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Research Article

Analysis of Observed Trends in Daily Temperature and Precipitation Extremes in Different Agroecologies of Gurage Zone, Southern Ethiopia

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Ethiopian climate-sensitive economy is particularly vulnerable to the effects of climate-related extreme events. Thus, examining extreme daily precipitation and temperature in the context of climate change is a critical factor in advocating climate change adaptation at the local scales. Spatial changes of climate indices for extreme precipitation and temperatures were conducted for the period 1986–2016 in three different agroecologies of the Gurage zone, Southern Ethiopia. The study used the Mann–Kendall (MK) test and Sen's slope estimator to estimate the trend and magnitude of changes in precipitation and temperature. The analysis from the observation indicates that there had been a consistent warming trend and inconsistent changes in precipitation extremes in the study agroecologies. A statistically significant increase in the numbers of warm days and nights and a statistically significant reduction in the numbers of cold days and nights were observed in most of the agroecologies. The duration of extreme trend showed inconsistency; however, a drier condition is observed in lowland agroecology. Therefore, based on the findings of this study, appropriate climate adaptation efforts are needed at the local scale.

1. Introduction

Climatic extreme events may have significant impacts on human society and the environment [1]. Agricultural activities, particularly in developing countries, are highly affected by climatic extreme events such as drought, flood, and hail. This affects the food security and livelihood sources of small-scale farmers since the crop production system is greatly influenced by climate conditions. Precipitation and temperatures are useful indicators of climate variability and change [2]. Detection of the past trend, change, and variability in the time series of climatic variables is very important for understanding the potential impact of future changes and to improve climate risk management capabilities [3–5].

Several studies have been conducted to investigate climate trend analysis and trends of extreme climate events in different parts of the country. Regarding climate trend analysis, though the magnitude and trends of change reported varying with temporal and spatial scales, time-series analysis of mean maximum and minimum temperatures have shown positive trends accompanied by an inconsistent trend in precipitation in many parts of the country. For example, a study by Esayas et al. [6] in different agroecologies of Wolaita Zone reported a positive trend in the annual maximum and minimum temperature and a decreasing trend in the annual precipitation in the lowland and highland agroecologies. Similarly, precipitation exhibited statistically decreasing trends and temperature showed statistically significant increasing trends within the Upper Omo-Ghibe Basin [7], and in the Semiarid Highlands of Eastern Tigray Kahsay et al. [8]. However, Cheung et al. [9] did not find a trend in annual precipitation within the central highlands of Ethiopia.

Changes in climatic extremes are additionally witnessed in several parts of Ethiopia. Worku et al. [10] reported the

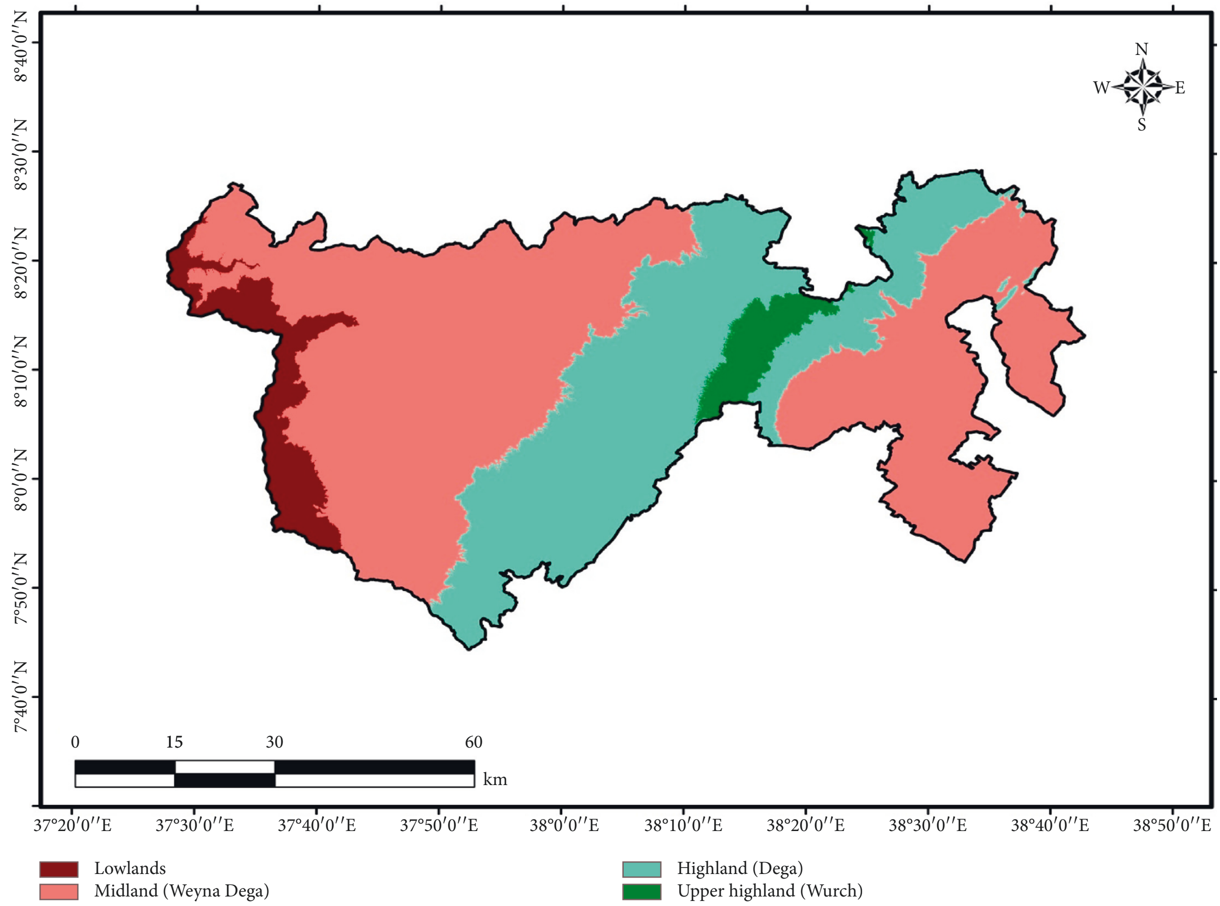

Figure 1: Agroecological map of the study zone.

presence of extreme precipitation and extreme temperature in the Jemma Sub-Basin. The study by Seleshi and Camberlin [11] also identified statistically significant declining trends for the wet day intensity and maximum consecutive five-day rain over eastern, southern, and southwestern parts of Ethiopia. Variation in climatic extremes also observed on the basis of ecoenvironment analysis, for example, a study by Mekasha et al. [12] reported a considerable variation in trends of extreme temperature and precipitation among stations located within a given ecoenvironment.

