Remote Sensing as a Tool for Agricultural Drought Alert Over the South Region of Brazil

Remote Sensing as a Tool for Agricultural Drought Alert Over the South Region of Brazil

Luciana Rossato Spatafora, Regina C. S. Alvalá, Ana Paula M. A. Cunha, José Antônio Marengo, Mercè Vall-llossera, Miriam Pablos, and Patrizia Savi

Abstract – In this study, the estimative of the Combined Drought Index (CDI) to identify agricultural drought over the South Region of Brazil is introduced. The CDI is based on a combination of three indicators: Standardized Precipitation Index, soil moisture anomalies, and Vegetation Health Index. The proposed CDI has four levels—watch, warning, alert I, and alert II—thus benefiting an increasing degree of severity. The CDI was applied during the first 6 months of 2020 to different study sites over the South Region representative of crop areas. The performance of CDI levels was assessed by comparison with risk areas. Observations show a good match between these areas and the CDI. Important crop drought events in 2020 were correctly predicted by the proposed CDI in all areas.

1. Introduction

Today, drought-related disasters are among the type of disasters that cause large impacts on several regions of the world, affecting economic, social, and cultural systems. Drought-related disasters cause significant damage and losses to the living conditions of populations, such as deficiency in the supply of water, losses in agriculture and livestock, population migrations, forest fires, degradation of water quality, health problems, conflicts, and poverty.

Remote sensing techniques have the advantage of spatial continuity to derive indicators that can be used for drought prediction [1–8]. One of the main strategies used to detect agricultural drought from remote sensing is the estimation of indices related to biomass and vegetation condition, such as the Vegetation Condition Index [9], the anomalies of the fraction of absorbed photosynthetically active radiation [10], or the Normalized Difference Water Index [11, 12]. Despite having numerous limitations, the Normalized Difference Vegetation Index is relatively simple and is still the most widely used for practical and historical reasons [13]. Another vegetation index, the Vegetation Health Index (VHI), was proposed in [14]. The VHI is used for different applications, such as drought detection, drought severity and duration, early drought warning, crop yield and production during the growing season, vegetation density and biomass estimation, assessment of irrigated areas, and estimation of excessive wetness. The main limitation in the use of these indices is that even if they have demonstrated their capability to detect vegetation stress, this stress is not necessarily related to drought. For example, change in land covers or pests and diseases can equally be responsible for variations in the indicator. Therefore, these indicators should be used in combination with other indicators providing information on the deficit of precipitation and/or soil moisture anomalies (SMAs) in order to determine if the remotely sensed vegetation response (signal) is related to a drought event.

The main objective of this work is to assess agricultural drought using the Combined Drought Index (CDI) for the South Region of Brazil during 2019–2020. The CDI is related to crop damage data in rain-fed wheat-producing regions at the agricultural province level, which corresponds to the most important item of available data. It is expected that the CDI will be useful at the local policy level and for planning farm-scale insurance schemes. Because the effects of drought in the South Region were considerable, causing losses in the productive potential of crops and water stress in several areas, the CDI will be assessed verifying the number of municipalities that have been affected by the drought.

Manuscript received 28 December 2021.

Luciana Rossato Spatafora and Patrizia Savi are with the Dipartimento di Elettronica e Telecomunicazioni, Politecnico di Torino, Corso Duca degli Abruzzi, 24, 10129, Torino, Italy; e-mail: luciana.rossato@polito.it, patrizia.savi@polito.it.

Regina C. S. Alvalá, Ana Paula M. A. Cunha, and José Antônio Marengo are with the National Center for Monitoring and Early Warning of Natural Disasters (CEMADEN), São José dos Campos 12247-016, Brazil; e-mail regina.alvala@cemaden.gov.br, ana.cunha@cemaden.gov.br, jose.mengo@cemaden.gov.br.

Mercè Vall-llossera and Miriam Pablos are with the Universitat Politècnica de Catalunya, UPC Campus Nord, E-08034 Barcelona, Spain; e-mail: merce@tsc.upc.edu, mpablos@icm.csic.es.

