DOI: https://doi.org/10.20372/afnr.v1i1.625
Journal of Agriculture, Food and Natural Resources
J. Agric. Food Nat. Resour., Jun-Sep 2023,1(1):40-50
Journal Homepage: https://journals.wgu.edu.et

Original Research

Climate variability and its implications on the production of Arabica coffee in Abe Dongoro district of Horro Guduru Wollega Zone, Oromia, Ethiopia

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Abstract

The agricultural industry, especially the production of coffee arabica, is significantly impacted by climate fluctuation in the world. As a result, the objective of this study was to evaluate how the climate impacts coffee production and trends, climate variability, and farmer adaptation techniques in Abe Dongoro area of Horro Guduru Wollega Zone, Oromia region, Ethiopia. Primary data were collected using household surveys and interviews, and secondary data were collected through documentary reviews and meteorological data. To choose a total of 116 respondents, five kebeles in the study district were purposefully chosen. Descriptive and inferential statistics were used to analyze the recorded variables. The outcome showed that over the previous ten years (2008-2018), coffee production has decreased along with both rainfall and temperature. The concept of climate variability varied across farmers, and nearly half of them (49.1%) described it as an extended dry season. The other respondents (32.8%) understood it as a decrease in rainfall, while 18.1% of respondents viewed it as an increase in temperature and rainfall variability. Mulching was the most common adaptation practice used by farmers to reduce evaporation (32.8%) followed by terracing to minimize soil erosion (6.9%),and planting shade trees to reduce increased temperature (23.3%). The study concluded that coffee production has shown a decreasing trend over the last ten years, and trends in rainfall and temperature also indicated variability which would affect coffee production. Further investigation may be required for more conclusive result.

Article Information

Article History:

Received : 22-06- 2023

Revised : 04-09-2023

Accepted : 04-09-2023

Keywords:

Climate change adaptation

Climate variability

Coffea arabica

Rainfall, Temperature

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INTRODUCTION

Climate variability already has a considerable impact on the agriculture sector (Jaramillo *et al.,* 2011). Rainfed agriculture is a significant economic activity in the developing countries (Hulme, 2014). The first national action plan on climate variety, which included an inventory of emissions by source and removal by sinks of greenhouse gases, aids farmers in adapting to new agricultural practices and technologies. According to NAPA (2007), agriculture is strongly influenced by weather and climate. While farmers are often flexible in dealing with weather and year-to-year variability, there is nevertheless a high degree of adaptation to the local climate in the form of established infrastructure, local farming practices and individual experience (Gornall *et al*., 2010).. Since the turn of the 20th century, people have noticed climate variation, and anthropogenic and natural climate drivers are typically to blame (Masters *et al*., 2010). One of the most pressing problems facing humanity today is the impact of climate change on natural systems (Jaramillo *et al*., 2009).

According to Kasterine *et al*. (2010), the burning of coal, oil, and natural gas over extended periods of time, as well as the mineralization of organic matter, are major contributors to climate variability and change. These factors raise the atmospheric concentration of carbon dioxide (CO2) and are major causes of natural climate variation that lasts for months to decades. The most prevalent greenhouse gases that affect the world climate through emissions are carbon dioxide (CO2) and methane (CH4) (Masters *et* *al*., 2010). Changes in weather patterns, such as irregular rainfall and dry seasons, when intense rain produces flooding and the temperature rises or falls significantly beyond normal reflect climate change and variability (Enomoto *et al*., 2011). Future coffee output in many nations is influenced by climatic variability, which has historically been the primary cause of the global decline in coffee yields (Kasterine *et al*., 2010). Depending on the coffee type grown, coffee requires extremely particular environmental conditions for successful production. It is a tropical crop that may flourish in both tropical humid/sub humid highlands and humid lowlands (Enomoto *et al*., 2011).

Coffee is a vulnerable crop that requires particular climatic conditions in order to thrive and yield a healthy crop. The ideal climate for growing Coffea arabica requires temperatures between 15 and 24 °C, 2000 mm of annual precipitation, and elevations between 1000 and 2000 m a.s.l (Agegnehu, 2015). However, extended temperatures above 30°C and rainfall that is either more or less than necessary have an impact on coffee output (Agegnehu, 2015). Due to environmental elements influencing plant growth and development in various ways during the growth phases of coffee crops, the linkages between climatic parameters and agricultural productivity are highly complex. Over a 120-year period, Ethiopia's mean temperature increased spatially and temporally in a range of 0.24°C to 1.92°C and 0.72°C to 1.08°C, respectively. Changes in rainfall patterns and temperature trends are projected to increase the frequency of extreme weather events and have an influence on ecosystem services (Berihun *et al*., 2023).

