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Length of the growing season for dry rainfed farming under Monsoon climate in Gedarif, Sudan

Lotfie A. Yousif[1], Abdelrahman A. Khatir[2], Faisal M. El-Hag[3], Ahmed M. Abdelkarim[4], Hussain S. Adam[5], Abdelhadi A. W.[6], Yasunori Kurosaki[7] and Imad-eldin A. Ali-Babiker[3,7*]

[1]Gedarif Research Station, Agricultural Research Corporation (ARC), Gedarif, Sudan.
[2]El Obied Research Station, Agricultural Research Corporation (ARC), El Obied, Sudan.
[3]Dry Lands Research Center (DLRC), Agricultural Research Corporation (ARC), Soba, Khartoum, Sudan.
[4]Sudan Meteorological Authority (SMA), Khartoum, Sudan.
[5]Water Management and Irrigation Institute, University of Gezira, Wad-Medani, Sudan.
[6]College of Graduate Studies, Desert and Arid Zones Sciences Program, Arabian Gulf University, Manama, Bahrain (ARC Professor), Sudan.
[7]Arid Land Research Center (ALRC), Tottori University, Tottori, Japan.

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Reliable information on the starting and ending of growing season as well as its length will greatly assist in appropriate planning for rainfed agriculture farming practices. The objective of this study is to determine the start, end and length of growing season, based on dependable rainfall during wet (20%), normal (50%) and dry (80%) years, which were retrieved from historical rainfall records analysis of seven stations in Gedarif state for the period 1985 to 2014. The seven studied stations were categorized into two groups according to the total seasonal rainfall. During wet years, Group I had about 900 mm/year and Group II about 700-790 mm/year. In normal years, Group I had about 660-700 mm/year and Group II had 515-570 mm/year. During dry years, Group I had 490-550 mm/year and Group II had 350-425 mm/year. The results showed consistent trend of starting dates of the growing seasons; regardless of the high seasonal variability and variation in amount and distribution of rainfall among the stations and seasons. Similar results were obtained using the MODIS Enhanced Vegetation Index (EVI) for three different years representing different probability levels (2013, dry; 2000, Normal; 2007, wet). Groups I and II in normal and wet years had 70 to 90% of the total annual rainfall during the growing season. In dry years, Group I had 70 to 80% of the total rainfall during the growing season, while Group II had only 50 to 65%. The two groups have indicated different seasonal characteristics (start of growth season, end of growth season and length of growth season) in the dry, normal and wet years. Length of the growth season increases with early start of the season and in wetter years.

Key words: Season start, season end, sowing date, dry season, normal season, wet season.

INTRODUCTION

Agricultural crops grow in favorable weather conditions for their emergence, vegetative growth, and ripening. For rainfed agriculture in the arid and semi-arid areas, like Gedarif State in Sudan, water availability is the main constraint that limits the time crops can grow. Irregularities in rainfall reliability and spread have contributed significantly to poor yields and high variability in production from year to year (Ogungbenro and Morakinyo, 2014; Araujo et al., 2016). The most important problems associated with rainfall variability as a result of changes in moisture availability are: (a) The highly variable dates of rainy season onset from one station to another; (b) The temporal (monthly and annual) distribution of the rainfall at each station or over a certain area; (c) The cessation and length of the rainy season. Hence, it is necessary to explore the rainfall and its spatial variability over space along with its length of growing period to make crop based decisions (Sathyamoorthy et al., 2017).

To avoid and mitigate the risks that accompanied annual rainfall variability, the concept of dependable rainfall is usually used in agricultural planning. The planner needs to know the amount of rainfall that can be depended upon with a certain degree of probability (Haque, 2005). Adam (2008) defined dependable rainfall as the rainfall which can be expected in a number of years out of a total number of years, expressed as percentage or probability. Accordingly, he described three types of years (seasons), dry, normal and wet, which corresponds to the probability of rainfall exceedance of 80, 50 and 20%, respectively. On the other hand, the availability of sufficient water at appropriate times is the most crucial factor determining the type and productivity of crops (Fox and Rockstrom, 2000). Thus, the rainfall distribution characteristics during the growing seasons affect the schedule of agricultural activities beginning with land preparation; through the crop variety selection and planting, to the time of harvest (Odekunle, 2004). In other words, reliable information of rainfall onset and cessation times, and thus the length of the growing season, will greatly assist on time land preparation, mobilization of inputs and equipment and will also reduce the risk involved in sowing too early or too late (Omotosho et al., 2000). Also, determination of the length of the growing season is a useful guide for fitting crops that are suitable for various agroecological zones (Adam, 2008; Legese et al., 2018).

Growing season can be defined as the period during which rainfall distribution characteristics are appropriate for crop germination, establishment, growth and ripening. Hence, the onset and cessation of rainfall are of special important in rainfed agriculture growing season. The combination of these two determines the length of the growing season. The length of the growing season, under rainfed conditions, is defined as the period from the date of the onset of the rainy season to the date of its cessation (Mhizha et al., 2012).

The length of the growing season can be estimated using different methods. Benoit (1977) and Adam (2008) used the relation between rainfall and evapotranspiration to determine the onset, cessation and length of the growing season (FAO, 1978); however, other researchers have used rainfall alone (Adejuwon et al., 1992; Ati et al., 2002). Odekunle (2004) identified two approaches in using rainfall data alone: one approach based on certain threshold value and the other one based on certain proportion relative to the total rainfall. Likewise, satellite images were also used to determine the characteristics of growing season's (Vrieling, et al., 2013).

Gedarif State in Eastern Sudan encompasses vast areas, around 3 million hectares, suitable for crop production, which depend totally on rainfall. These areas extend through different climatic zones, with different rainfall amount and onset and cessation dates. The annually cropped areas as well as crop yields fluctuate with the variability in rainfall amount and distribution (Ali Babiker et al., 2015). Therefore, to ensure maximum and sustainable agricultural productivity together with efficient water management, reliable information of dependable annual rainfall, the start and cessation dates of rainfall and the length of the rainy season are important. The objective of this study was to determine the start, end and length of the growing season based on dependable rainfall, expressed as a percent of the descending rank order of annual rainfall (Critchley et al.,1991 and Adam, 2008) as explained in the section below, namely: wet (20%), normal (50%) and dry (80%) years. These are retrieved from historical rainfall records analysis for seven stations in Gedarif State for the period 1985 to 2014.

MATERIALS AND METHODS

Study area and collected data

Gedarif State is in the Eastern part of the Sudan between latitudes 12.67° and 15.75°N and longitudes 33.57° and 37.0°E, covering 71000 km^2 (Figure 1). The state stretches from North to South through three climate zones: arid, semi-arid and the dry monsoon zones (Adam, 2008). The soil is heavy cracking clay soils (Vertisols), characterized by shrinking when dry and swelling when wet. The mean daily maximum temperature reaches 33.4°C in May and drops to about 26.3°C in January. The relative humidity varies from 22% in March to 71% in August, as published by Sudan Metrological Authority (SMA, 2010). Rainfall is always in summer and most of rainfall events occur within June to September (JJAS); resulting in a short-single rainfed growing season per year. To achieve the objectives of this study, rainfall data were obtained from the records of Mechanized Farming Corporation (MFC). Monthly data (April to October) for seven stations during 30 years (1985 to 2014) period were used. These stations are scattered in the major rainfed agricultural production areas of Gedarif State. Figure 1 portrays the names and geographical locations of these stations (Umseenat, Samsam, Douka, Alhawaata, Alhoory, Gedarif (MFC office) and Gadambalia). Moreover, monthly potential

*Corresponding author. E-mail: imadaa@gmail.com.