2. Data

2.1 Study Area

The South Region of Brazil is the smallest of the five regions of the country, with a territorial area of 576,774.31 km^2. It is larger than the area of metropolitan France and smaller than the Brazilian state of Minas Gerais. It is divided into three federative units—Paraná (PR), Santa Catarina (SC), and Rio Grande do Sul (RS)—being limited to the north by the states of São Paulo and Mato Grosso do Sul, to the south by Uruguay, and to the west by Paraguay and Argentina. To its east lies the Atlantic Ocean.

In order to obtain information on the spatial distribution of the most vulnerable population, the National Center for Monitoring and Early Warning of Natural Disasters (CEMADEN) [16] (a research unit of

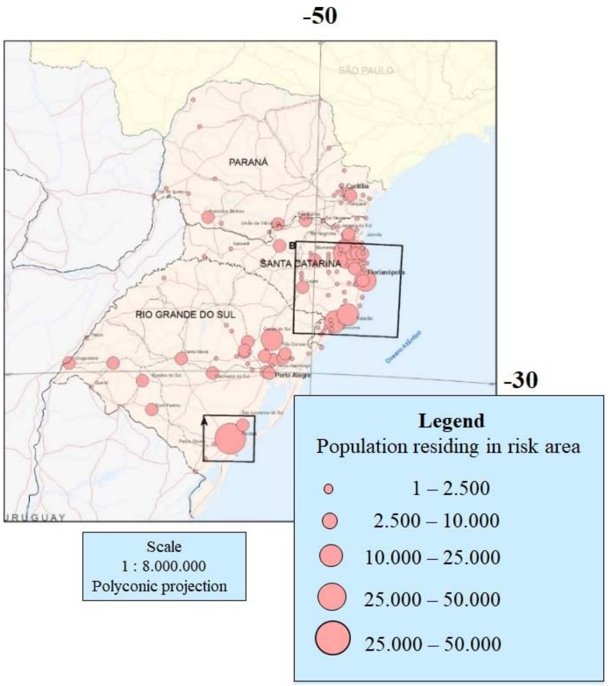

Figure 1. Exposed population in risk areas by municipality in the South Region of Brazil, 2010. Brazilian Institute of Geography and Statistics, Demographic Census, 2010.

the Ministry of Science, Technology, Innovations, and Communications) and the Brazilian Institute of Geography and Statistics [17] (a research unit of the Ministry of Planning, Development and Management) develop a database every 10 years referring to the estimate of the population exposed to risk of landslides, droughts, and floods. This database includes detailed information on the characterization of residents and residences, as shown in Figure 1 for 2010 (data for 2020 are not yet available). The radius of the pink circles is proportional to the population density in that spot. The areas included in the two black squares are particularly exposed to risk of floods and droughts.

Moreover, according to an unpublished survey [15] by the Confederação Nacional dos Municípios, RS is the second state with the highest number of emergency decrees due to natural disasters. According to the survey, 51% of the total incidents in RS were due to rain and 48.7% due to drought, which can be explained by the peculiar geographic location in which the state is settled. Between 2003 and 2008, there were 3,555 decrees of abnormality resulting from natural disasters due to rain (51%), drought (48.7%), and others (0.3%).

2.2 CDI

The CDI, proposed by [18], is an indicator of agricultural drought and combines the Standard Precipitation Index (SPI), SMAs, and the VHI.

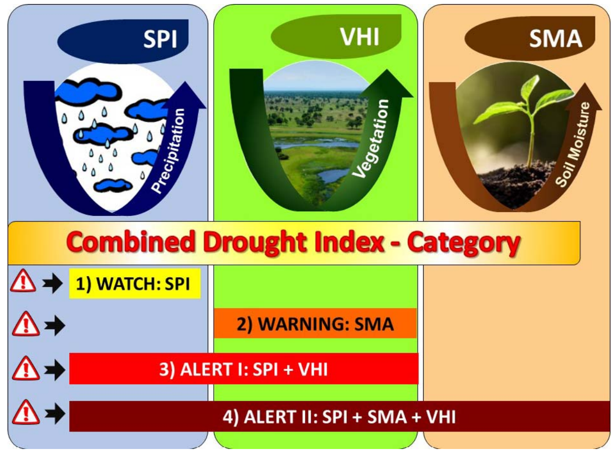

Figure 2. CDI categories and the associated warning levels [16].

