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Evaluating the Performance of 50mm Accumulated Rainfall Threshold for the Determination of the Start of Wet Season over Selected Stations, Ethiopia

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ABSTRACT

Reliable information on the start of the wet season is perceived by agricultural community as an essential part of agricultural monitoring tool. Timely information on the onset date can prominently reduce the risk of planting and sowing too late or too early. For this study in-situ rainfall data were obtained from the National Meteorological Agency of Ethiopia and daily cumulative precipitation for 17 meteorological stations were used to evaluate the 50mm cumulative rainfall threshold efficiency in determining the start of the wet season. In the evaluation, the definition suggested by SIVACUMAR was presented as a benchmark criteria to evaluate the ACMAD threshold. During the evaluation some viable statistical tests were used. The Standard Deviation (SD), the Standard Error (SE), the time-mean difference (Anomaly), coefficient of variation (CV), are applied to evaluate the performance of the ACMAD criteria over the selected stations in Ethiopia. The result indicates that the ACMAD criteria tend to exhibit an earlier onset over 15 stations out of 17 compared to the SIVACUMAR method and relatively the ACMAD criteria gave less variability in terms of the range of the onset date, the temporal variability and the coefficient of variation. Regarding the false onset test, the results shows that almost all selected stations experienced maximum dry spell length in the order of 10 to 27 days within 30 days after the 50mm cumulative rainfall requirement was satisfied. The large false onset years are more pronounced over the southwest parts of the country and which accounts about 17% in average. The second largest false onset years was found to the central parts of the country and which accounts 12 % in average. Stations belong to the south exhibited the small false onset years. Therefore, to ensure the reliability of the threshold and to reduce the risk related to false onset, the expert should look into climate drivers which could be a cause for the development of consecutive long dry spells after the attainment of the cumulative threshold.

Keywords: Meteorology; climate drivers; rainfall threshold

Acronym: ACMAD - African Center for Meteorology Application and Development; CV - Coefficient of Variations; ENACTS - Enhancing National Climate Services; FWESNET - Famine Early Warning Systems Network; ITCZ -

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Inter Tropical Convergence Zone; MoFA - Ministry of Finance; NMA - National Meteorology Agency (Ethiopia); NFCS - National Frame Work for Climate Service; NDRMC - National Disasters Risk Management Commission; OCHA - Organization for the Coordination of Humanitarian Affairs (UN); SE - Standard Error

1. INTRODUCTION

Agricultural communities are collectively agreed on that properly unmanaged seasonal variability of the onset date is potentially account for the reduction in agricultural production (Ati et al. 2002; Siddharam et al., 2020; Riaz et al., 2020). According to Mc-Cown (1991) and Mollah and Cook (1996) conclusions, the seasonal rainfall totals are less important than understanding the timing of the transition from dry to wet season. The information on the wet season onset date is long awaited, and perceived by farmers as an invaluable tool (Jones et al. 2000), and considered as an essential part of agricultural monitoring instrument (Verdin et al. 2000; Tadesse et al. 2008). According to Bombardier et al,. (2020), accurate knowledge of the onset date can meaningfully reduce the risk of planting and sowing too late or too early and this in turn enable farmers to manage any irregularity in rainfall during the season which potentially affects the prospect of yield production because of delayed planting and immature growth of crops. Specifically, the timely and reliable information on the transition time from dry to wet season are very important for Ethiopian agriculture since the crop production is highly dependent on rainfall amount and distribution. For this very reason, the communities in the agricultural sector are always in quest of onset date information for the purpose of planning for pre-planting provision and decision.

Before the emerging of the modern onset date definition, farmers often use scientifically unexplained traditional criteria which base on observing the changing behavior of the nearby living things and the pattern and movement of heavenly bodies (Makwara, 2013; Martha Kidemu et al., 2020). This clearly indicates that the information on the rainfall characteristics in general and awareness on the prospect of the possible onset date in particular is highly demanded by wide range of agricultural community. Therefore, proper monitoring and realistic prediction of the start of the wet season could potentially reduce the risk related to false onset alarm which possibly deceive farmers to plant their scarce seeds too early or too late, (Laux *et al.*, 2008), before approaching the real and well-established seasonal rainfall systems (Robertson *et al*., 2019. Timely and reliable onset date information can lead farmers to conduct better decision on the optimum time of land preparation, cultivar selection, sowing and transplanting dates of crops (Laux *et al*., 2008).

So, to satisfy the users need at this end, various scholars and researchers have been trying to develop objective threshold definitions (Shaw, 1987; Jolliffe and Sarria-Dodd, 1994; Drosdowsky, 1996; Odekunle, 2004) and some are widely used in Ethiopia to determine the mean onset date condition at national level (Tesfy Haile 1989; Seggle and Lamb, 2005; Messay, 2006) and subnational scale (Girma, 2005).

Actually, defining the onset of the rainy season is an extremely complex problem and, thus, various definitions have been proposed (Moron and Robertson, 2014). Bombardier et al (2020) documented that scholars broadly classified the onset date definitions into two groups: regional to large-scale methods where parameters measure large-scale atmospheric dynamics and local-scale methods using fixed precipitation thresholds selected based on the climatology of rainfall over the region of interest.

However, most definitions have used only to determine the mean onset date of an area based on historical rainfall data. These definitions, however, are hardly possible to apply for operational purposes, like to integrate with seasonal outlook product and monitoring before the start of the climatological onset date. In my few experience on working with the agricultural community, I have learn that farmers are not much worry about the climatological onset date. This is because they are thinking as if they have some experience on the average conditions of their locations. Farmers are more interested to be informed on the level of the variability on the start of the rain of the season quiet ahead of them.

During my stay at ACMAD, Niamey, Niger, as a seconded expert, I have learnt how they are monitoring and predicting the onset date of a location a month before the climatological mean onset date based on cumulative rainfall approach. Using this simple approach, they are able to look into how the onset of the season ahead of us is progressing forward and how it behave against its mean condition. This is one of the best experience, among others, that I have acquired during my stay at ACMAD. However, the question comes next to this good experience was how to test the reliability of this definition in the national context. After discussing with the ACMAD management, I include in my activity plan to evaluate the 50mm cumulative rainfall threshold over selected stations in Ethiopia.

2. DATA AND METHOD

Study Area

Ethiopia is among the largest countries in Africa having a total area of approximately 1.14 million Km^2 (944,000 square miles) (MoFA 2013) and it is characterized by a wide variety of landscapes, with marked contrasts in relief and altitudes ranging from about 160 m below sea level, which is found in northern exit of the Rift Valley (Danakil depression) to about 4600 m a.s.l. in the northern mountainous regions, (Ras Dashen) (Asaminew et al., 2019). Among other regional factors, topographical features are significantly playing its noticeable share on determining the climate of the country (M. Fazzini et al., 2015). Ethiopia is located within $3-15^0$ N and $33-48^0$ E, bordered with Djibouti to the east, Somalia stretch from east to south, Kenya to the south, Sudan to the west and Eritrea to the north. Given its geographic position close to the equator and the Indian Ocean, the country is subjected to large spatial variations in temperature and precipitation.

Climate of Ethiopia

Mostly from the highland perspective Ethiopia has three climatological seasons (Viste et al., 2012): February–May which is the second and small rain season and locally known as Belg; June–September which is the main rainy season and locally referred as Kiremt; and October–January which is the drier period for most parts of the country and locally known as Bega. As for confirmed by large number of studies, Ethiopia's climate is mainly controlled by the hemispherical change in the position of the tropical rain belt following the position of the sun and the associated atmospheric circulation (M. Fazzini et al., 2015; Viste et al., 2012; Segele, Lamb et al. 2009). According to these studies, the far northern migration of ITCZ often result in bountiful rains particularly to the northern highland parts of the country, where most of the annual precipitation falls during July and August. When we look into the spatial annual rainfall climatology of the country, one may roughly comprehend that precipitation various with latitude, decreasing from south-west to north-east (M. Fazzini et al., 2015) as it does in the altitude. The study by Griffiths (1972), complemented the above fact and said the low land areas of the country receive lower annual rainfall compared to the high land section. Viste et al., (2012) confirmed that in most parts of Ethiopia rainfall increases with elevation. Given the fact that precipitation increases with elevation, but the relationship between rainfall amount and altitude is not straightforward (Dinku, Connor et al. 2008). However, it is known that the geographical variation markedly influence the country's rainfall pattern. But, the increasing of precipitation with elevation is not continue up to the top of the mountain. The study by Dinku, et al. (2008) confirmed that precipitation increases up to about 2000 m.a.s.l., then decreases with elevation again.

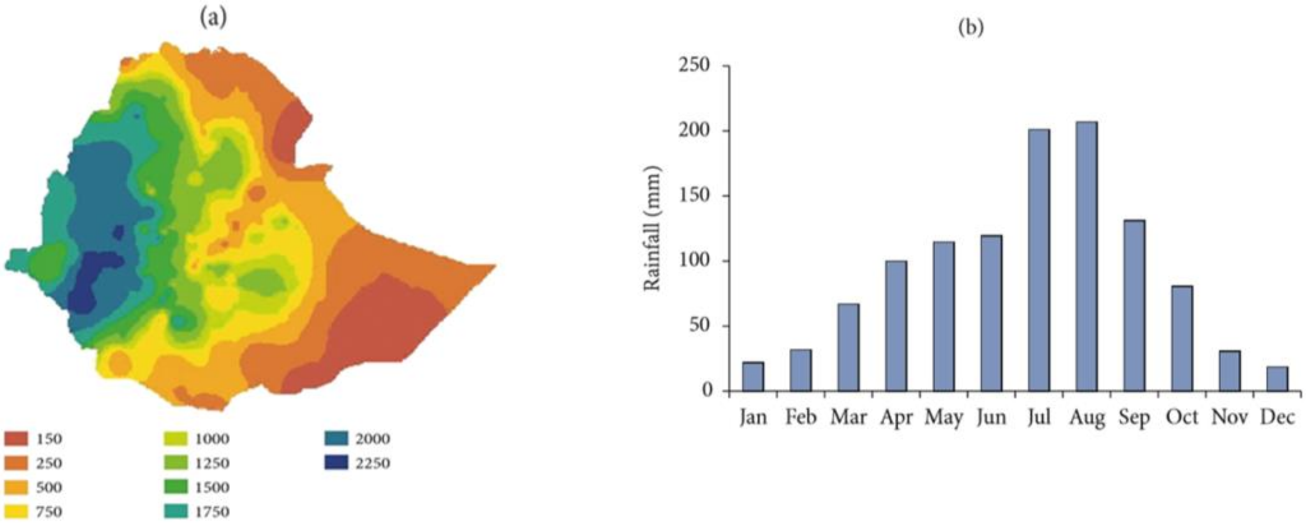

Figure 1: (a) Mean annual rainfall climatology (mm). (b) Monthly rainfall cycle (Source: Asaminew et al., 2019)

Rainfall Data

Meteorological observation in Ethiopia traced back to the early 19th. However, the agency was established as autonomous institutions in early of 1980. Since then, the agency has routinely been collecting climate data in both manual and automatic observing systems for the last more than four decades. Out of the total observation, 81% the meteorological observation is conducted manually while the remaining 19% are through automatic data recording systems (NFCS, 2019, unpublished baseline document). According to the base line study result, more than 300 AWS are joining the weather observing network up to 2019 and the agency also still have a long term plan to enhance the number of AWS to 700, which approximately one AWS per Wereda (But due to the recent political reform in the country, the administrative boundaries have been revised hence the agency's plan also expected to be revised accordingly). In addition to collecting data from conventional and Automatic stations, NMA (through the ENACTS project) provides 4 km gridded resolution historical rainfall and temperatures data on 10-daily basis. National climate data is centrally managed by NMA head office.

