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Start, End and Length of Growing Season between 1987 and 2018 over the Upper Blue Nile Basin, Ethiopia

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Abstract

The growing season indices (start, end, and length) are highly dependent on rainfall in areas where agricultural production is led by rain-fed agricultural systems. Planning agricultural activities may require reviewing statistics on the onset and cessation of the main rainy season, particularly to decide when to prepare the field for sowing and planting. The main objective of this study was to ascertain the characteristics of growing season over the Upper Blue Nile (UBN) basin. For this study, data from the National Meteorological Agency of Ethiopia for 16 stations between 1987 and 2018 has been taken. A threshold based method relating rainfall and potential evapotranspiration has been used to evaluate the growing season. The results show that the starting date of the growing season on the scale of stations shows a decreasing and an increasing trend from the eastern part to the western part below and above 100 N, respectively. The northern and central parts of the basin start the growing season later than the other regions, with a high amount of variability around the eastern part and a low amount of variability around the southern part. The end dates of the growing season show an eastward decline trend from the other sides of the basin. Most of the northern and eastern parts show a positive trend, with the positivity inclined towards the north. The variability of the end of the growing season has been low around the northern and central parts and high around the eastern and western parts. The shortest length of the growing season was observed around the eastern and northern parts of the study area, while the longest mean length of the growing season was seen over the western and southern parts. The advancement of LGS seems to happen towards the south from the north-eastern part of the UBN basin. On stations in some eastern, north-eastern, and northern parts of the UBN basin, a positive trend (enhancement) was observed, whereas the rest of the basin showed a negative trend (decrement). In addition, stations in most of the study area show strong variability for the LGS, which conveys the message that caution, should be taken when planting cultivars in the study area. In general, within the study period, there exist spatial as well as temporal variations on all parameters of the growing season over the UBN basin.

Keywords: Growing season indices; Rainfall variability; Length of growing season; PET; UBNB; Threshold based method

Introduction

Rain-fed agriculture is the most important economic sector in Ethiopia. Agriculture significantly contributes to national economy by employing a large portion of the workforce, generating revenue from exports, and others (CSA, 2005; FAO, 2006). Rainfall is the most important and sensitive climatic factor which affects agricultural output. Depending on whether there was a surplus or deficit of rainfall throughout the growing season, crop failure can be total or partial. Changes in rainfall patterns consequently have an instant and direct impact on both the performance of the agriculture sector and the total GDP of the country (Edao et al., 2018; FAO, 2006; Hassan, 2006). However, agricultural output can be increased and risk reduced by making an informed decision based on an analysis of the long-term rainfall pattern and variability as well as by harvesting extra water and using it as supplemental irrigation during times of scarcity [1].

In the upper Blue Nile (UBN) basin, the annual mean rainfall is 1470 mm, with spatial ranges of 970 mm in the northwest (Metema) to 2410 mm in the southwest (Masha), with the summer (Kiremt) rainfall accounting for an average of 93 percent of that total (Mellander et al., 2013). The length of the winter (Bega) dry season and the amount of summer (Kiremt) rains have shown persistent spatial trends over the UBN basin over the second half of the 20th century (Mellander et al., 2013), but show a variation in timing [2]. The basin's highlands are especially vulnerable to the negative effects of a changing climate (Zaitchik et al., 2012), as changes in local temperatures and precipitation will have a big impact on the security of the local food supply (World Bank, 2006). As agricultural productivity is dependent on both time and amount of rainfall, the boundary conditions for sustainability in the UBN basin are thus tightly related to the climate. Ethiopia's average annual rainfall has not altered over the past 40 years (Tessema et al., 2010), and while temperatures have grown over the past few decades (Jury, 2010; Mohammed, 2005), there has been inter-decadal fluctuation. According to Zeleke and Damtie (2017), between 1979 and 2014, there was a lot of variation in rainfall over the western regions in the spring and over the southern regions of the UBN basin in the summer [3]. There has been a high variability of rainfall with an increasing trend (not statistically significant) from 1987–2016 and a projected decreasing trend in the upper Blue Nile basin (Tariku et al., 2021 and Takele et al., 2022); a decreasing trend in most of the basin area between 1979 and 2014 (Zeleke & Damtie, 2017). Over northern Ethiopia, it shows a high variability trend (Zeleke et al., 2017). Average, maximum, and minimum temperature in the basin shows an increasing trend in the past as well as in the future (Roth et al., 2018; Mengistu et al., 2021; Tariku et al., 2021). Variability in climate variables, especially rainfall, has a significant impact on crop productivity and production.

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In order to plan cropping and manage water resources, it is necessary to study the parameters of the growing season (GS), as they are dependent on rainfall in countries like Ethiopia [4].

