



Climate change posed agricultural drought and potential of rainy season for effective agricultural water management, Kesem sub-basin, Awash Basin, Ethiopia

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Abstract

The Intergovernmental Panel on Climate Change concluded that climate has changed over the past century and the trend is anticipated to continue in the future. This study examines climate change posed drought and potential of rainy season rainfall in Kesem sub-basin. Rainfall variability is examined using statistical descriptors. Also, the onset and cessation dates, length of growing season, and probability of dry and wet spell are analyzed using INSTAT Plus software. On the other hand, long-term drought is analyzed using reconnaissance drought index. Rainfall variability result showed high coefficient of variance (CV) of 46.8 to 179.2% on monthly and 39.1% on annual basis. The mean duration of the main rainy season is 91 days with standard deviation of 18.5 days and CV of 20.4%. The probability of dry decade in the main rainy season is more than 50% for the 16th to 18th and 25th to 27th decades. Whereas probability occurrences of dry decades preceded by dry decades were more than 50% for decades 16th to 18th and 23th to 27th. Potential evapotranspiration showed increment of 25.9 mm from the base period for RCP 4.5 (2020) and 26.7 mm for RCP 8.5 (2020), and 55 mm for RCP4.5 (2050) and 56.8 mm for RCP8.5 (2050). Regarding the long-term drought, there were 9.7% extreme, 6.5% severe, 3.2% moderate, and 48.4% mild drought on the basis of observed data. The inter-annual variability of growing seasons, probability occurrence of dry decade, and drought during growing season are revealed. So, policymakers need to consider supplementary irrigation for crops in the area because there are high probability occurrences of dry decades.

1 Introduction

Currently, the Intergovernmental Panel on Climate Change (IPCC) concluded that climate has changed over the past century and the trend is anticipated to continue in the future (Seneviratne et al. 2012). Even under conservative scenarios,

future climate changes are likely to increase with mean temperature of 2–4 °C globally (IPCC 2007). This change poses drought, reduction of rainfall potential, and then loss of agricultural productions (Kumar et al. 2010; Feyssa and Gemedo 2015).

Most of East African countries (Burundi, Eritrea, Ethiopia, Kenya, Uganda, Tanzania, Rwanda, and Somalia) are the most vulnerable to the effects of climate change, climate variability, and drought due to their dependency on rain-fed agriculture (IPCC 2007; Kotir 2011). Particularly, Ethiopia is one of the most susceptible countries to the impacts of climate variability and change (Slingo et al. 2005; Challinor et al. 2007; Thornton et al. 2011). Viste et al. (2013) reported that all zones in Ethiopia experienced some degree of drought annually during the last 10–15 years.

According to Desalegn et al. (2010), drought-affected Ethiopia in 1888 led to the historic deadly famine of 1888/1889. About 1/3 of the population died because of the famine and 90% of the animals perished. Then, the 1957/1958 drought led to famine in Tigray region and the 1972/1973 famine caused by drought took 200,000 lives in Wollo, and

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the 1984 drought in the latter area led to a 61% and 94% decline in the yield of teff and sorghum respectively, which are the two most important crops in the country. Although less serious, significant droughts occurred in the years 1987, 1988, 1991–1992, 1993–1994, 1999, and 2002.

The populations living in drylands are the worst affected due to climate change–related impacts. Thus, of the basins in Ethiopia, Awash is the most vulnerable to climate change and variability impacts (Hirut and Kindie 2015; Tsegaye et al. 2015; Daniel et al. 2017). Drought affects the environmental and socio-economic conditions causing children malnutrition, starvation, migration, and livestock demise, as well as degradation of natural resources in the basin (Desalegn et al. 2010). In the basin, severe droughts have led to the deterioration of crop yields and death of livestock; it also radically increased the proportion of food-insecure households (Conrad et al. 2010).

In the Awash basin, the Kesem sub-basin has good agricultural and pastoral activities (CSA 2011), which are being worsened by the variability and change of climate and decline of potential of rainy seasons. The investigation of potential of rainy season's rainfall for agricultural productions includes the trend, start and cessation, length of the rainy season, variability and distribution of the rainfall, and the extent of dry and wet spells during the rainy season (Hirut and Kindie 2015; Sifer et al. 2016).

Definition of rainy season onset/cessation is versatile. For instance, agro-climatologists usually define the onset at the rain gauge scale, using a variety of empirical thresholds (Stern et al. 1981; Sivakumar 1988). These authors considered that the rainy season onset is the first wet day of a spell receiving a given rainfall amount and not followed by a long dry spell during subsequent weeks. The rainfall thresholds are determined empirically in order to fit the requirements of a given crop and are adjusted to local-scale climatic conditions (Stern et al. 1981; Sivakumar 1988).

Likewise, the definitions of dry and wet spells are different things to different people. Many researchers define a dry spell as consecutive days without appreciable rainfall (Ceballos et al. 2004; Gong et al. 2005). Ochola and Kerkides (2003) defined critical dry spell as the longest duration of dry days while the critical wet spell as the longest duration with uninterrupted rainfall. Reddy (1990) defined dry day as the rainfall below 3 mm per day. This definition is the most pertinent for agriculture because a rainfall of 3 mm is considered as the threshold water value that crops need per day (Sifer et al. 2016).

Similarly, agricultural drought is defined as the decline in the productivity of crops and pastures due to spatio-temporal irregularities in the rainfall as well as decrease in the soil moisture and likely increase in potential evapotranspiration (Sruthi and Aslam 2014). Many researches were carried out to investigate the characteristics and

variability of Ethiopian rainfall (e.g., Conway et al. 2004; Seleshi and Zanke 2004; Woldeamlake and Conway 2007; Wing et al. 2008; Kassie et al. 2013; Degefu and Bewket 2013; Mengestu et al. 2014; Solomon et al. 2017; Daniel et al. 2017). The rainfall having a coefficient of variation greater than 30% is considered to be highly variable (Araya and Stroosnijder 2011; Kisaka et al. 2015; Mehari et al. 2017).

In another way, in dryland areas like Kesem sub-basin in middle Awash, where there is a deficiency in rainfall, in contrast to this, there is huge loss of water through potential evapotranspiration which is the main cause of drought. Therefore, estimation of potential evapotranspiration during rainy season has a significant implication on the potential of agricultural production seasons and severity of agricultural drought.

