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# Analysis of the Recent Trends of Two Climate Parameters over Two Eco-Regions of Ethiopia

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**Abstract:** The changes in climatic variables in Ethiopia are not entirely understood. This paper investigated the recent trends of precipitation and temperature on two eco-regions of Ethiopia. This study used the observed historical meteorological data from 1980 to 2016 to analyze the trends. Trend detection was done by using the non-parametric Mann-Kendall (MK), Sen's slope estimator test, and Innovative Trend Analysis Method (ITAM). The results showed that a significant increasing trend was observed in the Gondar, Bahir Dar, Gewane, Dembi-Dolo, and Negele stations. However, a slightly decreasing trend was observed in the Sekoru, Degahabur, and Maichew stations regarding precipitation trends. As far as the trend of temperature was concerned, an increasing trend was detected in the Gondar, Bahir Dar, Gewane, Degahabur, Negele, Dembi-Dolo, and Maichew stations. However, the temperature trend in Sekoru station showed a sharp decreasing trend. The effects of precipitation and temperature changes on water resources are significant after 1998. The consistency in the precipitation and temperature trends over the two eco-regions confirms the robustness of the changes. The findings of this study will serve as a reference for climate researchers, policy and decision makers.

**Keywords:** trend analysis; precipitation; temperature; eco-region; Ethiopia

## 1. Introduction

Extreme climatic and weather events in recent decades have been a critical global issue due to the severity of the impacts on natural environments, economy, and on human life [1–3]. These extreme events are unpredictable and destructive, especially, on agriculture production. The likelihood of fewer cool days and nights, increasing heavy precipitation events, and droughts has increased since the 1970s [4]. This indicates that the global climate is undergoing a significant change which is manifested by rising temperature, droughts, rainstorms, and flooding. Scientific studies showed that the mean global temperature could rise by 1.4 to 5.8 °C in 2100 with a mean sea level rise of 10 cm over the same period as reported by Intergovernmental Panel for Climate Change in 2008 [5]. However, considerable regional and seasonal changes in the climate are expected, affecting climatic variables differently depending on the regions with great impact on environments and human systems [6]. The recent increasing frequency of heavy rainfall and severe droughts in many parts of the world is an indication of these situations [7]. Any change of mean global and regional temperature will impact the spatial and temporal distribution of rainfall [8]. This, in turn, affects the hydrological cycles and the availability of water resources [9]. The probability of the frequency of extreme events in the near future is very likely to increase and thus understanding the recent trends is crucial in order to predict the future climate changes. Hence, climate change is perceived through extreme events which tend to alter the magnitude of the predicted climate impacts and this may also be supported by severe flood events. The impacts of climate change on different regions are very different. In this regard, different studies have been conducted in many regions of the world such as in China [10–12], Iran [13], Senegal [14], and India [15,16].

Ethiopia is the most vulnerable country with regard to climate change due to its climatic, hydrology, and low economic conditions [17]. Annual rainfall is highly variable, ranging from less than 200 mm in the southeast, east, and northeast borders to 1200 mm in the central and western highlands of the country [18]. Notably, the country mainly depends on rainfed agriculture and available water resources in the highlands, while large parts of its southern and eastern regions are extremely arid and prone to drought and desertification [5]. Hence, the rainfall is determined by seasonal and interannual variability in the country. Changes in precipitation have a direct impact on floods, droughts, and water resources [19].

Climate change threatens to increase temperature and evapotranspiration; and hence, increasing the risks of heat waves associated with drought [20]. Thus, the change in climate is expected to increase vulnerability in all eco-regions through the increased temperature and more erratic rainfall, which will impact food security and economic growth. Some regional analysis was undertaken to understand the extreme climate and trends. However, the trend indices showed significant increases and decreases in seasonal and annual precipitation, for example, Asfaw et al. [21] reported a decreased rainfall in annual, Belg, and Kiremt in the Woleka sub-basin of Ethiopia. On the other hand, Bewket and Conway [22] reported variations in daily rainfall with no consistent trends. Mekasha et al. [23] also reported increasing warm extremes in temperature and increasing precipitation in different stations across Ethiopia.

Thus, extreme climate indices should be tested for future studies on the perception of climate change with a wide coverage within the country. Therefore, it is essential to analyze the recent trends of climatic variables as these show the climate-related adaptation and mitigation strategies employed by different entities to improve the agrarian economy of the country at large. Furthermore, trend analysis of climatic variables is very important to understand the climate system of the country and has become a vital research area for other researchers. The objective of this study was to assess the recent trends of precipitation and temperature between 1980 and 2016. Therefore, the output of this paper will provide insights for concerned body with ecological and sustainable economic development.