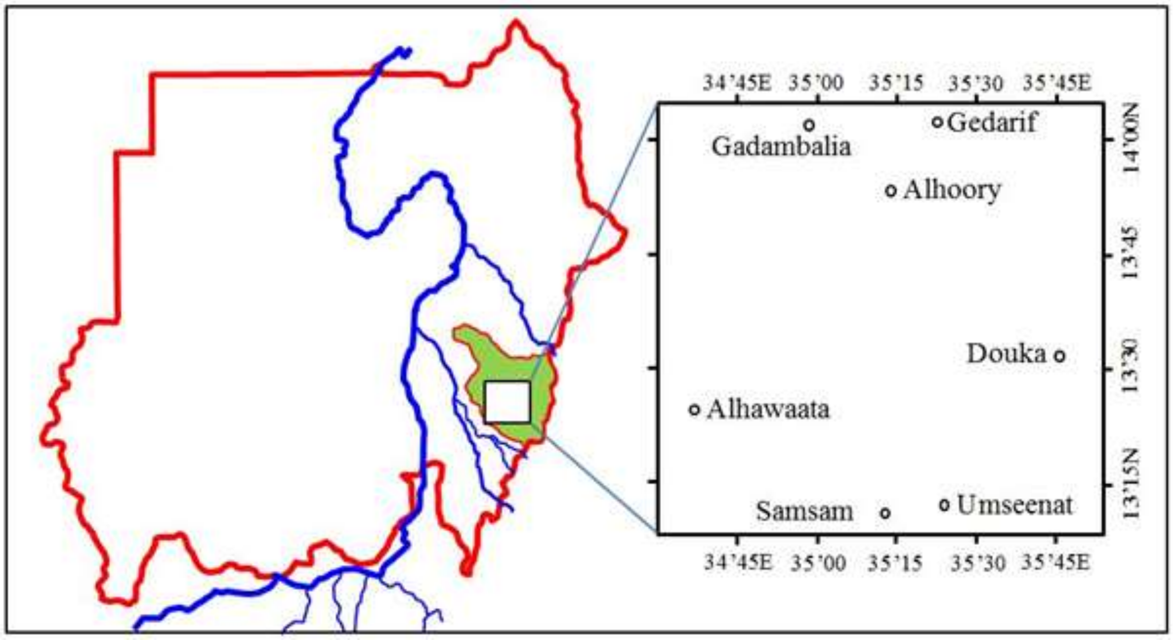

Figure 1. Sudan map showing Gedarif State (Green) and the studied area with the 7 Stations**.**

evapotranspiration (PET) data were obtained from Adam (2008).

Dependable rainfall and season type

Rainfall data of each station were ranked in descending order (highest to lowest). The probabilities for wet, normal, and dry years are 1-20% (denoted 20%), 21-70% (denoted 50%), and 80-100% (denoted 80%), respectively. This procedure was adopted from Critchley et al. (1991) and Adam (2008). Furthermore, the percent of normal (PN) was calculated based on the season normal for each station to categorize the years in different classes (Morid et al., 2006). The classes for the PN are: Extremely dry (ED): ≤39%; Severely dry (SD): 40-54%; Moderately dry (MD): 55-79%; Normal (N): 80-109%; Moderately wet (MW): 110-124%; and Very wet (VW): ≥125%.

Length of growing season (LGS)

The length of the growing season was determined using PET and rainfall. On the other hand, the length of the growing season was determined based on the green vegetation, using MODIS Enhanced Vegetation Index (EVI) time series. The PET of the Gedarif station was used for all the stations assuming that its value will increase by 10% in the northern station (Gadambalia) and decrease by 10% in the southern stations (Umseenat, Samsam, Douka, Alhawaata and Alhoory). For determining the length of the growing season rainfall and potential evapotranspiration (PET) were used (FAO, 1978). Both rainfall and PET were segregated into 5 days for every month. The beginning of the growing period occurs when rainfall (R) equals half PET and marks the start of growing season (R > PET/2). The end of the growing period occurs at the point where the rainfall is less than half PET (R < PET/2).

The MODIS EVI were used based on the BLUE, RED and NIR reflectance bands at 8-day intervals, acquired by MODIS on the Aqua platform (MYD09A1), to derive EVI time series and seasonality parameters for seasons 2000, 2007 and 2013. EVI was developed to improve the Normalized Difference Vegetation Index (NDVI) by optimizing the vegetation signal using the blue reflectance to correct soil background signals and reduce atmospheric influences, including aerosol scattering. EVI is defined by the following equation:

$$EVI = 2.5 * \left\{\frac{NIR - RED}{NIR + 6RED - 7.5BLUE + 1}\right\}$$

The value of this index ranges from -1 to 1. The common range for green vegetation is 0.2 to 0.8 (Huete et al., 1997). This resulted in 46 composite EVI images (periods) per year. The MODIS EVI images were re-projected into a *WGS_1984_UTM_Zone_36N* projection, which is suitable for analysis. For each season we extracted MODIS EVI time series data from the 65th period of the first year (2000) through the 57th period of the second year (2001). Seasonal phenological metrics were then extracted for the same period. These data provided the basis for examining the seasonality and anomalies in EVI and the associated phonology metrics for the different metrological stations and the entire study area.

Derivation of phenological metrics using TIMESAT software

The TIMESAT program package is designed primarily to analyze time-series of satellite data and it uses an adaptive Savitzky-Golay filtering to smooth original data (Jönsson and Eklundh, 2009). This filter is the most consistent at maintaining unique vegetation time series fits, while accounting for atmospheric effects like clouds. From the fitted model functions, a number of seasonality parameters, e.g. beginning and end of the growing season, can be extracted. Parameters for a number of pixels can be merged into a map displaying seasonality on a regional or global scale (Jönsson and Eklundh, 2003). MODIS EVI based phenological metrics were calculated seasonally to characterize the phenology of different vegetation type in the study area. The phenometrics for each growing season are depicted in Figure 2.

