Brazilian Experience on the Development of Drought monitoring and Impact Assessment Systems

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1. Introduction

Possibly related to global warming, droughts have increased in frequency and intensity in several countries of the planet in the recent decades (Dai, et al, 2004; IPCC 2014, Zhou, et al, 2012). Brazil is not an exception; the country is affected in the present and possibly in the future by more intense and frequent weather and climate extremes. Northeast Brazil (NEB) and Brazilian Amazon (Figure 1) appear as the most vulnerable regions to droughts and floods (PBMC, 2013 a,b). In the recent years, droughts have affected different regions of Brazil: Northeast Brazil during 2012-2017; southeastern Brazil in 2014-15; Amazonia in 2005, 2010 and 2016; Southern Brazil in 2005 and 2012 (Coelho et al., 2016b; Cunha, et al, 2018a; Marengo, et al, 2008, Marengo and Espinoza 2016; Marengo, et al, 2017, 2018; Cunningham, et al, 2017; Nobre, et al, 2016). To face this challenge and enhanced early warning for early action to drought risk management is essential to increase society's resilience, by means of enhancing knowledge about drought occurrence, its potential social and economic effects and the related vulnerabilities of potentially affected people.

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). In 2013 the National Integration Ministry (MI) established partnerships with National Water Agency (ANA) and with the State of Ceará Foundation for Meteorology and Water Resources (Funceme), together with other institutions, implemented an strategy for drought monitoring named as *Monitor de Secas* (Martins, et al, 2015), which was based on the methodology of the United States Drought Monitor, developed at the University of Nebraska.

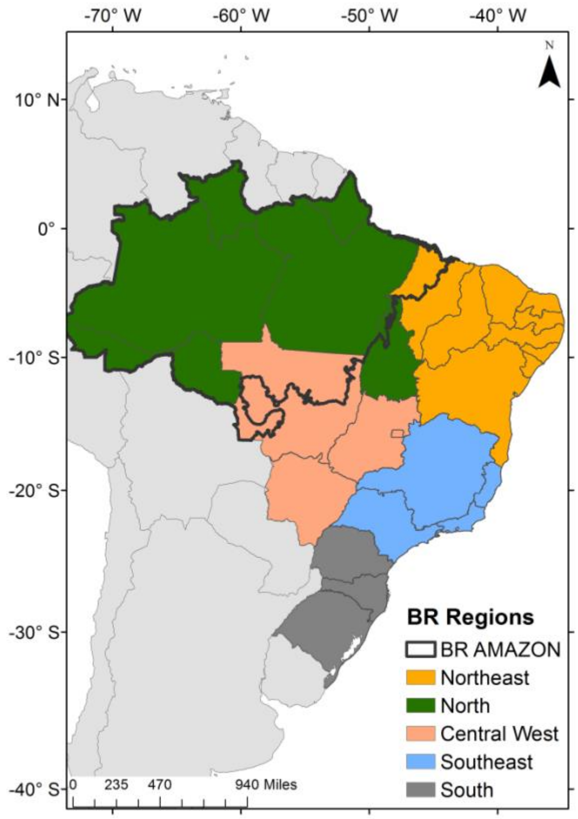


Figure 1 - Geographical location of Brazilian Regions

Drought is a recurrent phenomenon in Brazil (PBMC, 2013 a). For instance, as a consequence of the drought that has been affecting the semiarid region, in the Northeast Brazil (NEB) since 2012; the federal government has requested information to identify municipalities affected by this phenomenon with the main objective of supporting emergency impact mitigation measures in favor of small-scale farmers in this region. In this context, the National Center for Monitoring and Early Warning of Natural Disasters (CEMADEN) has been monitoring, since 2012, the drought situation and its impacts. All this information is available in monthly bulletins from September 2015 onwards at the CEMADEN website (http://www.cemaden.gov.br/categoria/monitoramento/secas-no-semiarido).

Assessing the spatial and temporal identification of drought episodes is an extremely complex process. Accurate monitoring of the temporal, spatial distribution and severity of drought represent effective means to reduce associated losses. Several methodologies and indices have been developed to monitor and quantify drought intensity and impacts, based on climatic and hydrological variables, as precipitation (Palmer, 1965; Gibbs and Maher, 1967; McKee, et al, 1993), soil moisture and water balance (Palmer, 1968), evapotranspiration, streamflow, reservoir, groundwater levels and vegetation conditions (Kogan 2005; Hao et al, 2018), or using a blend of indices (Abbas, et al, 2014).

Drought indices are particularly useful for characterizing water deficit, as well as to monitoring the impact of climate variability on natural vegetation and crops robustness. Due to the different sources of information and methodologies that are used for drought indices, the monitoring of droughts from various indices may vary. It must be highlighted that any single index is enough for precisely depicting drought characteristics (Zhou, et al, 2012). Thus, the combination of different indicators that integrate various sources of information may help to better achieve consistent monitoring of drought risk and their characteristics. Based on this concept, CEMADEN has developed drought indicators that combine rainfall-based drought index and remote sensing-based index. Through these drought indicators, the magnitude or intensity, speed of onset, duration, and area of extent of drought can be estimated. These drought characteristics are valuable for the impact assessment, which plays an important role in drought risk management. This is important for identifying most vulnerable groups and sectors affected by drought as recommended by UNISDR (2009).

Therefore, the purpose of this paper is to present the efforts developed by CEMADEN especially related to (i) the progress already achieved in drought hazard monitoring system in Brazil; (ii) the development of drought impacts assessment for the last 6 years in different regions of Brazil; (iii) the challenges ahead in assessing the drought risks and their impacts on the national level for disaster risk reduction.

2. Background of drought and impacts in Brazil

Historically, during periods of extreme drought, food, water and energy issues have been affected. The most vulnerable communities in the drylands of NEB are under severe risk due to reduced subsistence production, reduced income and increased pricing of agricultural products. The recent drought events in the region (2012-2017) continued to highlight the vulnerability of this area and confirm the risk of major impacts due to climate change. This 6-year drought shows an intensity and impact not seen in several decades in the regional economy and society. The analysis of this event, using drought indicators as well as meteorological data show that since the middle 1990s to 2016, 16 out of 25 years experienced rainfall below the historical average. This suggests that the recent drought in Northeast Brazil may have in fact started in the middle-late 1990s, with the intense droughts of 1993 and 1998, and then the sequence of dry years (interrupted by relatively wet years in 2007, 2008, 2009 and 2011) after that may have affected the levels of reservoirs in the region, leading to a real water crisis that was magnified by the negative rainfall anomalies since 2010 (Marengo, et al, 2017). The Três Marias reservoir, located in the upper São Francisco basin in NEB, was one of the most affected. Mean discharge in the summer (Out – Mar) of 2014 was 357.0 m^3/s and in 2015 was 378.0 m^3/s, far below the average, 988.0 m^3/s (64% and 62%, respectively), for the period 1941 – 2015. The useful volume of Três Marias was approximately 3–10% from July 2014 to January 2015 (Zhang, et al, 2018). The São Francisco Region plays an important role in electric power generation, irrigation and water supply for the Southeast and Northeast Regions of Brazil. The Três Marias reservoir also regulates the flow of the main river and contributes to the replenishment of the Sobradinho and Itaparica reservoirs located downstream.

