crop Guarantee Program (as the majority of the municipalities that are outside the limits of the semiarid region). The number of municipalities in the states where underestimation was observed may be correlated with the municipality's policies with regard to insurance application. In general, other reasons for the discrepancies may be associated with the fact that the family farming business units are included in small areas, or the fact that the municipalities have more or fewer field workers to develop reports from *in loco* inspections (and this is one of the criterion adopted by the *Garantia Safra* Program).

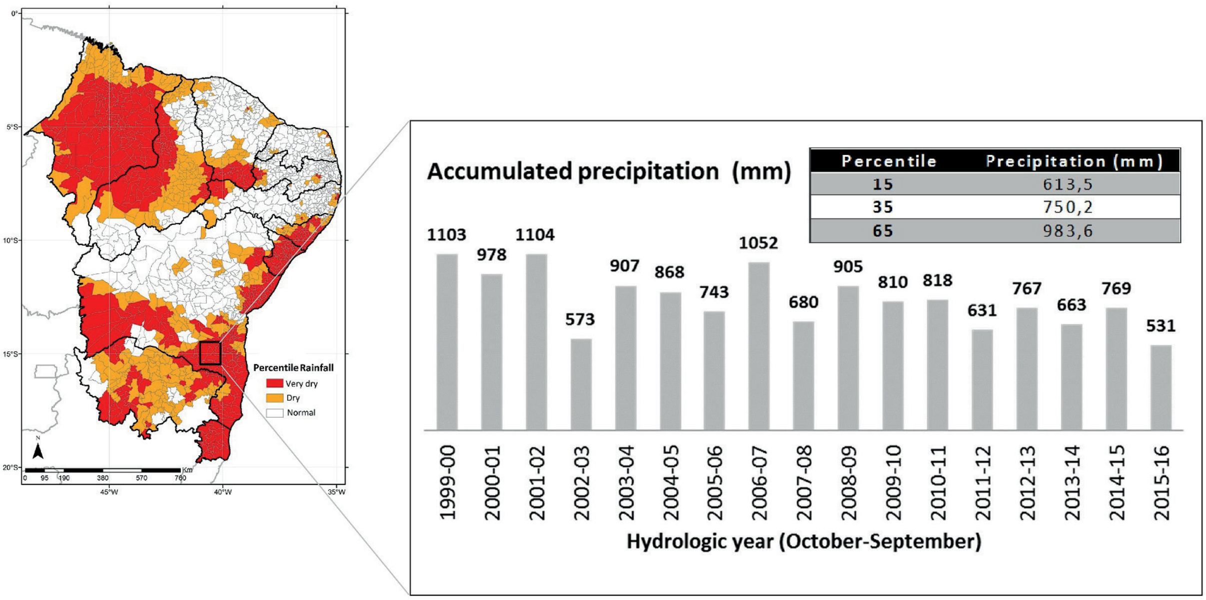

Figure 4 - Accumulated precipitation (mm) for a selected area characterized by a "Very Dry" condition (black box) for the period of 1999-2016, including the values of percentiles.

Figure 8 presents the number of individuals affected by droughts and dry periods in 2016 that are recognized by the Federal Government, as well as the estimated number of individuals affected by droughts based on the municipalities identified by the VSWI and precipitation percentile indexes. In general, the indicators overestimate the number of individuals affected, except those estimated for the states of Ceará and Paraíba, which were underestimated. For the states of Ceará, Espírito Santo, Paraíba and Rio Grande do Norte, the indexes showed better correlations, whereas the worst estimate was observed for the state of Maranhão. It is noted that the number of people affected by droughts and reported by the MI is inferior to the total number of inhabitants in those municipalities, and these are considered to be estimates of the number of people affected by the VSWI and percentile indexes.

According to data from the Special Bureau for Family Agriculture Business and Development, 1,220 municipalities received the *Garantia Safra* owing to crop losses in 2015−2016, providing assistance to approximately 700,000 farmers, all due to losses associated with droughts (SAF/MDA 2017).

