Analysis of climatic parameters in the upper Awash River basin of Ethiopia

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Abstract

The study analyzed trends and variations in climate parameters in the Upper Awash River Sub-Basin using linear regression line, standardized anomalies, and coefficient of variation as an analytical tool. The pooled seasonal rainfall showed a positively significant increasing trend in the long-season in the sub-basin, with magnitudes of 2.753mm. The trend of seasonal rainfall in some individual stations confirms the presence of an increasing seasonal rainfall portraying a positively significant increasing trend during both short- and long- seasons. Analysis of pooled and individual stations' CGS maximum and minimum temperatures portrayed a positive and increasing trend, with a magnitude of 0.052^{o}C and 0.001^{0}C/year respectively, which are highly significant. Overall, the results depicted an increasing trend for both maximum and minimum temperatures implying the presence of warming along the sub-basin, aligning with global warming.

Variability analysis of rainfall variables along the sub-basin exhibited both positive and negative anomalies for short-season rainfall, with the lowest anomalies from the years 1994, 1997, 1999, 2002, and 2009, representing drought years. Equally, long-season rainfall exemplified high variations over the years 1994/95, 2001/02, 2009, and 2014/15 with anomalies of (-2.3), (-1.8), (-1.4), and (-1.0), which coincided with severe drought years. The CV for both seasons confirms the presence of high variability, particularly the short-season with 32.5% CV. Mean CGS maximum and minimum temperatures in most cases depicted positive anomalies evidencing the existence of strong warming along the sub-basin.

The crop yield anomalies for teff, wheat, and maize in the sub-basin depicted high variations; exhibiting negative values from 1991 to 2005 (53%), positive values from 2012 to 2020 (30%), and fluctuations between2006 to 2010. This implies that the years from 1991 to 2004 were severe drought years while the years from 2013 to 2020 were cooler years. The variations and fluctuation in the crop yield anomalies resulted from variations that prevailed in the annual main-season rainfall along the sub-basin.

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1. Introduction

Nowadays, climate change has become a global challenge due to its associated influences and vulnerabilities on plants and food supply[1][2]. These associated influences with changes in climate and global warming are regarded as the most decisive environmental dilemma in the world today[3][4]. Some studies indicate that the global climate is undergoing a significant change which is manifested by rising temperature, droughts, rainstorms, and flooding[5]. Scientific studies confirmed that the mean global temperature could rise by 1.4 to 5.8^{0}C by 2100 with a mean sea level rise of 10 cm over the same period[6]. In Africa, rainfall and temperature have shown declining and increasing trends, respectively[7]. In Ethiopia, the mean annual temperature has risen by 1.3^{0}C between 1960 and 2006 and is projected to increase up to 1.8^{0}C by 2050s and 3.7^{0}C by the end of the century, under a high-emission scenario (RCP8.5). However, a high level of spatial-temporal variability and uncertainty in rainfall was observed and projected in the future[8][9].

Evidence shows that the Continent of Africa exhibits higher inter-annual and intra-seasonal climate variability[10], Ethiopia being among the countries most susceptible to climate change and variability[11]. Some studies show that climate change has contributed to climate variability which has to be studied further[12]. Studies explored that the historical climate record for Africa showed a warming of temperature by about 0.7°C and a declining rainfall over large parts of the Sahel. Similar studies also reported that warming due to increasing surface and atmospheric temperature in Ethiopia has occurred at varying rates but broadly consistent with global and African trends while rainfall portrayed both an increasing and declining trend in different areas of the country[12]. Further studies by other researchers confirmed that most East African Countries (Burundi, Eritrea, Ethiopia, Kenya, Uganda, Tanzania, Rwanda, and Somalia) are the most vulnerable to the effects of climate change, climate variability, and drought due to their dependency on rain-fed agriculture[13][14]. They confirmed that Ethiopia is one of the most susceptible countries to the impacts exerted by climate variability and change[14][15]. Equally, a study by Tirfi[16] on the characterization of rainfall and temperature in specific crop-growing areas of Ethiopia discovered a decreasing pattern in short-season rainfall in teff, wheat, and maize growing belts while long-season rainfall depicted a rising trend in teff and wheat growing belts and a declining tendency in maize growing belts. Furthermore, the analysis of maximum and minimum temperatures showed an increasing trend over the period under study in teff and wheat growing belts.

Analysis of trends and variability in climate parameters were investigated by some researchers in the Awash River Basin of Ethiopia as well; for example: Bekele *et al.*[17] studied the Keleta watershed of the Awash River Basin; Kassie*et al.*[18] studied the Central Rift Valley of Ethiopia; and Tibebe,*et al.*[19] studied Modjo watershed area. The results of these researches demonstrated an increasing trend in temperature, although no significant trend was observed in seasonal and annual rainfall patterns. The majority of the stations studied revealed a high variability in the amount and distribution of rainfall.

Even though the above-mentioned research has been conducted within the basin, it covered a few pocket areas mainly focusing on the hydrological aspect and gave less attention to the study of rainfall and temperature trend and variability[20]. In view of this, studying the trends and variability of rainfall and temperature parameters along the Awash River Basin becomes obligatory for agriculture, energy, and drinking water production and supply, as well as the management and utilization of resources[17]. Thus, there is a need to study and understand the temporal variation of rainfall and temperature parameters prevailing in the Upper Awash River Basin of Ethiopia. The objective of the study was to analyze and characterize the trend and variability of climate parameters of the Upper Awash Sub-Basin using secondary time series data from the period 1991 to 2020.

2. Materials and Method

2.1. Description of the Study Area

The Awash River Basin (ARB) is located at 7̊53′ N to 12°N latitude and 37°57′ E to 43∘25′ E longitude. The basin extends from the central Ethiopian highland at an elevation of 4,195 meters above mean sea level (a.m.s.l) to the lower arid regions at an elevation of 210 m.a.s.l in the Danakil Depression. The Awash River begins from the high plateau near the Ginchi town located west of Addis Ababa at an altitude of about 3,000 m. a. s. l. and flows along the Rift Valley into the Afar triangle[21]. The climate of the Awash River Basin varies from humid subtropical over central Ethiopia to arid tropical over the Afar lowlands. According to Nemera[22] and Mersha[23], the Awash River Basin is divided into three distinct sub-basins based on different inter-related factors: the Upper Sub-Basin (all lands above 1500m.a.s.l), the Middle Sub-Basin (1500 – 1000m.a.s.l), and the Lower Sub-Basin (1000 – 500m.a.s.l). The Upper Awash Sub-basin is located in the western highland part of the Awash River Basin covering some parts of the basin above Hombole drainage. The Upper Awash River rises on the high plateau near Ginchi town, west of Addis Ababa, and first flows towards the east, draining the Becho plains, and then joined by a number of tributaries before it enters Lake Koka[24]. The major tributaries upstream of the Koka reservoir include Kebena, Akaki, and Mojo Rivers. The Sub-basin further comprises the mountainous landscape of the Bishoftu area and the Upper Valley Sub-basins (Wonji, Melkassa, Tibila, and Nura-Era), which form part of the Great Rift Valley area (Figure 1). The altitude of the sub-basin ranges from 794 to 4,187 m.a.s.l. and its size is about 10,841 km^2. The sub-basin is delimited on its western side by the Abbay River basin, to the southwest by the Omo-Gibe and Rift Valley Lakes Basin, and to the southeast by the Wabi Shebele River Basin[25].

Climatically, the Upper Awash Sub-basin comprises humid subtropical vicinities at the upper basin and a semi-arid climate at its lower vicinity. According to Edossa[26], the mean annual rainfall varies from 160mm in the northern part of the sub-basin to 1,216mm at the headwater of the Awash River (near Ginchi Town).

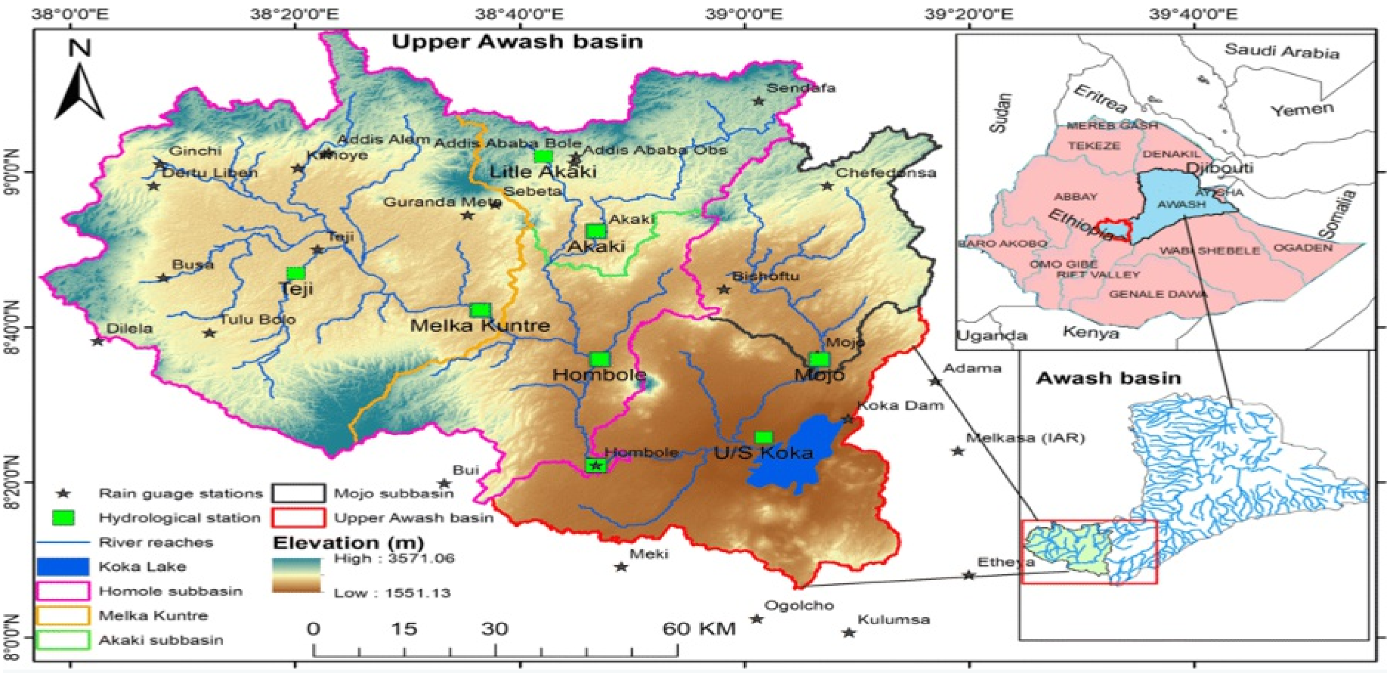

Figure 1. *Location Map of Upper Awash River Basin*

2.2. Weather Stations Selected for the Study

In order to characterize climatic factors (rainfall and temperature) of the study sub-basin, 5 representative weather stations were selected for detailed study. The stations representing the upper sub-basin are relatively located at a medium altitude ranging from 1410 m.a.s.l at Abomsa in Arsi Zone to 2,240 m.a.s.l at Ejere in West Shewa Zone.