Although the abovementioned studies have documented the spatiotemporal trends and extremes of precipitation and temperature in different parts of Ethiopia, there is still limited work has been done on trends and variability of extreme events in Southern Ethiopia, which may not fully explain the situation at the local level. For the Gurage zone, the analysis of extreme trends and variability in precipitation and temperature has not been reported in much detail within the literature. In line with this fact, using global or regional scale observations of historical climate is less useful for efficient and effective local-level decision-making [13–15]. Thus, trend analysis on low-scale time-series climate data is more preferential than global or regional scale observations for local-level climate change adaptation planning. Likewise, McSweeney et al. [16] reported that the existing information available so far on climate extremes in Ethiopia is limited in scope, fragmented in coverage, and does not give a full picture of the diverse topography, relief features, and ecoenvironments.

Thus, this study is aimed to study trends in temperature and precipitation extremes in the Gurage zone, Southern Ethiopia, to consider the local-level analysis of extreme climate events. The local-level analysis can help in the design of context-based adaptation strategies (e.g., [3, 5, 17] to the associated shocks).

2. Methodology of the Study

2.1. Study Area: Gurage Zone. The subsistence rain-fed agriculture activity is the main livelihood source in the study area. The annual average temperature of the zone ranges from 13 C to 30 C, and the mean annual rainfall ranges from 600 to 1600 mm. The zone has three main agroecological zones (Figure 1). The Lowland zone (locally called Kola) is located in the Rift Valley drainage system in the East and Omo Valley drainage system in the West. The Midland (Woina-dega) is located on the Eastern and Western escarpments of the Gurage Mountains. The Highland (Dega) covers parts of Ezha, Enemor and Ener, Sodo, Gumer, and Mehur Aklil Woredas [18, 19].

2.2. Data and Data Quality Control. Observed daily precipitation, and maximum and minimum temperature data from 1986 to 2016 were collected from the National

Table 1: Characteristics of selected climate stations.

No.	Station Name	Longitude	Latitude	Elevation (m)	Agroecology	Period
1	Wolkita	37.75	8.27	1550	Lowland	1986–2016
2	Endibir	37.93	8.12	2082	Midland	1986–2016
3	Agena	38.02	8.12	2310	Highland	1986–2016

Table 2: Selected ETCCDI precipitation and temperature extreme indices for the study stations.

Index	Index name	Definition of the Index	Units
	Temperature intensity		
TXx	Max Tmax	Monthly maximum value of daily maximum temp	°C
TNx	Max Tmin	Monthly maximum value of daily minimum temp	°C
TXn	Min Tmax	Monthly minimum value of daily maximum temp	°C
TNn	Min Tmin	Monthly minimum value of daily minimum temp	°C
DTR	Diurnal temperature range	Monthly mean difference between TX and TN	°C
	Duration		
WSDI	Warm spell duration indicator	Annual count of days with at least 6 consecutive days when TX > 90th percentile	Days
CSDI	Cold spell duration indicator	Annual count of days with at least 6 consecutive days when TN < 10th percentile	Days
	Frequency		
TN10p	Cool nights	Percentage of days when TN < 10th percentile	Days
TX10p	Cool days	Percentage of days when TX < 10th percentile	Days
TN90p	Warm nights	Percentage of days when TN > 90th percentile	Days
TX90p	Warm days	Percentage of days when TX > 90th percentile	Days
	Precipitation Intensity		
RX1day	Max 1-day precipitation amount	Monthly maximum 1-day precipitation	Mm
Rx5day	Max 5-day precipitation amount	Monthly maximum consecutive 5-day precipitation	Mm
SDII	Simple daily intensity index	Annual total precipitation divided by the number of wet days (defined as PRCP ≥ 1.0 mm) in the year	Mm/day
R95p	Very wet days	Annual total PRCP when RR > 95th percentile	Mm
R99p	Extremely wet days	Annual total PRCP when RR > 99th percentile	mm
PRCPTOT	Annual total wet day precipitation	Annual total PRCP in wet days (RR ≥ 1 mm)	mm
	Duration		
CWD	Consecutive wet days	Maximum number of consecutive days with RR ≥ 1 mm	Days
CDD	Consecutive dry days	Maximum number of consecutive days with RR < 1 mm	Days
	Frequency		
R10 mm	Number of heavy precipitation days	Annual count of days when PRCP ≥ 10 mm	Days
R20 mm	Number of very heavy precipitation days	Annual count of days when PRCP ≥ 20 mm	Days

Meteorological Agency of Ethiopia for nine stations located in different parts of the study area. Data quality control tests were conducted to exclude and minimize unreliable and missed climate data for all stations. Considering spatial distribution, the proportion of missing data, and the length of record period three climate stations representing each agroecology setting were selected for the study. The stations include Wolkita, Endibir, and Agena (Table 1). RClimDex 1.1 [20] was used to check the quality of the data for each station. Errors like TMIN greater than TMAX, duplicated years, negative precipitation values, and outliers, i.e., values above or below the mean plus or minus four times the standard deviation [21], were compared and replaced by using information from the day before and after the event and also by reference to nearby stations.

2.3. Statistical Methods for Testing and Estimating Trends and Extremes. Trend testing is useful to analyze trends of the values of a random variable over some time in statistical terms [22]. Mean annual trends of the precipitation, TMAX, and TMIN were estimated using the nonparametric Mann–Kendall (MK) test [23, 24]. The Mann–Kendall test is a statistical test widely used for the analysis of the trend in climatologic and hydrologic time series [1]. Compared to other parametric tests, the MK test does not require the data to be normally distributed. In addition, it has an advantage over other parametric tests since the test has low sensitivity to outliers and skewed distributions.

Mann–Kendall S statistic is calculated:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sign}(Xj - Xi), \tag{1}$$

$$\operatorname{sign}(Xj - Xi) = \begin{cases} 1, & \text{if } Xj - Xi > 0, \\ 0, & \text{if } Xj - Xi = 0, \\ -1, & \text{if } xj - Xi < 0, \end{cases} \tag{2}$$

