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# Variability and time series trend analysis of rainfall and temperature in northcentral Ethiopia: A case study in Woleka sub-basin

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ABSTRACT

Examining the spatiotemporal dynamics of meteorological variables in the context of changing climate, particularly in countries where rainfed agriculture is predominant, is vital to assess climate-induced changes and suggest feasible adaptation strategies. To that end, trend analysis has been employed to inspect the change of rainfall and temperature in northcentral Ethiopia using gridded monthly precipitation data obtained from Global Precipitation and Climate Centre (GPCC V7) and temperature data from Climate Research Unit (CRU TS 3.23) with 0.5° by 0.5° resolution from 1901 to 2014. Data have been analyzed using coefficient of variation, anomaly index, precipitation concentration index and Palmer drought severity index. Furthermore, Mann-Kendall test was used to detect the time series trend. The result revealed intra- and inter-annual variability of rainfall while Palmer drought severity index value proved the increasing trend of the number of drought years. Annual, belg and kiremt rainfall have decreased with a rate of 15.03, 1.93 and 13.12 mm per decade respectively. The declining trend for annual and kiremt rainfall was found to be statistically significant while that of belg was not significant. The rate of change of temperature was found to be 0.046, 0.067 and 0.026 °C per decade for mean, minimum and maximum respectively. The Mann-Kendall trend analysis test result revealed increasing trend for mean and minimum average temperatures through time significantly while the trend for maximum temperature exhibited a non-significant increasing trend. We recommend strategies designed in the agricultural sector have to take the declining and erratic nature of rainfall and increasing trend of temperature into consideration.

## 1. Background of the study and problem statement

Warming of our planet due to the emission of Greenhouse Gases (GHGs) is now undeniable; and over the last century, atmospheric concentration of $CO_2$ has increased significantly which induced the average global temperature to increase by 0.74 °C as compared with the pre-industrial era (UNFCCC, 2007). Smallholder subsistence farmers are among the worst hit by climate change due to their low adaptive capacity and their dependence on rain-fed agriculture which is very sensitive to climate variability (Ifejika Speranza, 2010; Easterling, 2011). In Africa, precipitation amounts are likely to decrease for most parts of Sub-Saharan Africa (SSA) while rainfall variability is expected to increase (IPCC, 2014). Ifejika Speranza (2010) and World Bank (2010) argued that Africa is expected to experience mainly negative climate change impacts, in terms of an increase in the already high temperatures and a decrease in the largely erratic rainfall in its context of widespread poverty and low development. Africa, due to low adaptive capacity and high sensitivity of socio-economic systems, is one of the most vulnerable regions highly affected and to be affected by the impacts of climate change (IPCC, 2014). By 2100, parts of the Sahara are likely to be the most vulnerable, showing likely agricultural losses of up to 7% of GDP (Below et al., 2010). UNDP (2014) stressed that the adverse impacts of climate change will be felt most acutely by the smallholder farmers in developing countries because they are by large dependent on natural systems for growing crops and raising livestock.

Current climate variability is already imposing a significant challenge to Ethiopia by deterring the struggle to reduce poverty and sustainable development efforts (NMA, 2007). World Bank (2010) has ranked Ethiopia among the most vulnerable countries in the world to the adverse effects of climate change; mainly due to its high dependence on rain fed

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agriculture, low adaptive capacity and a higher reliance on natural resources base for livelihood, among others (NMA, 2007; World Bank, 2010; EPCC, 2015). In terms of livelihood, smallholder rain-fed subsistence farmers and pastoralists are considered to be the most vulnerable to climate variability and change and need interventions to adapt their livelihood systems to changing climatic conditions (NMA, 2007; EPCC, 2015). Due to the smaller per capita land availability and highly fragmented parcel of farmland coupled with low productivity of land due to impoverishment in soil fertility as well as lower level of asset building, erratic nature of rainfall and lower level of experience to adapt to climate change impacts, EPCC (2015) has identified the highland areas in Ethiopia as among the most vulnerable agroecology. Northcentral part of Ethiopia (where this study area was conducted) is among the drought prone areas in Amhara National Regional State (ANRS) and it is among the food insecure areas of the country and farming is practiced in the context of unreliable rainfall (World Bank, 2010; Muluneh and Demeke, 2011) and has frequently suffered from recurrent drought often followed by devastating famine (Amare et al., 2011; Daniel, 2011).

Precipitation and temperature are two of the most important variables in the field of climate sciences and hydrology frequently used to trace extent and magnitude of climate change and variability (IPCC, 2007). Cheung et al. (2008) emphasized that in countries where their economy is heavily dependent on low-productivity rainfed agriculture, rainfall trends and variability are frequently mentioned factors in explaining various socioeconomic problems such as food insecurity. As a result, investigating the spatio-temporal dynamics of these meteorological variables is very crucial so as to provide input for policymakers and practitioners that help to make informed decisions. Riddle and Cook (2008) pointed out that since agricultural calendars in most parts of Africa are closely tied to the timing of local rainfall, improved forecasts of rainy season onset and termination would greatly benefit particularly for smallholder farmers. The implication here is therefore, quantification of climate change is necessary in order to detect the change that has already occurred and this will be further helpful to make predictions and for better preparedness. Tabari and Talaee (2011) have noted that trend analysis of climatic variables has received a great deal of consideration from scholars recently. Characterization of the intra-and inter-annual spatio-temporal trend of meteorological variables in the context of a changing climate is vital to assess climate-induced changes and suggest feasible adaptation strategies and agricultural practices.

As a result, careful observation, recording and analysis of meteorological data is very essential.

The long-term climatic change related to changes in precipitation patterns, rainfall variability, and temperature is most likely to increase the frequency of droughts and floods in Ethiopia. The country's heavy dependence on rain-fed and subsistence agriculture increases its vulnerability to the adverse effects of these changes (Gissila et al., 2004; Kassa, 2015). In terms of rainfall occurrence, there are three seasons in Ethiopia, namely *bega* (dry season) which extends from October–January, *belg* (short rainy season) which extends from February–May and *kiremt or meher* (long rainy season) which lasts from June–September (NMA, 2007). Rainfall in the short rainy season (*belg*) is caused by moist easterly and south-easterly winds from the Indian Ocean, while in the main rainy season (*kiremt*) is a result of convergence in low-pressure systems and the Intertropical Convergence Zone (Workineh, 1987; Daniel, 2011; Tabari et al., 2015). Sea surface temperature changes and El-Niño Southern Oscillation (ENSO) episodes in the Atlantic and Indian Oceans do have remarkable implication in the timing and amount of rainfall in Ethiopia (Shanko and Camberlin, 1998; NMA, 2007; Daniel, 2011; Kassa, 2015). Haile (1988) particularly underscored that, drought events in Ethiopia are caused by ENSO along with sea surface temperature (SST) anomalies in the Southern Atlantic and Indian Oceans combined which is exacerbated with anthropogenic activities. Rainfall distribution in Ethiopia affected by ENSO events and SST anomalies by displacing and weakening the rain-producing air masses. *Kiremt* rain account for 50–80% of annual rainfall totals in Ethiopia, which has high contribution to agricultural productivity and major water reservoirs. Thus, the most severe droughts in Ethiopia are usually related to a failure of the *kiremt* rainfall to meet the agricultural and water resource needs (Diriba and Barnston, 2007; Kassa, 2015). On the other hand, spring rain which is important not only just for the *belg* crops (accounting for 5–15% of the national food crop) but also for improving pasture for livestock, and for the planting of long-season crops as well as useful for land preparation for *meher* production and supplementing water for irrigation purposes has been decreased substantially (Eiste et al., 2012; Workineh, 1987). Hence, agricultural production in Ethiopia is predominantly rain-fed whereas inter and intra-annual rainfall variability is high and droughts are recurrent in many parts of the country, variation of rainfall in space and time affects the agricultural production system and needs a close study (NMSA, 2001; Woldeamlak, 2007; Rosell and Holmer, 2007; Haileselassie et al., 2008; Kassa, 2015). In a highly agrarian community like Ethiopia, where the livelihood of the population and the gross domestic product of the country are almost entirely dependent upon rain-fed agricultural production, analysis of precipitation and temperature patterns has paramount importance to cope with impacts on crop yields, animal breeding, power production and ecosystem management. Considering the history of recurrent drought and rainfall variability in Ethiopia, conducting long-term trend and variability studies with robust methods to obtain important information on what has been changing in the past few decades has a vital contribution (Daniel et al., 2014). As a result, accurate estimation of the spatio-temporal distribution of rainfall; and observing its trends are crucial input parameters for securing sustainable agricultural production (Dereje et al., 2012).