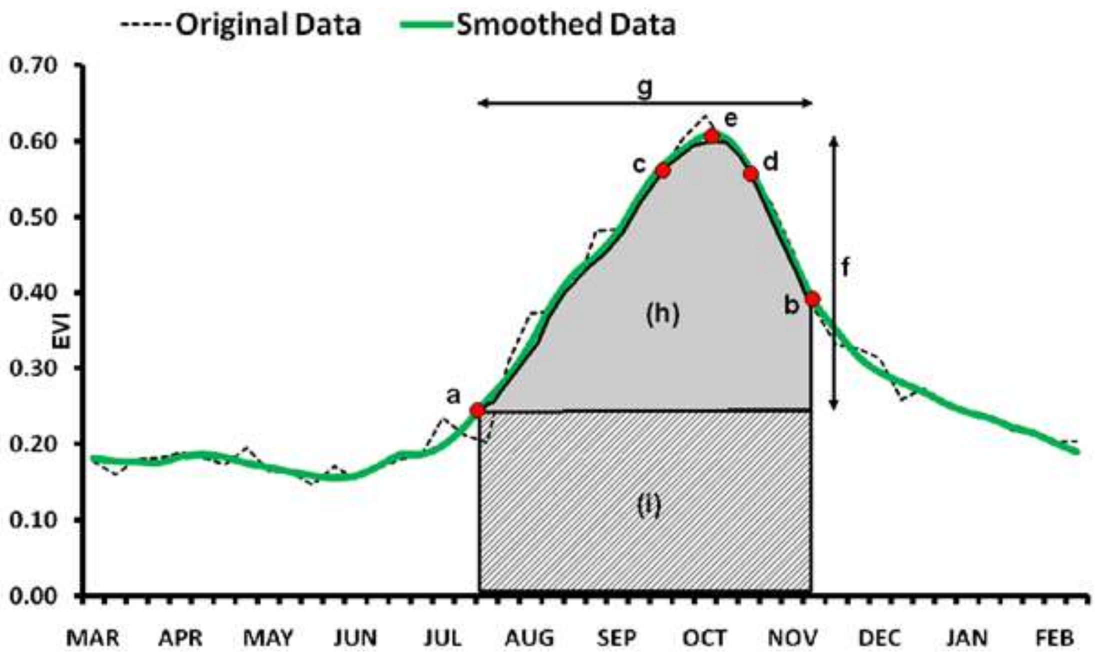

Figure 2. The points (a) and (b) mark the start and end of the season, respectively. Points (c) and (d) give the 80 % levels. Point (e) displays the largest value. Point (f) displays the seasonal amplitude (the increase in EVI value between the time of season start and time of maximum growth) and point (g) the seasonal length. Finally, (h) and (i) are integrals showing the cumulative effect of vegetation during the season. Redrawn from Jönsson and Eklundh, (2009).

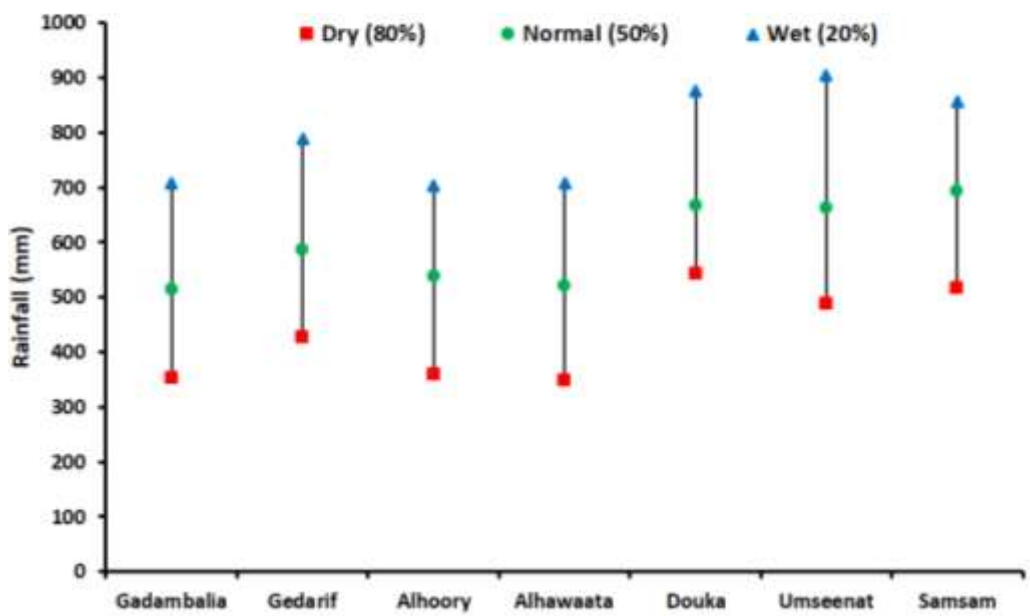

Figure 3. Rainfall mean (mm/year) at different probability levels for the seven studied stations during the period 1985-2014.

RESULTS AND DISCUSSION

Results of rainfall probability at different levels of dry (80-100% denoted as 80%), normal (21-79% denoted as 50%) and wet (1-20% denoted as 20%) years for all stations during the period 1985 to 2014 are shown in Figure 3. Umseenat, Samsam and Douka stations had the highest rainfall in wet years (20%), with an average of

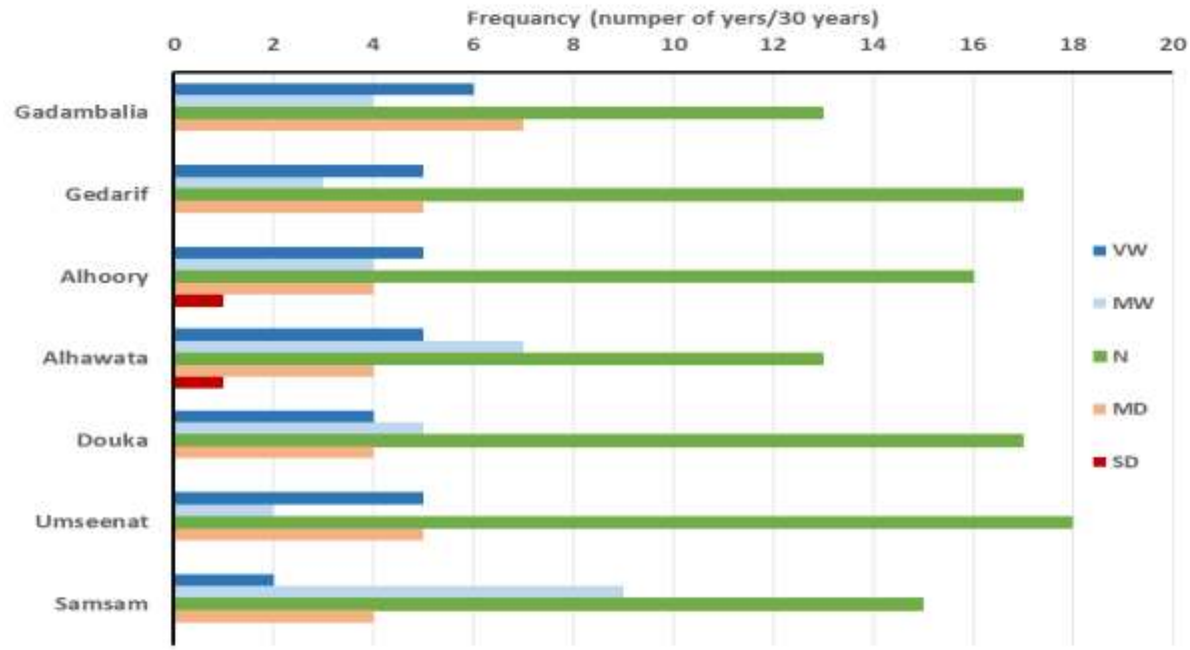

Figure 4. The number of years (frequency) for different classes of Percent of Normal (PN) are: Extremely dry (ED): ≤39%; Severely dry (SD): 40-54%; Moderately dry (MD): 55-79%; Normal (N): 80-109%; Moderately wet (MW): 110-124%; and Very wet (VW): ≥125%. the percent of normal (PN) was calculated based on the season normal for each station for the period 1985-2014.

about 900 mm/year. Alhawaata, Alhoory, Gedarif and Gadambalia had the lowest values of rainfall in wet years, which ranged between 700 and 790 mm/year. In normal years (50%) rainfall was high in Samsam, Douka and Umseenat (660 to 700 mm) compared to the other four stations, which ranged between 515 and 570 mm/year. Rainfall in dry years (80%) followed the same trends and was higher in Umseenat, Samsam and Douka stations (490-550 mm/year) than the other four stations (Alhawaata, Alhoory, Gedarif and Gadambalia) in which the range was between 350-425 mm/year. From these results, based on the probability and total amount of rainfall, the stations of Umseenat, Samsam and Douka could be grouped in the same rainfall-zone (Group I: rainfall range from 500 to 900 mm/year). On the other hand, Alhawaata, Alhoory, Gedarif and Gadambalia could be grouped in another rainfall-zone (Group II: rainfall range 350 to 790 mm/year). These results were supported by the earlier classification of the stations into two groups (Yousif et al., 2018). This information on rainfall amount at different probability levels is useful as guidelines for farmers in these sites, because it can facilitate their seasonal planning choices based on the seasonal forecasts delivered to them by the meteorological services.