However, quite large number of researchers are unsatisfied on the historical climate data due to its poor and large size missed value and artificial heterogeneity (M. Fazzini et al., 2015; Viste et al., 2013). The recent NFCS baseline study has confirmed that this gap is practically existing in the country. In this study we had an interest of considering large number of weather stations, but it was hardly achieved to get adequate number of stations to represent the whole country due to both the existing large size (> 10%) missed value and the shorter temporal horizon. Therefore, we were unwillingly enforced to limit the number of stations to 17 (Table 1). The relative short climate data (short temporal horizon) of some stations was not enable us to compute some statistical parameters, such as a long term average (normal) and trend of the locations. However, all efforts have been made during the selection of weather stations so that they may able to be representative of the major geographical features of the country. Bearing this in mind, we took stations even having short temporal horizon (<30 years) particularly at places where inadequate station network exist. For that end, the 17 climate stations were categorized based on their geographical distribution and all the analysis and the conclusion of the result done accordingly.

In-situ observations were obtained from the National Meteorological Agency (NMA) of Ethiopia. Collectively, the time horizon of the data was ranging from 1951–2018, with 15 stations having more than 30 years of records. The two remaining stations have 23 years of data each. The station locations and the corresponding temporal horizons are summarized in table 1.

Table 1: Stations, their geographical locations and the range of the historical data length

No	Name of Station	**Longitude**	Latitude	**Temporal horizon (historical dataset)**
1	Addis Ababa	**38.8**	9.0	**1954 - 2018**
2	A/Minch	**6.1**	37.6	**1987 - 2018**
3	Awassa	**7.1**	38.5	**1972 - 2018**
4	Axum	**14.14**	38.78	**1995 - 2018**
5	Bahir Dar	**11.60**	37.39	**1995 - 2018**
6	Combolcha	**11.10**	39.72	**1953 - 2018**
7	D/Markos	**10.33**	37.74	**1954 - 2018**
8	D/Zeit	**8.73**	38.95	**1951 - 2018**
9	Dire Dawa	**9.97**	42.53	**1953 - 2018**
10	Gondar	**12.52**	37.43	**1952 - 2018**
11	Gore	**8.13**	35.53	**1952 - 2018**
12	Jimma	**7.67**	36.81	**1953 - 2018**
13	Mekele	**13.47**	39.53	**1960 - 2018**
14	Metehara	**8.86**	39.92	**1985 - 2018**
15	Negele	**5.42**	39.57	**1953 - 2018**
16	Nekemt	**9.08**	36.46	**1971 - 2018**
17	Robe	**7.13**	40.05	**1985- 2018**

Onset date determination

Determining onset dates of rainy season is usually based on the exceedance of single- or multi-day rainfall amount thresholds every so often in aggregation with the absence of subsequent rainless periods. Of course, this fixed threshold definitions are frequently used by agroclimatologists (Stern et al. 1981; Sivakumar 1988) and other definition have also been suggested by Climatologists, agronomists, or hydrologists (Moron et al. 2009; Marteau et al. 2009). For operational purposes, a simple fixed threshold based on the accumulation of rainfall has also been suggested by Leo et al., (2002). On the other hand, other scholars have obviously raised their concern on these accumulated rainfall total thresholds since it doesn't account for all dry spell situations particularly when it applied in semi-arid areas (Example; Olaniran, 1983) and its sensitivity for parameterization (for example; Smith et al. 2008; Boyard-Mi Cheau et al., 2013). However, those who are applying the accumulated threshold assume that after a particular level of rainfall is reached, the probability of a long dry spell that leads to crop failure is relatively small (Ati et al., 2002). Beyond the above scientific argument among researchers, the accumulated rainfall threshold can easily capture the attention of NMHs or other regional and continental institutions, like ACMAD, for its simplicity to apply and easiness for close monitor and prediction. As it was suggested by Leo et al., (2002) using a simple index of onset date determination technique based on rainfall accumulation can easily be applied and should be readily applicable to many agricultural practices. Moreover this index is enable agricultural meteorologist to produce a prediction a month in advance of rainfall onset based on the climatological onset date. According to this definition, the computation of the cumulative rainfall must be started just 30-days before the climatological onset date.

ACMAD Onset Date Definition

In my some experience of working at national and collaborating with regional climate institutions, I think ACMAD might be the first in Africa using the 50mm cumulative rainfall threshold for onset date monitoring and prediction along with the seasonal climate outlook. Undocumented information from the institution indicates that ACMAD has integrated the cumulative rainfall threshold since 2016 along with the seasonal climate outlook product. For this very reason the term "ACMAD onset definition" has been used in this study to refer the 50 mm cumulative rainfall threshold. The Idea of implementing a cumulative rainfall threshold for operational purposes at ACMAD was probably conceived after the Leo's publication (Leo, 2007), which asserts the application of accumulative rainfall threshold for monitoring and prediction of onset date in Australian or adopting the well-known Remdan traditional method which has been widely applied in the northern part of Nigeria since long years before (Ati et al., 2002). Leo's criteria simply says a wet-season onset date is defined based on the accumulation of rainfall to a predefined threshold, starting from 1 September, for each square of a 1° gridded analysis of daily rainfall across Australia and the major aim was to produce a forecast technique that can make predictions a month in advance. While the Ramadan traditional onset date index explains the planting of crops can begin with the first good rain after Ramadan provided that it is at least 7 months from the last effective rain of the previous season which has the accumulated rainfall totals equal or exceed 50.8 mm. The definition that has been used at ACMAD much close to the above two definitions and is defined as "*the daily accumulated precipitation averaged over the past 30years and the date corresponding to 50mm daily accumulated precipitation is considered as the transition of wet season of a given area provided that the start of computing the cumulative rainfall should start 30-days before the climatological onset*".

Methods

To evaluate the efficiency of ACMAD's onset date definition and its ability to define the rainfall onset date, some viable statistical tests were applied. The temporal variation (Standard Deviation), the Standard Error (SE) and coefficient of variation (CV), are applied to evaluate the performance of the ACMAD criteria over the selected stations in Ethiopia. In addition, secondary data were reviewed to single out some years particularly marked as "Late onset years" and afterward the ACMAD criteria was evaluated against these selected years to understand how the definition could capture the delay in the start of the rainfall during these years.

Statistical Test

Standard Deviation as measure of Inter-Index variance

In statistical sense, the standard deviation is nothing but simply indicates in what extent the given data concentrate around the mean. As the result, the more concentrated is interpreted as the smaller the standard deviation.

In this study, the standard deviation (SD) is used mainly to assess the inter-index variance between the mean onset date and onset date of individual years throughout the temporal horizon of the data set. The SD is calculated as follows:

$$SD = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2} \qquad (4)$$

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \qquad (5)$$

Where;

Here, $\bar{x}$ represents the inter-model arithmetic mean, and x_i represents individual sample years.

Coefficient of Variations

The coefficient of variation shows the extent of variability of data in a sample in relation to the mean of the population and it represents the ratio of the standard deviation to the mean. In essence, it is a useful statistic for comparing the degree of variation from one data series to another, even if the means are drastically different from one another. Below is the formula for how to calculate the coefficient of variation:

$$\mathrm{CV} = \frac{\mathrm{SD}}{\mathrm{Mean}}$$

Standard Error

Standard Error (SE) is one of the statistical tool which infer whether the arithmetic mean is a good reflection of the entire dataset or poorly representing the dataset. The larger the value of the SE, the poor reflection of the mean. Below is the formula for how to calculate the SE:

$$SE \quad = \frac{\sigma}{\sqrt{n}}$$

Where;

- SE is Standard Error
- σ the standard deviation
- n number of total years

Agro climatic and Agro ecological classifications

According to the Food and Agriculture organization (Papadakos 1966 & 1975; FOA 1986), Ethiopia has mainly divided in to six major agro-ecological zones (Arid, Semi-arid, Moist, Sub-moist, Humid and Sub-humid). The classification is made on the bases of temperature and moisture regimes. Regarding the Agro climatic classification, the country is divided in to three distinct zones namely the area without a significant rain-fed growing period, areas with a single growing period and area with a double growing period (NMSA 1996). The agro-climatic classification was made on the bases of the water balance concept and the length of the growing season. Table 2 is the brief presentation of the agro-ecological and agro-climatic zones and the range of the crop planting dates of the 17 stations.

Secondary data review

To evaluate the efficiency of the ACMAD onset date criteria, some assessment reports were considered as the reliable source of information on the status of the start of rain season. These reports are produced based on field assessment and are often done before the start of crop harvest. The reports are developed by different governmental and nongovernmental organization and usually it assess the rainfall performance and its impact during the season. In this study, these reports were used basically to identify the late or early onset years based on the ground report and evaluate the ACMAD index against these identified years. The reports produced by NDRMC, OCHA and FWESNET were widely reviewed and the years were selected as late onset year or early onset year or normal years.

3. RESULT AND DISCUSSION

Agro ecological zonation and the corresponding planting window

According to the Food and Agriculture organization (FOA 1986), Ethiopia has mainly divided in to six major agro-ecological zones (Arid, Semi-arid, Moist, Sub-moist, Humid and Sub-humid). The classification is made on the bases of temperature and moisture regimes.