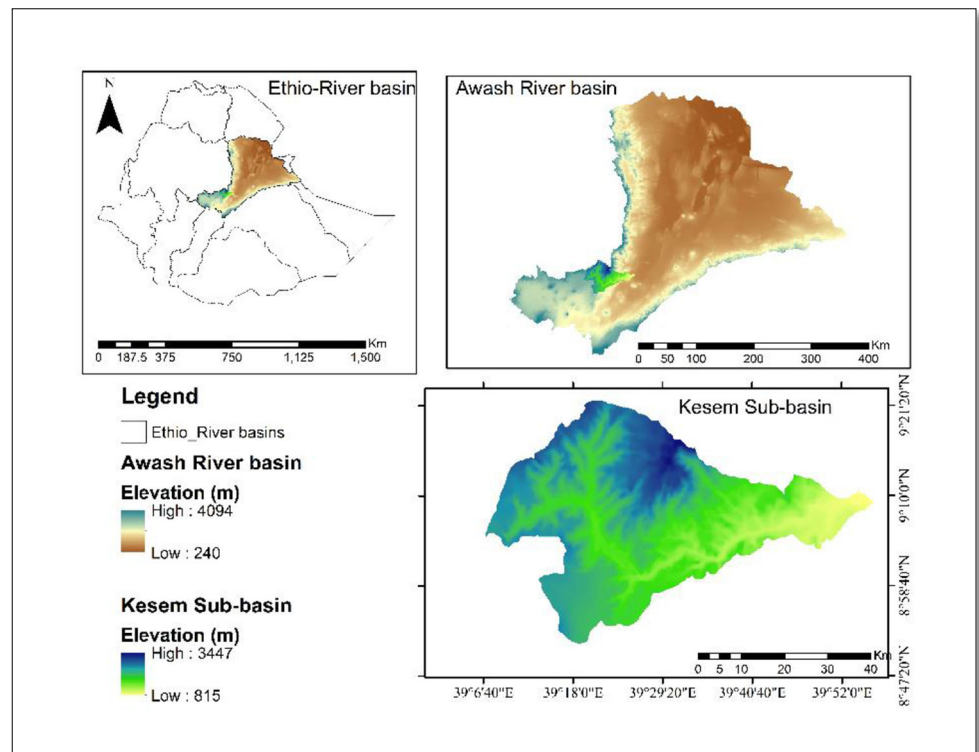
Lack of good agro-climatic information like the start and end of rainy season and drought occurrences affects agricultural productivity in Ethiopia. So, the analysis of potential of rainy season by determining the reliable start and end dates, length of the season, estimation of dry and wet spell extents during the season, and rainfall characteristics are vital for planning agricultural activities, determining a less risky planting date, less risky crop varieties, and reduce crop failure. Hence, this study attempts to examine the rainfall variability and agricultural drought under changing climate condition in the Kesem sub-basin.

2 Materials and methods

2.1 Description of the study area

In middle Awash River basin, Kesem sub-basin is situated in the longitudes of 39° 9' 36" to 39° 52' 48" E and latitudes of 8° 55' 12" to 9° 12' 36" N in the Eastern part of Ethiopia. Its area is about 2325 km² (Fig. 1). It is surrounded by mountains and plateaus in the northern part. Higher mountains exist at the upper margin and low landform at the lower margin. The altitude ranges from 815 to 3447 m above mean sea level. According to the USDA soil classification system, six soil types are identified in the sub-basin namely chromic luvisols, eutric cambisols, eutric leptosols; eutric vertisols, lithic leptosols, and vertic cambisols. The lithic leptosols occupy the steep mountainous slopes while eutric cambisols and vertic cambisols are situated on flat and gentler slopes. The climate system of the sub-basin is characterized by a semi-arid to sub-humid with majority falls in sub-humid zone in the northern and northwest and at semi-arid in the north and southeast, receiving a mean annual rainfall of 1009 mm and 534 mm respectively. The mean annual maximum and minimum temperatures are 26.8 °C and 10.56 °C, respectively.

Fig. 1 Location and elevation map of study area



2.2 Data collection

2.2.1 Primary data

For the purpose of the primary data collection, about 700 households in the catchment were invited to respond to the focused group discussion regarding the variability of the climate in the last 30 years. Households with members older than 30 years were purposively invited believing that they could know and remember about the past 30 years' climate of the catchment. We compared our analyzed information with one obtained from the respondents to make our finding more reliable.

2.2.2 Secondary data

Meteorological data Observed meteorological data (rainfall and temperature) were collected from the Ethiopian National Metrological Agency (NMA). A summary of the stations with years of record and percentages of the missing data which are filled and later used in the study are given in Table 1.

Future scenario weather generation For future climate projection, even though there are several local climate data downscaling techniques, most recently, the GCM running MarkSim is found to be better and used in many operations particularly in Africa and Latin America. It divides the world into 720 clusters of climate that are distinct from one another and fits a third-order Markov model to the rainfall data, the temperature data simulation is derived from SIMMETEO (Geng et al. 1988). Concerning the bias correction, it is already bias corrected to WorldClim.v1.3 using the delta bias correction method (Jones and Thornton 2013), which needs to be done manually while using other downscaling techniques. It requires only geographical location (latitude and longitude) to generate daily future weather data for a given site.

Currently, 17 global climate models (*BCC-CSM 1.1*, *BCC-CSM 1.1(m)*, *FIO-ESM*, *GFDL-CM3*, *GFDL-ESM 2G*, *GFDL-ESM 2M*, *GISS E2-R*, *HadGEM2-ES*, *IPSL-CM5A-LR*, *IPSL-CM5A-MR*, *MIROC-ESM*, *MIROC-ESM CHEM*, *MIROC-ESM MIROC5*, *MRI-CGCM3*, *NorESM1-M*, *CSIRO-Mk3.6.0*) are operating on it; hence, the ensemble

Table 1 Summary of the metrological stations

S.N	Station name	Latitude (°)	Longitude (°)	Altitude	Period	Missed (%)	Remark
1	Shola Gebeya	9.21	39.55	2500	1984–2014	3.38	Filled
2	Awara Melka	9.17	39.88	960	1984–2014	5.63	Filled
3	Arerti	8.92	39.42	1806	1984–2014	9.83	Filled
4	Aleltu-Agriculture	9.21	39.16	1977	1984–2014	0.36	Filled

average of the 17 GCMs atmosphere-ocean climate models had been used for RCP 4.5 and RCP 8.5 emission scenarios for two time slices of future period 2020 (2015–2044) and 2050 (2045–2075). Therefore, for the current study, future scenario weather data were downloaded from web-based software tool by applying the aforementioned climate models accessed from <http://gismap.ciat.cgiar.org/>.

