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Climate Change Trends and its Effects on the Production of Selected Food Crops: Evidence from Amaro Kelle District of Southern Ethiopia

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Abstract

Amaro Kelle district of Southern Ethiopia is a rainfall-based agricultural districts that is vulnerable to the impacts of climate change and risk. This study analysed climate change trends and effects on the selected food crops production: evidence from the Amaro Kelle district of Southern Ethiopia. Secondary data on climate change trends and food crop production from the Ethiopian national meteorological agency and the Amaro Kelle agricultural and rural development office were used for the study. Microsoft Excel was used to analyse the data on temperature, rainfall and crop production trends. The result on Trend analysis showed an increase in maximum and minimum temperatures at the rate of 0.056 and 0.0787 0C per 32 years, while there is a decrease in annual rainfall at the rate of -7.6012 mm per 32 years. These climatic conditions increased maize and sorghum productivity at the rate of 713.69 and 376.56 tonnes per 12 years, respectively, and decreased productivity of teff and wheat at the rate of -2618.5 and -30.892 tonnes per 12 years, respectively. These findings indicated that climate change positively and negatively affected the district's food crop production and food security. Finally, the study recommends that farmers in the district should focus on the cultivation of those crops that correlate positively with increasing temperature and decreasing rainfall trend in the study area.

Keywords: Climate Change, Trends, Production, Food Crops, Effects, Amaro Kelle, District

1. Introduction

Yield in staple crops like teff, soybean, maize, rice, and wheat, is a crucial measure of agricultural productivity and solution to food security. In developing economies like Ethiopia, crop yield trends exhibit different patterns when compared with developed economy as it faces various challenges due to factors such as climate variability (Olumide, 2024). Ethiopia recorded the lowest annual rainfall in 30 years in 2015 as a result of El Niño which affected the economy of a country where half of GDP comes from agriculture and 99% of electrical energy depends on the volume of rainfall (Ketema, and Negeso, 2020). The global warming trend has been increasing, probably due to deforestation and urbanization (Fikru and Gemechu, 2020). It could negatively affect the agricultural sector and lead to poor harvest or complete crop failure (Bouteska et al., 2024). For instance, the warming trend increased the yields of rice and soybean, whereas the yields of major food crops such as maize and wheat showed a decreasing trend in China (Cai et al., 2021). Studies revealed that increasing temperature and the changing pattern of rainfall have a considerable impact on food production (Bouteska et.al., 2024). According to Mwangi (2023), another significant impact of climate change on agricultural food production is the alteration of temperature regimes. Rising temperatures can affect crop growth, flowering, and development, leading to changes in phenology and productivity thus impacting negatively on agricultural yields. Climate change-induced temperature change can disrupt the delicate balance of pollination processes, affecting crop pollination and potentially reducing fruit set and yields and the cost of adopting a response to extreme weather events is high (Mesfin, 2022). Therefore, there is need to arrest this challenge through the use of crops that are tolerant to changes in temperature and rainfall. The main objective of this paper is to identify crop types with good yield under increased or decreased temperature and rainfall, to enable the researcher recommend same to the farmers for adoption to enable them overcome the high cost of climate change in the study area. Also, there is lack of research on the trend and impacts of climate change on specific crop type. Most available research was centered on adaptation and mitigation of climate change in the study area using additional input or through mitigation. Such research includes a work done by Bouteska et al., (2024) on impacts of the changing climate on agricultural productivity and food security; Leon, (2023) worked on impact of climate change on agricultural food production; Mesfin (2022) worked on climate variability patterns and farmers' perceptions of its impact on food production. A cursory look on these studies showed that none focused on the trend and impact of climate variation on crop type. Major issues not addressed is identification of crops that can grow under increase or decrease of a particular climate element, analyses of the trends of temperature, rainfall and selected crop types to understand how climate change affects the selected crop types in the area. Therefore, their studies cannot recommend a particular crop for a particular variation in temperature and rain fall. Hence, the need for this research. This research also, bridged the gap in literature as some scholars recommended more works on climate change trends and effects on the selected food crops production (Anderson et al., 2010; Howden et al., 2007; Shobha et al., 2017).

1.1 Literature

Globally, Climate change has adversely affected agricultural production (Al-Fawwaz & Ahmed, 2016). According to Zelda et al., (2017), there has been a consistent trend in increased drought, flooding and erosion. For example, increase in natural hazards, such as flooding and drought, has posed a tremendous challenge to the international community, whose aim is to achieve food security in the year 2030 (FAO, 2017). It could be a significant reason why recent scholars have devoted their works to finding lasting adaptation strategies to climate change in developing countries (Zelda et al., 2017; Badjie et al., 2019; Simane et al., 2016).