The SPI is commonly used to monitor conditions associated with drought and excessive rain [19, 20]. It is based only on the monthly precipitation product, in our case, produced by CEMADEN, from different data sources in Brazil. The main feature of the SPI is the possibility of using it to monitor both wet and dry conditions at different timescales. This temporal flexibility makes it possible to use the SPI in several applications.

Another product used to estimate the CDI is the SMA. In this study, SMAs are obtained from soil moisture maps at high resolution (1 km), distributed by the Barcelona Expert Center (BEC) with an algorithm developed to retrieve high-resolution SMA maps from low-resolution SMOS SM maps [21]. The SM level 5 product is produced using an algorithm developed at BEC for retrieving high-resolution soil moisture maps (1 km) from low-resolution SMOS SM maps. The SMOS satellite operates in ascending and descending orbits, passing over the equator at 6:00 a.m. 6:00 p.m., respectively [22]. In this study, monthly SMA data sets were obtained from BEC at 1 km for 2020.

The VHI [13] is an index composed of a set of subindices related to the state of vegetation. These are calculated from satellite observation products. The information is almost real time, on a regular basis and with spatial continuity. VHI maps are available in the National Environmental Satellite, Data, and Information Service of the National Oceanic and Atmospheric Administration [23].

Note that [18] used the SMA derived from the LISFLOOD, whereas in this article, we used information from the SMOS satellite. Moreover, in [18], the fraction of absorbed photosynthetically active radiation derived from a medium-resolution imaging spectrometer was used, whereas in this article, the VHI derived from a moderate-resolution imaging spectroradiometer is used.

Representation of the concept of the CDI and the associated warning levels that are outputs of the CDI [18] are shown in Figure 2. The figure shows the stages

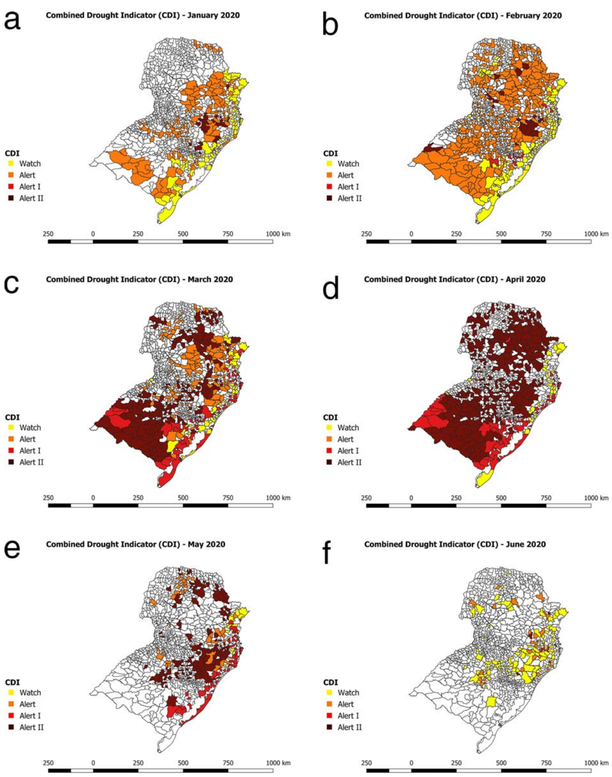

Figure 3. Spatial-temporal variation of the CDI obtained during January to June 2020 for South Region of Brazil. Black points are the risk areas presented in Figure 1.

of the cause-and-effect relationship and associated warning levels, classified as watch, warning, alert I, and alert II. With these warning levels, it will be possible for authorities to be better prepared for agricultural drought events.

The highest stage (alert II) is based on all three indicators composing the CDI (SPI, SMA, and VHI) so that these give more secure evidence for the existence of an agricultural drought.

3. Results

In order to evaluate the drought that occurred in the South Region for the first semester of 2020, we used the CDI to characterize the different stages of agricultural drought. In Figure 3, the performance of the CDI, including exposed population in risk areas of the South Region using the SMOS satellite ascending and descending pass average, are shown.