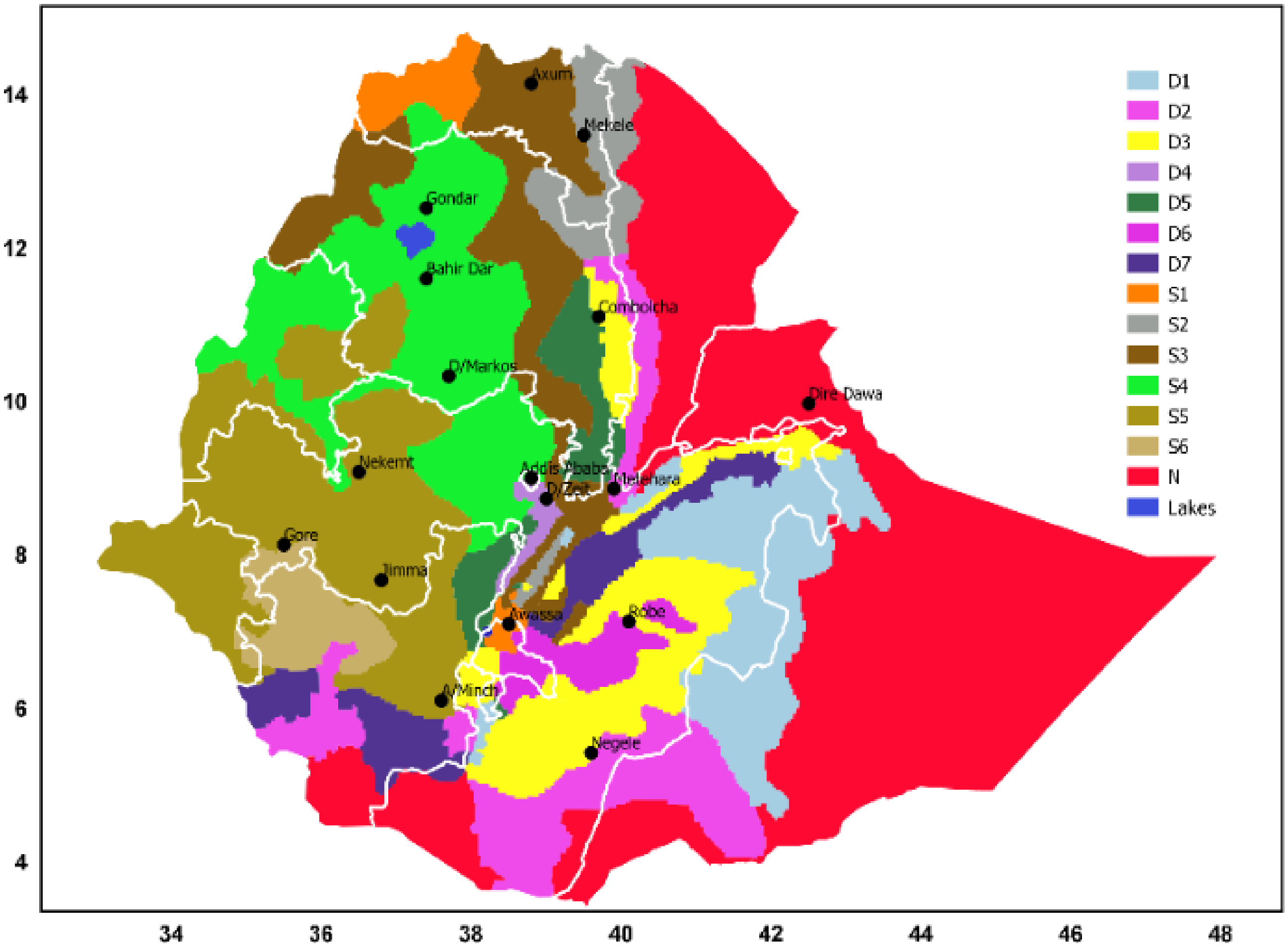

Figure 2: Agro-ecological Zone (AEZs) of Ethiopia and the location of the study area in reference to (AEZs).

Table 2a: Agro-ecological and agro-climatic zones and the range of the crop planting dates of the 17 stations

Stations	ACMAD_Onest date range	AEZ_Onset date range	Agro-Ecological zone	Agro-climatic zone of stations
Addis Ababa	9 May – 13 Jul	05 Feb- 30 June	Sub-humid	**S4**
Arba Minch	21 Mar-3 May	05 Feb- 30 June	Sub-humid	**S6**
Awassa	21-May-24-Jun	05 Feb- 30 June	Sub-humid	**S1**
Axum	23-Jun-8-Jul	15 May-31_Jul	Semi-arid	**S3**
Bahir Dar	14-May-2-Jul	05 Feb- 30 June	Sub-humid	**S4**
Combolcha	22-May-26-Jul			**D3**
Debre Markos	23-Apr-16-Jun	05 Feb- 30 June	Sub-humid	**S4**
Debre Zeit	4-May-13-Jul			**D4**
Dire Dawa	22-Jun-26-Aug	15 May-31_Jul	Semi-arid	**N**
Gore	23-May-30-Jun	05 Feb-30 June	Humid	**S5**
Gondar	31 Mar-10 May	15 May-31_Jul	Semi-arid	**S4**
Jimma	14-Mar-23-Apr	05 Feb-30 June	Humid	**S4**
Metehara	25-Jun-3-Aug			**D2**
Mekele	1-Jul-4-Aug	15 May-31_Jul	Semi-arid	**S2**
Nekemt	9 Apr-12 May	05 Feb- 30 June	Sub-humid	**S5**
Negele	12 Apr-28 May	05 Feb- 30 June	Sub-humid	**D3**
Robe	8 Apr-7 May			**D2**

Regarding the Agro climatic classification, the country is divided in to three distinct zones namely the area without a significant rain-fed growing period, areas with a single growing period and area with a double growing period (NMSA 1996). The agro-climatic classification was made on the bases of the water balance concept and the length of the growing season.

Table 2a is the brief presentation of the agro-ecological and agro-climatic zones and the range of the crop planting dates of the 17 stations.

As it is indicated in the ACMAD onset date criteria, before starting to compute the cumulative rainfall of a location, knowledge on the climatological onset date of the area is regarded as the prerequisite step for computing the cumulative rainfall. Bearing in mind the above fact, the following steps were taken to compute the onset date using ACMAD criteria. Initially, an attempt was made to compute the mean annual onset date using the ACMAD criteria by running from 1st of January until the first wet day threshold was obtained. In doing so, it was realized that stations selected from the northern, central and eastern parts of the country appeared with unreasonable early onset date.

This impractical early seasonal onset date obtained after the 50mm cumulative rainfall threshold mostly due to the availability of intermittent rainfall event in the month often marked as dry-month. This intermittent rainfall occurred before the true start of the season could satisfy the 50mm cumulative rainfall threshold, but not realistic. Actually, such unreasonable early onset is not because of the weakness of the index. Segele and Lamb (2005) also observed same problem while they were using other onset date definition. To avoid such unrealistic result, we first determine the climatological onset date of each station based on the proposal by SIVAKUMAR (1988). After the identification of the climatological onset, we started computing the cumulative rainfall 30-days before the climatological onset date. As documented in table 2b, the starting date for monitoring the cumulative rainfall of each stations were proposed. For instance, the climatological onset date of Addis Ababa station is 8th of June, therefore, the monitoring of cumulative rainfall to be started at 9th of May until the 50mm accumulative rainfall requirement is satisfied.

Table 2b: The climatological onset date determined by the SIVACUMAR, Segele & Lamb and the proposed starting date for computing cumulative rainfall

Station	Onset date determined by SIVACUMA_(1954 – 2018)	Onset date determined by Seggle and Lamb (1943–1999)	Starting date for computing Cum rainfall for ACMAD definition
Addis Ababa	**8-Jun**	8-Jun	**9-May (129 DOY)**
Arba Minch	**24-Apr**	-	**25-Mar (84 DOY)**
Awassa	**18-Apr**	-	**19-Mar (78 DOY)**
Axum	**13-Jul**	-	**14-Jun (165 DOY)**
Bahir Dar	**8-Jun**	-	**9-May (129 DOY)**
Combolcha	**21-Jun**	2-Jul	**22-May (142 DOY)**
Debre Markos	**21-May**	19-May	**22-Apr (112 DOY)**
Debre Zeit	**30-Jun**	-	**31-May (151 DOY)**
Dire Dawa	**18-Jul**	10-Jul	**19-Jun (170 DOY)**
Gore	**29-Apr**	-	**30-Mar (89 DOY)**
Gondar	**13-Jun**	27-May	**14-May (134 DOY)**
Jimma	**11-Apr**	-	**12-Mar (71 DOY)**
Metehara	**20-Jul**	-	**21-Jun (172 DOY)**
Mekele	**15-Jul**	4-Jul	**16-Jun (167 DOY)**
Nekemt	**23-Apr**	-	**24-Mar (83 DOY)**
Negele	**18-Apr**	-	**19-Mar (78 DOY)**

In the illustration (Table 2b), the selected station from the central parts of the country (Addis Ababa, Debre Zeit and Metehara) exhibited first dekad of May to second dekad of June is the starting date for monitoring cumulative rainfall, while, from 12th to 30th of March is the start of monitoring both the southern parts (which include Arba Minch, Awassa and Negele), and the southwestern part (Jimma, Gore and Nekemt) of the Country. To the northern and eastern part of the country, the monitoring should be started from last dekad of April to last dekad of June; depends on the climatological character of the stations.

Start of wet season based on 50mm accumulated rainfall threshold

In figure 2, the mean onset date and interannual variability is presented. The result indicates the start of the wet season begins from the last dekad of March to mid of April over the stations located to the southwestern part (Jimma, Nekemet and Gore) (Fig 2a) and the wet season transition advances toward the south (Negele, Awassa, A/Minch) around early to mid of April (Fig 2b) and along with the northward advancement of the weather system, the wet season starts from the first week of June upto second week of July over the stations located to the northern parts of the country (Bahirdar, Combolch, Axum and Mekele) (Fig 2c) and progressed toward the east and central parts and reaches around mid-to-end of July (Debre Zeit, Metehara and Diredawa) (Fig 2d). It was noted that the average patern in the start of wet season appears earliest to the southwest and latest to the northern and eastern parts of the country. Such a temporal variation and pattern on the mean onset date accros variouus geographical locations are consistance with the privious study done by segele and Lamb (2005).