2.2.3 Preprocessing of data

In order to make the data amenable to further analyses, missing values were filled using first-order Markov chain model with the aid of INSTAT plus V 3.37 (Stern et al. 2006). The consistency and homogeneity of rainfall were checked using double mass curve technique (Subramanya 2008) and Standard Normal Homogeneity test method respectively in XLSTAT 2019 software.

2.2.4 Data summary

After the preprocessing stage, the meteorological data are organized on daily basis at each station. The daily basis precipitation at each station was transformed into areal rainfall based on Theissen polygon method. Then, the areal rainfall (rainfall of the catchment) and daily maximum temperature (Tmax) and minimum temperature (Tmin) at the stations were averaged on monthly basis for base and future periods using Pcp STAT program package. The Tmin and Tmax were first used for computation of PET at each station and the PET of each station was transformed into areal PET based on Theissen polygon technique. The areal rainfall data was organized on a daily basis for base period as per the format required by Instat statistical tool and used to determine the onset, offset, and length of rainy season and characterize the dry and wet spell. For the analysis of long-term drought conditions using RDI, the areal mean monthly precipitation and PET were used. The Tmin and Tmax of each station are transformed into areal using simple arithmetic average method and their changes at time slices were detected at the sub-basin level.

2.3 Estimation of potential evapotranspiration

Numerous methods were employed to estimate potential evapotranspiration. Haid et al. (2017) stated that in arid and semi-arid regions where temperature is the main factor for PET loss, the empirical methods are preferable for estimating PET. Also, in terms of the availability of data, these methods are the preferred methods. Despite the fact that these equations are shown by many researches to underestimate in some cases and overestimate in others, taking their average value is a retiring method (Haid et al. 2017). So, in this study, temperature-based computation of PET was undertaken through the empirical methods listed above with the aid of

DrinC software and then their average value was used for further analysis.

The equations are as follows: Eq. (1) Hargreaves, Eq. (2) Thornthwait, Eq. (4) Blaney–Criddle method.

$$PET = 0.0023 (T_m + 17.8) \left(\sqrt{T_{\max} - T_{\min}} \right)^{0.5} Ra \quad (1)$$

Where

T_m	daily mean air temperature (°C)
T_{\max}	daily maximum air temperature (°C)
T_{\min}	daily minimum air temperature (°C)
Ra	extra-terrestrial radiation ($MJm^{-2} day^{-1}$)

$$PET = 16 \times \left(\frac{N}{12} \right) \times \left(\frac{m}{30} \right) \times \left(\frac{T_m}{I} \right)^\alpha \quad (2)$$

Where N is the average monthly possible sunshine hour (hr/day), m is the number of days of each month, T_m is the mean monthly temperature (°C), and α is estimated as

$$\alpha = 6.75 \times 10^{-7} \times I^3 - 7.71 \times 10^{-5} \times I^2 + 1.79 \times 10^{-2} \times I + 0.49 \quad (3)$$

Where I is a heat index for the year calculated as:

$$I = \sum_{i=1}^{12} \left(\frac{T(i)m}{5} \right)^{1.514} \quad (4)$$

$$PET = k \times p \times f$$

$$f = (0.46 \times T_m + 8.13)$$

Where T_m is the average temperature (°C), k is a monthly coefficient representing consumption, p is the ratio of the mean number of daylight hours in a day for the specified month over the total of daylight hours in the year, which is a function of the latitude of the study area and the month required.

$$p = 100 * \left(\frac{\sum_{i=d_1}^{d_2} Ni}{\sum_{i=1}^{365} Ni} \right) \quad (5)$$

Where Ni is the theoretical number of daytime hours i , and d_1 and d_2 are the last days of the month.

2.4 Transformation of station rainfall and PET data into areal

Geospatial technique, Theissen polygon method is used to estimate areal rainfall and PET. Four stations of rainfall within or in the vicinity of the boundary of the catchment were used for rainfall and PET estimation. Thus, the study was undertaken at the sub-basin level, not at station level.

2.5 Rainfall variability

Several methods are employed to inspect the variability of rainfall. Among these, the statistical descriptors like the mean, variance, standard deviation, and coefficient of variations are the most common for decision making in agriculture (Araya and Stroosnijder 2011).

$$CV = \frac{SD}{\bar{X}} \quad (6)$$

Where CV is the coefficient of variation of rainfall of particular time, SD is the standard deviation of rainfall, and \bar{X} is the arithmetic mean of the rainfall.

2.5.1 Onset, offset, and length of rainy season

In the current study, the onset date of rainy season was defined as the first occasion that records 20 mm of rainfall amount or more occur over a 3-day period, and will not be followed by a period of more than 9 consecutive dry days in the following 30 days (Stern et al. 2006). The condition of having no dry spells of more than 10 days after the start of rainy season eliminates the possibility of a false start of the season (Stern et al. 2006). A period of 30 days is the average length for the initial growth stage of most crops (Allen et al. 2005). The cessation of the seasons was computed by considering maximum daily evapotranspiration of 5 mm and soil available water holding capacity of 100 mm/m of the plant available soil water (Girma 2005) and when the soil water balance reaches zero (Stern et al. 2006). This definition was applied by many researchers for instance Barron et al. 2003; Kassie et al. 2013; and Daniel et al. 2017.

Given the above definitions, Instat plus (Version 3.37) was used to analyze the daily rainfall data for start and end of rainy season. The acquired information was compared with local farmer experience and the proper onset and offset dates, and lengths of rainy season were recommended for the stakeholder in the area.

2.6 Dry and wet spell analysis

Daily rainfall data of the stations which are transformed into the areal rainfall of the catchment were fitted to the simple Markov chain model through Instat plus Version 3.37 to determine the probability of dry and wet spell. In each month, the first decade is the first 10 days and the second decade is the second 10 days and the third decade is the remaining days. Hence, the initial and conditional probabilities were estimated for the decades on the basis of the aforementioned per day crop water requirement threshold value which is 3 mm per day in the literature by (Reddy 1990) given that, a single decade contains ten (10) days, the summation of 3 mm for

10 days which is 30 (thirty) mm was considered as threshold value for each decade (Table 2). Thus, the decade whose summation is less than 30 mm of rainfall was considered as the dry decade and if it is above 30 mm, it was considered as wet decade. The distributions of the spells by lengths (or duration) are found to be geometric (Gabriel and Neumann 1957).