In Africa, particularly Sub-Saharan Africa (SSA), studies showed significant changes in the trends of temperature and rainfall and their effects on rain-fed crop production (Serdeczny et al., 2017; Speranza and Scholz, 2013; Anderson et al., 2010; Manyeruke et al., 2013). If nothing is done, the marginal cropping lands may be severely affected due to limited adaptation capacity (Jones and Thornton, 2009).

Leon (2024) indicated that absolute dependence of agriculture on weather patterns in the SSA had led the region into a food insecurity crisis. Other scholars in different parts of Ethiopia have investigated the effects of rising temperature and decreasing rainfall on crop production and food security but were not crop-specific (Al-Fawwaz, and Ahmed, 2016; Aberra, 2011; Deressa et al., 2011; Wondimagegn and Seifu, 2016; Baya et al., 2019). Location-specific adaptation strategies are appreciated and highly recommended in the area (Paulos Asrat & Belay Simane, 2018). Other scholars also suggested use of local experience-based adaptation strategies to combact climate change effects (Hassan and Nhemachena, 2008; Asrat and Simane, 2017).

Ethiopians' concerns over the impacts of climate change and variability on agriculture and food security have grown, which are highlighted in a recent study (Alemu, and Mengistu, 2019). Because of climate change and its unpredictability, there is a growing need to develop and execute adaptation and mitigation measures. Climate change and variability have been critical environmental issues for many years, and studies have shifted towards increasing attention to these issues in recent years. Ethiopia's vulnerability to climate change and variability is particularly pronounced because of its dependency on rain-fed agriculture and natural resources as drivers of economic growth (Dendir, and Simane, (2019). Ethiopia is expected to see both an increase in temperature and a decrease in rainfall over the next several decades, increasing the need for crop type specific adaptation and mitigation actions (Tenali, and McManus, 2022). In recent decades, Ethiopia has placed a greater priority on creating and implementing mitigation and adaptation approaches.

In the Amaro Kelle district, farmers have perceived the changing trend of climate but do not know how to correlate food crops to temperature and rainfall changes (Baya et al., 2019). Hence, the ever-increasing risk of crop failure, associated with the increased frequency of extreme climatic events (drought, flooding, soil erosion etc.), has been posing a clear and remarkable threat to food security (Baya et al., 2019). Research on farmers' perception and adaptation to climate change alone will not result in a considerable solution to fight against the impacts and sustain food security unless the meteorological data on climate change elements are correlated with given years of crop yields. Making a difference in its scope, context and content. The present study aims to analyses climate change trends and their effects on the yields of selected food crops that have been ignored in other previous studies in the study district. This work's main expectation is that a simple way of identifying positive and negative correlations of crops with increasing temperature and decreasing rainfall trends will be shown. It will help agricultural development agents correctly recommend farmers to use the correct crop type in the right climatic environment, which will, in turn, help the nation's food security.

1.2 Theoretical Framework

Theory of Ecological Modernization: This theory was developed by Joseph Huber and it revolves around the idea that economic development and environmental protection can go hand in hand (Leon, 2023). In the context of Climate Change Trends and Effects on the Selected Food Crops Production, this theory suggests that innovative, sustainable farming practices such as use of climate element specific crop type in responding to climate change impact can improve food production while mitigating environmental impact. It emphasizes the role of technology, policy, and social innovation in addressing climate-induced challenges in agriculture (Mol & Spaargaren, 2016).

The Risk Society Theory: This theory was proposed by Ulrich Beck and it centers on the idea that modern society is increasingly preoccupied with the future, and also with safety, resulting from human-induced risks (Beck, 2016). As per the theory, climate change represents one such global risk affecting agricultural food production. The theory underscores the necessity of societal shifts and transformations in dealing with these risks, necessitating the development of risk management strategies in agriculture that are environmentally friendly to cope with climate change.

2. Materials and Methods

2.1 The Study Area

This study was conducted in Amaro Kelle district, South Nation Nationalities People Regional State of Ethiopia. This district is situated between latitudes 50 40' and 60 0' north of the equator and longitudes 370 40' and 380 0' east (Figure 1). The study area is located at a distance of 671 km from Addis Ababa and 412 km from the regional city, Hawassa. Amaro Kelle district comprises three topographical zones: Highland, Middle altitude area and Lowland (Amaro Ward Agriculture and Rural Development Office, 2010).

