The trend in the annual rainfall data for the lower Lake Tana Basin is presented in **Figure 2**. The trend analysis shows how the annual rainfall data behaved for the 30-year period between 1989 and 2019. The result shows a decreasing trend in annual rainfall with a strong annual rainfall variability that can also be seen in the trend line equation given by the equation.$y = -3.2517x + 1562.2$. This equation has at least two important implications: 1) it shows the existence of a decrease in rainfall that is indicated by the negative slope (-3.25) of the equation, and 2) the R^2 shows the variation due to the independent variable in the model is 5 percent.

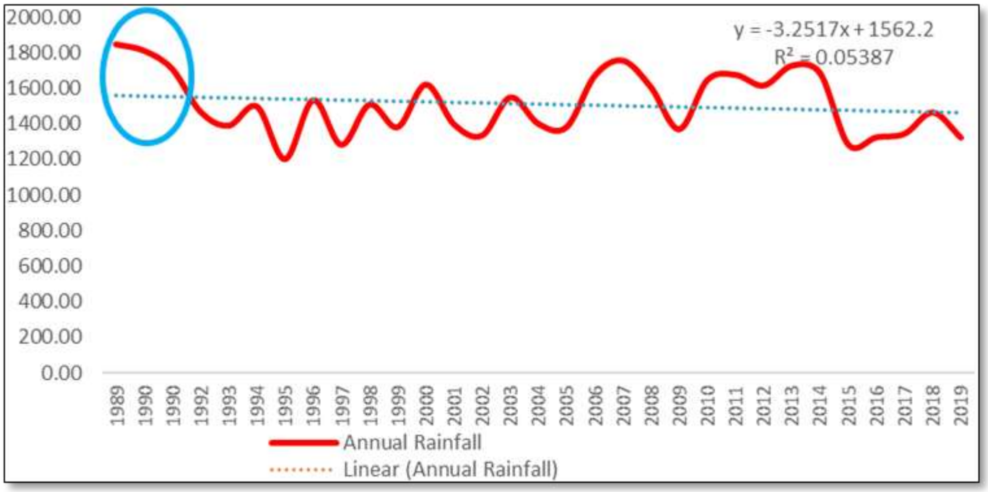

Figure 2. The trend in annual rainfall data in the lower basin.

The trend in rainfall data obtained from station in the upper basin of Lake Tana Basin is presented in **Figure 3**. As is the case for the lower basin, the result in **Figure 3** shows a decreasing trend in annual rainfall for the upper basin. This can be seen from the trend line equation given by the formula $y = -7.2914x + 16062.2$. The equation's slope (-7.29) indicates a decreasing trend and the value for R^2 shows that the variation in the dependent variable is 10 percent.

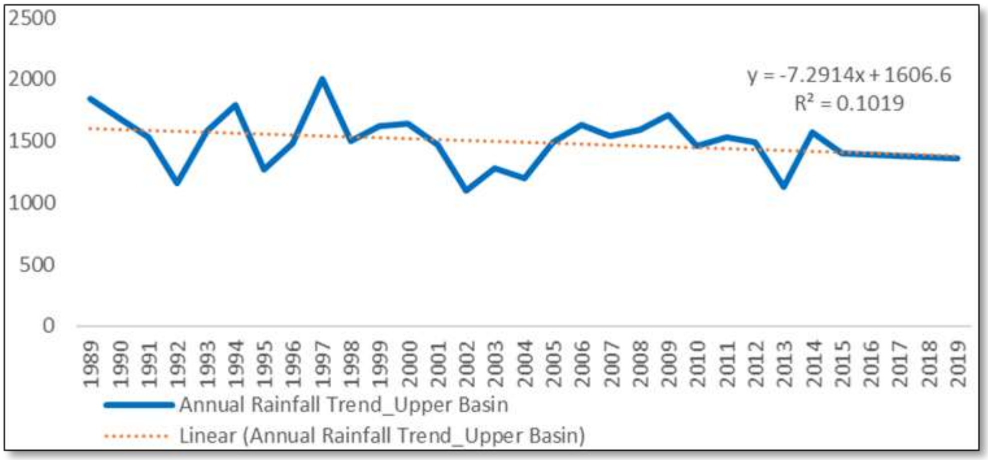

Figure 3. Trend in annual rainfall in the upper basin.