Different trend analysis studies have been conducted in Ethiopia at different spatio-temporal scales and came up with mixed results. A study by Gebremedhin et al. (2016) in Northern Ethiopia disclosed a mix of non-significant positive and negative trends. Daniel et al. (2014) revealed a statistically significant increasing trend of temperature while the case for precipitation was mixed over the upper Blue Nile river basin of Ethiopia. Seifu and Abdulkarim (2006) had tried to cover relatively wider spatial coverage and disclosed no significant trend of *belg* rainfall totals while *kiremt* rainfall exhibited a significant decreasing trend. Osman and Sauerborn (2002), on the other hand, had reported a clearly decreasing trend of annual and summer rainfall which was started around the end of the 1910s and continued with a progressive downward trend. NMSA (2001) had reported an increasing trend in annual rainfall in central Ethiopia while a declining trend has been observed over the Northern half and Southwestern part of the country. Negash et al. (2013) had investigated the spatiotemporal variability of annual and seasonal rainfall over Ethiopia and reported a decreasing trends of *kiremt* and annual rainfall in northern, northwestern and western parts of the country; while an increasing trend in annual rainfall was observed in a few grid points in eastern parts of the country.

A study by Woldeamlak (2007) pointed out that, though there were intra-annual and intra-regional differences in amount and variability of rainfall in Amhara region (where the extent of variability is higher in the eastern part of the region, geographical area where our study area is found), no systematic pattern of change across the region regarding trends in annual and seasonal rainfall was obtained. Conway (2000), after analyzing data for longer period of time in Wollo and Tigray, had concluded absence of evidence for a long-term trend or change in the annual rainfall except a slight increase in *belg* rainfall (from 1980s up to 1996) and very slight decrease in *kiremt* rainfall up to the mid of 1980s at Kombolcha. Another study in the upper Blue Nile river basin by Tabari et al. (2015) revealed insignificant decreasing trends in annual precipitation at most of the stations. A study by Meze-Hausken (2004) in Northern Ethiopia, which was accompanied by the perception of local communities, have asserted that small rainy season (*belg*) has been lost and the main summer rains have shortened in duration. Gutu et al. (2012) had reported a gradual decline in yearly average rainfall and pronounced reduction both in *belg* and *meher* rains. Additionally, irregularities in onset and cessation have been observed which affects the cropping calendar of the farmers. Marked onset and cessation variability in both space and time was also reported by Segele and Lamb (2005).

A relatively recent study conducted in central highlands of Ethiopia (which is very similar to our study area) by Arragaw and Woldeamlak (2017) disclosed that annual and June–September (*kiremt*) rainfall exhibited statistically insignificant increasing trends while March–May (*belg*) rainfall depicted significant decreasing trends. Rosell and Holmer (2007) in the eastern part of South Wollo (Ethiopia) had found a slight decrease in rainfall during the short *belg* season while the long rainy season (*kiremt*) had shown an increasing trend through time. Both the short and the long rainy seasons have become shorter and rainfall variability had increased. Jury and Funk (2012) using long term gridded data had reported upward trends in air temperature and downward trends in rainfall over Ethiopia's southwestern region in the period 1948–2006. Similarly, Yilma and Zanke (2004) disclosed a significant decline in the annual and *kiremt* rainfalls for the eastern, southern and southwestern stations since about 1982.

From the ongoing discussion, trend analysis studies conducted so far in Ethiopia are not conclusive and some are conducted at macro scale; which needs further research. The impact of climate change on precipitation in Ethiopia is more of on its distribution and timing than the total amount. For agricultural activity, seasonal reliability is more important than annual reliability (King'uyu et al., 2000; NMA, 2007; Belay et al., 2014). This proved that focusing on annual or seasonal trend alone might mislead and should be supported by variability analysis and perception of the farmers. Besides, using varied techniques enable to have a clear picture of the situation than relying on a single method to detect variability and trend in climatic variables. Moreover, incorporating the experience of farmers in trend analysis discourse which could offer important insights on the nature of meteorological processes that could not capture by the analysis of recorded data alone. But the perception and experience of farmers were not included in most analyses. Furthermore, most studies (except Riddle and Cook, 2008; Jury, 2010; Jury and Funk, 2012; Negash et al., 2013) focused on the seasonal and annual variability and trend based on observed data. Gridded satellite data enables to overcome the problem of missing data which is common in observational data. Moreover, decent data length and quality, which is rare in observational data in Ethiopia particularly in Wollo and Tigray (Conway et al., 2004) are needed for temporal and spatial characterization of a rainfall (Wossenu et al., 2009). Gissila et al. (2004), as well as Mekonnen and Woldeamlak (2014) recommended that, since there are complex patterns of rainfall trends in Ethiopia, micro-scale studies into variability and trend of extreme rainfall events are essential to understanding local-scale manifestations of climate change and so as to design context specific adaptation interventions. Micro-level trend investigation is highly recommended because studies of rainfall and temperature variation focusing on large areas would be of no use for local agriculture, particularly in places where rainfall is highly variable and geophysical characteristics vary within a short distance. Besides micro-level trend analysis is vital for context-specific planning and implementation of climate change adaptation interventions (Gebre et al., 2013; Arragaw and Woldeamlak, 2017). Though trend analysis of meteorological variables is not new in Ethiopia, no prior comprehensive study was conducted in the study area. Since it is among drought-prone areas of the country, due attention should be given in thoroughly detecting trends of climatic variables. As a result, this study incorporates both variability investigation, trend analysis (based on historical data of 1901–2014 years) for total annual, *kiremt* and *belg* rainfall using descriptive and statistical tests; and the perception of smallholder farmers have been incorporated so as to have a better picture on the climate change induced variability and trend of meteorological variables in *Woleka* sub-basin (northcentral Ethiopia).

## 2. Materials and methods

### 2.1. Familiarizing the study area

#### 2.1.1. Location and biophysical situation of the sub-basin

*Woleka* sub-basin (in the North central part of Ethiopia), covers an estimated area of 6415 km$^2$ and situated approximately between 10 °15′-10°55′N and 38 25′-39 -30′E (Fig. 1). The altitude of the sub-basin ranges between 1070 and 4200 m above sea level (masl) and characterized with agroecology types ranging from tepid to cool moist and sub moist mid highlands (*woinadega*), and cold to very cold moist/sub moist sub afroalpine to afroalpine in parts of the highlands (*dega and wurch*); and the lowlands in the western and southern parts of the basin being hot to warm moist lowlands (*kolla*). This diverse agroecology enables the sub-basin to produce different crop, fruits and vegetable types; and rearing of varied types of livestock (SWDoFED, 2017). It has an annual rainfall ranging between 800 and 1390 mm; while the annual maximum and minimum temperature range between 13-31 °C and −0.5-16 °C respectively (Aster and Seleshi, 2009). The distribution of rainfall mostly occurs from June to mid-September (main rainy season), locally known as *kiremt*, and February to May is the small rain season, which is locally known as *belg* (Workineh, 1987; Aster and Seleshi, 2009; Rosell, 2011). Thus, crop production follows a bimodal rainfall regime (but with single maxima) leading to two harvesting periods (Aster and Seleshi, 2009) but the small rainy season is erratic and highly variable and experienced frequent failure which hampers *belg* harvesting (Rosell, 2011; Dereje et al., 2012). Delayed onset and early cessation as well as poor *belg* performance make the sub-basin as food insecure and highly reliant on food aid Lakew et al., 2000; Amare et al., 2011; Daniel, 2011; Kahsay, 2013). The delayed onset of *meher* rains in sorghum and maize surplus producing areas (in Abay-Beshilo livelihood zones) has forced farmers to shift to short-maturing and lower yielding varieties.

#### 2.1.2. Demographic and socioeconomic situation of the sub-basin

Woleka sub-basin, which consists seven woredas of South Wollo administrative zone, has a total rural population of 950, 126 (Male comprises 50.4percent while female population accounts 49.6percent) (2017 estimate); which is around 91 percent of the total population of the sub-basin. With an estimated area of 6415 km$^2$, the sub-basin has a rural population density of 148per/km$^2$ which makes the area as among the densely populated rural areas of the country (SWDoFED, 2017). Rainfed crop production (wheat-barley-teff dominated) supported by livestock rearing is the main economy of smallholder farmers (SWDoFED, 2014) which are both under mercy of nature. Agriculture is constrained by poor soil fertility, small per capita landholding, soil degradation, and erratic rainfall; as a result, most parts of the area are chronically food insecure (Amare et al., 2011; Kahsay, 2013; SWDoFED, 2014; Kebede and Zewdu, 2014). It is among the drought prone areas in Amhara National Regional State (ANRS) and it is among the food insecure areas of the country. Cafer and Rikoon (2017) have also labelled the area as the ‘famine belt of Ethiopia’. Due to unreliable rainfall and poor soil fertility (Amare et al., 2011; SWDoFED, 2014; Kebede and Zewdu, 2014), greater proportions of farmers did not produce enough food and depended largely on food aid (Lakew et al., 2000; SWDoFED, 2014). Besides, nonfarm livelihood activities are not well developed (Amare et al., 2011; Kebede and Zewdu, 2014) due to limited access of infrastructure and low level of urban development, among others. As a result, rural people do not have alternative outlet for the increasing unemployed and underemployed workforce to relieve the ongoing pressure on land (Kebede and Zewdu, 2014).