DISCUSSION

In this paper, the efforts of the National Center for Monitoring and Early Warning of Natural Disasters (CEMADEN) to monitor the impact of drought in the semiarid region of Brazil are presented. The methodology used for monitoring and an analysis of the hydrological period of 2015−2016 are presented here. This last year is included in the period comprising the past five hydrological years, which has been marked by drought recurrence in the semiarid region.

The drought that has been affecting the Brazilian semiarid region since 2012 until today is characterized by an intensity and impact in agriculture and water supply not seen in the past decades. The hydrological year 2015−2016 was the second-driest period after 2011−2012. The

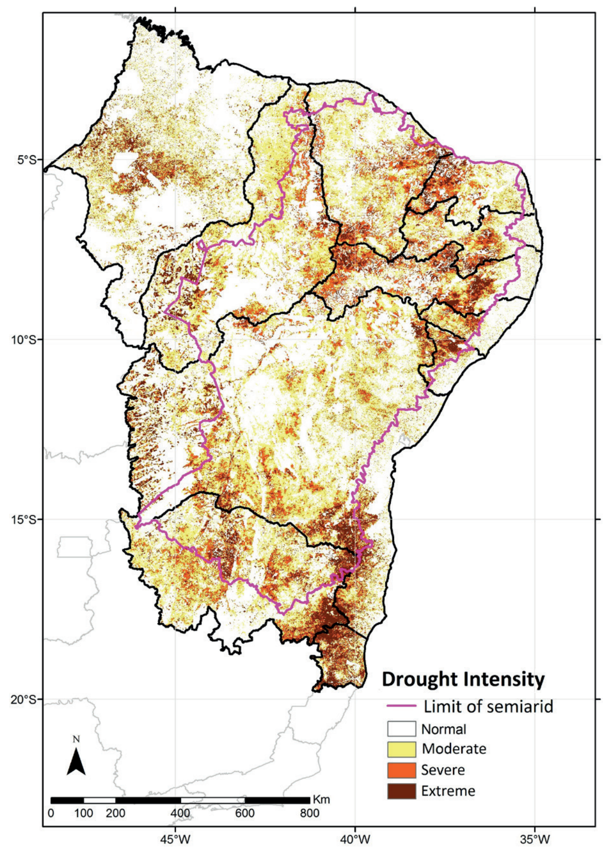

Figure 5 - Drought intensity based on the VSWI anomaly for hydrological year 2015−2016.

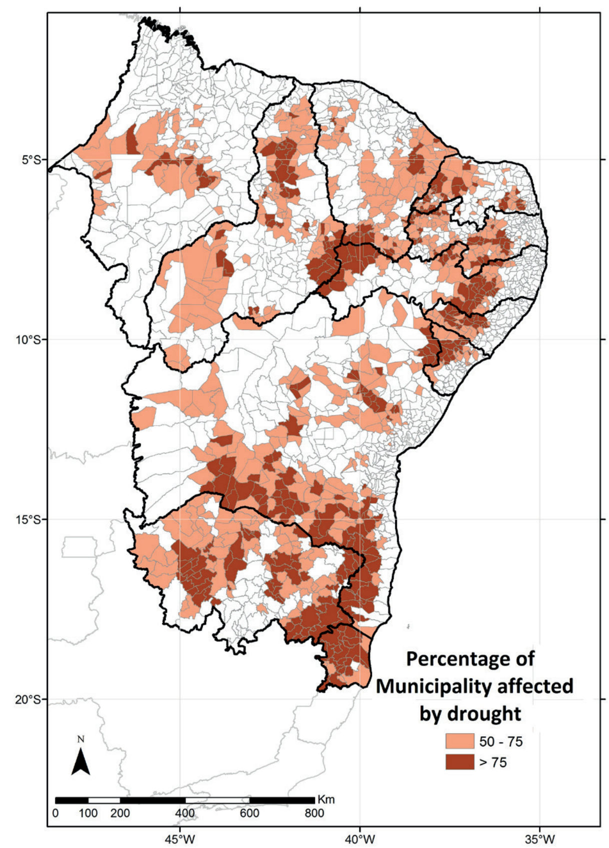

Figure 6 - Municipality area percentage affected by drought according to VSWI anomaly percentage for hydrological year 2015−2016.

