

Assessment of the Application of the Integrated Multi-Satellite Retrievals for GPM Satellite Precipitation Products for Extreme Dry and Wet Events Monitoring in Togo (2001-2019)

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Abstract

Togo's economy is heavily dependent on rainfed agriculture. Therefore, anomalies in precipitation can have a significant impact on crop yields, affecting food production and security. Thus, monitoring anomalous climate conditions in Togo through the combination of precipitation satellite-based data and the Standard Precipitation Index (SPI) can help anticipate the development of drought scenarios or excessive rainfall, allowing farmers to adjust their strategies and minimize losses. Continuous and adequate spatial monitoring of these climate anomalies provided by satellite-based products can be central to an effective early warning system (EWS) implementation in Togo. Precipitation satellite-based products have been presented as invaluable tools for assessing droughts and wet events, offering timely and comprehensive data that supports a wide range of applications. In this study, we applied the Integrated Multi-satellite Retrievals for GPM (IMERG) rainfall product, a unified satellite global precipitation product developed by NASA, to identify and characterize the severity of dry and wet climate events in Togo during the period from 2001 to 2019. The Standard Precipitation Index (SPI), as the main index recommended by the World Meteorological Organization to monitor drought wide world, was selected as the reference index to monitor dry and wet climate events across Togo regions. The results show two distinct major climate periods in Togo in the timeframe analyzed (2001-2019), one dominated by wet events from 2008 to 2010, and a second marked by severe and extreme dry events from 2013 to 2015; IMERG rainfall and SPI combination were able to capture these events consistently.

Keywords

IMERG, Rainfall Anomaly, Monitoring, SPI, Droughts, Wet Events

1. Introduction

Africa is one of the most vulnerable continents to climate variability and climate change impacts due to its high exposure and low adaptive capacity (IPCC, 2014). From 1900 to 2005, long-term trends were observed in rainfall amounts in many regions of the continent, as well as significant interannual variability in rainfall (Laban, 2009; IPCC, 2014). Increased variability of rainfall combined with the prediction of higher temperatures and increasing evapotranspiration are expected to significantly impact the economic and social characteristics worldwide (Xu et al., 2019). Climate extreme events' frequency increase constitutes a challenging aspect among the impact of climate change on society compared to long-term changes in mean climate conditions (Katz & Brown, 1992).

Within Africa, the West Africa region has been an area of great concern; almost 419 million people are highly dependent on rain for sustenance. Enhancement of precipitation variability is projected to increase both the risks of flooding and drought, therefore affecting agricultural production and water security, leading to severe socio-economic disruption (FAO, 2015; IPCC, 2021). That has been the case in the past in West Africa and, under the ongoing global climate change, precipitation and dry extreme events frequency is predicted to increase in the future (IPCC, 2013). Therefore, monitoring capability and understanding of climate extreme events consequence (droughts and floods) as regard to their temporal and spatial variabilities is fundamental for countries in the region to build the needed knowledge to assess their vulnerability and to develop effective early warning systems in order to support mitigation and adaptation policies.

Rainfall is one of the most usable variables for determining climate variability, particularly in West Africa, and it is related to drought scenarios (Kouadio et al., 2003). Drought phenomena is not fully understood because the processes that drive their onset and duration are diverse, while recovery occurs at multiple temporal (seasonal, annual, and decade) and spatial (local, regional, and continental) scales (Kao & Govindaraju, 2010; Aghakouchak et al., 2015; Dai, 2013).

There are several indices to evaluate precipitation anomalies in the literature, Palmer Drought Severity Index (Palmer, 1965), Deciles Method (DM, Gibbs & Maher, 1967), the Standardized Precipitation Index (SPI, McKee et al., 1993) and Standardized Precipitation Evapotranspiration Index (SPEI, Vicente-Serrano et al., 2010). Their importance as tools to support public policies, agricultural systems monitoring, and to study climate variability and trends has been largely recognized (Nandintsetseg & Shinoda, 2013; Parry et al., 2016). For the present study, SPI was selected; it is a simple measure of drought and wet periods and considers only precipitation data as input, which is a differential in relation to the other

indices (McKee et al., 1993). SPI quantifies the deficit or excess rainfall accumulated at different time scales, allowing the monitoring of short and long-term droughts (McKee et al., 1993). Usually calculated for periods of 1 to 48 months, along with the timescale nature, it also provides the evaluation of the intensity of the dry and wet periods. Due to its practical application, SPI has been recommended by the WMO (World Meteorological Organisation) as the main meteorological drought index that countries should use to monitor and follow drought conditions (Hayes, 2011). WMO also provided guidelines for countries trying to use SPI in their drought early warning system.

The distribution of rainfall events spatially and temporally is not homogenous across the West Africa region. This inhomogeneous rainfall distribution can cause significant negative socio-economic and environmental impacts. For example, the deficit and rainfall irregularities can lead to persistent drought. That was the case in the early 1970s, during which the Sahel region experienced a severe drought and devastating famine (L'homme, 1982). On the other hand, flood periods can also have disastrous consequences in West African countries. In 2020, flooding affected 2.7 million people in 18 West and Central Africa countries, with many regions recording excess rainfalls (OCHA, 2020).