In the Horro Guduru Wollega Zone, Abe Dongoro district of Oromia State is the only district from the zone is known for its special coffee production locally known as *Buna Dongoro* and *Buna Lage*. However, there was no available information regarding the effects of climate variability on coffee production, farmers' perception on climate variability, and farmers' adaption to climate variability in the study area. Therefore, this study was conducted to assess the effects of climate variability on coffee production, farmers' perceptions of climate variability and farmers adaption to climate variability specifically in the Abe Dongoro district of Horro Guduru Wollega Zone, Ethiopia.

METHODOLOGY

Description of the study areas

This study was conducted in the coffee-producing area of the Abe Dongoro district of Horro Guduru Wollega Zone, and is located in the western part of the zone, covering a total land area of 1092.09 km^2. Currently, this district is subdivided into 22 kebeles for its administrative purpose, including two urban kebeles and 20 rural kebeles (smallest administration unit) (Figure 1). Tulu wayu is the capital town of this district located approximately 47 km away from the zonal capital Shambu and 360 km from the capital town of Oromia called Finfinne (Fanta *et al.,* 2018).

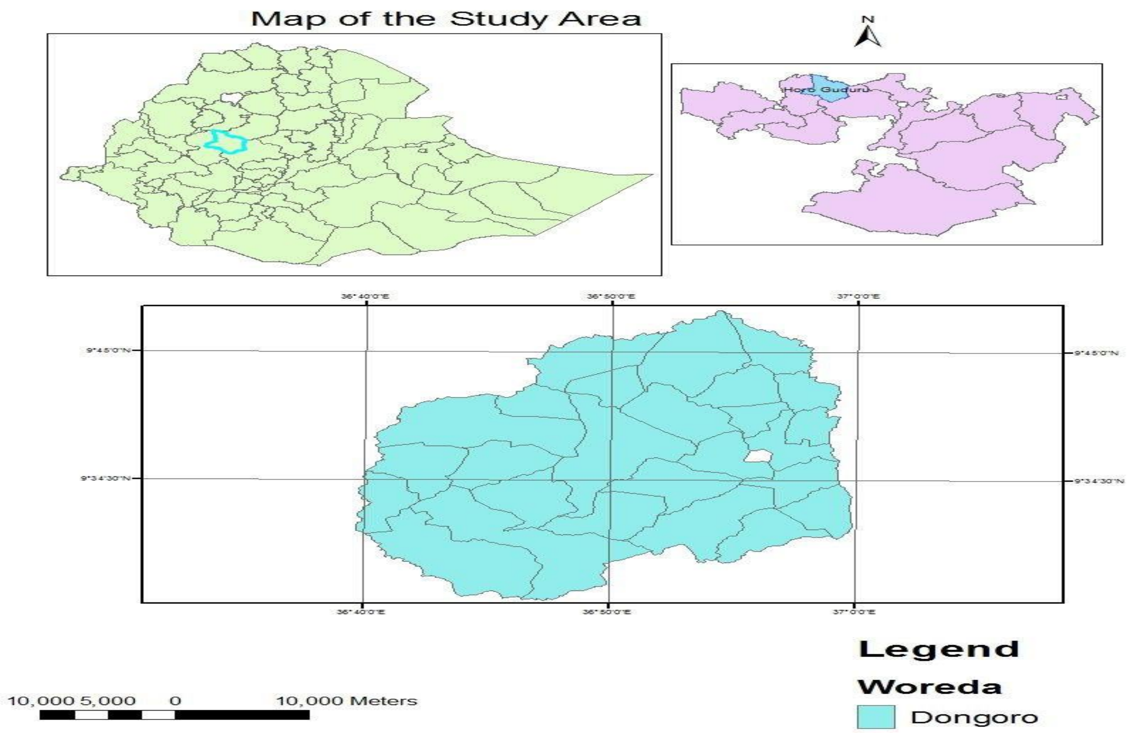


Figure 1: Map of Abe Dongoro district

Study design

The study used a cross-sectional study design, and both quantitative and qualitative data were gathered. The household served as the sampling unit, and a total of 116 respondents were chosen from five kebeles in the district. The collected data were analyzed using descriptive and inferential statistical analysis for quantitative variables, and the Microsoft Office Excel worksheet and STATA Version 13 were used for the analysis of both secondary and primary data.

Data source and methods of collection

The source of primary data was from key informants, which were producers and managers, as well as the heads of agricultural offices managing or responsible for the particular coffee production system. In this study, both quantitative and qualitative data were gathered; quantitative data for temperature and rainfall from national meteorological stations were compared with data on coffee production from the district agricultural office. The primary data were gathered through household surveys and interviews; secondary data were gathered through the documentary method. Open-ended and closed-ended questions were included in semi structured questionnaires used to collect data from the households.

Sample size and sampling technique

An appropriate and representative sample size of households was determined using Yamane's (1967) formula. To determine the required sample size at a 95% confidence level, with a 0.5 degree of variability and a 9% level of precision. $n = \frac{N}{1+N\,(e)^2}$, where n is the sample size for the research use, N is the population size in the district, and e is the level of precision (=0.09).

Table 1: Sample size distribution for selected kebeles', Abe Dongoro district.