Figure 4 shows the number of years for different classes of Percent of Normal (PN). In all stations, the years with normal rainfall (80-100%) were the most frequent. In Group I stations (Samsam, Douka and Umseenat), 50-60% of their years were normal. In Group II ((Alhawaata, Alhoory, Gedarif and Gadambalia), 40-55% of their years were normal. The other classes of the PN did show consistency in their frequency to the two groups of stations. However, the dry year's classes (Severely dry (SD): 40-54%; Moderately dry (MD): 55-79%) tended to have more frequency in Group II stations. None of Group I stations showed any incidence of severely dry (SD) years (40-54%). All the stations did not show any incidences of extremely dry (ED) years (≤39%). Previous regional studies in eastern Africa showed future drying will have a radical impact on growing season length and agriculture (Cook and Vizy, 2012; Cook and Vizy, 2013). Sayari et al. (2013) reported that higher drought (dry years) frequency associated with global warming and increase in drought frequency would have major implications for natural resource management, water security planning, and water demand management strategies.

Figure 5 displays the start, length, and end of the growing season at the seven stations during the period at dry (80%), normal (50%) and wet (20%) years. There were variations in the start of the growing season in these stations. The growing season in dry years started between 25 and 30 of June in Group I; while it started late between the 1st and 20th of July in Group II. For normal years it started in first half of June in Group I;

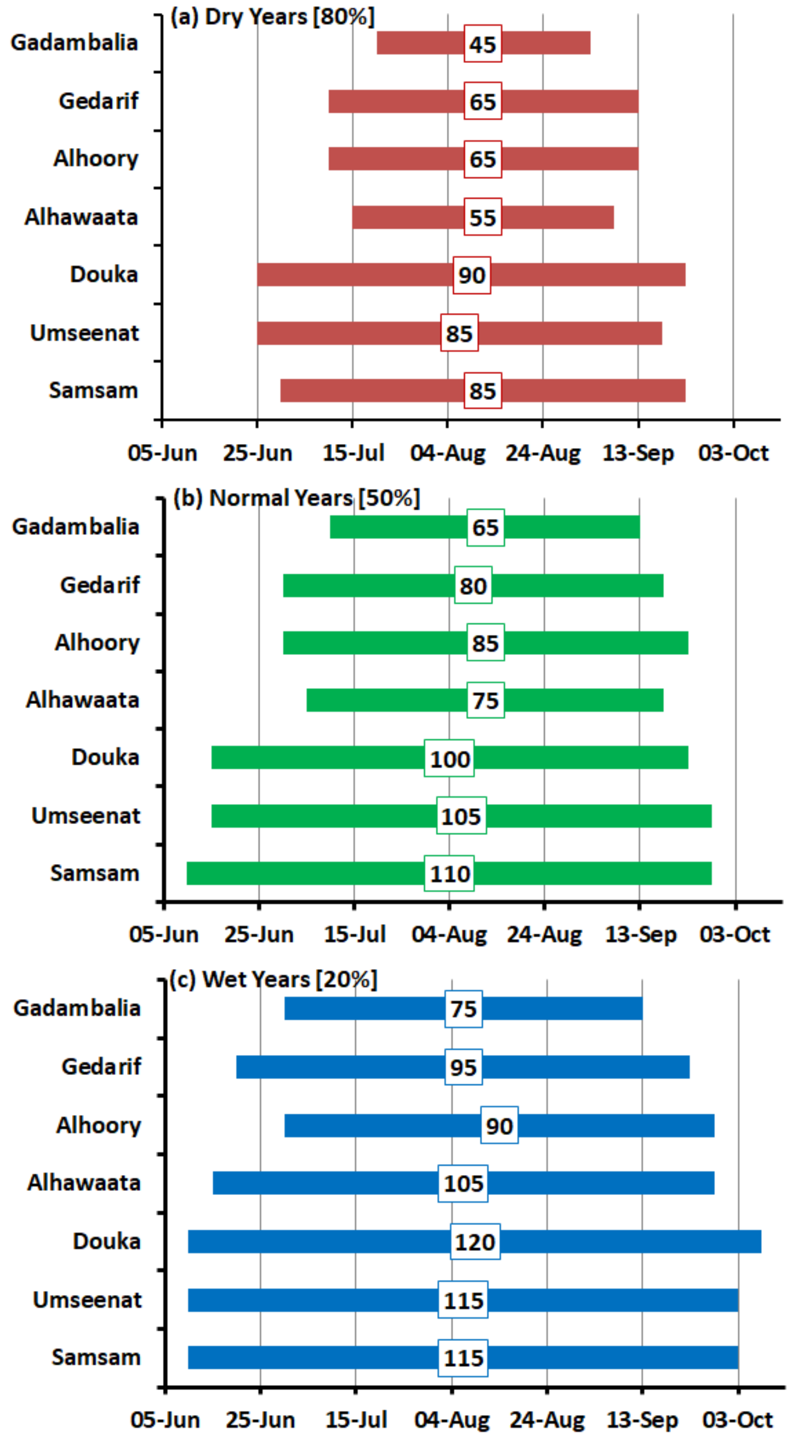

Figure 5. Growing season start, length and end determined by the Rainfall/Evapotranspiration (R/ET) ratio at different probability levels (Dry, 80%; Normal, 50%; Wet, 20%) for the seven studied stations during the period 1985-2014. Numbers in the centre of the bars indicate the length of the season.

while in Group II, started late between the last week of June and first week of July. In wet years it started earlier in the first 10 days of June in Group I and in the last days of June in Group II. These results revealed a consistent trend of starting dates of the growing seasons; regardless of the high seasonal variability and variation in amount and distribution of rainfall among the stations and seasons. Similar results were obtained (Figure 6) using