In Togo, rainfed agriculture contributes to approximately 45% of the country's Gross Domestic Product (Batebana et al., 2015). In addition to direct environmental impacts, such as soil degradation and loss of biodiversity, the socio-economic consequences of extreme precipitation events, especially those related to drought, include a reduction in agricultural yields, death of livestock, reduction in agricultural revenue, an increase in rural to urban migration, exacerbation of famine, and an upsurge in water and vector-borne diseases. Several studies have revealed a persistent rainfall deficit in Togo since 1970 (Adewi et al., 2010; Adewi, 2009). Sogbedji (1999) found that the decrease in seasonal rainfall represents a serious threat to maize growth during the second growing season. Koffi and Komla (2015) used reference evapotranspiration (ET_o) and aridity index from 1961 to 2011 and found a declining trend in the ratio of precipitation/ET_o, which adversely implies an increase in the severity of the aridity in some cities of Togo such as Lomé, Tabligbo and Sokodé.

Rainfall distribution over Togo in seasonal and interannual scales, is mainly associated with the seasonal displacement of ITCZ and West African Monsoon (WAM) variability (Batebana et al., 2015). The spatial dimension, intensity, and timing of the Inter-Tropical Convergence Zone (ITCZ) and West Africa Monsoon (WAM) play a significant role in regional agriculture and water resources (Hall & Peyrillé, 2006; Sultan & Janicot, 2000).

Therefore, continuous monitoring and a better understanding of extreme drought and precipitation events scenarios are crucial to develop a warning system able to allow, as early as possible, adaptation plans and to mitigate their socio-economic impacts, especially for long-lasting drought events. In this regard, while rain gauges' ability to represent valuable and accurate information at local level is

well established, West Africa countries' sparsely rain gauge networks has been a long-term challenge for country and regional level monitoring of precipitation (Winifred Ayinpogbilla Atiah et al., 2020). On the other hand, in addition to the regional perspective, the new set of high spatial resolution spaceborne rainfall products have the potential to provide local and national level monitoring, which added to the limited rain gauges network, that can contribute to support the development of a more robust and comprehensive national warning system. To date, several Satellite Precipitation Products have been made available for open access to the public, e.g., TRMM Multi-satellite Precipitation Analysis (TMPA; Huffman et al., 2007), Climate prediction center MORPHing method (CMORPH; Joyce et al., 2004; Joyce & Xie, 2011), Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks family (PERSIANN family; Hong et al., 2004; Nguyen et al., 2018; Sorooshian et al., 2000), Global Satellite Mapping of Precipitation (GSMaP; Kubota et al., 2007), and more recently the NASA Integrated Multisatellite Retrievals for GPM (IMERG; Huffman et al., 2019).

In the present study, Togo was selected as the geographical domain to focus on and to perform an investigation of the IMERG satellite precipitation products ability to describe precipitation variability and the occurrence of dry and wet events across the country's administrative regions for the period from 2001 to 2019. The pursuit of these goals was carried out by using IMERG monthly rainfall datasets and applying the SPI as reference to identify wet and dry significant events. The final goal is to evaluate the application of this relatively recent satellite-based precipitation product to monitor dry and wet events across Togo regions.

2. Study Area, Materials, and Methods

2.1. Study Area

Togo is located between the latitudes 6° and 11° North and the longitudes 0° and 1.40° East (Figure 1). With an area of 56,600 km² and a population estimated to be 8,095,000 inhabitants in 2022 (5th RGPH, 2022), Togo domain consists of a corridor that stretches over 650 km long between Burkina-Faso, to the north, and the Atlantic Ocean, to the south, over a maximum width of 150 km, between Benin, to the east, and Ghana, to the west. This configuration helps to explain the climatic, biological, economic, and social diversity that characterizes Togo. The country has a sandy coastline of around 60 km, which has suffered from severe marine erosion and experience a tropical climate influenced by trade winds: the Harmattan, hot and dry wind blowing from the Northeast to the Southwest; and the Monsoon, a hot and humid wind blowing from the Southwest to the Northeast. The agricultural sector occupies a preponderant place in the Togolese economy since it represented 35.1% of the GDP in 2000 and 38% on average during these last years and provided more than 20% of export earnings. Togo is subdivided into 5 economic regions (Savannah, Kara, Centrale, Plateaux and Maritime) which correspond to the 5 ecological zones (Pessiezoum Adjoussi, 2000). The map of Togo (Figure 1) showing the station locations within the 5 regions, along

IMERG grid points, highlights the limited spatial coverage of rain gauges across the country and IMERG product potential to cover areas unmonitored. Consequently, the use of satellite precipitation products is essential.