### 2.2. Research design

#### 2.2.1. Data type and source

Rainfall and temperature data for variability and trend analysis have

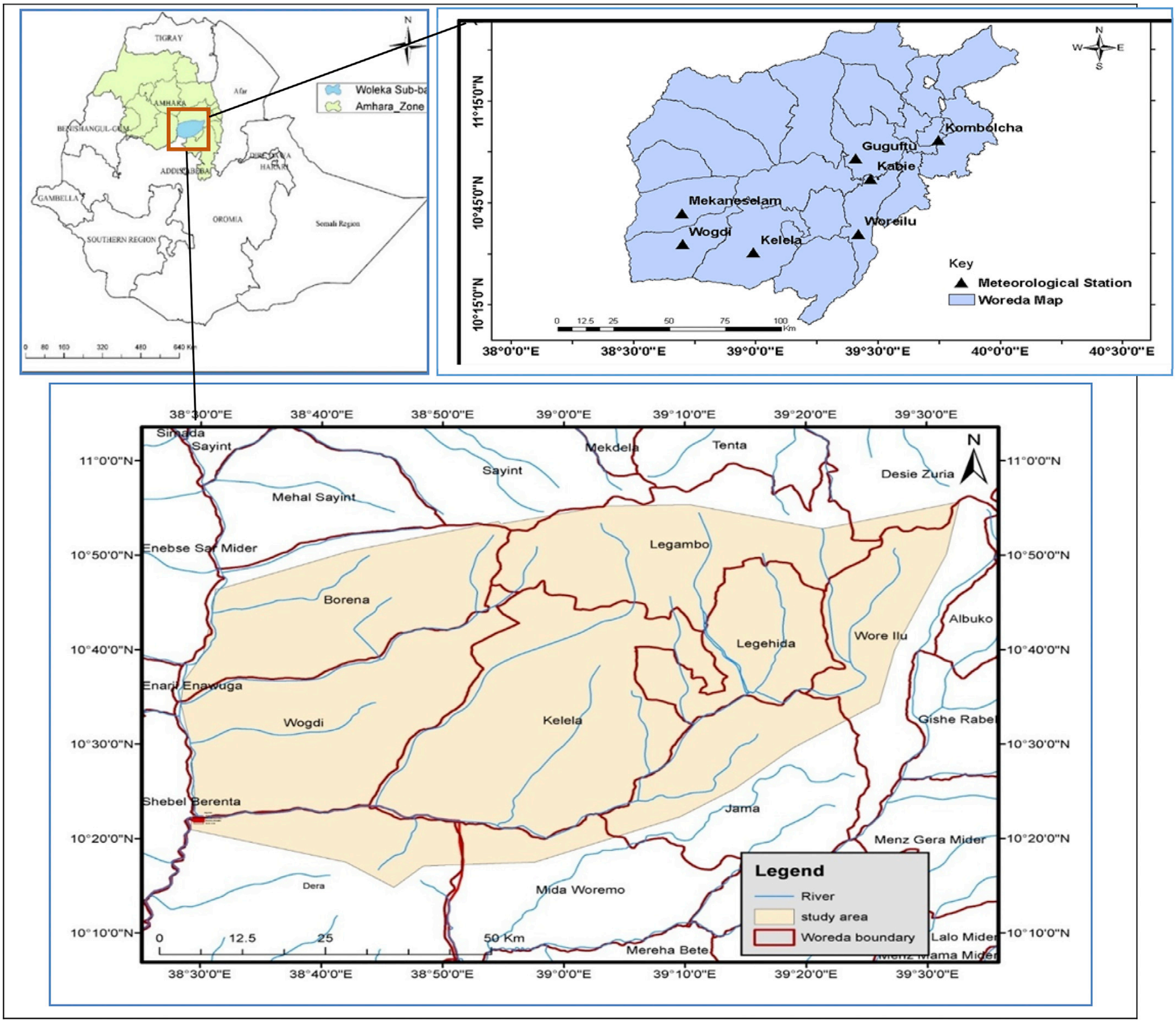


**Fig. 1.** Relative Location of Woleka Sub basin and Major meteorology stations.
Source: Wollo University GIS team (2016)

been obtained from different sources. Gridded monthly precipitation from Global Precipitation and Climate Centre (GPCC V7)[1] and temperature data from Climate Research Unit (CRU TS 3.23) with 0.5° by 0.5° resolution from 1901 to 2014 was obtained and used for trend analysis (downloaded from Climate explorer: KNMI Climate change atlas. https://climexp.knmi.nl/plot_atlas_form.py). Furthermore, Palmer Drought Severity Index (PDSI) data for the year of 1951–2013 was also obtained from the same source. The gridded data are a reconstructed data series based on records of gauge stations and meteorological satellite observations. The gridded data set is very useful in view of the fact that weather stations are limited in number, unevenly distributed, have a missing data problem and a short period of observation. Gauge station data for Mekaneselam (1982–2015), Guguftu (1987–2014), Kabie (1981–2015), Kelela (1993–2015), Wegidi (1996–2015) and Wereillu (1971–2015), which are the major gauge stations in the sub-basin, were also obtained from Kombolcha regional meteorological station. In the case of station data, missing cases were handled by taking the average of the preceding and succeeding months (for monthly missed data) but years with missed data were excluded from analysis. The perception and experiences of elders regarding the long-term trend of rainfall and temperature have been included.

### 2.2.2. Data analysis techniques

A number of techniques have been developed for the analysis of rainfall and temperature, which generally fall into variability and trend analysis categories. Variability analysis involves the use of Coefficient of Variation (CV), percentage departure from the mean (Anomalies), Precipitation Concentration Index (PCI) and moving average. Trend detection and analysis are performed through parametric and non-parametric tests only for consistent data. Normality and homogeneity of variance throughout the series may be adversely affected by outliers and missing data in parametric tests. The advantage of non-parametric statistical test over the parametric test is that the former is more suitable for non-normally distributed, outlier, censored and missing data, which are

[1] Validation of satellite and gauge data was computed using correlation and Kolmogorov-Smirnov tests.

frequently encountered in hydrological time series. As a result, Mann-Kendall (MK) test is widely used to detect trends of meteorological variables (see Yilma and Zanke (2004); Mekonnen and Woldeamlak (2014); Tabari et al., 2015; Gebremedhin et al., 2016). MK test is a non-parametric test, which tests for a trend in a time series without specifying whether the trend is linear or non-linear (Yue et al., 2002).

In this study, rainfall and temperature variability have been computed using CV, Standardized Precipitation Anomaly and PCI. Furthermore, MK was used to detect the trend of rainfall and temperature with Sen's slope estimator (test Pettitt's test was used to test the degree of homogeneity of the data); while PDSI was applied to examine the extent of meteorological drought through time. Data analysis was undertaken using XLSTAT software and excel spreadsheet. The perception of smallholder farmers on rainfall and temperature changes through time was analyzed using descriptive statistics and qualitative analysis. CV is calculated to evaluate the variability of the rainfall. A higher value of CV is the indicator of larger variability, and vice versa which is computed as:

$$CV = \frac{\sigma}{\mu} \times 100$$

where CV is the coefficient of variation; σ is standard deviation and μ is the mean precipitation. According to Hare (2003), CV is used to classify the degree of variability of rainfall events as less ($CV < 20$), moderate ($20 < CV < 30$), and high ($CV > 30$). PCI is used to examine the variability (heterogeneity pattern) of rainfall at different scales (annual or seasonal). The PCI values were computed, as given by Oliver (1980) and modified by De Luis et al. (2011), as:

$$PCI_{annual} = \frac{\sum_{i=1}^{12} P_i^2}{\left(\sum_{i=1}^{12} p_i\right)^2} \times 100$$

where: $P_i$ = the rainfall amount of the *i*th month.

According to Oliver (1980), PCI values of less than 10 indicates uniform monthly distribution of rainfall (low precipitation concentration), values between 11 and 15 denote moderate concentration, values from 16 to 20 indicates high concentration, and values of 21 and above indicate very high concentration. On the other hand, standardized anomalies of rainfall have been calculated to examine the nature of the trends, enables the determination of the dry and wet years in the record and used to assess frequency and severity of droughts (Agnew and Chappel, 1999; Woldeamlak and Conway, 2007; Eiste et al., 2012; Gebre et al., 2013) as:

$$Z = \frac{(X_i - \overline{X}_i)}{s}$$

where, $Z$ is standardized rainfall anomaly; $X_i$ is the annual rainfall of a particular year; $\overline{X_i}$ is long term mean annual rainfall over a period of observation and 's' is the standard deviation of annual rainfall over the period of observation. The drought severity classes (Agnew and Chappel, 1999) are extreme drought ($Z < -1.65$), severe drought ($-1.28 > Z > -1.65$), moderate drought ($-0.84 > Z > -1.28$ and no drought ($Z > -0.84$). PDSI uses readily available temperature and precipitation data to estimate relative dryness. It is a standardized index that spans −5 (dry) to +5 (wet) which is reasonably successful at quantifying long-term drought. As it uses temperature data and a physical water balance model, it can capture the basic effect of global warming on drought through changes in potential evapotranspiration. The PDSI is a meteorological drought index, and it responds to weather conditions that have been abnormally dry or abnormally wet. Since PDSI is most effective in measuring impacts sensitive to soil moisture conditions (like agriculture), it is more popular and has been widely used for a variety of applications. PDSI[2] has been widely used to recognize long-term agricultural drought and hydrological drought, and to identify the abnormality of a particular drought in a region.

