

## Research Article

# Climate Variability and Farmers' Perception in Southern Ethiopia

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Received 1 February 2019; Accepted 11 April 2019; Published 2 June 2019

Academic Editor: Gabriele Buttafuoco

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The study aims to analyze climate variability and farmers' perception in Southern Ethiopia. Gridded annual temperature and precipitation data were obtained from the National Meteorological Agency (NMA) of Ethiopia for the period between 1983 and 2014. Using a multistage sampling technique, 403 farm households were surveyed to substantiate farmers' perceptions about climate variability and change. The study applied a nonparametric Sen's slope estimator and Mann-Kendall's trend tests to detect the magnitude and statistical significance of climate variability and binary logit regression model to find factors influencing farm households' perceptions about climate variability over three agroecological zones (AEZs). The trend analysis reveals that positive trends were observed in the annual maximum temperature,  $0.02^{\circ}\text{C}/\text{year}$  ( $p < 0.01$ ) in the lowland and  $0.04^{\circ}\text{C}/\text{year}$  ( $p < 0.01$ ) in the highland AEZs. The positive trend in annual minimum temperature was consistent in all AEZs and significant ( $p < 0.01$ ). An upward trend in the annual total rainfall ( $10\text{ mm}/\text{year}$ ) ( $p < 0.05$ ) was recorded in the midland AEZ. Over 60% of farmers have perceived increasing temperature and decreasing rainfall in all AEZs. However, farmers' perception about rainfall in the midland AEZ contradicts with meteorological analysis. Results from the binary logit model inform that farmers' climate change perceptions are significantly influenced by their access to climate and market information, agroecology, education, agricultural input, and village market distance. Based on these results, it is recommended to enhance farm households' capacity by providing timely weather and climate information along with institutional actions such as agricultural extension services.

## 1. Introduction

The global average temperature has increased by  $0.78^{\circ}\text{C}$  between 1850 and 2012. Intergovernmental Panel on Climate Change (IPCC) [1] noted the projected increase will range from  $1.5^{\circ}\text{C}$  to  $2^{\circ}\text{C}$  towards the end of the 21<sup>st</sup> century. Many scholars have produced evidence of global climate change and their projections show that the rate of change will likely increase [2–4]. The case in Africa will be more pronounced than the global average, suggesting warming in all seasons [1]. Most regional studies use long-term changes in rainfall and temperature patterns as a proxy indicator of climate change.

East Africa region is not an exception. Studies have reported high variability in rainfall and the associated adverse effects of rainfall changes in East Africa [5–7]. The impact is primarily associated with higher instability in the interannual rainfall primarily affecting rainfall fed livelihood groups [8].

Various studies have investigated historical trends of climate change and variability in Ethiopia. For instance, a  $0.2^{\circ}\text{C}$  to  $0.28^{\circ}\text{C}$  rise per decade in the average annual maximum temperature between 1960 and 2006 was reported in recent studies [4, 9], whereas,  $0.37^{\circ}\text{C}/\text{decade}$  increase was observed in the minimum temperature between 1951 and 2006 [10]. A projection suggests that

Ethiopia will experience a  $1.7^{\circ}\text{C}$ – $2.1^{\circ}\text{C}$  increase in the mean temperature by 2050 [11].

As [12] pointed out, special attention should be paid to assessing farmers' climate change perception as it requires continued data collection from different contexts and dissemination of new knowledge due to the complex and dynamic nature of climate change [13]. Moreover, Broomer et al. [14] noted that perceived personal experiences can affect climate change belief and the corresponding adaptation and mitigation measures to be taken.

Some attempts have been made on the climate trend analysis in Ethiopia, reporting mixed findings. For example, an insignificant trend was reported on the annual rainfall amount in the Nile basin [15–21]. Similarly, a nonsignificant trend in annual and seasonal rainfall was reported in Southwestern Ethiopia [22] and North Ethiopia [23]. Other studies show positive trends in air temperature and negative trends in rainfall [24–27]. Other studies [28–30] observed both increasing and decreasing trends in the climate parameters, including extreme climate in the study area. However, none of the previous studies have linked their climate trend analysis with farmers' perceptions and its influencing factors.

The existing evidence for farmers' perception of climate change suggests that studies are of three types. The first group includes [31–34] that used Heckman probit selection model to study factors affecting farmers' perception of climate change and their adaptation strategies. The second group comprises of [35–37], which applied binary logit/probit and multinomial logit models focusing on factors influencing only adaptation strategies. Finally, [38, 39] used binary logit/probit/recursive bivariate probit model to examine factors impeding households' perception of climate change and their link with meteorological data.

The mentioned studies tried to document the trends in rainfall and temperature data at national, regional, and local levels. They reported complex patterns in the climate parameters. However, most of the studies emphasized on mean climate trend analysis using either station-based or downscaled data. Accessing the latter is difficult in the situation like the study Agroecological Zones (AEZs). Other studies focused on climate change perception with an emphasis on either factors affecting climate change perception and adaptation or both based on household surveys, mainly geographically confined to the Nile basin and Northern Ethiopia, with few others conducted in other parts of Ethiopia.

Even recent studies in Wolaita and its surroundings by other researchers [28, 29, 40] assessed only trends in extreme and mean climate and adaptation strategies to climate change, respectively. Others have examined the link between farmers' perception of climate change and trends of change in the meteorological data using station-based data and household surveys at national and subnational levels, which may not fully explain the situation at the local level. Cross-sectional data from farm households located at different AEZs have also been used for exploring factors affecting farmers' perception of climate change and linking recently promoted gridded time series data for analyzing trends in

the climate parameters. There is a paucity of studies that use gridded data sets to analyze climate trends relating to the household perception of climate change in Ethiopia.

This study puts emphasis on disaggregation by AEZs because of the increasing role of agroecology. This explains why agroecological-based approach is rapidly advancing as a sustainable farming approach, social movement, and scientific discipline [41]. Understanding the relation between national and Local level climate parameters as and farmers' views is crucial for drafting development plans and programs, early warning systems, and integrated adaptation strategies that fit the local reality. This study contributes to the rapidly advancing climate change and farmers' perception literature by providing empirical evidence of the climate trend analysis and factors affecting perceptions and their correlation with the trend results over AEZs in Southern Ethiopia.

In summary, the purpose of this study is to give a better understanding of recent changes and variability in the rainfall and temperature data and factors affecting farm households' perception of climate variability and change over three AEZs in Wolaita Zone, Southern Ethiopia. This paper is organized into four sections. Section 2 gives a brief account of the data and methodology. Section 3 presents and discusses the study results. Conclusions and recommendations are provided in Section 4.

## 2. Study Area, Sample Size, and Procedure and Methodology

**2.1. Study Area.** Wolaita Zone is located in Southern Nations and Nationalities People (SNNP) region. It lies between  $6.4^{\circ}$ – $7.1^{\circ}\text{N}$  and  $37.4^{\circ}$ – $38.2^{\circ}\text{E}$  (Figure 1). It is subdivided into three traditional AEZs: 56% of the area is a Midland (*Woyna-Dega*); 35% of the area is Lowland (*Kola*); and the rest 9% of the area is covered by Highland (*Dega*) [42]. The area generally has a highland relief that covers most parts of the midland while the peripheries are lowland areas (Figure 1). The altitude ranges from 501 meters in the lowlands at Bilate Tena to 3000 meters above sea level in the highlands of Damota mountain. The lowest average annual rainfall was recorded as 800 mm in Bilate Tena and the highest was 1200 mm in Wolaita Sodo. Rainfall is unpredictable by nature and variable, occurring in two different seasons. The pattern of rainfall distribution is bimodal. The main rainy season (*Kirmet*) begins in mid-June and extends to the end of September, whereas the *Belg* season/short rains extends from end of February to early April [42]. The average annual minimum temperature was observed to range between  $15.1^{\circ}\text{C}$  and  $25.1^{\circ}\text{C}$  in 2015/2016. However, temperature is usually high with minimal seasonal variability. The average maximum temperature was between  $17.1^{\circ}\text{C}$  and  $29.7^{\circ}\text{C}$ . In terms of livelihood activities, the area is characterized by a mixed farming involving the production of cereals, root crops, *Enset*, and coffee. Crop production is the main means of livelihood while livestock serves as a source of food, cash income, and insurance against uncertainty [42]. After [43], this study adopted the traditional AEZ grouping approach to