The results were classified into four levels: watch, warning, alert I, and alert II. The dynamics of the CDI were assessed for a period of 6 months during 2020. In this period, a severe drought occurred. Critical CDI levels shown in Figure 3 coincide with the risk areas shown in Figure 1 (mainly in February and April for RS, SC, and Paraná). The periods of greatest damage to crops were March and April 2020 in both ascending and descending passes. Considering only the SMA values, an indication of drought from January to May in the south of RS, east of SC, and northwest and east of PR is found, whereas if the three indicators combined in CDI are used, we can predict the alert I and alert II levels. Thus, the CDI has several advantages over the use of a single indicator, as evidenced by trends in precipitation, SMAs, and vegetation. In addition to the spatial-temporal CDI shown in Figure 3, the corresponding number of municipalities affected by drought was calculated and is reported in Table 1.

Table 1. Number of municipalities affected by drought in each state in the South Region of Brazil derived from CDI maps

States of the Brazil	Number of municipalities affected by drought in 2020					
	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*
Paraná	54	203	179	196	64	24
Santa Catarina	74	104	101	105	70	53
Rio Grande do Sul	101	208	204	213	77	43
Total	229	515	484	514	211	120

The states of RS, SC, and PR were the most affected by drought during March and April, as shown Table 1. Many municipalities declared an emergency situation [23]. Losses in agriculture were increasing month by month. In agriculture, the Paraná Technical Assistance and Rural Extension Institute estimated losses of around 20% in the production of fruits, such as grapes, peaches, apples, and figs. In the corn crop, the number increases to 35% loss and in the soybean crop to 33% loss. Milk, bean, and corn production were feeling the impacts. In livestock, the same happened [24].

Starting from the study reported in [18] of a CDI for Europe, in this article, we developed a CDI based on SMA, VHI, and SPI in order to analyze the South Region and showed that it accurately captured two important drought periods.

4. Conclusions

This study demonstrates the use of remote sensing techniques to identify agricultural drought in the South Region of Brazil. A CDI has been defined using a combination of SPI, SMA, and VHI parameters to detect different stages of agricultural drought.

Drought events as occurred in the South Region during 2020 show that, although they are short, the very extreme rainfall deficits followed by high temperature can have important agricultural consequences. For this reason, the CDI becomes a tool of great information for decision makers. The indicator CDI serves as a tool to describe the intensity, spatial extent, and potential impacts of drought. Improvements in drought monitoring and forecasting techniques will increase management practices and responses, reducing exposure to drought risks and their immediate impact on the population's life.