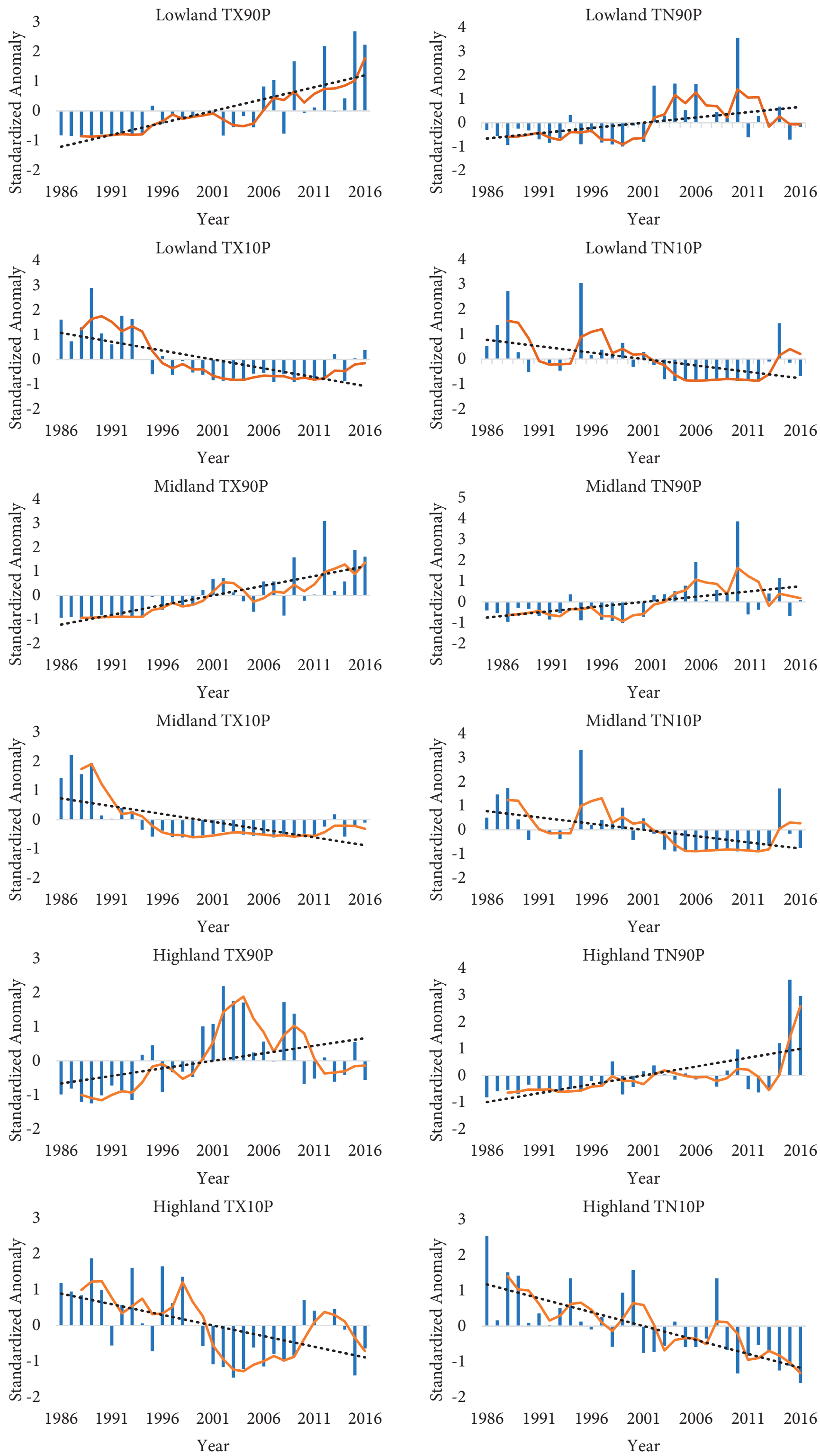

FIGURE 2: Annual trends in TX90P, TN90P, TX10P, and TN10P for the period 1986–2016.

where Xj and Xi are the annual maximum daily values in years' j and i, $j > i$, respectively.

Theil–Sen's slope estimator test was used to calculate the magnitude of the detected trends [25, 26]. Theil–Sen's slope estimator is a robust nonparametric estimator that uses the median slope to assess the trend over time [25, 26].

Theil–Sen's slope estimator is computed:

$$b_{\mathrm{Sen}} = \mathrm{median}\left(\frac{yj - yi}{xj - xi}\right), \quad (3)$$

where $i < j$ and $j = 1, 2, \ldots, n-1$ and $j = 2, 3, \ldots, n$.