## 2. Materials and Methods

### *2.1. Study Area Description*

Ethiopia lies between 3°–15° N and 33°–48° E. The total area of the country is about 1.13 million km$^2$ [18], see Figure 1. The country is characterized by a diversified climate due to its equatorial positioning and topography. Its climate is controlled by atmospheric circulations, complex physiography, and the marked contrast in elevation [18]. The country is mainly divided into two eco-regions, namely lowlands and highlands, where the lowest point is at Danakil Depression and the highest point (4543 m) is at Ras Dejen, above sea level [24]. This classification is mainly based on altitudinal classes, precipitation, and temperature variations. We mainly focused on precipitation and temperature variations for this paper. The lowest mean minimum temperature and high precipitation mostly occur in the highland regions of the country. The highest mean temperature and low precipitation occur in lowland parts of the country. The rainfall also showed seasonal and interannual variability [25].

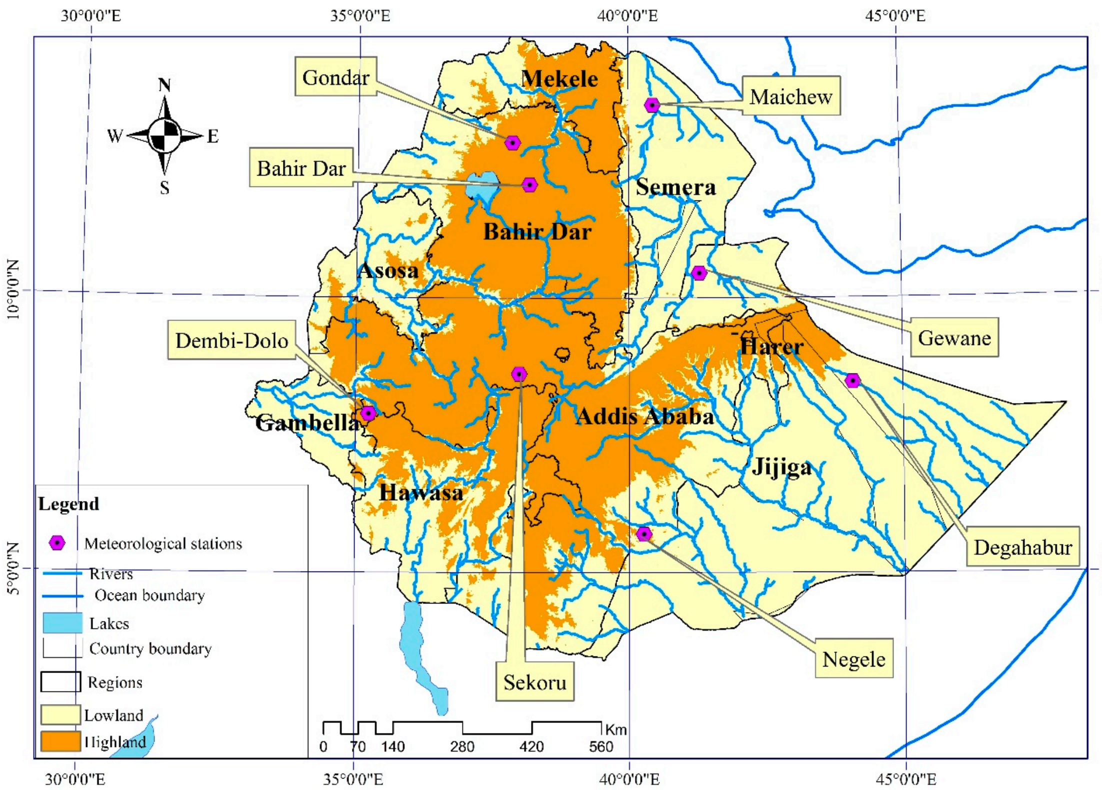


**Figure 1.** Location map of the study area.

## 2.2. Data Sources

The raw climatic data were collected from the National Meteorological Services Agency of Ethiopia [26]. As the data series from 1980 to 2016 are complete, the observed precipitation and temperature data were selected as the basic analysis data in this study. All the necessary data for this manuscript were provided after quality control. The stations were also selected based on the completeness of the data during the study periods. We have selected eight stations from two eco-regions (four from highland and four from lowland eco-regions to represent the entire study regions) for this study, see Table 1.