5. References

1. W. C. Palmer, *Meteorological Drought*, Washington, DC: U.S. Department of Commerce, 1965, pp. 1-58.

2. W. M. Alley, "The Palmer Drought Severity Index: Limitations and Assumptions," *Journal of Climate and Applied Meteorology*, **23**, 1984, pp. 1100-1109.
3. N. B. Guttman, J. R. Wallis, and J. R. M. Hosking, "Spatial Comparability of the Palmer Drought Severity Index," *Water Resources Bulletin*, **28**, 6, 1992, pp. 1111-1119, http://dx.doi.org/10.1111/j.1752-1688.1992.tb04022.x.
4. V. Sridhar, K. G. Hubbard, J. You, and E. D. Hunt, "Development of the Soil Moisture Index to Quantify Agricultural Drought and Its 'User Friendliness' in Severity-Area-Duration Assessment," *Journal of Hydrometeorology*, **9**, 4, 2008, pp. 660-676, http://dx.doi.org/10.1175/2007JHM892.1.
5. E. H. Hogg, A. G. Barr, and T. A. Black, "A Simple Soil Moisture Index for Representing Multi-Year Drought Impacts on Aspen Productivity in the Western Canadian Interior," *Agricultural and Forest Meteorology*, **178–179**, 2013, pp. 173-182, http://dx.doi.org/10.1016/j.agrformet.2013.04.025.
6. M. R. Keshavarz, M. Vazifedoust, and M. A. Alizadeh, "Drought Monitoring Using a Soil Wetness Deficit Index (SWDI) Derived From MODIS Satellite Data," *Agricultural Water Management*, **132**, 2014, pp. 37-45, http://dx.doi.org/10.1016/j.agwat.2013.10.004.
7. A. P. M. A. Cunha, M. Zeri, K. D. Leal, L. Costa, L. A. Cuartas, et al., "Extreme Drought Events Over Brazil From 2011 to 2019," *Atmosphere*, **10**, 2019, p. 642.
8. M. Jiménez-Donaire, A. Tarquis, and J. Giráldez, "Evaluation of a Combined Drought Indicator and Its Predictive Potential for Agricultural Droughts in Southern Spain," *Natural Hazards and Earth System Sciences*, **20**, 2020, pp. 21-33.
9. F. N. Kogan, "Droughts of the Late 1980s in the United States as Derived From NOAA Polar-Orbiting Satellite Data," *Bulletin of the American Meteorological Society*, **76**, 1995, pp. 655-668.
10. N. Gobron, B. Pinty, F. Melin, M. Taberner, and M. M. Verstraete, *Sea Wide Field-of-View Sensor (SeaWiFS)—Level 2 Land Surface Products —Algorithm Theoretical Basis Document*, EUR Report No. 20144, Institute for Environment and Sustainability, 2002,
11. B. C. Gao, "NDWI—A Normalized Difference Water Index for Remote Sensing of Vegetation Liquid Water From Space," *Remote Sensing of Environment*, **58**, 1996, pp. 257-266.
12. Gu, Y., J. F. Brown, J. P. Verdin, and B. Wardlow, "A Five-Year Analysis of MODIS NDVI and NDWI for Grassland Drought Assessment Over the Central Great Plains of the United States," *Geophysical Research Letters*, **34**, 2007, p. L06407, doi: 10.1029/2006GL029127.
13. C. Leprieur, M. M. Verstraete, and B. Pinty, "Evaluation of the Performance of Various Vegetation Indices to Retrieve Vegetation Cover From AVHRR Data," *Remote Sensing Review*, **10**, 1994, pp. 265-284.
14. F. N. Kogan, "Application of Vegetation Index and Brightness Temperature for Drought Detection," *Advances in Space Research*, **15**, 11, 1995, pp. 91-100.
15. Confederação Nacional dos Municípios, "Proteção Civil e Estudos Técnicos." http://www.cnm.org.br (Accessed June 23, 2022).
16. National Center for Monitoring and Early Warning of Natural Disasters, "População em áreas de risco no Brasil." http://www.cemaden.gov.br (Accessed June 23, 2022).
17. Brazilian Institute of Geography and Statistics, "População em áreas de risco no Brasil." http://www.ibge.gov.br (Accessed June 23, 2022).
18. G. Sepulcre-Canto, S. Horion, A. Singleton, H. Carrão, and J. Vogt, "Development of a Combined Drought Indicator to Detect Agricultural Drought in Europe," *Natural Hazards and Earth Systems Sciences*, **12**, 2012, pp. 3519-3531.
19. T. B. McKee, N. J. Doesken, and J. Kleist, "The Relationship of Drought Frequency and Duration to Time Scales," Eighth Conference on Applied Climatology, Anaheim, CA, USA, January 17–22, 1993, pp. 17-22.
20. F. N. Kogan, "Global Drought Watch From Space," *Bulletin of the American Meteorological Society*, **78**, 4, 1997, pp. 621-636.
21. M. Pablos, M. Piles, and C. Gonzalez-Haro, "BEC SMOS Land Products Description," http://bec.icm.csic.es/doc/BEC-SMOS-0003-PD-Land.pdf (Accessed 22 December 2020).
22. National Oceanic and Atmospheric Administration, "Global Vegetation Health Product." http://www.star.nesdis.noaa.gov (Accessed June 23, 2022).
23. Copel, "Sul do Brasil enfrenta, além da pandemia, forte seca e reflexos na economia." http://www.copel.com.br (Accessed June 23, 2022).
24. V. Fernandes, A. P. Cunha, L. Cuartas, K. Deusdará-Leal, L. Costa, et al., "Secas e os impactos na região Sul do Brasil," *Revista Brasileira de Climatologia*, **28**, 2021, doi: 10.5380/rbclima.v28i0.74717.