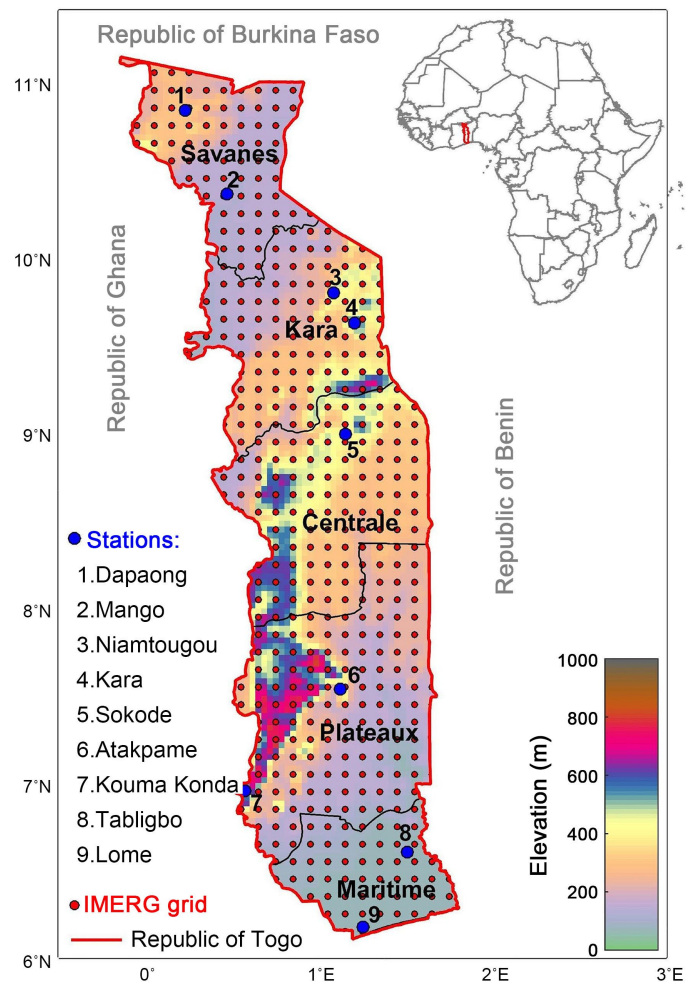


Figure 1. Togo domain with its 5 administrative regions. Country rain gauge stations network is displayed along IMERG grid points.

2.2. IMERGE (Integrated Multi-Satellite Retrievals for GPM) Rainfall Dataset

The IMERG (Huffman et al., 2019) rainfall data is available globally at a spatial resolution of $0.1^\circ \times 0.1^\circ$, which is considered as a high-resolution product. The products are available with various latency periods, the early-run (IMERG-E) and late-run (IMERG-L) products, which are released 4 hours and 12 hours after a real-time, respectively; and the final run (IMERG-F), which is post-real-time and calibrated with the GPCP data and released after about two months. For the present study, we selected the final run (IMERG-F) at monthly temporal resolution for the period spanning from January 2001 to December 2019. The IMERG rainfall dataset was obtained from NASA's website. The performance of IMERG precipitation products has been evaluated worldwide under distinct topographical

features and also used to characterize rainfall variability in different climate regimes (arid and wet) across the world. Sun et al. (2018) found IMERG rainfall final-run product IMERG-F at a monthly timescale to have good detection ability in the Northeast of China, therefore, able to provide data support for long-time series analyses.

The observations from the GPM system have been used for characterizing changes in the Earth's water cycle, quantifying freshwater fluxes and reservoirs, and advancing our predictive capability of natural hazards and extreme weather events (Skofronick-Jackson et al., 2018). IMERG spatial and temporal resolutions provide a valuable product for examining precipitation extremes that may result in flooding, landslides, or other meteorologically-induced phenomena and supporting disaster response and recovery (Schumann et al., 2016).

2.3. Methods

Dry and wet events identification and characterization were done using the Standardized Precipitation Index (SPI). For this study, SPI calculation is based on the density and probability function Gamma (Equation (1)), where, $F(x)$ is the general formula for the probability density function of the exponential distribution, $\alpha > 0$ and $\beta > 0$ are, respectively, the form and scale parameters, $\Gamma(\alpha)$ is the gamma function, and x is the rainfall amount, with x varying according to α and β . Apart from being the most used distribution function in SPI studies, Guenang and Kamga (2014) found that gamma and the Weibull are the functions that best fit precipitation in Cameroon, which is dominated by a climate regime similar to Togo, tropical and strongly influenced by the West African Monsoon.

$$F(x) = \int_0^x f(x) dx = \frac{1}{\Gamma(\alpha)\beta^\alpha} \int_0^x x^{\alpha-1} e^{-\frac{x}{\beta}} dx \quad (1)$$

The SPI values represent the number of standard deviations from the mean at which an event occurs. For instance, the 6-month SPI value compares accumulated rainfall over that specific 6-month period with the mean accumulated rainfall for the same period calculated over the full study period (Guenang & Kamga, 2014). This applies to any n-month SPI value, where n, the number of months of accumulation, is the time scale. SPI positive values indicate wet conditions, and negative values correspond to dry scenarios. According to Guttman (1998) time scales of the order of 3 to 6 months are important to evaluate drought scenarios (negative SPI) for agricultural applications, while for water-supply management longer time scales, one year or more, are of more interest (Guttman, 1998). Although it is possible to determine specific thresholds (Guenang & Kamga, 2014), SPI scales and categories of dryness and wetness events that are followed in this study are those based on McKee et al. (1993) and presented in Table 1.