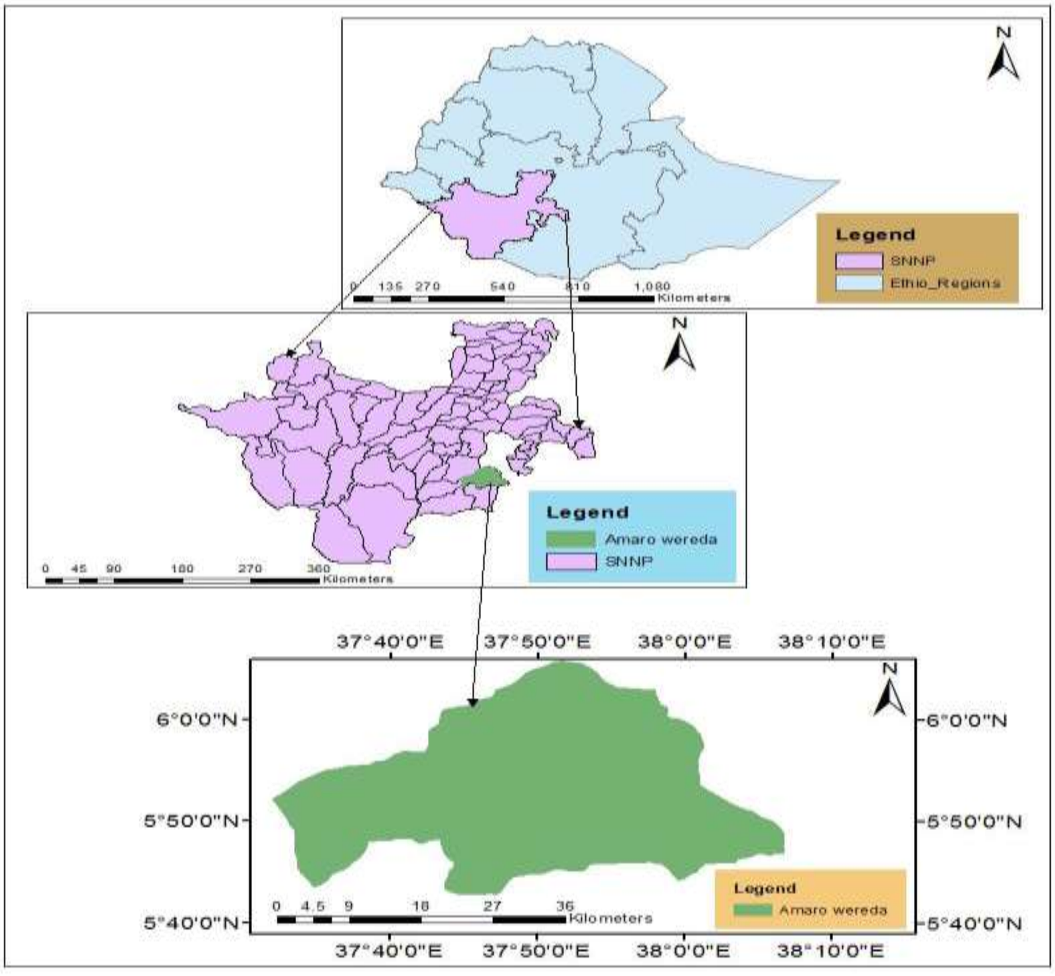

Figure 1. Administrative Map of the Study District
Source: Ethio Arc GIS (2024)

2.2 Data collection

Secondary data were used for this study. The monthly and annual rainfall and temperature data from the National Meteorological Agency office (NMAO) for the period of 1983-2015 were collected and used for the study while crop production data were obtained from the Amaro Kelle district rural development and agriculture office and used for the study. . Climate change was measured by comparing current data to 32 years of retrospective data collected in 2021 from the National Meteorological Agency office (NMAO) on temperature and rainfall patterns of the study area. Likewise, 12 years of retrospective data were collected on crop yield in the study area from the Amaro Kelle district's Ministry of Rural Development and Agriculture Office (MRDAO).

2.3 Data analysis

Microsoft Excel was used to analyses the trends of temperature, rainfall and selected food crop yield in the district. Microsoft Excel is one of the top tools used to analyses data such as temperature and precipitation trends (Hayelom, Chen et al., 2017). This study was used to achieve the district's temperature trends, rainfall and selected food crop production. To achieve the relationship between climate change and food-chosen crop yield in the area, the study used 32 years of climate change data and 12 years of crop production data from the district. In this case, the temperature, precipitation and crop yield trend were analyzed using an excel spreadsheet. Analysis of the annual maximum and minimum temperature trend and total annual rainfall trend was correlated with the average crop yield of a given year to see the relationship between climate change on food security.