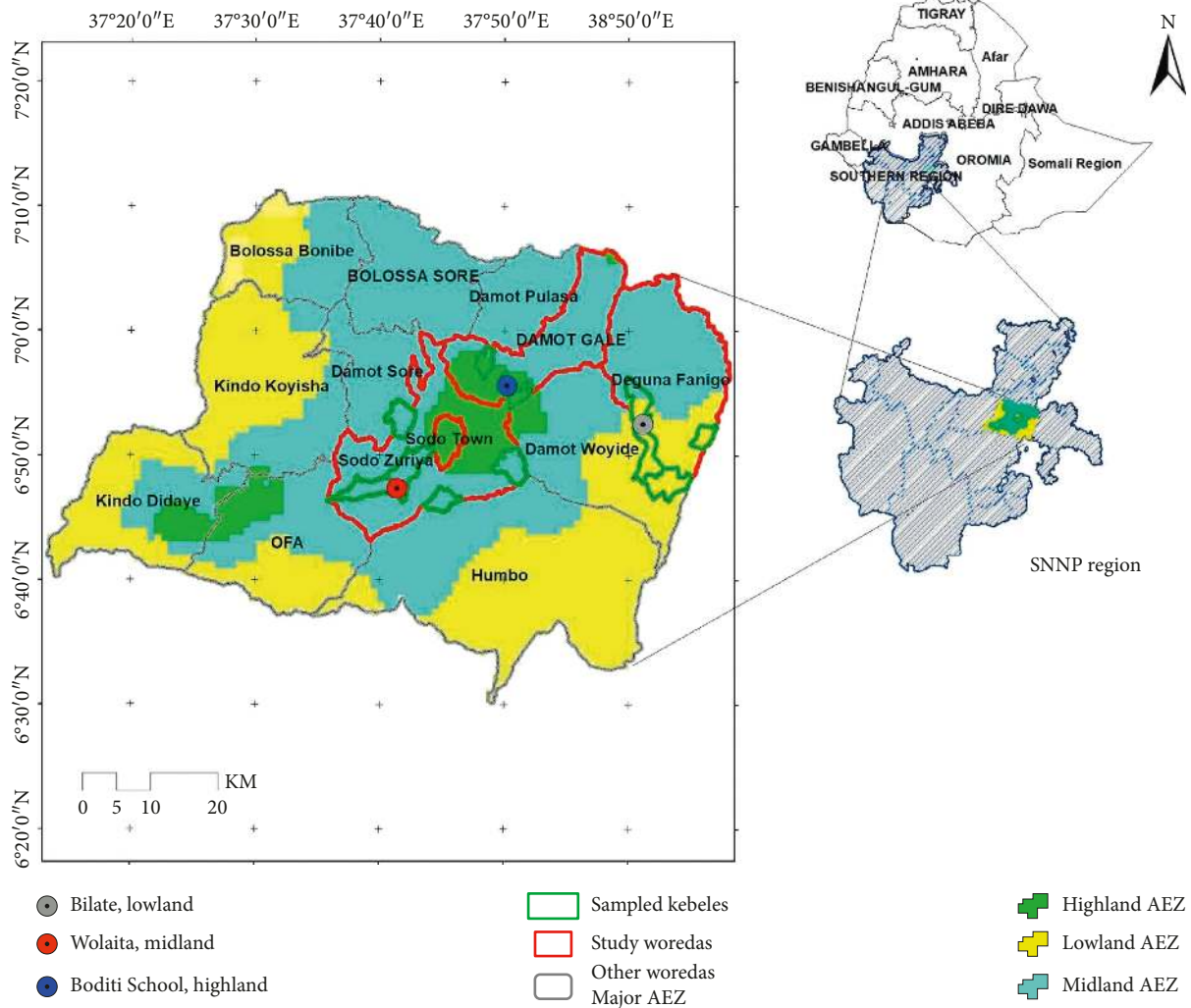


FIGURE 1: Location of the study agroecological zones.

compare and represent highland, midland, and lowland AEZ, respectively (Figure 1).

**2.2. Sample Size and Procedure.** Following Esayas et al. [30], this study is based on a gridded daily (4 km by 4 km spatial resolution) temperature and rainfall data running from 1983 to 2014. The data are a combination of two data sets. First, station data were used sourced from the National Meteorological Agency (NMA) of Ethiopia. Second, the satellite rainfall and temperature approximations obtained from the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) and the US National Aeronautics and Space Administration (NASA) were used. Data reconstruction was conducted by NMA in corporation with the International Research Institute for Climate and Society at Columbia University, USA. In other words, the gridded data set integrated quality-controlled station data from the national observation network with locally calibrated satellite-derived data that were used to fill spatial and temporal gaps in the Ethiopian national observations. Data

reconstruction was undertaken by the NMA in partnership with International Research Institute for Climate and Society at Columbia University, USA, whereas data calibration and validation were carried out by Reading University, UK.

Due to high missing values, poor data quality, and measurement errors on the station based data, the aforementioned gridded data set were used to address the data quality problems. On this account, this study considered three existing stations, which are located over the AEZs using the gridded data set for the purpose of comparison by AEZ, which in turn is assumed to represent each AEZ with the available climate data over the study period (1983–2014). The stations include Bilate (Lowland), Wolaita (Midland), and Boditi School (Highland) (Figure 1). The stations were selected purposively as they have long years (over 30 years) of observed temperature and rainfall data. The analysis period, 1983–2014, was chosen due to available data and to explore recent changes in temperature and rainfall, which help to recognize trends and data coverage across the AEZs. The gridded data can be accessed at NMA (<http://www.ethiomet.gov.et/>) for the climatic stations located in the AEZs.

In terms of survey design, the study employed a quantitative-dominant, qualitative mixed research design to select farmers for analyzing factors affecting perception of climate variability [44]. In selecting representative sample households, this research followed a three-stage sampling procedure. The approach allows taking small sample units from larger ones that offers an equal chance for all the elements chosen [45]. In the first stage, three districts, including Damote Gale (highland AEZ), Sodo Zuria (midland AEZ), and Duguna Fango (lowland AEZ), were selected purposively (Figure 1). The criteria include a district with dominant AEZ, long years of climate data availability (i.e., above 30 years), existence of meteorological stations, and demographic and livelihood conditions. In the second stage, following the characterization of the AEZs by Gecho et al. [42], list of all villages in the selected AEZs were used to further cluster them into the respective AEZs. Hence, a proportional three highland, five midland, and three lowland villages were selected randomly (Figure 1). Lastly, a probability proportional to size sampling technique [44] was applied to select 403 farm household heads in the area of study. The total sample size was calculated using a sample size computation technique that was proposed by Kothari [46]. We also used a purposive sampling technique to identify and undertake 11 focus group discussions (one per village) and 15 key informant interviews (five per district) to gather qualitative information to incorporate climate change perceptions, both on temperature and rainfall indicators, and demographic, socioeconomic, and contextual factors affecting climate change perception. Instrument validation and piloting was conducted in a nearby nonsurvey district aimed to check the appropriateness, completeness, and validity of the data collection tools through a household survey for the quantitative data and expert judgment and elders' feedback for the qualitative tools. Scientific jargons, inappropriate variables, and indicators were dropped and corrected accordingly.

**2.3. Data Analysis.** ClimPACT2 Software in R was used for meteorological data quality control [47]. It was tested to label potentially wrong values and to remove them from the analysis. Outliers were detected and rejected for daily maximum and minimum temperatures exceeding  $\pm 3$  standard deviation. After quality control, the trend was computed for daily maximum, daily minimum, and daily rainfall amount on annual time scale. The parameters for annual time scale include annual maximum temperature (ATmax), annual minimum temperature (ATmin), and annual total rainfall (ATR) using XLSTAT® 16. The households survey data management and analysis was carried out in Cspro® 6.3 and Stata® 14. To statistically compare variables between perceived and not perceived households, a *t*-test was employed for interval variables. A thematic analysis including description and classification of data and seeing how concepts interconnect was employed for qualitative information [48] to explain and triangulate the survey results. To see the presence of trends in both annual temperature and rainfall data, we used the

nonparametric Mann–Kendall (MK) test statistic [49, 50] and Sen's estimator test [51].

**2.3.1. Mann–Kendall Test.** The MK uses the relationship between the ranks of a time series and their sequence. A hypothesis test is formulated as a null hypothesis ( $H_0$ ) when there is no trend and the alternate hypothesis ( $H_1$ ), as a trend in mean climate, where there is an increasing or decreasing monotonic trend. The *Z* score is computed and the confidence limits of the standard normal *Z* are equally determined. For a ranked set of observations  $n$ ,  $X = x_1, x_3, \dots, x_n$ , the MK trend statistic *S* is computed using

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^n \text{sgn}(x_j - x_i), \quad (1)$$

where  $x_j$  are the sequential data values,  $n$  is the data length of the time series, and

$$\text{sgn}(x_j - x_i) = \begin{cases} 1, & x_j > x_i, \\ 0, & x_j = x_i, \\ -1, & x_j < x_i. \end{cases} \quad (2)$$

The variance of *S* is calculated using

$$\text{Var}(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^p t_i(t_i-1)(2t_i+5)}{18}, \quad (3)$$

where  $n$  is the number of data points,  $\rho$  is the number of tied groups, and  $t_i$  is the number of data values in the  $\rho^{\text{th}}$  group. A tied group is sample data with the same value, where there is zero variance between the compared values. The summary of Equation (3) can be ignored if there are no tied groups. The significance of a trend is calculated by the *Z*-score using

$$Z = \left. \begin{aligned} &= \frac{S-1}{\sqrt{\text{Var}(S)}}, & \text{if } S > 0, \\ &= 0, & \text{if } S = 0, \\ &= \frac{S+1}{\sqrt{\text{Var}(S)}}, & \text{if } S < 0. \end{aligned} \right\} \quad (4)$$

When *Z* value exceeds either of the confidence limit lines, it shows a significant trend at a given significance level. Hence,  $H_0$  is rejected and in place  $H_1$  is accepted.

**2.3.2. Sen's Slope Estimator Test.** The Sen's slope estimator (SSE) [51] is employed to estimate the magnitude of the trends in the time series data. Thus, if a linear trend exists in a time series, then the true slope of the trend is estimated using a Sen-Theil trend line [51, 52], an alternative to linear regression, in combination with the MK test. The slope ( $T_i$ ) of all data sets is calculated as

$$T_i = \frac{X_j - X_k}{j - k}, \quad \text{for } i = 1, 2, \dots, N, \quad (5)$$



where  $X_j$  and  $X_k$  are taken as data values at time  $j$  and  $k$  ( $j > k$ ), respectively. The median of these  $N$  values of  $T_i$  is denoted as Sen's estimator of slope, which is expressed as

$$Q_i = \begin{cases} T_{(N+1)/2}, & N \text{ is odd,} \\ \frac{1}{2}(T_{N/2} + T_{(N+2)/2}), & N \text{ is even.} \end{cases} \quad (6)$$

Sen's estimator is calculated as  $Q_{\text{med}} = T_{(N+1)/2}$  if  $N$  appears odd, and it is used as  $Q_{\text{med}} = T_{N/2} + T_{(N+2)/2}$  if  $N$  appears even. Lastly,  $Q_{\text{med}}$  is computed by a two-sided test at  $100(1-\alpha)\%$  confidence interval, which is then used to obtain the true slope through the nonparametric test. A positive value of  $Q_i$  suggests an increasing trend and a negative value of  $Q_i$  offers a decreasing trend in the time series. Both the MK and SSE tests were performed using R software.