Farmers in the study area typically made traditional crop planning decisions based on the start of the Belg season rains (a small amount of rain before the main rainy season). Low crop output in the rain-fed agricultural system is highly linked with the irregularity in the onset, timing, and spatial distribution of rainfall. Rainfall variability, unreliable occurrences in sufficient amounts, and delayed commencement dates all lead to a drop in crop yields in nearly all regions of the nation (Bekele et al., 2017) [5]. The timing of the rainy season's onset, withdrawal, and length is crucial for crop planning, selecting the best crop varieties, and developing compressive techniques for effective rainwater management (Mandal et al., 2013). In addition, farmers can pick the correct cultivar for their area or region if they know how long the GS will last and when it will end (Moeletsi & Walker, 2012), so that it gains high attention in many parts of the world (e.g., Cook & Vizy, 2012; Cui et al., 2017; Ronchail et al., 2002; Sabziparvar & Jahromi, 2018; Segele & Lamb, 2005). As a result, evaluating data on the onset and cessation of the major rainy season might be crucial for planning agricultural activities, particularly for deciding when to prepare the ground for planting [6].

Studies on the rainfall trends have been well documented (e.g., Mellander et al., 2013; Mohammed et al., 2022; Zeleke & Damtie, 2017), but changes in the seasonality of rainfall (onset and cessation) have gotten less attention despite being a factor in the timing of cropping calendar activities. This study has been carried out to determine the start, end, and length of the growing season and to ascertain the climatology of the parameters over the upper Blue Nile basin, Ethiopia, from 1987 up to 2018 [7].

Materials and Methodology

Study area description

The upper Blue Nile Basin, which runs from 340 25' to 390 49' E and 70 40' to 120 51' N in Ethiopia's north-western and western regions, covers an area of 199,812 km2 (Figure 1). The highland plateaus, steep slopes abutting the plateaus that tilt west and the western lowlands with mild topography make up the basin's topographical divisions. The basin's topography heights range from 500 metres above sea level (near the Sudan border) to more than 4200 metres above sea level [8].

The basin is characterised by high biophysical variability (elevation, slope, climate, and soil type). Approximately agricultural land covers 55.94% of the Upper Blue Nile basin, followed by closed forest (18.04%), mixed forest (14.5%), shrubs (6.12%), and other land-use classifications (5.4%). Eutric nitosols (30%), eutric cambisols (24%), humic cambisols (16%), cambic arenosols (14%), dystric cambisols (5%), eutric regosols (3%), water bodies (2%), eutric fluvisols (2%), chromic vertisols (2%), pellic vertisols (1%), and orthic acrisols (1%), are among the soil (Takele et al., 2021). The basin's upper elevation zones have a humid climate, while the lower elevation zones have a semi-arid environment. The annual rainfall ranges between 787 mm and 2200 mm per year. The Inter-Tropical Convergence Zone (ITCZ) passes over the UBN once a year, creating a unique wet season from June to September and delivering roughly 70% of its yearly rainfall (Conway, 2000) [9].

Data and data analysis

The rainfall and maximum and minimum temperature data used to determine the start, end, and length of the growing season over the study area was obtained from the National Meteorological Agency of Ethiopia (NMA). The data includes 16 unevenly distributed stations in the UBN basin with a temporal coverage of 1987–2018, which have a missing data <20%. The Standard Normal Homogeneity Test (SNHT) method was used to check the data set for homogeneity; heterogeneity was not found. Alexanderson (1986) proposed the SNHT to identify

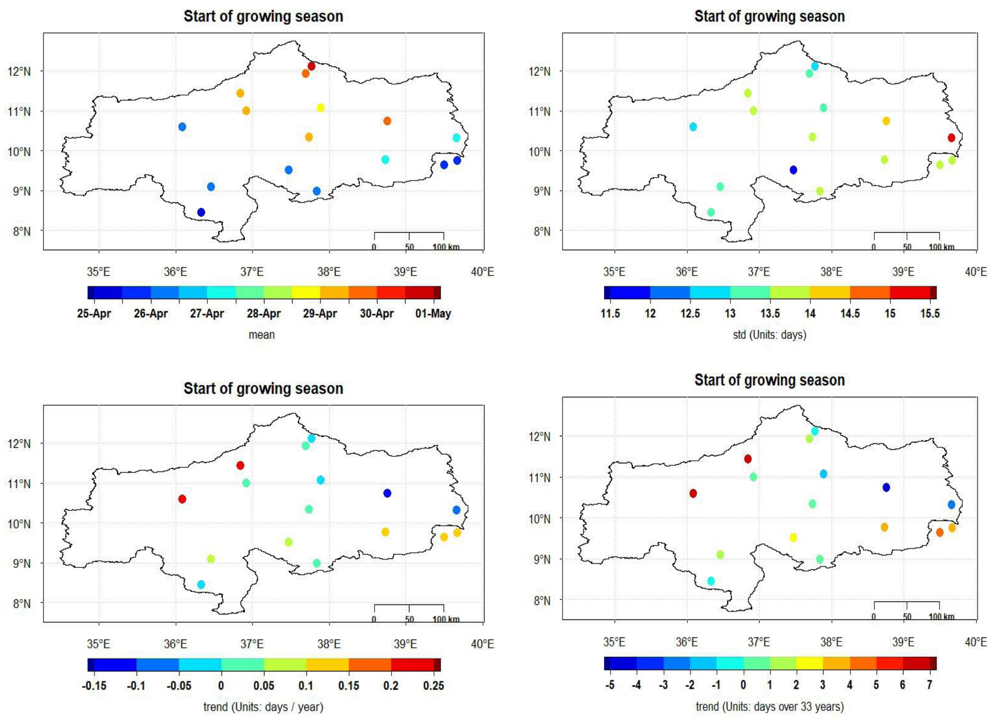

Figure 1: Mean (top left), standard deviation (top right) and trend (days/year, bottom left and days over study year (31 years), bottom left) of start of growing season over stations in the UBN basin