Based on this, dry and wet events (an accumulation of dry or wet conditions over a certain period of time) were accessed at different time scales. To characterize these events, their Peak Intensity (PI), which indicates the lowest SPI value (Dry) or the highest SPI value (Wet) reached in a dry and wet event respectively,

and Duration (number of months between the beginning of a dry or wet event and its end) were calculated.

Table 1. Categories and scale of SPI index adapted from (McKee et al., 1993).

SPI values	Categories
≥ 2	Extremely humid
1.50 to 1.99	Very humid
1.00 to 1.49	Moderately humid
0.99 to -0.99	Close to normal
-1.0 to -1.49	Moderately dry
-1.50 to -1.99	Very dry
≤ -2	Extremely dry

To compute SPI at 6- and 12-month, from IMERG-GPM rainfall product a SPI function developed for MATLAB software (Taesam Lee, 2021) was applied, which considered the gamma function distribution.

IMERG rainfall averaged across each Togo administrative region domain was taken as representative of the regional domain and used to obtain the SPI values for the 5 administration regions.

SPI 6-months (SPI-6) indicates the medium-term variability in precipitation. Additional to the agriculture application, it also gives information about anomalous stream flows and reservoirs levels. SPI-6 can be effective in showing precipitation over distinct seasons, for example, during the monsoon season.

SPI 12-months (SPI-12) gives information of long-term precipitation variability and is associated with streamflow, reservoir levels, and it can start to provide information related to groundwater levels.

3. Results and Discussion

In this section, SPI-6 and SPI-12 are applied to characterize dry and wet events across the five Togo administrative regions.

Figure 2 shows the time series of SPI-12 for each region. It is possible to identify a long-term wet event from 2008 to 2010 and also the dry one from 2014 to 2016, both affecting the entire country.

Tables 2-6 show the details of the dry and wet events observed over each region for the entire study period based on SPI-6 and SPI-12. The following SPI analysis focuses on very wet/dry and on extremely wet/dry events (considering the threshold defined in **Table 1**; SPI values between 1.5 to 1.99); extremely wet event (SPI values higher than +2.0); very dry events (SPI values between -1.5 to -1.99); and extremely dry events (SPI values lower than -2), because these are the events expected to have the largest social, economic and environmental consequences.