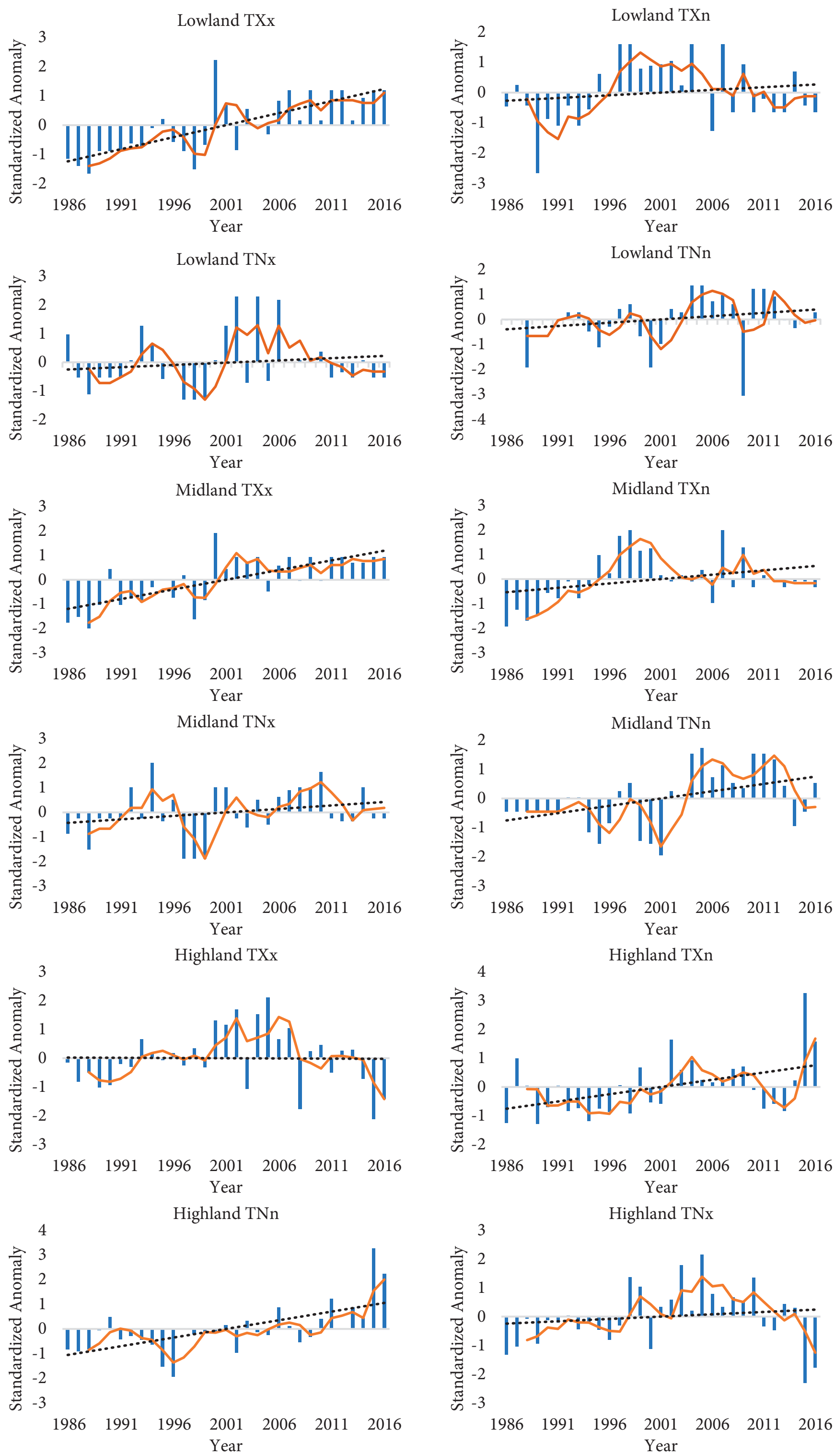

Figure 3: Annual trends in TXx, TXn, TNx, and TNn for the period 1986–2016. The dashed line and straight line on the bar chart represent the linear trend and 5-year moving average, respectively.

Addinsoft's XLSTAT 2018 and RClimDex packages were used for performing the analysis [27].

The temperature and precipitation extreme indices were computed for the period 1986–2016. Indices were defined by the Expert Team on Climate Change Detection and Indices (ETCCDI) (http://cccma.seos.uvic.ca/ETCCDI). Based on ETCCDI, 9 precipitations and 12 temperature extreme indices were selected for this study area (Table 2). The RClimDex tool [20] was used to measure the indices for each agroecology representing stations.

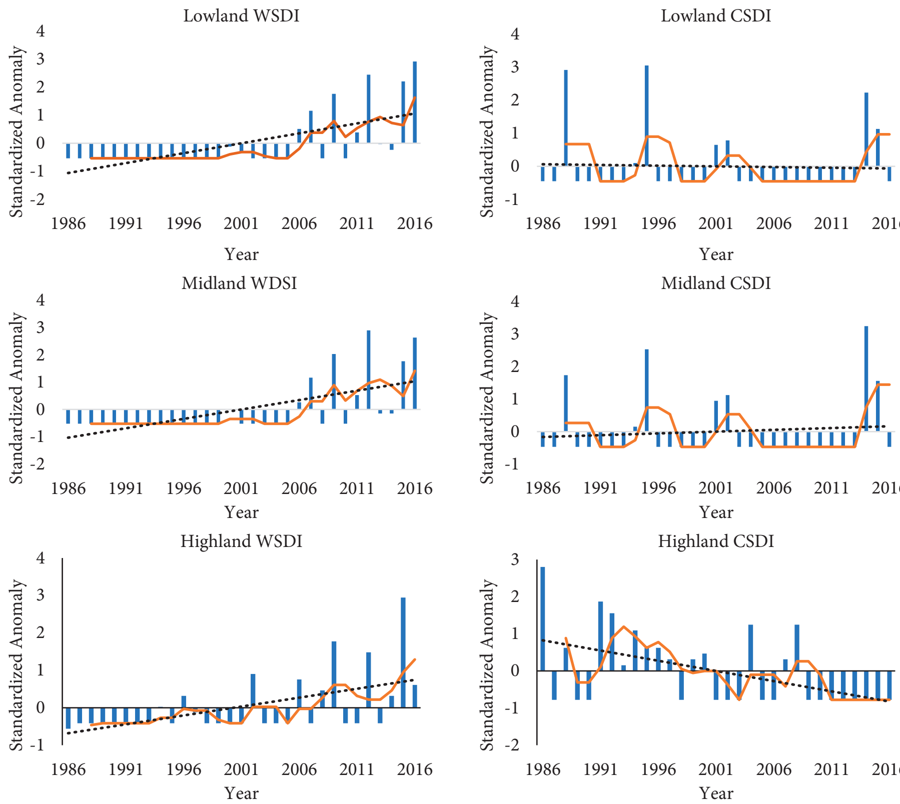

Figure 4: Annual trends in WSDI and CSDI for the period 1986–2016. The dashed line and straight line on the bar chart represent the linear trend and 5-year moving average, respectively.

3. Results and Discussion

3.1. Trends in Temperature Extremes

3.1.1. Warm Days (TX90p) and Warm Nights (TN90p), Cool Days (TX10p) and Cool Nights (TN10p). An increasing trend of warm extreme indices (TX90p and TN90p) was observed in all agroecology zones considered for this study. Only a significant TX90p was observed in the highland agroecology zone; however, the trends in TN90p were significant in the three agroecologies at a different significance level. This finding implies that warming anomalies are increasing in all stations. A significant decreasing trend in the frequency of cool days (TX10p) and cool nights (TN10p) was observed in all stations. In general, the observation indicates that there are an increasing trend in the warm extremes (TX90p and TX90p) and decreasing trends in the cold extremes (TX10p and TN10p) in all agroecologies of the study area (Figure 2). Consistent with the present result, different studies in different agroecologies across Ethiopia reported an increasing trend in the occurrences of TX90p and TN90p while decreasing trends in TX10p and TN10p [6, 10, 12, 16].

The dashed line and straight line on the bar chart represent the linear trend and 5-year moving average, respectively.

3.1.2. Max Tmax (TXx) and Min Tmax (TXn). The temperature trend of TXx and TXn showed an increasing trend within the study stations (Figure 3). However, inconsistency in magnitude was observed among the stations. A statistically significant trend in TXx was observed in both lowland and midland agroecology stations, while a significant increase in TXn only in highland agroecology was observed. Similarly, Worku et al. [10] reported an upward trend in TXx and TXn in Jemma Sub-Basin, Upper Blue Nile Basin.

3.1.3. Max Tmin (TNx) and Min Tmin (TNn). Similarly, an increasing trend but inconsistent in magnitude was observed over time in TNx and TNn. Except in midland agroecology, the trend in TNx and TNn is statistically insignificant (Figure 3). In line with this, increasing intensity of temperature extremes indices was also reported in Ethiopia [10, 12]. On the contrary, Esayas et al. (2018) reported a statistically significant decreasing trend in TXx in the midland agroecology in southern Ethiopia.