Rainfall variability was examined using standardized rainfall anomaly (SRA), precipitation concentration index (PCI), and coefficient of variation (CV). The descriptors were computed using equations (7) and (8). SRA was obtained using equation (7) [53]. The SRA features have contributed to its acceptance for drought monitoring while enabling to identify the dry and wet years in the record [54]. Therefore, the drought severity is categorized as, extreme drought ( $\text{SRA} < -1.65$ ), severe drought ( $1.28 > \text{SRA} > -1.65$ ), moderate drought ( $-0.84 > \text{SRA} > -1.28$ ), and no drought ( $\text{SRA} > -0.84$ ).

$$\text{SRA} = \frac{P_t - P_m}{\sigma}, \quad (7)$$

where SRA is Standardized Rainfall Anomaly,  $P_t$  is annual rainfall in year  $t$ ,  $P_m$  is long-term mean annual rainfall for the period 1983–2014, and  $\sigma$  is the standard deviation of annual rainfall for the period 1983–2014.

Oliver [55] recommends the use of PCI to get information about any possible variations in the rainfall distribution over the year. Hence, PCI values are interpreted as typical of a uniform monthly rainfall distribution (PCI below 10), seasonality in rainfall distribution (PCI between 11 and 20), and a high variability in monthly rainfall amounts (PCI above 20). Using the PCI, data related to the long-term variability in rainfall amount were obtained and computed using equation (8) on annual scale, which was applied to examine heterogeneity of annual rainfall:

$$\text{PCI}_{\text{annual}} = \frac{\sum_{i=1}^{12} \rho_i^2}{\left(\sum_{i=1}^{12} \rho_i\right)^2} * 100. \quad (8)$$

Moreover, interannual variability of rainfall and temperature for the selected AEZs was determined by CV (i.e., standard deviation divided by the mean of ATmax, ATmin, and ATR), respectively. Z-score was adapted to compute the temperature anomalies, which is commonly used for rainfall anomalies.

**2.3.3. Binary Logit Model Estimation.** Methodologically, so far farmers' perception of climate change has been studied in

three different ways as discussed under the introduction section. Nevertheless, following the assumption of standard logistic probability distribution like the previous studies, including [39, 56–58] and the suggestions made by Gujarati [59], we applied binary logit model, mainly to identify factors affecting farmers' perception of climate variability and change over AEZs.

The logit model considers that the outcome variable is dichotomous in nature, which assumes a value of 1 or 0. It also adopts a discrete vector of repressors  $X$ , which are assumed to influence the outcome  $Y$ . In line with Abid et al. [60], our dependent variable (i.e., *perceive climate change*,  $Y = 1$  or *not perceive climate change*,  $Y = 0$ ) was taken as a combination of an increase in temperature being accompanied by a decrease in rainfall, which results in accurate perception coded as 1 "*perceive climate change*" and coded as 0 "*not perceive climate change*". Gujarati [59] stated the functional form of logistic model (the log-odds ratio) as

$$P_i = E \frac{Y_i}{X_i} = \frac{1}{1 + e^{-(\beta_o + \beta_i X_i)}}, \quad (9)$$

$$P_i = E \frac{Y_i}{X_i} = \frac{1}{1 + e^{-Z_i}},$$

where  $P_i$  is the probability of  $i^{\text{th}}$  household to be in the first category-perceive climate change, which ranges from 0 to 1 and  $Z_i$  is a functional form of  $m$  explanatory variables ( $X$ ), which is

$$Z_i = \beta_o + \sum_{i=1}^m \beta_i X_i, \quad 1, 2, 3, \dots, m, \quad (10)$$

where  $\beta_o$  is an intercept and  $\beta_i$  are slope parameters of the model or slopes of the equation. It indicates that how the log-odds are in favor of a given household which perceives climate change as an independent variable change. If  $P_i$  shows the probability of a given household which perceives climate change, then  $1 - P_i$  shows the probability of a given household is not perceiving climate change, which is expressed as

$$1 - P_i = \frac{1}{1 + e^{Z_i}}. \quad (11)$$

When equation (9) is divided by equation (10), the simplified form is stated as

$$e^{Z_i} = \frac{P_i}{1 - P_i} = \frac{1 + e^{Z_i}}{1 + e^{-Z_i}}. \quad (12)$$

It explains a ratio of the probability that a household perceives climate change to the probability a household does not perceive climate change. Finally, the logit model is obtained by taking the natural log of

$$Z_i = \ln\left(\frac{P_i}{1 - P_i}\right) = \beta_o + \beta_i X_i. \quad (13)$$

Including an error term  $\varepsilon_i$  into the model is expressed as

$$Z_i = \beta_o + \beta_i X_i + \varepsilon_i. \quad (14)$$

In order to interpret and compute the results, it is relevant to compute the marginal effects using equation (15). It describes the effect of a unit change in the explanatory variable on the probability of a dependent variable, i.e.,  $\Pr(Y = 1)$ . Marginal effects can be computed using

$$\frac{\partial P_{\kappa}}{\partial X_{\kappa}} = \frac{\beta_{\kappa} e^{-Z_{\kappa}}}{(1 + e^{-Z_{\kappa}})^2}. \quad (15)$$

The logit model was regressed on a set of relevant explanatory variables hypothesized based on literature and data availability that are assumed to affect farmers' perception of climate variability and change (Table 1). Factors included are of two types. The internal factors include farm-specific, socioeconomic, and demographic variables such as gender, age, education, landholding, age dependency ratio, nonfarm participation, food secured months, and household productive assets [26, 32–35, 38, 39].

External factors that affect farmers' perception to climate variability and change comprise access to the village market, climate information, market information, credit services, trainings, agroecology, access to irrigation, and agricultural input use [33, 34, 38, 39, 57, 60]. Variables such as total farm size (ha), household productive assets (local currency-*birr*), age dependency ratio (number), distance to the village market (km), age of the farmer (years), and food secured months (number) are continuous variables and measured in the respective unit, while all other variables are dummies and take the value of one and zero (Table 1). Using these variables, the empirical specification of the logit model was described as

$$\begin{aligned} Z_i = & \beta_0 + \beta_1 \text{age} + \beta_2 \text{land} + \beta_3 \text{mard} + \beta_4 \text{adr} + \beta_5 f \text{ sec} \\ & + \beta_6 \text{asset} + \beta_7 \text{sex} + \beta_8 \text{edu} + \beta_9 \text{cliinf} + \beta_{10} \text{marinf} \\ & + \beta_{11} \text{nonfarm} + \beta_{12} \text{credit} + \beta_{13} \text{aez} + \beta_{14} \text{input} \\ & + \beta_{15} \text{train} + \beta_{16} \text{irruise} + \varepsilon_i. \end{aligned} \quad (16)$$

### 3. Results and Discussion

#### 3.1. Variability and Trends in Temperature

**3.1.1. Variability and Trends in Annual Maximum Temperature.** The CV of the highland AEZ is nearly double that of the midland and lowland AEZs, suggesting a high variability in the ATmax over the 32 years under study. The year 2012 was observed as the hottest year in AEZs while 1989 was the lowest ATmax year for the midland and lowland AEZs (Table 2 and Figure 2). The hottest and coldest years are consistent with a study by Mengistu et al. [17], which reported that AEZs in the Upper Nile basin experienced relatively cold years in the 1980s and warm years from the early 1990s to the 2000s.

Table 3 and Figure 2 show the temporal and spatial variability and trend of ATmax in the AEZs. It exhibited an upward trend of 0.02°C/year ( $p < 0.01$ ), signifying 0.64°C increase between 1983 and 2014 in the lowland AEZ. The highland AEZ experienced significantly increased

temperature in the ATmax. The rate of change in the ATmax was 0.04°C/year ( $p < 0.001$ ). However, the result for midland AEZ reveals a nonsignificant downward trend in the ATmax (0.01°C/year) (Table 3). In terms of AEZs, the highland AEZ experienced 1.28°C change ( $p < 0.001$ ) compared to the lowland AEZ that exhibited 0.64°C increase ( $p < 0.01$ ), notifying highly rapid rate of change in the ATmax over three decades. The warming trend observed in the study area is relatively higher than the historical trend reported at national and subnational levels. For instance, a warming trend of 0.1°C/decade was observed in Ethiopia between 1953 and 1999 [61] while it was 0.2°C/decade for Addis Ababa from 1951 to 2002 [62].

The interannual variability of the ATmax presented in (Figure 2) indicates that the AEZs have experienced both warm and cool years during the 32 years. Therefore, the anomaly detected was complex for midland AEZ. A warming trend in lowland and highland AEZs was reported, informing the recent years are warmer than the earlier years. Even though the magnitude in the ATmax differs, the general warming trend matches with studies reported both at national level [61] and local level [17, 32].

Several other studies at various spatial and temporal scales have recognized warming trends in maximum temperature [4, 20, 21, 28, 63]. On the rate of increase, without adaptation, more than 1°C warming has adverse impacts [3]. In this case, the trend analysis over three decades suggests that the highland AEZ has exhibited warming of 1.28°C while the lowland experienced 0.64°C increase, implying some possible negative impacts on the lives and livelihoods of smallholder farmers mainly in the highland AEZ. Relating rapid change in the climate, the shifting nature of the AEZ and its contributing factors, farmers in the highland AEZ stated:

“Previously, there were big trees that used to pull down rain and cold air. Today, these trees are not there due to high deforestation and expansion of farmland. These trees have been cleared and the land is open for wind. Rather, the lands are covered by eucalyptus, which does not maintain soil fertility. Because of the change in climate, we are not sowing crops during the same time as we used to do before. The farm calendar of both cultivation and harvesting has changed over time. This was a highland before as cold as Damota-highest point. It is like a lowland now. We have thus suffered from high temperatures day in and day out.” [Discussions in Highland AEZ, March 2017].

Supporting this idea, one of the key informants from the same AEZ shared his experiences:

“Malaria was one of the major shocks that claimed the lives of many people before the recent expansion of health services in the lowland areas. Currently, with the change of temperature from lowland to highland areas, malaria occurred in areas where there were no incidences before, indicating that the highland AEZ is no longer highland in its main characteristics.” [Discussions in Highland AEZ, March 2017].