Agriculturally, the Upper Awash Sub-basin is suitable for a wide range of crops, fruits, and vegetables which include: wheat, teff, maize, beans, field peas, chickpeas, green peas, lentils, fruits, and vegetables.

Table 1. Geographical location of the weather stations selected for the study

Name of Station	Latitude	Longitude	Elevation	Major Crops Grown
1. Ejere	8°47`N	39°16`E	2,240m	Wheat, teff, beans, chickpea, lentils
2. Tulu Bolo	8°40`N	38°13`E	2,193m	Wheat, teff, chickpea, lentils
3. Bishoftu	8°45`N	38°59`E	1,920m	Teff, wheat, chickpea, green peas, lentils
4. Modjo	8°39`N	39°5`E	1,850m	Teff, maize, wheat, chickpea, lentils
5. Abomsa	8°35`N	39°51`E	1,410m	Fruits, vegetables, cotton, maize, teff, wheat

Source: Compiled from previous Studies and websites

2.3. Data Type and Sources

In this study, the investigator used time series secondary data on all the variables. The required data on weather conditions (*temperature and rainfall*) for the period from1991 to 2020 were purchased from the National Meteorological Agency (NMA) of Ethiopia. Representative weather stations based in the Upper Awash basin were selected and average monthly data for *Short-rainfall Season* (February - May) and *Long-rainfall season/* main crop season (June - September) were taken from the NMA record. An aggregate average data at the sub-basin level for both crop growing seasons were calculated by the investigator for the weather stations selected for the period from 1991 to 2020. Furthermore, secondary data on *crop yields* were taken from the Central Statistical Authority (CSA) and the characteristics of the Upper Awash Sub-Basin from previous study documents and the internet.

2.4. Model Selection and Method of Analysis

In practice, researchers have used different analytical methods to detect trends and variability in climatic parameters. The most commonly used methods include *parametric* (*t*-tests, F-tests, and Linear Regression), innovative graphical, and *non-parametric* (Mann–Kendall test, Sen's Slope estimator, etc.) methods[27]. Among the methods, it has been reported that the linear regression (parametric tests) and Mann–Kendall (nonparametric tests) approaches were the most widely to detect trends in climatic parameters[28].

2.4.1. Linear Regression Test (Parametric)

A linear regression test is a parametric test that assumes that the variables are normally distributed. It tests whether there is a linear trend by examining the relationship between time (X) and the observed climate variable (Y). Linear regression is one of the classical and widely used methods for detecting linear trends in climate time series[29][30]. In this method, the slope and intercept coefficients (b_0 and b_1) in the best fitting line can be solved by using ordinary least squares (OLS), which is to find the coefficient values that minimize the square difference between the observed and predicted values of Y. Mathematically, the linear regression equation is expressed as:

$$Y = b_0 + b_1 X \qquad (1)$$

Where Y is observed climate parameter values, X is time sequence (independent variable), and b_0 and b_1 are intercept and slope respectively.

Trend derived from Linear Regression can be determined by the slope coefficient (b_1), and its OLS estimate can be expressed as:

$$b_1 = \frac{\sum x - \ddot{x} * (y - \bar{y})}{\sum (x - \ddot{x})2} \qquad (2)$$

The sign of the slope coefficient (b_1) indicates trend direction (i.e., positive upward and negative downward), and the significance of the upward/downward trend is usually assessed by checking the p-value of the slope coefficient. A common choice of p-value is <0.05 for a significant trend.

2.4.2. Mann-Kendall Test (Non-Parametric)

The non-parametric statistical test Mann-Kendall (MK) is well suited for the analysis of trends in long-time period meteorological data[31][32]. The Mann-Kendall statistic S measures the trend in the data and is mathematically expressed as:

$$S = \sum_{i=1}^{n-1} . \sum_{j+i}^{n} . sgn(X_j - X_i) \qquad (3)$$

Where X_i and X_j represent data points at the time i and j respectively. The positive values of ‘S’ indicate an increasing trend, whereas negative values indicate a decrease in value over time. The strength of the trend is proportional to the magnitude of S (i.e., the larger the S value, the stronger the trend).

The sign of the difference between the consecutive sample sets is given by the following equations.

$$Sgn(x_j - x_i) = +1, \text{if } x_j - x_i > 0 \qquad (4)$$

$$Sgn(x_j - x_i) = +1, \text{if } x_j - x_i > 0 \qquad (5)$$

$$Sgn(x_j - x_i) = -1, \text{if } x_j - x_i < 0 \qquad (6)$$

Where, $Sgn(x_j\text{-}x_i)$ is an indicator function that results in the values 1, 0, -1 according to the sign of $x_j x_i$ where j > i.

The advantage of the non-parametric statistical test over the parametric test is that the former is more suitable for non-normally distributed, outlier, censored and missing data, which are frequently encountered in hydrological time series. Conversely, the parametric test (linear regression) has got the following advantages over the non-parametric test[33]. The advantages of the parametric approach include: the parametric tests have more statistical power than non-parametric tests; the parametric techniques are indeed more accurate for large datasets than their non-parametric alternatives; its mathematical results can be proved parametrically specifying some parts of the model; and parameters of a parametric model can often be interpreted easily (which helps to understand and summarize the data).

In view of the above-described advantage of the parametric approach over the non-parametric test, this study used the parametric approach to detect presence trends in climatic data series.

2.5. Empirical Model Specification

In order to address the *objective* of this study, the linear regression line technique was used to model the trends in climate variables (temperature and precipitation) over the period of 30 years. In applying this technique to the data, the equation of the least squares line was first of all determined and then plotted. This technique can be expressed in the form:

$$R_t = \alpha + bX_t \quad \text{for rainfall,} \qquad (7)$$

Where: α is the intercept; b is the regression coefficient (slope); R is the rainfall value; X is the time in years. Similarly, the linear regression line equation for temperature can be expressed as:

$$T_t = \alpha + bZ_t \quad \text{for temperature.} \qquad (8)$$

Where: α is the intercept; b is the regression coefficient (slope); T is the temperature value; Z is the time in years.

Furthermore, the year-to-year variation of rainfall and temperature parameters have been characterized using standardized anomaly of rainfall (ΔR_t) or anomaly of temperature (ΔT_t) and the coefficient of variation (CV) of the climate data series. Accordingly, the long-term standardized anomaly of rainfall (ΔR_t) for a given locality or pool of locations over a period t is given by:

$$\Delta R_t = \frac{Rt - \bar{R}t}{\sigma} \qquad (9)$$

Where: ΔR_t is standardized rainfall anomaly, R_t is the mean annual rainfall of a particular year t, $\bar{R}_t$ is the long-term mean over a period of observation, and σ is the standard deviation of annual mean rainfall over the long run (period of observation).

Equally, the long-term standardized anomaly of temperature (ΔT_t) for a given location or pool of locations over a period t is given by:

$$\Delta T_t = \frac{Tt - \bar{T}t}{\sigma} \qquad (10)$$

Where: ΔT_t is the standardized temperature anomaly for period t, T_t is the mean annual temperature of a particular year t, $\overline{T}_t$ is the mean annual temperature over a period of observation, and σ is the standard deviation of annual mean temperature for the long-run (over a period of observation).

Furthermore, the inter-seasonal variability of basin level aggregated or pool of locations rainfall and temperature variables were estimated using the coefficient of variation (CV), which can be expressed as:

$$CV_{R,T} = \frac{100 \ x \ \sigma}{\bar{R}, \overline{T}} \qquad (11)$$

Where: $CV_{R,T}$ represents the coefficient of variation of pooled rainfall or temperature variables, σ is the standard deviation of rainfall or temperature data series, and $\bar{R}, \overline{T}$ are mean rainfall and temperature data series observed in the considered water basin area. In this study, a CV of <20, ≥20≤30, and >30 was considered normal, moderate, and highly variable rainfall, respectively.

Additionally, variability in crop yields has been measured using long-term standardized crop yield anomaly (ΔY_t) which can be expressed as:

$$\Delta Y_t = \frac{Yt - \bar{Y}t}{\sigma} \qquad (12)$$

Where: ΔY_t is the standardized crop yield anomaly for period t, Y_t is the annual mean crop yield for year t, $\bar{Y}$ is the mean crop yield for the observation period, and σ is the standard deviation mean crop yield over the observation period.

Subsequently, analysis and interpretation of the results have been carried out using equations 7 – 12 specified above. Furthermore, descriptive analysis and graphics were used to visually portray the results.

3. Results

3.1. Linear Trend Analysis of Climate Parameters

In this sub-section, a trend analysis of seasonal rainfall and temperature parameters for the Upper Awash Sub-basin has been conducted. The findings of the analysis have been presented as follows.

3.1.1. Linear Trend Analysis of Seasonal Rainfall

In this analysis, rainfall time series data obtained from five (5) representative stations of the Upper Awash River Sub-basin have been pooled and used for the analysis. Figure 2 presents the results of linear trend regression for *Short-Season*/*Belg* and *Long-Season/Meher* rainfalls in the Upper Awash River Sub-basin over the observation period from 1991 to 2020. As can be seen from the figure, both *belg* and *meher* season rainfalls showed a positive and increasing trend in the sub-basin, with magnitudes of 1.974mm/year and 2.753mm/year, respectively. However, the result of *meher-season rainfall* had a positive and significant (at 10% level) increasing trend over the observation period. The result implies that a 1% change in time trend would be responsible for an increase of 2.75% in *meher season rainfall* (see Table 2 for statistical significance).