No:	Name of kebele	Number of households	Sample unit
1.	Gararo	462	26
2.	Botoro Bora	301	17
3.	Tige	431	24
4.	Lomicha	640	36
5.	Wolage	223	13
Total		2057	116

As indicated above, the Yamane (1967) formula was used to determine sample respondents from the total households in the study areas. A purposive sampling technique was employed to select kebeles that are well-known in coffee production in the study area, and stratified sampling techniques were used to select the households that are the greatest producers of coffee in the area.

Approach to data analysis

The Statistical Package for Social Science (SPSS) for Windows version 20.0 was used to edit, compile, code, enter, and analyze the obtained data. Descriptive and inferential statistical analyses were conducted for all quantitative variables to check for outliers and consistency of data. Descriptive statistics, including frequency distribution, were computed. Additionally, cross-tabulation was performed to make the comparison. In inferential statistical analysis, correlation analysis was used to examine the relationship between rainfall variability and coffee production in the area, while a simple linear regression was used to study the effect of the independent variable (amount of rainfall in millimeters) on the dependent variable (amount of coffee in kg). The quantitative and qualitative data were analyzed using a Microsoft Office Excel worksheet, and Stata version 13 was used for the analysis of both secondary and primary data.

RESULTS AND DISCUSSION

Socio demographic and Economic Characteristics

Age, sex, family size, marital status, and education are socio demographic factors that are important to farm decisions and performance when it comes to climate variability. While age represents agricultural experience, respondents' education level aids in their comprehension of broad farm requirements and how to apply them during the appropriate weather season. Family size gives a good determination of the labor force on production, and sex and marital status determine the responsibilities of male and female farmers in the entire process of crop production. The socio demographic characteristics of the sample population in the study area showed approximately 66.4% of the household heads were under 50 years old, 11.2% were between 51 and 60 years old, and 22.4% were between 61 and 70 years old (Table 1).

On the other hand, approximately 87.9% of the studied households were headed by a male, while 12.1% of the households were headed by females. Regarding their education level, 81.9%, 86%, and 17.3% of the respondents had a primary, secondary, and no formal education, respectively (Table 2).

Table 2: Sociodemographic and socioeconomic characteristics of the respondents (n =116) in Abe Dongoro district, Horro Guduru Wollega Zone, Oromia, Ethiopia.

Categorical variables	Respondents	Percentages
Age of respondent	**Freq.**	**Percent**
Respondents less than 50 age	77	66.4
Respondents between 51 to 60	13	11.2
Respondents between 61 to 70	26	22.4
Total	**116**	**100.00**
Sex of the respondents	**-**	**-**
Male	102	87.9
Female	14	12.1
Total	**116**	**100.00**
Level of education	**-**	**-**
Primary school education	95	81.9
Secondary school education	1	0.86
Non educated	20	17.3
Total	**116**	**100.00**
The economic activity of the household	**-**	**-**
Crop production	13	11.2
Both crop and livestock production	103	88.8
Total	**116**	**100**

In terms of socioeconomic characteristics of the respondents and family size, approximately 88.8% depend on the mixed farming system, which is both crop and livestock production, for their daily livelihoods, whereas approximately 11.2% of the households depend on crop production only for their livelihoods (Table 2). Study demonstrated that age, gender, family size, farm income, and farm size had a significant influence on the farmers' choice of climate change adaptation techniques (Mequannt *et al*., 2020).

Trends in coffee production

In Abe Dengoro, maximum total annual coffee production was 1820.7 kg/ha in 2011, followed by 1690.5 kg/ha in 2012 and 1113.8 kg/ha in 2010 (Figure 2) and has since then the production declined.

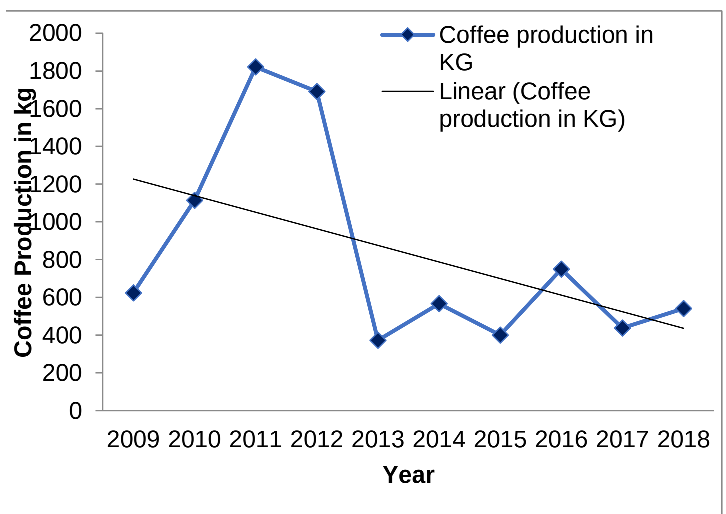


Figure 2: Coffee production trend in the Abe Dongoro district (2009-2018)

Accordingly, the productivity of coffee in the region decreased by an average of 584.91 kg/ha from 2009 to 2018. For instance, the average annual coffee production in the district from 2009 to 2013 was 1124.28 kg/ha, whereas it was 539.37 kg/ha from 2004 to 2018. This might be due to the influence of climatic variability. According to a report by the International Coffee Council (ICC, 2009), Africa's annual coffee production has dropped from 1,126.5 to 869.6 thousand tons. According to the research, production has declined in 16 countries while increasing in 9. The ICC study, which depicts a diminishing trend in African countries, and the Abe Dongoro coffee output trend are consistent.