3. Results and Discussion

3.1. Temperature and Rainfall Trend Analysis

The analysis showed that the average annual minimum and maximum temperature generally increased (Figures 2 and 3), but total yearly rainfall showed a decreasing trend (Figure 4). The average annual temperature trend from 1983 – 2015 in the area showed a warming climate. Several studies reports are in line with this findings. Eg. The study of Charity et al (2013), reported that declining rainfall patterns and increasing temperature trends have affected the agricultural sector. Beyene (2015) envisaged an increasing trend in both minimum and maximum temperature, whereas the average rainfall trend indicated a decrease in the Tigray regional state of Ethiopia. Studies also revealed that increasing temperature records and the changing pattern of rainfall have a substantial impact on food production (African Technology Policy Studies Network (ATPS), 2013; Mahmood et al., 2012). However, the work of (Hayelom et al., 2017) slightly opposed the result as increase in temperature had an increase in food production this may be because a different crop was selected by the researcher; although, the minimum temperature decreased from 1985 to 2010.

From the trend analysis result, the rate of change is defined by the slope of the trend line, which in this case is about 0.0787oC/32 years, 0.056 oC /32 years and -7.6012 oC /32 years for average minimum annual temperature, average maximum yearly temperature and total annual rainfall respectively during the period of 1983 to 2015 (Figures 2, 3 & 4).

The slope of the graph indicates a positive value for average minimum and maximum annual temperature and a negative value for total annual rainfall. It indicates an increase in maximum and minimum temperatures and a decrease in annual rainfall. The minimum and maximum average annual temperature recorded was 26.5 0C and 29.30C, respectively, between 1983 and 2009. Whereas the maximum yearly rainfall was recorded in 1988 with 1479.9 mm rainfall, the minimum rainfall was recorded in 2015 with 646.1 mm rainfall.

Table 1 shows the results of the analysis of maximum and minimum temperatures between 1983 and 2015: the rates of change are about 0.0787 oC/32 and 0.056 oC/32 years, respectively. Rainfall data for 32 years were analysed. Table 1 shows the descriptive statistics of monthly rainfall. The coefficient of variation (CV) ranges from 73.71298% – 130.319 % (Table 1). According to the result of the analysis, all months have represented extreme CV, meaning that all months have a homogenous character in terms of rainfall variations (Table 1). The total annual rainfall of the study area is slightly low and decreasing, ranging from 1200.8 mm to 646.1 mm (Figure 4). The result indicates that the amount of rainfall in the area is highly variable. This extreme variability and unusual rainfall amount and distributions usually lead to poor harvest and complete crop failure in the study area.

The CV (9.515% to 14.2%) for the monthly mean minimum temperature shows a slightly high month-to-month variation (Table 1) compared to the monthly mean maximum temperature with CV (2.95% to 5.53) (Table 1). As indicated in Table 1, the lowest (14.5) and highest (16.4) monthly mean minimum temperature was recorded in June and March, respectively. Furthermore, the highest variation of mean minimum monthly temperature occurred in March, while the lowest (25.5) and highest (30.6) monthly mean maximum temperature was recorded in July and February, respectively (Table 1). Besides, July was the month with the highest variation of mean maximum temperature (Table 1). There is also a positive correlation between the monthly mean temperature and the period. It could be because the area's temperature is increasing due to global climate change.

According to Hayelom et al. (2017), CV is used to classify the degree of variability of rainfall events as follows: low (CV < 20), moderate (CV < 30), high (CV > 30), very high (CV>40%) and extremely high (CV>70%) inter-annual variability of rainfall. Based on this categorisation and the observed data, the inter-annual rainfall variability in the study area is extremely high, as all the months had a CV higher than 70% (Table 1). The graph (Figure 4) depicts a significant variability in the volume of rainfall over the years. The rainfall trend for 32 years witnessed a decreasing mean rainfall at -7.6012 mm and high annual variation with a coefficient of determination (R2) of 0.1207. According to Amaro Kelle Agriculture and Rural Development Office (2010), the district had temperatures ranging from 12.6 0C to 25 0C. The amount of rainfall in the area ranges from 800mm to 1000mm. From the analysis of the results, there are changes in the maximum temperature, minimum temperature and annual rainfall ranges.