inhomogeneous structures in time series. The inhomogeneous structures are picked up by the SNHT at the beginning and/or near the end of the series. Numerous investigations can be used to determine the SNHT method's mathematical framework and specifics (see Alexanderson, 1986; Alexanderson and Moberg, 1997; Gonzalez-Rouco et al., 2001, and the references therein). The missing data has been filled using the Modified Shepard Interpolation Method (MSM), sometimes called Shepard's method (Malvić, 2020 & Shepard, 1986) at a 95% confidence level. MSM interpolation is a modification of the inverse distance weighted (IDW) approach with the goal of lowering the expressive local values (outliers, extremes) that could result in "bull-eyeing" or "butterfly shape" effects (Malvić, 2020). The mathematical formulations and further explanations about the MSM method are presented in (Malvić, 2020, and the references therein) [10].

The potential evapotranspiration (PET) has been calculated using a modified Hargrave's method (Droogers and Allen, 2002; Shah, 2022). This method uses rainfall and maximum and minimum temperatures to calculate evapotranspiration. The basic mathematics and extra explanations are presented in Droogers and Allen (2002), Shah (2002), and references therein.

Similarly, the water balance of the soil in the study area has been undertaken using precipitation and PET data using the soil water retention capacity of 100 mm as recommended by the FAO (1978) [11].

Climate data tool (CDT)

Climate Data Tool (CDT) is an open-source, R-based software package that runs under multiple operating systems and has an easy-to-use graphical user interface (GUI). It is an easy-to-use and friendly tool for performing different tasks, especially preparing for 24 national meteorology stations (NMS) in Africa (primarily), Asia, and Latin America [12]. This tool was developed by the International Research Institute (IRI). After extensive development for about five years, it has now become a powerful, dynamic, intuitive, and user-friendly tool (Dinku et al., 2022). For this particular study, the analysis (filling in missing data, outlier checking, and calculations of indices of GS and so on) and graphical visualizations have been performed using CDT [13] (Table 1).

Methods of determining onset, end and length of growing season

Segele and Lamb (2005) come to the conclusion that regionally specified onset and cessation definitions are necessary over Ethiopia due to the country's complex orography and significant variability. According to Liebmann et al. (2012), rainfall is the primary climate variable used to establish the parameters of GS in nations like Ethiopia. Based on this, the starting date for wetter areas is the day that the 3-day accumulated rainfall over the subsequent five days is greater than 20 mm, provided that there are no dry spells lasting longer than 7 days within the following 21 days. Due to the mono-modal rainfall pattern-long rains from April to September-that the study region exhibits, the earliest planting date was set at April 1. The 0.85 mm daily criterion for precipitation was established. The beginning of the growing season was therefore decided to be the first time after April 1 that at least 20 mm of rain fell over a three-day period [14]. Experimental results validated the choice of 50% PET as the threshold for water availability because serious crop water stress occurs when available water is less than 50% of what is needed (0.5 PET). The minimum amount of precipitation required on a particular date of onset should therefore be at least equal to that date's PET (Edao, 2018).

The end of the growth season (EGS) was determined by the relationship between rainfall and potential evapotranspiration. According to Edao (2018), FAO (1978), Stern et al. (1982), and Traoré et al. (2000), the end of the season occurs simultaneously with the end of the wet season plus the amount of time required evaporating 100 millimetres of soil water that had been stored. When it was humid, the PET in the study areas was lower than the amount of rain. Soil water that was saved in excess could have been used to prolong the growing season, either past the end of the rainy season or during the growing season itself. After September 1st, it was believed that the rainy season had ended when the 5-day total rainfall was less than 0.5 of the PET [15].

The length of the growing season over the UBN basin within the study period has been found by subtracting the start of growing season with its corresponding end of growing season.

Station-wise anomalies in the beginning, end, and duration of the growing season over the UBN basin from 1987 to 2018 were estimated to look into shifts in the timing of the observed GS parameters. Positive anomalies suggest later dates or more days in the year (length). Then, we divided anomalies in growing season length, beginning, and end into two groups: (1) years with growing season advances and/or rises and (2) years with growing season delays and/or decreases. Additionally,

Table 1: Description of meteorological stations used in the stud.