**Table 1.** Meteorological information's of stations.

| Station's Name | Elevation (m) | Latitude (N) | Longitude (E) | Eco-Regions |
|---|---|---|---|---|
| Dembi-Dolo | 1850 | 34.8° | 8.5167° | Highland |
| Gondar | 1973 | 37.4319° | 12.5212° | Highland |
| Bahir Dar | 1827 | 37.322° | 11.6027° | Highland |
| Sekoru | 1928 | 37.4167° | 7.9167° | Highland |
| Gewane | 568 | 40.633° | 10.15° | Lowland |
| Maichew | 2432 | 39.5337 | 12.7841° | Lowland |
| Degahabur | 1070 | 43.55° | 8.2167° | Lowland |
| Negele | 1544 | 39.5667° | 5.4167° | Lowland |

## 2.3. Methods

This paper used various methods to detect trends in the precipitation and temperature. The methods are either Parametric or non-parametric which are essential to detect the trends of hydrometeorological observations [27]. Following, are the lists of trend detection non-parametric tests used in this paper, see Figure 2.

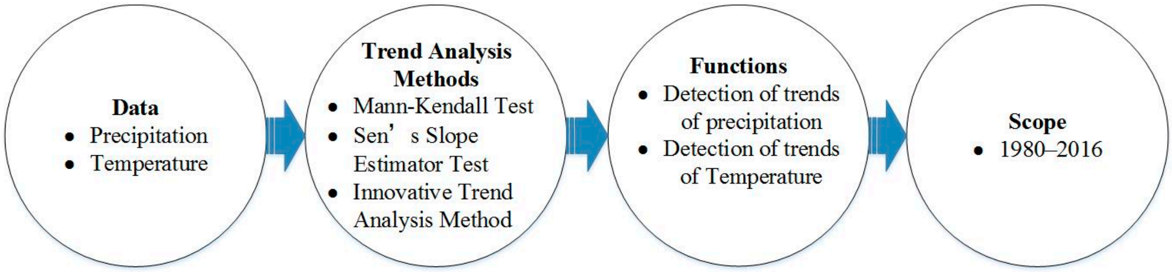


**Figure 2.** Flow diagram to detect trends of precipitation and temperature.

2.3.1. Mann-Kendall (MK) Test

The Mann-Kendall (MK) test is suited for hydrometeorological observations where the data points are not necessarily uniform [13,28–31]. It is used to detect the presence of either increasing or decreasing monotonic trends in the study area and to see whether the trend is statistically significant or not. Since the test statistics of the MK test are based on plus or minus signs, the determined trends are less affected by the outliers. It is given by:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn\left(X_j - X_i\right) \quad (1)$$

where, $X_i$ ($i$ = 1, 2, . . . , $n$−1) and $X_j$ ($j$ = $i$ + 1, 2, . . . , $n$). The observations of each $X_i$ and $X_j$ are calculated as:

$$sgn\left(X_j - X_i\right) = \begin{cases} +1 \text{ if } \left(X_j - X_i\right) > 0 \\ 0 \text{ if } \left(X_j - X_i\right) = 0 \\ -1 \text{ if } \left(X_j - X_i\right) < 0 \end{cases} \quad (2)$$

where $X_i$ and $X_j$ are the data points in $i$ and $j$ years. The variance is calculated with the following equations when the data points ($n \geq 10$) and the mean $E(S) = 0$ [32]:

$$Var(S) = \frac{n \times (n-1) \times (2\mathrm{n}+5) - \sum_{q=1}^{p} t_q \times \left(t_q - 1\right) \times \left(2t_q + 5\right)}{18} \quad (3)$$

where $p$ is tied groups in data points, and $t_q$ is the time series in the $q$th tied groups. The $Z_{(mk)}$ is given as:

$$Z_{(mk)} = \begin{cases} \frac{S-1}{\delta} \; if \; S > 0 \\ 0 \; if \; S = 0 \\ \frac{S+1}{\delta} \; if \; S < 0 \end{cases} \quad (4)$$

When $Z_{(mk)} \geq 10$, it shows an upward trend and when $Z_{(mk)} < 10$, it shows a downward trend. In a time series data sequence, the test statistics are defined separately:

$$UF_k = \frac{d_k - E(d_k)}{\sqrt{var(d_k)}} \; (K = 1,\, 2,\, 3, \ldots, n) \quad (5)$$

If $UF_k > UF\alpha/2$, it shows that the trend is significant.

$$UB_k = -UF_k \quad (6)$$

$$K = n + 1 - k \quad (7)$$

Finally, $UB_k$ and $UF_k$ are drawn as $UB$ and $UF$ curves. The intersection is the beginning of mutation between the two curves [33].