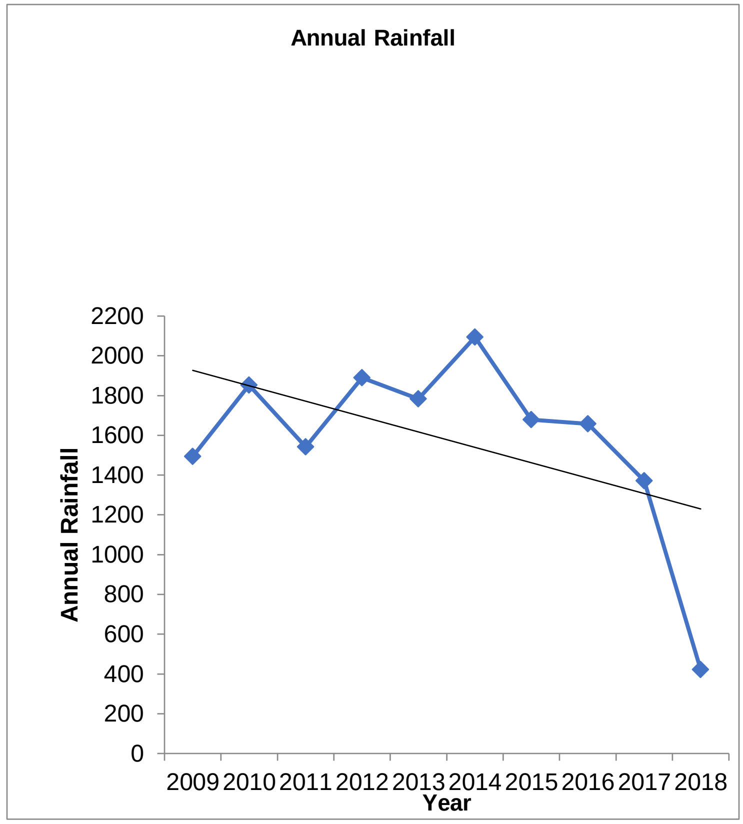
The majority of the farmers in the research region who were interviewed claimed that non-climatic reasons including a lack of agricultural inputs and insufficient extension services were to blame for the fall in coffee yield. Their opinions are in line with the findings from an analysis of the relationship between rainfall variability and coffee production in the research area. When examining the Abe Dongoro district's coffee production trend from 2009 to 2018, it indicates that output was strong in the early years (2009–2013) compared to the succeeding years from 2014–2018

Rainfall trends

The rainy season of Abe Dongoro starts in the middle of March and ends in October. On average, the warmest months are January and February, and the coolest month is August. The findings of trend analysis of rainfall data (Figure 3) demonstrate a slight fluctuation in interannual rainfall, with a downward trend for the last 10 years from 2009 to 2018 during the rainy season from March to April.. However, it was discovered that the total amount of rainfall has decreased over time. The Ethiopian National Meteorological Services Agency (NMSA) (2001) revealed that in
Ethiopia, climate variability is mainly manifested through the variability and a decreasing trend from 2009-2018 in rainfall and an increasing trend in temperature.

Fluctuations in annual rainfall occurred during the past ten periods of years (2009-2018). The highest total annual rainfall according to National Meteorology Agency records was in 2014, with the highest rainfall of 2094.3 mm. The total annual rainfall over the past ten years (2009-2018) indicated that there is a high fluctuation in rainfall (Figure 3). The highest total annual rainfall was recorded in 2014 while the lowest rainfall was obtained in 2018. Similarly, Kufa (2012) stated rainfall is highly variable, and there is no clear trend in the amount of rainfall over time in Ethiopia.

Figure 3: Annual rainfall trend in the Abe Dongoro district (2009-



2018).

Relationship between Rainfall and Coffee Production

A slight correlation was found between the amount of coffee produced (kg) and the amount of rainfall (mm) between 2001 and 2010. The line graph elaborates more on the relationship between the two variables (Figure 4).

