

Research Article

Meteorological Drought Monitoring Based on Satellite CHIRPS Product over Gamo Zone, Southern Ethiopia

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Drought is a frequent occurrence in semidesert areas of southern Ethiopia that significantly affect regional, social, economic, and environmental conditions. Lack of rainfall monitoring network, instrument measurement, and failure are major bottlenecks for agro- and hydroclimate research in developing countries. The objectives of this study were to evaluate the performance of CHIRPS rainfall product and to assess meteorological drought using SPI for the period 2000 to 2020 over Gamo Zone, southern Ethiopia. The performance of CHIRPS v2 was assessed and compared to station observations (2000–2020) in the study domain to derive SPI on a three-month timescale. The Pearson correlation coefficient (R), bias, probability of bias (PBias), mean error (ME), mean absolute error (MAE), root mean square error (RMSE), and Nash simulation efficiency (NSE) values across the zone for CHIRPS v2 were found to be 0.88, 1.02, 2.56, 0.25, 22.41, 33.14, and 0.77, respectively. The results indicate that CHIRPS performed good ability to analyze the drought characteristics in the Gamo Zone. The spatial and temporal distribution method of meteorological drought has been evaluated using the Climate Data Tool (CDT). The Standardized Precipitation Index (SPI) was computed using the gamma distribution method. The magnitude of (SPI-3) of monthly and seasonal (MAM) meteorological drought in the zone from 2000 to 2020. The result shows that the known historic drought years (2014, 2015, 2010, 2009, and 2008) were indicated very well. Furthermore, severe and extreme droughts were observed in 2008 and 2009 with drought duration of 6.7 and 6.3, respectively, in most areas of the zone. Hence, this study revealed that CHIRPS can be a useful supplement for measuring rainfall data to estimate rainfall and drought monitoring in this region.

1. Introduction

1.1. Background of the Study. Drought is a natural hazard causing adverse impacts on vegetation, animals, people, and the ecosystem [1]. In recent years, it has been occurring frequently in all climatic zones and significantly affects crop yields causing a shortage of food as well as animal forage [2, 3]. Drought is a complex phenomenon considered a natural hazard causing several environmental, societal, and economic problems [4–8]. Even though drought is a recurring phenomenon and affects all geographical areas [9], its impacts are more severe in arid and semiarid regions [10] where there already exists high natural variability in the rainfall pattern [11, 12].

Drought is a recurring phenomenon in Ethiopia [13] that significantly impacts the socioeconomic sector and various components of the environment [14]. It affects many sectors,

causes large economic losses, and threatens human life and the environment [15]. Ethiopia has been hit by recurring and long-lasting drought [16] that have damaged a huge section of the population, ruined crops, and killed livestock [17] as well as severe historic drought occurrences in the last few decades [1, 18].

Rainfall data plays an important role in drought monitoring and disaster prevention. Rainfall is also an important part of the hydrological cycle used to control and predict droughts around the world [19, 20]. However, ground observations that offer accurate precipitation data, on the other hand, are limited in many drought-prone areas of the world and are even falling in most of Africa. Furthermore, due to regulatory constraints, a lack of dissemination capability, or the high cost of data in many parts of Africa, existing station records are frequently of poor quality and difficult to acquire [21, 22].

With the advent of technology, remote sensing technologies such as satellite-based rainfall forecasting have become better options and a good alternative to bridge the gap. In areas where rain gauge networks are lacking, satellite-based rainfall products have become valuable for a wide range of drought and forecasting, assessing water resources, and water management [23]. The satellite-based rainfall product provides continuous spatial and temporal measurements of rainfall rather than rain gauges [24], and it is also found in most oceans and uninhabited land areas.

The satellite has become vital, particularly for timely revealing [25] and observing drought due to the availability of spatiotemporal data over the entire globe [26]. Satellite imagery can help monitor the atmosphere by detecting changes in Earth's vegetation, quality of atmospheric trace gas, sea state, ocean color, and ice fields [27, 28]. Over time, drought can be tracked by comparing the current rainfall and vegetation condition to its long-term average by measuring changes [29].

Ethiopia has been affected by meteorological drought in major parts of the country such as Amhara region [30]; Tigray region, Afar, Somalia [31], Oromia, and SNNPR are the first parts of the country affected by drought (Mera, 2018). Successive droughts in this region during 2009 and 2014 reflect its episodic nature, and more than 60% of the land area experienced moderate drought; however, the spatial extent varied [32].

Since Ethiopia is an agricultural country [33] and is prone to frequent droughts, systematic drought monitoring can significantly contribute to the sustainable development of agriculture. Drought occasionally covered large areas of the Gamo Zone and SNNPR [34]. Drought in Gamo Zone is primarily caused by a deficit of rainfall [35], which is driven by the interaction of multiple climate systems at different spatiotemporal scales. Populations living in poor socioeconomic conditions have been more vulnerable to the impacts of drought [36]. Furthermore, drought has caused severe economic damage to the countries of Ethiopia including Gamo Zone primarily because of the loss of agricultural production and its subsequent impact on the associated sectors [37].