2.7 Application of drought index

Analysis of agricultural drought for both historical and future climate condition was undertaken by RDI based on 4 months time scale (JJAS). Long-term monitoring of soil moisture is a time and cost-intensive challenge. Therefore, drought indices are commonly used alternatives of periods of significant soil moisture deficit. However, the question remains whether soil moisture deficit can be adequately characterized using meteorological variables such as rainfall and potential evaporation, or whether a more physically based approach is required. For this question, the newly developed drought index, the RDI has an answer, without going for a more vigorous physically based approach; devoid of consuming energy, time, and cost, it can monitor a long-term soil moisture deficit by evaluating rainfall and PET during a particular season.

As stated by Tigkas et al. (2015) and Mishra and Desai (2006), agricultural drought is more noticeable if analyzed for crop growing period. It reflects a short- and medium-term soil moisture condition (WMO 2012; Lee and Kim 2012). So, in this study, agricultural drought was analyzed for the main rainy season (JJAS) due to shortage of short rainy season.

Reconnaissance drought index The formulation of reconnaissance drought index (RDI) passes through three phases. These are the initial, the normalized and the standardized values. In the current study, for the purpose of simplicity and comparability of the value, the standardized values of RDI were considered in the interpretation of the results. The formulations of the three phases are presented below.

The initial value (αk) of RDI is calculated for the i th year in a time basis of k (months) as follows:

$$\alpha k^{(i)} = \frac{\sum_{j=1}^k P_{ij}}{\sum_{j=1}^k PET_{ij}}, i = 1(1)N \text{ and } j = 1(1)k \quad (7)$$

In which P_{ij} and PET_{ij} are the precipitation and potential evapotranspiration of the j th month of the i th year starting usually from October as it is customary for Mediterranean countries and N is the total number of years of the available data. The values of αk follow satisfactorily both the lognormal and the gamma distributions in a wide range of locations and different time scales, in which they tested (Tigkas et al. 2015).

The second expression, the *normalized* RDI (RDIn) is computed using the following equation for each year, in which

Table 2 The formulations of Markov chain model

Formulations	Descriptions
$PD = \frac{FD}{n}$	Initial probabilities
$Pw = \frac{Fw}{n}$	Initial probabilities
$PWW = \frac{FWW}{FW}$	Conditional probabilities
$PDD = \frac{FDD}{FD}$	Conditional probabilities
$PWD = 1 - PDD$	Conditional probabilities
$PDW = 1 - PWW$	Conditional probabilities
$P(W = K) = (1 - P_1) P_1^{K-1}$	Wet and dry spell duration
$P(W > K) = (1 - P_1) P_1^K$	Wet and dry spell duration
$P(D = m) = P_0(1 - P_0)^{m-1}$	Wet and dry spell duration
$P(D > m) = (1 - p_0)^m$	Wet and dry spell duration

where

PD is the probability of a decade being dry

PW is the probability of a decade being wet

FD is the number of dry decades

FW is number of wet decades

PWW is the probability of wet decades preceded by another wet decade

FWW is number of wet decades followed by other wet decades

PDD is the probability of a dry decade preceded by another dry one

FDD is number of dry decade followed by another dry one

PWD is the probability of a wet decade preceded by another dry decade

PDW is the probability of a dry decade preceded by a wet one

k is wet spell duration, a sequences of “W” wet decades preceded and followed by dry decades (D)

m is dry spell duration, defined as sequences of “D” dry decades preceded and followed by wet decades

$P(W = K)$ is the probability of wet spell of length “ k ”

$P(W > K)$ is the probability of wet sequences with length greater than “ k ” (probability of exceedance)

$P(D = m)$ is the probability of a dry spell of length “ m ”

$P(D > m)$ is a dry sequence greater than “ m ” (probability of exceedance)

it is evident that the parameter αk is the arithmetic mean of αk values calculated for the N years of data.

$$RDIn(i) = \frac{\alpha k(i)}{\alpha k} - 1 \quad (8)$$

Since the *lognormal distribution* was applied for the current study, the following equation had been used for the calculation of the standardized RDI (RDIst).

$$RDIst^{(i)} = \frac{y^{(i)} - \bar{y}}{\sigma \hat{y}} \quad (9)$$

In which $y^{(i)}$ is the $\ln(\alpha k^{(i)})$, \bar{y} is its arithmetic mean and $\sigma \hat{y}$ is standard deviation. Positive values of RDIst indicate

wet periods, while negative values indicate dry periods compared with the normal conditions of the area (Table 3).

3 Results and discussion

3.1 Potential evapotranspiration

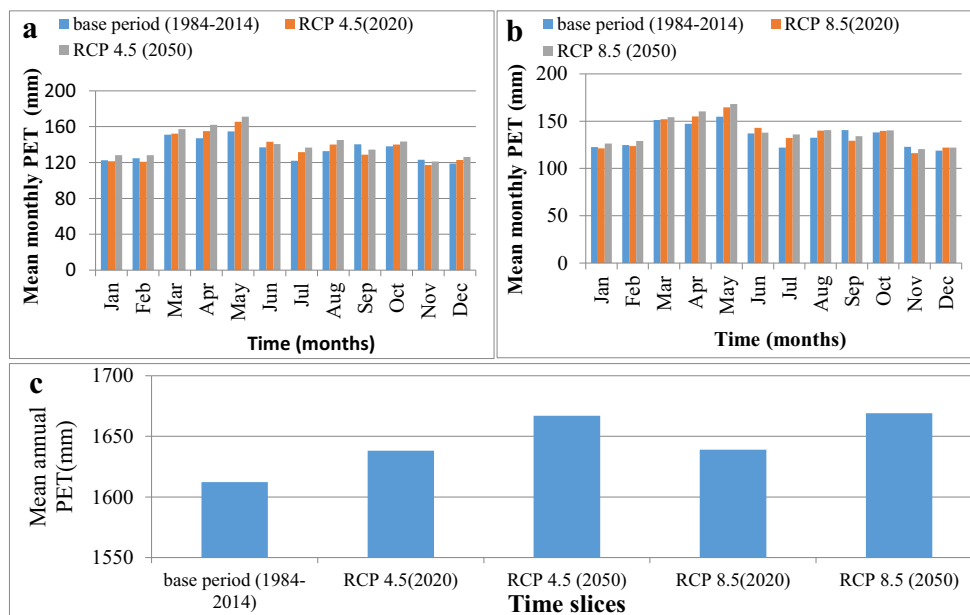
The result indicates that the mean annual potential evapotranspiration (PET) of 1612.2 mm, 1638.1 mm, 1667 mm, 1639 mm, and 1669 mm for baseline period (1984–2014), RCP 4.5 (2020) and (2050), and RCP 8.5 (2020) and (2050) respectively. There is increment of PET by 1.6% from base period to RCP 4.5 (2020) and by 1.67% to RCP