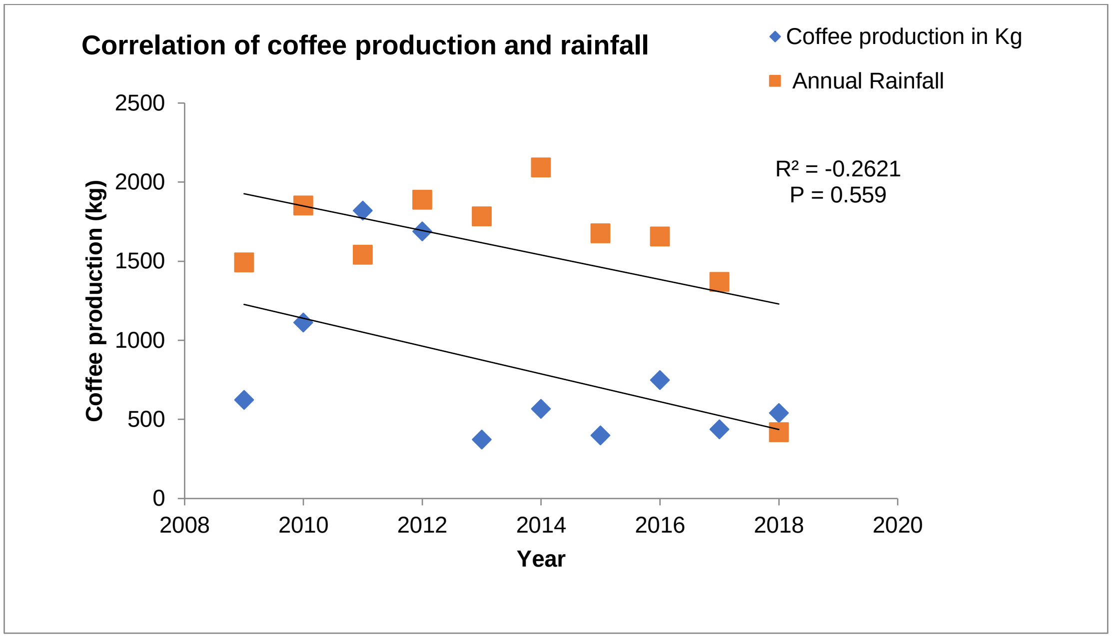


Figure 4: The relationship of coffee production in kg versus rainfall (mm).

The relationship between the amounts of coffee (kg) produced and the amount of rainfall (mm) was not statistically significant (p > 0.05). This indicates that coffee production was not greatly influenced by rainfall, but there must be some other factors which would have influence on coffee production in the study area (Table 3).

Table 3: Correlation analysis between the amount of coffee (kg) and amount of rainfall (mm)

Character	Correlation(r)	Amount of coffee	Rainfall (mm)
Amount of coffee produced (kg)	R	1	.211
	Sig. (2-tailed)		.559
	N	10	10
Rainfall (mm)	R	.211	1
	Sig. (2-tailed)	.559	
	N	10	10

On the other hand, linear regression model was employed to see the effect of the independent variable (amount of rainfall in millimeters) on the dependent variable (amount of coffee in kg). According to the results of the regression study, only 4.4% of the overall fluctuation in coffee production can be attributed to rainfall, with other factors accounting for the other 95.6%. This means that the amount of rainfall has less effect on the amount of coffee produced (Table 4).

Table 4: The regression analysis between climate variability and coffee production in Abe Dongoro District

Model	Unstandardized Coefficients		Standardized Coefficients		P value
	B	Std. Error	Beta	T	Sig.
Constant	445.097	657.739		0.677	0.518
Rainfall (mm)	0.245	0.402	0.211	0.610	0.559

Fluctuation in the temperature

The past 10 years have seen an increase in temperature, with certain months seeing bigger fluctuations in maximum and minimum temperatures than others, with their temperatures deviating significantly from the mean temperature for those months. Line graphs have been used to further explain this.

Maximum temperature changes (°C)

The two months with the biggest temperature fluctuations from 2009 to 2018 were February and March, which had significant temperature increases and drops as well as wide differences from the mean maximum temperatures for both months for the past eight years (2009–2018). Fluctuations in maximum temperature were recorded in all months of the year (Figure 5). Historical climate analysis for Ethiopia indicates that the mean annual temperature increased by 1.3°C between 1960 and 2006, with an average rate of 0.28°C per decade. Study in Ethiopia indicated that increase in temperature has been most rapid in June, August, and September at a rate of 0.32°C per decade (Kufa, 2012).