Table 1. Statistical Summary of Monthly Rainfall, Mean Minimum and Maximum Temperature for the Station from 1983 -2015

Statistical Summary of monthly Mean Minimum Temperature								
Month	N	Range	Minimum	Maximum	Mean	SD	Variance	CV%
Jun	33	7	11	18	16.097	1.65972	2.755	10.31074
Feb	33	6.9	11.7	18.6	16.3091	1.86922	3.494	11.46121
Mar	33	12.1	7.5	19.6	16.4	2.32298	5.396	14.16451
Apr	33	5.9	12.1	18	15.9	1.80745	3.267	11.36761
May	33	6.4	11.2	17.6	15.5606	1.65604	2.742	10.64252
Jun	33	6.9	10.3	17.2	14.8727	1.8259	3.334	12.27686
Jul	33	7.1	10.7	17.8	14.5788	1.50639	2.269	10.33274
Aug	33	6.5	10.8	17.3	14.9091	1.49883	2.246	10.05312
Sep	33	7.4	11.2	18.6	15.3455	1.46011	2.132	9.514907
Oct	33	6.4	10.8	17.2	15.2485	1.73081	2.996	11.35069
Nov	33	7.6	9.8	17.4	15.4061	1.67909	2.819	10.89886
Dec	33	7.5	10.6	18.1	15.5182	1.60418	2.573	10.33741
Statistical Summary of Monthly Mean Maximum Temperature								
Month	N	Range	Minimum	Maximum	Mean	SD	Variance	CV%
Jun	33	2.9	28.1	31	29.903	0.8837	0.781	2.955222
Feb	33	4.5	28.3	32.8	30.6788	1.22978	1.512	4.008566
Mar	33	4.7	27.9	32.6	30.2939	1.17152	1.372	3.867181
Apr	33	5.2	25.4	30.6	28.0788	1.06265	1.129	3.784528
May	33	4.5	24.6	29.1	26.8394	1.12637	1.269	4.196703
Jun	33	5.9	23.1	29	26.4364	1.26536	1.601	4.786431
Jul	33	6.1	22.8	28.9	25.5758	1.41311	1.997	5.525184
Aug	33	4.5	24.1	28.6	26.0758	1.27525	1.626	4.89055
Sep	33	5.1	24.7	29.8	26.9909	1.20917	1.462	4.479917
Oct	33	3.3	24.8	28.1	26.797	0.79431	0.631	2.964175
Nov	33	4.1	25.6	29.7	27.5848	0.79652	0.634	2.887532
Dec	33	4.5	25.9	30.4	28.6273	1.00507	1.01	3.510879
Statistical Summary of Monthly Rainfall								
Month	N	Range	Minimum	Maximum	Mean	SD	Variance	CV%
Jan	33	57.3	0	57.3	17.5121	12.90869	166.634	73.71298
Feb	33	86.2	0	86.2	21.597	18.03206	325.155	83.49336
Mar	33	169.3	16.7	186	51.9848	40.30796	1624.732	77.53797
Apr	33	387.3	16.7	404	111.1515	100.1494	10029.9	90.10167
May	33	295.1	16.1	311.2	110.8061	96.67001	9345.09	87.2425
Jun	33	196.6	15	211.6	49.0364	41.26272	1702.612	84.14712
Jul	33	113.2	2.8	116	35.8788	28.63097	819.732	79.79913
Aug	33	138.1	9.7	147.8	43.9091	40.01777	1601.422	91.13776
Sep	33	131.4	15.4	146.8	54.7394	43.8384	1921.806	80.08564
Oct	33	288.3	15.6	303.9	96.8394	71.58068	5123.793	73.9169
Nov	33	213	0	213	41.4939	53.41902	2853.591	128.7395
Dec	33	137.6	0	137.6	19.6273	25.57811	654.24	130.319

Note: SD: Standard Deviation, CV: Coefficient of Variance, 95% confidence level
Source: Ethiopian National Meteorological Agency (ENMA), 2015