precipitation percentile and VSWI anomalies percentage depict a drought situation, indicating that all the states in the SUDENE's acting area were affected by drought during the hydrological year 2015−2016. It is highlighted that the impact of drought on the vegetation was not restricted only to the limits of the semiarid area, i.e. parts of the states of Maranhão and Espírito Santo were also affected. Figure 9 presents the spatial pattern of agreement of the drought monitoring methodologies considered in this study. In total, the agreement of the methodology (percentile and VSWI indicators) occurred in approximately 60% of the municipalities. Since the indicators are calculated with different data types, some divergences were expected to be found. The low density of rainfall stations in some regions (such as in the State of Maranhão) certainly corroborates for the greatest discrepancies in the final result. As highlighted by Cunha et al. (2015), due to the different sources of information and principles that are used for drought indices, monitoring results that are obtained from indicators often have certain differences. It can be determined that any single index is not sufficient for precisely depicting drought characteristics. Thus, the combined use of different indicators at the same time or indices that integrate various sources of information may achieve results that are more consistent with the actual situation.

In general, the indexes were adequate for the estimation of the number of municipalities and individuals affected, which can be seen through the magnitude of the estimated values. It should be noted that, in some cases, local policies and

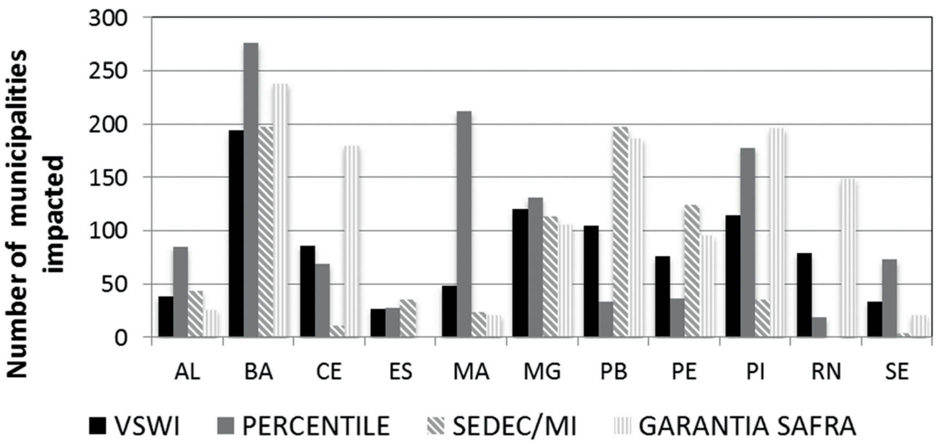

Figure 7 - Municipalities affected by drought according to the methodology proposed (VSWI index and precipitation percentile) and those duly recognized by the National Integration Ministry and the Crop Guarantee Program.

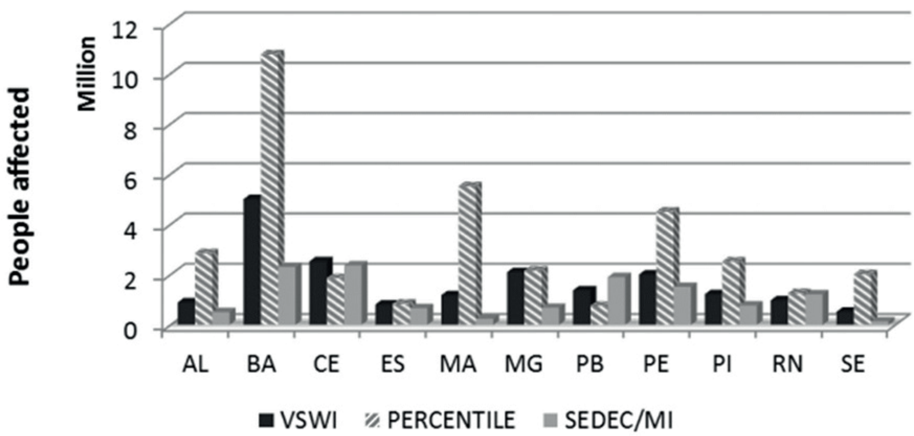

Figure 8 - People affected by droughts according to the methodology proposed (VSWI and precipitation percentile) and those duly recognized by the National Integration Ministry.

actions may have validated some of the differences identified. In addition, it is important to highlight that improvements are already being made in order to include socioeconomic aspects in the methodology used.