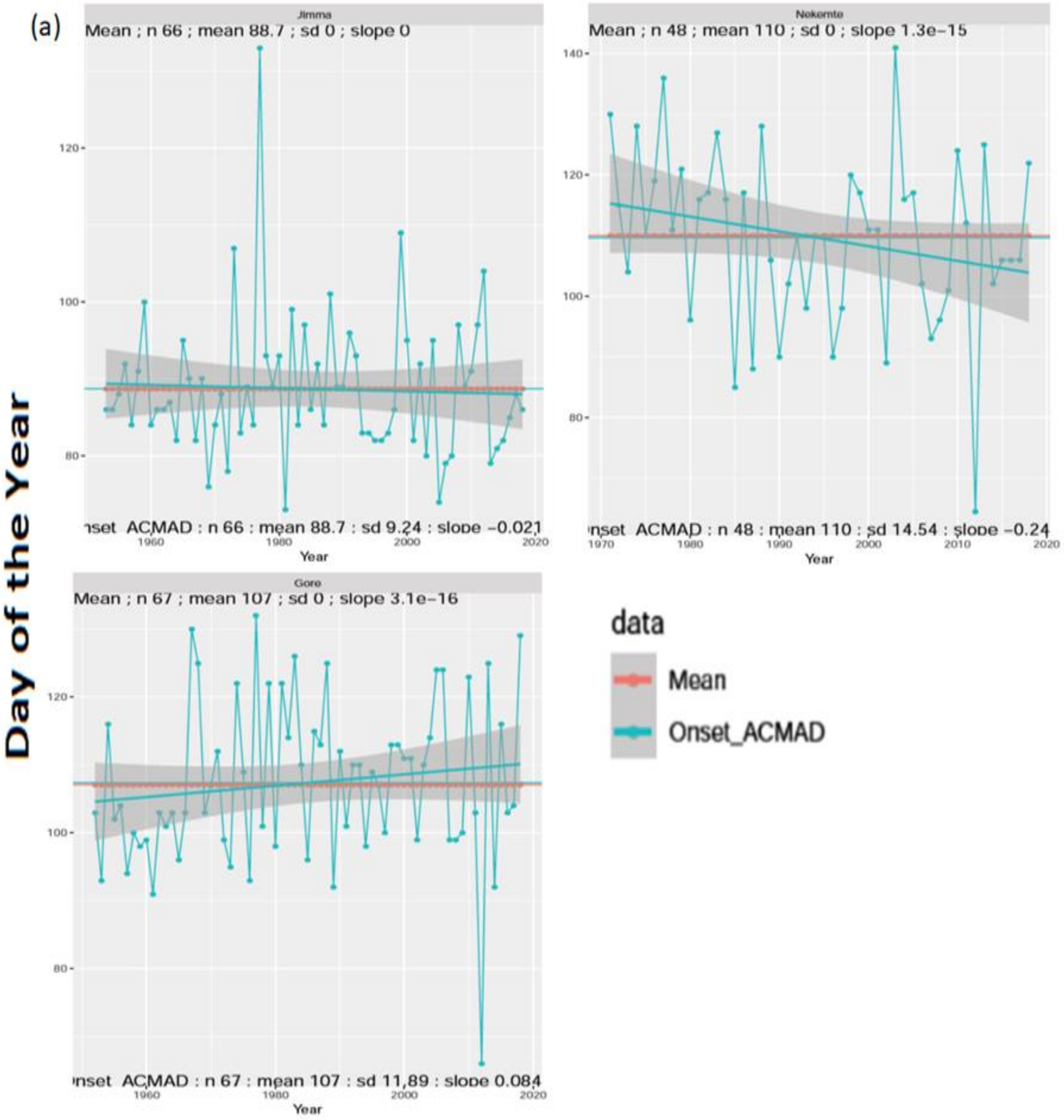

Figure 2a:The mean onset date, Sd and SE of stations from the western part of the country

Figure 2 also depicts the range of temporal variability of the onset date, which means how each data points close to the mean value. Statistically, this deviation from the mean is regarded as Standard deviation (SD). In some occasions, a mean value alone may not a good indicator of the nature of dataset because the mean is always sensitivity to extreme events. Thus, understanding on the nature of the temporal variability of the parameter is important for a proper management of the possible deviation from the mean. Figure 2a documents both the Standard Deviation and the Standard Error of the stations from the southwestern part of the country. Accordingly, the station Nekemt exhibits quiet largest deviation (SD>14 days), while, Jimma appears with the smallest temporal variability (SD<10 days). But one must be cautious to interpret the result of the SD. The large or small values of the SD doesn't indicate the right or wrong of the mean. It simply convey how close the individual data values around the mean.

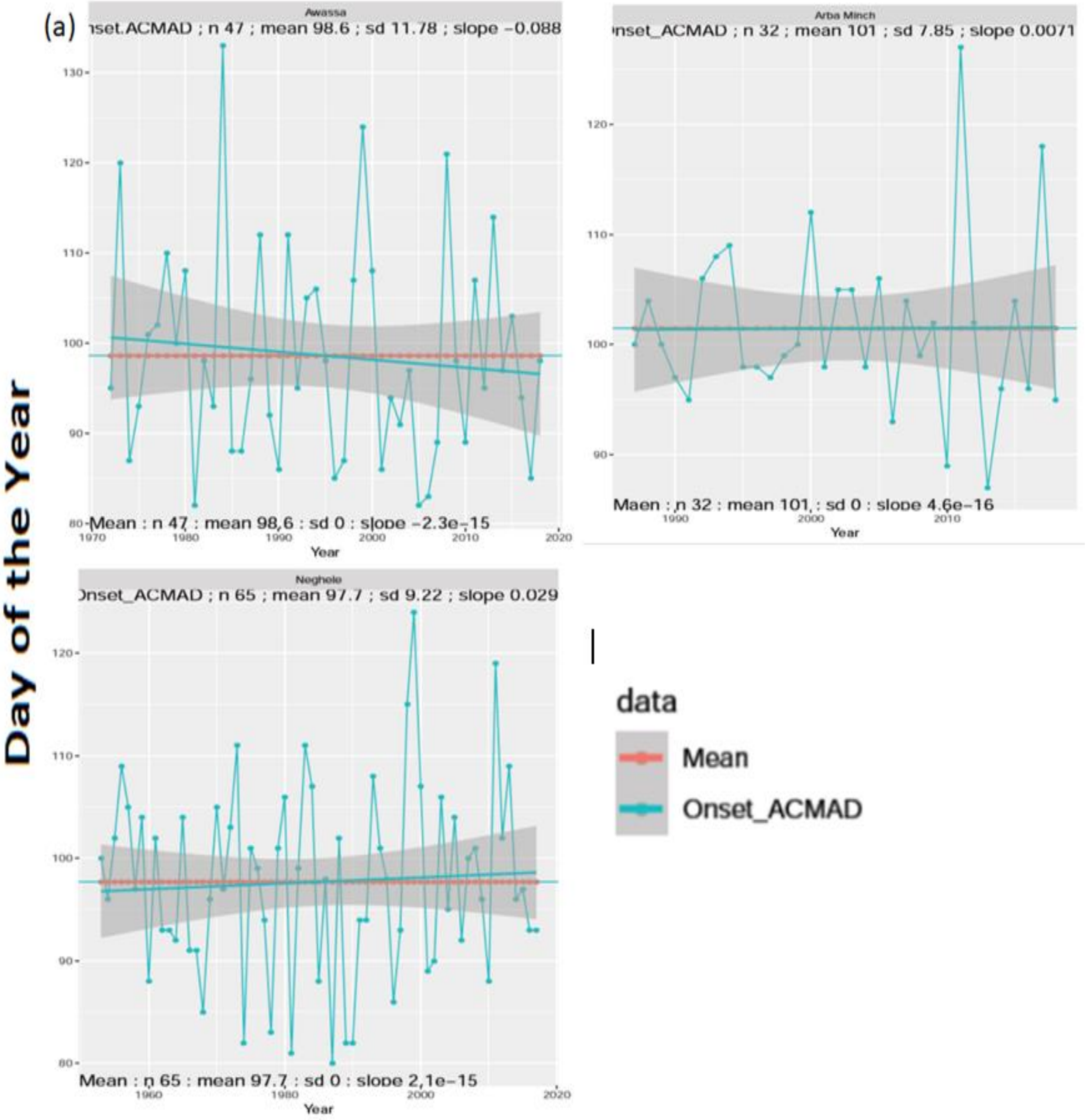

Figure 2b: The mean onset date, Sd and SE of stations from the southern part of the country

The level of accuracy of the mean value in the given dataset is explained by the statistical parameter called "Standard Error" (SE). The dark shaded region in all graphs indicates the level of the error of the mean with respect to the variability of the onset date. The larger the shaded area is the lesser the accuracy of the mean toward reflecting the whole dataset. As depicted in the graphs presented in figure 2a, relatively large size of shaded areas appeared at station Nekemt, therefore, the mean onset date at this station is not a good reflection of the dataset compared to the other two stations selected from the western part of country.

Likewise, Figure 2b unveils that Awassa exhibits quiet largest deviation (SD>11 days) compared to other stations from the southern section of the country, whereas, Arba Minch appears with the smallest temporal variability (SD<8 days).

Therefore, the mean onset date at the station Negele is a more reliable reflection of the temporal variability than the other two stations (Awassa and A/Minch).

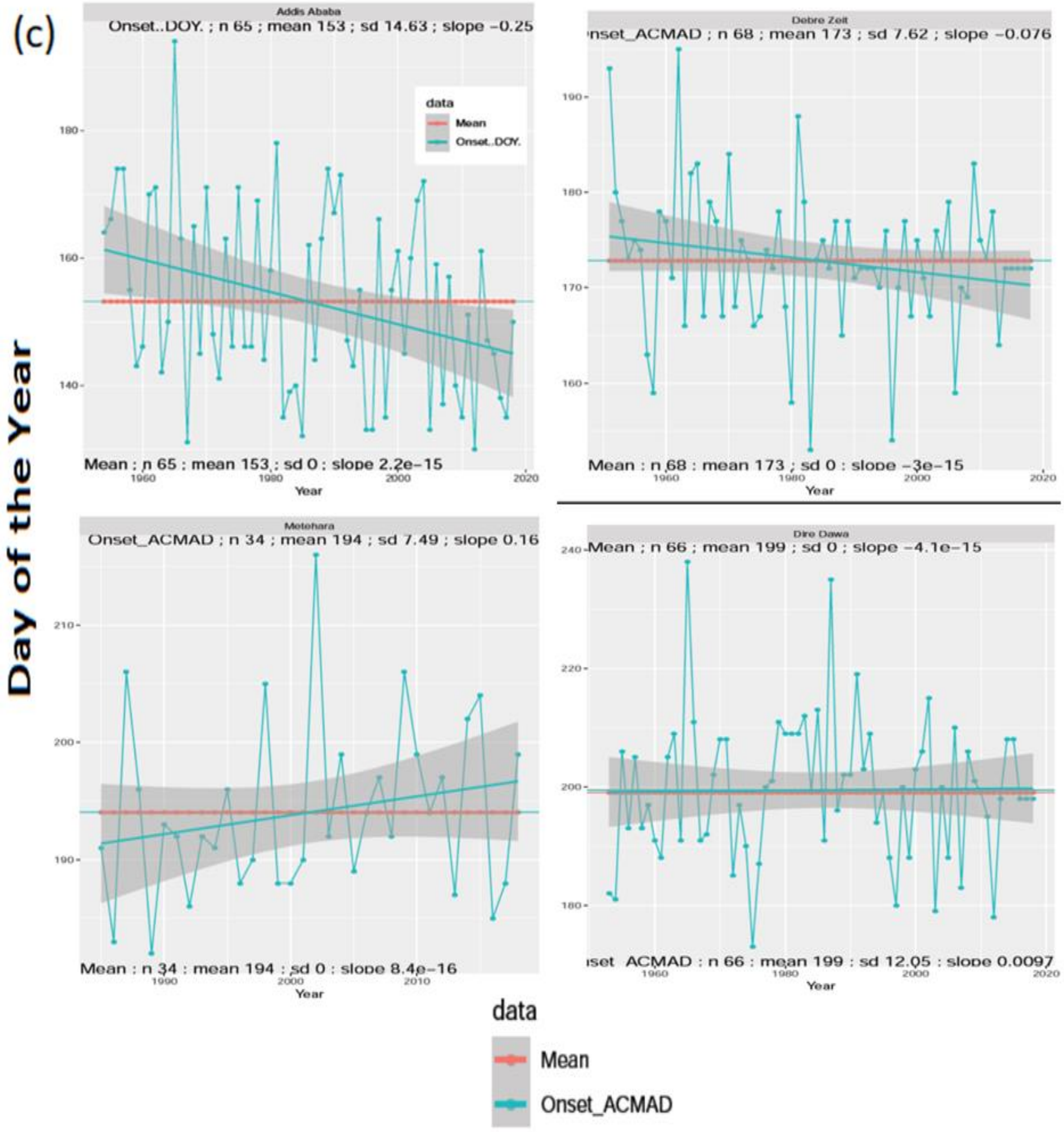

Figure 2c: The mean onset date, Sd and SE of stations from the central part of the country

The analysis of the stations mostly from the central parts of the country, Fig. 2c, shows that the largest range of onset date variation was found at Addis Ababa (SD>14 days), whereas the smallest temporal variability (SD<8 days) was obtained over Metehara stations, where also the largest standard error (largest shaded area) was found.