Station ID	Name	Longitude	Latitude	Altitude	Data Period	Percentage of available data
GNADDI13	Addis Zemen	37.7731	12.12	1984	1987-2018	87.44
SHAMBO11	Ambo	37.8397	8.985	2067	1987-2018	80.09
ILBEDE11	Bedele	36.3333	8.45	2011	1987-2018	89.45
GOBULL11	Bullen	36.082	10.6	1450	1987-2018	82.38
GODANG11	Dangila	36.846	11.43	2116	1987-2018	94.72
SHDEBR11	Debre Birhan	39.5	9.633	2750	1987-2018	94.1
GODEBR12	Debre Markos	37.7392	10.33	2446	1987-2018	96.88
GOENJA14	Enjibara	36.9193	11	2568	1987-2018	94.22
SHFICH11	Fiche	38.7333	9.767	2784	1987-2018	96.7
SHMEHA11	Mehal Meda	39.6603	10.31	1987	1987-2018	87.06
WOMEKA11	Mekane Selam	38.7567	10.74	2600	1987-2018	82.38
GOMOTT11	Motta	37.89	11.07	2417	1987-2018	87.3
WENEKE12	Nekemte	36.4633	9.083	2080	1987-2018	86.94
GNWERE13	Wereta	37.6958	11.92	1819	1987-2018	87.65
SHGUDO13	Gudoberet	39.6667	9.75	2600	1987-2018	93.17
WECOMB13	Combolcha	37.4727	9.502	2341	1987-2018	80.07

for a comparable research period, the climatological mean, standard deviation, and trend (trend in days/year and days over 33 years) were computed throughout the entire study area [16].

Results and Discussion

Start, end and length of growing season over UBN basin

Start of growing season: The investigation of rainfall, minimum and maximum temperatures across the UBN basin revealed that more than four stations had the earliest GS starts in the years 1987, 1997, 1993, 2004, 2008, and 2014. The earliest beginnings were made 3 to 12 days (April 4 to April 13) before the reference day of April 1. On some sites, the latest start of the GS was also determined: 52–58 days late from the reference day in the years 1991, 2002, 2009, and 2018 [17].

The outcome also demonstrates that SGS had significant year-to-year variability on a single station as well as between stations on a given year. There were notable differences in SGS from the rest areas in Dangila and Bullen in 1989, Addis Zemen in 1997, Mekane Selam in 2007, Addis Zemen, Dangila and Wereta in 2011, and Gudoberet in 2016. In the years 1997, 2006, 2009, 2011, and 2006, stations showed a substantial variance in SGS.

The earliest dates when the growing season began with 25%, 50%, and 75% probability were 03 May (Bedele, Bullen, and Combolcha), 23 April (Bedele and Bullen), and 11 April (Debre Birhan). On the other side, the growing season has recently begun with 25%, 50%, and 75% chance on dates of 08 May (Addis Zemen, Enjibara, Mekane Selam, and Wereta), 02 May (Addis Zemen), and 22 April (Addis Zemen, Mekane Selam, and Motta). In general, 25%, 50%, and 75% of the dates that the growing season is likely to begin represent the potential late, typical, and early dates in each site in the UBN basin, respectively [18].

End of growing season: The earliest ending of GS was made over Gudoberet in 1997 (177 days from April 1). Over all stations in 2000, over Bullen and Dangila in 1997, and over Bedele in 2001 (212 days from April 1st), the late EGS has been estimated. Early ending of the growing season has been computed for 1994, 1995, and 1997 throughout the majority of the research region, while the late ending of the growing season has been calculated for 1989, 1997, 1998, 1999, 2000, 2001, 2009, 2013, and 2018. EGS has also varied greatly between and within sectors within a single year. In 1997, the largest fluctuation in EGS was computed at 35 days. Additionally, there was a notable change between 1989 and 2001 [19] (Table 2).

The UBN basin had a 25%, 50%, and 75% likelihood that the growing season will conclude between October 18 and 26, October 9 and 16, and October 5 and 9, respectively. According to the aforementioned likelihood percentages, there are eight, seven, and four days between the earliest and latest finish dates for the growing season in the UBN basin, respectively. The likelihood of the growing season beginning at the earliest possible time and ending at the latest possible time had an impact on this probability, and vice versa. These 25%, 50%, and 75% odds of exceeding the end of the growing season represent the region's late, typical, and early end dates, respectively [20,21].

Length of growing season: In the UBN basin, the LGS ranged from 127 days at Nekemte in 2002 to 206 days at Bullen and 205 days at Dangila in 1997. Intriguing differences in LGS between regions have been calculated in 1989, 1991, 1997, 2006, 2007, and 2009. In addition, extended growth seasons have been computed for the years 1987, 1989, 1997, 2000, 2004, and 2014, whereas short growing seasons have been identified for the years 1989, 1991, and 2002. The findings clearly demonstrate the need for caution when planting in such a variable pattern of LGS days, where various cultivars require various day lengths and amounts of rainfall for optimal development [22,23].

There was fluctuation in LGS between stations in addition to year-to-year variation within a station. In a single year, significant differences in growth timing have been seen between various stations. For instance, a notable variance in the length of the growing season has been observed among stations for the years 1997, 2001, 2006, 2007, and 2009. As a result, the UBN basin saw both temporal and spatial changes in LGS between the years 1987 and 2018 [24].