Drought indices are important instruments for defining and monitoring drought because they simplify complex meteorological functions and can quantify climatic abnormalities in terms of severity, length, and frequency [38, 39]. Moreover, over the last few decades, many studies have been conducted to monitor the drought in Ethiopia, and most of these studies are SPI-based drought [40, 41] analyses based on location-specific observed or stationed rainfall data. Reconnaissance drought index (RDI) [42], normalized difference vegetation index (NDVI), land surface temperature (LST), vegetation condition index (VCI), temperature condition index (TCI), and vegetation health index (VHI) [43] methods were used to measure drought, and the Mann-Kendall and Sen's slope test to detect rainfall and temperature trend over the central Rift Valley and Gamo Zone regions of Ethiopia, which depend on weather station data and vegetation condition. Many studies [44–46] have also evaluated satellite products and compared them with ground

weather station data for Ethiopia, and those studies indicated that the CHIRPS satellite rainfall product performed best for the Gamo Zone and the regions. However, most of these research have not focused on using satellite remote sensing to map the geographical and temporal patterns of meteorological drought hazards in Gamo Zone with limited station coverage. Due to the scarcity of rainfall stations in the study area, drought distribution and temporary distribution were not effectively represented [47, 48]. Satellite remote sensing data can help monitor the atmosphere by detecting changes in Earth's vegetation, quality of atmospheric trace gas, sea state, ocean color, and ice fields [49–51]. Satellite remote data is very crucial for meteorology and agricultural planning [52], disaster prevention, early warning system [53], drought adaptation, and mitigation.

As a result, it is both timely and important to conduct a comprehensive drought analysis that depicts the spatial and temporal distribution of drought in satellite remote sensing. This is especially important for the timely detection and monitoring of drought due to the increased availability of spatiotemporal data across the globe. Henceforth, this study specifically focuses on investigating the use of CHIRPS satellite-based meteorological drought monitoring using the standard precipitation index (SPI) for Gamo Zone, southern Ethiopia.

2. Materials and Methods

2.1. Description of the Study Area. Gamo Zone is located in Southern Nations, Nationalities, and People between 5°55'N and 6°20'N latitude and between 37°10'E and 37°40'E longitude (Figure 1). Elevation ranges between 600 and 4,207 m above sea level, and it covers an area of 6,735 km². The average temperature ranges from 10°C to 25°C, whereas the mean annual rainfall ranges from 200 mm to 2,000 mm. The rainfall pattern can be characterized as a bimodal minor rainy season (September–November) and the major rainy season (March–May) [54]. The main rainy season accounts for 70–90% of the total annual rainfall [55]. A small rainy season, originating from moist south-easterly winds, occurs between March and May. Due to their nature, these rainfall events are more pronounced in the highlands. Air temperature largely depends on the altitude [56] means that it decreases with increasing altitude. The annual average temperature ranges from 15°C to 28°C [57]. Most of the natural vegetation consists of woodland and savannas. In the highlands, afro Montana forests are found. Cultivated land is mostly located on the valley floor, and the major field crops are teff, barley, maize, lentils, horse beans, chickpeas, and field peas [58]. Most importantly, vegetables such as haricot beans, tomato, onion, cabbage, broccoli, and others are cultivated under irrigation [59].

2.2. Data

2.2.1. Meteorological Station Data. The historical daily rainfall data from 2000 to 2020 for 10 meteorological stations were obtained from the Ethiopian National Meteorological Agency (NMA), and the data were analyzed using

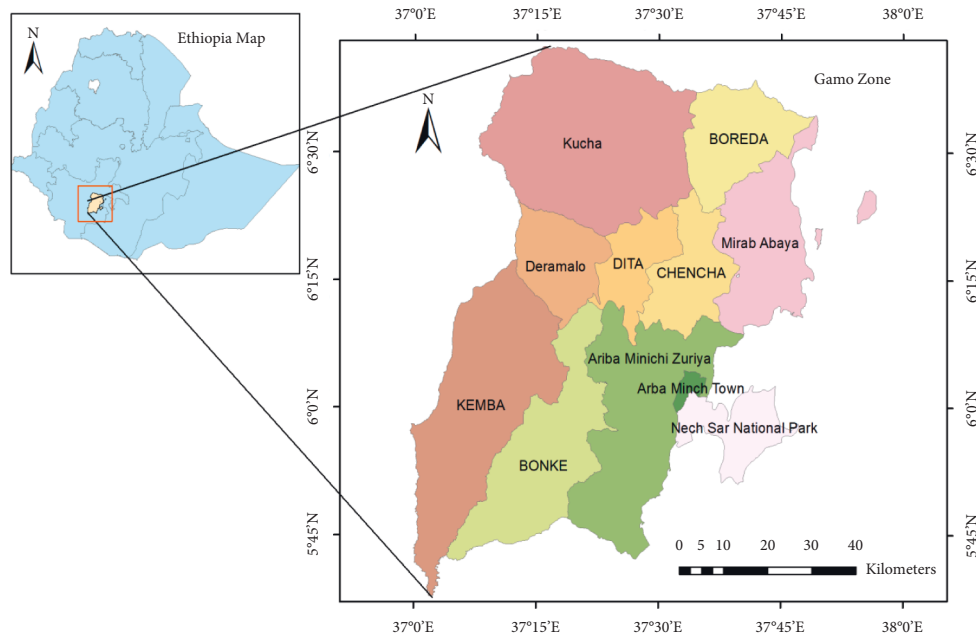


FIGURE 1: Map of the study area.

Climate Data Tool (CDTv6.5) [60]. The information about synoptic weather stations are presented in Table 1.