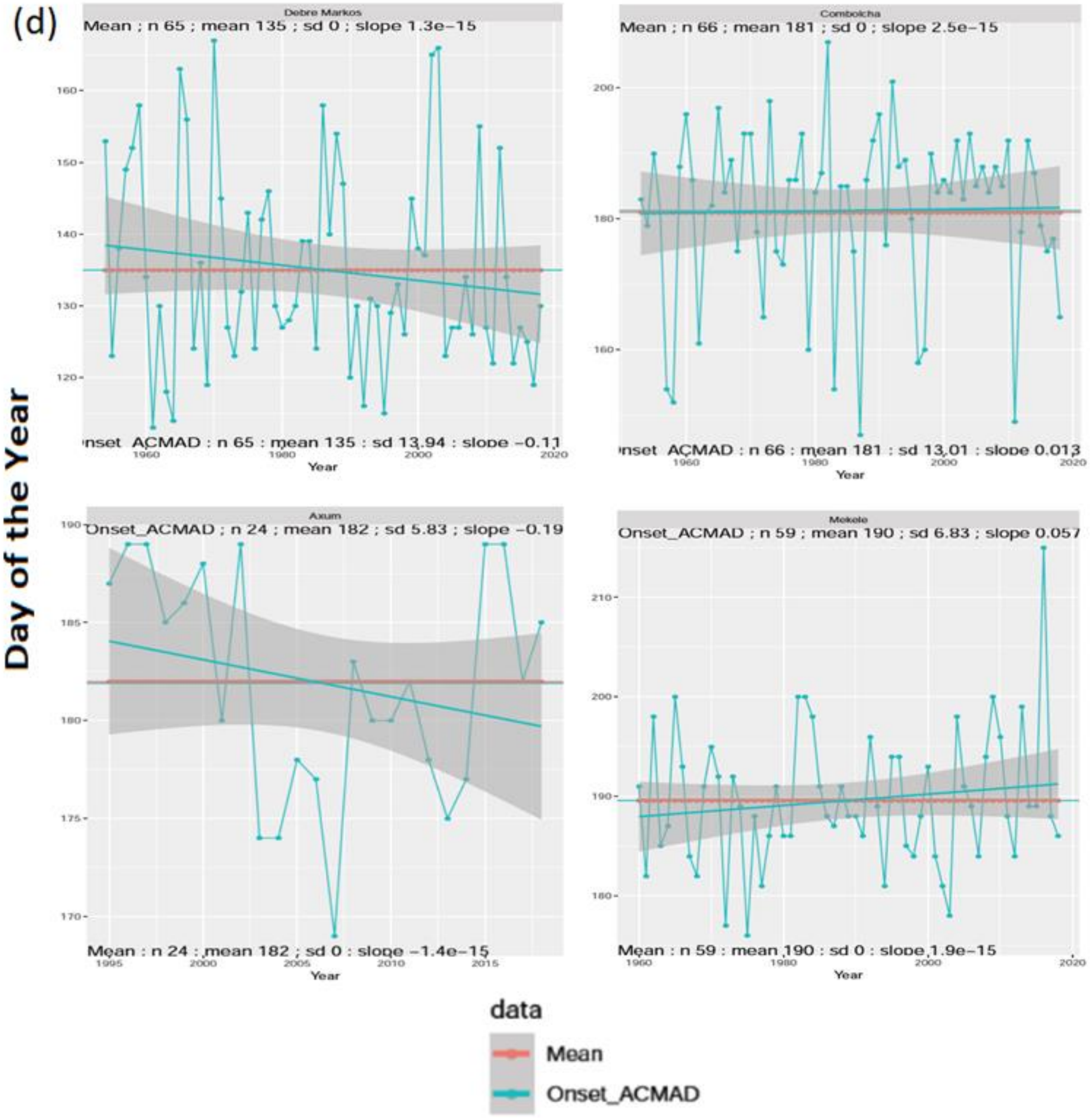

Figure 2d:The mean onset date, Sd and SE of stations from the northern part of the country

Figure 2d documents the range of temporal variability and the level of SE over the selected stations from the northern portion of the country (D/Markos, Combolch, Mekele and Axum). Quiet largest temporal variation (SD>14 days) was observed over D/Markos and the smallest variation was noted over Axum (SD<6 days). However, the largest error of the mean was also found over Axum (largest shaded area), while the smallest error on the mean was observed over Mekele stations (smallest shaded area) compared to other stations. The result on the temporal variability of the onset date is quite consistent with the previous study by Segele and Lamb (2005).

Mean onset date

In many previous research papers, SIVACUMAR onset date definition is widely applied to determine the mean rainfall onset date at national scale (Tesfy Haile 1989; Seggle and Lamb, 2005; Messay, 2006) as well as at local scale studies in Ethiopia (Girma, 2005; Wodaje et al 2016; Girmay 2019). For this reason a large number of researchers consider the Sivacumar definition as the Bench-Mark for determining the start of the wet season in Ethiopia.

In this study, the mean date of onset calculated by the two criteria are presented in figure 3. As documented by Ati et al., (2002), it is hardly possible to compare onset date among different stations due to highly variable rainfall distributions between stations, and here even more so because of different temporal data length. However, the two methods can be intercomparable for the same station. However, one should note here, comparison between the two indices is not the objective of this study. The clear aim is simply to evaluate the result of the 50mm accumulated rainfall threshold; how close to the widely applied definition over the country.

The result in Fig 3 indicates that the ACMAD criteria tend to exhibit an earlier onset over most stations except in Combolcha and Dire Dawa. In the former station, the wet season started earlier than the Sivacumar by about ten days, while the later shows no difference in the mean onset date. Generally, the mean date of onset determined by SIVACUMAR method gave by far the latest mean onset date by nearly a week than the ACMAD definition**.** The only station appeared with late onset by about a week was Combolcha. The nature of the delay in the onset date of the SIVACUMAR method was also observed in the study by Ati et al., 2002, when they compared different onset date methods for determining the start of the wet season in northern Nigeria.

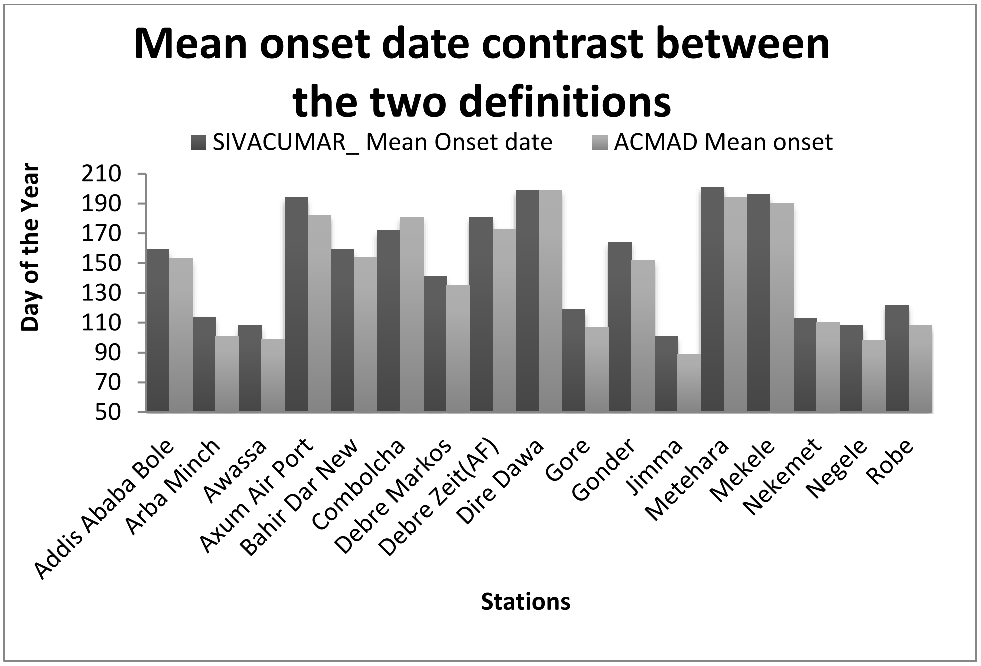

Figure 3: The mean onset date calculated by the two methods (SIVAKUMAR and ACMAD)

Variability and Pattern of Onset date

In general, the time series analysis is one of the powerful statistical technic to get a clear view of how the data points are arranged through the given temporal horizon yet the time is regarded as an independent variable. As illustrated in figure 4, the ACMAD criteria more or less shows similar pattern with the Sivacumar one. It is noted that, however, the Sivacumar criteria appears with high variability and fluctuations in the time series analysis. Among the stations, Addis Ababa exceptionally shows similar variability and pattern in the onset date.