3.1.4. Warm Spell Duration Indicator (WSDI) and Cold Spell Duration Indicator (CSDI). An increasing warm spell duration indicator (WSDI) index was observed in all agroecological stations, while it was significant only in lowland and highland agroecologies. In regards to cold spell duration indicator (CSDI), a decreasing trend was observed in lowland and highland agroecologies whereas an increasing trend was observed in midland agroecology but the trend

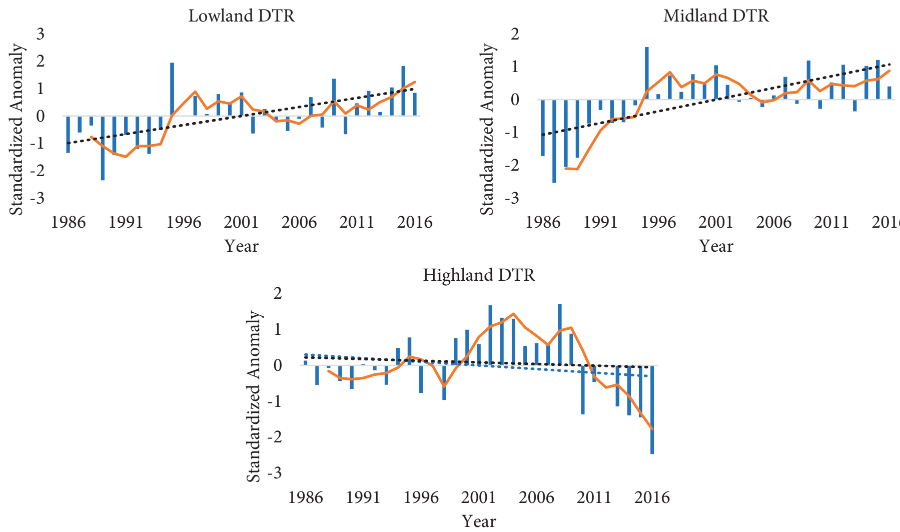

FIGURE 5: Annual trends in DTR for the period 1986–2016. The dashed line and straight line on the bar chart represent the linear trend and 5-year moving average, respectively.

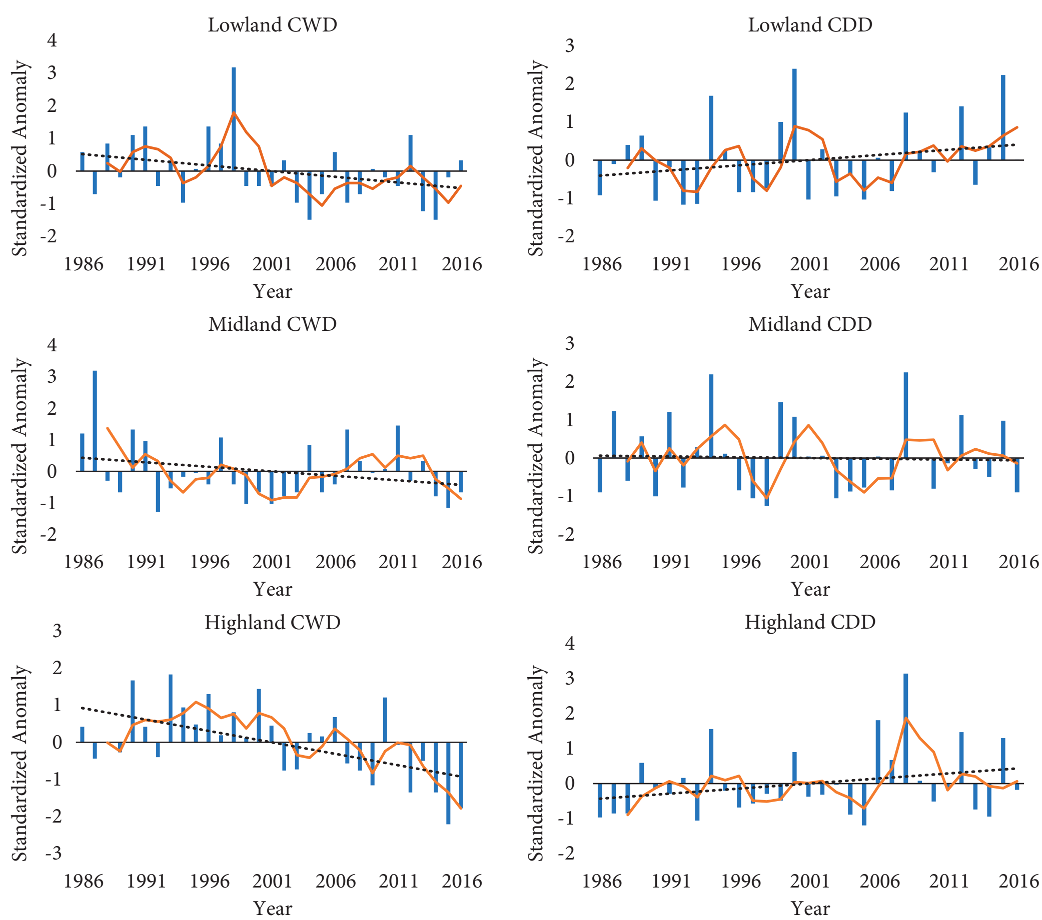

FIGURE 6: Annual trends in CWD and CDD for the period 1986–2016. The dashed line and straight line on the bar chart represent the linear trend and 5-year moving average, respectively.

was insignificant (Figure 4). Similar mixed WSDI and CSDI trends were reported in the Upper Blue Nile Basin [10]. However, decreasing CSDI trends were observed in the Arab region [28] and Southern Ethiopia [6].

3.1.5. Diurnal Temperature Range (DTR). Trends of DTR exhibited an insignificant trend in all of the agroecologies in Figure 5, indicating that the differences between TXmean and TNmean are not changing in the opposite direction.