2.2.2. CHIRPS Data. Most of the satellite precipitation products fall short of the time series for a historical record [61]. As a result, scientists and researchers are finding it difficult to analyze the distribution of drought and space and to better predict climate change for the future of the world. As listed in Table 2, from 19 satellite rainfall products, the Climate Hazards Group InfraRed Precipitation (CHIRPS) satellite product was selected, due to the availability of time series data of more than 30 years, free access of data, and spatiotemporal resolution of $0.05^\circ \times 0.05^\circ$, 1 day and widely used. In addition to this, the CHIRPS satellite rainfall product was previously evaluated against surface rain gauges by Gedle (2018), over the Abaya Chamo basin that is found in Gamo Zone and showed an excellent result. Similar other studies [62–64] evaluated the performance of CHIRPS over different parts of Ethiopia and Gamo Zone. Because of the accessibility of a longer time series of data in near real time, reasonably high spatial and temporal resolutions, and open access to the data, CHIRPS satellite data were chosen. CHIRPS was developed by the US Geological Survey (USGS) and the Climate Hazards Group at the University of California, Santa Barbara (UCSB). CHIRPS is a hybrid product that combines a pentadal precipitation climatology with quasiglobal geostationary (thermal infrared) TIR satellite measurements from the CPC and the National Climate Forecast System version 2 (CFSv2), as well as in situ precipitation observations. The CHIRPS product, which has a spatial resolution of 0.05° (approximately 5.3 km) and a quasiglobal coverage of 50°S – 50°N and 180°E – 180°W , is accessible at pentadal, decadal, and monthly temporal resolution from 1981 to the near present [65]. The monthly

scale was chosen because it is suitable for drought monitoring using indicators like the Standardized Precipitation Index [66]. In this study, the CHIRPS product was utilized for monthly comparison for the period 2000–2020, which overlaps the period of ground-based rainfall data.

2.3. Methods

2.3.1. Evaluation of CHIRPS Rainfall. In this study, CHIRPS data sets were compared with measured rainfall data using the Climate Data Tool. The Climate Data Tool (CDT) is a free, open-source R package and has been used to analyze CHIRPS and station observation data. The Climate Data Tool has been used to combine station observation with CHIRPS satellite rainfall to fill the temporal and spatial gaps in the observational record. In this study, spatial interpolation bias correction method such as empirical quantile mapping, validation, and drought indices such as SPI has been analyzed using Climate Data Tool (CDT).

2.3.2. Performance Evaluation. To evaluate the CHIRPS rainfall product performance, five of the most common statistical error indices such as root mean square error (RMSE), mean absolute error (MAE), bias, Nash–Sutcliffe efficiency coefficient (NSE), and correlation coefficient (R) were used for comparison between CHIRPS and station observations at month time frame Table 3.

2.3.3. Standardized Precipitation Index (SPI). The World Meteorological Organization (WMO) has designated Standardized Precipitation Index (SPI) as the reference drought index, and it is the most widely used drought indicator globally [86–88]. SPI is a drought index that is used to investigate the intensity, and spatial configuration of

TABLE 1: Meteorological stations information of the study area.

No.	Station name	Latitude	Longitude	Elevation (m)	Small seasonal rainfall (mm)	High seasonal rainfall (mm)	Annual rainfall (mm)
1	Mirab_Abaya	6.27	37.77	1,221	202.0	306.69	799.55
2	Arba_Minch	6.06	37.56	1,220	293.51	373.47	949.99
3	Dara_Malo	6.32	37.3	1,057	272.19	356.96	921.83
4	Gerese	5.92	37.3	2,217	523.94	879.81	1,205.99
5	Morka	6.42	37.31	1,065	313.02	403.96	853.14
6	Chencha	6.25	37.56	2,631	355.00	694.90	1,234.30

TABLE 2: Common satellite rainfall products for rainfall estimation (source: [67]).

No.	Product name	Operational period	Temporal resolution	Spatial resolution	Reference(s)
1	CFSR	1979–Present	1 h	$0.5^\circ \times 0.5^\circ$	[68]
2	CHIRPS	1980–Present	1 day	$0.05^\circ \times 0.05^\circ$	[69]
3	CMAP	1979–2009	5 days	$2.5^\circ \times 2.5^\circ$	[70]
4	CMORPH	2002–Present	30 min	$0.07^\circ \times 0.07^\circ$	[71]
5	CPC-RFE 2.0	2001–Present	1 day	$0.10^\circ \times 0.10^\circ$	[72]
5	GPCP 1DD	1997–2008	1 day	$1.0^\circ \times 1.0^\circ$	[73, 74]
6	GPCP-V2	1979–2008	1 month	$0.5^\circ \times 0.5^\circ$	[73, 74]
7	GSMaP	2003–2006	1 h	$2.5^\circ \times 2.5^\circ$	[75]
8	Hydro Estimator	2006–Present	15 min	$0.04^\circ \times 0.04^\circ$	[76]
9	IMERG	2000–Present	30 min	$0.1^\circ \times 0.1^\circ$	[77]
10	MPE	2004–Present	15 min	$0.03^\circ \times 0.03^\circ$	[78]
11	MSWEP-V1.1	1979–2015	3 h	$0.25^\circ \times 0.25^\circ$	[79]
12	MWCOMB	2002–Present	3 h	$0.25^\circ \times 0.25^\circ$	[80]
13	NRL_Blended	2003–Present	3 h	$0.25^\circ \times 0.25^\circ$	[81]
14	PERSIAN	2000–Present	1 h	$0.25^\circ \times 0.25^\circ$	[82]
15	TAMSAT	1983–Present	10 days	$0.25^\circ \times 0.25^\circ$	[83]
16	TRMM-TMPA 3B42	1998–Present	3 h	$0.25^\circ \times 0.25^\circ$	[84, 85]
17	TRMM-TMPA 3B42-RT	2000–Present	3 h	$0.25^\circ \times 0.25^\circ$	[84, 85]
18	TRMM-TMPA 3B43	1998–Present	1 month	$0.25^\circ \times 0.25^\circ$	[84, 85]