The Amazon region is vulnerable to the effects of extreme climatic events such as prolonged “mega-droughts”, to changes in the rainy and dry seasons (period, intensity and extent), and to increase in the risk of fires. Three “mega droughts" in 2005, 2010 and 2016, and intense floods in 2009, 2012 and 2014 and their impacts on population and biodiversity are examples of what could happen in Amazonia as consequence of climate change. Past mega-droughts were registered in 1925-26, 1982-83 and 1997-98 due to El Niño. These events were classified at the time of their occurrence as “one-in-100 year event”, as well as their impacts on natural and human systems in the region show the vulnerability of population and ecosystems to the occurrence of hydro-meteorological extremes in the region (see reviews in Marengo and Espinoza, 2016; Jimenez-Muñoz, 2013; Tomasella, et al, 2011, 2013; Aragão, et al, 2018; Marengo et al, 2018). Although drought and burning may have natural causes, such as the ones related with the events observed in 2005, 2010, and 2016, human activities such as deforestation for cattle ranching may also be important in increasing the number of fires, as in 2004 and in 2016 (Aragão, et al, 2018).

In the Southeast region of Brazil rainfall has decreased around 5 mm $year^{-1}$ (or 165 mm in total) for both the annual and wet season of the period 1979–2011, and inflows to most hydroelectric dams of the region have decreased around 20% for the same period (Rao, et al, 2016). This region experienced during 2014-2015 one of the most severe droughts in decades. This rainfall deficiency of about 45-50% during summer of 2014 (Nobre et al, 2016) has generated water shortages and a water crisis that have affected population and local economies in the metropolitan region of Sao Paulo, the largest megacity in South America. By January 2015, main reservoirs had reached storage levels of only 5% of their 1.3 billion m^3 capacity. The water crisis was aggravated by a combination of lack of rainfall and higher temperatures, the summer of 2014 being the warmest and driest over the Cantareira reservoir system since 1951. Human-induced warming may not have generated the atmospheric conditions behind the 2014 and 2015 summer droughts in Southeast Brazil, it is more likely that temperatures, augmented evaporation and excessive demand of electricity power, have affected the severity of the drought and exacerbated the impacts on the population (Nobre, et al, 2016; Coelho, et al, 2016a, b; Seth, et al, 2015; Otto, et al, 2016). However, since the austral summer of 2014, rainfall in the Southeast has been below the mean long term, affecting important reservoirs for hydropower generation in Brazil.

The central-western region has also experienced intense droughts, although less frequently than the northeast and north regions. An example of this is the most recent drought 2016-2017 started in April, beginning of the dry period, but remained throughout the wet season (October 2016 to March 2017), impacting about 75% of crops and pasture lands (Cunha et al, 2018b) in the Federal District's area.

3. Drought Monitoring and Impact Assessment

To perform drought monitoring activities and impact assessment, we consider a variety of information from various institutions, such as hydrological variables, vegetation conditions, crop yields, livestock losses, local crop information (coming from Crowdsourcing data from Seca-wiki project - field collection of agricultural data through a mobile application - CEMADEN). The main datasets used will be detailed in the next topics.

3.1 Drought indices

a) Remotely sensed data

To perform the drought monitoring and assessment impacts, CEMADEN considers both Vegetation Health Index (VHI, Kogan, 2005) and Vegetation Supply Water Index (VSWI, Carlson, et al, 1990, 1994, Cunha et al., 2015). Although the two indices provide the same information, they are calculated from different satellite sensors and have present different spatial and temporal resolutions. Thus, the indices are complementary, mainly for the characterization of vegetative/agricultural drought to the Brazilian territory. 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. The index indicates a drought condition when the NDVI 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).

b) Meteorological data

In general, droughts events are triggered by a propagation of precipitation deficit, and indices that quantify and characterize this deficit in space and time are useful for early warning drought monitoring systems. In recent years, a great number of meteorological drought indices were developed, such as the Standardized Precipitation Index (SPI - Mckee, et al, 1993), Standardized Precipitation and Evapotranspiration Index (SPEI - Vicente-Serrano, et al, 2010). Most of these indices have a statistical base methodology which has the advantage of being able to identify the rarity (return time) of drought, as well as the probability of occurrence of precipitation necessary to reduce dry conditions. The SPI is a drought index proposed by Mckee, et al, (1993), to quantify the probability of occurrence of a precipitation deficit at a specific monthly time scale. To calculate the SPI we fitted the precipitation data to a gamma probability distribution function, and then used the inverse normal distribution function to rescale the probability values, resulting in SPI values with mean of zero and standard deviation of one.

For the drought monitoring performed by CEMADEN, SPI is calculated from monthly accumulated rainfall from different sources (National Institute for Space Research - INPE, CEMADEN, National Meteorology Institute - INMET and the State Meteorology Centers) for the period 1981-2018. The data are interpolated in a regular grid of 5 km of spatial resolution, using the ordinary kriging technique (Matheron, 1969).

c) Integrated Drought Index (IDI)

IDI consists of combining the Standardized Precipitation Index (SPI) with the Vegetation Supply Water Index (VSWI) anomalies. The SPI is calculated considering the scales of 3, 6 and 12 months and AVSWI is calculated on the monthly scale. For the IDI calculation, the SPI and AVSWI data are reclassified and matched so that the classes of both indices translate into the same drought intensities, which vary from abnormally dry to exceptional drought. The IDI is calculated on the monthly scale and presented with different classes for the drought intensities. Since the IDI is generated in a georeferenced basis throughout Brazil, it is possible to compute this index at the municipal level.

d) Agro-meteorological Monitoring System

A network of soil moisture sensors was established from 2014 to 2015 by CEMADEN, in order to monitor water into to the soil over the Brazilian semiarid region (SAB), the driest and poorest region in the country (Figure 2).

The SAB covers an area of 1,128,697 km^2 and encompasses 1262 municipalities (most of these are included in the NEB). The official limits of the SAB include parts of 10 states over NEB (Sudene, 2017).

Soil moisture is currently being monitored over 595 locations, in depths ranging from 10 to 40 cm. The stations are also equipped with rain gauges, and over a subset of locations additional measurements are carried out, specifically air temperature, relative humidity, wind speed, soil temperature and solar radiation. The main goal of this soil moisture network established by over the semiarid region of NEB was to support the development of tools to characterize and quantify the risks associated with drought conditions.

Daily monitoring of water deficit for the top 20 cm layer of soil is being done. The monitoring makes use of the soil moisture index, a normalization of soil moisture (Sridhar, et al, 2008) that uses the field capacity and the wilting point as references for maximum and minimum water content in soils, respectively. The index makes possible to compare the status of water deficit over different regions and soil classes. The index is updated daily as new information is retrieved from the stations on the field.