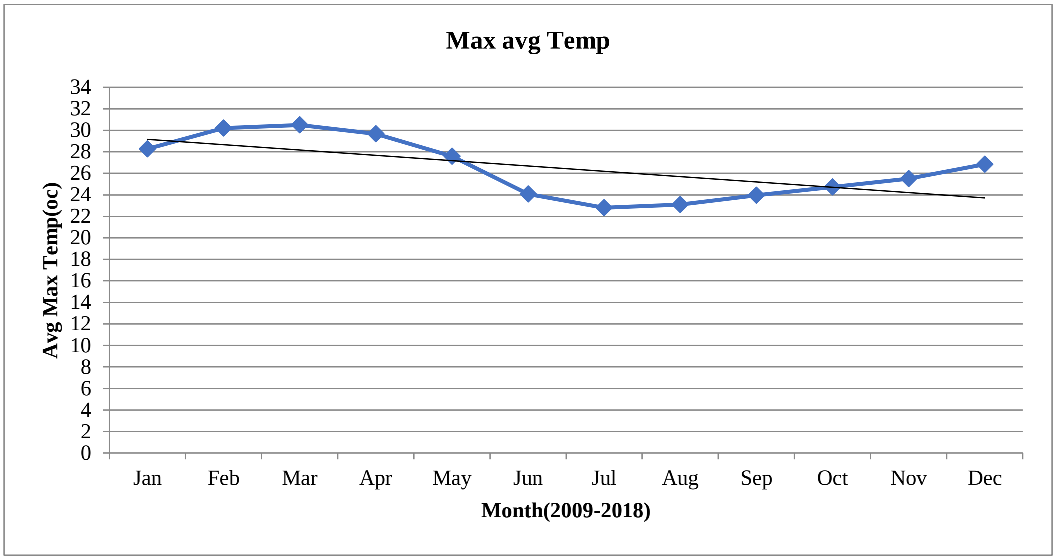


Figure 5: Changes in monthly maximum temperature of each year (2009-2018) (Source: National Meteorology Agency, Ethiopia).

The highest increases in temperature occurred in February (30.2°C), March (30.5°C), April (29.7°C), and January (28.3°C) on average from 2009-2018. The highest decreases in temperature occurred in July (22.8°C), August (23.1°C), September (24°C), and October (24°C) on average in the same years with the highest recorded temperature. The largest variations from the mean occurred in February (30.2°C) and March (30.5°C) on average in 2009-2018 (Figure 5).

Changes in minimum monthly temperatures (°C)

According to National Meteorology Agency data, the months with the most changes in monthly minimum temperatures were January and April, with large decreases and increases in temperature and variations from the mean minimum temperature (2009-2018) (Figure 6).

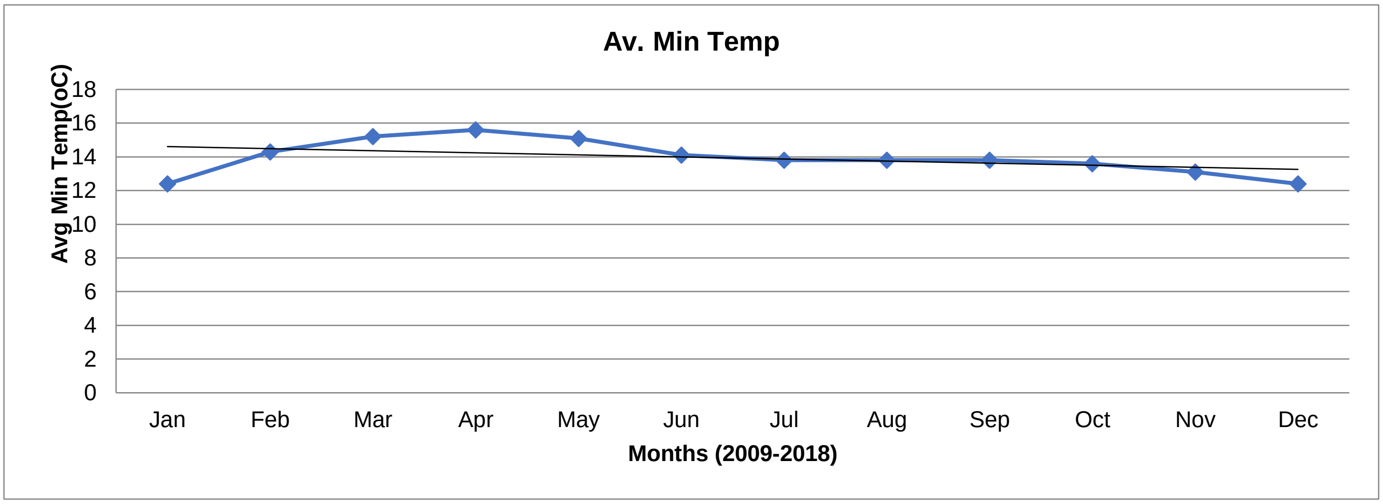


Figure 6: Changes in monthly minimum temperature of each year (2009-2018) (Source: National Meteorology Agency)

Changes in monthly minimum temperatures were recorded in all months of the years from 2009-2018, with some of these temperatures greatly varying from the mean average temperature (Figure 6). The highest minimum temperature occurred in March (15.2°C) and April (15.6°C) from 2009-2018. There was also an increase in minimum temperature in February (14.3°C) and May (15.1°C) from 2009-2018. The highest decreases in temperature occurred in December (12.4°C) and January (12.4°C) from 2009-2018. The highest variations from the mean occurred in December (12.4°C) and January (12.4°C) from 2009-2018).