The trend in annual rainfall for the lower and upper basin is presented together in **Figure 4**. As the slope of the coefficients of the linear trend estimation indicates, there is a decline in the volume of rainfall both in the lower and upper basins of the Lake Tana Basin. From **Figure 4**, it can be said, the trend in annual rainfall was erratic for both basins. Moreover, from the regression coefficient, annual rainfall has declined by an average of 7.2mm and 3.2mm for the lower basin (-7.2914x + 1606.6) and the upper basin (-3.2517x + 1562.2) respectively. Thus, for every additional year we can expect rainfall to decline by an average of

7.2mm and 3.22mm for the lower basin and the upper basin respectively.

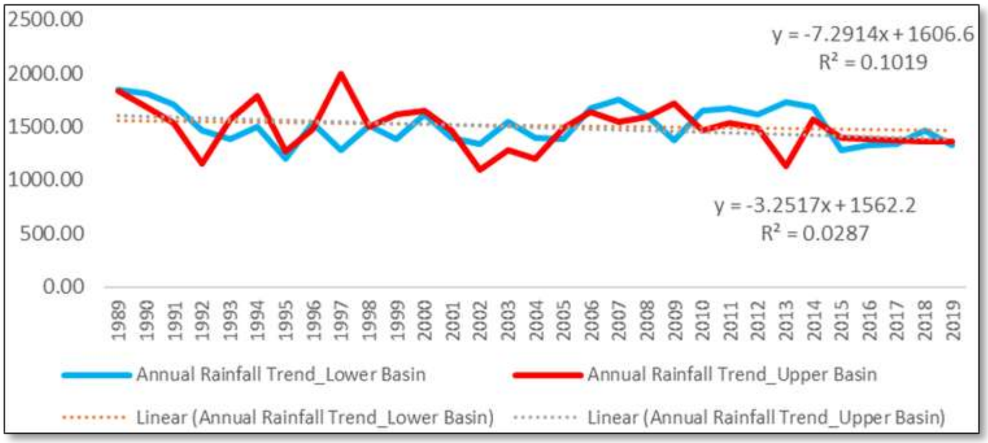

Figure 4. Trend in annual rainfall in the lower and upper basin.

Table 1 summarizes the mean, standard deviation and coefficient of variation and Precipitation Concentration Index (PCI) for both the lower and upper basins of the Lake Tana Basin system. The result that the mean rainfall is 1510mm and 1489.9mm in the lower and upper basins respectively. And the coefficient of variability (CV), which is obtained by dividing standard deviation by mean value and multiplying by 100, is 12 mm and 14 mm in the lower and upper basins respectively **(Table 1).** Accordingly, the result in table 5.3 shows that there is low rainfall variability both in the lower and upper basins. However, other studies have indicated that there is high rainfall variability (inter-annual variability of rainfall distribution) when one considers the different seasons separately [18]. The implication is that there is a need to consider multiple aspects of rainfall variability measurements.

Table 1. Comparison between the two basins.

Measurements	**Lower basin**	**Upper basin**
Mean (mm)	1510	1490
Standard deviation (SD)	175	208
Coefficient of variability (CV)	12	14
Precipitation Concentration Index (PCI)	22	18

Table 1 also shows Precipitation Concentration Index (PCI) values. According to Hundera, Mpandeli & Bantider (2019), this value can be interpreted in four ways: 1) if the value of PCI is less than 10, it shows the existence of uniform distribution of precipitation, 2) if it lies between 11 and 15, it shows moderate precipitation concentration, 3) if it lies between 16 and 20, it shows irregular distribution of precipitation, and 4) if it is greater than 20, it can be interpreted as strong irregularity of precipitation (high concentration). The PCI is greater than 20 for the lower basin which indicates irregular precipitation and it is between 16 and 20 for the upper basin which indicates strongly irregular precipitation **(Table 1)**. The implication is that both the upper and lower basins are experiencing changes in rainfall pattern which is a key indicator of climate change in the area. This has an implication for the community as most depend on agriculture which as noted earlier is the most sensitive sector when it comes to climate change.