Note. CFSR (Climate Forecast System Reanalysis), CMAP (merged Analysis of Precipitation), MORPH (Climate Prediction Centre MORPHing), CPC-RFE (Climate Prediction Centre-RainFall Estimation), GPCP 1DD (Global Precipitation Climatology Project 1 Degree Daily), GPCP-V2 (Global Precipitation Climatology Project-version 2), GSMaP (Global Satellite Mapping of Precipitation), MPE (Multi-sensor Precipitation Estimate), MWCOMB (simple average of the microwave-based estimates used in creating the CMORPH), NRL-Blended (Naval Research Laboratory-Blended), PERSIAN (Precipitation Estimation from Remotely Sensed Information using Artificial Neural Network), TAMSAT (Temporal Applications of Meteorology using SATellite), Tropical Rainfall Measurement Mission (TRMM) TMPA (Multi-satellite Precipitation Analysis), TMPA-RT (TMPA-Real Time), MSWEP (Multi-Source Weighted-Ensemble Precipitation), Integrated Multi-satellites Retrievals for GPM (IMERG), and CHIRPS (Rainfall Estimates from Rain Gauge and Satellite Observations).

TABLE 3: Statistical measures of performance used for analysis based on continuous metrics.

Statistic	Formula	Range	Best value
Root mean square error (RMSE)	$RMSE = ((Rs - Rg)^2 / N)^{1/2}$	$-\infty$ to ∞	0
Percent of bias (PBIAS)	$PBIAS = \sum_{i=1}^n (Rsi - RGi) / \sum_{i=1}^n Rsi \times 100$	$-\infty$ to ∞	0
Mean absolute error	$MAE = (1/N) \sum (Rs - Rg)$	0 to ∞	0
Nash–Sutcliffe efficiency coefficient	$NSE = 1 - \sum (Rg - Rs)^2 / \sum (Rg - \overline{Rg})^2$	$-\infty$ to ∞	1
Bias	$Bias = \sum Rs / \sum Rg$	0 to ∞	1
Correlation coefficient (R)	$R = (Rg - \overline{Rg})(Rs - \overline{Rs}) / \sqrt{\sum (Rg - \overline{Rg})^2 \sum (Rs - \overline{Rs})^2}$	-1 to 1	1

Note. Rg , Rs , \overline{Rg} , and N represent rainfall at the rain gauging station, chirping satellite rainfall, the mean of observed rainfall, and the number of data pairs compared, respectively.

drought distribution in a particular region [89, 90] has compared the Effective Drought Index (EDI) and SPI and recommends SPI as a drought index because it is simple to calculate and has greater spatial consistency. It has been used in many studies to determine the spatial distribution and classification of drought patterns [8, 90–94].

The Standardized Precipitation Index (SPI) at various timescales (1–12 months) was computed to identify and describe drought events [95]. Depending on the drought impact in question, SPI values for 3 months or less might be useful for basic drought monitoring, especially for meteorological drought [96]. Therefore, in this study, the SPI value

at three timescales (SPI-3) was computed to determine meteorological drought. In this study, monthly rainfall data have been used as an input to compute the SPI for the period 2000–2020. Climate Data Tools (CDT) were used to determine drought indices such as SPI. The gamma distribution methods [97] have been used to monitor three timescale SP droughts.

Mathematically, SPI is calculated based on the following gamma distribution formula [98]:

$$g(x) = \frac{1}{\beta^\alpha \Gamma(\alpha)} x^{\alpha-1} e^{-x/\beta}, \quad \text{for } x > 0, \quad (1)$$

where α and β are the shape and scale parameters, respectively; x is the precipitation amount, and $\Gamma(\alpha)$ is the gamma function. Parameters α and β of the gamma PDF will be estimated for each station and for each timescale of interest (1, 3, 6, 9, and 12 months). Maximum likelihood estimations of α and β are

$$\alpha = \frac{1}{4A} \left(1 + \sqrt{1 + \frac{4A}{3}} \right), \quad \beta = \frac{\bar{x}}{\alpha}, \quad \text{where } A = \ln(\bar{x}) - \frac{\sum \ln(x)}{n}. \quad (2)$$

The cumulative probability of an observed precipitation event for the specified month and timescale for the location is questionable [99]. The gamma function is undefined for $x = 0$, and a precipitation distribution may contain zeros; the cumulative probability will be determined:

$$H(x) = q + (1 - q)G(x), \quad (3)$$

where q is the probability of zero precipitation and $G(x)$ is the cumulative probability of the incomplete gamma function. If m is the number of zeros in a precipitation time series, then q is estimated by m/n . The cumulative probability $H(x)$ is then transformed to the standard normal random variable z with a mean of 0 and variance of 1, which is the value of the SPI [100].

According to [101], the SPI values were reclassified based on drought severity classes (Table 4). The positive SPI values indicate the rainfall is greater than the median and negative values indicate less than the median rainfall.

Droughts are characterized by drought duration, drought magnitude, and drought intensity, as shown in Figure 2.

Drought duration (D_d): It refers to the number of consecutive months (or weeks) in which precipitation (or soil moisture or runoff) is below the chosen threshold [102, 103]. The duration is highly dependent on the chosen threshold for the declaration of the start and end of the drought episode (Figure 2).

$$D_d = \frac{\sum_{i=1}^n d_i}{n}, \quad (4)$$

where d_i is the duration of the i^{th} drought event in an area and n is the total number of drought events.