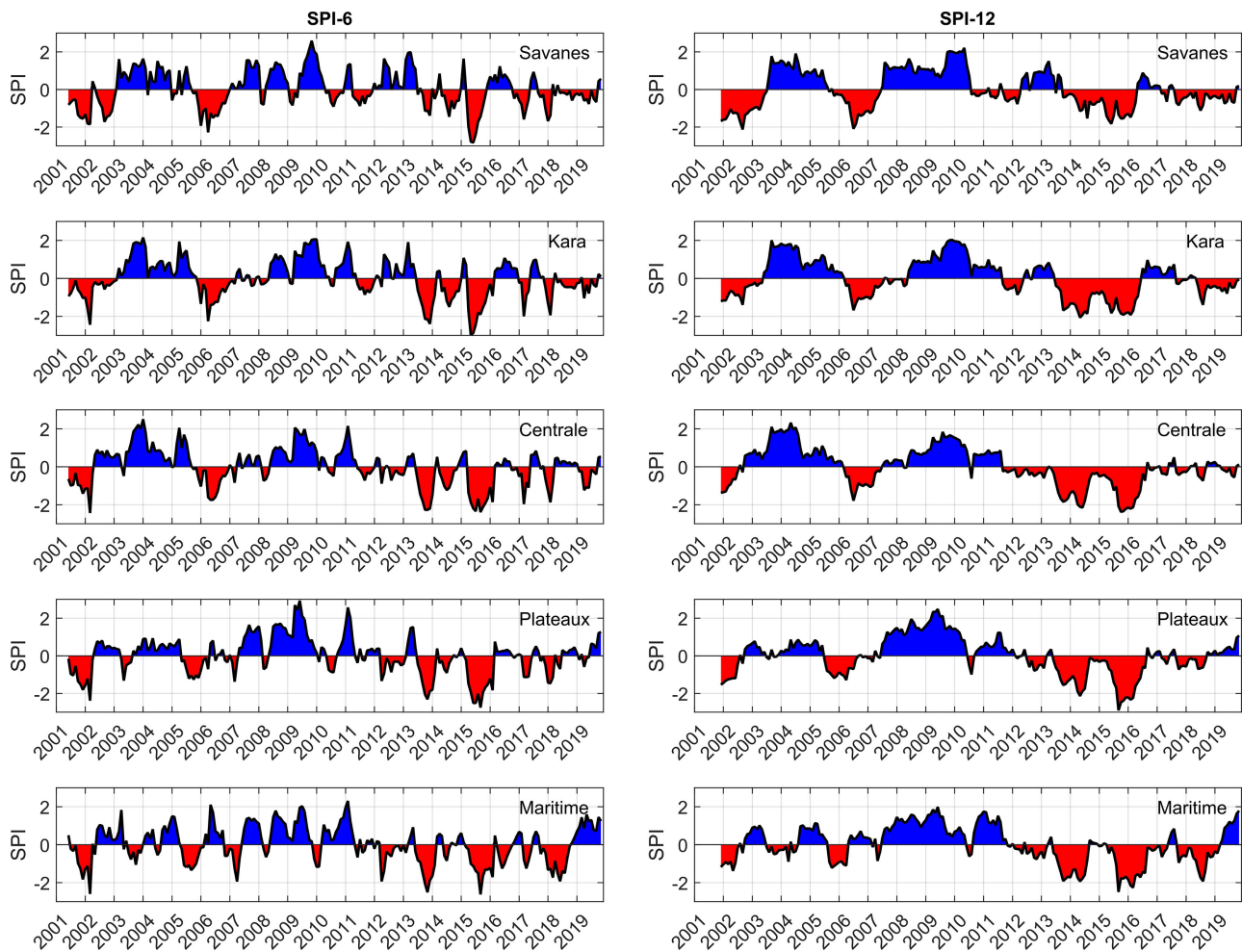


Figure 2. SPI-6 (left) and SPI-12 (right) time series for Togo administrative regions during 2001-2019. Data: IMERG.

Table 2. Dry and Wet events at SPI-6 and SPI-12 scales for the Maritime region. The numbers in gray refer to the longest duration and highest maximum peak intensity of the events.

Dry events at SPI-6, and SPI-12 month scales for Maritime region							
SPI-6				SPI-12			
Start date	End date	Duration	Peak intensity	Start date	End date	Duration	Peak intensity
Aug 2001	Apr 2002	9	-2.60	Jul 2013	Sep 2014	15	-1.92
Jul 2013	Mar 2014	9	-2.51	Jun 2015	Jun 2017	25	-2.49
Apr 2015	Mar 2016	12	-2.51	Dec 2017	Apr 2019	18	-1.92
Nov 2017	Nov 2018	13	-1.92				
Wet events at 6, and 12-month SPI scales over Maritime region							
Jul 2002	Mar 2003	11	1.83	Nov 2002	Jul 2003	9	1.01
Oct 2004	Mar 2005	8	1.50	Sep 2004	Sep 2005	13	1.13
Mar 2006	Dec 2006	8	2.60	Aug 2007	Jun 2010	35	2.00
Jul 2007	Mar 2008	9	1.41	Oct 2010	Dec 2011	14	1.74
Jul 2008	Dec 2009	18	2.03	Mar 2019	Dec 2019	7	1.79
Apr 2010	Mar 2011	14	2.31				
Dec 2018	Dec 2019	13	1.59				

Table 3. Dry and Wet events at SPI-6 and SPI-12 scales for the Plateaux region. The numbers in gray refer to the longest duration and highest maximum peak intensity of the events.

Dry events at 6, and 12-month SPI scales over Plateaux region							
SPI-6				SPI-12			
Start date	End date	Duration	Peak intensity	Start date	End date	Duration	Peak intensity
Jul 2001	Mar 2002	11	-2.38	Jan 2002	Aug 2012	8	-1.45
Jun 2005	May 2006	12	-1.26	Aug 2005	Sep 2006	14	-1.29
Aug 2013	Mar 2014	8	-2.31	Jul 2013	Sep 2016	40	-2.90
Apr 2015	Mar 2016	12	-2.75				
Wet events at 6, and 12-month SPI scales over Plateaux region							
Jun 2007	Mar 2008	10	1.64	Aug 2007	Jul 2010	36	2.48
Jul 2008	Feb 2010	20	2.94	Dec 2010	Feb 2012	17	1.33
Nov 2010	Mar 2011	7	2.57				
Aug 2019	Dec 2019	5	1.27				

Table 4. Dry and Wet events at SPI-6 and SPI-12 scales for the Central region. The numbers in gray refer to the longest duration and highest maximum peak intensity of the events.