TABLE 1: Results of the binary logit model for aggregate sample and agroecological zones.

Explanatory variables	Mean	SD	Aggregate (1)		Highland AEZ (2)		Midland AEZ (3)		Lowland AEZ (4)	
			Regression	Marginal effect	Regression	Marginal effect	Regression	Marginal effect	Regression	Marginal effect
Age (years)	44.62	14.06	-0.014	-0.003	-0.019	-0.004	-0.013	-0.003	-0.041	-0.081
Total land size (ha)	0.78	0.79	-0.200	-0.046	-0.161*	-0.030	-0.041	-0.010	-0.338	-0.081
Distance to village market (km)	2.87	4.98*	-0.082**	-0.019**	-0.563	-0.107	-0.047	-0.011		
Dependency ratio (number)	0.87	0.73	-0.231	-0.053	-0.063	-0.012				
Food secured months (number)	7.29	2.85	-0.148***	-0.034***	-0.243	-0.046	-0.141**	-0.033**	-0.249***	-0.060***
ln (household productive assets)	6.21	1.10			-0.243	-0.046				
Gender (1 = male)	264	65.51%	-0.666***	-0.148***	-0.894	-0.157	-0.489	-0.111	-1.253***	-0.276***
Education (1 = primary)	154	38.21%	0.654***	0.147***	0.855	0.149	1.650***	0.387***	0.103*	0.025*
Climate information (1 = yes)	280	69.48%	1.113***	0.264***					0.030	0.007
Market information (1 = yes)	234	58.06%	0.590**	0.137**	1.193*	0.229*			0.960**	0.228**
Participation in nonfarm (1 = yes)	109	27.05%	-0.585**	-0.139**	-1.621**	-0.341**	-0.408	-0.096		
Access to credit (1 = yes)	120	29.78%	-0.177	-0.041			-0.250	-0.059		
Agroecology (1 = lowland)	115	28.54%	-0.774***	-0.184***					0.868*	0.208*
Improved seed (1 = yes)	154	38.21%	0.851***	0.189***	2.418***	0.388***				
Received training (1 = yes)	80	19.85%	1.078***	0.220***	0.340	0.062	1.305***	0.257***	-0.786	-0.194
Irrigation use (1 = yes)	19	4.71%							1.671*	
Constant			1.808***		3.945*		1.528**		1.15	
N			403		90		198		28.73	
LR chi <sup>2</sup>			85.95		34.16		47.14		0.001	
Prob > chi <sup>2</sup>			0.001		0.001		0.001		0.001	
Pseudo R <sup>2</sup>			0.160		0.302		0.178		0.183	

\*\*\* Significant at  $p < 0.01$ ; \*\* significant at  $p < 0.05$ ; \* significant at  $p < 0.1$ .

TABLE 2: Annual maximum temperature variability by agroecological zones.

Station	AEZ	Mean (°C)	Std. deviation	Max (°C)	Year	Min (°C)	Year	CV (%)
Bilate	Lowland	27.87	0.45	28.65	2012	26.75	1989	1.62
Wolaita	Midland	26.59	0.36	27.59	2012	26.01	1989	1.35
Boditi school	Highland	25.50	0.66	26.76	2012	23.33	2006	2.59

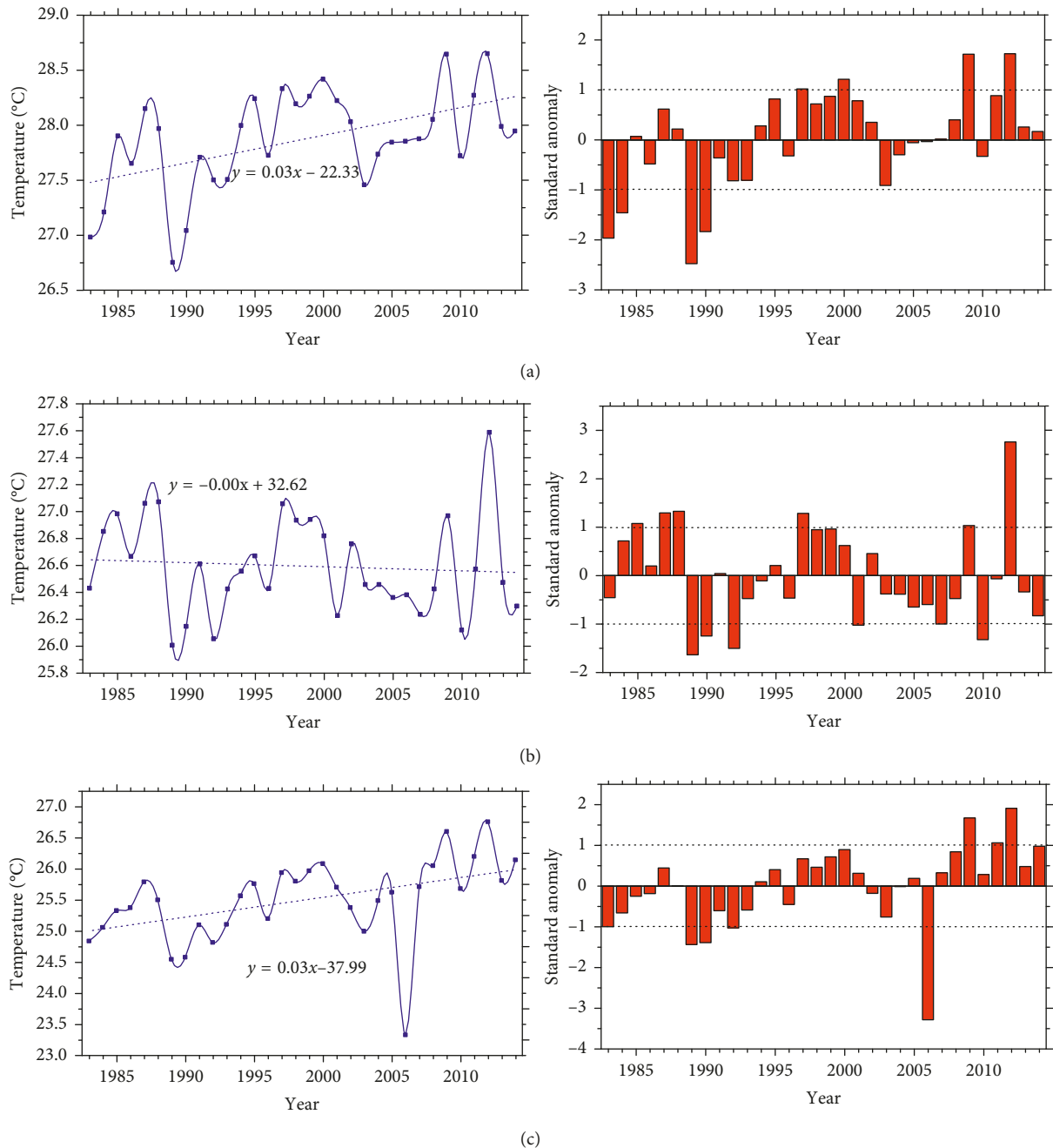


FIGURE 2: Spatial and temporal variations in the annual mean maximum temperature over the three agroecological zones, (a) lowland, (b) midland, and (c) highland, for the period 1983–2014: trends (left) and anomalies (right).

The rapid change in the ATmax reveals the shift in the AEZ where the highland AEZ is changing in its main features and showing somewhat different patterns in the climate components, specifying changes in the climate in the past years in Wolaita.

**3.1.2. Variability and Trends in Annual Minimum Temperature.** The ATmin is 14.80°C (CV = 6.49%), 14.86°C (CV = 5.10%), and 13.64°C (CV = 7.26%) for lowland, midland, and highland AEZ, respectively (Table 4). It shows relatively high variability in the highland AEZ than the other



TABLE 3: Trend statistics of annual maximum temperature by AEZs (1983–2014).

Station	AEZ	MKZ	S	Sen's slope (°C/year)
Bilate	Lowland	0.35	172	0.02***
Wolaita	Midland	-0.11	-56	-0.01
Boditi school	Highland	0.46	226	0.04***

\*\*\*Significant at  $p < 0.01$ ; \*\*significant at  $p < 0.05$ ; \*significant at  $p < 0.1$ .

TABLE 4: Annual minimum temperature variability by agroecological zones.

Station	AEZ	Mean (°C)	Std. deviation	Max (°C)	Year	Min (°C)	Year	CV (%)
Bilate	Lowland	14.80	0.96	15.97	2010	12.74	1986	6.49
Wolaita	Midland	14.86	0.76	15.97	2012	12.96	1986	5.10
Boditi school	Highland	13.64	0.99	15.04	2014	11.11	1986	7.26

AEZs. The year 1986 was the coldest year in all AEZs. The finding agrees with the cold and warm years reported among AEZs of the Upper Nile basin [17].

It is clear that the change in the ATmin both for lowland and midland AEZs was the same (Table 4). It accounts for 0.05°C/year, signifying 1.6°C increase in the ATmin in lowland and midland AEZs  $p < 0.001$  and  $p < 0.01$ , respectively. The result for highland AEZ was 0.07°C/year ( $p < 0.001$ ), suggesting a highly warming trend observed in highland AEZ compared to other AEZs (Table 5). For example, Conway et al. [62] observed an increasing trend in ATmin from 1951 to 2002 (0.4°C/decade) for Addis Ababa; Mengistu et al. [17] found 0.15°C/decade in the Upper Nile basin while Tekleab et al. [15] reported significant increases in ATmin at the annual timescale for many stations studied in the Abay basin. Moreover, ATmin increased by about 0.37°C/decade between 1951 and 2006 [10]. Earlier studies have also shown [64, 65] that most parts of the Greater Horn of Africa (GHA) show warming trends for both ATmax and ATmin. On a global scale, studies [66, 67] reported an increase in the annual maximum temperature by 0.15°C/decade. However, in this study, findings show relatively higher rate of changes in the ATmax and ATmin than was reported by Camberlin [65] for GHA and other studies at national level [4, 9].