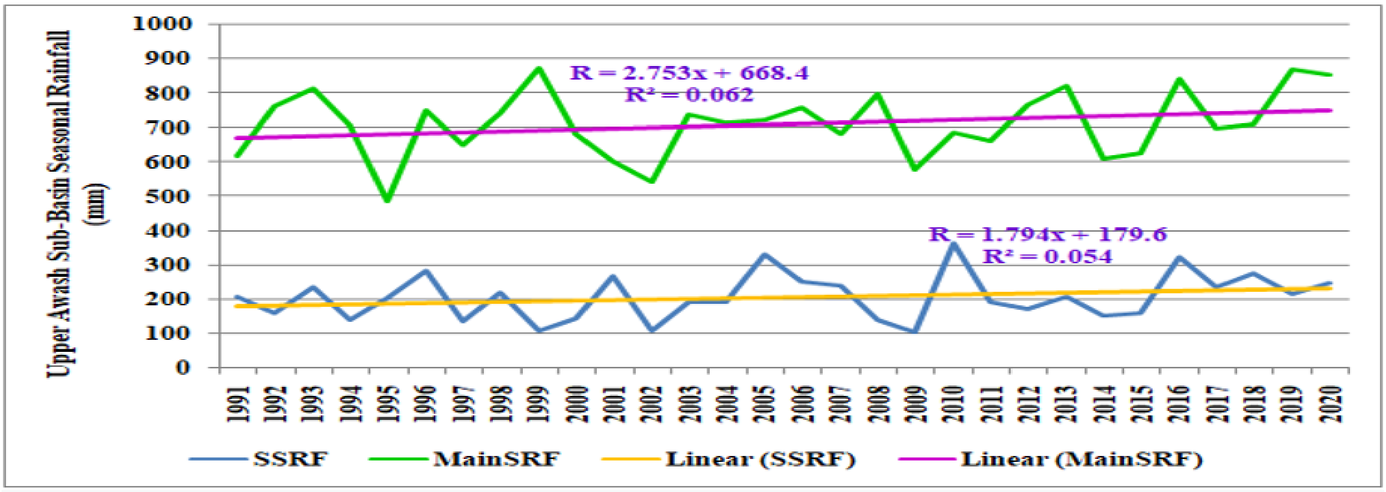

Figure 2. *Trend of pooled seasonal rainfall in Upper Awash Sub-basin*

Table 2. Linear trend regression test statistics for seasonal rainfall in Upper Awash Sub-basin over the period 1991 – 2020

Variables	β (Slope)	Std. Error	t-Stat	P-value	R-square (R^2)
1. Pooled Seasonal Rainfall					
Belg-season rainfall	1.7880	1.4056	1.2722	0.2138	0.055
Main-season rainfall	2.7482*	2.0182	1.3617	0.1841	0.062
2. Ejere Station/ Watershed Seasonal Rainfall					
Belg-season rainfall	3.4884**	1.4625	2.3833	0.0242	0.168
Meher/Main-season rainfall	15.920***	3.6837	4.3256	0.0002	0.401
3. Abomsa Station/ Watershed Seasonal Rainfall					
Belg-season rainfall	0.138	1.9143	0.0766	0.9395	0.0002
Main-season rainfall	1.272	2.0311	0.6271	0.5357	0.0138

, ** and * indicates significance level at 10%, 5% and 1%.*

Source: Computed based on raw data from NMI, April 2022

In order to confirm the changes observed in the pattern of seasonal rainfall based on pooled rainfall data, an analysis of some individual stations representing high and low land watershed areas has been carried out, i.e. Ejere and Abomsa stations from highland and lowland areas, respectively. Figures 3 and 4 present the trend of seasonal rainfall for Ejere and Abomsa weather stations respectively. The seasonal rainfall in both Ejere and Abomsa stations showed a positive and increasing trend in both seasons, i.e. *Belg* and *Meher* seasons. However, the trend of seasonal rainfall in Ejere station portrayed a positive and significant increasing trend during both *belg* and main/*meher* seasons (see Table 2). The result indicates that a unit change in time variable would lead to an increase of belg and main season rainfalls in the Ejere watershed area by 3.49% and 15.9%, respectively. The above trend analysis of seasonal rainfall in both pooled and individual stations (Ejere and Abomsa stations) confirms the prevalence of an increasing trend of seasonal rainfall in the Upper Awash River Sub-basin.

Trend analysis of seasonal rainfalls for Abomsa weather station shows positive and a slightly increasing trend, although statistically insignificant for both *belg* and *meher* seasons. However, it can be seen from Figure 4 that high variability exists in both seasonal (*belg* and *meher*) rainfalls, which has been assessed in the next sub-section.

In conclusion, the seasonal rainfall in the Upper Awash River Sub-basin showed an increasing trend since the upper part of the basin is surrounded by hills, high mountains, and escarpments that are constantly covered with clouds giving the orographic type of rainfall to the area located downward. That was why the sub-basin's seasonal rainfall remained increasing although the temperature parameter portrayed warming over the observation period.

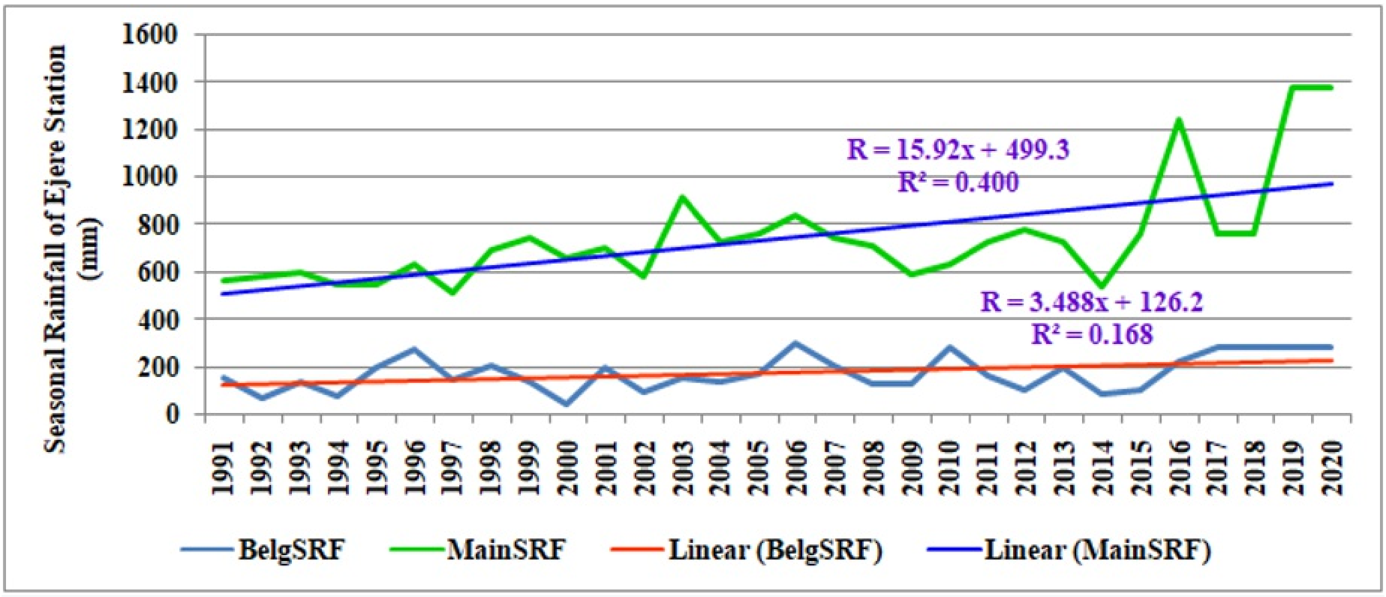

Figure 3. *Trend of Seasonal Rainfall of Ejere Station of Upper Awash Sub-basin.*

Source: Author's computation from raw data of NMI, April, 2022.

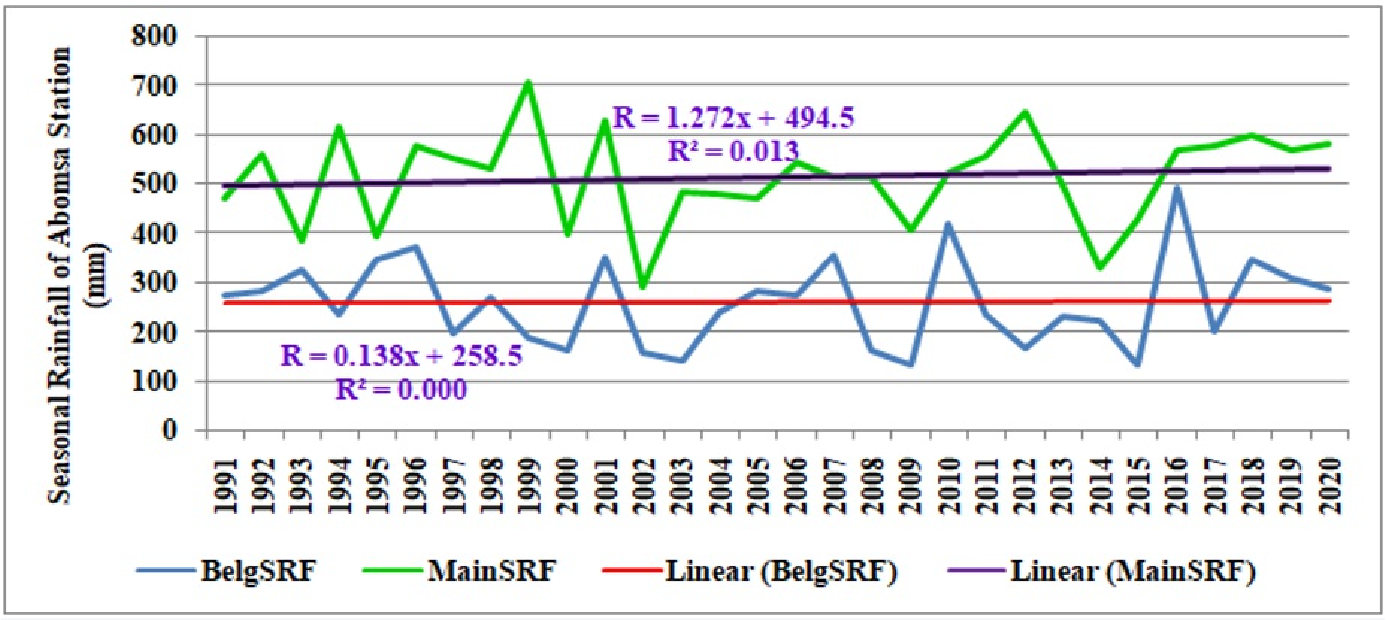

Figure 4. Trend of Seasonal Rainfall of Abomsa Station of Upper Awash Sub-basin

Source: Author's computation from raw data of NMI, April, 2022.

In the Awash River Sub-basin,*belg-season* rainfall is used for crops such as maize, sorghum, cotton, etc. However, the most important rainfall in the sub-basin is the *meher-season* rainfall, particularly for farmers growing rain-fed crops for seed sowing, crop vegetative growth, grain filling, and maturity.

3.1.2. Linear Trend Analysis of Temperature

Linear trend analysis for maximum and minimum temperature variables has been carried out for the Upper Awash River sub-basin. Figure 5 shows pooled mean maximum temperature for Upper Awash Sub-basin. The results portrayed a positive and increasing trend in both crop-growing season and annual mean maximum temperatures for the Upper Awash sub-basin, with a magnitude of 0.052mm and 0.063mm per year respectively. The rate of increase in CGS mean maximum and in annual mean maximum temperatures were highly significant, at 1% level of significance (see Table 3).