MK trend test is a non-parametric test commonly employed to detect monotonic trends in series of environmental data, climate data or hydrological data. MK test has been used to detect the presence of monotonic (increasing or decreasing) trends in the study area and whether the trend is statistically significant or not. Since there are chances of outliers to be present in the dataset, the non-parametric MK test is useful because its statistic is based on the (+or -) signs, rather than the values of the random variable, and therefore, the trends determined are less affected by the outliers (Birsan et al., 2005). Trend analysis has been carried out on annual bases, as well as for *belg* and *kiremt* seasons. Since the study area gets its *kiremt* rainfall from June to September, monthly trends for these four months have been analyzed separately. This enables us to see the trend especially for the onset and cessation months. Homogeneity test was undertaken using Pettitt's test. Each data value is compared with all subsequent data values. If a data value from a later time period is higher than a data value from an earlier time period, the statistic S is incremented by 1. On the other hand, if the data value from a later time period is lower than a data value sampled earlier, S is decremented by 1. The net result of all such increments and decrements yields the final value of S. The MK test statistic 'S' is calculated based on Mann (1945), Kendall (1975) and Yue et al. (2002) using the formula:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}(x_j - x_i) \tag{1}$$

The application of trend test is done to a time series $X_i$ that is ranked from i = 1, 2 … n-1 and $X_j$, which is ranked from j = i + 1, 2 …. n. Each of the data point $X_i$ is taken as a reference point which is compared with the rest of the data point's $X_j$ so that:

$$\mathrm{Sgn}\ (X_j - X_i) = \begin{cases} +1 if\left(X_j - X_i\right) > 0 \\ 0 if\left(X_j - X_i\right) = 0 \\ -1 if\left(X_j - X_i\right) < 0 \end{cases} \tag{2}$$

where $X_i$ and $X_j$ are the annual values in years i and j (j > i) respectively.

It has been documented that when the number of observations is more than 10 ($n \geq 10$), the statistic 'S' is approximately normally distributed with the mean and E(S) becomes 0 (Kendall, 1975). In this case, the variance statistic is given as:

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{t=1}^{m} t_1(t_1 - 1)(2t_1 + 5)}{18} \tag{3}$$

where n is the number of observation and $t_i$ are the ties of the sample time series. The test statistics $Z_c$ is as follows:

$$Z = \begin{cases} \dfrac{S-1}{\sigma} & if\ S > 0 \\ 0 & if\ S = 0 \\ \dfrac{S+1}{\sigma} & if\ S < 0 \end{cases} \tag{4}$$

where $Z_c$ follows a normal distribution, a positive $Z_c$ and a negative $Z_c$ depict an upward and downwards trend for the period respectively. Sen's Slope estimation test computes both the slope (i.e. the linear rate of change) and intercept according to Sen's method. The magnitude of the trend is predicted by Theil (1950) and Sen (1968) slope estimator methods. A positive value of β indicates an 'upward trend' (increasing values with time), while a negative value of β indicates a 'downward trend'. Here, the slope ($T_i$) of all data pairs is computed as (Sen, 1968). In general, the slope $T_i$ between any two values of a time series x can be estimated from:

[2] PDSI has been interpreted as wet (greater than 2), normal or near normal (−1.99 up to 1.99) and drought (less than −2) (WMO, 2005; Antofie et al., 2015).

$$T_i = \frac{x_j - x_i}{j - i} \quad (5)$$

where $x_j$ and $x_k$ are considered as data values at time j and k (j > i) correspondingly. The median of these N values of $T_i$ is represented as Sen's estimator of slope which is computed as $Q_{med} = T_{(N+1)/2}$ if N appears odd, and it is considered as $Q_{med} = [T_{N/2}+T_{((N+2)/2)}/2]$ if N appears even. A positive value of $Q_i$ indicates an upward or increasing trend and a negative value of $Q_i$ gives a downward or decreasing trend in the time series.

## 3. Results and discussion

Data validation analysis results revealed that rainfall data obtained from GPCC V7 has been strongly correlated with the gauge station data than CRU data. The combined average gauge rainfall for the basin (average of Mekaneselam, Kelela, Wereillu, Kabie, Wegidi and Guguftu; see Table 1) was found to be highly correlated with GPCC V7 ($r = 0.72$; $p < .001$) while the correlation coefficient with CRU was low and non-significant ($r = 0.27$, $p > .1$). Furthermore, comparison was computed to test whether the data from gauge stations and satellite follow the same distribution or not using a nonparametric test called Kolmogorov-Smirnov test. We failed to reject the null hypothesis (the gauge station data and GPCC V7 data follow the same distribution) because the p-value was greater than the required threshold. On the other hand, the result for CRU was significant and we accept the alternative hypothesis (the distribution of the two samples are different) which evidenced better compatibility of the gauge station data with GPCC V7 than CRU data. In short, very strong agreement between the gridded precipitation data obtained from GPCC V7 and the average of reference rain gauge station data was found.

The annual and seasonal mean of time series data of climatic parameters, particularly temperature (maximum and minimum) and precipitation were analyzed using MK test for *Woleka* sub-basin. Table 2 shows MK statistics and p-values derived at 10% and 5% level of significances. In the MK test, parameters like Kendall's tau, S statistic, and the Z statistic were considered to identify the increasing or decreasing trend in the time series of climatic parameters. The test results are discussed in detail separately for each parameter.

**Table 1**
Characteristics of stations for recorded precipitation and temperature data.

| Station Name | Latitude | Longitude | Altitude | Period |
|---|---|---|---|---|
| *Woleka*[a] | 10°15′-10°55′N | 38 25′-39°30′E | 1070–4200 m | 1901–2014 |
| Mekaneselam | 10.61°N | 38.76°E | 2620 m | 1982–2015 |
| Guguftu | 10.97°N | 39.41°E | 3829 m | 1987–2014 |
| Kabie | 10.87°N | 39.47°E | 2810 m | 1981–2015 |
| Wereillu | 10.6°N | 39.42°E | 2740 m | 1963–2015 |
| Kelela | 10.37°N | 38.8°E | 2580 m | 1993–2015 |
| Wogdi | 10.55°N | 38.7°E | 2450 m | 1996–2015 |

[a] Data were taken from satellite sources (GPCC V7 and CRU TS 3.23).

### 3.1. Descriptive statistics and variability analysis (rainfall)

The mean annual rainfall of the area during the study period was 1151.4 mm with 182.44 mm standard deviation and 15.85% CV. The minimum and maximum ever recorded rainfalls were 783.7 mm (in 1984- the driest year) and 1899.5 mm (in 1947-the wettest year) per year respectively. The result of normality test (using Kolmogorov-Smirnov and Shapiro-Wilk tests) for the distribution type indicated that *kiremt* rainfall data of the area is approximately normally distributed at a significance level of 5%; while *belg* and annual rainfall data were not found to be normally distributed. As depicted in Table 2, summer is the major rain season in the study area which contributes about 74.4% of the total rainfall (where nearly 56% comes only in two months: July and August while June and September contributed 6.4 and 12.1 percent of the summer rainfall respectively) which clearly revealed the presence of high concentration of rainfall. The short rainy season which lasts from February to April/May (called *belg*) also contributes a substantial amount of rainfall (around 12.8% of the total). When the rainfall amount of the recent decades (1981–2013) is compared with the first four decades of the $20^{th}$C, a dramatic reduction in annual mean and *kiremt* (main rainy season) had recorded. For instance, the mean annual and *kiremt* rainfall (June–September) in the study area from 1901 to 1940 was 1188.5 and 890.11 mm respectively. This amount had decreased to 1167.21 and 871.98 mm during 1941–1980 for annual and *kiremt* respectively. Further decrement had been recorded from 1981 to 2013 which became 1087.31 mm (for annual) and 797.5 mm (for *kiremt*). That means, mean annual and *kiremt* rainfall has decreased, on average, by 101.19 mm and 92.61 mm respectively in the past three decades as compared with the first four decades of the last century. On the other hand, the total amount of *belg* rainfall had shown no significant change through time (it was 149.46, 148.57 and 143.59 mm for 1901–1940, 1941–1980 and 1981–2013 respectively). As depicted in Table 2, though the declining trend of *belg* rainfall is not statistically significant, the CV (56.57) is higher than that of *kiremt* rainfall (17.51) which implies more interannual variability of *belg* rainfall than *kiremt* one. The result agrees with the findings of Yilma and Zanke (2004), Aklilu (2006), Rosell and Holmer (2007), Cheung et al. (2008), Viste et al. (2013) and Arragaw and Woldeamlak (2017) where more variability in *belg* rainfall than the *kiremt* rainfall in most parts of Ethiopia was disclosed. Philippon et al. (2002) also found a strong interannual variability over the last four decades in equatorial East Africa as opposed to the long *kiremt* rains. Using a linear regression model (see Fig. 2), the rate of change is defined by the slope of