Relation of temperature and coffee production

The information on average temperature was compared to information obtained from district agricultural offices about coffee production. The relationship between temperature fluctuation and coffee output was examined using a correlation analysis, and the impact of the independent variable (temperature in °C) on the dependent variable (amount of coffee in kg/ha) was investigated using a simple linear regression. Statistically, the result showed a weak relationship between the amount of coffee (kg) produced and the temperature in (°C) from 2009 to 2018 (Figure 7).

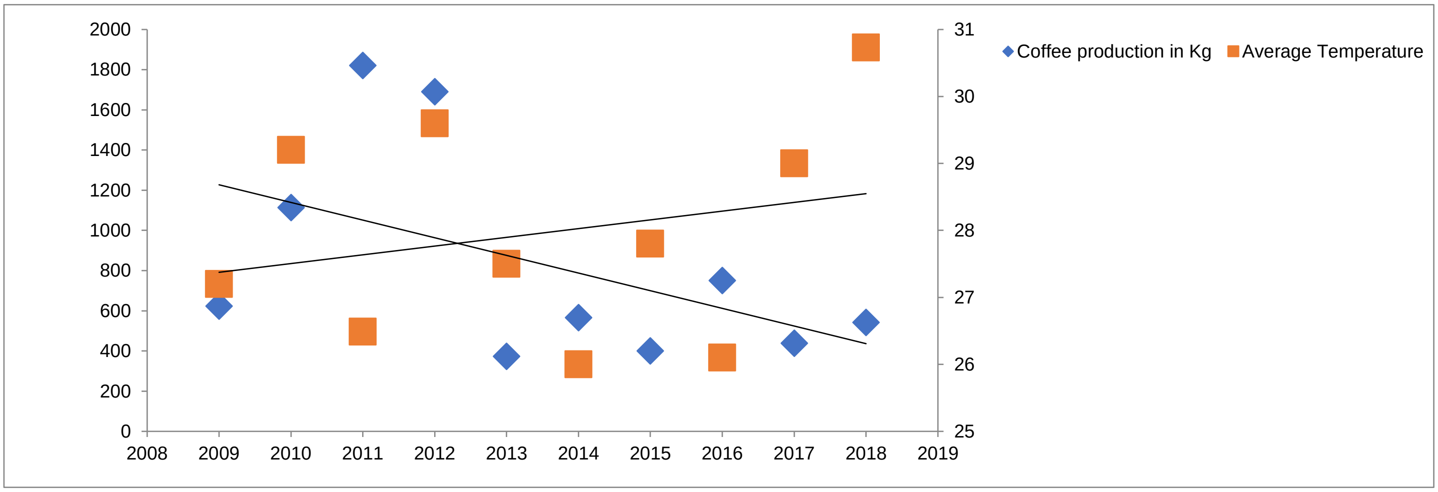


Figure 7: Relationship between average temperature and coffee production

The relationship between the amount of coffee in kilograms produced and the average temperature (°C) was not statistically significant at a 5% probability level (p = 0.628) indicating that coffee production was not much influenced by temperature, but there must be other factors and interaction (Table 5).

Table 5: The correlation between average temperature (°C) and Coffee production/Correlations

		Amount of coffee	Average temperature
Amount of coffee produced in kg	Pearson Correlation	1	0.175
	Sig. (2-tailed)		0.628
	N	10	10
Average temperature	Pearson Correlation	.175	1
	Sig. (2-tailed)	.628	
	N	10	10

To examine how the dependent variable (quantity of coffee in kg) was affected by the independent variable (average temperature in °C), a simple linear regression model was utilized. According to the regression analysis results, only 3.1% of the total variation in coffee production can be attributed to temperature, with other factors accounting for the remaining 96.9% (Table 6). The results also revealed that a change of one unit in the average temperature (°C) results in a change of 561.094 kg/ha in coffee production.

According to Camargo (2010) although the relationships between climatic parameters and agricultural production are quite complex because environmental factors affect the growth and development of the plants under different forms during the growth stages of the coffee crop. However, some climatic factors such as adverse air temperatures happened during different growth stages can reduce the productivity. Solar radiation and relative humidity influence many physiological processes of the coffee tree but are not generally thought to play an important role as thermal and rainfall conditions in defining potential yield or ecological limitations for this crop. Bongase (2017) indicated that the impact of climate variation in all producing countries is predicted to be negative, even though within each country, it would vary a lot. Temperature and rainfall conditions are considered to be important factors in defining potential coffee yield. Both factors interfere with crop phonology, growth, development and consequently in productivity and quality.

Table 6: Regression analysis results of coffee production and average temperature (°C)

Model	Unstandardized Coefficients		Standardized Coefficients		P value
	B	Std. Error	Beta	T	Sig.
Constant		22517.682		-0.467	0.653
Average temperature (C°)	561.094	1114.151	.175	0.504	0.628

From Table 6 above, the results show that if the average temperature in °C increases by a unit (1°C), coffee production will rise by 561.094 kg/ha.