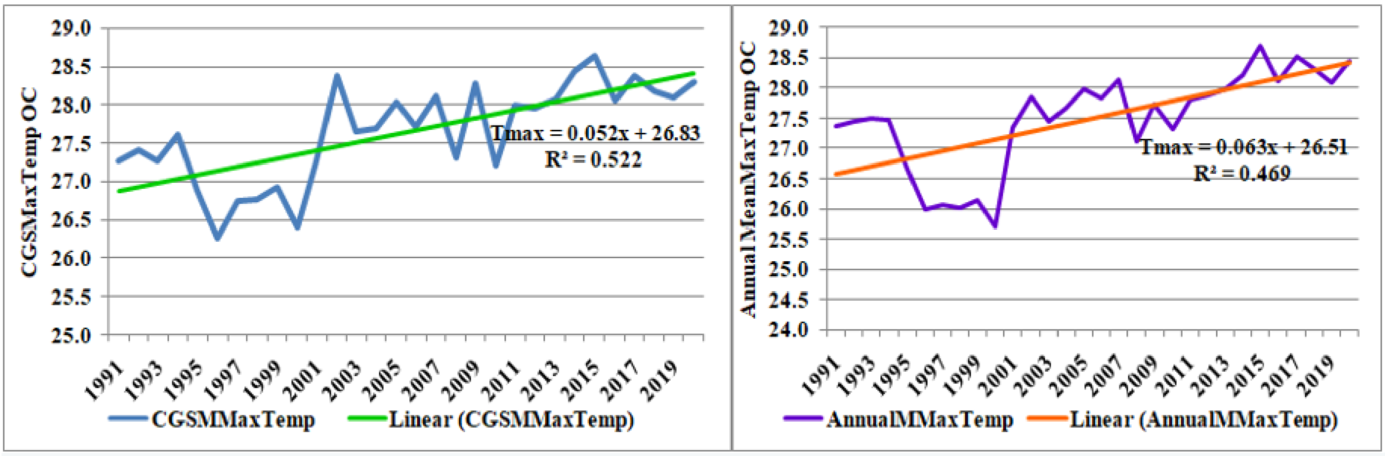

Figure 5. *Trend of pooled maximum temperature for Upper Awash Sub-Basin*

Source: Constructed using raw data from NMI, March 2022.

Table 3. Linear trend regression test statistics for mean maximum temperature for Upper Awash Sub-basin over the period 1991 – 2020

Variables	β (Slope)	Std. Error	t-Stat	P-value	R-square (R^2)
1. Trend of Pooled Crop Growing Seasonal Maximum Temperature					
CGS MeanMaxTemp	0.052***	0.010	5.425	0.000	0.522
Annual MeanMaxTemp	0.062***	.013	4.783	0.000	0.469
2. Trend of CGS MeanMaxTemp for Abomsa and Tulubolo Stations					
Abomsa Station CGS MeanMaxTemp	0.065***	0.011	5.806	0.000	0.546
Tulubolo Station CGS MeanMaxTemp	0.062*	0.036	1.721	0.096	0.097

, ** & * indicates significance level at 10%, 5% and 1% respectively*

Source: Computed from raw data of NMI, March 2022.

The trend analysis has been done for some individual stations as well, i.e. Abomsa and Tulubolo representing lower and upper vicinities of the sub-basin. Figure 6 presents the trend of CGS mean maximum temperatures for Abomsa and Tulubolo stations. The results exhibited a positive and increasing trend of CGS MeanMaxTemperature in both Abomsa and Tulubolo stations. The increasing trend was significant for both stations, with 1% and 10% levels respectively. The results signify that the rate increase was highly significant for the Abomsa station located at lower vicinity of the sub-basin, which aligns with global warming.

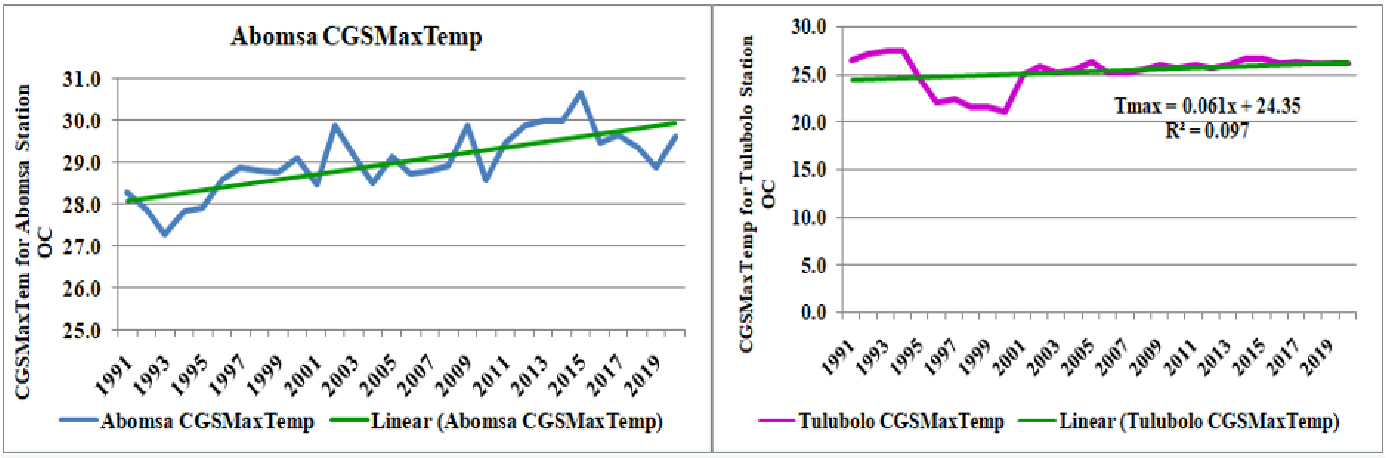

Figure 6. Trend of CGS MeanMaximum Temperature for Abomsa and Tulubolo Stations

Source: Constructed using raw data from NMI, March 2022.

The trend analysis for minimum temperature has also been done for the Upper Awash Sub-basin. Figure 7 presents the trend of pooled minimum temperature for the Upper Awash River sub-station. The result indicates a decreasing trend in CGS mean minimum temperature with a magnitude of 0.001^{0}C/year, although the result is statistically insignificant. Conversely, the annual average minimum temperature exhibited an increasing trend over the observation period with a magnitude of 0.004^{0}C/year. Subsequently, individual weather stations' trend analysis for minimum temperature exhibited an increasing trend for Abomsa and Tulubolo stations (Figure 8). The results show that CGS mean minimum temperatures for Abomsa and Tulubolo had a positive and increasing trend with a magnitude of 0.031^{0}C/year and 0.05^{0}C/year respectively. Both results are highly significant at 1% level, evidencing the presence of warming along the Awash River sub-basins (Table 4).

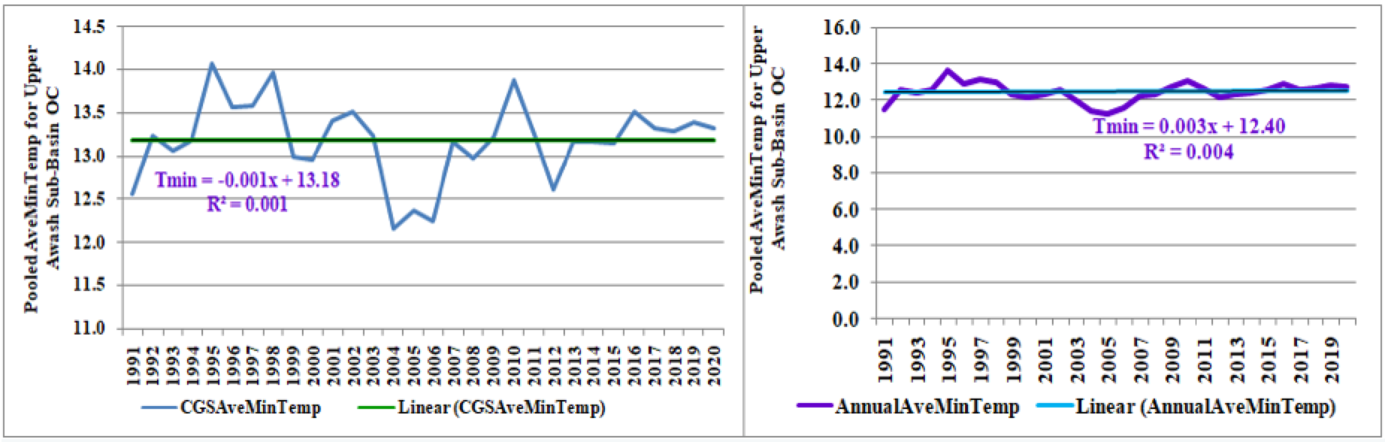

Figure 7. *Trend of pooled MinTemp for Upper Awash Sub-basin.*

Table 4. Linear trend regression test statistics for mean minimum temperature for Upper Awash Sub-basins over the period 1991 – 2020

Variables	β (Slope)	Std. Error	t-Stat	P-value	R-square (R^2)
1. Trend of Pooled Crop Growing Seasonal Minimum Temperature for Upper Awash					
CGS MeanMinTemp	-0.001	0.010	-0.127	0.900	0.001
Annual MeanMinTemp	0.004	0.011	0.373	0.712	0.005
2. Trend of CGS MeanMinTemp in Abomsa and Tulubolo Stations					
CGS Mean MinTemp for Abomsa Station	0.031***	0.007	4.312	0.000	0.387
CGS Mean MinTemp for Tulubolo Station	0.050***	0.021	2.353	.026	0.169

**** indicates statistical significance at 1% level*

Source: Computed using raw data from NMI, March 2022.