Table 3 Drought severity based on RDI values

Drought severity classification	Mild	Moderate	Severe	extreme classes
Corresponding values	> -1.0	-1.0 to -1.5	-1.5 to -2.0	< -2.0

Source: Tigkas et al. 2015

Fig. 2 Areal mean monthly PET of Kesem subbasin **a** base period (1984–2014), RCP 4.5 (2020) and (2050), and **b** base period (1984–2014), RCP 8.5 (2020) and (2050), **c** annual PET (mm) of all time slices



8.5 (2020), and by 3.4% to RCP4.5 (2050) and by 3.5% to RCP8.5 (2050). In general, it is observed that there is increment of PET in the study area for all the scenarios (Fig. 2). This result is analogous to Engida (1999), who reported the highly increasing PET over the northeastern and northwestern lowlands of Ethiopia. Furthermore, Taye et al. (2018) stated the likely increase in water deficiency in Awash basin due to increase in potential evapotranspiration in the future periods.

3.2 Rainfall variability

Based on observed data, the result illustrates the highly variable nature of the rainfall in the area having a CV of 46.8% (July) to 179.2% (December) on monthly and 39.1% on annual basis. Similar to these results, NMSA (1996) reported that the value of CV of rainfall varies from 10 to 70% in Ethiopia and even more than 70% in the low rainfall areas of the north, northeastern, and southeastern regions. This variability of rainfall in time and space makes its occurrence very difficult to predict and it is this spatio-temporal variation in the

rainfall distribution that creates serious problems like drought (Raiford et al. 2007) and crop failure. Minimum mean annual rainfall was observed in 2002, which was a year with severe drought. Large average monthly rainfall is observed during June, July, August, and September. These months are the main rainy seasons (JJAS). Peak rainfall is observed during July and August and, hence, excess rainwater can be stored in the form of ex situ and/or in situ conservation practices during these months. Average rainfall of main rainy seasons (JJAS) ranges from 175.5 mm (severe drought year) to 1267 mm (normal year) in the area (Table 4). Our survey (focused group discussion) result reveals that the temporal variability predominantly exists and affects agriculture than spatial variability in the area.

3.2.1 The onset, offset, and length of rainy season

The mean onset of main rainy season (JJAS) was during 169 DOY or the second meteorological decade of June (decade 17), the mean offset was during 260 DOY or the second meteorological decade of September (decade 26). Therefore, the

Table 4 Descriptive statistics of monthly rainfall base period (1984–2014)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Min (mm)	0	0	0	2.0	0	23.4	77.3	73.1	1.68	0.0	0.0	0.0	341.6 (2002)
Max (mm)	70	89.6	151.3	197.1	107.5	248.5	519.3	360.9	138	72.5	43.5	38.8	1755.2 (2013)
Mean (mm)	14	17.9	46.6	61.5	30.1	81.2	211.9	165.3	45.2	12.5	6.5	5.3	698.0
Std (mm)	16.1	19.8	40.3	44.5	29.7	56.7	99.3	68.9	32.5	16.7	11.7	8.5	273.0
Median (mm)	7.4	12	33.8	62.5	16.6	65.7	188.1	147.0	33.7	5.2	1.4	2.2	611.7
CV (%)	115.3	110.8	86.6	72.4	98.8	69.8	46.8	41.7	71.8	134.4	179.2	159.7	39.1
Slope (mm/yr.)	0.47	-0.02	1.84	1.33	-0.6	1.14	4.37	2.49	0.84	0.34	0.41	0.20	12.42

Table 5 The onset, offset, and length of rainy season of short rainy (FMAM) and main rainy season (JJAS) based on base period data

Main rainy season (JJAS)						Short rainy season (FMAM)			
Years	Onset (DOY)	Decade	Offset (DOY)	Decade	LRS (days)	Year	Onset (DOY)	Offset (DOY)	LRS (days)
1984	153	16	245	27	92	1984**	134	122	–
1985	178	18	266	27	88	1985*	118	146	28
1986	165	17	264	27	99	1986	57	122	65
1987	153	16	245	27	92	1987	56	122	66
1988	175	18	276	28	101	1988*	105	122	17
1989	178	18	245	27	67	1989	90	122	32
1990	170	17	245	27	75	1990*	108	122	14
1991	164	17	267	27	103	1991	63	122	59
1992	159	16	269	27	110	1992**	198	122	–
1993	154	16	262	27	108	1993*	99	122	23
1994	173	17	270	27	97	1994**	179	122	–
1995	179	18	256	27	77	1995*	100	122	22
1996	157	16	264	27	107	1996**	148	123	–
1997	153	16	245	27	92	1997	77	122	45
1998	166	17	280	28	114	1998*	107	122	15
1999	174	18	255	27	81	1999**	184	122	–
2000	175	18	266	27	91	2000*	116	128	12
2001	160	16	255	27	95	2001**	202	122	–
2002	197	20	246	27	49	2002**	208	122	–
2003	175	18	254	27	79	2003*	98	122	24
2004	163	16	245	27	82	2004*	96	122	26
2005	177	18	249	27	72	2005*	107	122	15
2006	176	18	259	27	83	2006	86	122	36
2007	165	17	245	27	80	2007**	169	122	–
2008	161	16	245	27	84	2008**	163	122	–
2009	182	18	245	27	63	2009	82	122	40
2010	185	19	269	27	84	2010	54	130	76
2011	170	17	284	28	114	2011*	111	122	11
2012	163	16	279	28	116	2012	82	123	41
2013	157	16	292	28	135	2013	72	152	80
Mean	169	17.1	260	27.2	91	Mean	72	126	54
SD	10.8	1.1	13.7	0.38	18	SD			16.4
CV (%)	6.4	6.3	5.3	1.4	20	CV(%)			30.5
Min	153	16	245	27	49				
Max	197	20	292	28	135				
Q1 (25th percentile)	160	16	245	27	80				
Q2 (50th percentile)	168	17	258	27	91.5				
Q3 (75th percentile)	176	18	269	27	103				