**Table 2**
Basic statistics and MK trend analysis of rainfall in Woleka sub-basin (1901–2013).

| Month | Min | Max | Mean | % | SD | CV(%) | MK test | Sen's slope |
|---|---|---|---|---|---|---|---|---|
| January | 0 | 94.68 | 13.73 | 1.2 | 18.96 | 138.09 | 0.0623 | 0.0183 |
| February | 0 | 140.33 | 27.24 | 2.4 | 28.214 | 103.58 | **−0.1132*** | −0.0671 |
| March | 0 | 250.49 | 59 | 5.1 | 45.19 | 76.59 | −0.0264 | −0.0505 |
| April | 0 | 281.02 | 61.19 | 5.3 | 43.71 | 71.43 | 0.0299 | 0.0505 |
| May | 4.36 | 293.14 | 73.66 | 6.4 | 50.37 | 68.38 | −0.0708 | −0.1313 |
| June | 11 | 244 | 73.58 | 6.4 | 45.53 | 61.88 | −0.0705 | −0.1214 |
| July | 100 | 519.09 | 318.41 | **27.7** | 72.31 | 22.71 | −0.0338 | −0.1059 |
| August | 146.6 | 594.55 | 325.26 | **28.2** | 67.18 | 20.65 | −0.0875 | −0.2569 |
| September | 16.9 | 518.86 | 139.4 | 12.1 | 62.69 | 44.97 | **−0.1779**** | −0.4263 |
| October | 0 | 203.34 | 33.52 | 2.9 | 33.55 | 100.09 | **0.1195*** | 0.1033 |
| November | 0 | 105.56 | 16.52 | 1.4 | 22.68 | 137.29 | −0.0626 | −0.0208 |
| December | 0 | 66.52 | 9.91 | 0.9 | 13.27 | 133.91 | −0.0319 | −0.0045 |
| *Belg* (FMA) | 2.054 | 626.12 | 147.43 | **12.8** | 83.4 | 56.57 | −0.0149 | −0.0416 |
| *kiremt*(JJAS) | 401.9 | 1331.3 | 856.65 | **74.4** | 150.0 | 17.51 | **−0.1723**** | −0.9699 |
| Annual | 783.7 | 1899.5 | 1151.4 | 100 | 182.44 | 15.85 | **−0.1375**** | −1.1236 |

Note: * and ** statistically significant at 0.1 and 0.05 alpha level of significance respectively.

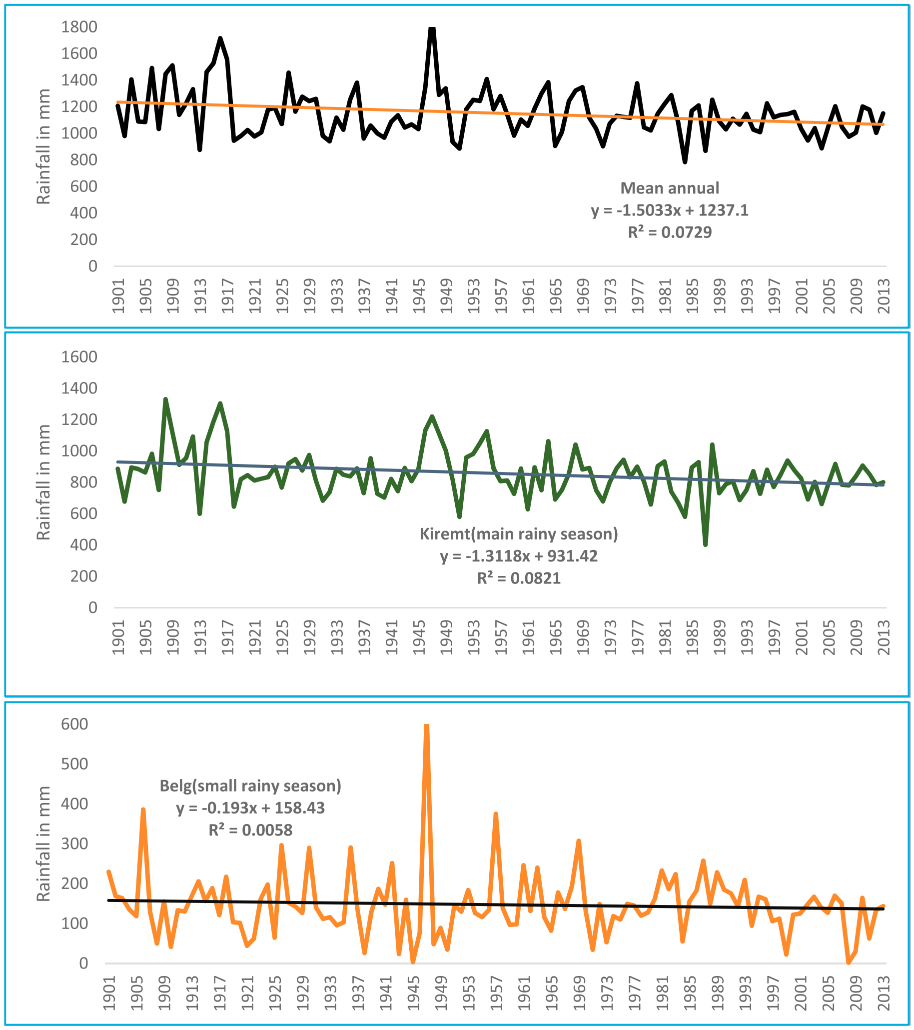


**Fig. 2.** Rainfall pattern of (Annual, *kiremt* and *belg*) *Woleka* sub-basin (1901–2013).

regression line which in this case is about −1.503 mm/year, −0.193 mm/year and −1.312 mm/year for annual, *belg* and *kiremt* rainfall respectively. The declining trend for annual and *kiremt* rainfall was found to be statistically significant while that of *belg* was non-significant (Table 3). The annual rate of reduction is higher which is caused by the reduction of the main (*kiremt*) rainfall season.

Independent samples *t*-test was employed to compare the mean difference in annual rainfall before and after 1960. Statistically significant mean difference was obtained (t (111) = 2.423; p < .05) at 95% level of significance. The mean annual rainfall for the period 1901–1960 (m = 1189.67; SD = 212.7) was statistically higher than the mean annual rainfall of the basin for the period 1961–2013 (m = 11 108.1; SD = 129.4). The result revealed that rainfall has been decreased since the 1960s. The rainfall anomaly also witnessed for the presence of inter-annual variability and the trend being below the long-term average becomes more pronounced particularly since the 1960s (Fig. 3).

Very low values of rainfall anomaly correspond to severe drought periods and the value in the study area ranges from +4.23 in 1947 to −1.89 in 1984. Historical droughts in Ethiopia had been linked with ENSO events in the past (Shanko and Camberlin, 1998; NMA, 2007; Daniel, 2011; Kassa, 2015). Recent documented droughts of 1913–14,1920–21, 1932–33, 1965, 1974, 1984, 1987, 1991–1992, 1993–94, 2002, 2009, 2012, 2015/16 were either coincide or follow El Nino events shortly. As depicted Fig. 3; the rainfall anomaly for these drought years were found to be very low. On the other hand, regression output indicated that mean annual and mean *kiremt* rainfall had decreased by 15 and 13 mm/decade respectively and the result was statistically significant at 0.05 level of significance (see Table 3 and Fig. 2). The precipitation concentration index (Table 4) revealed the presence of a high and very high concentration of rainfall. Similar high concentration of rainfall was reported by Arragaw and Woldeamlak (2017) in central highlands of Ethiopia.

It is revealed from the PDSI result (Fig. 4) that since the early 2000s the study area has experienced successive years with more drought years as measured in PDSI while 1990s were better than the preceding decade (1980s). The number of drought years has increased from 2 (1951–1980) to 13 during 1981–2013.