ATmin shows a significantly increasing trend across all AEZs, but ATmax has revealed both increasing and decreasing trends. The rate of change for ATmin is faster than the ATmax both in time and space. The faster rate of change in the ATmin than the ATmax is in line with trends found by NMA [61]. As suggested by Peterson et al. [68], the changes are attributed to the decreasing night-time cooling. McSweeney et al. [10] thus indicated that at national level, the average number of hot nights has increased by 137 whereas the hot days by 73 days per year from 1960 to 2003.

The results in Figure 3 affirm that all AEZs have experienced both warm and cool years during three decades. Starting from 1998, a warming trend was observed in all AEZs except in 2006 which was the coldest year both in the midland and highland AEZs. In contrast, the 1980s were the coldest years with the ATmin below the mean across all AEZs, which concur with the observation made by Mengistu et al. [17]. Hence, the rapid rate of changes both in the

ATmax and ATmin signifies the change in temperature is one of the climate elements in the studied AEZs.

**3.2. Variability and Trends in Annual Rainfall.** On annual scale, rainfall is variable in the AEZs (Table 6). The ATR in the study AEZs varies from 697 mm in the lowland AEZ to 1,181 mm in the midland AEZ. The CV ranges from 18.57% in the highland AEZ to 25% in the lowland AEZ, suggesting a high rainfall variability in the lowland AEZ while similar patterns being observed in the midland and highland AEZs.

The CV of rainfall exhibits nearly similar patterns, both in the midland and highland AEZs (above 18%) on an annual scale, whereas the highest CV(25%) was reported in the lowland AEZ, signifying moderate rainfall variability (Table 6). From Table 7, similar PCI values were detected in the midland and highland AEZs while lower PCI value was sensed in lowland AEZ, showing irregularity in the rainfall distributions between and among AEZs. On the variability of PCI values, empirical studies reported differently in different contexts. For example, a moderate-to-high interannual rainfall concentration was observed in Amhara region [69] while the same pattern was reported by Kassie [8] in the Central Rift. In contrast, Gebre et al. [70] found that high and very high concentrations were observed in the Northern Ethiopia, suggesting poor monthly rainfall distribution.

Table 7 and Figure 4 show the trend test results of rainfall on the annual time scale. Though not statistically significant, a decreasing trend was observed (1.80 mm/year and 0.11 mm/year) in the lowland and highland AEZ, respectively, while an increasing trend (10 mm/year) ( $p < 0.05$ ) was exhibited in the midland AEZ. The increasing trend in the ATR in the midland AEZ was in line with findings of other researchers [28, 30], in which the midland AEZ experienced an increasing trend in the ATR. Likewise, Weldegerima et al. [21] reported an increase in ATR in three stations in Northern Ethiopia. To this end, the figures suggest that the ATR trend was neither decreasing nor increasing between 1983 and 2014 in all except the midland AEZ. The findings are consistent with a study in three meteorological stations, including Bilate, which did not show a significant trend in ATR [29]. Similarly, the total rainfall trend in the selected AEZs is in agreement with most

TABLE 5: Trend statistics of annual minimum temperature by AEZs (1983–2014).

Station	AEZ	MKZ	S	Sen's slope (°C/year)
Bilate	Lowland	0.64	318	0.05*
Wolaita	Midland	0.44	220	0.05*
Boditi school	Highland	0.57	284	0.07*

\*Significant at  $p < 0.01$ .

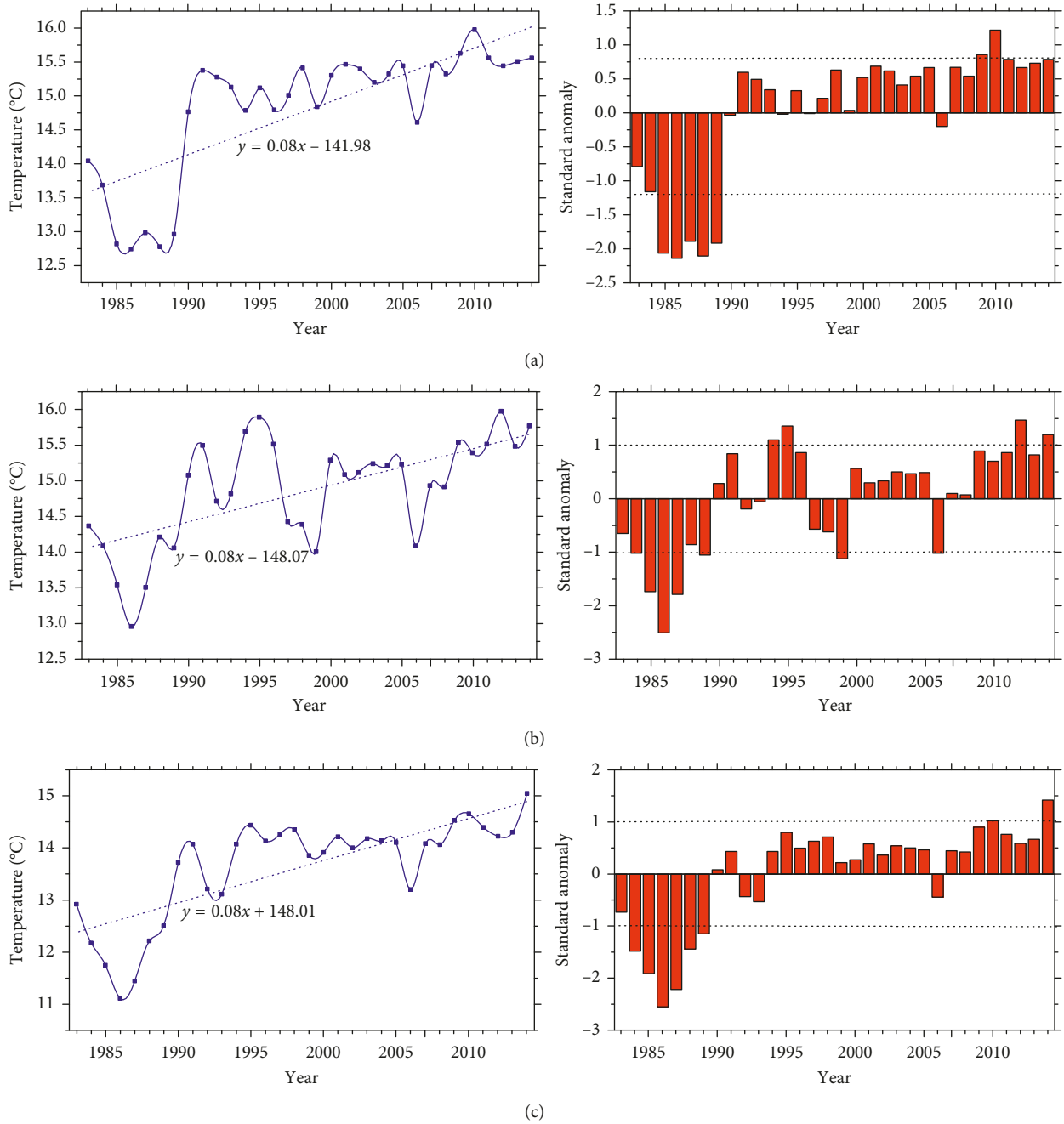


FIGURE 3: Spatial and temporal variations in the annual mean minimum temperature over the three agroecological zones, (a) lowland, (b) midland, and (c) highland, for the period 1983–2014: trends (left) and anomalies (right).

TABLE 6: Annual rainfall variability by agroecological zones.

Station	AEZ	Mean (mm)	Std. deviation	Max (mm)	Year	Min (mm)	Year	CV (%)	PCI
Bilate	Lowland	696.66	173.47	1064	1987	435	1999	24.90	10.88
Wolaita	Midland	1180.91	223.89	1474	2006	605	1984	18.96	11.38
Boditi school	Highland	881.13	163.64	1252	2007	555	2009	18.57	11.13

TABLE 7: Trends statistics of total rainfall by AEZs (1983–2014).

Station	AEZ	MKZ	S	Sen's slope (mm/year)
Bilate	Lowland	-0.075	-37.00	-1.80
Wolaita	Midland	0.274	136	10*
Boditi school	Highland	-0.01	-5	-0.11

\*Significant at  $p < 0.05$ .