The descriptive statistics for the monthly temperature data of the lower and upper basins of the Lake Tana Basin system is presented in annex C and D respectively. The result for the lower basin in annex C shows that the top 3 highest maximum temperatures are recorded for the months of April, May and June with values of 24°C, 27°C and 25°C. The same table shows that the highest mean temperature was recorded in the month of May. Moreover, the highest variations of mean monthly temperature were recorded for the months of December and March.

Similarly, for the upper basin, appendix D reveals that the top 3 highest mean temperatures were recorded for the months of March, April and May with values of 17.5°C, 17.3°C and 17.2°C respectively and the top 3 maximum temperatures were recorded for the same months of March, April and May with values of 24.4°C, 19.7°C and 19.1°C respectively. The same table shows that the highest coefficient of variation was recorded for the month of December.

The time series mean monthly temperature was analyzed for the period of 30 years ranging from 1989 to 2019. The data for the analysis came from two stations, one from the upper basin (Debretabor station) and the other from lower basin (Bahir Dar station). According to the results in **Figures 5 & 6**, the fitted linear trend line for the lower basin shows the existence of an increasing trend in temperature in the basin and this is reflected by the positive coefficient of the slope of the linear equation. Likewise, the result for the upper basin also reveals the existence of an increasing trend in the mean temperature in the period considered. The positive coefficient of the slope of the fitted linear equation indicates this rising trend.

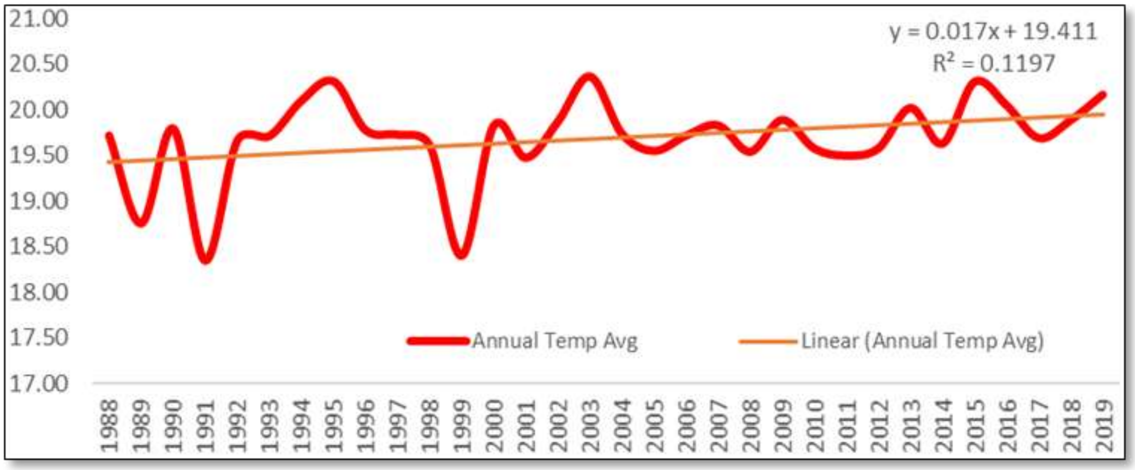

Figure 5. Trend in annual average temperature in the lower basin.