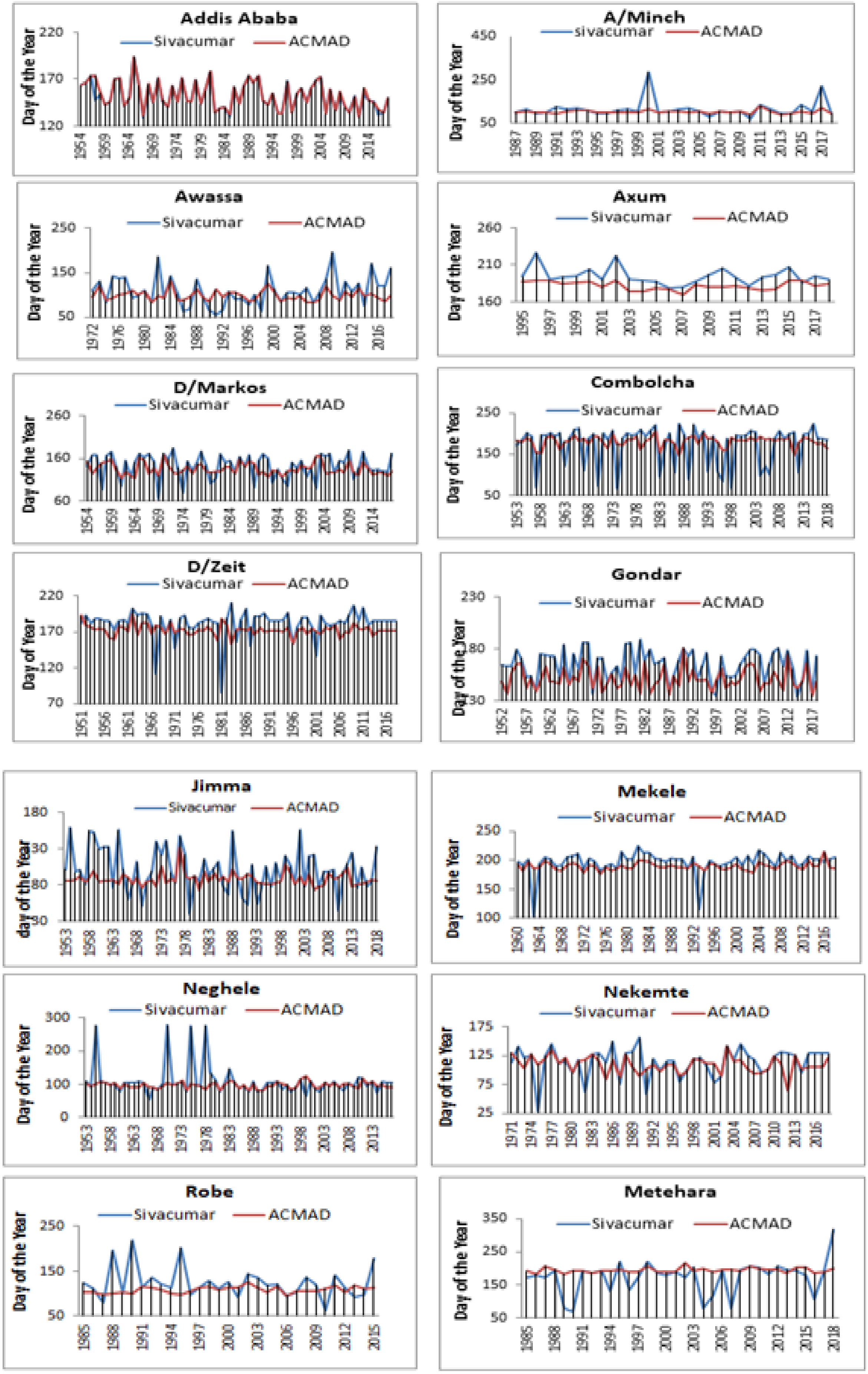

Figure 4: Variations in the pattern of the onset date in the time series between SIVACUMAR and ACMAD definitions.

In the rest of the stations the higher the variability was found in the Sivacumar definition. The higher the variability often regarded as the larger the noise in the dataset. Therefore, the ACMAD criteria exhibits less noisy in determining the onset date compared to the Sivacumar definition. Furthermore, the variability of the onset date in terms of the range, mean, standard Error and Coefficient of variation at the selected seventeen stations is presented in Table 3.

Table 3: Summary for the statistical description of the onset date over the selected stations in Ethiopia

Stations	mean onset date		Range of the onset date by station		SD (days)		CV (%)	
	SIVACU	ACMAD	SIVACU	ACMAD	SIVACU	ACMAD	SIVACU	ACMAD
Addis Ababa	**8, June**	29 May	**15-Mar-26-Jul**	9 May – 13 Jul	**15**	15	**9.4**	**9.8**
A/Minch	**24 April**	17 April	**10 Mar-10 Oct**	21 Mar-3 May	**39**	8	**34.0**	**7.9**
Awassa	**18 Apr**	13 April	**28-Feb-15-Jul**	21-May-24-Jun	**32**	12	**29.6**	**12**
Axum	**13 July**	30 June	**27-Jun-14-Aug**	23-Jun-8-Jul	**12**	6	**6.2**	**3.3**
Bahir Dar	**8, June**	21, June	**5-May-4-Jul**	14-May-2-Jul	**18**	15	**11.3**	**9.7**
Combolcha	**21, June**	3 July	**7-Mar-3-May**	22-May-26-Jul	**47**	13	**27.3**	**7.2**
D/Markos	**21, May**	9, May	**6-Mar-4-Jul**	23-Apr-16-Jun	**28**	14	**19.9**	**10.4**
D/Zeit	**30, June**	22, June	**26-Mar-30-Jul**	4-May-13-Jul	**20**	8	**11.0**	**4.6**
Dire Dawa	**18, Jul**	17, Jul	**6-Mar-3-Jun**	22-Jun-26-Aug	**49**	12	**24.6**	**6.0**
Gondar	**13, June**	5, June	**14-May-8-Jul**	23-May-30-Jun	**15**	10	**9.1**	**6.6**
Gore	**29, April**	1, May	**1-Feb-26-May**	31 Mar-10 May	**36**	12	**30.3**	**11.2**
Jimma	**11,April**	25, Mar	**10-Feb-8-Jun**	14-Mar-23-Apr	**29**	9	**28.7**	**10.1**
Mekele	**15, Jul**	9, Jul	**14-Apr-12-Aug**	25-Jun-3-Aug	**19**	7	**9.7**	**3.7**
Metehara	**20, Jul**	25, Jul	**11-Mar-13-Nov**	1-Jul-4-Aug	**50**	8	**24.9**	**4.1**
Negele	**18, Apr**	9 Apr	**24-Feb-4-Oct**	9 Apr-12 May	**45**	9	**41.7**	**9.2**
Nekemt	**23, Apr**	4, May	**29-Jan-5-Jun**	12 Apr-28 May	**25**	15	**22.1**	**13.6**
Robe	**2, May**	4, May	**2-Mar-6-Aug**	8 Apr-7 May	**35**	7	**28.7**	**6.5**

The result in the table shows the ACMAD criteria, in general, gave less variability in terms of the range of the onset date, the temporal variability and the coefficient of variation. The higher variability in rainfall onset (> 30%) was found in the SIVACUMAR criteria over Neghele (41.7%) and Gore (30.3%) stations. On the other hand, higher variability (>30%) was not found in the ACMAD criteria across the stations. The lower values of CV shows that the variation in start of the wet season is more or less consistent compared to variations in the growing season and the higher variability in the onset is known to affect the cropping calendar of rain-fed agriculture (Kisaka et al., 2015). A better understanding on the temporal and spatial variation of the onset date receives higher attention by the agricultural community in relation to agricultural planning and decision.

Viability of the onset date index for operational purpose

In the Sivacumar definition, the start of wet season is defined as rainfall accumulated over three consecutive days was at least 20 mm and when no dry spell within the next 30 days exceeded 7 days. This definition can work to determine the mean onset date of a given place. However, this calculation is quite backdated and in reality to wait for 30 days to know whether a dry spell is occurring or not, is shortening the growing season too much. This waiting period may account the loss of the good advantage of early planting and reduction in agricultural productions. The risk of waiting period could be more pronounced at areas where moisture is highly scarce. To avoid the waiting period and planting at the earliest possible date, the ACMAD criteria can play crucial role. According to this criteria once the required cumulative rainfall threshold achieved, farmers no need of waiting additional weeks to check whether the wet season is started or not. Because it is assumed if once this cumulative rainfall threshold achieved, the possibility of longer consecutive dry spells is less (in the later section we will check the ability of ACMAD's criteria toward avoiding the possible false onset). Therefore, the later criteria can potentially be applied for operational monitoring and prediction of the onset date. Moreover, its feasibility to present along with the selected analogue years in the seasonal climate outlook is another merit of the definition.

The test with historically late onset years

The ACMAD onset date index was subjected to the test against historically identified late onset years so as to check its capability to capture the reality on the ground. To select historically late onset years, intensive research papers and various officially published reports (SJOUKJE PHILIP, 2017; G.A. Mera, 2018; *FEWS NET, 2015/2016/2017;* Liou, Y.-A and Getachew, 2019; Terefe, T. 2013) were reviewed. Having the fact that these papers focused more on discussing the drought events, but they have also looked into the start of the wet onset in their analysis and they claimed late onset was one of the clear manifestation in the drought years. On that background, some of the drought years are taken as the late onset years. At first nine drought years were selected from different literatures as late onset years, finally, however, we stick to five years because we got clear evidence from the literatures that on those years the rain had markedly late start. The selected years are 2000, 2003, 2009, 2011 and 2015. After the computation of the cumulative rainfall of each years, it was evaluated against the 50mm cumulative rainfall along with the two acceptable range (75%, the lower acceptable range and the 125%, the upper acceptable range).

The result documented in figure 6. The Figures are grouped in to four parts and in the first group (Fig 6a) we discussed on the years which are identified as late onset in the western part of the country. In the 2nd, 3rd and the last figures (Fig. 6b, 6c and 6d), the same discussion was done to the south, the east and central and the northern parts of the country, respectively.

Stations from the western parts of the country (Jimma, Gore and Nekemt) exhibited late onset ranging from 7 to 30 days. Out of the selected five years, three years (2000, 2003 and 2015) were found late by 7 to 15 days over Gore stations, while 2 years (2000 and 2011) was late onset by about 10 days over Jimma stations. In Nekemt, one year (2003) was identified as late onset year by about a month. Earlier onset was observed over Jimma, in 2003 and 2005, and over Nekemt, in 2009. The rest years were found within the normal acceptable range.