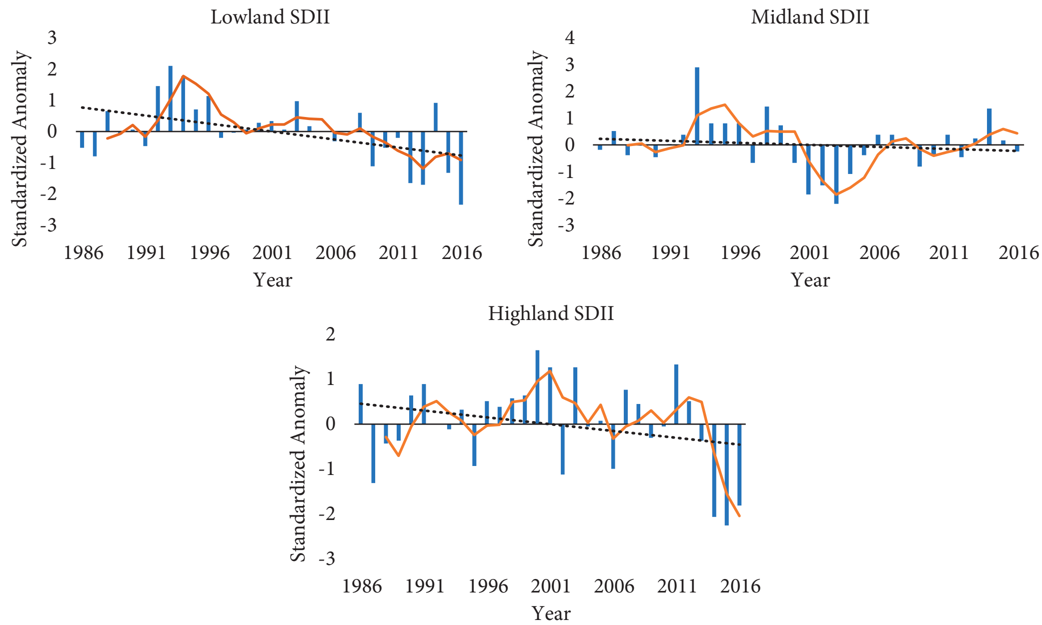

Figure 7: Annual trends in SDII for the period 1986–2016. The dashed line and straight line on the bar chart represent the linear trend and 5-year moving average, respectively.

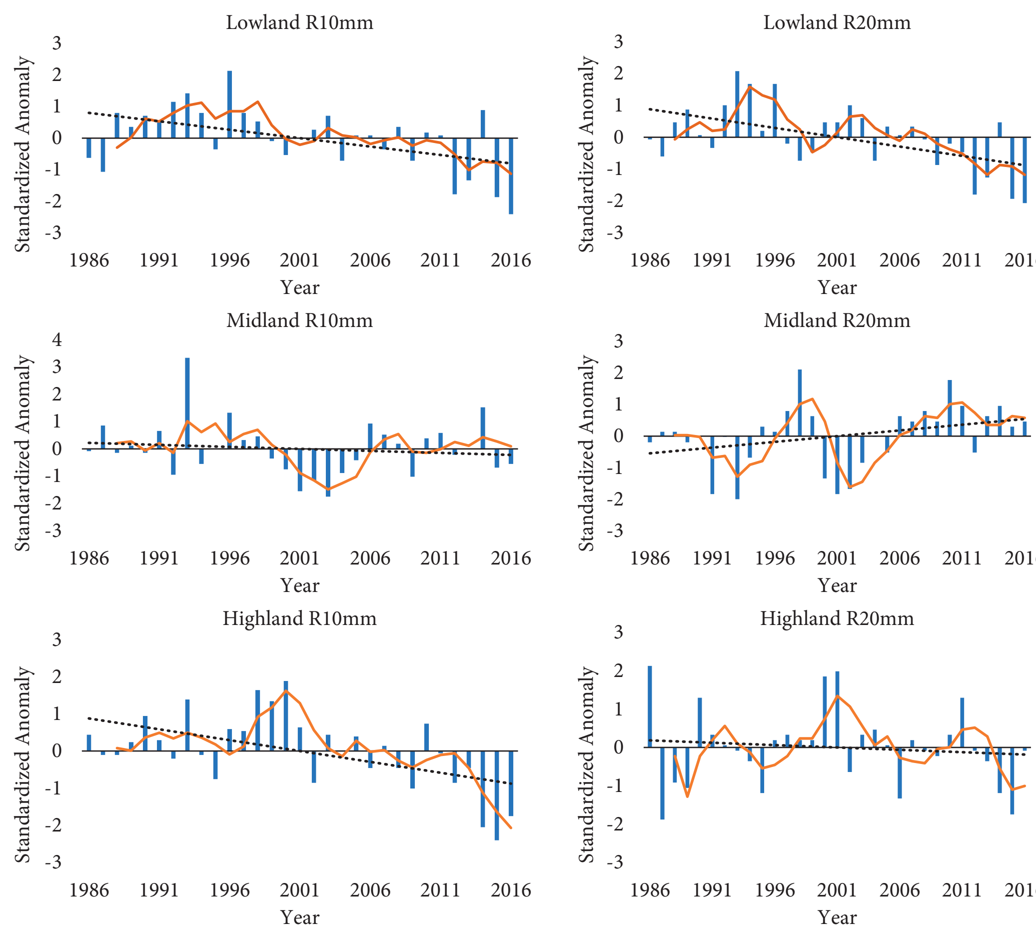

Figure 8: Annual trends in R10 mm and R20 mm for the period 1986–2016. The dashed line and straight line on the bar chart represent the linear trend and 5-year moving average, respectively.

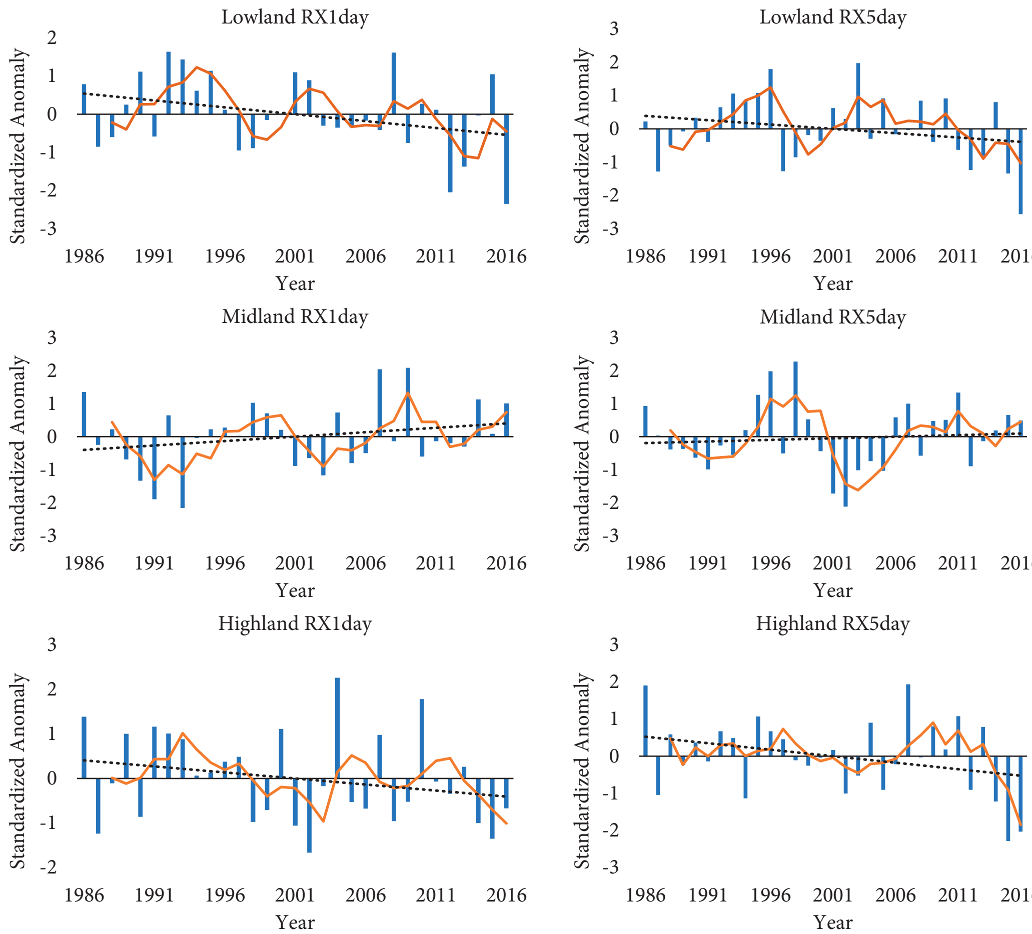

Figure 9: Annual trends in RX1day and RX5day for the period 1986–2016. The dashed line and straight line on the bar chart represent the linear trend and 5-year moving average, respectively.