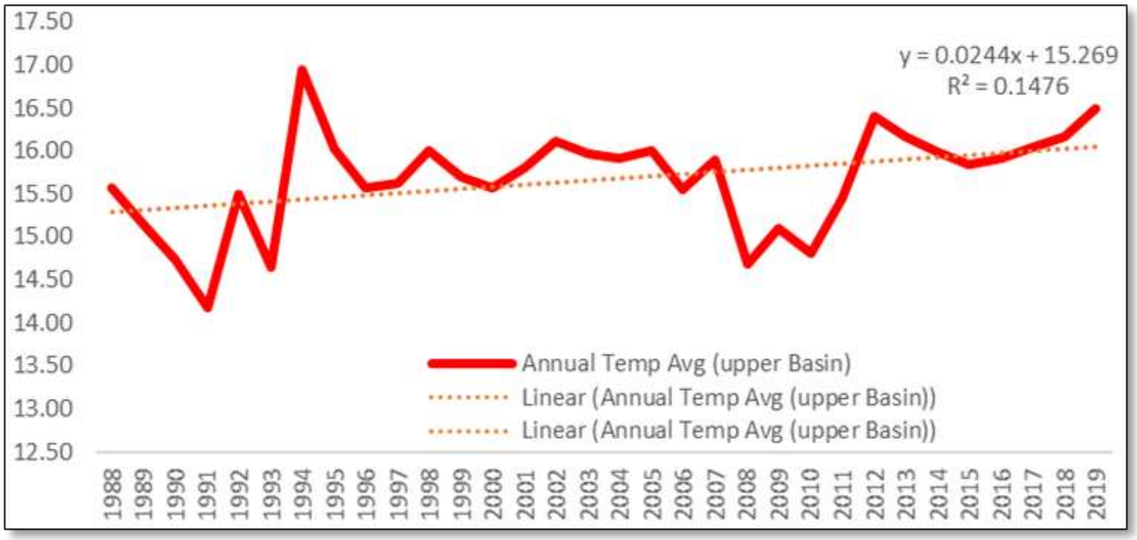

Figure 6. Trend in annual average temperature in the upper basin.

From **Figures 5 & 6** it can be observed that the relative increase in temperature was gradual. Moreover, from the regression coefficient, annual temperature has increased by an average of 0.01°C and 0.02°C for the lower basin (y = 0.017x + 19.411) and the upper basin (0.0244x + 15.269) respectively. Thus, for every additional year we can expect temperature to increase by an average value of 0.01°C and 0.02°C for the lower basin and upper basins respectively.

Moreover, **Figure 7** shows the aggregate mean monthly temperature data for lower and upper basin stations of the Lake Tana Basin. The chart generally indicates that the values of aggregated mean monthly temperature data in the lower basin tend to be greater than the values in the upper basin. The same figure also shows that the top 2 highest mean monthly temperatures were recorded for the months of April and May both for the lower and upper basins.

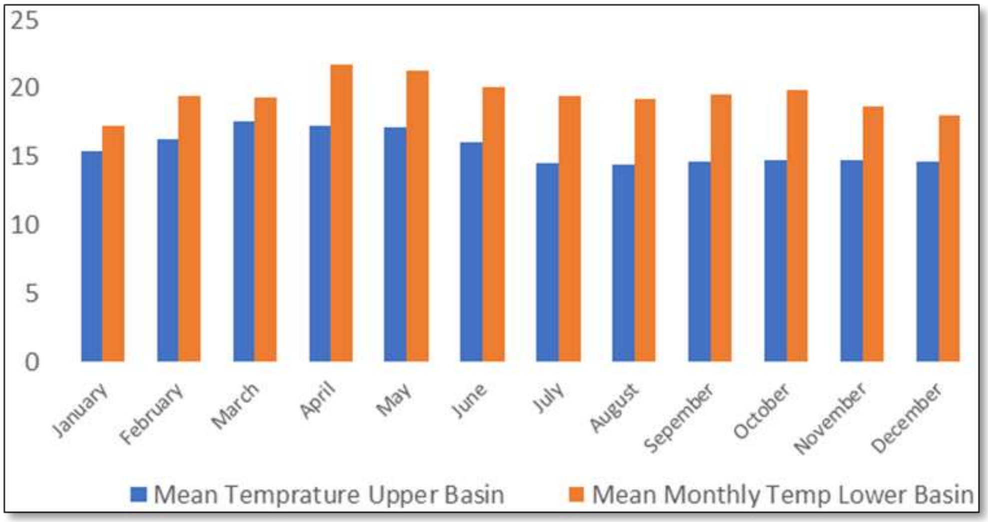

Figure 7. Aggregated mean monthly temperature.

On the other hand, agriculture is an important source of livelihood for community members in both the lower and upper basins. Thus, there is a need to examine the relationship between climate change variables and crop production. The trend in the following figure shows that there is variability in crop production over the period considered. This has been especially observed for the periods 2000/2001, 2006/07, 2011/12 and 2015/2016. Other studies have also indicated that these periods were characterized by severe droughts [19] **(Figure 8)**.