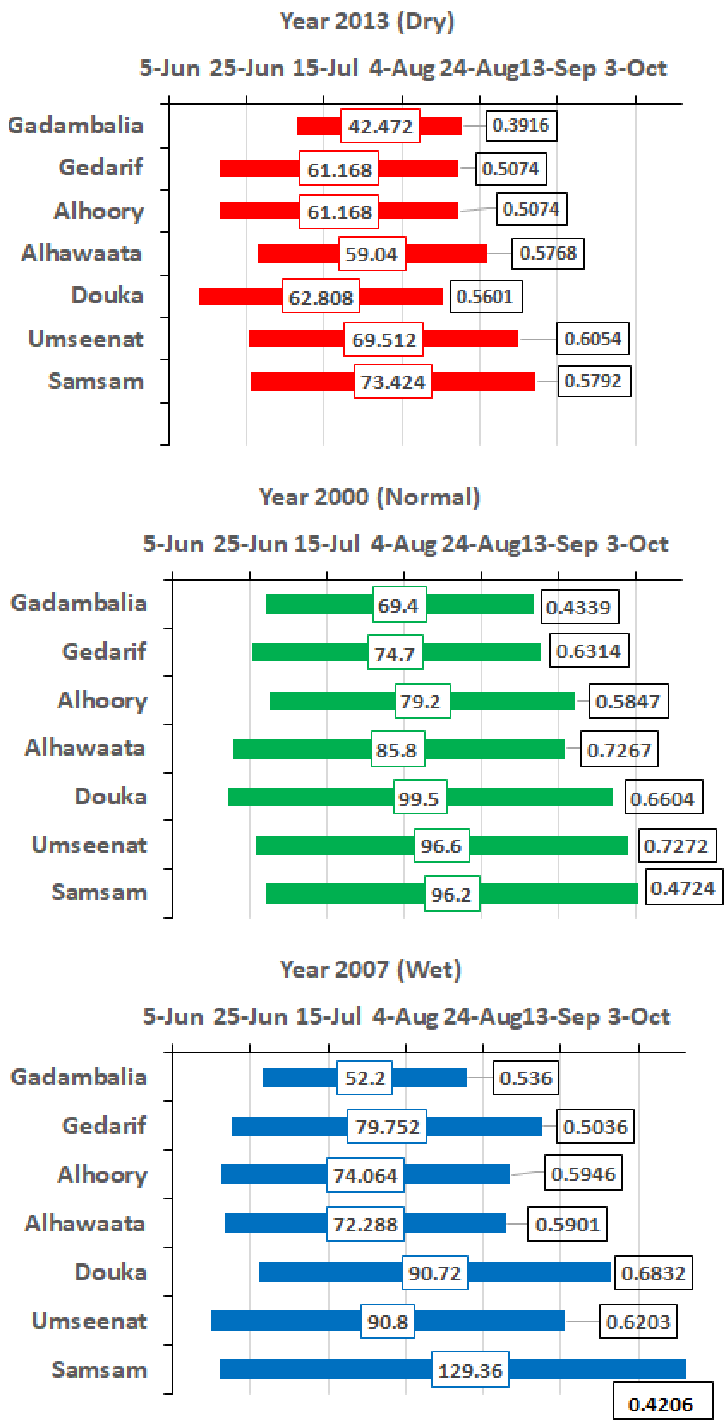

Figure 6. Growing season start, length and end determined by the MODIS Enhanced Vegetation Index (EVI) for three different years represent different probability levels (2013 dry; 2000 Normal; 2007 wet) at the seven studied stations during the period 1985-2014. Numbers in the centre of the bars indicate the length of the season. Numbers at the right side of the bars indicate the maximum EVI.

the MODIS Enhanced Vegetation Index (EVI) for three different years representing different probability levels (2013 dry; 2000 Normal; 2007 wet). In Figure 7, the green color in the image of season start indicates earlier start, whereas the red color indicates later start. In 2000, the season start in the majority of the study area was on

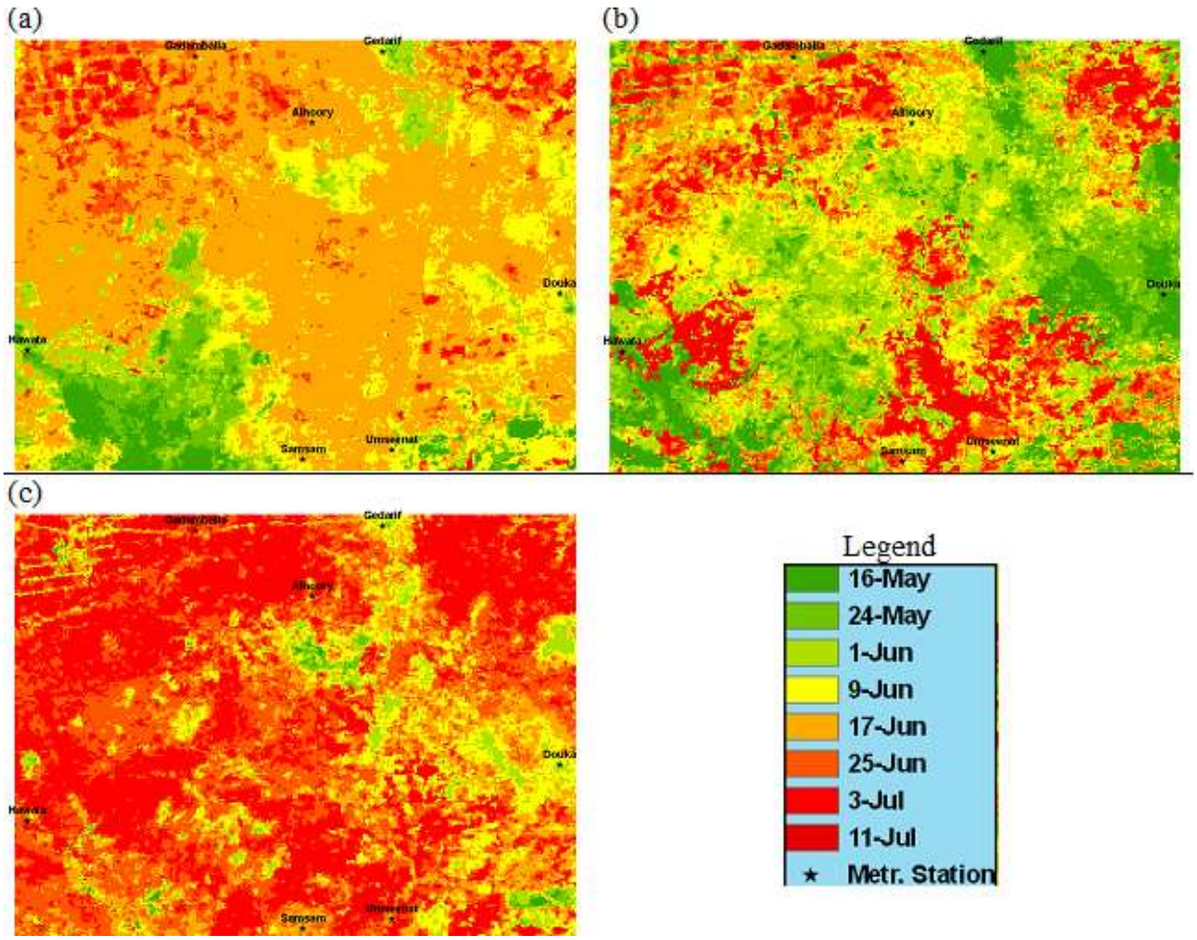

Figure 7. Starts of the growing seasons in the study area covering the 7 stations for seasons (a) 2000, (b) 2007, and (c) 2013 as detected by the MODIS Enhanced Vegetation Index (EVI) based on the BLUE, RED and NIR reflectance bands at 8-day intervals, acquired by MODIS on the Aqua platform (MYD09A1).