Over the UBN basin, it was determined that there was a 25%, 50%, and 75% chance that the lowest growing season days would be exceeded. This equates to 178, 161, and 152 days, respectively [25]. The greatest durations of the growing season across the research region, however, were 188 days with a 25% chance, 174 days with 50% probability, and 165 days with 75% probability. The earliest possible commencement and/or latest probable finish dates led to the shortest and longest probable days of LGS, respectively. For instance, late starts-08 May

Table 2: Different stations in the UBN basin experienced early (75% likelihood of exceeding), normal (50%) and late (25%) onset and cessation dates as well as long (25% probability of exceeding), normal (50%) and short (75%) lengths of the growing season (days)

Station ID	25%(Late)			50%(Normal)			75%(Early)		
	Start	End	Length	Start	End	Length	Start	End	Length
GNADDI13	8-May	22-Oct	178	2-May	12-Oct	161	22-Apr	8-Oct	157
SHAMBO11	4-May	22-Oct	184	25-Apr	12-Oct	170	16-Apr	7-Oct	162
ILBEDE11	3-May	25-Oct	184	23-Apr	14-Oct	174	16-Apr	8-Oct	165
GOBULL11	3-May	26-Oct	188	23-Apr	16-Oct	174	16-Apr	9-Oct	162
GODANG11	6-May	25-Oct	184	1-May	14-Oct	166	19-Apr	9-Oct	158
SHDEBR11	4-May	18-Oct	181	26-Apr	10-Oct	167	11-Apr	6-Oct	159
GODEBR12	7-May	22-Oct	180	30-Apr	12-Oct	167	19-Apr	7-Oct	160
GOENJA14	8-May	23-Oct	181	1-May	14-Oct	168	20-Apr	7-Oct	160
SHFICH11	4-May	18-Oct	180	29-Apr	10-Oct	167	16-Apr	6-Oct	160
SHMEHA11	6-May	18-Oct	179	26-Apr	9-Oct	166	12-Apr	5-Oct	156
WOMEKA11	8-May	18-Oct	180	30-Apr	10-Oct	164	22-Apr	6-Oct	152
GOMOTT11	6-May	21-Oct	178	30-Apr	11-Oct	165	22-Apr	7-Oct	158
WENEKE12	4-May	24-Oct	184	25-Apr	14-Oct	172	18-Apr	8-Oct	162
GNWERE13	8-May	22-Oct	180	1-May	12-Oct	164	20-Apr	8-Oct	157
SHGUDO13	5-May	18-Oct	180	25-Apr	10-Oct	167	13-Apr	5-Oct	158
WECOMB13	3-May	22-Oct	181	26-Apr	13-Oct	169	19-Apr	8-Oct	162

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with a 25% probability and 02 May with a 50% probability-and comparatively early endings result in Addis Zemen's shortest LGS. As a result, the chance of lengthening was influenced by comparatively earlier starts and later endings, whereas the probability of shortening was influenced by substantially later starts and earlier finishes. The longest, average, and shortest lengths are generally represented by the 25%, 50%, and 75% odds of exceeding the LGS, respectively.

Climatology of start, end and length of growing season

Start of growing season: For the beginning of the growing season, the climatological analysis, including mean, standard deviation, trend, and anomaly, has been made. In the western, southern, and south-eastern regions of the UBN basin, the climatological mean starting dates of the growing season were April 25 and 26. The typical beginning of the growing season has been seen between April 29 and May 1 in the northern and central regions of the UBN basin. On the other hand, in the eastern and southern-eastern regions of the research area, April 27 marked the average beginning of the growing season. Additionally, the GS begins in the northern and central portions of the UBN basin later than it does in the other sections of the study area. The spatiotemporal mean of Kiremt began on April 25 between 1952 and 2004 in the area, according to Mellander et al. (2013) (Figure 1).

The values of standard deviation for SGS fall in the range suggested by Reddy et al. (2008). Hence, we can say that SGS is stable in the study area over the study period, though relatively high variability of SGS has been seen around the eastern part and relatively low variability around the southern part of the UBN basin (Figure 2).

Regarding the SGS trend, the bottom left panel shows that the yearly change in SGS, which varies between -0.15 and 0.25 days each