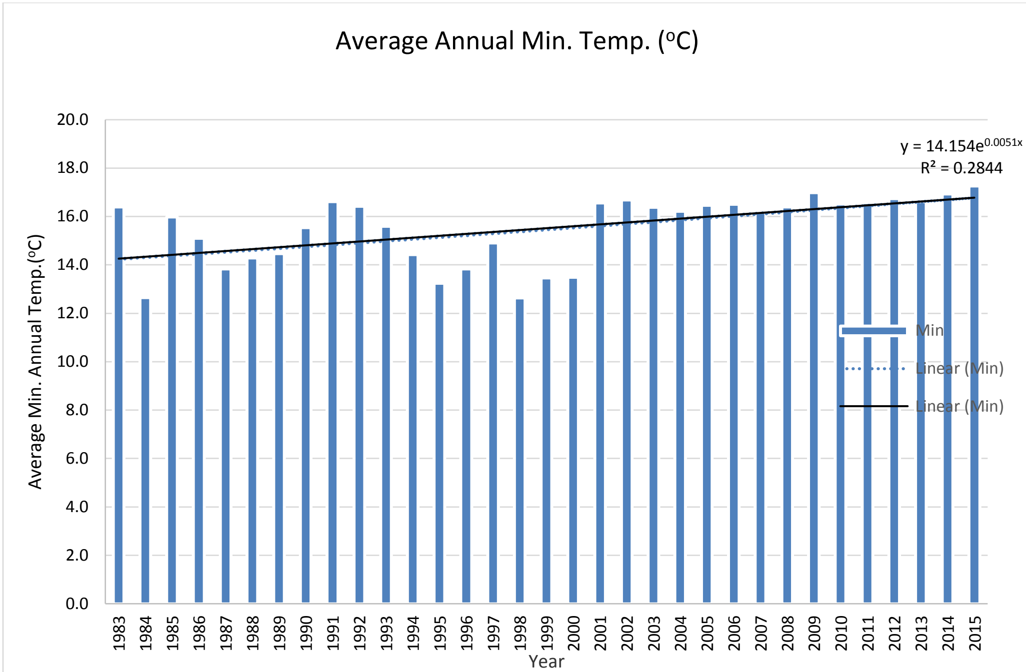

Figure 2. Average Annual Min. Temp. (°C) (1983-2015)
Source: Ethiopian National Meteorological Agency (ENMA), 2015

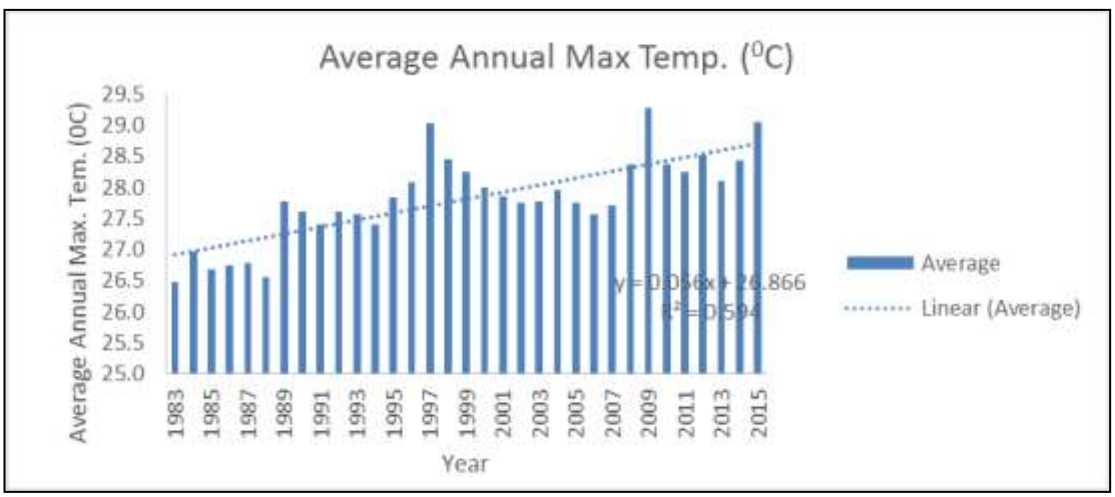

Figure 3. Maximum Annual Temperature Trend for the Period of 1983-2015
Source: Ethiopian National Meteorological Agency (ENMA), 2015

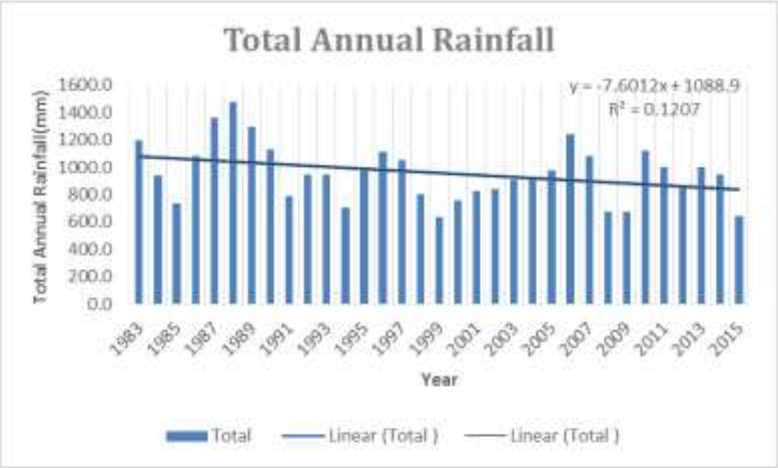

Figure 4. Annual Rainfall Trend for the Period of 1983-2015.
Source: Ethiopian National Meteorological Agency (ENMA), 2015

3.2 Climate Change and its Effects on the production of Selected Food Crops

The above temperature and rainfall trend analysis showed that less and extreme temperature variability adversely affected crop production (Figure 2, Figures 3 and 4). The following graphs showed the decreasing and increasing production trends of four major food crops in the study area for the whole period (2004-2015).