Dry events at 6, and 12-month SPI scales over Central region							
SPI-6				SPI-12			
Start date	end date	duration	Peak intensity	Start date	End date	Duration	Peak intensity
Jul 2001	Mar 2002	11	-2.44	Jan 2002	Aug 2002	8	-1.37
Nov 2005	Jan 2007	15	-1.61	Apr 2006	Jul 2007	16	-1.78
Jul 2013	Mar 2014	9	-2.27	Jun 2013	Sep 2016	41	-2.37
May 2014	Dec 2014	8	-1.23				
May 2015	Mar 2016	11	-2.39				
Nov 2016	Jun 2017	8	-1.97				
Mar 2019	Oct 2019	9	-1.22				
Wet events at 6, and 12-month SPI scales over Centrale region							
Jul 2003	Jan 2005	19	2.51	Nov 2002	Mar 2006	41	2.33
Mar 2005	Oct 2005	8	2.06	Jul 2008	Aug 2010	27	1.84
Sep 2008	Feb 2010	20	2.06				
Oct 2010	Jun 2011	9	2.15				

The SPI-6 time series data for the Savanah region illustrates notable patterns. The longest dry spell persisted for 15 months, spanning from November 2005 to January 2007. The most intense dry event occurred from July 2009 to May 2010, peaking at 2.59. Conversely, the wettest episode during this period lasted 11 months, starting in July 2009 and ending in May 2010, also peaking at 2.59. In relation to SPI-12, the Savanah region witnessed a prolonged dry spell lasting 20 months, from January 2002 to August 2003, reaching a peak intensity of -2.13. The wettest event lasted from August 2007 to July 2010 and endured for 37

months, marking the longest and most intense wet period with a peak intensity of 2.21.

Table 5. Dry and Wet events at SPI-6 and SPI-12 scales for the Kara region. The numbers in gray refer to the longest duration and highest maximum peak intensity of the events.

Dry events at 6, and 12-month SPI scales over Kara region							
SPI-6				SPI-12			
Start date	End date	Duration	Peak intensity	Start date	End date	Duration	Peak intensity
Jul 2001	Mar 2003	21	-2.44	Jan 2002	Jun 2003	18	-1.39
Jan 2006	Apr 2007	16	-2.26	May 2006	Aug 2007	16	-1.68
Aug 2014	Mar 2014	8	-2.40	Aug 2013	Jul 2016	36	-2.07
Jun 2014	Feb 2015	9	-1.50	Jul 2018	Dec 2019	18	-1.40
May 2015	Mar 2016	11	-3.01				
Jan 2018	Apr 2018	4	-1.94				
Wet events at 6, and 12-month SPI scales over Kara region							
Apr 2003	Dec 2005	33	2.15	Jul 2003	Apr 2006	35	2.00
Jul 2008	Feb 2009	8	1.99	Jul 2008	Nov 2011	39	2.02
May 2009	Jul 2010	15	2.06				
Sep 2010	Jun 2011	9	1.93				
Nov 2012	Jul 2013	9	1.91				
Apr 2016	Oct 2017	10	1.7				

Table 6. Dry and Wet events at SPI-6 and SPI-12 scales for the Savanah region. The numbers in gray refer to the longest duration and highest maximum peak intensity of the events.

Dry events at 6, and 12-month SPI scales over Savanah region							
SPI-6				SPI-12			
Start date	End date	Duration	Peak intensity	Start date	End date	Duration	Peak intensity
Jul 2001	Apr 2002	10	-1.84	Jan 2002	Aug 2003	20	-2.13
Jul 2002	Feb 2003	8	-1.72	Dec 2005	Jul 2007	20	-2.08
Dec 2005	Jan 2007	15	-2.28	Nov 2013	May 2016	31	-1.83
Jun 2014	Jan 2015	8	-1.45	Sep 2017	Oct 2019	26	-1.12
Apr 2015	Dec 2015	9	-2.82				
Oct 2017	Mar 2018	6	-1.68				
Wet events at 6-, and 12-month SPI scales over Savanah region							
Mar 2003	Mar 2004	13	1.64	Sep 2003	Sep 2005	25	1.91
May 2004	Jan 2005	9	1.51	Aug 2007	Jul 2010	37	2.21
Feb 2007	Feb 2008	13	1.56	Oct 2012	Jul 2013	10	1.50
May 2008	Feb 2009	10	1.46				
Jul 2009	May 2010	11	2.59				
Oct 2013	Jul 2014	10	1.98				

At Kara region, the longest and intense dry event considering SPI-6 lasted 21 months (from July 2001 to March 2003). It reached in April 2002 a PI of -2.44 . For wet periods in Kara, the longest one lasted 33 months (from April 2003 to December 2005) with a PI of 2.15 reached in February 2004. The SPI-12 showed that, for the same region, the most important dry event lasted 36 months (August 2013 to July 2016) with a PI of -2.07 in June 2014. The wet event that occurred from July 2008 to September 2011 (39 months) was the most significant, with a PI of 2.02 in January 2010.

In the Centrale region, for SPI-6, the most intense dry event reached a PI of -2.39 in October 2015 and lasted 11 months (May 2015 to March 2016). On the other hand, the most important wet event lasted 19 months (July 2003 to January 2005) with a PI of 2.51 in February 2004. For the same region, SPI-12 showed the longest and most intense dry event, which lasted 41 months (June 2013 to September 2016), with a PI of 2.37. For the wet event, there was one important event, which also lasted 41 months (November 2002 to March 2006) and reached a PI of 2.33 in June 2004.

At the Plateaux region, the SPI-6 revealed one intense and longest dry event, which lasted 12 months (April 2015 to March 2016), with a PI of -2.75 in October 2015. Regarding the wet event that occurred from July 2008 to February 2010 (20 months), it was the most intense for the region, with a PI of 2.94 in July 2009.