*Very short and intermittent shortrain

**Years with no short rainyseason

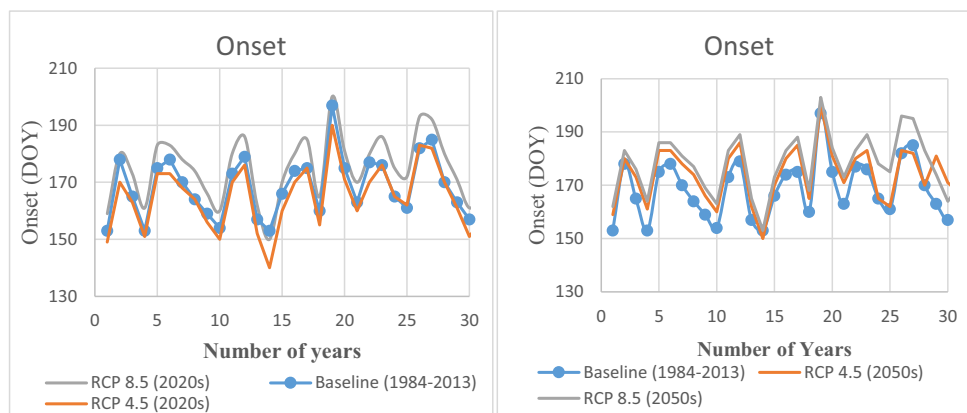
–No rainy season

duration of main rainy season (JJAS) is 49–135 days. The mean length of main rainy season is 91 days having standard deviation of 18.53 days and CV of 20.36%. This indicates the inter-annual variability of the onset and offset and length of the growing season. In line with this, Araya and Stroosnijder (2011) state that the major cause for failure of crops during rainy season is delaying of the start of the season.

Allen et al. (2005) stated that a period of 30 days is the average length for the initial growth stage of most crops. Therefore, for the short rainy season, omitting the years of no short rainy season and very short rainy season less than a month, the mean onset was during 72 DOY or the second meteorological decade of March (decade 8) and the mean offset was during 126 DOY or the first meteorological

decade of April (decade 13). Thus, the mean length of short rainy season was only 54 days having standard deviation of 16.54 days and CV of 30.5%. The result shows that short rainy season is not dependable in this area because over the base period, 66.67% (20 years) of the period was irregular short rainy season. Out of these 9 years, 30% of the period was with no short rainy season and 11 years (36.67%) of the period was with intermittent short rainy season (FMAM) (Table 5). Additionally, from our survey results, only 57% of the respondents responded that rainfall during short rainy season is liable for very early maturing crops and land preparation and 43% of them said it is not liable for any purpose. Thus, future climate impact assessment is done for the main rainy season.

Fig. 3 Projected change of onset (DOY) from the baseline for both RCP 4.5 and RCP 8.5 (all RCPS and baseline represent 30 years)



The mean onset of main season is during 169 DOY, 165 DOY, 174 DOY, 175 DOY, and 178 DOY as to base period, RCP 4.5 2020, RCP 4.5 2050, RCP 8.5 2020, and RCP 8.5 2050 respectively. Future scenario with respect to base period, the result shows increasing of DOY, which means late start of main rainy season except RCP 4.5 2020 (Fig. 3). Mean offset of main rainy season is during 260 DOY, 260 DOY, 258 DOY, 25 DOY, and 251 DOY as to base period, RCP 4.5 2020, RCP 4.5 2050, RCP 8.5 2020, and RCP 8.5 2050 respectively. Evaluating the periods, there is no recognized trend, which shows unstable cessation of rainy season in the sub-basin (Fig. 4).

The mean length of main rainy season is 91, 96, 84, 79, and 74 days as to base period, RCP 4.5 2020, RCP 2050, RCP 8.5 2020, and RCP 8.5 2050 respectively. Comparing future scenarios with baseline, it shows decreasing of duration of the season except for RCP 4.5 2020 (Fig. 5). In line with these, Araya and Stroosnijder (2011) stated that, the major causes of failure of crops during rainy season (agricultural drought) are late start, early cessation, and shortening of rainy season duration. This result is similar with Abiy et al. (2014) and Daniel et al. (2017). Also, Messay (2006) and NMA (2012) stated the Rift valley regions generally have short growing

seasons which are manifested as late-onset dates and early cessation dates.

3.3 Markov chain modeling of dry and wet spell

3.3.1 The short rainy season

The probability of having a dry decade (PD) is greater than 81% for the decades 4th to 8th and 13th to 15th and less than 81% for decades 9th to 12th. The probability occurrence of a wet decade (PW) with more than 19% is between 9th to 12th decade and the remaining decades are less than 19%. Similarly, probability of occurrences of dry decades preceded by dry decades (PDD) is more than 80% for all decades. Conditional probability of wet decade preceded by a wet decade (PWW) is greater than 50% for the decades 7th, 8th, 9th, 11th, and 14th and less than 50% for the remaining decades. Moreover, the probability of occurrence of dry decade preceded by wet decade (PDW) is more than 50% for decades 4th to 7th, 12th to 13th, 9th to 10th and 15th, and less than 50% for the remaining decades. Likewise, the probability of occurrence of wet decade preceded by dry decade (PWD) is more than 10% for decades 9th to 12th and less than 10% for the remaining decades (Table 6).

Fig. 4 Projected change of offset (DOY) from the baseline for both RCP 4.5 and RCP 8.5 (all RCPS and baseline represent 30 years)