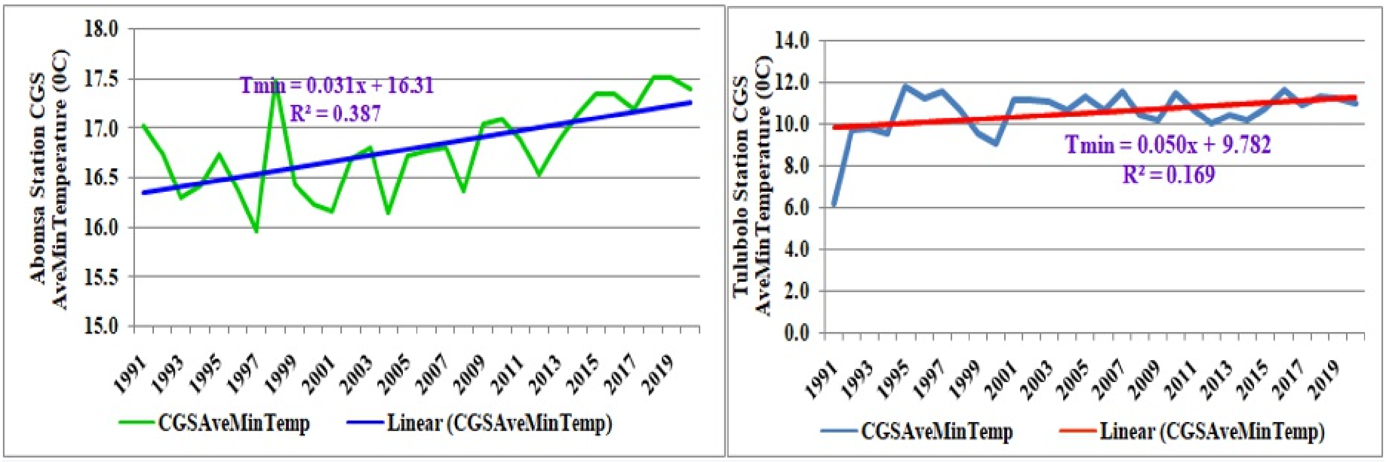

Figure 8. *Trend of CGS Average MinTemp for Abomsa and Tulubolo Stations*

Source: Computed from NMI, March 2022

3.2. Variability of Climatic Parameters and Crop Yields

In this sub-section, an analysis of climatic and crop yield variables has been undertaken to characterize and quantify the variability of climatic and crop yield variables in the Upper Awash River sub-basin. The variability in rainfall, temperature, and crop yield variables have been carried out using standardized anomaly indexes and CVs of the variables under consideration as follows.

3.1.2. Variability of Rainfall

The standardized anomaly of rainfall displays the difference between the most recent seasonal rainfall and the long-term average (from 1991 to 2020). Positive (negative) anomaly values indicate seasonal rainfalls that are above (below) the long-term mean or climatology. Figure 9 presents the anomalies of pooled *Belg Season rainfall* in the Upper Awash Sub-basin. The result exhibited both positive (50%) and negative (50%) anomalies for *belg season* rainfall over the observation periods of 1991 and 2020. According to the study reported by Dereje *et al,*[34], severity of drought is classified as: extreme drought (SRA < -1.65), severe drought (-1.28 > SRA > -1.65), moderate drought (-0.84 > SRA > -1.28), and no drought (SRA > -0.84).

The result of this study depicted the lowest *belg season* rainfall for the years 1994, 1997, 1999, 2002, and 2009, which represented drought years that coincided with previous drought years[35][36]. Equally, the *main season* rainfall exemplified high variations over the observation period with the years 1994/95, 2001/02, 2009, and 2014/15 being severe drought years (Figure 10) with anomalies of (-2.3), (-1.8), (-1.4), and (-1.0). The coefficient of variation (CV) for the *Belg* and *Main Season* rainfalls also confirms the presence of high variability, particularly during the *belg season* with a CV of 32.5% (Table 5).

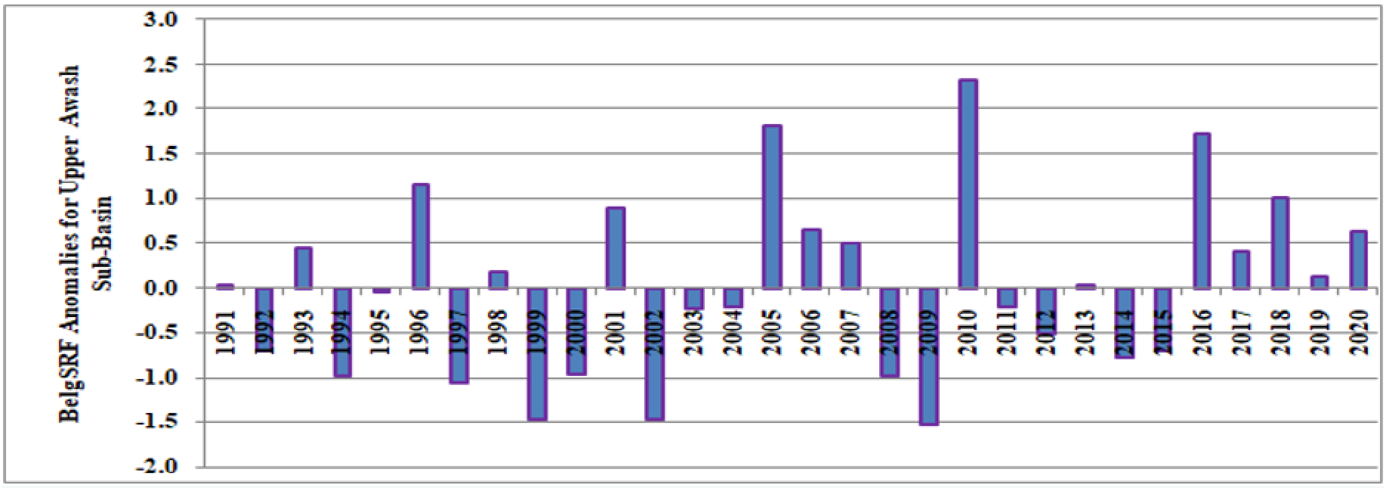

Figure 9. Anomalies of *Belg Season Rainfall* for Upper Awash Sub-basin

Source: Constructed using raw data from NMI, March 2022.

Table 5. Descriptive Analysis of Seasonal Rainfall for Upper Awash Sub-basin

Variable	Mean	Std Error	StdDev	t-Stat	CV (%)
Belg Season Rainfall	207.5	12.2948	67.5	0.2548	32.5
Main Season Rainfall	711.2	17.7234	97.2	1.958**	13.7

Source: Computed from raw data of NMI, March 2022.

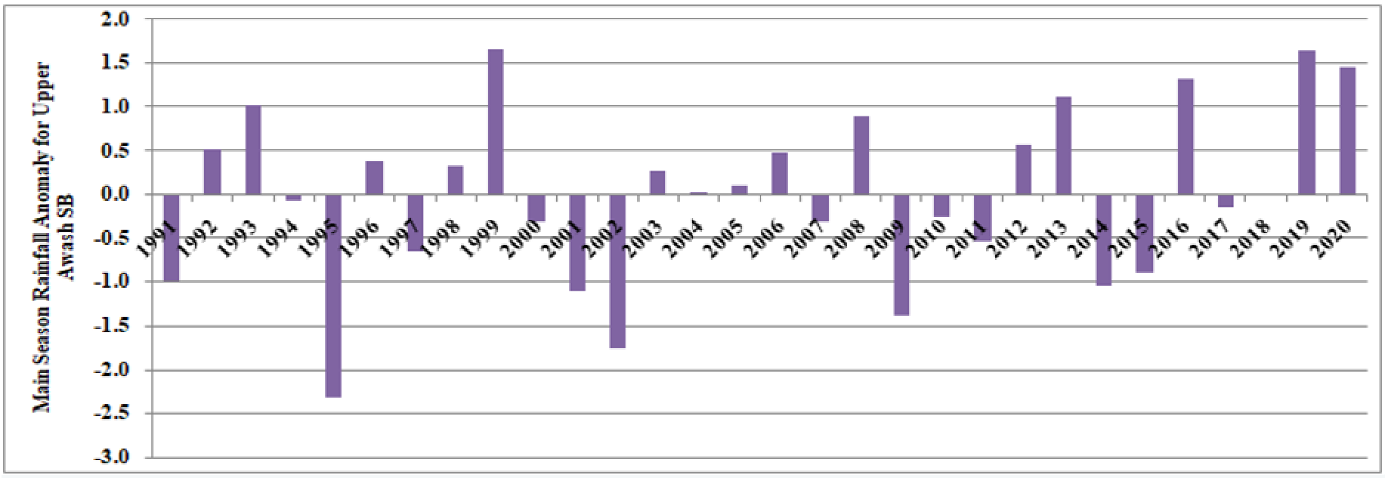

Figure 10. Anomalies of *main season* rainfall for Upper Awash Sub-basin

Source: Constructed from raw data of NMI, March 2022.

3.2.2. Variability of Temperature

Temperature anomaly is defined as a departure from a reference value or long-term average of a temperature variable of at least 30 years. A positive anomaly depicts that the observed temperature is warmer than the reference value, while a negative anomaly indicates that the observed temperature is cooler than the reference value. Table 6 shows pooled CGS and annual mean maximum and minimum temperature for the Upper Awash Sub-basin over the observation period of 1991 to 2020. The CGS mean maximum temperature in the sub-basin was 26.8 ^{0}C while the annual mean maximum temperature was 27.5^{0}C, both being highly significant at 1%. Consequently, the CGS and annual mean minimum temperatures were 12.8^{0}C and 12.5^{0}C respectively.

Table 6. Descriptive Analysis of Maximum and Minimum Temperatures for Upper Awash River Sub-basin

Variable	Mean	Std Error	Std Dev	t-Stat	CV (%)
1. Pooled Mean Maximum Temperature					
CGS MeanMaxTemp	26.8	0.010	0.6365	5.425***	2.4
Annual MeanMaxTemp	27.5	0.013	0.8140	4.783***	3.0
2. Pooled Mean Minimum Temperature					
CGS MeanMinTemp	12.8	0.010	0.4568	-0.1270	3.6
Annual MeanMinTemp	12.5	0.0110	0.5224	0.3730	4.2

Source: Computed using raw data from NMI, March 2022

Figures 11 and 12 show long-range anomalies of CGS and annual mean maximum and minimum temperatures. The result depicted that the trend of CGS mean maximum temperatures after 2001 was greater than the long-term average, ranging from 0.80 to 2.93. The results evidenced strong warming along the sub-basin, which further aligns with the global warming seen during the last two decades. Equally, about 83% of the CGS minimum temperature anomalies were positive, although non-significant, and showed a decreasing trend.