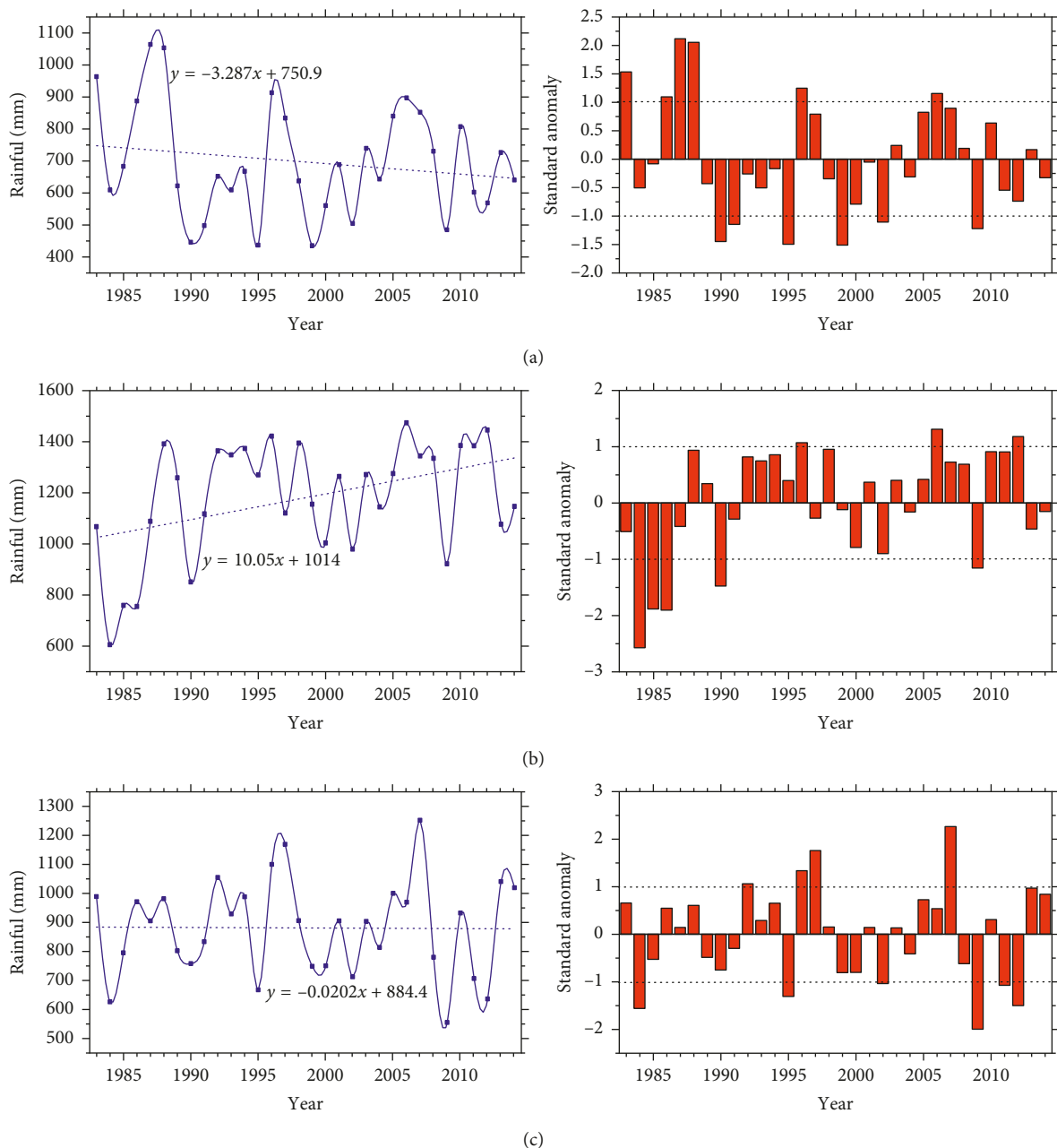


FIGURE 4: Annual total rainfall trends over the three agroecological zones, (a) lowland, (b) midland, and (c) highland, for the period 1983–2014.

of the empirical studies in Ethiopia that reported neither decreasing nor increasing patterns of rainfall amounts over time [15–17].

The interannual rainfall variability informs that AEZs have experienced negative and positive anomalies in the ATR (Figure 4). Hence, 1999, 1984, and 2009 were the driest and 1987, 2006, and 2007 were the wettest years in the lowland, midland, and highland AEZ, respectively. Drought categories are summarized in Table 8 based on McKee et al.'s [71] drought classification. As a result, 13 (40.63%), 10 (31.25%), 4 (12.50%), and 2 (6.25%) were observed as mild drought, normal, moderate drought, and severe drought years in the lowland AEZ, respectively. Only, 2 (6.25%) was reported as extreme wet years in the lowland AEZ, signifying nearly 60% of observed drought conditions. Likewise, the 1980s were detected as a wet decade in the lowland AEZ (Figure 4(a)). In midland, 17 (53.13%) were normal years while extreme wet conditions have not been observed at all. In highland, 16 (50%) was a normal year, whereas 2 (6.26%) were reported as severe wet and extreme wet years. 14 (44%) were drought years with varying levels of severity (Table 8 and Figure 4(c)). One key informant vividly noted the frequent occurrence of drought in the area as follows:

“Hitherto, drought occurred at least on a decadal basis, which was the case for the introduction of the bigger nongovernmental organizations like World Vision in Wolaita. Its occurrence continuously increased from time to time and begun to happen on a yearly basis. For example, due to El Niño, we faced a drought last year (2016), which affected animals and caused even complete crop failure. There was also the outbreak of pest (virus) that damaged maize. This was a strange phenomenon.” [Key informant Interview in Lowland AEZ, March 2017].

In general, 44% were observed as normal years across AEZs while 50% were drought years (Figure 5). The study result partly agrees with the national level anomaly trend reported by McSweeney et al. [10]. The national worst drought years also fits with realities in the study area. However, the anomaly trend in the study area partly differs with the national level figures when seen from the AEZs perspectives. In the lowland, 1980s was the wettest decade, while it was the 1990s in the midland and partly wettest in the highland in the 2000s (Figures 4 and 5), respectively. The differences in the anomaly years suggest the high annual rainfall variability among the AEZs.

**3.3. Spotting Farmers' Perception of Local Climate Variability and Change.** Depending of the research contexts, different studies have been carried out to examine how farmers perceive changes in the climate system. Understanding farmers' perception levels and the various adaptation strategies individual households employ would benefit to gather supplementary information relevant to policy and intervention to tackle the challenges of climate change.

The descriptive analysis show that about 248 (61.54%) of the farmers perceived changes in the climate parameters

(i.e., increased temperature and decreased rainfall) in the aggregate sample. As for AEZ, 61 (67.78%), 121 (61.11%), and 66 (57.39%) farmers perceived the changes in highland, midland, and lowland AEZs, respectively (Figure 6). This is in agreement with the household perception regarding increased temperature and decreased rainfall reported in Ethiopia and other countries [25, 26, 31, 32, 38, 39, 58, 72–74]. In our case, the proportion of farmers who perceived increasing temperature and decreasing rainfall is slightly different compared to studies in Ethiopia and other countries, being influenced by factors affecting their level of perception in general and the type of meteorological data (station vs. gridded data) and climate data availability (longer vs. shorter time period) in particular. Moreover, Schwartz [75] pointed that people believe climate may change owing to fresh climate experiences, such as the recent 2015/2016 El Niño events prior to the data collection period may contribute to their perception in the study area context.

The data on the temperature indicators also revealed that farmers perceived an increase in dry season temperature and hot days' temperature, which are consistently increasing over the AEZs. In addition, over 60% of farmers in the highland AEZ perceived an increase in rainy season temperature while a comparable proportion of farm households perceived increased temperature in the rainy season both in the midland and lowland AEZs (Figure 7). The farmers' perception results are in line with a recent study in the same AEZs [30]. Others studies observed similar patterns in different parts of Ethiopia [25, 26, 32, 38, 39, 76].

Farmers in all AEZs perceived that rainfall comes late. Farmers in the highland AEZ perceived that the rainfall goes early and observed decreasing trend in the short rains. In the same AEZ, farmers have better perceived for all rainfall indicators compared to those in the lowland AEZ. In general, farmers in all AEZs perceived declining trends both for the *belg*/short-rains and *meher*/long-rains over the last two decades, which makes rainfall erratic (Figure 8). The result agrees with empirical studies [25, 26, 32, 38, 39], which reported that farmers perceived declining trend in the rainfall amount over years in Ethiopia. Similarly, a study by Mkonda et al. [74] reported that a significant increasing temperature was observed locally in all the AEZs in Tanzania.

Regarding the perceived impacts of climate change, farm households witnessed impacts, including, crop productivity decline (98.26%), food price inflation (98.01%), increased frequency of drought (94.79%), increased crop pest (70.72%), increased frequency of floods (68.73%), shortage of water for human use (63.03%), emergence of new pests (61.79%), shortage of water for irrigation (61.04%), increased livestock disease (58.81%), and conflict over diminishing resources (55.83%) in order of severity across AEZs (Figure 9). Similarly, Tesso et al. [32] documented perceived impacts of climate change among AEZs in North Shewa, Ethiopia. Hence, farmers' perception of the climate-induced impacts over years is indicative of Ethiopia's vulnerability to climate change and variability. Thus, studies recognized that Ethiopia suffers from problems associated with high rainfall



TABLE 8: Standardized rainfall indices over the three agroecological zones, (a) lowland, (b) midland, and (c) highland, for the period 1983–2014.

Drought category	SRA ranges	Percentage and frequency of occurrence (Years)							
		Lowland (a)		Midland (b)		Highland (c)		Total (d)	
		N	%	N	%	N	%	N	%
Extreme drought	-2.0 or less	—	—	1	3.13	—	—	1	1.04
Severe drought	-1.5 to -1.99	2	6.25	2	6.25	3	9.38	7	7.29
Moderate drought	-1.0 to -1.49	4	12.50	2	6.25	3	9.38	9	9.38
Mild drought	-0.99 to 0	13	40.63	10	31.25	8	25	31	32.29
Normal	+0.01 to +1.49	10	31.25	17	53.13	16	50	43	44.79
Severe wet	+1.5 to +1.99	1	3.13	—	—	1	3.13	2	2.08
Extreme wet	+2.0 or more	2	6.25	—	—	1	3.13	3	3.13

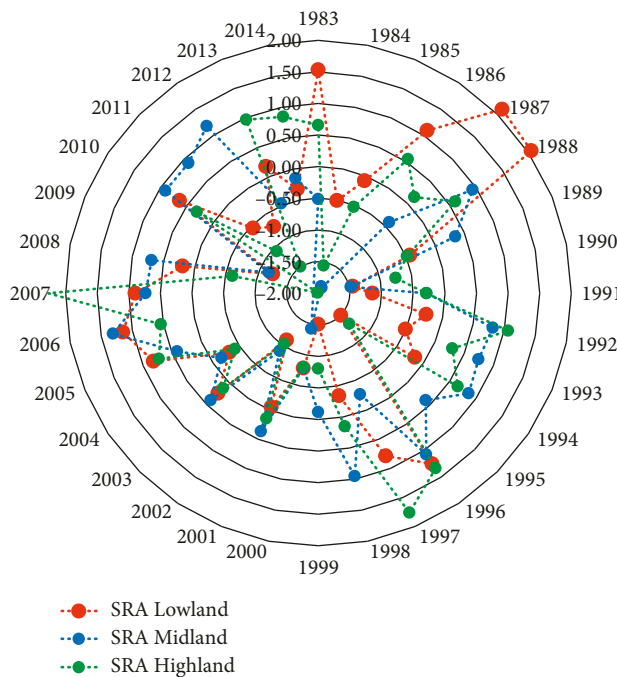


FIGURE 5: Drought occurrence years over the period of 1983 to 2014 in the three agroecological zones.

variability [77]. Specifically, Amsalu and Adem [78] show that climate change has both direct and indirect impacts on the occurrence and spread of pests and diseases. Moreover, extracts from qualitative information supports the changes in the climate parameters and the corresponding impacts over the last two decades as follows:

“Before 1999, the area was very green and we had adequate pasture for the cattle. Now, there is no grass for grazing, and there is a movement in search of grass. Since 1999, we have witnessed a decrease in rainfall and an increase in temperature warming. The springs have dried, and the vegetation cover has been declining. Where there is irrigation, production of crops is good.” [Discussions in Lowland AEZ, March 2017].