17 June. There was an earlier start (May) in the area extending between Samsam and Alhawaata, whereas later start (July) was around Gadambalia and east of Gedarif (Figure 7a). In 2007, the season started in almost half of the study area in the period extending from 16 May to the 1st of June (green-yellow color); whereas, in the other half (brown-red color) the season started between 25 June to 11 July (Figure 7b). In 2013, the season started in most of the study area as late as July. Smaller areas had earlier starting dates in late May and early June (Figure 7c)

Adam (2008) has studied the growing season in Gedarif during the period 1941- 1970. His results showed systematic trend of growing season commencement, it started early on 27 May and late on 21 July. The starting dates of the growing season denote dates of seeding or germination of crops, inferring that seedbed preparation must be done earlier; that is, before the start of the growing season. However, farmers have a propensity to delay sowing dates due to many reasons; a) they do not do seeding during the beginning of the wet period (22 July to 3rd of August), the period is locally known as “Natra”, because of remarkable insect's activity (Adam, 2015); b) they wait until the soil moisture is sufficient to seal all the soil cracks and adequate to germinate the seeds; and c) after weed germination to control weeds using wide level disc harrow with seeding box in one operation for economic considerations. Generally, it could be avowed that in Southern areas (Group I) the season started as early as mid-June and in Northern areas (Group II) it started around mid-July. For the ending of the season (Figures 5 and 6), the growing season in dry years (80%), ended in the third week of September in areas of Group I, while it ended earlier in first week of September in areas of Group II. In normal years, it ended in the fourth week of September for stations of Group I and second to third weeks of September in stations of Group II. In wet years, it ended in the first week of October in Group I areas and third to fourth weeks of September in Group II areas. It could be stated that in southern areas (Group I) the end of the growing season occurred late September and early October; while in

Central-Northern areas (Group II) it ended in early to mid-September. A pervious study (1941-1970) by Adam (2008) showed that the growing season in Gedarif (Group II area) ended around the first week of October. It seemed that the growing season in this study ended earlier by 7 to 10 days compared to this previous study. An early cessation of the growing season will adversely affect the rainfed agriculture (Amekudzi et al., 2015), these periods are critical to crop maturity, and may also lead to crop failure. This implies that farmers have to grow short maturing varieties for successful production, especially in the dry years that are characterized by early seasonal cessations.

Length of the growing season (LGS) is also depicted in Figure 5. In dry years it varied from 85 to 90 days in areas of Group I, while between 45 to 65 days in areas of Group II. The general trend is that the wetter the years the longer the growing season. In normal years, it ranged between 100 to 110 days and 65 to 85 days for areas of Group I and Group II, respectively. In wet years it ranged between 115 to 120 days for Group I areas and 75 to 105 days for Group II areas. It is clear that areas of Group I have longer growing seasons compared to areas of Group II. This was due to the early start and later end of the growing season. This is in agreement with Mubvuma (2013) who showed that there was a strong correlation between the onset of the rainy season and the LGS. He showed that the LGS increases with the earlier onset of the rainy season. In this study, the LGS increased with the early start of the growing season and late end of it. The LGS was variable among the studied stations, however, it was generally longer in Group I and shorter in Group II. The length of the growing season varies from one station to another due to variation in rainfall (Amekudzi et al., 2015) and also it is possible there is a very high spatial variability between stations, and temporal variability within each station (Ayanlade et al., 2018). However, variability in the length of growing season is dominant in arid and semi-arid areas, and is susceptible to crop failure risk (Vrieling et al., 2013).

The MODIS Enhanced Vegetation Index (EVI) determination of LGS in year 2000 (normal year) revealed that the LGS varied between 85 to 70 days for Group II with no variations for Group I (Figure 6). In year 2007 (wet), much variation was noticed in the length of the season in both groups. In Group II, Gadambalia recorded lower days (52 days) than the other three stations in the range of 72 to 79 days. In Group I, Samsam recorded as high as 129 days, while the other two stations about 90 days. In year 2013 (dry), there was a shorter LGS with fewer variations, which was between 42 days in Gadambalia and 73 days in Samsam. Over all, the LGS based on the R/ET ratio at different probability levels and EVI displayed that in the wet years it was longer and in the dry years was shorter. For the study area as a whole (Figure 8a), the length of the season during the year 2000 (normal) was two months, but in some locations (between Alhawaata and Samsam), the length was three months. Smaller areas recorded one month, while in the areas around water courses the length was four months. In year 2007 (wet), the growing season was very long in more than half of the study areas, especially in the east-south direction, where the season was recorded as four months. When analyzing data in the north-west direction, the length becomes less (three months), and finally it becomes two months in the north-west corner (Figure 8b). The LGS was similar in the years 2000 and 2013 (two months in general), with the exception of areas in the north-west corner (one month) and areas in the east-north corners (three months). In the areas around water courses (Figure 8c), the length of the season was four months.

The maximum EVI value during the growing season indicates maximum vegetative growth (Figure 9). For the three different years representing different probability levels (2013 dry; 2000 Normal; 2007 wet); the maximum value in Gedarif, Umseenat and Alhawaata was recorded in year 2000. In Gadambalia, Alhoory and Douka the maximum production was recorded in year 2007. Samsam is the only station that recorded maximum vegetative growth in year 2013. Regarding the entire study area, it could be noted that years 2000 and 2007 were similar in most areas recording higher values (0.60-0.95); whereas the recorded lower values (0.15, 0.30) were in very small patches (Figure 10.a and 10.b). In year 2013 values of maximum EVI decreased (Figure 10c), as the majority of study area recorded medium value (0.45- 0.60). There was less area recorded in the north-east corner (0.60-0.75), and lower values of EVI (0.15-0.30) in the north-west corner (Figure 10c).

The average distribution of rainfall received in each station before, during and after the growing season for different rainfall probabilities (20%, 50%, and 80%) seasons is shown in Figure 11. The rainfall amount during the growing season in areas of Group I ranged between 370 - 400 mm; 565 - 610 mm; and 765 - 825 mm, in dry, normal and wet years, respectively. For Group II, rainfall ranged between 170- 265 mm; 360 - 460 mm; and 540 - 660 mm in dry, normal and wet years, respectively. It is clear that for both Group I and Group II in normal and wet years that the growing season received 70 to 90% of the total rainfall during the year. This is in agreement with and confirms, the early start of the growing season during wet and normal years with lower rainfall risks in all the studied areas. However, in dry years, Group I received 70 to 80% of the total rainfall during the growing season, while Group II received only 50 to 65% of total rainfall during the growing season. This shows that the rainfall risks during the dry years is higher for Group II than Group I. Before and after the growing season, fewer rain amounts occurred in areas of Group I compared to areas of Group II. Generally, less than 20 mm rainfall occurred before or after the growing season in areas of Group I; however, in areas of Group II, about