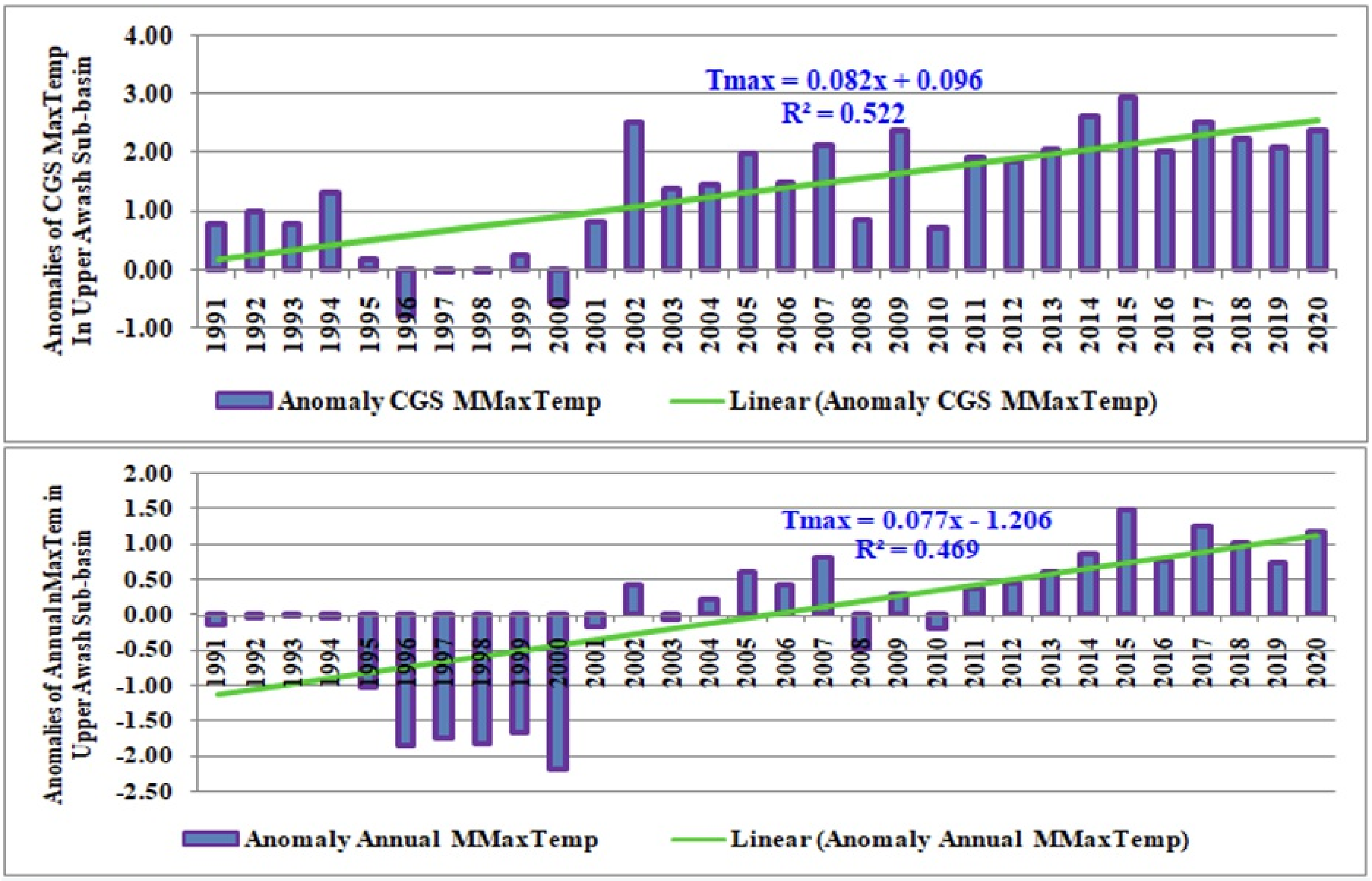

Figure 11. *Anomalies of CGS & Annual Mean MaxTemperature for Upper Awash Sub-basin*

Source: Constructed using raw data from NMI, March 2022.

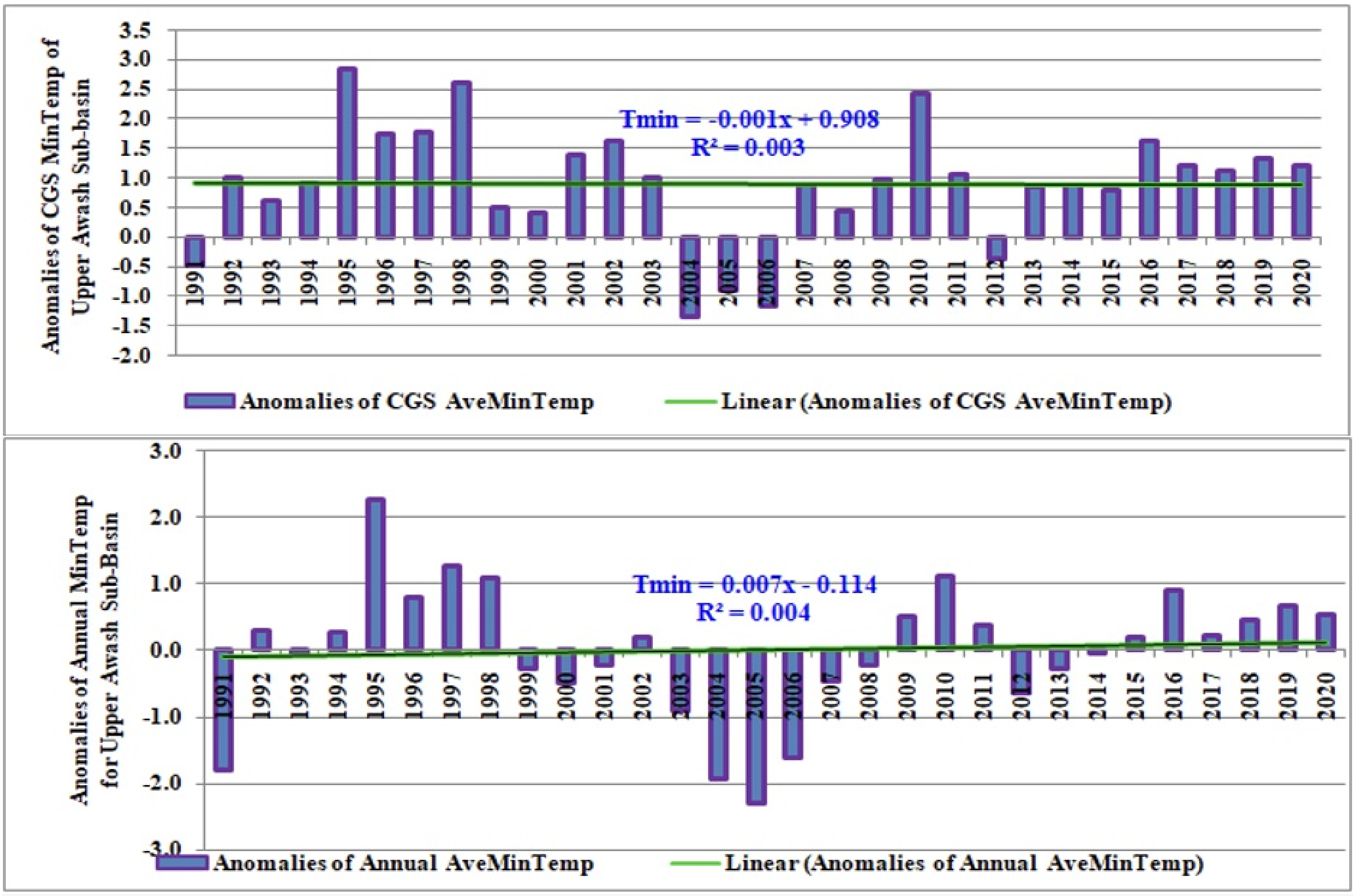

Figure 12. *Anomalies of Mean Minimum Temperatures for Upper Awash Sub-basin*

Source: Constructed using raw data from NMI, March 2022.

3.2.3. Variability in Crop Yields

In this study, the degree of cereal crop yield variability has been measured using crop yield anomaly and coefficient of variation (CV). Figure 13 presents the yield anomalies of teff, wheat, and maize crops along the Upper Awash River Sub-basin. The year-to-year teff yield anomalies depicted negative values from 1992 to 2005 (47%) and positive values from 2011 to 2020 (33%). The yield anomalies between 2006 and 2010 were a mixture of positive and negative values with minimal magnitude. The result depicts that the years from 1992 to 2004 were severe drought years while the years from 2013 to 2020 were cooler years. Equally, the year-to-year yield anomalies of wheat crops exhibited negative values from 1991 to 2006 (53%) and positive values from 2012 to 2020 (30%). The result for yield anomalies for maize crops was negative from 1991 to 2005 (50%) and positive from 2011 to 2020 (33%).

In general, the yield anomalies depicted fluctuations between the years 2006 to 2010 for the three crops along the Upper Awash River sub-basin. The variations and fluctuation in the crop yield anomalies resulted from the variations that prevailed in the annual main-season rainfall along the sub-basin.

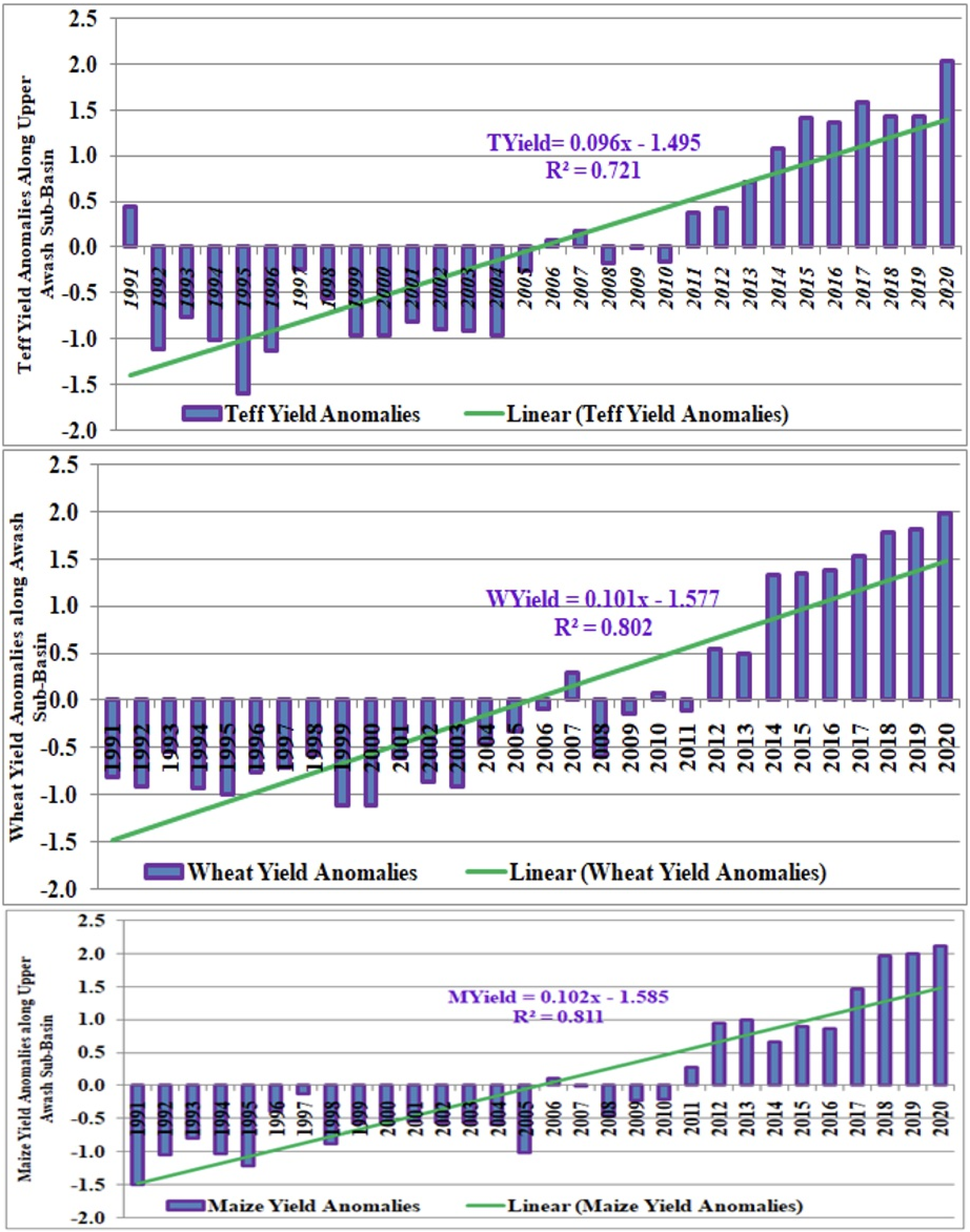

Figure 13: Year-to-year yield anomalies of teff, wheat, and maize crops along Upper Awash Sub-basin