2.3.2. Sen's Slope Estimator Test

This test is used to estimate the magnitude of trends in time series data [9]. The slope ($Q_i$) between two time series data is given as:

$$Q_{i=} = \frac{X_p - X_t}{p - t},\ for\ i = 1,\ 2, \ldots, N \quad (8)$$

where $X_p$ and $X_k$ are time series at period $p$ and $t$ ($p > t$), respectively. If there is single datum in each time, then $N = \frac{n(n-1)}{2}$; $n$ is number of time series. Whereas, if there are many data points, $N$ is computed as $N < \frac{n(n-1)}{2}$; $n$ total number of observations. The $N$ values of the slope estimator are arranged from smallest to biggest.

A positive value of $Q_i$ indicates an upward trend and a negative value of $Q_i$ represents a downward trend in the time series data. The median of these $N$ values of $Q_i$ is represented as Sen's slope estimator. The median of slope ($\beta$) is given:

$$\beta = \begin{cases} Q \times [(N+1)/2] & \text{when } N \text{ is odd} \\ Q \times [(N/2) + Q \times (N+2)/(2)/(2)] & \text{when } N \text{ is even} \end{cases}. \quad (9)$$

When $\beta$ is positive, it indicates the trend is increasing. However, a negative value of $\beta$ represents a decreasing trend.

2.3.3. Trend Analysis by Innovative Method (ITAM)

Trend Analysis through Innovative Method (ITAM) is also used for trend detection and its reliability was checked with the MK test [9,34]. The observational time series data were classified into two classes and then the data points were arranged independently in ascending order. The mean difference between $X_i$ and $X_j$ would give the magnitude of the trend of the data series. The first observed time series data in this paper were not considered since the total time series data are odd. The test is multiplied by 10 to make the scale similar to MK and Sen's slope estimator tests [9]:

$$\Phi = \frac{1}{n}\sum_{i=1}^{n}\frac{10\left(X_j - X_i\right)}{\mu} \quad (10)$$

where, $\Phi$ = slope estimator, $n$ = number of time series in the subseries, $X_i$ = observations in the first half subseries, $X_j$ = observations in the second half subseries and $\mu$ = mean of data series $X_i$ subseries.

When $\Phi$ is positive, it indicates the trend is increasing. However, a negative value of $\Phi$ represents a decreasing trend.

## 3. Results

### *3.1. Analysis of Mean Annual Precipitation*

From 1980 to 2016, the mean annual precipitation of the study area was found to be 834.97 mm, with a CV (coefficient of variation) of 15% and a standard deviation of 122.27 mm. Quantities of 509.93 and 1015.90 mm were the minimum and maximum precipitation per annum, respectively. An increase in the precipitation levels was observed in 2000, 2005, 2007, 2010, and 2013 ($R^2$ = 0.01), with a sharp decreasing trend in 1992. The highest annual precipitation was recorded at the highland eco-region stations (Gondar, Bahir Dar, Sekoru, and Dembi-Dolo), which accounts for approximately 20.3% of lowland eco-regions (Gewane, Degahabur, Negele, and Maichew). The annual precipitation was mainly contributed by the Kiremt months of June–August (47.58%), especially in July and August. These two months contributed 56% of the total annual rainfall.

As far as the seasonal rainfall was concerned, the values varied from 133.82 to 2018.24 mm (Kiremt), from 1176.13 to 1219.32 mm (Meher), from 59.73 to 80.80 mm (Bega), and 551.63 to 1144.75 mm (Belg).

### 3.2. Trend Analysis of Precipitation

The MK curve annual precipitation (*UF* and *UB* = Changing Parameters) shows the trends of precipitation in highland and lowland eco-environments of the study area. The result showed that the trend in Gondar (Z = 1.69), Dembi-Dolo (Z = 0.28) and Bahir Dar (Z = 0.72) was increasing and the trend in Sekoru (Z = 0.45) was decreasing. On the other hand, in lowland eco-regions, a significant increasing trend was observed in the Gewane (Z = 0.80) and Negele (Z = 0.72) stations, respectively. However, the trend in Degahabur (Z = 0.30) and Maichew (Z = 0.51) was a decreasing one, see Figure 3.