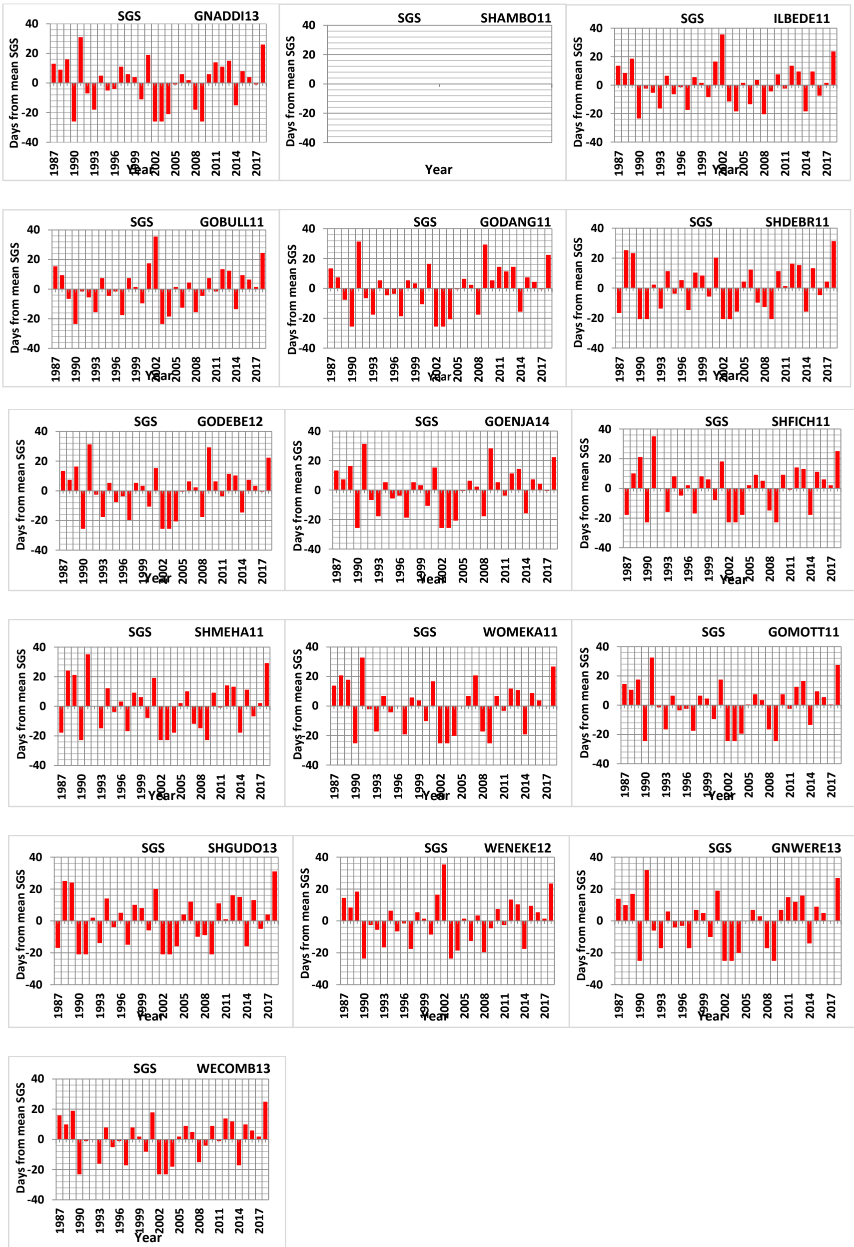

Figure 2: Anomaly bars of the start of growing season for each station in the UBN basin. The code at the right corner of panels refers to the stations' ID.

year, is insignificant. There is basically no SGS trend visible on various southern, middle, and northern parts of the UBN basin. Certain positive and negative trends have been observed in the UBN basin's northwest and east, respectively. The outcome of the standard deviation is consistent with the SGS's stability, emphasizing how planting days stayed basically constant over time. According to the other trend that was estimated, the beginning of the growing season varied by -5 to 7 days over the course of the entire study period, or approximately 12 days. Both strong positive and powerful negative trends have been observed in the UBN basin's northwest and east. SGS has been observed to be expanding and contracting in opposite directions from east to west, above and below 100 N.

Strong positive SGS anomalies of varying magnitude were seen on practically all of the stations in 1989, 1991, 2001, and 2018. Strong positive anomalies have also been seen in 1988, 2002, and 2007 at various sites in the UBN basin, where a pentad trend is likely. The years 1993, 1997, 2004, 2008, and 2014, on the other hand, regularly exhibit substantial negative anomalies at stations of varying size. The years 1987 and 2000 also exhibit substantial negative anomalies at several locations. The overall anomaly analysis of SGS reveals that negative lags behind positive, indicating that the growing season began earlier than usual in most years. The variability of the start of growing season is due to the high variability of rainfall during the autumn (Belg in Amharic) season relative to the summer (Kiremt in Amharic) (Bayable et al. 2021) [26].

The end of the growing season is often measured climatologically between the dates of 12 and 18 October. The growing season finishes in the eastern portions of the UBN basin on average around October 12, but it does in the southern, western, and northwestern portions on average between October 16 and October 18. On average, the growing season ends in several central and northern regions between October 13 and October 15. According to this data, the eastern portion of the UBN basin was where the GS ceased the earliest relative to the other regions.

The eastern and western portions of the UBN basin exhibit considerably higher EGS variability than the remainder of the basin, as can be seen in the top right panel. We can state that the EGS over the UBN basin is stable and determinable since the values of the EGS standard deviation fall within the stable zone as suggested by Reddy et al., (2008).