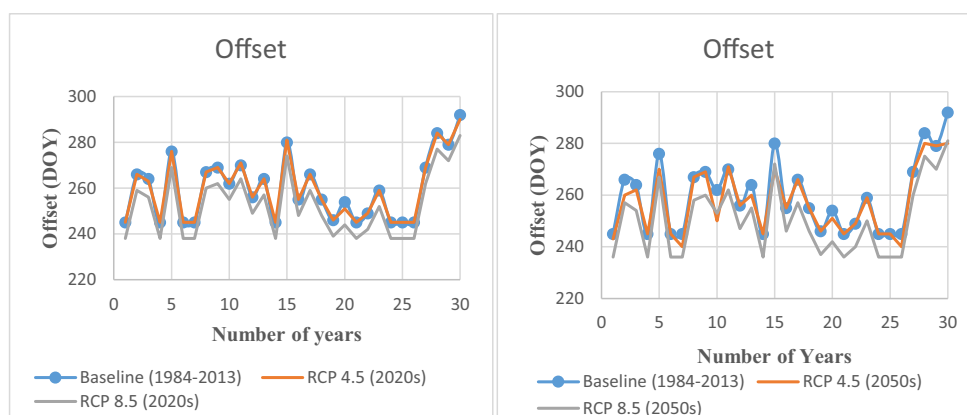
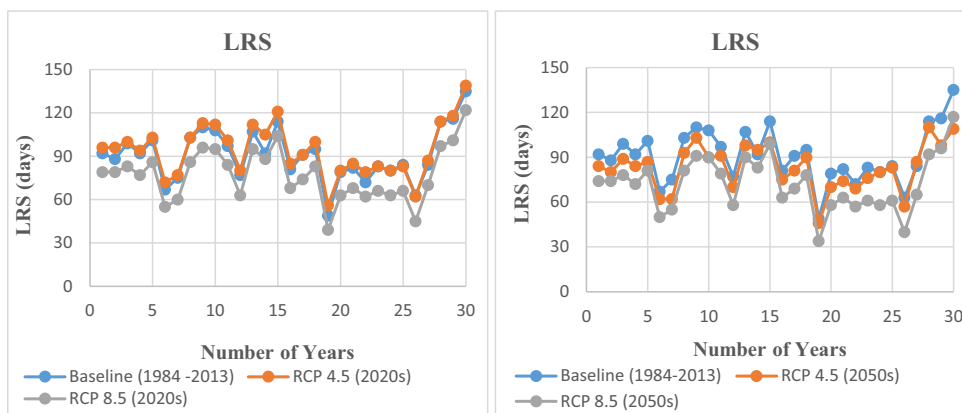


Fig. 5 Projected change of length rainy season (day) from the baseline for both RCP 4.5 and RCP 8.5 (all RCPS and baseline represent for 30 years)



3.3.2 The main rainy season

The probability of having a dry decade (PD) of greater than 50% occurred during the 16th, 17th, 18th, 25th, 26th, and 27th decades. The probability of occurrence of a wet decade (PW) with more than 50% probability of occurrences is observed between the 19th to 24th decades. Conditional probabilities of wet decade preceded by a wet decade (PWW) are greater than 50% (50–84%) except for decades 26th and 27th, which had 30 and 25% respectively. Similarly, probability of occurrences of dry decades preceded by dry decades (PDD) is more than 50% for decades 16th to 18th and 23th to 27th and less than 50% for decades 19th to 22th. Moreover, the probability of occurrence of dry decade preceded by wet decade (PDW) is more than 50% for decades 26th and 27th and less than 50% for the remaining decades. Likewise, the probability of occurrence of wet decade preceded by dry decade (PWD) is more than 50% for decades 19th to 22th and less than 50% for the remaining decades (Table 7) so crops need supplementary

irrigation during the high probability occurrences of dry decades. These results in both seasons are similar with Messay (2006) and Siferet et al. (2016).

3.4 Agricultural drought

In the base period, extreme agricultural drought was experienced in 1987, 1992, and 2002, severe agricultural drought was observed in 1984 and 2014, moderate agricultural drought was observed in 2009, and mild agricultural drought was observed in 1985, 1989, 1990, 1994, 1995, 1997, 1999 to 2001, and 2003 to 2008. Generally, there was 9.7% extreme, 6.45% severe, 3.2% moderate, and 48.4% mild drought. Only 32% of the season was normal condition (Fig. 6). In addition, the survey conducted based on focused group discussion shows that out of 700 respondents, 550 (76.8%) are able to list 1984, 1987, 1992, 2002, and 2014 as years of extreme and severe drought.

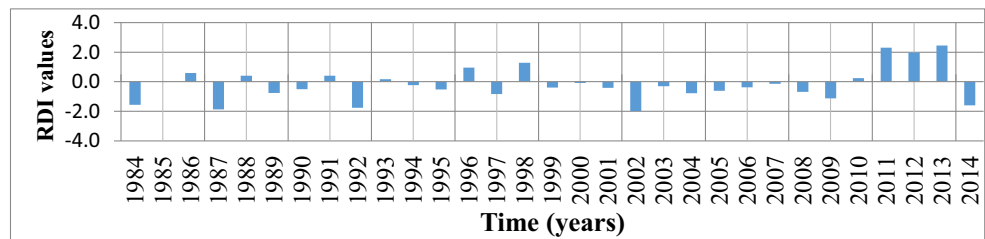
Table 6 Dry-wet spell probability distribution of short rainy (FMAM) based on the Markov chain model

Decade	Initial		Conditional			
	PD	PW	PDD	PDW	PWD	PWW
4	93	6.7	95	75	5	25
5	94	6	94	78	6	22
6	90	10	96	52	4	48
7	86	14	92	50	8	50
8	86	14	93	45	7	55
9	78	22	87	50	13	50
10	78	22	85	51	15	49
11	72	28	84	41	16	59
12	80	20	86	54	14	46
13	91	9	93	65	7	35
14	88	12	94	48	6	52
15	92	8	94	63	6	37

Table 7 Dry-wet spell probability distribution of main rainy season (JJAS) based on the Markov chain model

Decade	Initial		Conditional			
	PD	PW	PDD	PDW	PWD	PWW
16	87	13	95	48	5	52
17	74	26	84	47	16	53
18	52	48	75	33	25	67
19	35	65	45	31	55	69
20	25	75	43	21	57	79
21	24	76	40	19	60	81
22	27	73	46	16	54	84
23	34	66	51	24	49	76
24	49	51	64	34	36	66
25	66	34	79	34	21	64
26	86	14	86	70	14	30
27	92	8	93	75	7	25

Fig. 6 Main rainy season (JJAS) agricultural drought of base period (1984–2014)



In RCP 4.5 (2020), there is likely extreme agricultural drought in 2027 and 2029, severe in 2028, moderate in 2030, and mild in 2021, 2022, 2026, 2031 to 2034, 2036, and 2038. There is likely 6.67% extreme agricultural drought, 3.33% severe, 3.33% moderate, and 30% mild. Only 56.67% of the period is possible normal and wet condition (Fig. 7). In RCP 4.5 (2050), there is likely severe in 2072 and 2073, moderate in 2071, and mild agricultural drought from 2045 to 2056, 2058, and 2067 to 2070, and 2074. Generally, there is likely 6.67% severe, 3.33% moderate, and 56.67% mild agricultural drought. In this scenario, extreme drought is not detected. However, the overall agricultural drought condition is increased to 66.67%. This shows increasing of overall agricultural drought from near future to mid-century scenarios of RCP 4.5 (Fig. 8).