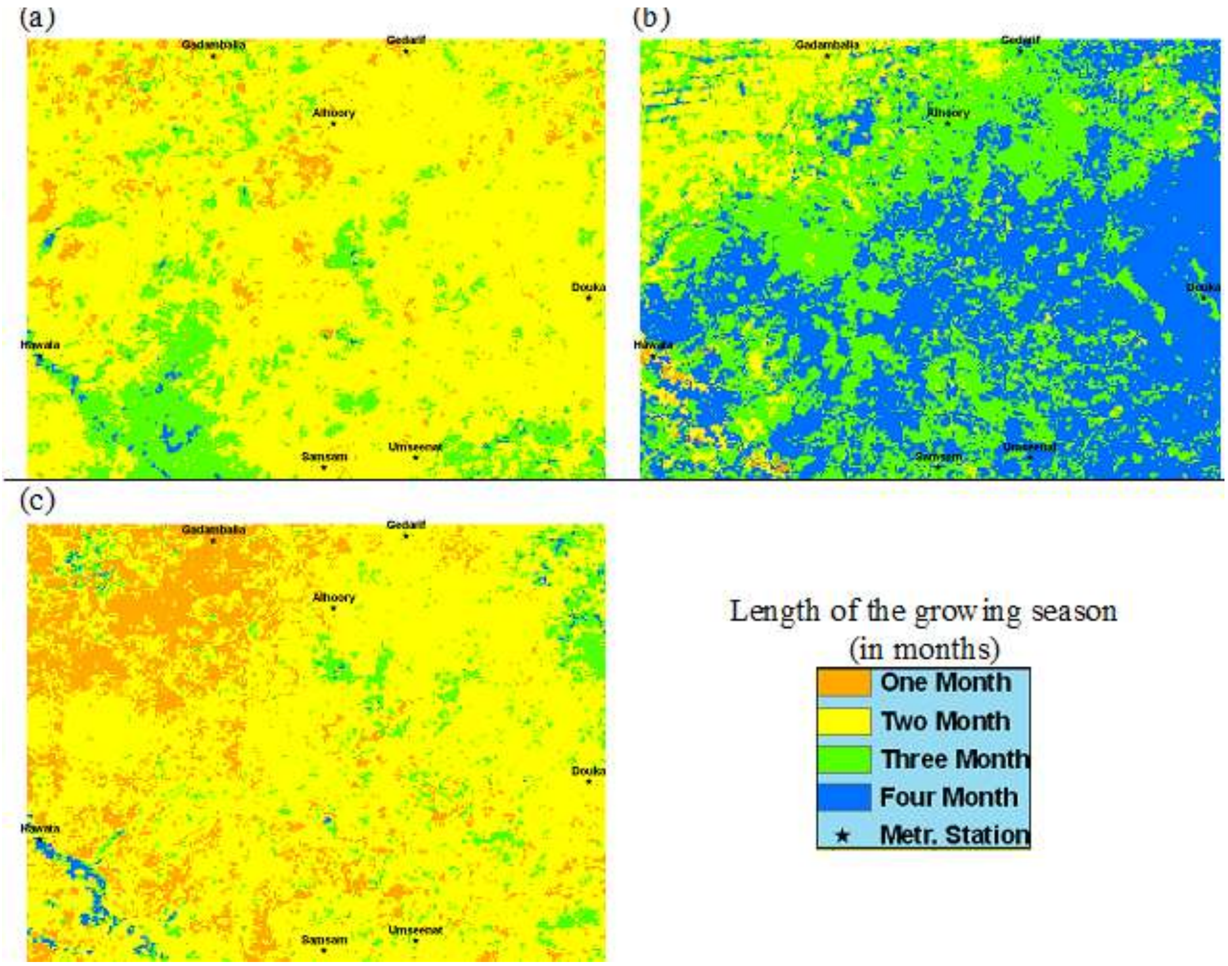

Figure 8. Length of the growing seasons in the study area covering the 7 stations for seasons (a) 2000, (b) 2007, and (c) 2013 as detected by the MODIS Enhanced Vegetation Index (EVI).

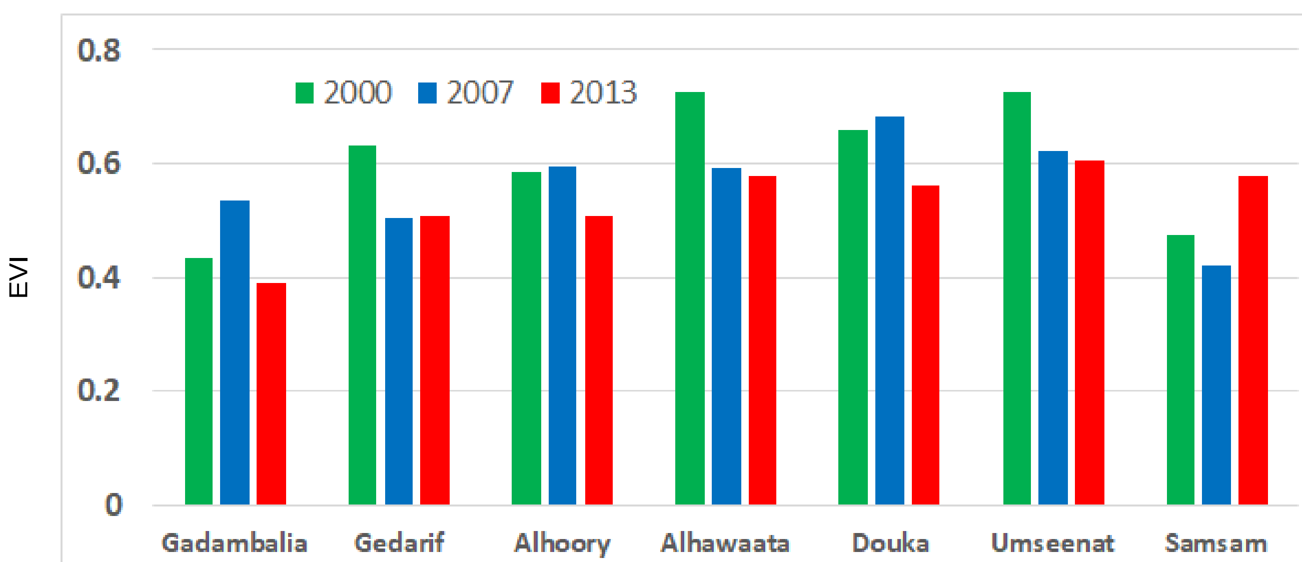

Figure 9. Maximum EVI values in seven studied stations for three different years represent different probability levels (2013 dry; 2000 Normal; 2007 wet) at the seven studied stations during the period 1985-2014.