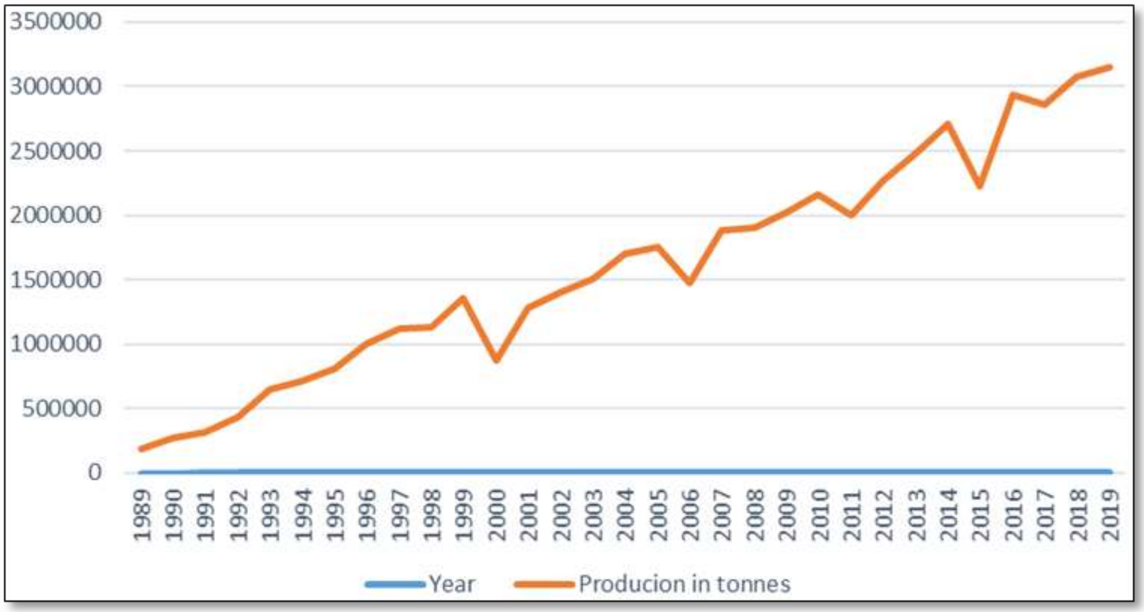

Figure 8. Trend in crop production in the Lake Tana basin.

Time series analysis

In many instances, multivariate time-series data is non-stationary. Thus, descriptive analysis is important to understand the properties and the behavior of the study variables before estimating the time series model. In this regard, the result in **Table 2** shows that all variables included in the model have less standard deviation than the mean values; this indicates the normality of the variables. Moreover, to avoid the variation of the variables as well as homogeneity, variables are changed to their logarithmic form.

Table 2. Descriptive summary of variables.

Variables	**Mean**	**Standard deviation**	**Skewness**	**Kurtosis**
Quantity of crop production (tons)	1275124	765	0.9420	2.530
Fertilizer used kilograms per hectare	18.72	12	0.915	2.181
Rainfall (mm)	1576	238	0.899	2.435
Land cultivated	6000	1785.4	1.476	3.803

In a multivariate time-series model, one should check the stationarity of the variables using the Dickey-Fuller (DF) unit root test. This test can be used both at level and first difference form. If variables are non-stationary at level but stationary at first difference, we will use vector error correction model. As the result of **Table 3** shows, all the variables are none stationary at level. However, they are all stationary at 1 percent level of significance in their first difference form.

Table 3. Stationarity test of the variables.

Variables at level	**Computed DF at lag**		**Variables in difference**	**Computed DF at lag**	
	0	**1**		**0**	**1**
LQ	1.762	0588	DLQ	-4.220*	-4.976*
LRaindev	-2.317	-2.532	DRrain	-3.934*	-3.226**
LTempdev	-3.417	-2.832	DTemp	-7.934*	-7.226**
LFertilizer	-1.835	-2.441	DFertilizer	-4.423*	-2.437
Lland	-1.685	-2.741	DFertilizer	-3.423*	-3.1437

Critical value at; 1 percent; 5 percent and; 10 percent

After controlling the impacts of cultivated area and fertilizer, the impact of rainfall and temperature has an expected sign in the crop equation. The result of the estimated model is given in table 4. The result shows that a 1 percent increase in temperature will lead to a decrease in cereal crops production by 2.2 percent. In the case of rainfall, a 1 percent increase in rainfall divergence from its optimal level will lead to a decrease in cereal crops production by 0.23 percent. When the annual rainfall diverges from its mean (both upward and downward), the level of production of crop diminishes significantly. Thus, it is not the amount of rainfall per se that matters but how that rainfall diverges from its optimal level. However, other empirical studies that used actual amount of rainfall (than the mean deviation) found a positive and significant impact of rainfall on farming in Ethiopia [21].