EGS trends over the UBN basin were shown in the bottom left and right panels as trends in days/year (left) and days over 33 years (right) (right). The trend in days/year indicates little annual variation in EGS. It fluctuates between -0.12 and 0.08 days annually. Positive trends have been seen throughout the northern half of the UBN basin, but negative trends have been seen around the southern and western regions. A few areas in the south, west, and north-west exhibit a downward trend between -4 and -2. Over the research period, the eastern region exhibits essentially little trend. The area in the north, where the GS recently ends, has a favorable trend. Positive trend values indicate the latest end of the growth season, whilst negative trends indicate the earliest termination. As a result, during the research period, several areas in the south, west, and north-west of the UBN basin had an earlier end to the growing season. In contrast, a later finish to the growing season in the northern half of the UBN basin has increased the length of the growing season [27] (Figure 3).

Strong positive anomalies at the conclusion of the growing season were commonly seen in the years 1988, 1998, 1999, 2000, and 2018 at several sites, each time with a different magnitude. Over the research region, it appears that there is a decadal tendency toward the growing season concluding later. Additionally, substantial positive anomalies (late ending) were commonly seen across the research region by EGS in the years 1989, 2009, and 2013. In contrast, most of the stations in the research region exhibit large negative anomalies (early termination) for the EGS for the years 1989, 1994, 1995, 1997, and 2002, where a pentad trend is likely. At a few locations in the research region, 1995 also revealed a significant negative anomaly (Figure 4).

The basin's climatologically average growth season lasts between 166 and 176 days, where, it was between 166 and 170 across the eastern,

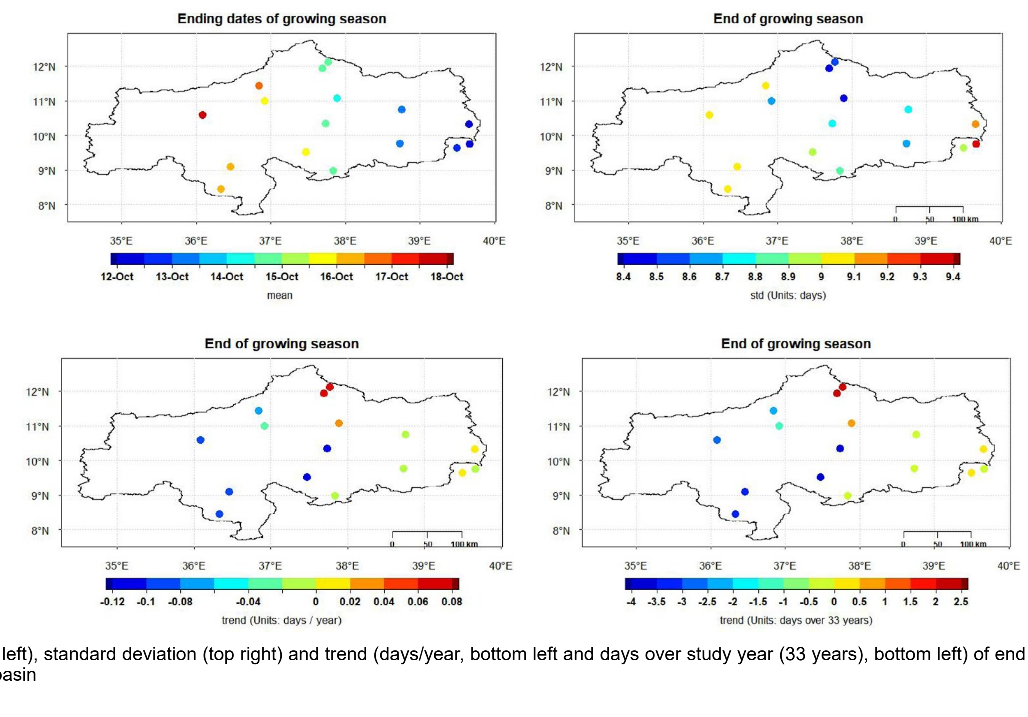

Figure 3: Mean (top left), standard deviation (top right) and trend (days/year, bottom left and days over study year (33 years), bottom left) of end of growing season over stations in the UBN basin