As shown in Figure 5, Maize production has an increasing trend from 2004 to 2015 with a positive rate of change (713.69/ 12 years). Sorghum production (Figure 6) from 2004 to 2015 showed an increasing trend, indicating a positive rate of change (376.56/12 years). This result is true probably because sorghum is a drought-tolerant food security crop grown in sub-Saharan Africa and Ethiopia (FAOSTAT, 2013; CSA, 2015). But, teff production (Figure 7) for the same period experienced a decreasing trend indicating a negative rate of change (-2618.5/12 years). The highest production of (1859.8 tonnes) was recorded in 2008 with less rainfall record of (56mm), indicating that teff grows well in the winter season with less rainfall, and it is an important crop for households in rural locations which are affected by change in climate elements such as rainfall leading to drought. (Bayecha, 2013). Similarly, wheat production (Figure 8) from 2004 to 2015 showed a decreasing trend with a negative rate of change (-30.892/12 years). It indicates that the increasing average minimum and maximum temperature with decreasing average annual rainfall significantly affected wheat production. The finding is in agreement with the findings of (Sajjad et al., 2017), who reported that maximum temperature adversely affects wheat production in Pakistan.

In general, the increasing trend of average minimum and maximum annual temperature with a decreasing yearly average rainfall trend had a positive effect on some crops' production and a negative effect on others' production. Therefore, it can be inferred that temperature and rainfall changes have positive and negative implications for food security in the Amaro Kelle district.

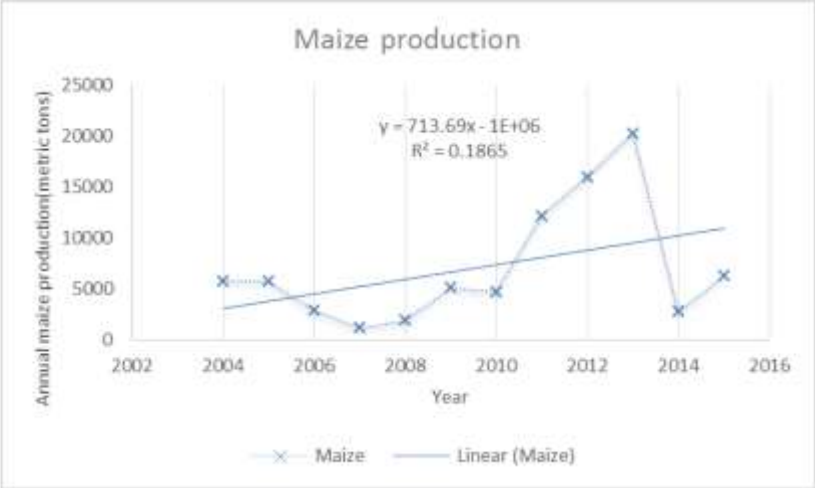

Figure 5. Maise Production for the Period of 2004-2015
Source: Amaro Kelle district Agriculture and Rural Development Office, 2015

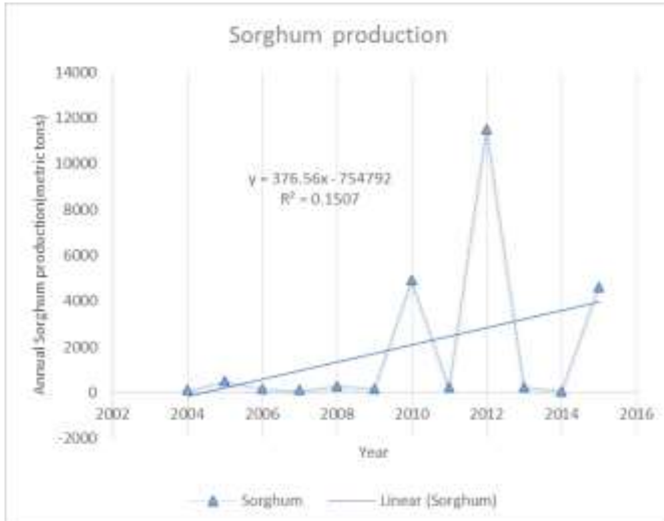

Figure 6. Sorghum Production for the Period 2004-2015
Source: Amaro Kelle district Agriculture and Rural Development Office, 2015