For the SPI-12, the dry event which started in July 2013 and end in September 2016 (40 months), was the longest and most intense. It reached a PI of -2.90 in October 2015. The most important wet event for the same time scale lasted 36 months (August 2007 to July 2010), with a PI of 2.48 in July 2009.

For the Maritime region, Togo's southernmost region, the most important dry event for SPI-6 lasted 1 year (April 2015 to March 2016), and it reached a PI of -2.62 in October 2015. For the same time scale, the most important wet event lasted 14 months (April 2010 to May 2011), with a PI of 2.31 reached in March 2011. On the other hand, SPI-12 showed one intense and the longest dry event from June 2015 to June 2017 (25 months). It reached a PI of -2.49 in October 2015. For the wet events, the one that occurred from August 2007 to June 2010 (35 months) was the most important in duration and intensity; its PI was 2.0 reached in July 2009.

Figure 3 depicts the SPI-12 map at the end of December spanning all years and the five regions examined within our study period. In the years 2001, 2013, and 2015, dry conditions prevailed across all regions, encompassing the entirety of the country. Notably, in 2015, 85% of the country experienced extremely dry conditions. Additionally, in 2001, Togo experienced predominantly dry conditions, with the exception of the Centrale region and the western part of the Savannas region, which were classified as extremely dry. The drought event of 2015 was widespread across the Gulf of Guinea countries due to a deficit in seasonal rainfall, which was associated with the 2015 El Niño event (Anyamba et al., 2019; Owusu et al., 2019). In 2002, except in the north part of the Savannas region, which was very dry, Togo experienced in general near-normal conditions. During 2003, very to extremely wet periods (exceptionally in the western part of Centrale region)

occurred in the Northern regions, while in the southern regions normal condition was observed. The year 2013 was extremely dry in the Maritime region and in the Southeast of Plateaux. The remaining country was very dry, except in the northern part of the Savannah region, which was under normal conditions.