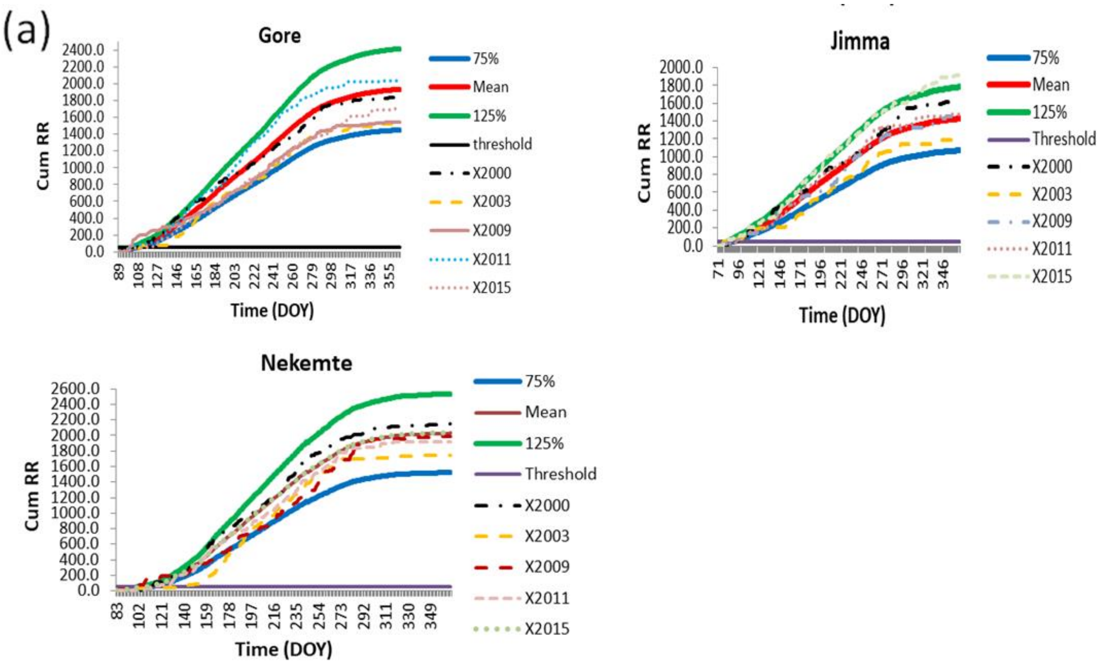

Figure 5a: the start of rainfall in the selected five years over the southwestern part of the country

Likewise, stations from the southern parts of the country (Awassa, Neghele, Robe and Arba Minch) shows collectively late onset in the range of 5 to 27 days. Out of the 5 years, three years (2000, 2011 and 2015) over Awassa and two years (2000, 2003, and 2011) over Negele stations exhibited late onset in average by about 8 to 25 days. The other two stations (Arba Minch and Robe) experienced late onset except in 2009.

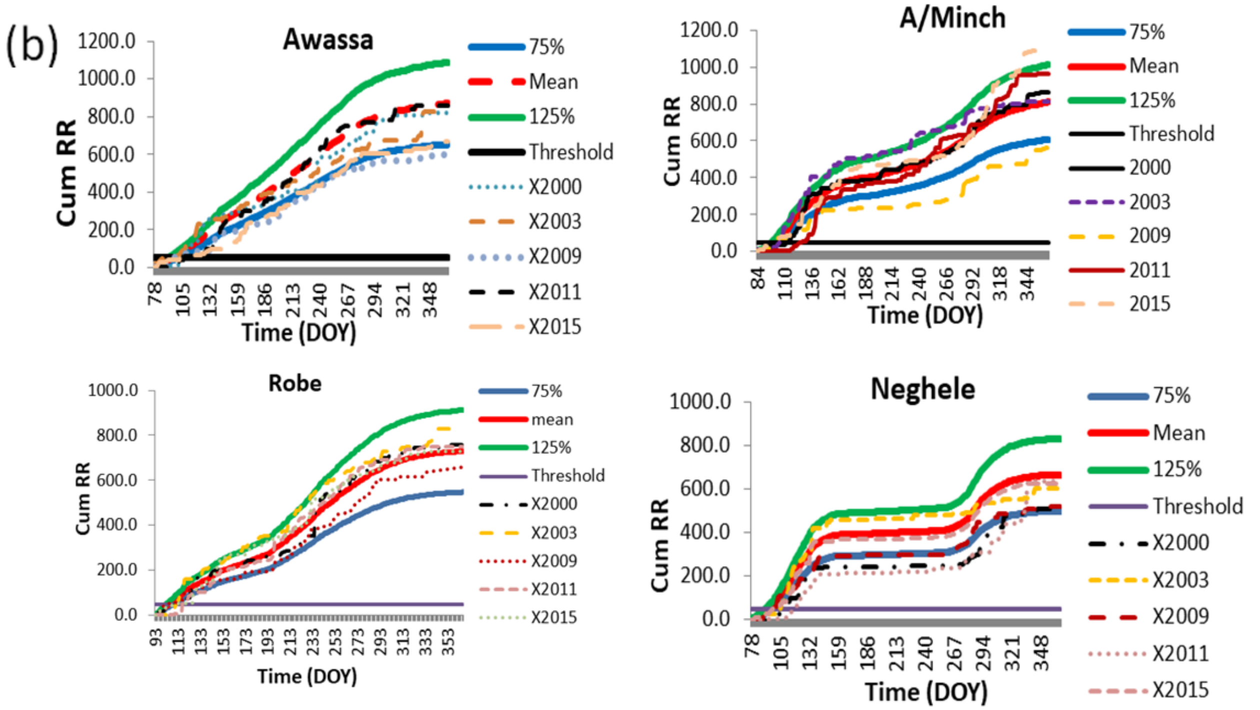

Figure 5b: the start of rainfall in the selected five years over the south part of the country

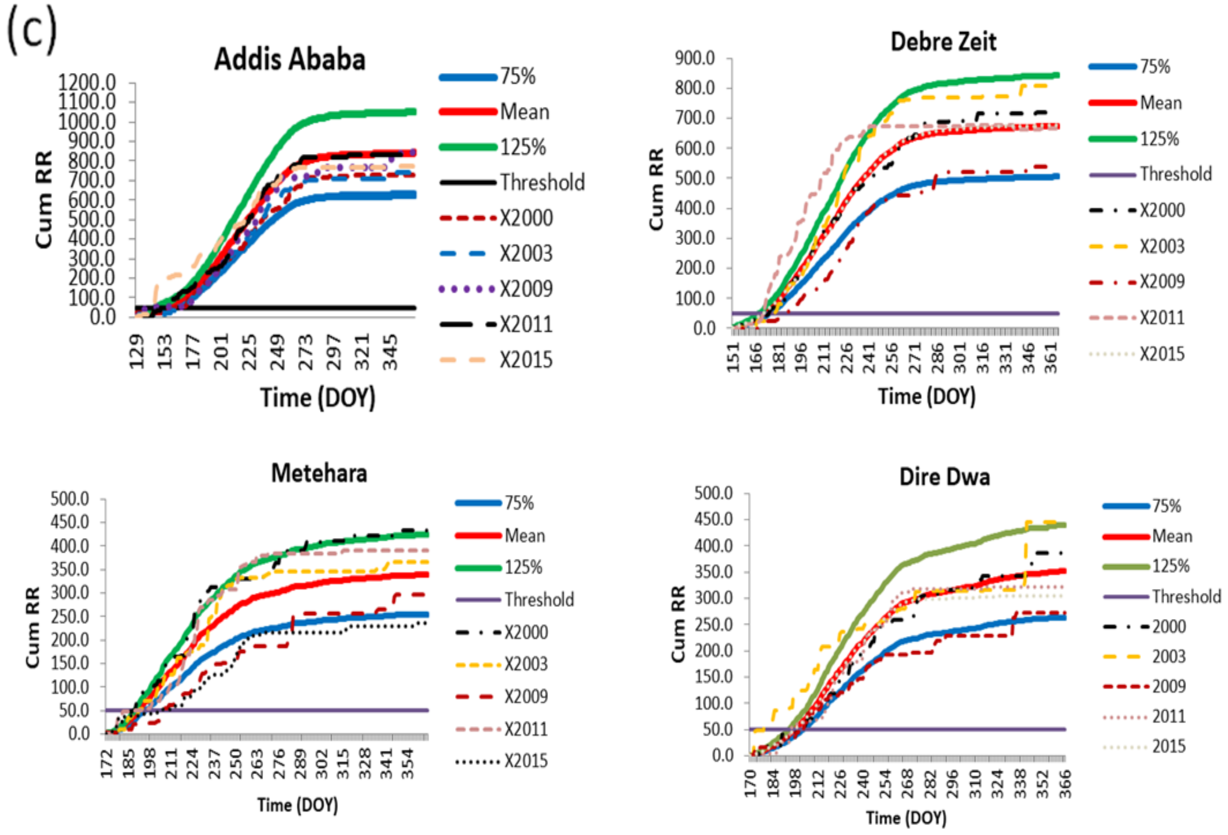

Figure 5c: the start of rainfall in the selected five years over the central and eastern part of the country

Stations belong to the central and eastern part (Addis Ababa, Debre Zeit, Metehara and Dire Dawa) generally exhibited late onset in the order of 5 to 14 days. Out of five years, two late onset years were recorded over Awassa, in 2000 and 2003, over Debre Zeit, in 2003 and 2009, and over Metehara, in 2009 and 2015. Station Dire Dawa, from the east part of the country, fails in the normal acceptable range of the onset category.

In the last group of the discussion, six stations (Mekele, Axum, Bahir Dar, Combolcha, Gondar and Debre Markos) from the northern portion of the country are considered. The result documented in Figure 6d, depicted late onset in the order of 5 to 36 days. The largest rainfall onset delay was observed over Debre Markos in 2003 which was later than the lower acceptable range (75%) by about 36 days. Whereas, the smallest delay in the rainfall onset (by about 5 days) was observed over Mekele in 2000.