Ethiopia has faced many droughts and floods since 1980 [79]. Since 1990, Ethiopia has confronted 47 major floods that killed nearly 2000 people and affected a population of

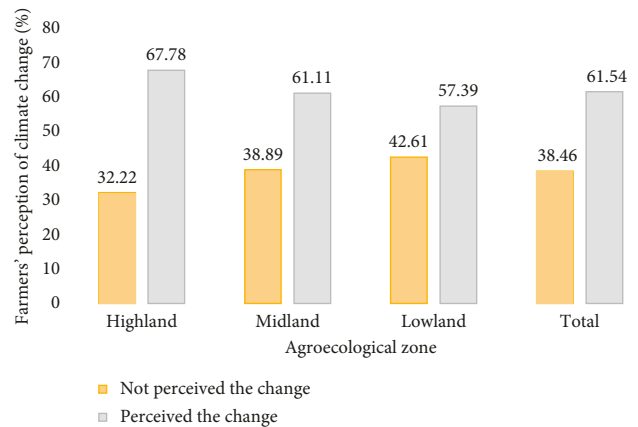


FIGURE 6: Farmers’ perception of climate change.

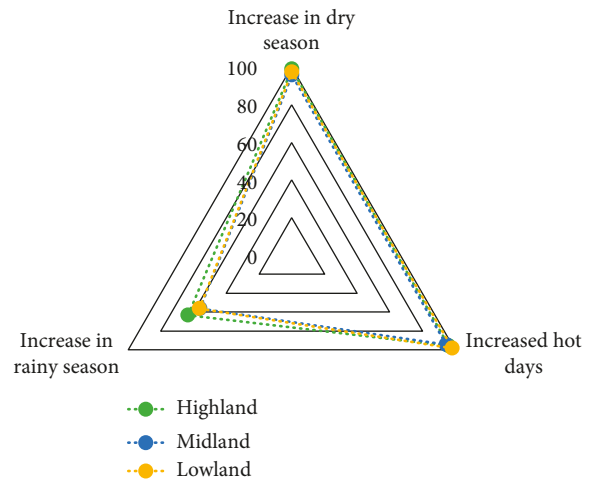


FIGURE 7: Farmers’ perception of temperature indicators.

about 2.2 million [80]. It also experienced 12 major droughts between 1900 and 2010 that claimed the lives of over 400,000 people and affected more than 54 million [80]. Very recently, the 2015/2016 El Niño-induced drought caused food security affecting an estimated 10.2 million people; one of the most severe on record [81]. Therefore, although the farmers’ perception of climate change differs in the study AEZs and parts of Ethiopia, farmers’ perceptions and the trends in climate change complement each other, showing a warming trend.

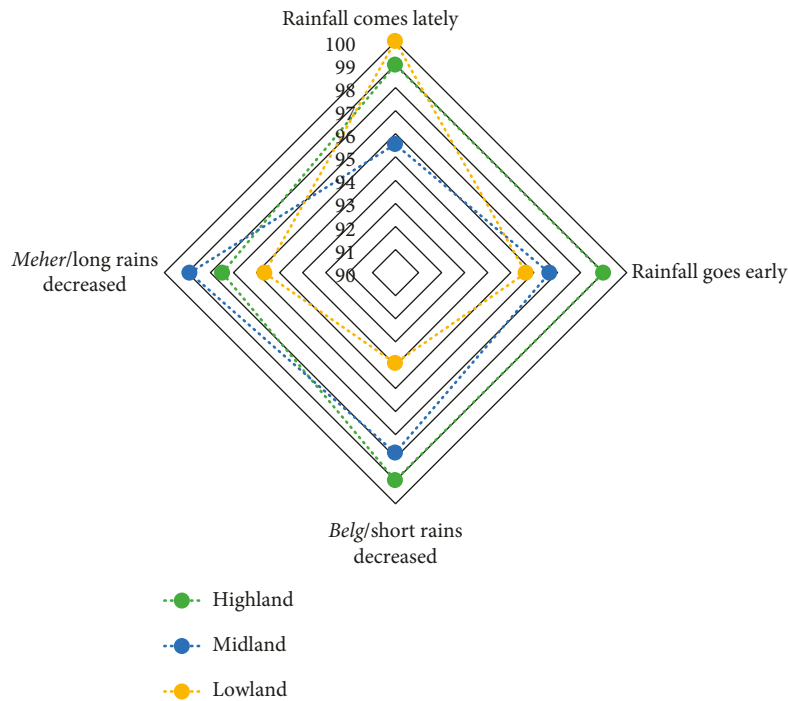


FIGURE 8: Farmers' perception of precipitation indicators.

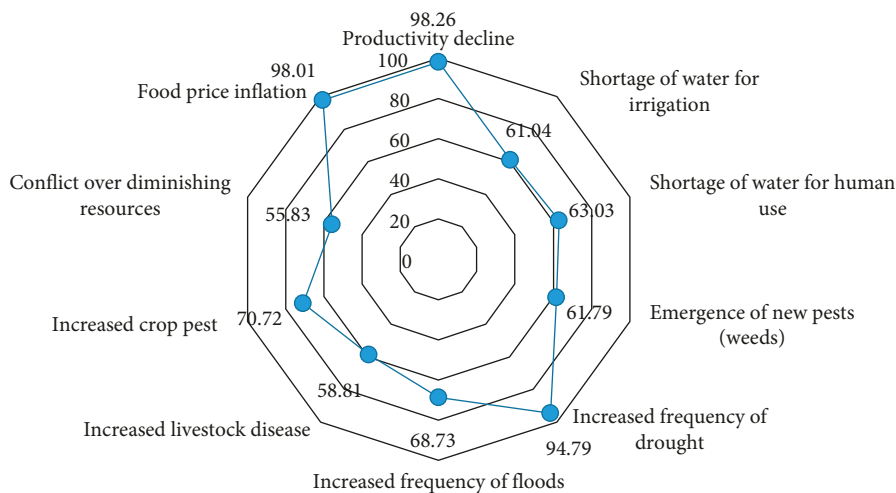


FIGURE 9: Perceived impacts of climate change and variability.

3.4. *Econometric Model Results.* A descriptive statistic of the explanatory variables used is summarized in Table 1. The average age was 44.62 years, suggesting that farmers are in the productive age category (16–64 years) [82]. The land-holding accounts for 0.78 hectare in all AEZs. A statistically significant difference was observed between farmers who perceived climate change (0.71 ha) and not perceived climate change (0.88 ha) ( $t = 1.96$ ,  $p < 0.1$ ). The average distance farmers travel to reach to the village market was 2.87 km. This was statistically significant between the perceived and not perceived farmers, 2.30 km and 3.79 km, respectively ( $t = 2.43$ ,  $p < 0.05$ ). Regarding food secured months, farmers in all AEZs were able to feed their families for 7.29 months. A

statistically significant difference was exhibited between farmers who perceived climate change (6.89 months) and not perceived climate change (7.92 months) ( $t = 3.65$ ,  $p < 0.01$ ), suggesting food-secured households are less likely to perceive climate change compared to their counterparts.

Most of the famers' households were male-headed (65.51%), with 38.21% having completed primary school (grade 1 to 8). In terms of access to information, it was evident that 69.48% had access to climate information and 58.06% to market information in all AEZs, supporting the positive role of information to farmers' livelihood improvement and preparedness to climate change impacts. Of the sample, 27.05% of farmers were involved in the nonfarm

income activities as a way to diversify livelihoods in the face of climate change and enable them to address food and income gaps. The result agrees with Gecho et al. [42], where they reported 37% of farmers derive income from farm and nonfarm activities in Wolaita. Only 29.78% had access to credit, indicating that farm household had limited access to credit services in AEZs. 38.21% farm households used improved seed in the production seasons, and a negligible percent of farmers had access to irrigation use. Likewise, only 19.85% of the sampled farmers received trainings important for their livelihood activities across AEZs. The binary logit model was first tested for its suitability and explanatory power for the variables used. In addition, the likelihood function of the binary logit model was significant (Likelihood-ratio (LR)  $\chi^2 = 85.95$  with  $p < 0.01$ ), signifying its strong explanatory power. The estimated coefficients of the parameters and the marginal effects in the binary logit model ( $p < 0.1$ ) for aggregate sample, highland AEZ, midland AEZ, and lowland AEZ are presented in Table 1.

Factors such as agroecological zone, head gender, nonfarm participation, food secured months, and distance to village market are significantly negatively correlated with climate change perception while access to climate and market information, attended training, use of improved seed, and completed primary school are significantly positively associated with climate change perception. Unlike our expectations, farmers who live in the lowland AEZ are less likely to perceive change than farmers who reside both in the midland and highland AEZ. Thus, the probability of perceiving climate change declines by 18.4% if a farmer resides in the lowland AEZ ( $p < 0.01$ ). This could be due to their inherent vulnerability to impacts of climate change while a small change in the climate parameters in other AEZs more likely affects the farmers to perceive climate change. In support of this, Ethiopian Panel on Climate Change (EPCC) [83] has recognized highland areas among the most vulnerable agroecology in Ethiopia. Esayas et al. [30] also reported that the highland AEZ in Wolaita experienced a rapid rate of change in the extreme climate events compared to the lowland AEZ over three decades. Deressa et al. [31] further noted that farmers from the highland AEZ in the Nile basin perceived climate change more than those in the lowland AEZ.