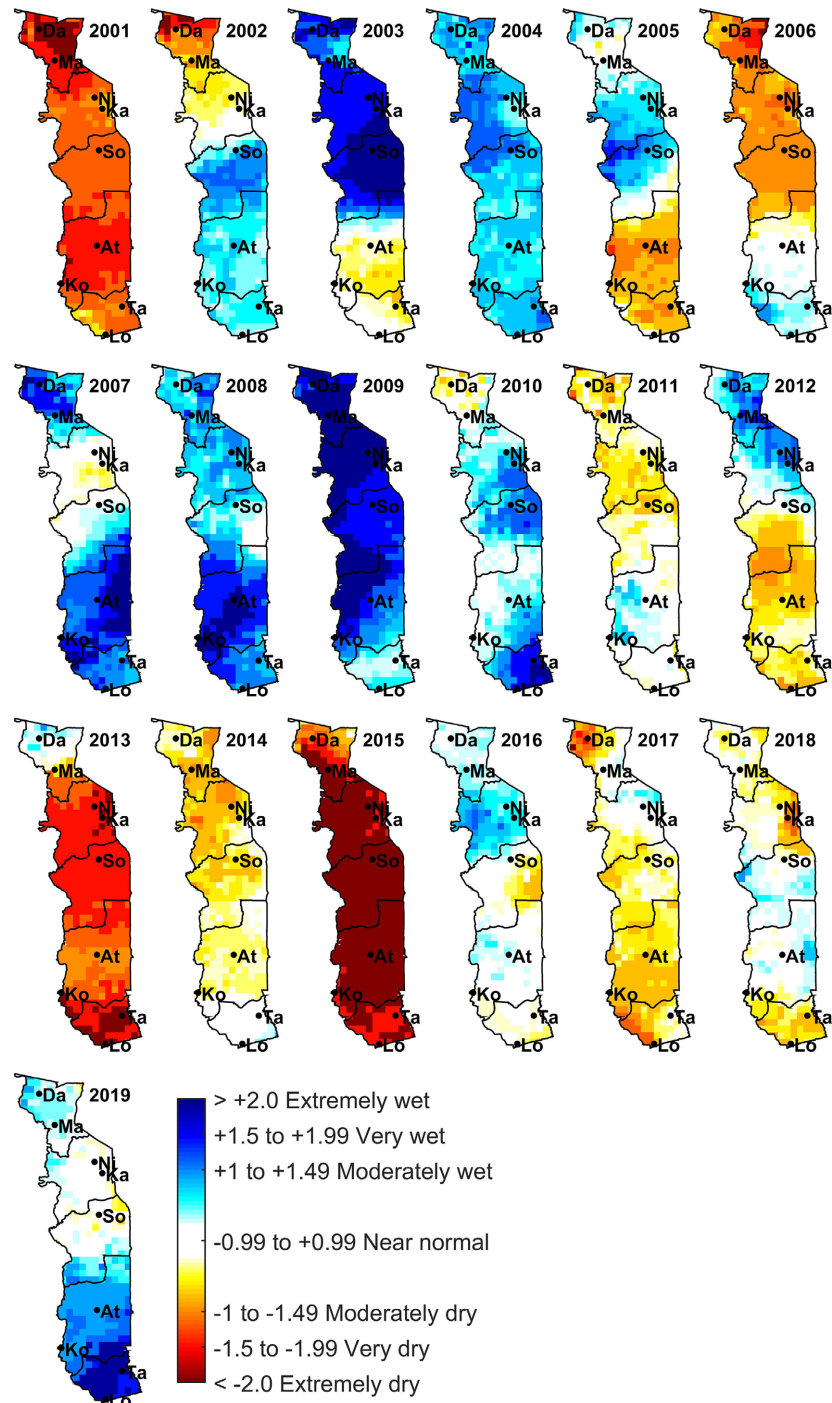


Figure 3. SPI-12-month for each year for Togo for the period from 2001 to 2019. From north to south, the five administrative divisions are displayed: Savannah, Kara, Centrale, Plateaux, and Maritime. The black dots indicate the rain gauge network sites in each region.

In 2006, the northern regions (Savannas, Kara, Centrale) experienced moderate to very dry periods, while the southern regions (Plateaux and Maritime) were under normal conditions. The situation was reversed in 2005, where the regions in the south undergone moderately dry periods, and those in the north experienced normal conditions to moderately wet periods. During the years 2007, 2008, and 2009, most of the country experienced very wet and extremely wet events. Nevertheless, the Kara region and the north part of the Centrale region presented normal conditions. Similar results were obtained by (Koudahe et al., 2017) for southern Togo, where SPI-12 showed significant wet events in 2007 and 2008, which caused sporadic flooding events. The flooding events destroyed 11,688 hectares of cultivated land, resulting in an important loss of income for farmers and creating a spike in food shortages across the region (World Bank, 2011).

The maritime region experienced moderate to very wet conditions in 2007-2008, near-normal conditions in 2009, wetness in the west portion, and extreme wetness in the east during 2010. This situation may have had positive impacts on agriculture, underground reservoir levels, and water supply. During the same year, the southeast of the Kara region and the eastern part of the Centrale region was also very wet, while the remainder of the country presented a situation near to normal conditions. For the years 2011, 2012, 2014, 2016, 2017, and 2018, the situation in most of the regions was close to normal, although there was a slight tendency for dry conditions in some regions.

These results show the diversity of scenarios that Togo can experience, and the importance of comprehensive geographical monitoring specially of drought events. So, resources can be properly and wisely directed to mitigate the extreme scenarios consequence.

4. Conclusion

In this study, dry and wet climate events from 2001 to 2019 at regional level in Togo have been analyzed. Based on monthly rainfall from a satellite-based product, the Integrated Multi-satellite Retrievals for GPM (IMERG), SPIs at 6- and 12-month scales were calculated, and dry and wet events across five Togo administrative regions have been assessed. The results obtained for the chosen time scale (6-month and 12-month) showed that the major climate events across the entire country were well accessed during the study period. For instance, the satellite-based product (IMERG) captured the widespread long-term wet event from 2008 to 2010, and also the dry event from 2013 to 2015, both documented in the literature. The analysis of SPI-6 and SPI-12 shows that 2015 was characterized by dry scenarios in all Togo regions as highlighted in the 2015 UN-WFP report. This event has been reported to cause a rainfall deficit across different west African countries and lead to a significant dry episode during that year with important consequences for the regional agriculture. The large amount of precipitation observed in 2007, 2008, and 2009, characterized by positive SPI-6 across the country led to severe flooding events in the Savanah, Centrale, and Southern Maritime

region, displacing thousands of people and causing important damages.

So, this study shows the ability of satellite-based products, in this case IMERG, to characterize dry and wet events that occurred during the last two decades in Togo, highlighting their regional features. These products are available and can be added to the national rain gauge network to improve the country's ability to monitor climate conditions, especially drought scenario development, across all administrative regions. Nevertheless, further studies are needed to monitor and predict these extreme climate events (drought and flood) over Togo regions in order to help the local communities and stakeholders in their decision-making to mitigate the effects of rainfall-related extreme climate events. To achieve this goal, long-term, regular temporally and high spatial resolution rainfall data are fundamental to establish a drought early warning system and critical to advance the understanding of rainfall distribution across the country.

Based on the findings of this study, two recommendations can be made:

The inclusion of new rainfall products from multiple satellite platforms is crucial complement regional rain gauge network in order to give reliable information to the decision-makers and populations as a whole. Nevertheless, the operational network of observation stations over Togo needs to be continuously improved in order to provide high spatial resolution observations that can be used to evaluate satellite-based and climate model rainfall information.

Additionally, for a more comprehensive understanding of drought dynamics in Togo, further studies are crucial to establish potential teleconnections between observed drought and large-scale climate drivers such as the El Niño-Southern Oscillation and the South Atlantic Ocean Dipole.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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