Drought intensity (DI): The intensity of a drought is the severity divided by the duration. Droughts that have shorter durations and higher severities will have larger intensities [104].

TABLE 4: Drought categories defined by SPI values.

SPI values	Class
Above 0	No drought
0 to -0.99	Normal condition/mild drought
-1.00 to -1.49	Moderate drought
-1.5 to -1.99	Severe drought
-2.00 and less	Extreme drought

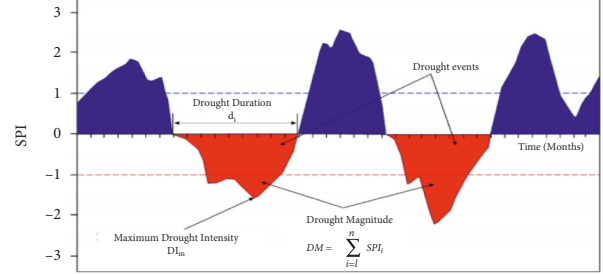


FIGURE 2: Definition of drought characteristics based on the SPI index (blue dashed line shows one standard deviation wetter than average, and while the red dashed line shows one standard deviation drier than average (Source: [107])).

$$\text{Intensity} = \frac{\text{severity}}{\text{Duration}}. \quad (5)$$

Drought severity (S): It refers to either the value of precipitation (or any other drought indicator) at a given month during the drought event or the minimum of precipitation during the event [105, 106]. The severity is the cumulative sum of the index values based on the duration and extent.

$$\text{Severity} = \sum_{i=1}^{D_d} \text{SPI}. \quad (6)$$

Figure 3 describes the methodology used in this study.

3. Results and Discussion

3.1. Evaluation of Satellite Rainfall. In this study, the CHIRPS satellite rainfall product was investigated to identify the spatial and temporal distribution of meteorological drought at monthly and seasonal timescales. The evaluation was carried out using data for the period from 2000 to 2020. The performance of the CHIRPS satellite-based rainfall estimates was analyzed based on different statistical performance evaluation criteria, which are listed in Table 1, and the result of a summary of statistical error metrics was presented in Table 5. The results obtained from these evaluation criteria show that the CHIRPS satellite rainfall estimates performed well as compared to ground-based gauge rainfall data.

Comparisons between the satellite CHIRPS and ground stations for monthly precipitation were processed for the areal average of Gama Zone as shown in the scatter and CDF plot in Figure 4, and each station satellite product performance comparison is presented in Table 6. Due to the poor performance reported in previous studies, no daily

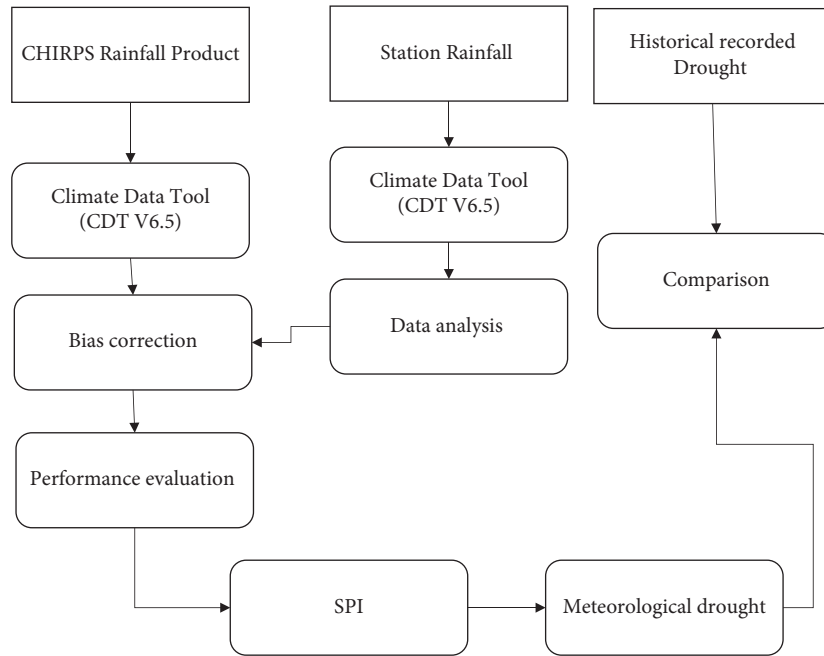


FIGURE 3: General framework of this study.

TABLE 5: Performance statistics by comparing monthly CHIRPS rainfall with gauge data during 2000–2020 to evaluate the performance of CHIRPS monthly rainfall (spatial average).

Statistical measure						
CORR	BIAS	PBIAS	ME	MAE	RMSE	NSE
0.88	1.02	2.56	0.252	22.41	33.14	0.77