4. Discussion

The study result showed that*meher-season rainfall* had a positive and significant (at 10% level) increasing trend over the observation period. In practice, the *meher-season* rainfall is the most important rainfall in the Awash River Sub-basin, particularly for farmers growing rain-fed crops for the processes of seed sowing, crop vegetative growth, crop grain filling, and maturity. The seasonal rainfall in the Upper Awash River Sub-basin showed an increasing trend since the upper part of the basin is surrounded by hills, high mountains, and escarpments that are constantly covered with clouds giving an orographic type of rainfall to the area located downward. That was why the sub-basin's seasonal rainfall remained increasing although the temperature parameters portrayed warming over the observation period. The results of the study are similar to the study findings of Kassie[18] who studied and characterized trends of agro-climatic conditions in the Central Rift Valley. In his study, he reported that *belg-season rainfall* had positive and increasing trends in Bishoftu and Nazereth stations (both located in the same study area) with a magnitude of 0.68 and 0.15mm/year respectively. However, the *meher/main-season* rainfall contracts with the result of this study which demonstrated a negative and decreasing trend in both stations (-0.34 and -0.33 mm/year respectively).

The study results on temperature parameters portrayed a positive and increasing trend of both Crop Growing Season (CGS) and Mean Annual Maxtemperatures (MAMaxT) for the Upper Awash River sub-basin, with a magnitude of 0.052mm and 0.063mm per year respectively. The rate of increase in both CGS and MAMaxT was found highly significant at 1% level of significance. Equally, the pooled average annual minimum temperature over the sub-basin exhibited an increasing trend over the observation period with a magnitude of 0.004^{0}C/year. In summary, the results depicted an increasing trend in both maximum and minimum temperatures in the Upper Awash Sub-basin exemplifying the presence of warming along the sub-basin. This may pose reductions in the yield and production of agricultural crops, which needs to be studied further. The results of this study are similar to the findings of previous studies conducted in the same basin and elsewhere in the country. Gedefaw, *et al.*[20] in their trend analysis of climatic and hydrological variables in the Awash River Basin, Ethiopia observed an increasing trend of temperature across the stations studied. Mahmood, *et al.*[37] in their analysis of the trend of temperature in the Lake Chad Basin explored extremely significant rising trends in annual temperature.

The study result on climatic variability exhibited both positive (50%) and negative (50%) anomalies for*belg season* rainfall over the observation periods of 1991 and 2020. The result portrayed the lowest *belg season* rainfall for the years 1994, 1997, 1999, 2002, and 2009, representing drought years that also coincided with previous drought years[35][36]. Equally, the *main season* rainfall exemplified high variations over the observation period with the years 1994/95, 2001/02, 2009, and 2014/15 being severe drought years with anomalies of (-2.3), (-1.8), (-1.4), and (-1.0). The coefficient of variation (CV) for the *Belg* and *Main Season* rainfalls also confirmed the presence of high variability, particularly*belg season* with a CV of 32.5%. The result of this study on variability in seasonal rainfall variables is consistent with the findings of Teshome, *et al.*[38] who in their analysis of past and projected trends and variability of rainfall and temperature parameters in East and West Hararghe zones, Ethiopia reported occurrence of high variability in *Belg season* rainfall (CV > 30%). They further observed the highest monthly and seasonal rainfall variability during January, February, and March.

Another study by Eshetu[10] on analysis of climatic parameters in Mojo River Watershed of Awash River Sub-basin revealed low variation in annual rainfall (CV% <20) while the main (Kiremt) and short (Belg) season rainfall exhibited CV ranging from low to high values.

The study result on the variability of temperature variables depicted that the trend of CGS mean maximum temperatures after 2001 was greater than the long-term average, ranging from 0.80 to 2.93. The results evidenced strong warming along the river sub-basin studied, which further aligns with the global warming seen during the last two decades. Equally, about 83% of the CGS minimum temperature anomalies were positive, although non-significant, and showed a decreasing trend. The study result aligns with the findings of other researchers like Mohamed, *et al.*,[39] and Brunet, *et al.,*[40]. Mohamed, *et al.*,[39] in their analysis of climate change's impact on extreme temperature variability in the Blue Nile Basin, Ethiopia reported that the long-term anomalies of mean annual minimum temperature depicted inter-annual variability while the trend after 1977 was higher than the long-term average, which is proof of the warming trend's existence during the last two decades of the 20th century. Furthermore, Brunet *et al.,*[40] on their part analyze temporal and spatial patterns of temperature change over Spain during the period 1850–2005 and reported a prevalence of significant (at 1% level) warming of 0.10^0C/decade for annual mean temperature over the 1850 – 2005 period. They further reported that overall warming was associated with higher rates of change for MaxT than MinT (0.11^o versus 0.08^oC/decade for the same period. Belay, *et al.*[41] in their analysis of climate variability and trend in Southern Ethiopia found a significant variation in temperature through the observing period. They also reported that the results are consistent with the drought years recorded in the past, which have been linked with the ENSO event.

The crop yield anomalies along the Upper Awash River Sub-basin depicted variations over the observation period. The year-to-year yield anomalies of the three crops (teff, wheat, and maize) exhibited negative values from 1991 to 2005 (53%) and positive values from 2012 to 2020 (30%). The result implies that the years from 1991 to 2004 were severe drought years while the years from 2013 to 2020 were cooler years. The yield anomalies further depicted fluctuations between the years 2006 to 2010 for the three crops along the Upper Awash River sub-basin. The variations and fluctuation in the crop yield anomalies resulted from the variations that prevailed in the annual main-season rainfall along the sub-basin. The results of this study are consistent with the findings of other researchers[42][43]. Ayanlade, *et al.*[42] in their study on climate variability and crop yield anomalies in the Middle Belt of Nigeria reported high variability in the yield of maize caused by considerable variability in annual rainfall. Omoyo, *et al.*[43] on their part explored the high yield variability of maize crop in Kenya which imply high vulnerability of poor households to food insecurity.

5. Summary and Conclusion

In this study, an analysis of trends and variations in climate parameters prevailing in the Upper Awash Sub-Basin of Ethiopia has been carried out. The study used time series quantitative secondary data of 5 representative meteorological stations in the sub-basin for the period 1991 to 2020.

The study result for pooled seasonal rainfall showed a positive and significant (at 10% level) increasing trend in *meher season* rainfall in the Upper Awash River Sub-basin, with magnitudes of 2.753mm. The result implies that a 1%

change in time period would be responsible for an increase in *meher season rainfall* by 2.75%. Furthermore, the trend of seasonal rainfall in Ejere station portrayed a positive and significant increasing trend during both *belg* and *meher* seasons in which a unit change in time variable will lead to an increase of belg and main season rainfall by 3.49% and 15.9% respectively. The trend analysis of seasonal rainfall in both pooled and individual stations (Ejere and Abomsa) confirms the prevalence of increasing seasonal rainfall in the Upper Awash Sub-basin.

Subsequently, pooled mean maximum and minimum temperatures were analyzed for the sub-basin. The results portrayed a positive and increasing trend of crop growing season mean maximum temperature for the Upper Awash sub-basin, with a magnitude of 0.052mm per year. The rate of increase in CGS mean maximum temperature was highly significant at 1% level of significance. Conversely, the trend of pooled CGS mean minimum temperature for the sub-station revealed decreasing trend in minimum temperature with a magnitude of 0.001^{0}C/year, though insignificant. However, the trend analysis of individual stations of Abomsa and Tulubolo exhibited a positive and significant increasing trend for CGS mean minimum temperature with a magnitude of 0.031^{0}C/year and 0.05^{0}C/year respectively. In general, the results depicted an increasing trend of both mean maximum and minimum temperatures exemplifying the presence of warming along the sub-basin. The result almost aligns with the global warming in temperature parameters. This may pose reductions in the yield and production of agricultural crops, which needs to be studied further.

Subsequently, the variability in rainfall variables along the Upper Awash Sub-basin exhibited both positive (50%) and negative (50%) anomalies for *belg season* rainfall over the observation periods of 1991 to 2020. The study revealed the lowest *belg season* rainfall for the years 1994, 1997, 1999, 2002, and 2009, which represent drought years that also coincided with previous drought years. Equally, the *main/meher season* rainfall exemplified high variations over the observation period with the years 1994/95, 2001/02, 2009, and 2014/15 being severe drought years with anomalies of (-2.3), (-1.8), (-1.4), and (-1.0). The coefficient of variation (CV) for the *Belg* and *Main Season* rainfalls also confirmed the presence of high variability, particularly *belg season* with a CV of 32.5%.

The variability of CGS mean maximum temperatures depicted that anomalies after 2001 were greater than the long-term average, ranging from 0.80 to 2.93. The results evidenced the existence of strong warming along the sub-basin, which further aligns with the global warming seen during the last two decades. Equally, about 83% of the CGS minimum temperature anomalies were positive, but non-significant and showed a decreasing trend.

The year-to-year yield anomalies of the three crops (teff, wheat, and maize) in the Sub-basin also depicted variations over the observation period, which exhibited negative values from 1991 to 2005 (53%), positive values from 2012 to 2020 (30%) and fluctuations between the years 2006 to 2010. The result implies that the years from 1991 to 2004 were severe drought years while the years from 2013 to 2020 were cooler years. The variations and fluctuation in the crop yield anomalies resulted from the variations that prevailed in the annual main-season rainfall along the sub-basin.

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Competing Interests

The authors declare that there are no competing interests.

Data Availability

All data generated during this study are included in this article. The data used for this study can be made available upon request provided there is going to be compliance with the owners' policy concerning sharing.