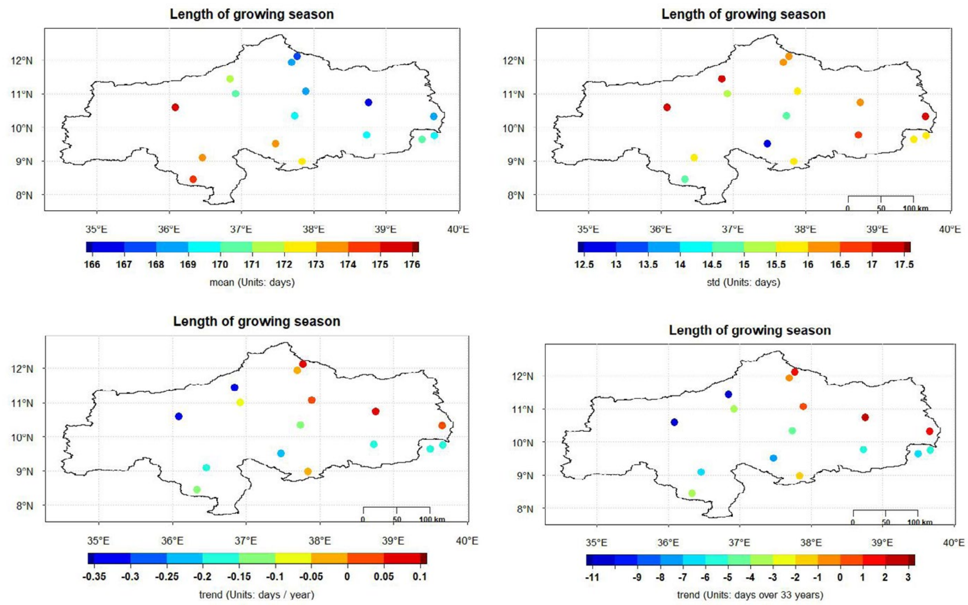

Figure 4: Mean (top left), standard deviation (top right) and trend (days/year, bottom left and days over study year (33 years), bottom left) of length of growing season over stations in the UBN basin.

some central and northern sections of the UBN basin, and between 172 and 176 around the western and southern parts. The research demonstrates that the growing season's climatological mean length progressed toward the western portion of the study region.

The average length of the region's summer rainy season shrank to two months between 1979 and 2014, according to a research by Zeleke and Damtie (2017), while substantial variability was seen over the western areas in spring and over the southern regions in summer.

In the research region, the length of the growing season varies from the climatological mean LGS by 12.5 to 17.5 days, with variations in magnitude at different sites. It is important to exercise caution when planting cultivars that need varying growth lengths since the LGS exhibit very significant variability in practically every section of the study area. The climatological standard deviation of the LGS is within a steady range, however, similar to that of the SGS and EGS.

The climatological trend of LGS over the region spans between -0.35 and 0.1 and -11 and 3 for the trend in year/days and days over 33 years, respectively, as can be seen in the bottom left and right panels. Over some eastern, north-eastern, and northern areas of the UBN basin, a positive trend of LGS on a year/days basis has been noted. Similar to other locations, the remainder exhibit a negative trend based on trend research. The similar manner has been seen with reference to the trend in days across the 33-year research period [28].

Some eastern, north-eastern, and northern regions exhibit positive trends lasting up to three days, whereas the remaining regions exhibit negative trends lasting up to seven days during the research period. Over the western and northern portions of the UBN basin, the growth season has been cut by more than a week. On the other hand, the LGS has grown by around three days during a 33-year period in locations where a positive trend has been seen.

On the years 1993, 2000, 2004, and 2014, strong positive anomalies in the length of the growth season (long days) over the study region were seen at all the stations. Several stations across the UBN basin reported high positive anomaly years in 1987, 1989, 1992, 2006, and 2008. On the other side, significant LGS (short days) negative anomalies have been noted since 1989, 1991, 1994, 2001, 2012, and 2015. Strong negative anomalies were also reported in 2002 and 2009. The strongest negative anomaly of LGS days was seen in various stations in the years 1989, 1991, and 2002. Growing seasons were lengthy in years where positive anomalies were observed and brief in years where negative anomalies were seen. Over the research region and during the study period, the length of the growing season has varied from year to year [29].

Conclusion

Crop yield and output are significantly impacted by climate variability, especially variations in rainfall. The poor crop yield in the rain-fed agricultural system is closely correlated with the irregularity in the onset, timing, and spatial spread of rainfall. Unpredictable rainfall patterns, unusual occurrences in sufficient amounts, and delayed planting dates all reduce crop yields. Knowing when the rainy season will begin, finish, and last is essential for crop planning, selecting the best crop varieties, and developing compressive techniques for effective rainwater management. Farmers can select the ideal crop for their region if they are informed of the start and end dates of the GS. Studying the GS parameters is crucial in this respect because crop planning and water resource management depend on rainfall in places like Ethiopia. Data on the start and end of the main rainy season may be crucial for planning agricultural activities, particularly when deciding when to prepare the ground for planting. While changes in the seasonality of rainfall (onset and cessation) have received less attention despite being a factor in the timing of cropping calendar activities, the majority of studies conducted in the UBN basin concentrated on rainfall and temperature trends as well as hydrology. The evaluation of the start, finish, and length of the growing season was the main goal of this research. Additionally, proper consideration has been made to the climatology of the GS parameters over Ethiopia's upper Blue Nile basin.

The findings indicate that there is no consistency over time in the temporal and spatial variability of the beginning, ending, and length of the growing season over the UBN basin. This necessitates careful consideration, particularly on the part of agricultural experts and other organizations working to advance agriculture and ensure food security. Future forecasts of the growing season for the entire study area or specific portions of it will use the findings of this research as a benchmark. This will make it easier for farmers and other interested parties to choose the best crop variety, use water resources efficiently, time their planting, and other important decisions.

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