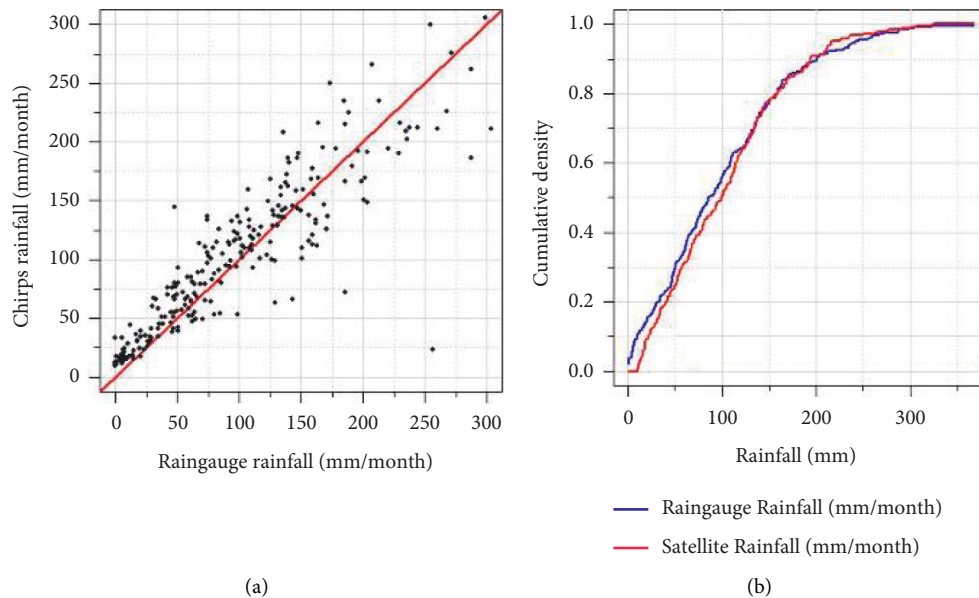


FIGURE 4: Scatter plot (a) and cumulative distribution function plot (b) comparison of monthly rainfall CHIRPS satellite rainfall estimates and rain gauge for 2000–2020 (spatial coverage).

comparisons were made [26, 108]. Five synoptic weather stations have been selected for validation and performance test due to the data availability and completeness of the station. As presented in Table 5, CHIRPS satellite product

performance evaluation statics performed very well with (NSE = 0.77 and CORR = 0.88). This implies CHIRPS has good performance over Gamo Zone at a monthly scale and can be a valuable precipitation product in this region.

TABLE 6: Monthly comparison of five rain gauges and the CHIRPS satellite at a point scale from 2000 to 2020.

Stations	CORR	BIAS	PBIAS	MAE	RMSE	NSE
Mirab_Abaya	0.76	1.02	1.95	26.80	39.97	0.57
Arba_Minch	0.77	1.06	6.13	27.75	53.53	0.58
Daramalo	0.85	1.40	38.32	41.23	54.13	0.37
Gerese	0.68	0.75	-24.95	75.84	119.95	0.37
Morka	0.83	1.25	26.87	36.30	49.85	0.51

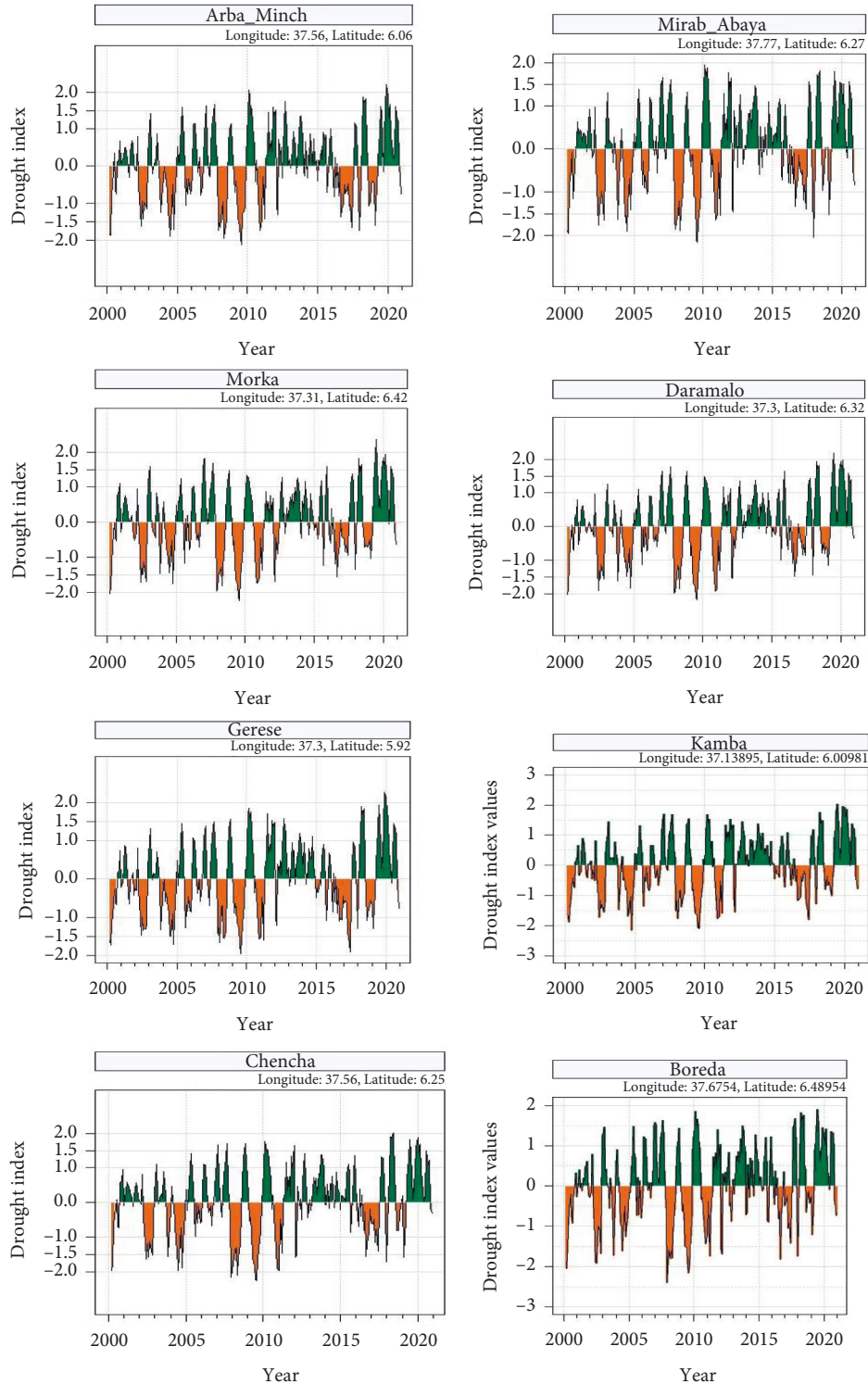


FIGURE 5: Time series plots of SPI-3 CHIRPS at eight selected stations for 2000–2020.