3.2. *Trends in Precipitation Extremes*

3.2.1. Consecutive Dry Days (CDD) and Consecutive Wet Days (CWD). The trend analysis of both consecutive dry days (CDD) and consecutive wet days (CWD) showed mixed results in the selected agroecologies (Figure 6). Only a decreasing trend in CWD showed in midland agroecology. A drier condition in both lowland and highland agroecologies was observed; that is, the agroecologies showed an increasing trend in CDD and a decreasing trend in CWD. The results are in line with similar findings reported in different parts of Ethiopia where CDD and CWD showed a mixed trend [6, 11]. However, Mekasha et al. [12] and Worku et al. [10] observed a significantly decreasing trend for CDD in Lemi and Asela stations, respectively.

3.2.2. Simple Daily Intensity Index (SDII). A decreasing trend in Simple Daily Intensity Index (SDII) was observed in all the agroecologies, where a significant SDII was observed only in lowland agroecology (Figure 7). Mekasha et al. [12] reported a similar finding where apart from a significant increasing trend at Koka and a significant decreasing trend at Negele-Borana, trends in SDII were not significant in the agroecologies studied.

3.2.3. Number of Heavy (R10 mm) and Very Heavy (R20 mm) Precipitation Days. Except for a significantly increasing trend in R20 mm in midland agroecology, the number of heavy (R10 mm) and very heavy (R20 mm) precipitation days showed a decreasing trend in both lowland and highland agroecologies (Figure 8). Both R10 mm and R20 mm precipitation days were significantly decreasing in lowland agroecologies. The study found that the midland agroecology was at risk particularly related to flooding unless measures are taken. The study is in line with recent findings from Esayas et al. [6] that reported a mix of an insignificant decreasing trend in the lowland and the highland agroecology in R10 mm while it was an insignificant increasing trend in the midland agroecology. Similarly, Mekasha et al. [12] observed insignificant trends in R10 mm and R25 mm at most of the stations over 42 years. However, a similar study showed a significant decreasing trend in R10 mm in Negele-Borena and Asela stations and significant increasing trends in R25 mm in Koka station.

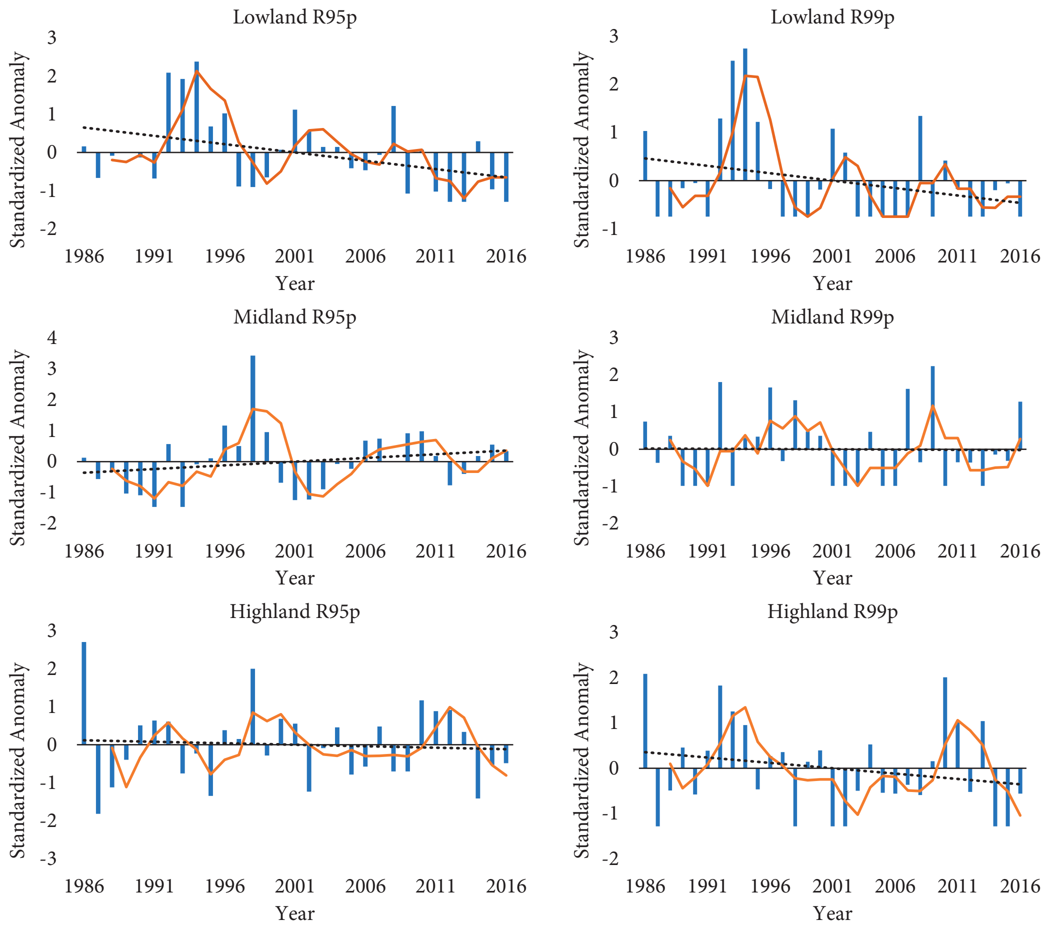

Figure 10: Annual trends in R95p and R99p for the period 1986–2016. The dashed line and straight line on the bar chart represent the linear trend and 5-year moving average, respectively.