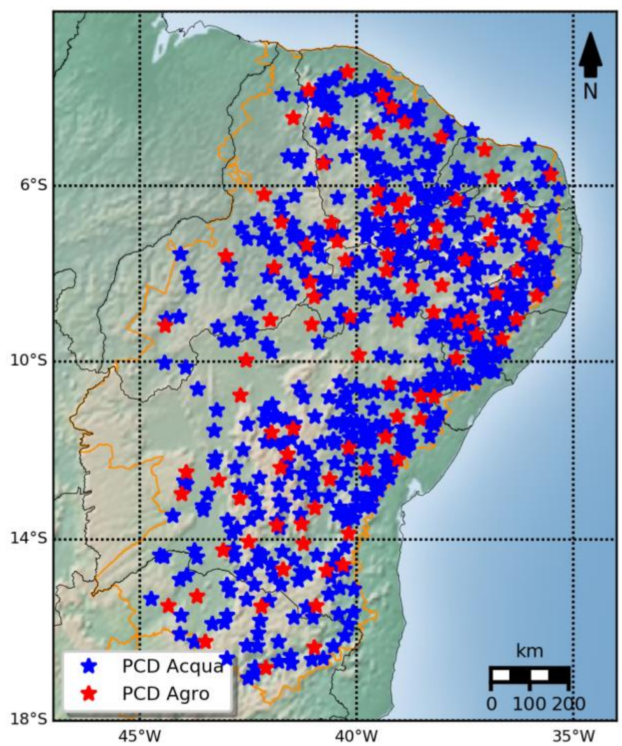


Figure 2 - Monitoring stations (PCDs) over the Brazilian Semiarid (SAB). PCD Aqua: soil moisture and rainfall; PCD Agro: soil moisture, rainfall and agrometeorological variables. The official limits of SAB are enclosed by the orange contour.

3.4 Drought impact: tools and databases

a) Integrated Disaster Information System - S2ID

In Brazil, every State, district or municipality must register in the Integrated Disaster Information System (S2ID) to request federal recognition of an Emergency Situation (SE) or State of Public Calamity (ECP) (BRASIL, 2017). The S2ID is a responsibility of the National Secretariat for Civil Protection and Defense - SEDEC; in this system, several levels of information about disasters happening in Brazil are gathered. The historical series offers generic, but relevant, information about disasters, such as location, event type and disaster date.

As for to the typology of disasters, the SEDEC adopts the classification of the EM-DAT (CRED, 2018), of the World Health Organization (WHO / UN), and their corresponding symbology, adapted to the Brazilian reality. Each occurrence, and therefore each document of the S2ID database, is related to a type of disaster, according to the Brazilian Code of Disasters - COBRADE (BRASIL, 2012).

The *Atlas Nacional de Desastres Naturais*, (CEPED, 2013) analyzed Brazilian disasters occurred between 1991 and 2012, also from the S2ID database, and conclude that dry spells and droughts were among the most frequent types of hazard in Brazil, and considered them as a major national problem. In this context, the World Bank report (CEPED and WB, 2016) showed that 48% of the total number of occurrences registered in the SEDEC database for the period 1995 - 2014 corresponds to hazards triggered by climatological events; 75% of this percentage refers to the Northeast region of the country. Damage and loss estimates in this report indicate that 54% of the country's disaster impacts are related to droughts.

b) Reservoir Monitoring System – SAR

The National Water Agency – ANA, is a regulatory agency that was linked the Ministry of the Environment (MMA) and is dedicated to enforcing the objectives and guidelines of the Brazilian Water Law (No. 9,433 of 1997). In January 2019, ANA was incorporated by the new Ministry of Regional Development, but is still responsible for monitoring the state of water resources in Brazil. It coordinates the National Hydrometeorological Network that collects, with the support of states and other partners, data and information such as river level, river discharge and sediment, reservoir levels, among others (http://www3.ana.gov.br/portal/ANA).

The Reservoir Monitoring System – SAR is a tool developed and used by ANA, which provides information on the operation and levels of the main reservoirs in the country, for hydropower generation and water supply (size over 10 hm^3).

c) Streamflow into the reservoir

Streamflow data that feed the reservoirs are obtained from ANA, the Brazilian National Electrical System Operator (ONS) and the São Paulo State Sanitation Company (SABESP).

4 Results and discussion

4.1 Analysis of the last six hydrological years over Brazil

Figure 3 shows the Integrated Drought Index (IDI) calculated to the last six hydrological years over Brazil. In NEB it is observed that the hydrological year 2011-2012 presented the most intense drought conditions. Most of the region was classified as severe drought and several subregions in the semiarid as extreme drought. In the Amazonian region, drought conditions were more intense, especially in the years 2015 and 2016. According to Erfanian, et al, 2017, the severity and extensiveness of the 2015-2016 drought in the Amazonian region surpasses the severity of the 2005 and 2010 droughts, both considered 100-year events. In addition, the ecohydrological consequences were also more severe and extensive, once substantial decreases in vegetation greenness were observed during the SON and DJF seasons over northeastern Amazon.

Figure 3 also shows that in 2012, most of the southern region of Brazil presented drought conditions in an extensive area. As determined by Getirana, 2016, the water deficit in this region reached -1.1cm, which was estimated from by Gravity Recovery and Climate Experiment - GRACE. According to data from S2ID, in 2012 the Federal Government recognized the emergency situation in 70% of municipalities (378 in total) in the Rio Grande do Sul State. Such recognition allows the municipalities to request the support of the Federal Government for emergency measures to face the water scarcity period (Alvala et a, 2017). The intense drought in these municipalities affected the water supply in the rural properties and the agricultural and livestock production.