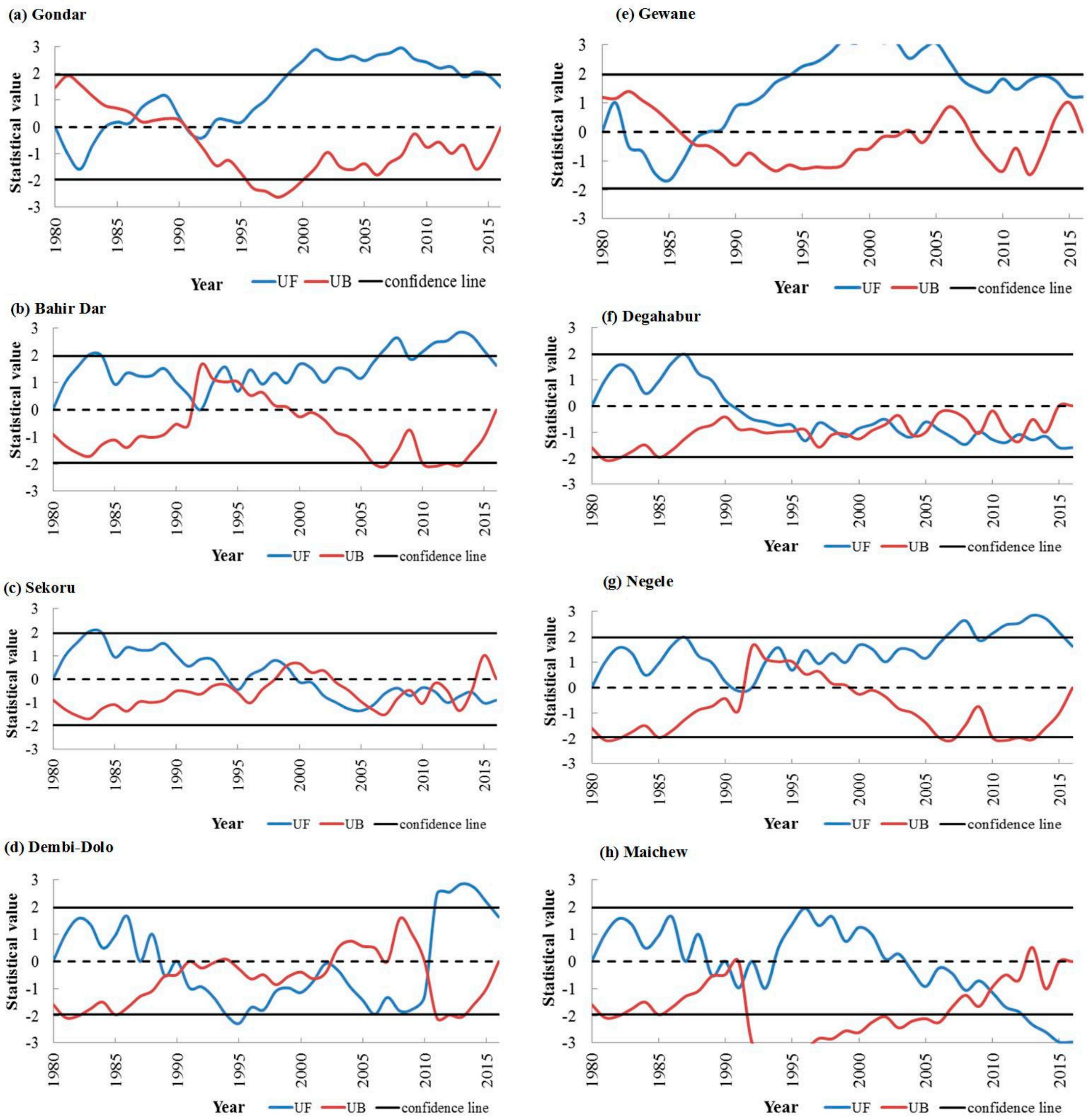


**Figure 3.** Mean annual precipitation trends of (**a**) Gondar, (**b**) Bahir Dar, (**c**) Sekoru, (**d**) Dembi-Dolo, (**e**) Gewane, (**f**) Degahabur, (**g**) Negele and (**h**) Maichew.

The trend results of precipitation by three trend detection tests are presented in Table 2 with a level of significance α = 5%, α = 10%.