Only considering the hydrologic year of 2015−2016, drought impacted approximately 12 thousand people in the acting area of SUDENE, thus exceeding the limit of the semiarid region. Concerning to economic losses, about R$ 600 million were spent, including only the Crop Guarantee Insurance. Drought also caused damage to agricultural production, with grain production in the Northeast region presenting a reduction of about 40% compared with the crop of 2014−2015. For sugarcane production, the reduction was in the order of 19% relative to the previous crop (CONAB 2017). Regarding the impact on water supply, the water reserves of the equivalent reservoirs in the Northeast have presented successive reductions

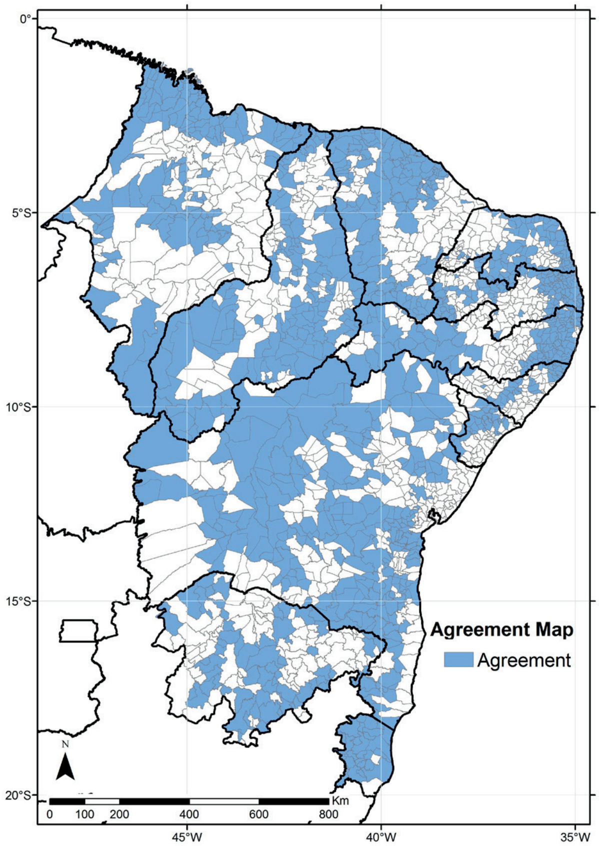

Figure 9 - Agreement spatial pattern (blue polygons), considering the drought monitoring methodology.

since 2012, which resulted in a stored volume of approximately 19% in January 2016 (ANA 2017).

The drought affecting the Brazilian semiarid since 2012 has triggered discussions about improvements in political actions and drought mitigation requirements, with consequently resulting management improvements at federal and state level. Despite of the efforts made in drought management, there are gaps and opportunities that should guide decision makers, aiming to focus on vulnerability reduction and resilience building. These should be supported through regular drought monitoring and forecasting and early warning systems, as well as through impact analyses and the promotion of mitigation and planning measures. In this scope, CEMADEN proposed drought monitoring methodology for the semiarid region, providing technical/scientific information to support the activities of the Federal Government related to the mitigation of drought impact, and considers as a priority the investment in improving impact monitoring methodologies. Seasonal weather forecasting, together with in situ and satellite data monitoring, enable future weather forecasts and the quantification of drought intensity and extension. The identification of the areas affected, in particular those that have been recurrently affected, is of utmost importance in order to guide local actions by the Federal Government. Then, the most vulnerable populations may receive assistance in a short time, as well as, the public expenses are prioritized to the necessary actions in a more direct manner. Additionally, the identification of the areas most affected is crucial to support managers in decision making in terms of drought adaptation measures.

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