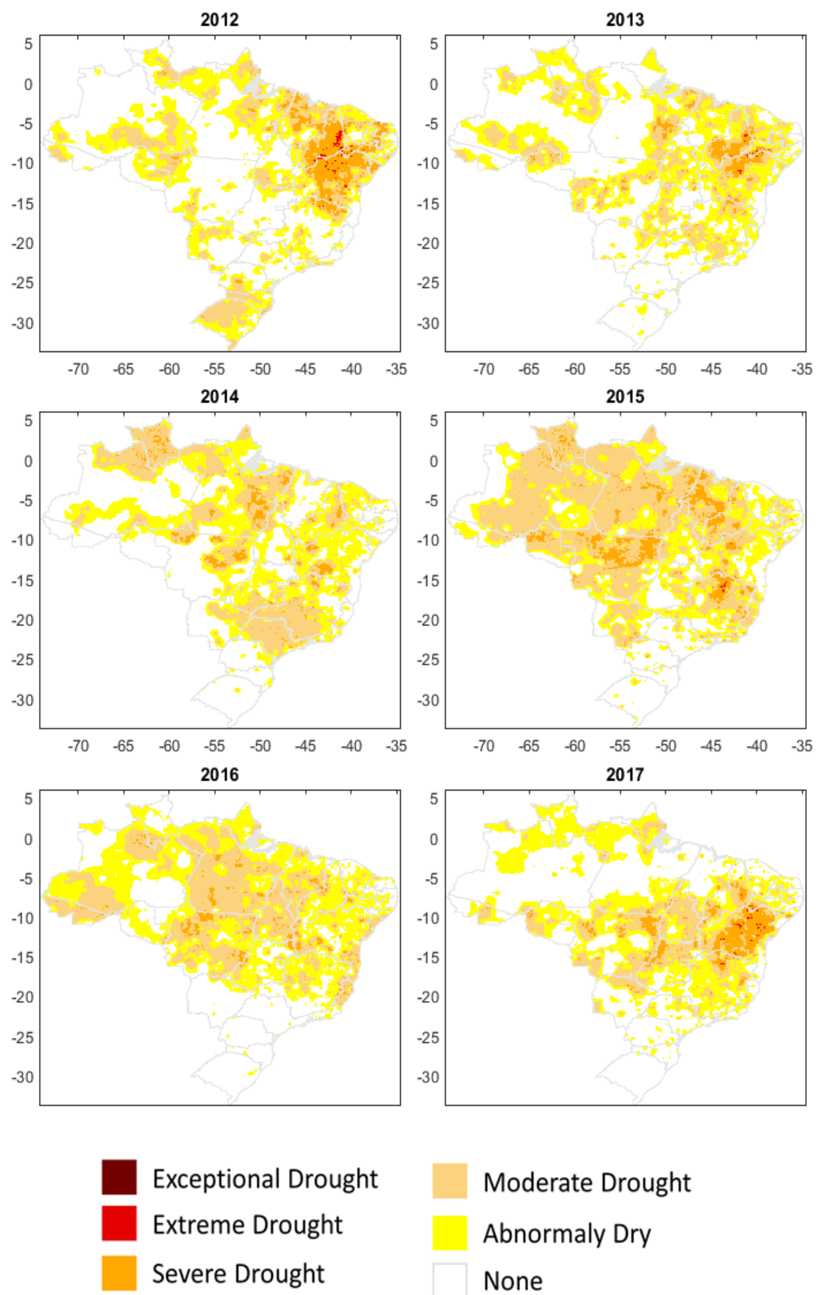


Figure 3 - Integrated Drought Index (IDI) calculated to the six hydrological years (from October to September) over Brazil.

In addition, the drought intensity and the extension of its impact were also evaluated through the AVSWI over the Brazilian territory. Figure 4 presents the affected area by the drought from 2012 to 2017. The total affected areas by the drought, in 2015-2016 add to approximately 2.5 million km^2, which is the highest value among the 6 years analyzed. This value is mainly associated to the simultaneous occurrence of drought in the northern and northeastern regions of Brazil. During 2015-2016, a strong El Niño event increased and prolonged the effect of the drought that started in 2011 in NEB (Marengo et al, 2017).

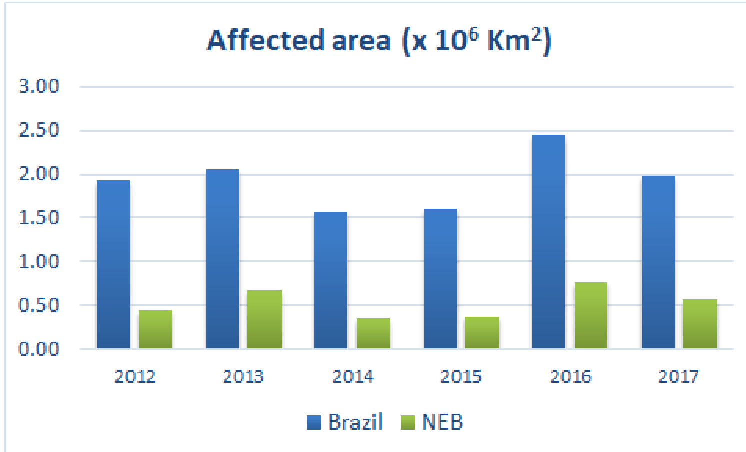


Figure 4 - Affected area by drought from 2012 to 2017 over Brazilian territory (blue bars) and over NEB (green bar).

4.2 Assessment of drought impacts on NEB

In Brazil, droughts are widespread and recurrent mainly in the Northeast region (NEB), which has approximately 53 million inhabitants. The NEB region has the highest proportion of people living in poverty in Brazil, with rainfed agriculture accounting for 95% of farmed land (IBGE, 2006). According to Vieira et al. (2015) the combination of high spatial and temporal rainfall variability, high dependence on rain, land degradation due to inadequate soil management, and the large-scale poverty in rural areas, make the drylands of NEB region one of the most vulnerable areas to the impacts of climate change in Brazil.

A first characterization of the meteorological drought in NEB, specifically over the semiarid, was conducted considering information from rain gauges obtained from the integrated network of precipitation data collected in during six consecutive hydrological years (from the start of the rainy period until the end of the dry period) from 2012. The concept of a hydrological year is used to enable an assessment of drought conditions considering the region's hydrological cycle, i.e. considering that it starts in October and ends in September . The recent hydrological years were marked by precipitation levels below the climatological average for the Brazilian semiarid region (SAB), as shown in Figure 5. According to Marengo et al,2017, since 2011 the NEB, including SAB, has been experiencing one of the longest and most intense droughts in decades. In general, the below normal precipitation condition observed during 2012-17 induced the low vegetation productivity in the region.