In this study, the gender of household head is inversely correlated with climate change perception. The probability of male-headed farmers' perception of climate change declines by 14.8% compared to female headed households ( $p < 0.01$ ). In terms of AEZ, the probability of perceiving the climate change for male headed households in the lowland AEZ decreases by 27.6% whereas it is nonsignificant both in the highland and midland AEZs. This might be because female headed households are more confined to home the most part of the day and, hence, are more concerned about environmental problems that impede their families and local people [84]. Nevertheless, previous studies [31, 38, 58] testified that there was no significant variation between male- and female-headed households on the perception of climate change. Hence, gender is not always positively associated with the perception of climate change; rather, it is a

mixed factor depending on the environmental issues studied.

Similarly, participation in nonfarm income, food-secured months, and distance to village market have negatively influenced farmers' perception of climate change. The probability of perceiving climate change, thus, decreases by 13.9% when a farm household is involved in nonfarm income across AEZs. This could be because nonfarm activities are less susceptible to climate change impacts. Ndambiri et al. [56] similarly reported an inverse relationship between participation in off-farm income and perceiving climate change.

The estimated marginal effect for one additional food-secured month of the household head decreases the probability of perceiving climate change by 3.4% ( $p < 0.01$ ) for the aggregate sample. The same pattern was observed both in the midland and lowland AEZs, where the probability of perceiving climate change decreases by 3.3% ( $p < 0.05$ ) for midland AEZ and by 6% for lowland AEZ ( $p < 0.01$ ), respectively. This signifies that food-secure farm households are less likely to perceive the climate change compared to the food insecure households, since the latter may attribute the food shortage to environmental challenges such as climate change.

The study revealed that there is an inverse relationship between distance to the village market and farmers' perception of climate change. Therefore, one extra km traveled to the village market by the household head decreases the probability of perceiving climate change by 1.9% ( $p < 0.05$ ) for all samples. Farmers residing farther away from the nearest input/output market are less likely to perceive climate change than farmers residing closer to the market. Market outlets offer a crucial linkage for farmers to collect and disseminate information between and among fellow farmers, and the further the farmer's distance from such a market linkage, the less likely the farmer would be to perceive climate change. Similarly, a negative influence of distance to village market on the perception of climate change was reported in other studies [32, 34, 39].

As expected, the logit model shows that there is a positive association between farmers' access to climate information and perception of climate change. Farmers' access to climate information increases the probability of perceiving climate change by 26.4% in an aggregate sample ( $p < 0.01$ ) while it enhances the probability of farmers' perception of climate change by 38.7% ( $p < 0.01$ ) in the midland AEZ. Studies also reported that farmers who have better access to climate information are more likely to perceive climate change [34, 38, 39]. Though farmers recognized these sources of information as vital, they still had their own ways of perceiving climate change [85].

Likewise, the availability of market information has significant positive correlation with farmers' perception of climate change. Hence, farmers who have access to market information are 13.7% more likely to perceive the climate change in the aggregate sample ( $p < 0.05$ ). In terms of AEZ, the probability of farmers who have access to market information increases the perception to climate change by 22.9% in the highland AEZ and 22.8% in the lowland AEZ.

This can be attributed to better access to input and output market information. The study shows that farmers using improved seeds are 18.9% more likely to perceive climate change in the aggregate sample ( $p < 0.01$ ), 38.8% in the highland AEZ ( $p < 0.01$ ) and 20.8% in the lowland AEZ ( $p < 0.10$ ).

The other variable of interest that influences the probability of farmers' perception of climate change is farmers' education level and received capacity building trainings (proxy variables for level of awareness). The marginal effect revealed that farmers who have completed primary school are 14.7% more likely to perceive climate change ( $p < 0.01$ ) in all samples while the increase was by 2.5% in the lowland AEZ ( $p < 0.10$ ). In this regard, the more educated the household head, the higher the probability of perceiving the climate change and vice versa. The result agrees with previous studies which reported the positive influence of household education on climate change perception in different contexts [32, 34, 38, 39]. Although a small number of farmers have attended capacity building trainings, the results imply that training has a positive influence on farmers' perception of climate change. The computed marginal effect indicates that receiving training increases the probability of perceiving climate change by 22% for an aggregate sample ( $p < 0.01$ ), whereas the increase was by 25.7% in the midland AEZ ( $p < 0.01$ ).

### 3.5. Climate Trend Analysis Nexus with Farmers' Perceptions.

It is evident that farmers' perceptions of climate change in the last two decades correlates with the meteorological data in the study area. Over 60% of farmers have perceived increasing temperature and decreasing rainfall in all AEZs. Likewise, the trend analysis reveals that positive trends were observed in the ATmax,  $0.02^\circ\text{C}/\text{year}$  ( $p < 0.01$ ) in the lowland AEZ and  $0.04^\circ\text{C}/\text{year}$  ( $p < 0.01$ ) in the highland AEZ, respectively. The trend for ATmin was consistent in all AEZs and significant ( $p < 0.01$ ). Regarding rainfall trend, a non-significant decreasing trend was observed ( $1.80\text{ mm}/\text{year}$ ) and ( $0.11\text{ mm}/\text{year}$ ) in the lowland and highland AEZs, respectively. However, an increasing trend in the ATR ( $10\text{ mm}/\text{year}$ ) ( $p < 0.05$ ) was experienced in the midland AEZ between 1983 and 2014. There are increasing temperature and decreasing rainfall trends both in the lowland and midland AEZs. Similarly, many studies in Ethiopia reported positive trends in the average ATmax [4, 20, 28, 38, 63] and increasing trend in the average ATmin [4, 9, 10, 17]. The total rainfall trend in two of the AEZs agrees with most of the empirical studies in Ethiopia [10, 15, 16, 61] that found neither decreasing nor increasing patterns in the total rainfall amounts. Nevertheless, the positive trend on the average total rainfall in the midland AEZ contradicts with household perceptions in the same AEZ over the study periods. The increasing trend in the ATR in the midland AEZ corroborates the earlier findings [28, 30] that reported that the midland AEZ experienced an increasing trend in the average ATR.

Nonetheless, the discrepancy between farmers' perception of rainfall amount in the midland AEZ and the climate

trend could be attributed to farmers' level of perception which are influenced by a number of factors including, agroecology, education, farm experience, resource endowments, access to climate information, and early warning systems [32, 34, 38, 39] while the trend is a cumulative result over three decades. Tadesse et al. [26] observed similar discrepancies between the climate trend analysis and farmers' perception in the adjacent area of the study AEZs. Therefore, farmers' perception cannot merely depend on the actual climate conditions and a change in the climate parameters. Instead, it can be affected by a number of social, economic, demographic, and institutional factors [32, 34, 38].

## 4. Conclusion and Recommendations

This study has analyzed trends of climate variability and farmers' perception in Southern Ethiopia using meteorological time series data from 1983 to 2014. Understanding the temperature and rainfall variability trends and farmers' perception of changes in the climate among agroecological settings would offer valuable information for the planning and implementing local level adaptations. The livelihood activities of most rain-fed farmers of the study area depend on the numerous climatic variables, mainly rainfall. The annual trend analysis of temperature and rainfall was carried out at agroecological zone level, while the survey was conducted at households' level representing three different (highland, midland, and lowland) AEZs. The Mann-Kendall trend analysis confirms that there was a significant upward trend in the annual minimum temperature across AEZs while the annual maximum temperature has exhibited both upward and downward trends.

Sen's slope confirms that the magnitude of change for the minimum temperature is faster than the maximum temperature both in time and space. The interannual variability of the annual maximum temperature suggests that AEZs have unveiled both warm and cool years during the 32 years, informing the recent years are warmer compared to the earlier years. The general warming trend observed in the study area agrees with empirical studies reported both at the national and local levels. The Mann-Kendall trend analysis reveals that there was an insignificant downward trend observed in the annual total rainfall both in the highland and lowland AEZs, whereas a significant upward trend was detected in the midland AEZ, indicating mixed results. Standardized rainfall anomaly confirms that the study AEZs have experienced many drought years between 1983 and 2014 that also fits to the nation's worst drought years.

The study established that farm households are becoming aware of local climate change more. Hence, farmers of Wolaita Zone have been facing the adverse impacts of climate variability and change as it impacted their lives and livelihoods over the last three decades. Results from the binary logit model inform that farmers' climate change perceptions are significantly influenced by their access to climate and market information, agroecology, education, agricultural input, and village market distance. The study concluded that farmers' perception of climate change reflects



the meteorological analysis, although their perceptions were grounded on local climate factors. Based on these results, it is recommended to enhance farm households' capacity by providing timely weather and climate information along with institutional actions, including agricultural extension services, farm input supplies, and viable livelihood diversification options. However, this study was limited in scope and sample size; it is suggested to undertake further studies at a larger scale to figure out the links between farmers' perceptions of climate change with meteorological data, in general, and explore socioeconomic and contextual factors affecting climate change perceptions, in particular.

## Data Availability

The climate data used to support the findings of this study are available from the corresponding author upon request.

## Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

## Acknowledgments

The study was carried out with the financial support from both Wolaita Sodo University and Addis Ababa University as part of the first author's PhD program. The authors appreciate the National Meteorological Agency for providing the gridded daily temperature and precipitation data. The authors are thankful to local-level government offices, farmers, and enumerators for their time and cooperation during field data collection.

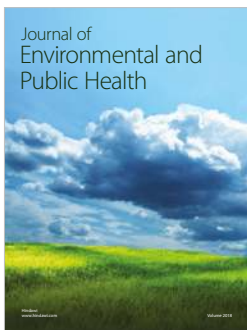
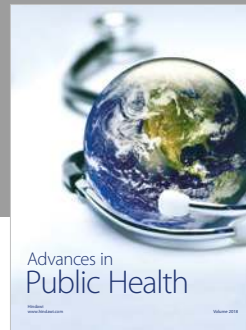
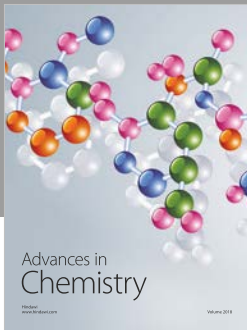
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