TABLE 7: Average drought duration in months for the Gamo Zone.

Weather station	Drought duration			
	2004	2008	2009	2017
Arba Minch	5	8	7	3
Mirab Abaya	5	7	7	3
Morka	4	7	7	2
Daramalo	4	7	6	2
Gerese	5	3	5	3
Chencha	4	8	6	3
Average	4.5	6.7	6.3	2.7

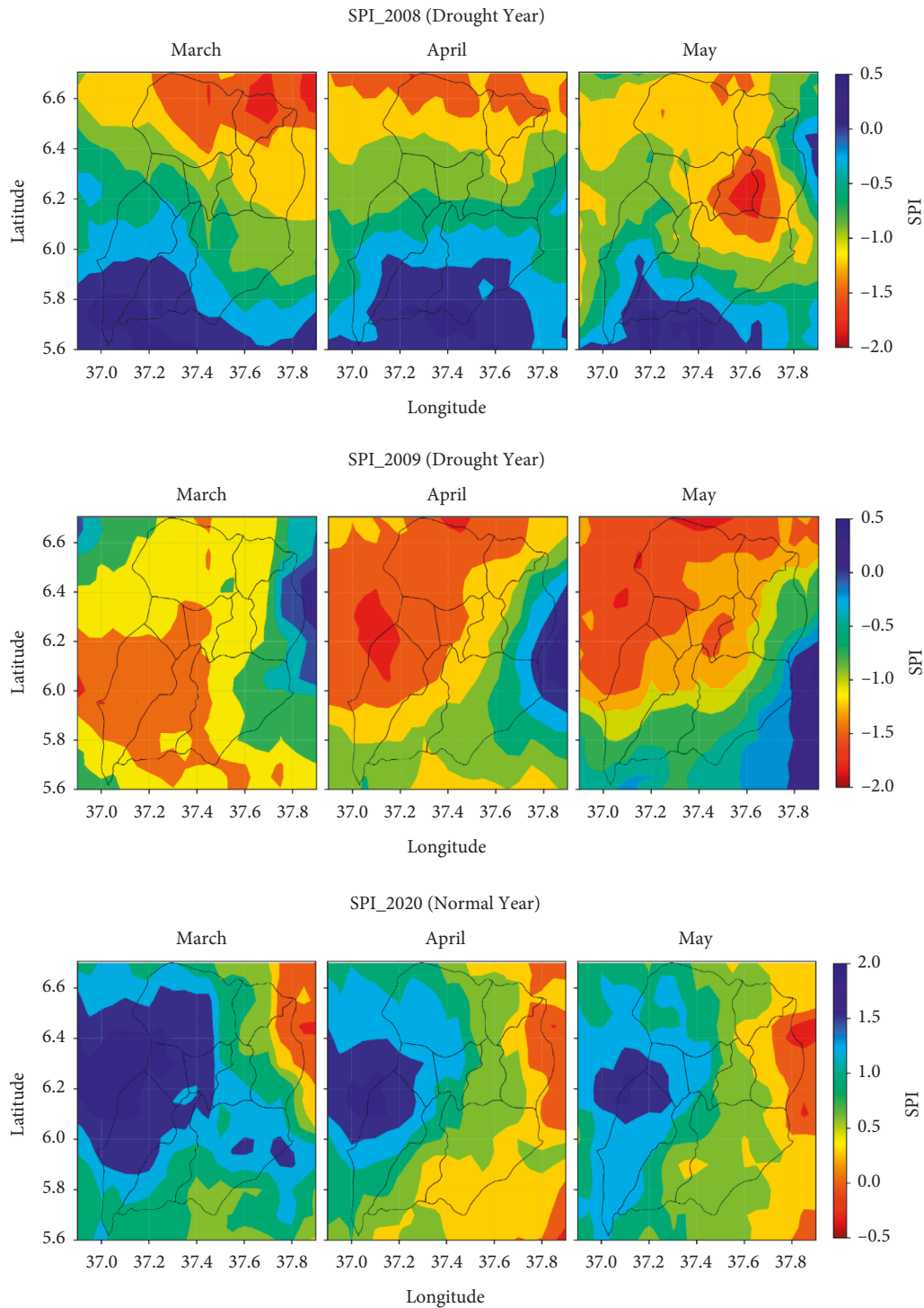


FIGURE 6: Spatial distribution of SPI for rainy season (March–May) of 2008, 2009, and 2020.

The scatter plot shows very good agreement with the ground gauge data observed for the CHIRPS satellite (Figure 4). CHIRPS satellite products show overestimation of rainfall values less than 200 mm and underestimation of rainfall values greater than 250 mm. This error may be due to the satellite precipitation algorithms and the unstable monsoon climate [61, 81]. And this is confirmed by the cumulative density plots (CDP) in Figure 4(b). This result is consistent with the previous studies including [26, 93]. Overall, the shape of the scatter diagram of the CHIRPS satellite rainfall estimate has reflected the strength of its correlation with the ground-measured rainfall (Figure 4(a)).