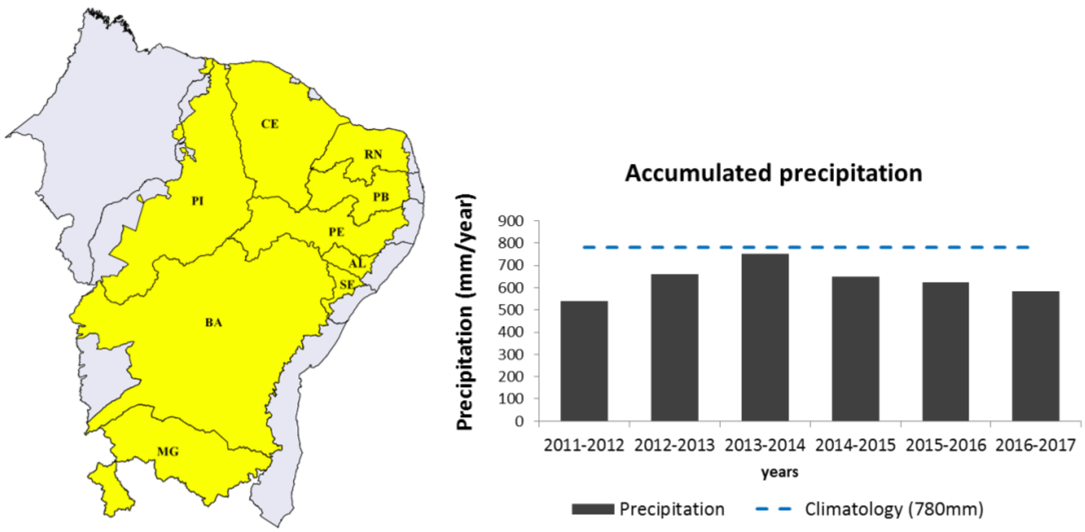
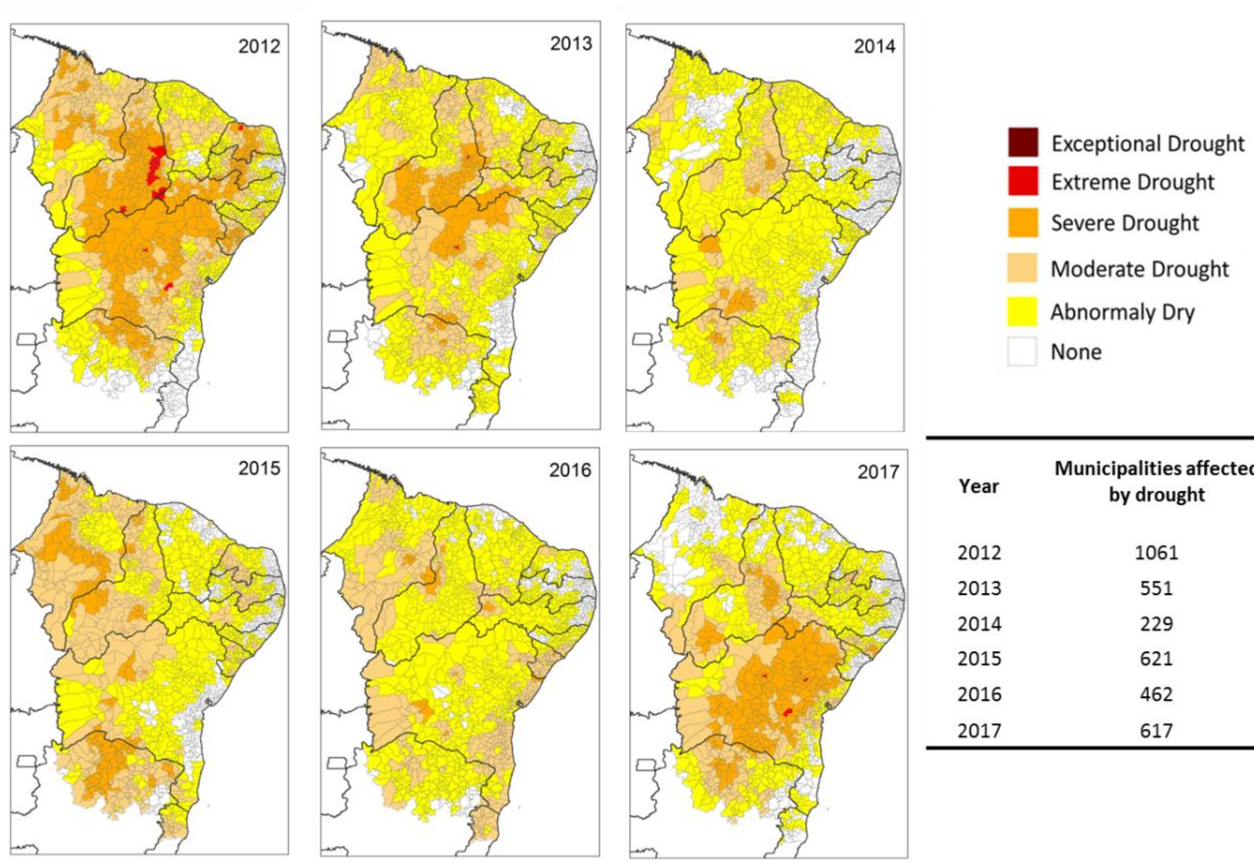


Figure 5 - Accumulated precipitation for hydrological years from 2011-2012 to 2016-2017 over SAB. Blue lines indicated the annual climate normal for 1981 to 2010. The yellow map on the left shows the geographical boundary of semiarid region of NEB.

MG = Minas Gerais State; BA = Bahia; SE = Sergipe; AL = Alagoas; PE = Pernambuco; PB = Paraíba; RN = Rio Grande do Norte; CE = Ceará; PI = Piauí.

Figure 6 presents the number of municipalities affected by the drought in six hydrological years, which were identified through the IDI calculated at municipality level over NEB. Drought conditions from 2012 to 2017 were also felt outside of the semiarid and NEB boundary (Figure 6). For this reason, we include the subjacent regions in the maps. It can be observed that 2012 presented the highest number of municipalities affected by drought (approximately 1000 municipalities), including around of 5 million people.

Damage due to droughts are related to decreased agricultural production, and effects on livestock farming, water supply and the economy, and to mitigate these impacts financial resources from the Federal Government are sent to the municipalities affected. According to S2ID, 50 million people were affected in NEB from 2012 to 2017. On average, 1000 municipalities were affected per year. As mentioned previously, these municipalities 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 Emergency Water Distribution Program (Water Tanker Operation), the federal recognition of state of emergency also allows municipalities to be entitled to other benefits. Among them, the debt renegotiation in the agriculture sector, the acquisition of basic food baskets to assist in the economic recovery of the regions affected and the *Garantia Safra Program - GS* (Alvala et al., 2017). The *GS Program* is action of the National Program for Strengthening Family Farming – PRONAF operated by the Secretary for Family Farming (SAF) since 2002. It aims to guarantee minimum conditions of survival of the rural family farmers affected systematically by drought or excess of rainfall. The family farmers may receive a benefit on the occurrence of drought or excess of rainfall, which causes at least 50% of loss on productions of beans, corn, rice, cassava or cotton crops at municipal level. The Garantia Safra covers the family farmers in the Northeast and those included in SAB.



Year	Municipalities affected by drought
2012	1061
2013	551
2014	229
2015	621
2016	462
2017	617

Figure 6 - Integrated Drought Index (IIS) calculated at municipality level to the last six hydrological years (from October to September) over NEB. The table on the right shows the total of municipalities affected by drought, considering the moderate to exceptional classes.

In the 2012-2017 harvest, due to the drought impacts, about 6 million smallholders experienced loss of their harvest in the NEB (Table 1). Approximately R$5.5 billion (or about US $ 1.6 billion) was spent on the GS insurance payment alone (SAF/MDA, 2018).

Regarding the impact on water supply, the water reserves of the equivalent reservoirs (reservoirs with storage capacity over above 10 hm^3) in the SAB presented successive reductions since 2012, what resulted in a minimum stored volume of approximately 13.8% in March 2017, according to ANA database.

Table 1 - Insurance payments (in Reais) during the period 2012-2017.

Crop failure insurance			
Harvest/year	**Municip.**	**Farmers**	**Insurance payments (USD)**
2011-2012	1015	769023	$828,888,143.71
2012-2013	1646	1563898	$658,967,775.51
2013-2014	894	1177452	$357,345,115.74
2014-2015	1010	975822	$249,083,693.69
2015-2016	1034	964789	$220,741,936.94
2016-2017	677	544377	$132,584,540.11
TOTAL		5995361	$2,447,611,205.71

Source: SAF/MDA, 2018.

Droughts also mobilized many Non-Governmental Organizations (NGOs) efforts, especially in semiarid areas of Brazilian Northeast. One of the biggest efforts of coordination is the network *Articulação do Semiárido-ASA*, created by 50 Brazilian NGOs in the 1990s. Currently, ASA is composed by three thousand organizations – including small farmers associations, NGOs, cooperatives etc. – distributed in ten states of semiarid region. One of the well-known measures to provide potable water for families living in rural areas is the program *Um Milhão de Cisternas* (One Million of Cisterns). The actions of this program started in the beginning of 2000s, and the goal of installing one million cisterns was achieved in 2014. After that, the program was complemented to include cisterns for productive use in agriculture and other public spaces such as schools (ASA, 2018). The program was designed as a bottom up process that involves training the local community to build cisterns and to learn new skills in ecological farming techniques (https://www.youtube.com/watch?v=uA9svbIsHBw). Cisterns are registered in the name of the female head of the household and they are tagged to make data public (http://www.asabrasil.org.br/mapatecnologias/#).