**Table 3**
Linear regression result (*belg*, *kiremt* and annual rainfall) (1901–2013).

| Season | Change in rainfall (mm/ year) | p-value | $R^2$ | CV | % of total rainfall |
|---|---|---|---|---|---|
| *Belg* | −0.193 | .425 | .006 | 56.57 | 12.8 |
| *kiremt* | −1.312 | .002 | .082 | 17.51 | 74.4 |
| Annual | −1.503 | .004 | .073 | 15.85 | 100 |

### 3.2. Trend analysis result

The MK test and Sen's slope estimator (with Pettitt's homogeneity test) were applied to the time-series data from 1901 to 2013 for *Woleka* sub-basin. During trend analysis, the autocorrelation has been taken into account using the Hamed and Rao method. The results of MK test for

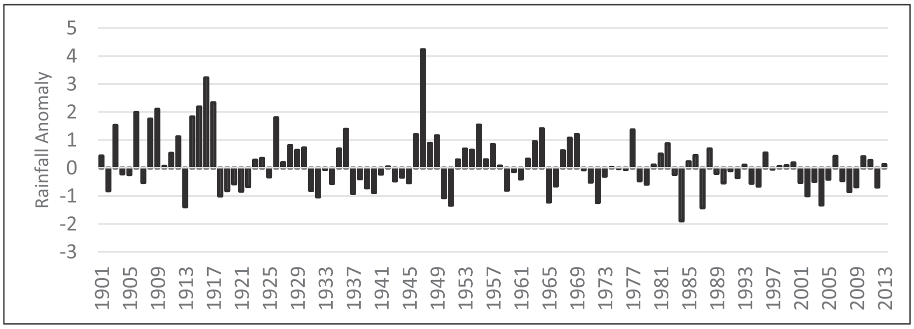


**Fig. 3.** Rainfall Anomalies of *Woleka* sub-basin (1901–2013) relative to 1961–1990 average.

**Table 4**
Precipitation Concentration Index (PCI) of Woleka sub-basin (1901–2013).

| Index | Description | Number of years (1901–2013) |
|---|---|---|
| <10 | Low precipitation concentration (almost uniform) | 0 |
| 11–15 | Moderate concentration | 3 |
| 16–20 | High concentration | 65 |
| ≥21 | Very high concentration | 45 |
| Mean PCI (1901–2013) = 20.18(High concentration of Rainfall) | | |

trend analysis are presented in Table 2. The trend analysis has been done for all months of the year, *belg* and *kiremt* seasons and the whole year. The results of MK test for monthly precipitation data revealed a statistically significant decreasing trend for the month of January (at 10% level of significance) and September (at 5% level of significance). On the other hand, a statistically significant increasing trend was observed for October (at 10% level of significance). The remaining months have a non-significant decreasing trend except January where a non-significant increasing trend was observed. Statistically significant decreasing trend was obtained for *kiremt* season (the major rain season in the study area) and for yearly annual at 10 and 5% of level of significances respectively. The Pettitt's homogeneity test revealed the presence of homogeneity except for September, October and *kiremt* season. The output agrees with the result disclosed by Osman and Sauerborn (2002); Cheung et al. (2008); Negash et al. (2013) where statistically significant declining *kiremt* rainfall at watershed level was reported in different part of Ethiopia including the central highland (where *Woleka* sub-basin also belongs). The results are different from the findings of Daniel et al. (2014) where statistically non-significant increasing trend was recorded in all seasons (including annual time scale) and Arragaw and Woldeamlak (2017) where statistically significant increasing trends in July and November in *dega* and *woinadega* agroecologies of central highlands of Ethiopia were reported. In our study, highly variable but non-significant decreasing trend of *belg* rain through time was obtained which coincides with Arragaw and Woldeamlak (2017) where *belg* rainfall showed a significant decreasing trend. The statistical test result coincides with the information obtained from interview and experience of the smallholder farmers except for the case of *belg* rainfall where a drastic reduction in amount and variability in the distribution of *belg* rainfall has been reported by smallholder farmers.

Case 1: 'No more *belg* rainfall'.

An informant from the lower *woinadega* area in Borena woreda (aged 56 and a father of 6 children) shared his experience regarding the contribution of small rain (called *belg*) as:

> [… …] *for agrarian communities, belg rain fall is as vital as that of kiremt due to different reasons. Availability of water and pasture becomes scarce after the long dry season (which extends from November–February). It is the belg rainfall which saves our livestock. Land preparation for kiremt planting should be undertaken ahead of time during winter and it is the belg rain which makes the task easy. Irrigation carried out using river diversion, springs and night storage modalities is also supplemented by belg rainfall whenever the availability of water during bega becomes less. Besides, we are using the belg rainfall to plant crops (like maize and sorghum) which need longer gestation period for harvesting. In short, belg rainfall is crucial for smallholder farmers. But, we lost all these opportunities due to failure or/and inadequate belg rain for the successive years.*

This interview result testified the importance of *belg* rainfall in the study area not only for belg dependent areas but also for *kiremt* rainfall regimes as well.

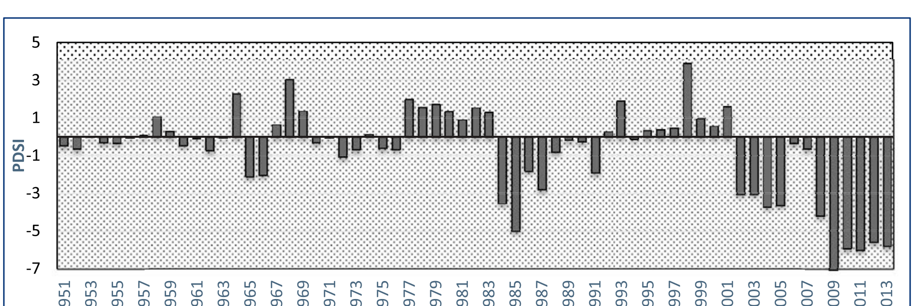


**Fig. 4.** Palmer Drought Severity Index (PDSI) of *Woleka* sub basin.

The major problem, as far as rainfall distribution is concerned, as narrated by elders in the study area is not the amount rather the variability and change on onset and cessation periods. The rain onsets late-recently the first two weeks of July and end up before September (which was formerly started around the mid of June and continued up to end of September). As depicted in Fig. 5, rainfall which is very crucial for *belg* (which is expected to begin in February), for *meher* (expected to onset in June) and September (the flowering stage of *meher* crops) has been decreasing. Rainfall during September is essential because the crops during this time are at flowering or ripening stage and require more water for maturation. Slight perturbations such as temperature fluctuations at critical points in crop growth can have considerable effects on later productivity. On the other hand, rainfall in October and November is not needed (it is time for harvesting particularly for *kolla* and lower *woinadega* agroecologies). What farmers have experienced for the last three decades has been a paradox: little or no rain when needed and more than enough when rain is not actually necessary. Such abnormality was described by an elder as- 'valuable resource in wrong time'. Basing their experience, they have stated that what determines the productivity and good harvest is the rainfall distribution in maturing period-particularly end of August and September.

Trend analysis was also conducted based on gauged data and mixed result was obtained. As depicted in Table 5, *belg* rainfall has been decreased in three stations (Mekaneselam, Kabie and Wereillu) and the trend is statistically significant. On the other hand, a decreasing but insignificant trend has been detected for Guguftu, Kelela and Wogdi stations. Furthermore, a decreasing trend has been observed for February which is a critical month for *belg* growing areas (the time when *belg* rain onsets) which revealed late onset of the *belg* rainfall. Overall, a decreasing trend in *belg* rainfall has been detected in the sub-basin and the result agrees both with the responses of farmers and the existing results. For the main rainfall (*kiremt*), no statistically significant trend was obtained except Guguftu where a statistically significant decreasing trend was found. Overall rainfall in the sub-basin has shown an insignificant decreasing trend. In the sub-basin, *kiremt* rainfall covers 68–78 percent of the total rainfall while *belg* constitutes 4.3–24percent of the rainfall. More variability of rainfall has been detected for *belg* rainfall than kiremt one.

### 3.3. Temperature trend analysis

An increase in temperature is among the manifestations of global climate change. Analysis of annual and monthly temperature data was undertaken to detect the variability and trend of temperature change in the study area for the periods of 1901–2014. Table 6 portrayed the monthly and annual temperature (minimum, maximum and mean) and its trend in the period of under examination. The mean temperature in the study area ranges from 9.96 °C (minimum) to 24.5 °C (maximum) with annual average temperature of 17.2 °C. Using a linear regression model, the rate of change is defined by the slope of the regression line (Fig. 6) which in this case is about 0.046, 0.067 and 0.026 °C per decade for mean, minimum and maximum temperature respectively during the period of 1901–2014. This finding is very close to global warming rate which is estimated 0.6 °C for the past century. The long range anomalies (Fig. 7) of mean annual temperature showed inter-annual variability while the trend after 1990 has been higher than the long term average which is evidence for the presence of warming trend since the last decade of 20th century.