The result in the same table shows that a 1percent increase in fertilizer consumption per arable land increases crops production by about 0.35 percent in the long run. This result is consistent with the empirical findings of Gebregeorgis [22] who reported a positive and significant effect of fertilizers on agricultural crop production in the long run.

In the long run, the coefficient of arable land indicated a positive and significant effect on cereal crops production, as a 1 percent increase in the area of arable land increases cereal crops production by 1.82 percent in the long run. This implies that cereal crops production is highly responsive to changes in the area cultivated which is consistent with the empirical research findings of Block (2008) **(Table 4).**

Table 4. The dynamic OLS model result.

Beta	Coefficient	P-value
C	1.975	0.000**
LRaindiv	-0.235; (0.0688)	0.031
LLand	1.7187; (0.3449)	0.000
LFerti	0.359; (0.0872)	0.002
LTemp	-2.234; (0.5644)	0.066
Rainvar(-1)	0.011; (0.0248)	0.2613
Rainvar(+1)	0.016; (0.0212)	0.0931
Ferti(-1)	0.344; (0.0212)	0.198
Ferti((+1)	0.069; (0.1249)	0.305
Area(-1)	0.065	0.305
Area(+1)	-0.429	0.0221*
AR	0.7512	0.000**
MA	0.97	0.000**

The coefficient of temperature shows that a 1 percent increase in temperature decreases crop production by 2.2 percent. Thus, temperature has a significant negative effect on cereal crops production. This result is consistent with conclusions made by Hariis [23].

The post estimation for the Dynamic OLS is presented in annex G. Based on the heteroscedasticity test (White's Heteroskedasticity) output, the prob>chi2 value is 0.643. Based on the hypothesis that has been created (Ho: constant variance), the results of the hypothesis testing indicate that the null hypothesis is accepted (p-value is greater than 0.05). Thus, it can be concluded that the residual variance is constant (homoscedasticity). Also, the Breusch-Godfrey serial correlation test shows based on the hypothesis that has been created (Ho: there is no serial autocorrelation in the model), the null hypothesis is accepted (p-value is greater than 0.05). Thus, there is no serial autocorrelation in the model. The same table indicates that the error term in the model is normally distributed (Jarque- Bera test).

CONCLUSION

The analysis of climate change variables involved different statistical measurements including descriptive statistics and regression model. The time series mean monthly temperature and rainfall was analyzed for the period of 30 years ranging from 1989 to 2019/2020. The result shows the existence of an increasing upward trend in mean temperature in the Lake Tana Basin. In addition, the separate results for the upper and lower basin also reveal the existence of an increasing upward trend in the mean temperature in the period considered. In addition, the rainfall data obtained from both the lower and upper basin satiation of the Lake Tana Basin shows a decreasing trend in annual rainfall.

The relationship between crop production and climate change examined for the period between 1989 to 2019/20 using a dynamic OLS model. The result shows the existence of relationship between cereal crop production and climate variables. The result of the model shows while rainfall and temperature have a significant negative effect on cereal crops production, fertilizer consumption and land cultivated have the exact opposite effects.

POLICY IMPLICATIONS

Climate change variability has a negative impact crop production in the Tana basin agriculture system of Ethiopia where millions of rural farmers rely on rain for crop production. Thus, there is a need to design specific adaptation measures to reduce the vulnerability crop-based livelihoods in the area. Moreover, since climate change crop has an impact on staple crops production (annual crops), the effect could also have repercussion for the food security conditions of millions of farmers in the Lake Tana basin livelihood system. In this regard, there is a need to integrate crop-based adaptation measures with local food systems-based adaptation measures.

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