4.2.1 Drought assessment from soil moisture index (SMI)

An example of the use of SMI is shown in Figure 7, for Jan 31st 2016. This date was chosen because January 2016 accumulated rainfall was higher than the climatology for all bands of latitude covering SAB. In addition, this period is important because it includes critical development stages for crops sowed in December or January, especially over the Northern and Northwestern parts of SAB. The figure 7 includes the spatial distribution of SMI (top panel) and the temporal evolution (bottom panel) for the previous 30 days, over a predetermined area (rectangle on top panel). On the top panel, SMI ranges from 0 to 1, but a threshold typically near 0.4 marks the triggering of water deficit impacts on plant physiology. Prolonged periods of water deficit on plants can lead to damages in vital plant functions during flowering or grain-filling states, for example. Periods of 4-5 days under water stress are known to induce damage in plants, causing impacts on yields, as pointed by Hunt et al (2014). Monitoring of daily status of SMI can support activities of immediate response to dry spell, such as delay in sowing dates, early harvest or irrigation, when it is available.

The bottom panel in Figure 7 shows the previous 30 days (before Jan 31st) of SMI for the selected rectangle on the top panel. The time series help to bring awareness of the memory of SMI, the response to rainfall events during the period, and possible trends given information on weather forecast of rainfall events.

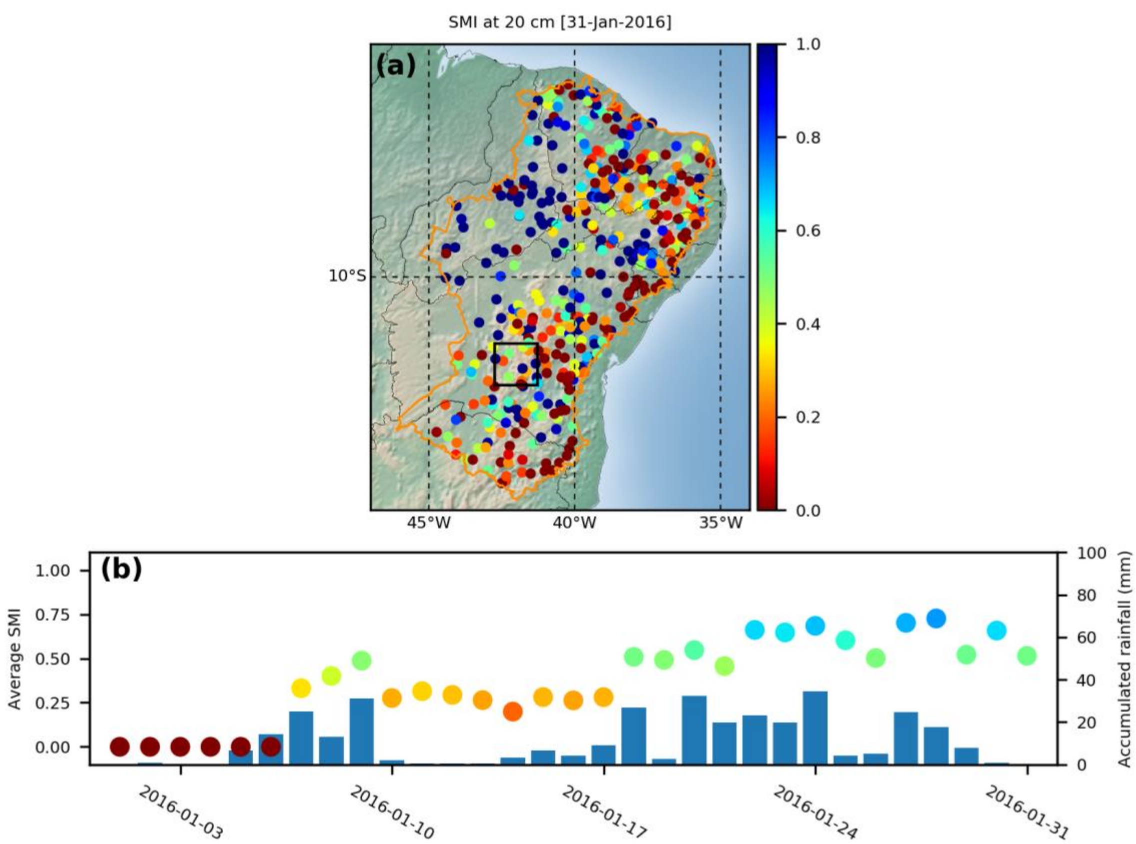


Figure 7 - (top panel) SMI over the Brazilian semiarid for Jan 31st 2016; (bottom panel) Temporal evolution of SMI for the average of stations inside the rectangle on top panel. Rainfall events represented as blue vertical bars.

4.2.2 Degradation estimations in the NEB

As shown by Tomasella et al. (2018), the Brazilian semiarid has been degraded by inadequate land management. The natural vegetation that dominates the SAB is a savanna-steppe known as Caatinga (Veloso, 1992), which vegetates only in the rainy period and remains as seeds during the unfavorable season. With few exceptions the woody species shed their leaves during the dry season. In addition, traditional agricultural practices involve slash-and-burn and shifting cultivation, grazing with cattle and sheep and exploitation of woody resources as a fuel source (Vieira, et al, 2015). Such fallow-farming system have converted Caatinga vegetation in a mosaic of regenerating forest patches with different ages (Sobrinho, et al, 2016).

Remote sensing products have frequently been used in land degradation studies, being the NDVI one of the most common indicators in the assessment of degradation / desertification (Dardel, et al, 2014). Field surveys in the Caatinga biome (Costa, et al, 2002) have shown that areas under severe degradation are associated with low biomass and consequently with low values of NDVI.

Due to the high inter-annual and intra-seasonal variability of rainfall, the Brazilian Caatinga exhibits large variations in vegetation greenness, coverage and tree mortality, both in space and time, which are directly reflected in the NDVI values. Additionally, land management practice causes complex spectral responses that vary from year to year. During the severe droughts, for instance, NDVI values similar to those of bare soil are relatively frequent, though values of NDVI recover with the return of regular rainfall. Unless regenerated patches, degraded areas show little or no signs of re-greening in the wet season. Therefore, we developed a degradation index based on the frequency and persistence of bare soil, which was used to characterize the degradation/desertification extension and intensity during the periods 2000-2016. The degradation index was calculated for ten-year periods starting in 2000, beginning with the period 2000-2009, 2001-2010, and 2007-2016. Figure 8 shows the map of the degradation index generated for the period of 2007-2016, together with the priority areas within the national plan to combat desertification identified by MMA (SAP, 2017). In general, it is possible to observe that areas with high and very high degradation are concentrated in the center of the NEB, which coincides with the priority areas to combat desertification.