**Table 2.** Statistical trend results of precipitation.

| No. | Stations | Z | Φ | β |
|---|---|---|---|---|
| 1 | Gondar | 1.69 ** | 0.54 | 1.84 ** |
| 2 | Bahir Dar | −0.07 * | −23.51 | 1.80 * |
| 3 | Sekoru | 1.37 | 0.21 | 0.01 |
| 4 | Dembi-Dolo | −0.28 | −0.07 | −11.55 |
| 5 | Gewane | 5.59 ** | 0.69 | 0.10 ** |
| 6 | Degahabur | 0.30 | −0.56 | 4.13 |
| 7 | Negele | 0.72 ** | −0.03 | 23.40 ** |
| 8 | Maichew | 0.51 * | −0.05 | 18.49 * |

**Note:** * $\alpha = 0.1$; ** $\alpha = 0.05$.

### 3.3. Analysis of Mean Annual Temperature

The mean annual temperature of the study area was found to be 29.16 °C during the study period. The minimum and maximum recorded temperature were 27.92 and 30.35 °C, respectively. An increasing temperature was recorded in 2010 and 2015 with ($R^2 = 0.67$), and a decreasing trend in the temperature was recorded in 1989. The highest temperature was recorded in the lowland eco-regions (Gewane, Degahabur, Negele, and Maichew). Whereas, a slightly lower temperature was observed in highland eco-regions (Gondar, Bahir Dar, Sekoru, and Dembi-Dolo).

### 3.4. Trend Analysis of Temperature

The statistical test result of this study showed that the trends of temperature in the Gondar (Z = 5.68), Bahir Dar (Z = 7.59), Dembi-Dolo (Z = 3.88), Maichew (Z = 6.45), Gewane (Z = 5.59), Degahabur (Z = 4.78), and Negele (Z = 8.01) stations are significantly increasing. However, a statistically significant decreasing trend was observed in Sekoru (Z = 1.37) station, as shown in Figure 4. The trend results of the temperature by three trend detection tests are presented in Table 3.

**Table 3.** Statistical trend results of temperature.

| No. | Stations | Z | Φ | β |
|---|---|---|---|---|
| 1 | Gondar | 5.68 ** | 0.35 | 0.04 ** |
| 2 | Bahir Dar | 7.59 ** | 0.62 | 0.08 ** |
| 3 | Sekoru | 1.37 ** | 0.21 | 0.01 ** |
| 4 | Dembi-Dolo | 3.88 * | 0.22 | 0.02 * |
| 5 | Gewane | 5.59 ** | 0.69 | 0.10 ** |
| 6 | Degahabur | 4.78 * | 0.18 | 0.03 * |
| 7 | Negele | 8.01 * | 0.48 | 0.07 * |
| 8 | Maichew | 6.388 ** | 0.42 | 0.06 ** |