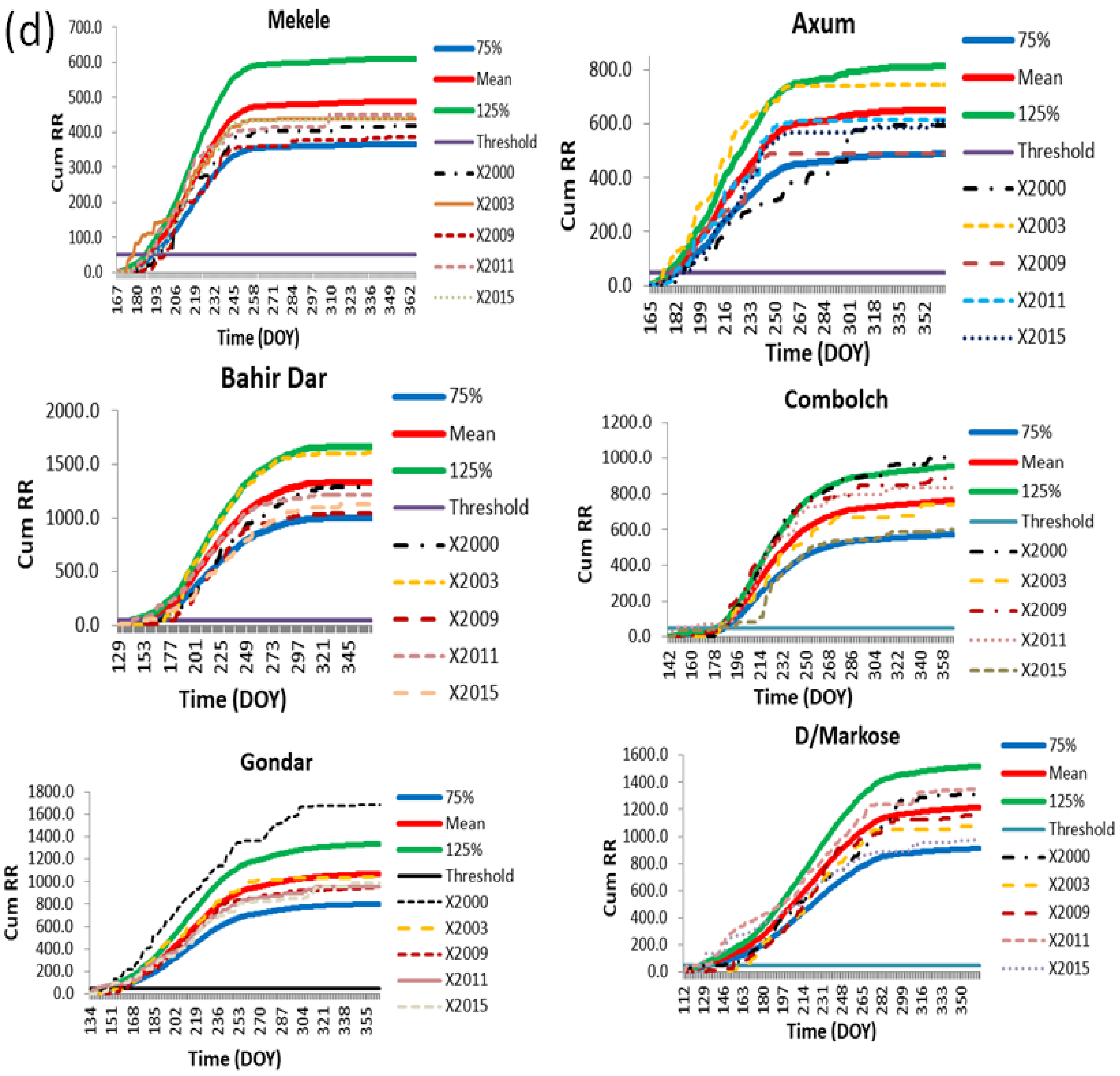

Figure 5d: the start of rainfall in the selected five years over the central and eastern part of the country

In general, stations from the southwestern and the central part of the country described 2 years out of 5 years as late onset years. The higher frequency of late onset is observed over Gore station which account 3 out of 5 late onset years, while the smallest frequency is noted over Nekemt station, which account 1 out 5 late onset years. Whereas, the stations belong to the southern part of the country exhibited 3.5 out of 5 late onset years. The high frequency of late onset years were observed over Arba Minch and Robe stations and each accounted 4 out of 5 years are identified below the lower acceptable range. On the other hand, the low frequency was observed over Awassa and Negele and both stations accounts 3 out of 5 are found below the lower acceptable range. Exceptionally, the stations Dire Dawa and Combolcha are found within the normal acceptable range in all selected years.

False onset test

One of the most critical point in relation to the start of the wet season is to comprehend the possible dry spell length after the predetermined rainfall onset date. In this regard the 50mm cumulative rainfall threshold not consider the possible consecutive dry days as it does in the SIVACUMAR definitions. However, there is strong assumption that once the 50mm requirement is satisfied, the possibility for the occurrence of longer dry spell (e.g. > 8 days) is supposed to be less. To test the steadfastness of the above assumptions and arguments, the ACMAD criteria was additionally subjected to calculate the percent of dry spell length at each stations. In previous study, Segele and Lamb (2005) have formed two category of dry spell length and labeled them as “Short”, if the dry spell is ≤ 5 days, and “Long”, if the dry spell is ≥ 9 days. In our study, however, we simply adhere to calculate the possible long dry days (> 8 days) immediately after the threshold requirement is satisfied.

The results, documented in Table 4, shows that almost all selected stations experienced maximum dry spell length in the order of 10 to 27 days within 30 days after the 50mm cumulative rainfall requirement was satisfied. The maximum per cent of false years found at Gore and Jimma stations (both are located at the western parts of the country) and each accounts 20% false onset year. On the other hand Gondar (northwest part of the country) and Metehara (located at Central part) experienced no false onset years at all. The large false onset years are more pronounced over the southwest parts of the country and which accounts about 17% in average. The second largest false onset years was found to the central parts of the country and which accounts 12 % in average. Stations belong to the south exhibited the small false onset years followed by the stations located in the northern portion of the country.

Table 4: the degree of false onset (>8 consecutive dry days within 30 day length) experienced by the ACMAD methods are presented with its percentage of false onset years with the maximum and minimum dry day length

Stations	ACMAD Criteria				
	Total Yrs.	**No of false Yrs.**	**% of false years**	**Maximum Dry spell length (days)**	**Minimum Dry spell length (days)**
Addis Ababa	65	14	21	25 /30	0/30
Arba Minch	32	2	6	14 /30	2/30
Awassa	47	2	4	10 /30	0/30
Axum	23	1	4	11/30	1/30
Bahir Dar	24	3	13	10/30	0/30
Combolcha	66	9	14	27/30	0/30
D/Markos	65	11	17	18/30	0/30
D/Zeit	68	12	18	26/30	0/30
Dire Dawa	66	7	11	11/30	0/30
Gondar	66	0	0	8/30	0/30
Gore	67	13	20	24/30	0/30
Jimma	66	13	20	14/30	0/30
Mekele	59	1	2	14/30	0/30
Metehara	34	0	0	8/30	0/30
Neghele	63	7	11	25/30	0/30
Nekemt	48	5	10	14/30	0/30
Robe	31	3	10	16/30	0/30

The above test made on the ACMAD criteria in relation to the possible false onset after the satisfaction of the required threshold give us an alert so that we may not fully rely on the satisfaction of the mere requirement of the threshold. Therefore, to ensure the reliability of the threshold, the expert need to do analysis on climate drivers which could be a cause for the development of consecutive long dry spells after the attainment of the cumulative threshold. For instance, the study by Segele and Lamb (2005) unveiled that the increased probability of long dry-spells in the central parts of Ethiopia during late Kiremt seasons has a linkage with the weakening of TEJ and the drying at the tropospheric level. The association between ENSO phenomena and the years appeared with long dry spells (≥ 8 days) are presented in table 5.

Table 5: Statistical summary for the possible association between the total long dry spell years (the dry spell years are the years on which the record of consecutive dry spells > 8 day after the satisfaction of the cumulative rainfall threshold were found) and ENSO phenomena (El Nino, La Nina and Neutral)

Stations	**All Yrs. With long dry spell (> 8 days)**	**El Nino Yrs.**	**La Nina Yrs.**	**Neutral Yrs.**
Addis Ababa	14	6 (43%)	4 (29%)	**4 (29%)**
Arba Minch	2	1 (50%)	0	**1 (50%)**
Awassa	2	1 (50%)	1 (50%)	**0**
Axum	1	0	0	**1 (100%)**
Bahir Dar	3	1 (33%)	2 (67%)	**0**
Combolcha	9	5 (56%)	3 (33%)	**1 (11%)**
D/Markos	11	3 (27%)	3 (27%)	**5 (46%)**
D/Zeit	12	5 (42%)	3 (25%)	**4 (33%)**
Dire Dawa	7	0	3 (42%)	**4 (58%)**
Gore	13	5 (38%)	4(31%)	**4 (31%)**
Jimma	13	4 (31%)	4 (31%)	**5 (38%)**
Mekele	1	1 (100%)	0	**0**
Neghele	7	2 (29%)	2 (29%)	**3 (42%)**
Nekemt	5	2 (40%)	1 (20%)	**2 (40%)**
Robe	3	0	1 (33%)	**2 (67%)**
Total ENSO Yrs.		36 (35.9%)	30 (27.8%)	**38 (36.3%)**

The result documented in table 5 revealed that of the total long dry spell years across the stations more than 36% of the consecutive dry spells after the attainment of the cumulative rainfall threshold was recorded during ENSO neutral years. Remarkably, more than 35% of the long dry spell occurred during the warm ENSO phase (El Nino). Collectively the stations belong to the central part (specifically the average condition over Addis Ababa and D/Zeit) and the northern parts of the country (specifically, the average condition over Mekele, Axum, Bahirdar, D/Markos and Combolcha) experienced longer dry spell during the El Nino event.

The occurrence of consecutive dry spell is something unavoidable and can occur at any time with the growing season, even at the sensitive stage of the crop. The early time study by Sivacumar (1992) confirmed that there is high probability of consecutive dry days ranging from 10-15 days within the rain season, regardless of the early or late onset. Other study by Baron *et al.* (2009) also found that the frequency of consecutive dry spells more than 10 in semi-arid locations in East Africa could occur in minimum probability (0.2 to 0.3) at any time of the growing season, while maximum and a probability of 0.7 dry spell could occur particularly during the sensitive flowering stage.

4. CONCLUSION AND RECOMMENDATIONS

Daily cumulative precipitation for 17 meteorological stations in Ethiopia were used to evaluate the 50mm cumulative rainfall threshold efficiency in determining the start of the wet season. In the evaluation, the definition suggested by SIVACUMAR was presented as a benchmark criteria to evaluate the ACMAD threshold. This is because the definitions suggested by SIVACUMAR is used by a large number of researchers in the country and currently it is widely used threshold to define mean onset date.

As for the outcome of this study, the ACMAD criteria for predicting and determining onset dates was shown to be reliable for the study locations. As it was checked in this case study, the result of the statistical test indicates that the mean onset date obtained by ACMAD method is quite consistent with the method suggested by SIVACUMAR. Better yet, the smaller temporal variability observed in the ACMAD method makes the definition more preferable than the definition suggested by SIVACUMAR. Its feasibility for monitoring and predicting the start of the wet season quite some time in advance could be found as an additional merit of the method. Moreover, the suitability of the cumulative rainfall threshold to be integrated along with the seasonal climate product both at national and subnational level could make the threshold worth for application. Particularly, the ability of cumulative rainfall threshold to be presented with the selected analogue years along with the seasonal climate outlook product could be another advantage of the definition. Currently, Ethiopian National Meteorology Agency has a plan to launch the climate service at the grass root level. The implementation of this simple and operationally feasible onset monitoring and predicting technique could complement additional value on the climate service to be given at Grass Root Level. The argument provided by LO et al (2007) confirmed the onset definition based on a constant threshold (e.g., 50 mm) is easier to understand, and in some instances more applicable, than other used definitions, such as a date based on the accumulation of a certain percentage of the annual or wet-season mean rainfall.

However, one should be noted that this method could be misleading if someone simply awaiting the satisfaction of the threshold for conclusion. The test made on the ACMAD criteria in relation to the possible false onset after the satisfaction of the required threshold give us an alert so that we may not fully rely on the mere requirement. Therefore, to ensure the reliability of the threshold, the expert need to do analysis on climate drivers which could be a cause for the development of consecutive long dry spells after the attainment of the cumulative threshold. For instance, the study conducted by Segele and Lamb (2005) unveiled that the increased probability of long dry-spells in the central parts of Ethiopia during late Kiremt seasons has a linkage with the weakening of TEJ and the drying at the tropospheric level. Further investigation on the linkage between the establishment of the seasonal system and the 50mm accumulated rainfall is recommended

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Conflicts of interests

The authors declare that there are no conflicts of interests.

Data and materials availability

All data associated with this study are present in the paper.

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