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References

1. ^Brown, A., Zhang, L., McMahon, T., Western, A. & Vertessy, R., 2005; A review of paired catchment studies for determining changes in water yield resulting from alterations in vegetation. Journal of Hydrology, Vol.310 (1), pp 28–61.
2. ^Birara, H., Pandey, R. P. and Mishra, S. K. 2018; Trend and variability analysis of rainfall and temperature in the Tana basin region, Ethiopia, Journal of Water and Climate Change. Vol. 09 (3); pp 555 – 569.
3. ^Solomon, S. (ed.), 2007; Climate Change 2007 - the Physical Science Basis: Working Group I Contribution to the Fourth Assessment Report of the IPCC, Vol. 4. Cambridge University Press, Cambridge, UK.
4. ^Shongwe, M., van Oldenborgh, G., van den Hurk, B. & van Aalst, M., 2011; Projected changes in mean and extreme precipitation in Africa under global warming. Part II: East Africa. Journal of Climate, Vol. 24 (14), pp 3718–3733.
5. ^Gedefaw, M., D. Yan, H. Wang, T. Qin & K. Wang, 2019; Analysis of the Recent Trends of Two Climate Parameters over Two Eco-Regions of Ethiopia, Water, Vol. 11, 161; pp 1 – 12. www.mdpi.com/journal/watern.
6. ^Roth, V.; Lemann, T.; Zeleke, G.; Teklay, A, 2018; Effects of climate change on water resources in the upper Blue Nile Basin of Ethiopia, Heliyon, [CrossRef] [PubMed]
7. ^IPCC, 2014; Climate Change: Impacts, Adaptation, and Vulnerability: Part A: Global and Sectoral Aspects: Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change; In: Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J., Mastrandrea, M.D., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., (Eds.); Cambridge University Press: Cambridge, UK; New York, NY, USA, pp 1132.
8. ^Haileab, Z., 2018; Climate Change in Ethiopia: Impacts, Mitigation and Adaptation. Int. J. Res. Environ. Stud. Vol. 2, pp 66–84.
9. ^World Bank Group, 2020; Climate Risk Profile: Ethiopia; World Bank Group: Washington, DC, USA, pp 24.
10. a, bEshetu, M., 2020; Hydro-Climatic Variability and Trend Analysis of Modjo River Watershed, Awash River Basin of Ethiopia; Hydrology: Current Research; Vol. 11 (2); pp 1 – 8.

11. ^Thornton, P. K., Peter G. J., Tom O., & Russel L K., 2006; "Mapping Climate Vulnerability and Poverty in Africa". Department for International Development. ILRI, Nirobi, Kenya.
12. a, bMohammed, O., Abebe M., Kabeto B., Woldegiorgis A., & Asefa K., 2007; "Climate Change National Adaptation Programme of Action (NAPA) of Ethiopia", Addis Ababa, Ethiopia.
13. ^IPCC, 2007; Summary for policymakers, In: Climate Change 2007: The Physical Science Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (Eds.)].
14. a, bYadeta, D., A. Kebede, and N. Tessema, 2020; Climate change posed agricultural drought and potential of rainy season for effective agricultural water management, Kesem sub-basin, Awash Basin, Ethiopia; Theoretical and Applied Climatology, https://doi.org/10.1007/s00704-020-03113-7.
15. ^Thornton, P. K., Jones, P. G., Ericksen, P. J. and Challiner, A. J., 2011; Agriculture and food systems in sub-Saharan Africa in a 4 WCP world. Phil Trans A Math Phys Eng Sci, Vol. 369: pp117–136.
16. ^Tirfi, A. G., 2022; Impact of climate change on yields and output supply responses of selected cereal crops in Ethiopia; Unpublished PhD Thesis, University of South Africa; https://uir.unisa.ac.za/handle/10500/28729.
17. a, bBekele, D., Alamirew T., Kebede A., Zeleke G., and Assefa M. M., 2016; Analysis of rainfall trend and variability for agricultural water management in Awash River Basin, Ethiopia. Water Clim Chang. Vol. 8: pp 127-141.
18. a, bKassie, B.T., R. P. Rötter, H. Hengsdijk, S. Asseng, & M. K. van Ittersum, 2013; Climate variability and change in the Central Rift Valley of Ethiopia: challenges for rainfed crop production; J Agric Sci. Vol. 152: pp 58-74.
19. ^Tibebe, T. M., L. Kumar, R. Koech, & B. Zemadim, 2019; Hydro-Climatic Variability: A Characterization and Trend Study of the Awash River Basin, Ethiopia; Hydrology Vol. 6: pp 1-19.
20. a, bGedefaw, et al. 2018; Trend Analysis of Climatic and Hydrological Variables in the Awash River Basin, Ethiopia; Journal Water, Vol. 10 (1554); pp 1 – 14; doi:10.3390/w10111554.
21. ^Bussi, G.; Whitehead, P.G.; Jin, L.; Taye, M.T.; Dyer, E.; Hirpa, F.A.; Yimer, Y.A.; Charles, K.J., 2021; Impacts of Climate Change and Population Growth on River Nutrient Loads in a Data Scarce Region: The Upper Awash River (Ethiopia), Sustainability, Vol. 13, 1254. pp 1 – 15. https://doi.org/10.3390/su13031254.
22. ^Nemera, G. T., 2020; Regional Flood Frequency Analysis and Flood Inundation Mapping: The Case of Middle Awash River Basin, Ethiopia, Unpublished MSc Dissertation, Adama Science and Technology University, Adama, Ethiopia.
23. ^Mersha, A. N., 2021; Integrated Water Resource Management: A Systems Perspective of Water Governanceand Hydrological Conditions, Unpublished Doctor Degree Thesis, Wageningen University & Ihe Delft Institute for Water Education, the Netherlands.
24. ^Tamirat, D. and Adane, A., 2016; Embankment Dam Spillway Adequacy Evaluation under Probable Maximum Flood: the Case of Tendaho Dam, International Journal of Science & Technoledge. Vol. 4 (9); pp 89 – 98.
25. ^Asfaw, H. B., van Esen, P. and Tsige, T. Z., (.); Integrated Water Resource Management Upper Awash River Basin, Central Ethiopia: Challenges and Possible Cooperation between Dutch and Ethiopian counterparts; Waterschap Hollandse Delta, Waterschap Zuiderzeeland & Waterschap Velt en Vecht. Available at: https://www.waterethiopia.org.
26. ^Edossa, D.C.; Babel, M.S.; and Das Gupta, A. 2010; Drought Analysis in the Awash River Basin, Ethiopia. Water Resour.Manag., Vol. 24, pp 1441–1460.

27. ^Sonali Sonali, P. and Nagesh, K. D., 2013; Review of trend detection methods and their application to detect temperature changes in India, J. Hydrol, Vol. 476, pp 212–227, https://doi.org/10.1016/j.jhydrol.2012.10.034.
28. ^Onoz, B. and M. Bayazit, 2003; The power of statistical tests for trend detection, Turkish Journal of Engineering and Environmental Sciences, vol. 27, pp. 247–251.
29. ^Huang J, Chen W, Wen Z, Zhang G, Li Z, Zuo Z, Zhao Q, 2019; Review of Chinese atmospheric science research over the past 70 years: Climate and climate change, Science China Earth Sciences, Vol. 62: pp 1514–1550, https://doi.org/10.1007/s11430-019-9483-5.
30. ^Mudelsee, M., 2019; Trend analysis of climate time series: A review of methods, Earth-Science Reviews, Vol. 190; pp 310–322; www.elsevier.com/locate/earscirev.
31. ^Thomas T, Gunthe, SS and Sudheer KP (2015); Analysis of monsoon rainfall variability over Narmada basin in central India: Implication of climate change, Journal of Water and Climate Change.
32. ^Varghese, A, Hajilal, M S, George, B A. 2017; Analysis of temperature and rainfall trends in the Bharathapuzha basin, India; Nature, Environment and Pollution Technology (Accepted).
33. ^Worms, J. and Touati, S. 2017; Parametric and Non-Parametric Statistics for Program Performance Analysis and Comparison, Research Report-RR-8875, INRIA Sophia Antipolis - I3S; ffhal-01286112v3f.
34. ^Dereje, T., Kinde, T. and Mulugeta, 2004, Climate Change, Variability and vulnerability in Ethiopia, Journal of African Agriculture and development, Addis Ababa, Ethiopia.
35. a, bWoldeamlak, B. and Conwayb D., 2007; A note on the temporal and spatial variability of rainfall in the drought-prone Amhara region of Ethiopia, International journal of climatology, Vol. 27: pp 1467– 1477.
36. a, bGetenet, K., 2013, Spatial and Temporal Uncertainty of Rainfall in Arid and Semi-Arid Areas of Ethiopia,Department of Geography and Environmental Studies, College of Social Science and Education, Wollega University, Nekemte, Ethiopia.
37. ^Mahmood, R., Jia, S., and Zhu, W., 2019; Analysis of climate variability, trends, and prediction in the most active parts of the Lake Chad basin, Africa; Scientific Reports, 9:6317; https://doi.org/10.1038/s41598-019-42811-9.
38. ^Teshome, H.; Tesfaye, K.; Dechassa, N.; Tana, T.; and Huber, M., 2022; Analysis of Past and Projected Trends of Rainfall and Temperature Parameters in Eastern and Western Hararghe Zones, Ethiopia; Atmosphere, Vol. 13 (67). https://doi.org/10.3390/atmos13010067.
39. a, bMohamed, M. A. H and M. E.-S. El-Mahdy, 2021: Climate change impact on extreme temperature variability in the Blue Nile Basin, Ethiopia, Geosci. Instrum. Method. Data Syst., Vol. 10, pp 45–54.
40. a, bBrunet, M. et al., 2007; Temporal and spatial temperature variability and change over Spain during 1850–2005, Journal of Geophysical Research, Vol. 112, D12117, doi:10.1029/2006JD008249.
41. ^Belay, A.; Demissie, T.; Recha, J.W.; Oludhe, C.; Osano, P.M.; Olaka, L.A.; Solomon, D.; and Berhane, Z.; 2021: Analysis of Climate Variability and Trends in Southern Ethiopia; Climate, Vol. 9 (96), https://doi.org/10.3390/cli9060096.
42. a, bAyanlade, A. Odekunle, T.O., Orinmogunje, O.I. and Adeoye, N.O, (2009); Inter-annual Climate Variability and Crop Yields Anomalies in Middle Belt of Nigeria, Advances in Natural and Applied Sciences, Vol. 3(3): pp 452-465.
43. a, bOmoyo, N. N, Wakhungu, J., and Oteng'i, S. (2015); Effects of climate variability on maize yield in the arid and semi

arid lands of lower eastern Kenya, Agriculture & Food Security Vol. 4 (8); DOI 10.1186/s40066-015-0028-2.