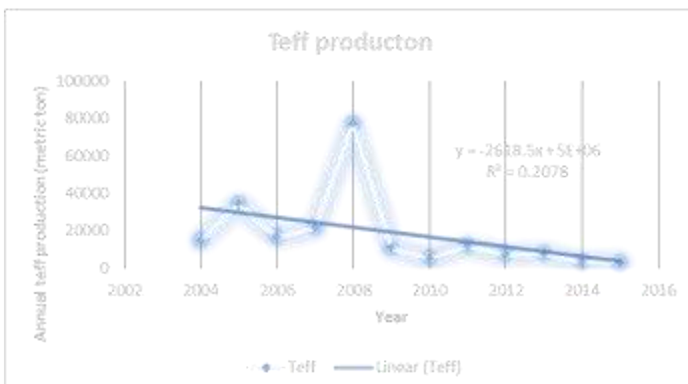

Figure 7. Teff Production for the Period 2004-2015
Source: Amaro Kelle district Agriculture and Rural Development Office, 2015

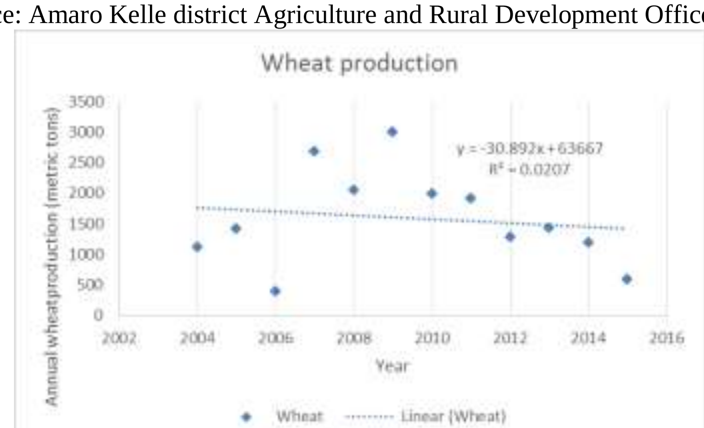

Figure 8. Wheat Production for the Period 2004-2015
Source: Amaro Kelle district Agriculture and Rural Development Office, 2015

Figure 9 showed the correlation between the variations in trend (upward and downward) shift of the two climatic variables and the four major crops over the whole period (2004–2015). The average annual maximum temperature has shown variability slightly, and minor variations were observed in maximum temperature for all crops. However, total annual rainfall showed significant variability, and the trend showed a decreasing rate. In addition, the production of maize and sorghum crops increased with increasing temperature and decreasing precipitation. Figure 9 shows that teff and wheat production decreased as maximum and minimum temperature increased, and annual rainfall decreased. Finally, it confirms that climate change affects household food security positively and negatively. Moreover, its positive effect stimulates higher crop yield with decreasing rainfall and increasing temperature, contributing to household food security.

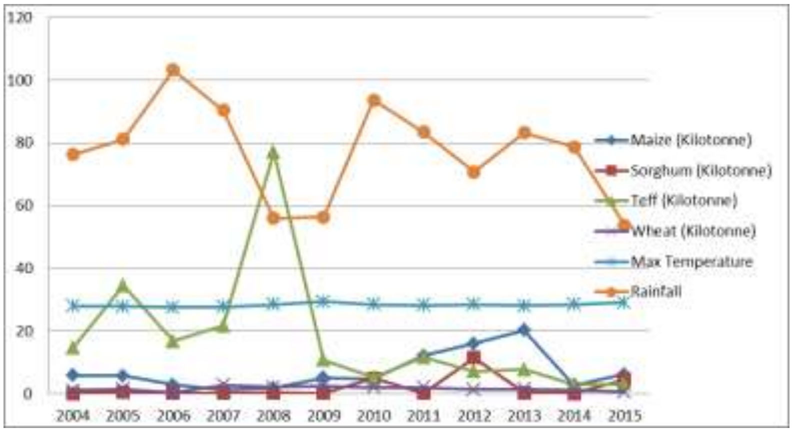

Figure 9. Summary of the Relationship between Temperature, Rainfall and Crop Production (2004-2015)
Source: Amaro Kelle district Agriculture and Rural Development Office and Ethiopian National Meteorological Agency (ENMA), 2015

4. Conclusion and Recommendations

The study analyzed climate change trends and their effects on selected food crops in Amaro Kelle District. The 32 years' temperature and rainfall data showed an increasing trend of minimum and maximum temperatures and decreasing rainfall trend in the district. The rising trend change in average annual minimum and maximum temperature and declining trend change in total yearly rainfall have resulted in an increase in the production of maize and sorghum but a decrease in the total production of teff and wheat in the study area. The study concludes that change in temperature and rainfall trends has both positive and negative implications to household food security in the area. Based on the findings, the study recommends that: (i)Farmers of the district should focus on crops that correlate positively with increasing temperature trend and decreasing rainfall trend in the area. (ii) Local governments and development agents of the study area should encourage farmers to select drought-tolerant crop varieties considering the current rainfall pattern in the area.

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