As demonstrated in Table 6, MK trend test result revealed that mean and minimum average temperatures have been increasing through time significantly at 95% confidence level. The trend for monthly maximum

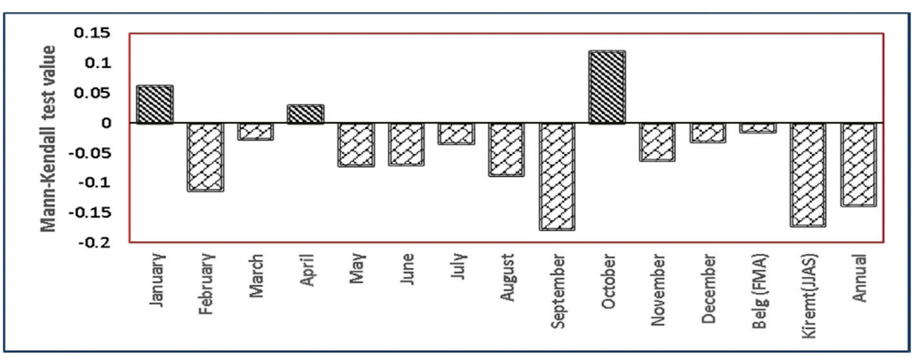


**Fig. 5.** Mann-Kendall trend test result of rainfall in *Woleka* sub-basin (1901–2014).

**Table 5**
Mann-Kendal rainfall and temperature trend analysis (Based on gauge stations).

| Variable | Attribute | | | M/Selam | Guguftu | Kelela | Kabie | Wereillu | Wogdi |
|---|---|---|---|---|---|---|---|---|---|
| Rainfall | Belg | % | | 24 | 17 | 4.3 | 20 | 17 | 17 |
| | | CV | | 40.9 | 41.8 | 98 | 51.9 | 84 | 44.7 |
| | | MK | Feb | **−0.24*** | −0.16 | 0.098 | −0.18 | **−0.22**** | 0.16 |
| | | | March | −0.09 | −0.06 | **−0.31**** | −0.08 | −0.06 | −0.10 |
| | | | April | **−0.42***** | 0.05 | −0.19 | −0.14 | −0.05 | −0.16 |
| | | | May | 0.04 | 0.21 | −0.06 | −0.17 | **−0.18*** | 0.14 |
| | | | Total | **−0.26**** | −0.02 | −0.064 | **−0.22*** | **−0.27***** | −0.08 |
| | Kiremit | % | | 68 | 76 | 78.2 | 76 | 78 | 76 |
| | | CV | | 23.9 | 22.3 | 20.7 | 25.1 | 40.1 | 13.7 |
| | | MK | June | 0.03 | −0.17 | −0.01 | 0.12 | 0.004 | 0.12 |
| | | | Sept | −0.06 | 0.069 | −0.05 | −0.12 | 0.032 | 0.12 |
| | | | Total | 0.18 | **−0.25*** | −0.11 | 0.18 | 0.098 | −0.07 |
| | Annual | CV | | 19.9 | 19.5 | 20.6 | 20.2 | 39.4 | 12.4 |
| | | MK | Total | 0.024 | −0.21 | −0.21 | 0.12 | −0.038 | −0.11 |
| Temp | Annual Mean | | | 16.62 | 9.42 | | 13.75 | 15.5 | 18.33 |
| | MK test result | Min | | **0.4***** | 0.21 | | **0.24**** | **0.68***** | 0.13 |
| | | Max | | **0.47***** | **0.43***** | | **0.58***** | **0.48***** | **0.63***** |
| | | Mean | | **0.46***** | **0.32***** | | **0.612***** | **0.74***** | **0.53***** |

Note: *, **, *** statistically significant at 0.1, 0.05 and 0.01 alpha levels.

**Table 6**
Monthly and annual MK result of temperature (1901–2014) based on gridded data.

| Month | Mean | $T_{min}$ | | | TMax | | | $T_{mean}$ | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | ZMK | P-value | slope | ZMK | P-value | slope | ZMK | P-value | slope |
| Jan | 15.7 | .1938 | **.0023** | .0091 | .0303 | .6347 | .0011 | .1601 | **.0117** | .0048 |
| Feb | 17.1 | .1898 | **.0028** | .0094 | .0802 | .2077 | .0041 | .1610 | **.0112** | .0059 |
| Mar | 18.3 | .2784 | **.0001** | .0102 | −0.002 | .9766 | 0 | .1781 | **.005** | .0048 |
| Apr | 18.8 | .3163 | **.0001** | .0108 | .1709 | **.0071** | .0081 | .2668 | **.0001** | .01 |
| May | 19.3 | .3024 | **.0001** | .0107 | .1018 | .1092 | .0042 | .2322 | **.0003** | .0079 |
| June | 19.1 | .2677 | **.0001** | .0083 | −0.064 | .3153 | −0.0031 | .0702 | .2694 | .0024 |
| July | 17.7 | .1377 | **.0304** | .0037 | .0449 | .4806 | .0015 | .1114 | .0795 | .0031 |
| August | 17.1 | .2014 | **.0015** | .0054 | .0908 | .1534 | .0031 | .1753 | **.0058** | .0045 |
| Sep | 17.1 | .1668 | **.0088** | .0037 | .1034 | .1039 | .0038 | .1529 | **.0161** | .0041 |
| Oct | 16.2 | .1442 | **.0232** | .0046 | .0521 | .4134 | .0022 | .1654 | **.0092** | .0035 |
| Nov | 15.5 | .1897 | **.0028** | .0075 | .1923 | **.0025** | .0078 | .1975 | **.0019** | .0065 |
| Dec | 14.9 | .1384 | **.0293** | .0063 | .0667 | .2946 | .0029 | .1221 | .0546 | .0042 |
| Average | **17.2** | .3609 | **.0001** | .0083 | .0883 | .1642 | .0025 | .2669 | **.0001** | .005 |

Bolded values indicate statisticaly significant results.

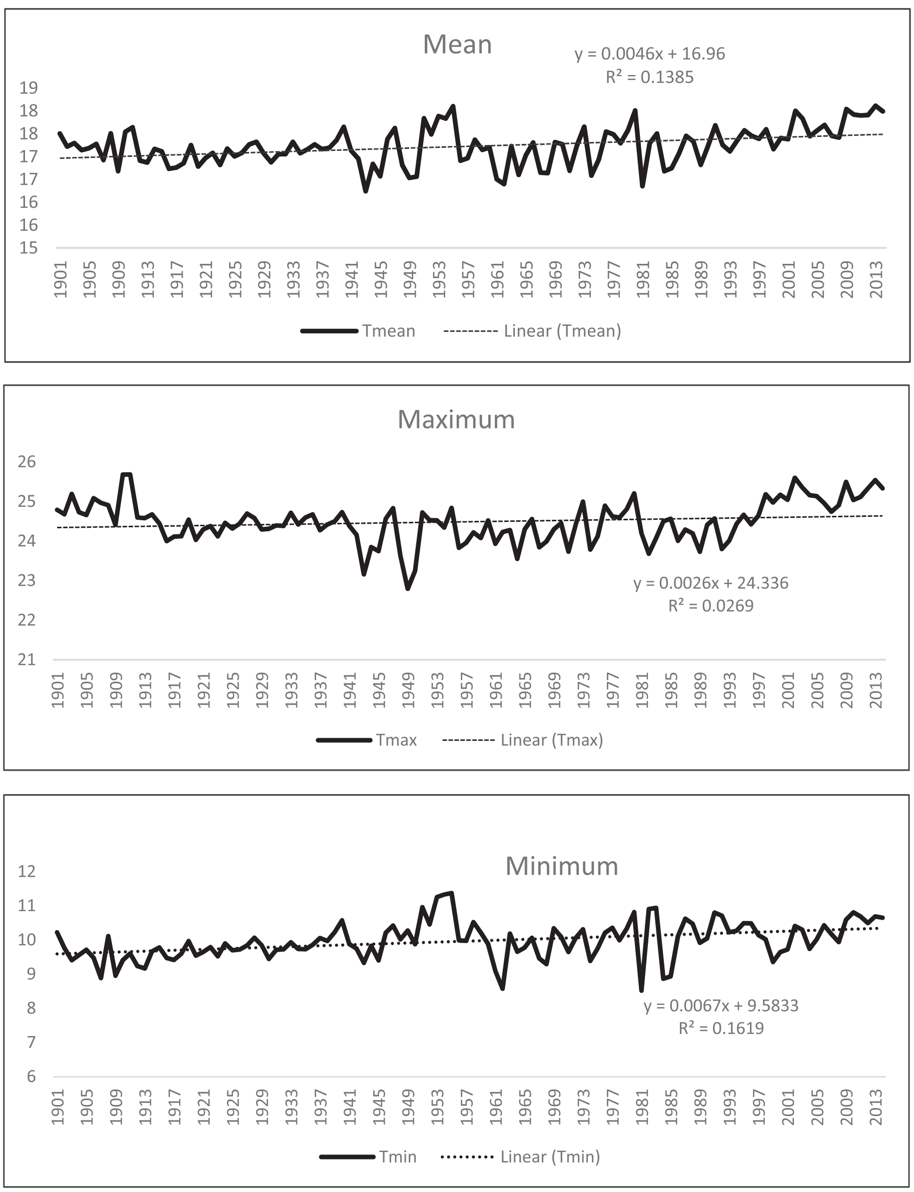


**Fig. 6.** Temperature pattern (Mean, Maximum and Minimum) of *Woleka* sub-basin (1901–2013) with linear least square regression lines.