In RCP 8.5 (2020), there is likely moderate agricultural drought from 2016 to 2019, and 2044, mild from 2031 to 2033, 2035, and 2037 to 2039. Generally, there will be 16.67% moderate and 23.3% mild agricultural drought and 60% of the period is likely wet and normal conditions (Fig. 7). In RCP 8.5 (2050), there is likely extreme in 2045, moderate in 2061 and 2064, and mild agricultural drought from 2046 to 2048, 2057, 2062, 2063, and 2065 to 2069. Generally, there is 3.33% extreme, 6.67% moderate, and 36.67% mild agricultural drought. The overall agricultural drought is likely to be 46.67%. It shows an increase of drought in the main rainy season (JJAS) from near future 40% to mid-century scenarios of RCP 8.5 (46.67%) (Fig. 8).

Inline to this, Desalegn et al. (2010) has conducted drought analysis in the whole Awash Basin using the data from (1964–2003) and found the years 1965, 1966, 1973,

1984, 1991, 1992, 1997, and 2002 to be the most critical drought years in the basin with more than 75% of the total basin area under drought. Similarly in our study, 1984, 1992, 1997, and 2002 are the years with severe to extreme drought. Likewise, the study conducted by Tagel et al. (2010) in Tigray region, Mekelle station shows that severe to extreme droughts occurred in the years 1984, 1985, 1986, 1987, and 1991. These years are also observed to be critical drought years in our study. Araya and Stroosnijder (2011) investigated the drought risk and irrigation need in Tigray region and reported similar drought episode. According to Viste et al. (2013) mild to severe drought was experienced in the central rift valley in the years similar to the findings of this study.

Suryabhadgavan (2016) studied climate variability and drought characterization during the period 1983–2012 across Ethiopia and found major droughts during 1983–1984 and 2002–2003, which affected over 60% of the country. Similarly, in our study, 1984 and 2002 were extreme drought years. Feyisa (2017) reported that in the years 1984, 1994, 1995, 2001–2002, 2009 and 2014/2015 there were drought incidences in the central rift valley of Ethiopia.

Zelege et al. (2017) conducted drought trend and periodicity investigation during (1979 to 2014) all over Ethiopia, and their study showed that the north and northwest regions of Ethiopia experienced frequent and more severe drought conditions around the years 1983/1984. Yimer et al. (2018) analyzed the patterns and trends of drought incidences in northeast highlands, which cover some part of Kesem sub-basin using monthly rainfall record for the period 1984–2014. The area experienced drought episodes in 1984,

Fig. 7 Main rainy season (JJAS) agricultural drought of RCP 4.5 (2020) and RCP 8.5 (2020)

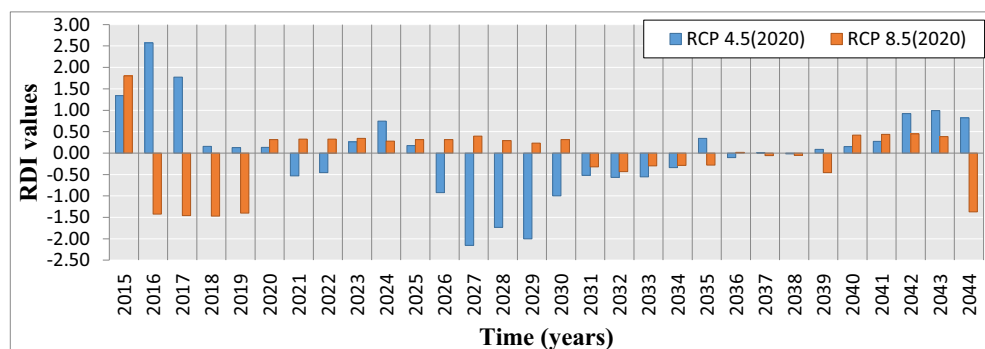
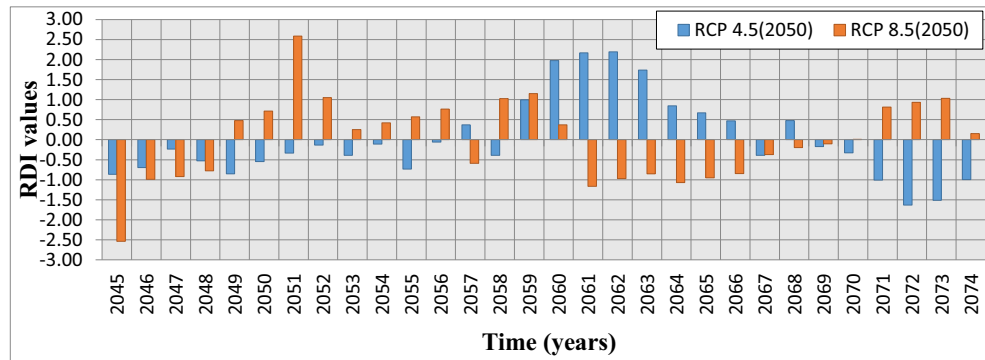


Fig. 8 Main rainy season (JJAS) agricultural drought of RCP 4.5 (2050) and RCP 8.5 (2050)



1987/1988, 1992/1993, 1999, 2003/2004, and 2007/2008 which were among the worst drought years in the history of Ethiopia.

4 Conclusions and recommendations

The study revealed that short rainy season (FMAM) rainfall is undependable for planting crops and thus, supplementary irrigation is critically required when there is true start of the season. Higher probability of occurrences of dry decades is observed in September. Thus, main rainy season (JJAS) also probably needs supplementary irrigation during September. Excess rainfall is recorded during June, July, and August and hence, this rainwater can be harvested during these months and supplement both seasons. Unless it is supplemented, short rainy season rainfall alone is risky for crop production. So, it can be used for land preparations when there is no supplementary irrigation. Main rainy season starts after 169 DOY, so farmers must plant crops after this day. The in situ and ex situ water storage practices should be adopted during the high rainfall period prominently during July and August. Extreme to severe drought is common in the area and hence drought-tolerant crops must be adopted to combat crop failure and enhance food security. Overall, it implies that there is an urgent need of new and sweeping climate mitigation policy whose key tenets involve on climate extenuation strategies.

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Compliance with ethical standards

Ethical approval The study has been approved by the Haramaya University research ethics committee whose names are Awol Seid (PhD) and Admkew Haile (M.Sc). Thus, all procedures performed in the study involving human participants were in accordance with the ethical standards of the Haramaya University research system. The study is retrospective; hence, formal consent is not required.

Conflict of interest The authors declare that they have no conflict of interest.

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