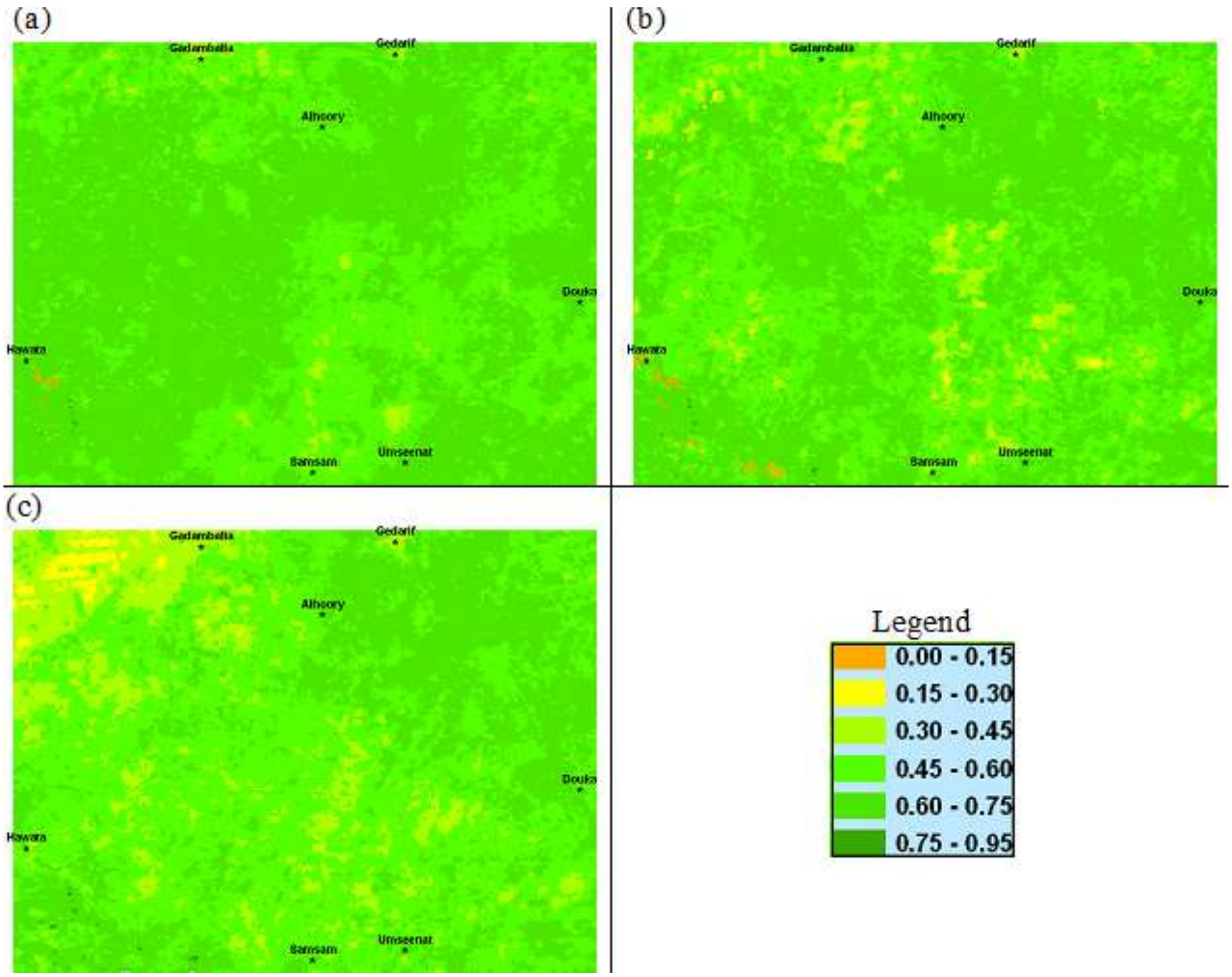

Figure 10. Maximum values of Enhanced Vegetation Index (EVI) values (maximum vegetative growth) in the study area covering the 7 stations for seasons (a) 2000, (b) 2007, and (c) 2013.

25 to 50% of rainfall happened outside the growing season period, especially in the dry years. This information on the amount of rainfall at different probability levels is useful for farmers in the studied areas, which can facilitate the choice of appropriate crop and variety that can be grown most productively.

Conclusions

The studied stations can be categorized into two groups according to the total seasonal rainfall. The two groups have indicated different seasonal characteristics (start of growth season, end of growth season and length of growth season) in the dry, normal and wet years. Length of the growth season increases with early start of the season and in the wetter years. In general, the results of this study suggest that adaptive, climate-informed practices, such as planting short maturing varieties and employing early sowing dates coupled with water harvesting techniques, should be used in areas of short growing seasons, (such as group II). In areas of extended growing season (such as group I), suitable crops and varieties with appropriate climate smart crop management practices should be used. Farmers are advised to use suitable adaptation cultural practices to avoid water logging during the seedling stage in areas of Group I, and appropriate strategies to avoid water shortage during flowering and maturity stages in areas of Group II.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests

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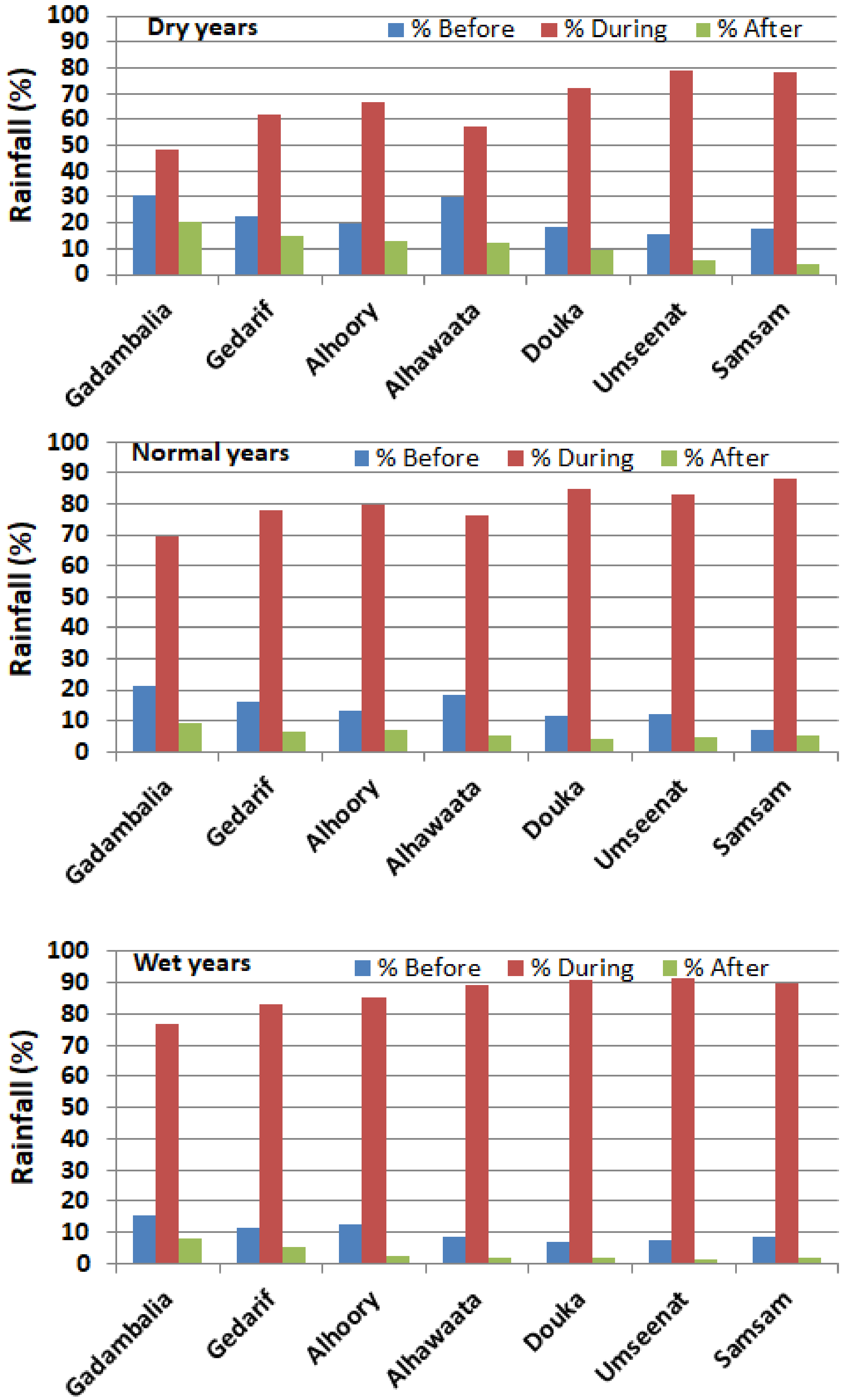

Figure 11. Seasonal rainfall distribution before, during and after the growing season at different probability levels (Dry, 80%; Normal, 50%; Wet, 20%) for the seven stations during the period 1985-2014.

providing rainfall data of the seven stations in the studied area.

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