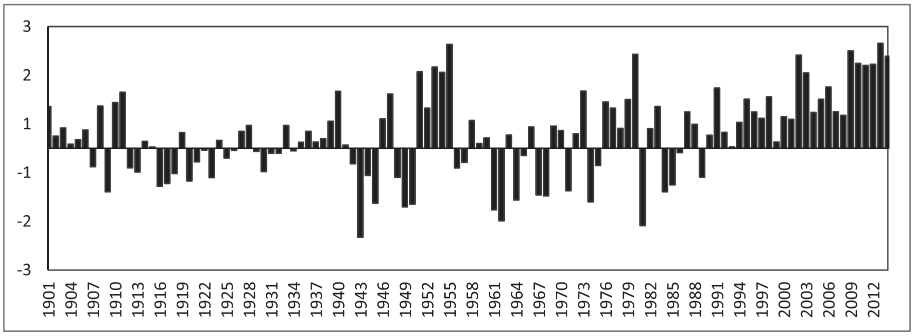

**Fig. 7.** Temperature anomalies ($O_C$) of *Woleka* sub-basin (1901–2014) relative to 1961–1990 average.

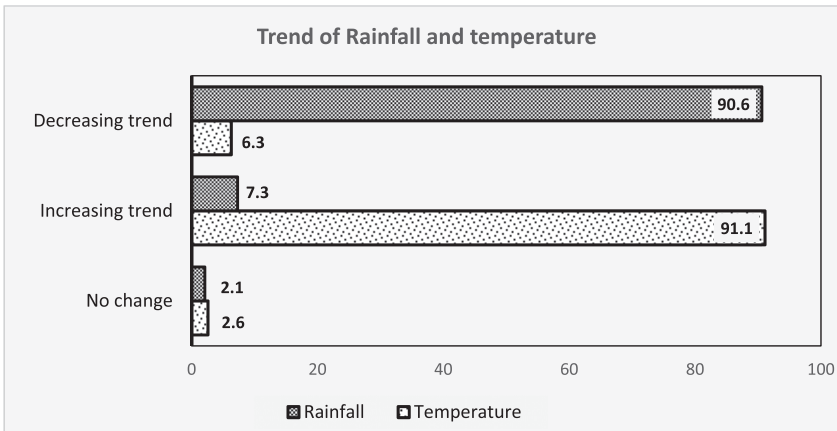


**Fig. 8.** Response of farmers on the trend of Temperature and Rainfall for the last 30 years.
Source: Own survey (2015/16)

temperature showed a non-significant increasing trend (except for the months of April and November) while a significant increasing trend for minimum monthly temperature was obtained for all months. The overall increase in annual temperature observed in the study area is attributed to an increase in the minimum temperature (the increment of the minimum temperature is more pronounced than the maximum). The empirical result agrees with the views of respondents; particularly farmers in *woi-nadega* and *dega* agroecologies have confirmed an increasing trend of temperature. The result is in agreement with the findings of Stafford et al. (2000), Conway et al. (2004), Tabari and Talaee (2011), Roy and Das (2013) and Daniel et al. (2014) where the increasing trends in the $T_{min}$ series were higher than those in the $T_{max}$ series. Based on the gauge data, temperature trend (both minimum, maximum and average) has shown a statistically significant increasing trend.

Based on the responses of surveyed household heads (Fig. 8), the temperature situation in their locality has been increasing (91.1%) as compared with the situation just 30 years back and the amount of rainfall has been decreasing (90.6%). Around 55.2 percent of them responded that rainfall has been decreased for both the main and short rainy seasons. A substantial proportion (31.5%) reported *belg* (short rainy season) has manifested more variability and inconsistency than main rain season while it was only 13.3 percent for the main rainy season. The response of smallholder farmers was different from the result of trend analysis, particularly for *belg* rainfall pattern, which proved for the incorporation of the actual experience of farmers while analyzing trends of meteorological variables.

Case Study 2: 'Farming under uncertainties'.

An elder (65 years old) from *kolla* agroecology (Dokis kebelle-Borena Woreda) has shared his experience regarding the variability and erratic nature of rainfall as follows:

> *… I have lived in this area since my childhood and have seen a lot in my life. Since the last years of the former government (Derge regime), life becomes complicated. One major challenge for us as a farmer is shortage and unpredictability of the rain seasons (both belg and meher). For instance, there was a total failure of meher rain in 2015/2016 cropping season and we had produced nothing. Things are becoming less reliable and unable to predict what will come next; rain starts late and ends very early; prolonged dry days lasting even for weeks during the main rainy season are common and intensifies the incidence of crop pests and diseases. In short, we are farming under such uncertainties … we thrust our God and planting even in the times of no good rain. This testimony is in line with the statistical output of meteorological variables where PDSI and variability have increased through time. Besides, the lifetime experience of farmers regarding the early cessation of main rainfall is in agreement with output of the MK test where statistically significant decreasing trend for September rainfall (which is very vital in agricultural production system) was found.*

Sampled households were asked to point out the manifestations of rainfall changes for the last 30 years. As compared with three decades ago, rainfall currently onsets late and ends early. Furthermore, the majority of respondents (97.7%) have agreed on the presence of variability in amount and distribution. Unusually prolonged dry days during summer or/and *belg* seasons has become a common phenomenon for the last three decades. Additionally, rainfalls are erratic and shortening of growing season has been revealed in the recent past. As narrated by elders, there is a shift in the agricultural calendar due to changes in the cessation and onset days and months of the rain; and they have reflected their pessimistic outlook for the future particularly in the agricultural sector. Though the overall picture seems like this, statistically significant disparities were observed in some cases agroecologically.

## 4. Discussion and conclusion

The study area is under the bimodal (with single maxima) rainfall regime where it receives the main rainfall during summer (June to September) while *belg* (February to April/May) rainfall provides a substantial amount of rainfall. Summer rainfall is highly concentrated where July and August alone covers more than half of the *kiremt* rainfall. The mean average rainfall concentration reveals the presence of high concentration of rainfall. The rainfall anomaly also witnessed for the presence of inter-annual variability and the trend being below the long-term average becomes more pronounced particularly since the 1960s. Based on PDSI value, the number of drought years has been increasing through time and the study area has encountered successive years of drought particularly since the early 2000s. Mean annual and *kiremt* rainfall have decreased, on average, by 101.19 mm and 92.61 mm respectively in the past three decades as compared with the first four decades of the last century. The model result for *belg* rainfall had shown no significant change through time (which contradicts with the experience of farmers). Annual, *belg* and *kiremt* rainfall have decreased with a rate of 15.03, 1.93 and 13.12 mm per decade respectively. The declining trend for annual and *kiremt* rainfall was found to be statistically significant while that of *belg* was non-significant. Though the declining trend of *belg* rainfall is not statistically significant, the CV is higher than that of *kiremt* rainfall which implies more inter-annual variability of *belg* rainfall than *kiremt*.

The results of MK trend analysis test found that statistically significant decreasing trend was obtained for the main rain season (*kiremt*) and for yearly annual which coincides with the life time experience of farmers. Furthermore, a statistically significant decreasing trend for the month of September, which has a determinant effect on crop productivity (because rainfall is essential in the maturing stages of crops), was obtained. On the other hand, a statistically significant increasing trend was observed for October which has an adverse impact on harvesting stage of crops. Besides, highly variable but a non-significant decreasing trend of *belg* rain through time was recorded. The major problem as far as rainfall distribution is concerned in the study area is more of the inconsistency as well as a change in onset and cessation periods than the total amount. The rain onsets late and ends up very early-which makes the cropping calendar being shorter than before. Moreover, erratic rainfall as well as prolonged dry-spell periods during the main rain season have reported as major phenomena which adversely affect agricultural activity. What farmers are experiencing for the last three decades has been a paradox: little or no rain when needed and more than enough when rain is not actually necessary.

The mean temperature in the study area ranges from 9.96 °C to 24.5 °C with annual average temperature of 17.2 °C. The rate of change of temperature was found to be 0.046, 0.067 and 0.026 °C per decade for mean, minimum and maximum respectively during the period of 1901–2014. The long-range anomalies of mean annual temperature showed inter-annual variability while the trend after 1990 has been higher than the long-term average which is evidence for the presence of warming trend since the last decade of 20th century. The Mann-kendall trend analysis test result revealed that mean and minimum average temperatures have been increasing through time significantly. The trend for maximum temperature exhibited non-significant increasing trend while a significant increasing trend for minimum temperature was obtained for all months (the rate for the minimum is more pronounced than the maximum). The overall increase in annual temperature observed in the study area is, therefore, largely attributed to an increase in the minimum temperature. The empirical result agrees with the views of respondents particularly farmers in *woinadega* and *dega* agroecologies has confirmed an increasing trend of temperature through time. From the discussion, we can conclude that rainfall in the study area is characterized by high CV, erratic, unreliable and concentrated into two months. Annual and summer rainfall have revealed statistically significant declining trend while decreasing but non-significant trend was obtained for *belg*. Furthermore, late onset, early cessation and prolonged dry spell periods are becoming common which adversely affect the agricultural system. It was also found that very low values of rainfall anomaly which corresponds to severe drought periods had been linked with ENSO events where they coincide or follow the episode shortly. It is, therefore, imperative to adjust the agriculture activity with the variability situation and design planned climate change adaptation strategies so as to enhance the adaptive capacity and resilience of rainfed dependent smallholder farmers.

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