3.2. CHIRPS Satellite Drought Monitoring

3.2.1. Temporal Monitoring of Meteorological Drought. CHIRPS was selected because it has a higher time resolution, and the data were also available for a long period of time [108], and it had relatively satisfactory performance in the rainfall estimates in various observations in Gamo Zone at different timescales (Table 5). For these reasons, in this study, we attempt to evaluate the effectiveness of CHIRPS satellite rainfall estimation in the study of spatiotemporal monitoring of meteorological drought for the period from 2000 to 2020 during Belg (March–May) season. Figure 5 shows the temporal variation in three-month SPI results. Negative SPI values indicate that the rainfall of the area is less than the median rainfall, and positive indicates that the rainfall is greater than the median rainfall. The result shows the occurrence of moderate to severe drought events in the study region during the study period 2000 to 2020. For example, 2000, 2003–2004, 2008–2009, 2011, and 2016–2017 were some of the historical drought years in the Gamo Zone with different severity levels. Belg (MAM) of the years 2013 and 2020 were moderately wet for all stations. And the rest years are under normal to near-normal conditions.

During 2008–2009, severe to extreme drought conditions were observed for all stations with drought intensity ranging from -1.5 to -2.5 . In 2009, an extremely dry condition was observed at all meteorological stations except Gerese where a severe dry condition was observed. The reason for this is that 2008 and 2009 were strong El Niño years of Ethiopia [109]. Hence, we classified 2008 and 2009 as major drought years and 2013 and 2020 as no drought/moderate wet years. The temporal assessment of meteorological drought results using the SPI approach obtained in this study are in line with the previous findings [93, 110, 111]. Therefore, drought years (2008 and 2009) and normal years (2013 and 2020) were selected for further demonstration and discussion in this study.

Drought Duration. Table 7 shows the average duration of months for meteorological droughts obtained with the CHIRPS satellite data. As shown in Table 7, the maximum duration of SPI-3 drought was recorded in Arba Minch and Chenchu stations in 2008, which stayed for eight continuous months. In 2009, the maximum drought duration was recorded in Arba Minch, Morka, and Mirab Abaya stations. As shown in Table 7, the severity and duration of drought in 2008 and

2009 were relatively higher than in the other years. In agreement with [18, 112], it is reported that the Belg season (MAM) in 2008 and 2009 were the driest years on the record in Ethiopia. References [4, 113] also showed a decline in rainfall causes an increase in drought duration and frequency for the same years over southern parts of Ethiopia. Therefore, the increase of drought indices in these has been observed due to a rainfall deficit in the rainy months of 2008 and 2009. The minimum average SPI-3 drought duration was recorded in 2004 and 2017 for all stations.

3.2.2. Spatial Variation of Meteorological Drought. Figure 6 shows the spatial persistence of drought detected by SPI during the rainy season (MAM) in the Gamo Zone over the past two decades. Considering the severity of drought conditions, drought maps were prepared for the 2008 and 2009 droughts and 2020 for the normal years. In this figure, the region indicated by yellow to red color indicates drought, whereas brown to blue color indicates normal or no drought condition. Severe-to-extreme droughts were identified in the years 2008 and 2009 for Kucha, Boreda, Dita, Chenchu, Mirab Abaya, and Northern and central part of Arba Minch, whereas Kamba, Gerese, southern parts of Daramalo and Arba, and Zuria Woreda were affected by mild to moderate drought where the areas are rainy season. According to [114], 2008 and 2009 are the El Niño years for Ethiopia. Therefore, drought may have occurred in those years due to the influence of ENSO over the Gamo Zone. On the other hand, the years 2018 and 2020 reflect the normal and near-normal condition in the Gamo Zone.

4. Conclusion

The monitor of meteorological drought with SPI from CHIRPS satellite rainfall data is useful to determine the spatiotemporal distribution and characteristics of drought and identify drought-affected areas in Gamo Zone. Our finding shows that in areas where station scarcity exists, satellite rainfall products such as CHIRPS can provide better decisions for understanding the temporal and temporal variability that provide more complete information on time and space than rain gauges. According to the study, 2008–2009 were the worst years of drought, and the severity has also ranged from severe (1.5) to extreme severe (2.5). For the spatial variation of drought during the study period, the most affected area of the drought was found in the central and northern part of the zone, and its severity was increasing from south to north. The study shows that CHIRPS rainfall products in combination with the standard precipitation index could be used to identify meteorological drought characteristics and to develop the drought monitoring systems for an early warning system in Gamo Zone.

In this study, only CHIRPS version 2 with SPI has been used. Therefore, further investigation is recommended to quantify multi-satellite rainfall products with multi-drought index in the study region.

Data Availability

The observed rainfall data used to support the findings of this study were supplied by National Meteorological Agency

of Ethiopia (<http://www.ethiomet.gov.et/>). The CHIRPS V2.0 (Climate Hazards Group Infrared Precipitation with Station data) dataset can be downloaded from the Climate Hazards Center, University of California, Santa Barbara (<https://data.chc.ucsb.edu/products/CHIRPS-2.0/>).

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Amba Shalisha Shanka was responsible for data analysis and writing the draft. Anirudh Bhowmick and Kumineger Elias analyzed the results and modified the manuscript.

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