**Note:** * $\alpha = 0.1$; ** $\alpha = 0.05$.

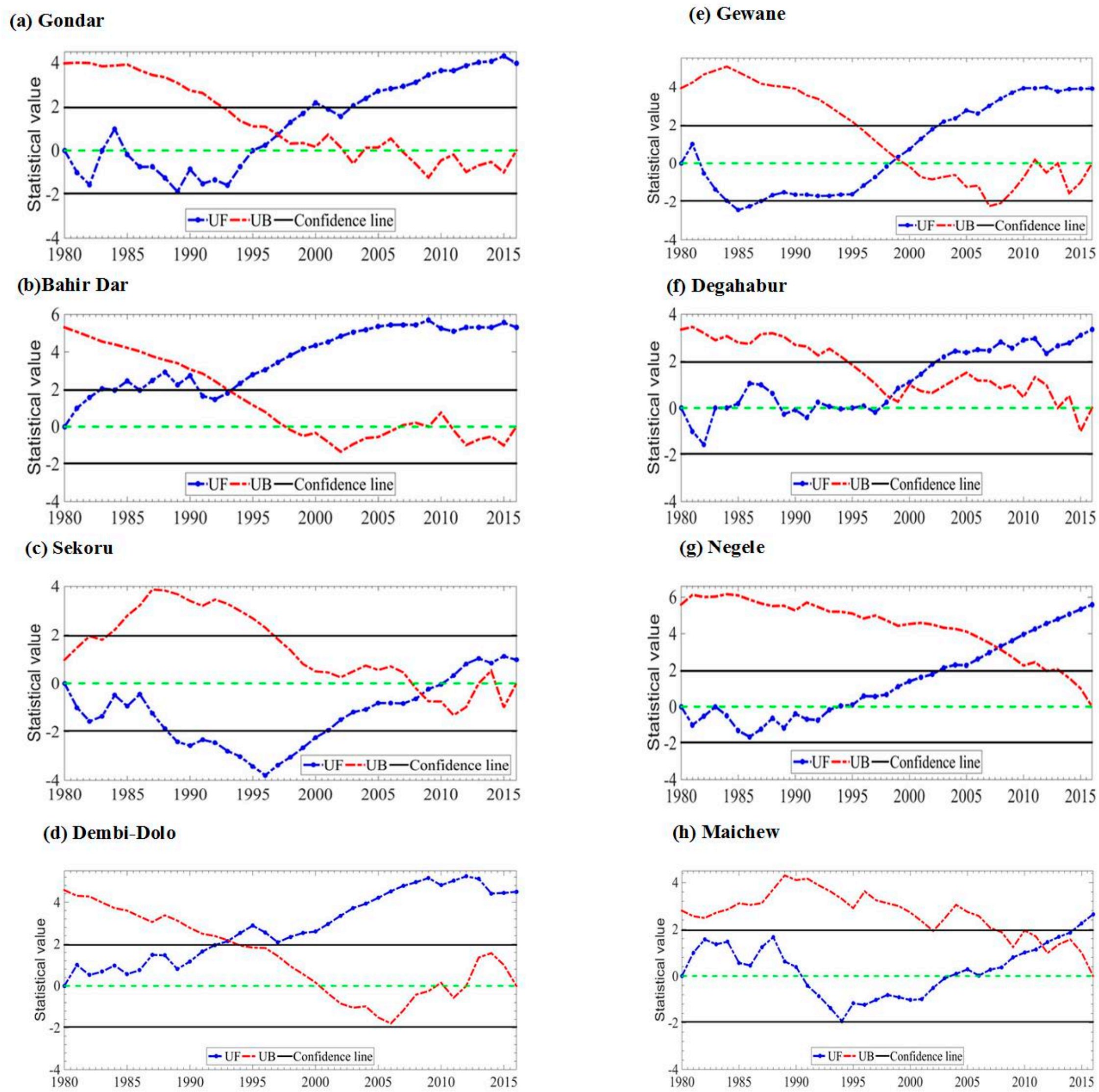


**Figure 4.** Average annual temperature trends of (**a**) Gondar, (**b**) Bahir Dar, (**c**) Sekoru, (**d**) Dembi-Dolo, (**e**) Gewane, (**f**) Degahabur, (**g**) Negele and (**h**) Maichew.

### *3.5. Temporal Patterns of Precipitation and Temperature in Individual Stations*

The temporal pattern (1980–2016) of precipitation and temperature is illustrated in Figure 5. It is observed that precipitation shows a sharply increasing trend in the Bahir-Dar station, though other stations showed a non-uniform pattern. However, all stations showed an increasing trend in the temperature.