Desertification priority areas located to the west and south of the study area that show little signs of degradation, with the exception of the Gilbués (#8), a well-known degraded area (MMA, 2007).
Figure 9 presents the time-evolution of the degradation index for the three categories used in the period of 2000-2016. In general, there is a positive trend (expansion) in areas considered degraded in the whole region, beginning in the period of 2003-2012. A severe and persistent drought has been recorded in the region in the period of 2011-2016, being the most intense in the center of the region. This suggests an association between the severe drought of the last five years, where the frequency, severity and area affected increased compared to past decades (Brito, et al, 2017) and the expansion of areas classified as degraded. Despite all categories of degradation being used in this study showing positive increased trends, the rate is more pronounced in the case of the moderate degraded areas, which suggests that the drought of 2011-2016 is playing a crucial role in those changes. The area estimated as degraded was 72,708 km2 in the period 2007-2016, which represents approximately 4% of the study area.

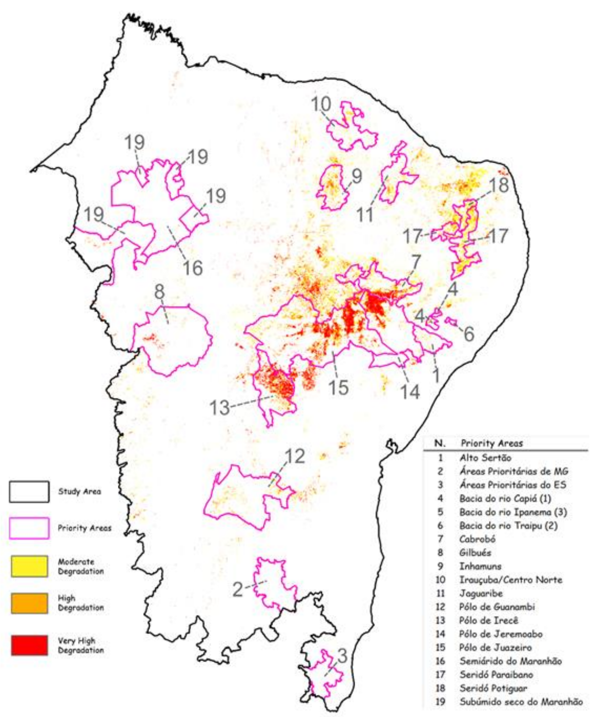


Figure 8 - Degradation map using data of the period 2007-2016 (Redrawn from Tomasella et al. 2018).

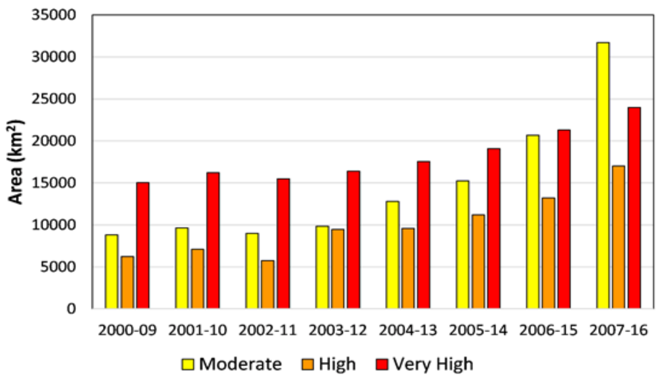


Figure 9 - Time-variation of the area classified as degraded over the period 2000-2016 (Redrawn from Tomasella et al. 2018).

4.3 Assessment of drought Impacts on water supplies and hydropower generation

Since the austral summer of 2014, different Brazilian metropolis has been facing water supply issues due to the intense droughts. Cities such as São Paulo, Rio de Janeiro and Belo Horizonte faced water shortages, putting a total of 40 million people at risk in the region. CEMADEN implemented, in 2014, a monitoring network for the upstream basins of the Cantareira reservoirs, the main water supply system of the Metropolitan Region of São Paulo State, Brazil. In addition, due to the continuity of rainfall below the historical average in the Southeast region, CEMADEN has been developing and updating a monitoring and prediction system (Figure 10) for the Cantareira, and also for Emborcação, Furnas, Mascarenhas and Três Marias reservoirs, the main hydroelectric power generation systems in southeastern Brazilian (more detailed information can be seen in Zhang, et al., 2018).

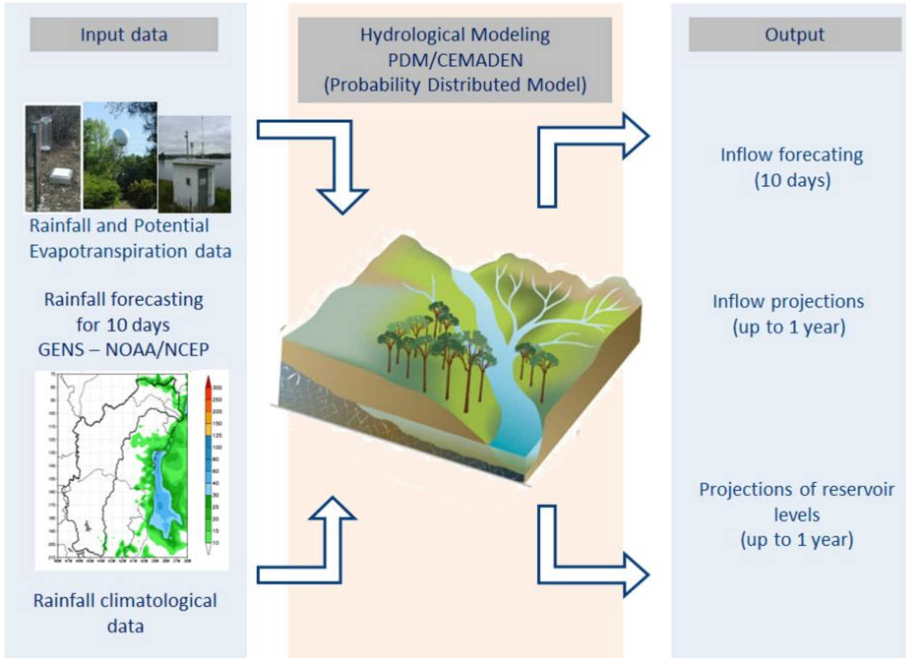


Figure 10 - Scheme for monitoring and prediction system of inflow and reservoir level.

The last one is the second reservoir for water supply for the Northeast of Brazil and hydropower generation in the São Francisco River. This system, through monitoring, allows the diagnosis of the current situation of the basins and reservoirs, as well as the prediction of the inflow to the reservoir (details about model are in Moore, 2007) for up to 10 days, and in the sequence, simulations considering several scenarios of rain are made to obtain projections of long term inflows to the reservoir (up to 1 year) (Figure 11) as well as the projections of reservoir levels (Figure 12).