3.2.4. Maximum 1-Day (RX1day) and 5-Day (RX5day) Precipitations. Insignificant trends of the maximum 1-day (RX1day) and 5-day (RX5day) precipitations were observed in most of the studied agroecologies. The evaluation in Figure 9 indicates that there was spatial inconsistency among the selected agroecological stations on the trend of Rx1d and Rx5d indices. Both lowland and highland agroecologies had a decreasing RX1day and RX5day trends, while an increasing trend both in the RX1day and RX5day was found in midland agroecology station. Similarly, Esayas et al. [6] reported an insignificant trend both in the RX1day and RX5day in lowland and midland agroecology in southern Ethiopia. Contrary, Worku et al. [10] reported significant increasing trends of Rx1d and Rx5d in Alem Ketema station and Fichie and Mendida stations, respectively. These contrasting results could also be explained by the geographical difference.

3.2.5. Very Wet Days (R95p) and Extremely Wet Days (R99p). The trend in very wet days (R95p) and extremely wet days (R99p) showed consistency among the observed agroecologies (Figure 10). Except for the lowland where a significant decreasing trend was observed in R95p (7.087 mm/year), the remaining stations had an insignificant trend in both R95p and R99p. An increasing trend for R95p was only observed in midland agroecology.

In general, the observed spatial and temporal characteristics of extreme precipitation in the studied climate stations had shown inconsistency in used climate indices and the trends are mostly insignificant.

4. Discussion

The findings of the results indicated that the observed spatial and temporal characteristics of extreme precipitation in the studied climate stations had shown inconsistency in used climate indices and the trends are mostly insignificant while analyses of temperature extremes revealed that there is a consistent warming trend in the study stations (Table 3). The changing condition which is manifested through extreme weather conditions and related shocks including drought, floods, weeds, and pest infestation have significantly affected agricultural systems, water resources, rural livelihoods, and food security of the area.

On the other hand, arguably more significant than the observed trends in climate and weather extremes, are projected changes in extremes. Likewise, by the end of the 21st century, a 2°C increase in annual temperature and reduction in precipitation is predicted [29] which will lead to increased

Table 3: Trends in climate extreme indices for the period 1986–2016 in different agroecologies.

Index	Units	Lowland Sen's slope	Midland Sen's slope	Highland Sen's slope
Temperature				
TXx	°C	0.159**	0.184**	0.017
TNx	°C	0.04	0.077*	0.06
TXn	°C	0.011	0.022	0.075**
TNn	°C	0.042	0.05**	0.068
DTR	°C	0.075	0.122	−0.022
WSDI	Days	2.375**	1.835*	0.226
CSDI	Days	−0.061	0.124	−0.353***
TN10p	Days	−0.573**	−0.565***	−0.511*
TX10p	Days	−0.851**	−1.252***	−0.291**
TN90p	Days	0.398**	0.445**	0.831*
TX90p	Days	0.965	0.863	0.292*
Precipitation				
RX1day	Mm	−0.35*	0.252	−0.186
Rx5day	Mm	−0.588	0.158	−0.657*
SDII	Mm/day	−0.095***	−0.022	−0.049
R95p	Mm	−7.087**	3.268	−0.768
R99p	mm	−2.342	−0.078	−1.388
CWD	Days	−0.134*	−0.23	−1.876***
CDD	Days	0.987	−0.159	1.015
R10 mm	Days	−0.6***	−0.219	−1.172***
R20 mm	Days	−0.438***	0.221*	−0.089

Note. Trends significant at $^{***}p \leq 0.001$; $^{**}p \leq 0.05$; $^{*}p \leq 0.01$.

stress on crop cultivation, livestock production, and water availability.

Extreme climate events are a major cause of the low productivity of the agriculture sector in sub-Saharan Africa [29–31]. Similarly, in Gurage Zone, smallholder farmers rely heavily on subsistence rain-fed agriculture for livelihood and the sector becomes comparatively more vulnerable to the adverse effects of changing climate conditions and experienced extreme weather events. For instance, a study by Gizachew & Shimelis [32] between 1970 and 2002 reported 4 major drought occurrences in Sodo Woreda of Gurage Zone. Similarly, some plant species such as *Lobelia rhychopetalum* existing in the Gurage Mountains are becoming extinct [33].

Additionally, Enset (*Ensete ventricosum*) "false banana tree" is among the main home garden food crops which is an indigenous agricultural system found in Gurage and much of southern Ethiopia. The plant is extensively cultivated and contributes to the long-term sustainability of food production. This drought-resistant plant can be harvested at any time and stored for long periods. Enset farming systems play a multipurpose role, for instance, used for food, animal forage, and fiber; improve the nutrient balance in the soil; promote compact and permanent villages, and provide shadow for coffee and khat plantation, thus moderating temperature [34–36]. However, due to severe drought, the area coverage of Enset-based plantation and its productivity decreased [33, 37].

Likewise, studies have suggested that unless mitigation measures are taken to climate change, 20–30% of plant and animal species extinction is predicted, which in turn has a significant effect on human and natural systems [38–40]. Concerning economic damage caused by extreme events on agricultural production and hence, food security, the study [29] argues that the increase in the exposure of people and economic resources to weather and climate disasters has been the main cause of the long-term increase in economic losses. Unless measures to improve their communities' preparedness and resilience at different levels are taken, these climate extremes changes are likely to worsen the existing drivers of poverty.

5. Conclusion

This paper has evaluated trends in temperature and precipitation extremes using the Mann–Kendall (MK) test and Sen's slope estimator in different agroecologies of Gurage Zone, Southern Ethiopia. The evidence indicates that the trends in temperature extremes are on the rise in different agroecologies of the study zone over the study period. The observation indicates that there is an increasing trend in the warm extremes and decreasing trends in the cold extremes. A statistically significant increase in the numbers of warm days and nights and a statistically significant reduction in the numbers of cold days and nights were observed in most of the agroecologies studied. Similarly, the IPCC AR4 assessed that it was very likely that there had been trends toward warmer and more frequent warm days and warm nights, and warmer and less frequent cold days and cold nights in most land areas. Also, positive trends in the intensity of temperature extremes indices (TXx, TXn, TNx, and TNn) with the inconsistent magnitude of change were observed. A higher length or number of warm spells and inconsistent trends in cold spell duration were observed in the studied agroecologies. In summary, analyses of temperature extremes revealed that there is a warming trend. Analysis of trends of precipitation extremes revealed spatial inconsistency in the study agroecologies. The duration of extreme precipitation trend showed inconsistency; however, a drier condition is observed in both lowland and highland agroecologies. There was spatial inconsistency among the selected agroecologies on the intensity of extreme precipitation. Finally, results from extreme event analysis revealed an increasing trend of climate extremes in most of the climatic stations. This could result in severe losses of livelihood sources and associated impacts on household food security unless appropriate adaptation measures are taken. Therefore, the findings of this study will help in initiating agroecological-based preparedness to offset and reduce the impact of climate variability and change.

Data Availability

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

Disclosure

A thesis has previously been published [41].

Conflicts of Interest

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

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