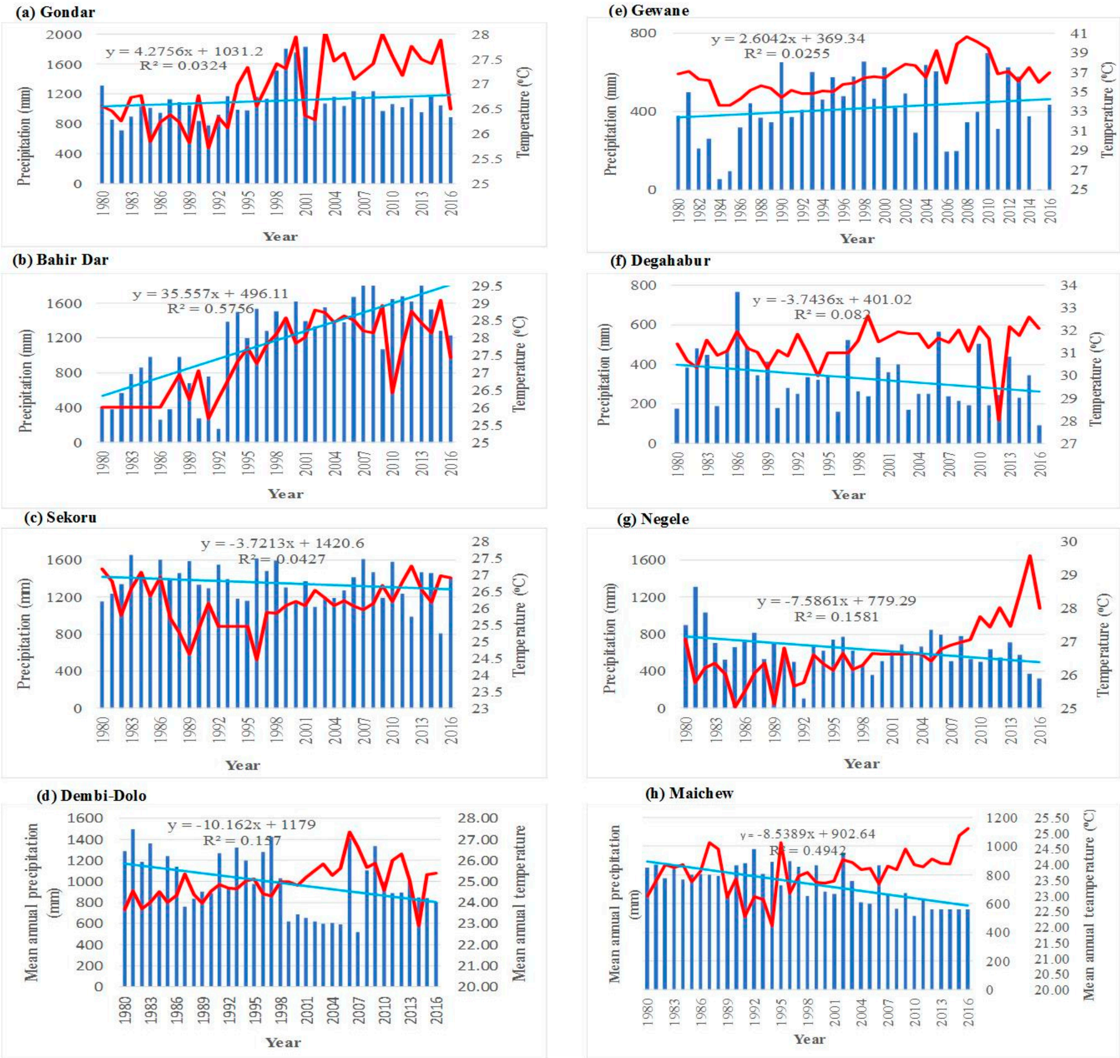


**Figure 5.** Temporal patterns of precipitation and temperature: (**a**) Gondar, (**b**) Bahir Dar, (**c**) Sekoru, (**d**) Dembi-Dolo, (**e**) Gewane, (**f**) Degahabur, (**g**) Negele and (**h**) Maichew.

## 4. Discussion

The trends in the precipitation and temperature were analyzed in two eco-regions of Ethiopia. The findings of the study indicated that there is a general tendency towards increasing temperature and a non-uniform pattern of precipitation trends across the stations. Increasing precipitation has been reported in the Gondar, Bahir Dar, Dembi-Dolo, Gewane, and Negele stations. However, slightly decreasing trends were detected in the Sekoru, Maichew, and Degahabur stations. As far as trends of temperature are concerned, almost all stations exhibit a general tendency of increasing temperature. The observed trends have an implication, particularly, on agriculture production of the two eco-regions which are unable to mitigate the impacts of climate change. The observed warming trend may lead to a high energy demand for cooling, high evapotranspiration rate, and weaken the economy at large [35]. Increasing temperature also increases transpiration which increases the chance of rainfall and may interfere with groundwater recharge triggered by reduction in Kiremt season. In the same way, an increasing occurrence of extreme rainfall events impacts the production systems.

The change in trends of precipitation and temperature observed in each station could imply that the variations are more pronounced for certain stations and less for others. It was confirmed that precipitation is mainly caused by a cold summer, and thus correlates to a large extent with temperature in the study area. Therefore, the cause of these variations needs to be studied further to link them with climate variability and change.

Our findings are consistent with previous studies concerning the variations of precipitation and temperature trends [3,7,23,36–41]. However, the causes of such changes of climatic trends across the stations during the study period (1980–2016) will require another detailed investigation.

## 5. Conclusions

This study analyzed recent changes in precipitation and temperature trends in Ethiopia for the study period from 1980 to 2016. The temporal variability of precipitation and temperature were analyzed. A Mann-Kendall test, Sen's slope estimator test, and Innovative Trend Analysis Methods were used to analyze the trends. Our results showed that five out of eight stations showed increasing trends of precipitation. On the other hand, the Sekoru, Degahabur, and Maichew stations showed decreasing trends of precipitation.

The study eco-regions are characterized by maximum precipitation in Kiremt (June to August) season. The trend is positive in Kiremt season and negative in Bega season which may lead to shifting of the annual cycles of the hydrologic regime. Furthermore, this paper would suggest other studies are conducted to confirm the changing climatic trends over two eco-regions by increasing the sample meteorological stations and, additionally, to investigate the rainfall intensity and frequency of wet and hot days. This finding thus provides insights for policy and decision makers to take proactive measures for climate change mitigation.

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**Conflicts of Interest:** All authors declare no conflict of interest.

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