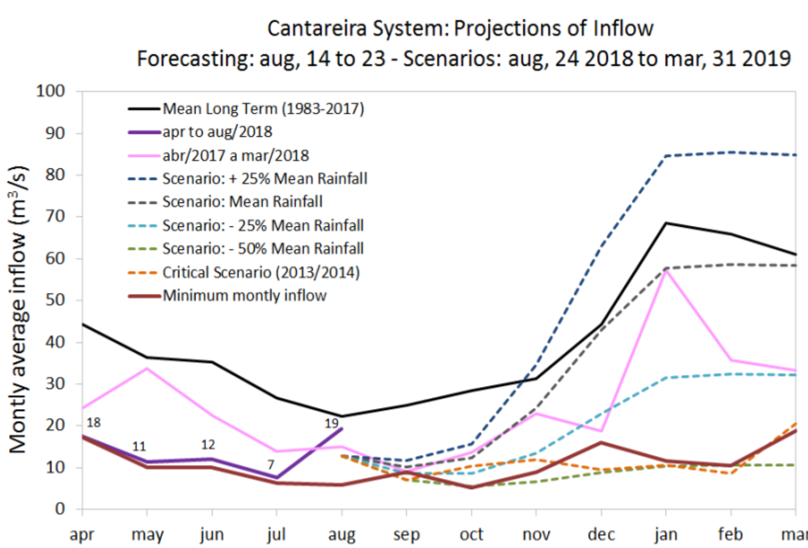


Figure 11 - Example of projection of inflow for the Cantareira System.

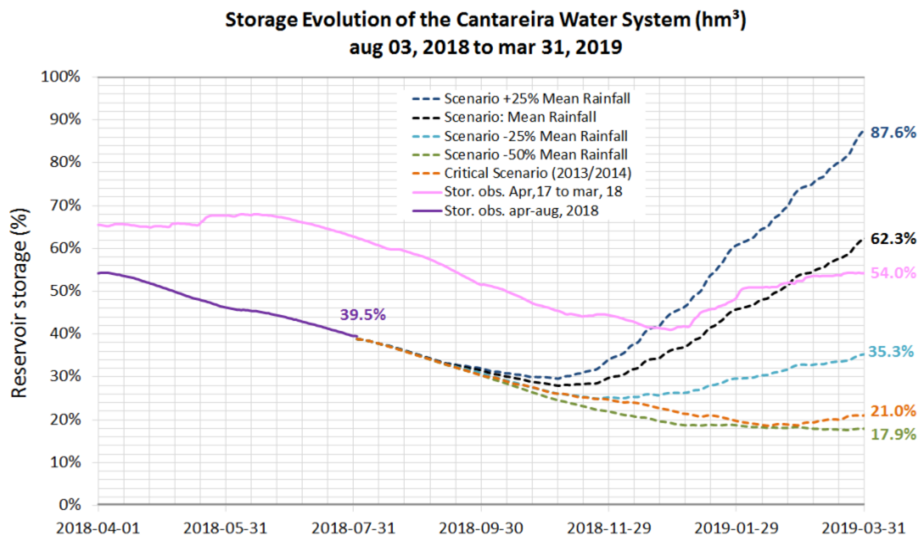


Figure 12 - Example of projection of reservoir level for the Cantareira System

5. Challenges ahead of Brazil Drought Risk Management

This multidisciplinary research generated results and products obtained by the drought monitoring system developed, which are relevant in actions to mitigate the drought´s impacts by the policymakers and practitioners from the different agencies and levels of government (national, state and local), by NGOs working to reduce the impacts of droughts – as exemplified by the ASA's initiative on building cisterns –, as well as by researchers working in transdisciplinary projects to face the challenges of droughts. CEMADEN participates in discussion and decision forums, convened by highest levels of federal government and, also by federal institutions, providing data and information relevant to support the country's strategic policies, fundamentally related to water resources and drought impacts.

In Brazil, drought is characterized mostly by its wide spatial coverage and is mainly recurrent in the Northeast region, mainly due to its water vulnerability. Considering the drought that has been affecting most of the Brazilian territory 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, CEMADEN, among other institutions, has been monitoring, since 2012, the drought situation that impacts different regions of Brazil. The recent drought of 2012-2017 in NEB is a sample of a pluriannual water deficit situation that has strong impacts on the regional population in whole country. Specifically over NEB, the 2012-2017 was the more intense drought in terms of duration, severity, and recurrence compared to the last drought events of at least 30 years. The drought affected areas that includes regions where farming is predominantly subsistence rain-fed.

Concerning the southeastern Brazil, the water crisis was aggravated by a combination of lack of rainfall and higher temperatures, with the summer of 2014 being the warmest and driest over the Cantareira reservoir system since 1951. The reservoirs for hydropower generation and water supply reached critical low levels during 2014/15. As mentioned by Nobre et al, 2016, increasing population and water consumption have intensified vulnerability in Brazil, and while human-induced warming may not have generated the atmospheric conditions behind the 2014 and 2015 summer droughts in Southeast Brazil, it is more likely that the warm temperatures have affected the severity of the drought and exacerbated the impacts on the population.

In general terms, a drought monitoring system allows identifying areas and municipalities affected by drought, which is the first step in drought risk management. The identification of areas and municipalities along with the drought event characterization (duration, severity and area extension) are also major aspects to evaluate the impacts, here pointed to rainfed agriculture and water supply.

Although Brazil has relevant scientific and technical knowledge about monitoring and forecasting of drought, these capabilities are not well used, integrated and institutionalized (Gutierrez, et al, 2014). The lack of appropriate coordination affects directly the initiatives to avoid the development of new disaster risks, i.e. the prospective disaster risk management. Considering the experience of the last years, the focus of the actions in the country were related to compensatory and corrective disaster risk management, it means reducing the risks already present. Thus, to break this status quo there are many challenges to overcome, the main ones are highlighted below.

- Associate the natural hazard with the social and economic vulnerability of a community or region and, then, get a move on the drought risk monitoring framework.

- Advances in understanding about the different types of drought, as well as their characterization and evolution. In addition, studies to assess the impacts of climate change on the occurrence of drought in Brazil and their application in strategies for drought risk management;
- Advances in studies on the impact (intensity) of the same drought (similar magnitude) on different sectors (agricultural, livestock, health, political, educational, electrical, potable water supply, industry and commerce, town, municipality, state, country, urban, rural, etc.);
- Building knowledge on social vulnerability in different drought scenarios in the Brazilian regions;
- Advances in knowledge about the cumulative effects of the drought on the social vulnerability, considering the spatio-temporal characteristics.
- Responsibility attribution among the national institutions involved with the drought theme, in order to guide actions to mitigate drought risks;
- Integration of the knowledge developed by Brazil and other South American countries that deal with the challenges of drought;
- Create knowledge about non-physical factors of the drought process (e.g., water demand, availability of surface deposits, or well construction) and develop strategies for reducing vulnerability;
- Development of communication strategies between scientists and: (i) communities; (ii) politicians or decision makers; (iii) productive sectors; (iv) educators; (v) other scientists.
- Incorporate scientific knowledge and local knowledge by policymakers, practitioners and decision makers for promoting the dialogue between governments, researchers, NGOs and local people, and increasing the capacity of implementation of transformative approaches, such as the initiative "One million of Cisterns".
- Define ways to increase the drought resilience, especially for those regions where the occurrence of drought is not natural or expected. In addition, to expand the policies made for coexistence with the drought in different Brazilian regions, providing means of implementation for initiatives leaded by local communities;

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