Farmers' perception of climate variability

Climatic variability is may be viewed differently by varied people even within the same level. The household interviews found that farmers had a different perspective of climatic variability. Nearly half of the farmers (49.1%) attributed the lengthened dry season to shifting/erratic/rainfall as their explanation for climate variability. While 18.1% of respondents defined climate variability as an increase in temperature and a change in rainfall, the remaining respondents (32.8%) understood it as decreases in rainfall (Table 7). These respondents thought that the current temperature was higher than it had been in the past.

On the other hand, when respondents were asked about the causes of climatic variability, the majority of them cited deforestation and the deterioration of water sources as the two main contributors, along with overgrazing and other problems. A lesser proportion of respondents, nevertheless, believed that breaking the norms led to climate variability. According to empirical findings from the analysis of rainfall and temperature trends using data from the national meteorological station, farmers' perceptions of temperature and rainfall variability are comparable to those obtained from empirical studies. The total annual rainfall has been dropping over time, according to a trend analysis of rainfall data (Figure 4). The drop from 2093.3 mm in 2014 to 421 mm in 2018 was more dramatic. The IPCC report (2007), which predicted increased warmth in most of western Ethiopia, and farmers' perceptions of rainfall trends in the region are very similar. The respondents claimed that from January to April, the region had gotten warmer over the previous ten years. The majority of respondents claimed that rainfall onset had changed because it used to start in the middle of March or at the beginning of April now instead of at the beginning of March. Marengo and Antonie (2009) reported similar outcomes. Wherein a sizable number of farmers in eleven African nations said that the temperature had risen and the amount of precipitation had decreased. Similar findings were reported by Morale *et al*. (2010) other opinions expressed by the respondents focused on the lack or drying up of a few water sources in the area, including rivers, natural springs, and natural water holes, which implied changes in the amount of rainfall.

Table 7: Farmer's perceptions of climate change and variability

No.	Farmers' perceptions and climate variability	Frequency	% of response
1	Climate variability as extended dry season due to shifting rainfall	57	49.1
2	Climate variability as decreases in rainfall	38	32.8
3	Climate variability as air temperature increases	21	18.1
	Farmers' perceptions on causes of climate variability		
5	Deforestation is a primary factor of climate variability	107	92.2
6	Overgrazing is the cause of climate variability	5	4.3
7	Climate variability as a result of breaking traditional rules	4	3.4
	Total	116	100.0

Farmers adaptation strategies

In order to reduce risk and susceptibility associated with climate variability in coffee production, farmers were questioned about their management methods (coping and adaptive measures). Coping mechanisms, which are short-term solutions, are the actual reactions to the crises in livelihood systems in the face of undesirable circumstances (Smith, 2007). The use of autonomous or planned adaptation as a response by a region or a sector to changes in their means of subsistence is known as an adaptive strategy (Smith, 2007). Most of the farmers who participated in the poll were aware of the connection between climate variability and coffee production. To combat the immediate and long-term effects of climatic variability, some of them have created adaption strategies.

In the families surveyed, 63% changed a variety of behaviors in response to alleged climatic fluctuation. The most popular techniques were mulching (32.8%), terracing/contouring (6.9%) to prevent soil erosion and promote soil fertility, and planting shade trees (23.3%) to limit temperature increases brought on by direct sun ray effects. Changes in cropping and planting practices, lower consumption levels, gathering wild foods, inter household loans and transfers, increased petty commodity production, temporary and permanent migration in search of employment, grain storage, sales of assets like livestock and agricultural tools, mortgages of land, credit from merchants, and money are just a few of the traditional and modern adaptation mechanisms used in Ethiopia to deal with climate variability and extremes. In a highland agro-ecology in northwest Ethiopia, another study found that soil and water conservation techniques (26.7%) were the primary adaptive responses.

Contrarily, in lowland agro ecology, supplemental feeding for livestock (56%) was the predominant adaptation response to the unfavorable consequences of climate extremes. Farmers in highland and lowland agro ecologies, respectively, recognized scarcity of land (25.84%) and lack of water for irrigation (28.57%) as important obstacles to adaptation (Esubalew *et al*., 2023). Farmers' ability to adapt to adverse weather events was significantly influenced by agro ecology, education level, age, active labor, number of livestock, off-farm income, frequency of extension contacts, financing availability, and market access (Esubalew *et al*., 2023). In contrast, 37% of the farmers said they had no significant farming issues attributable to weather unpredictability. Because of the variations in weather occurrences, they did not employ any copying or adapting tactics. Table 8 displays the farmers in the Abe Dongoro District's use of adaption strategies.

Table 8: Farmers' adaptation strategies in Abe Dongoro district

Adaptation Strategies	Frequency	Percent (%)
Mulching to reduce evaporation	38	32.8
Planting shading trees to mitigate increased temperature	27	23.3
Contouring to avoid soil erosion	8	6.9
Nothing	43	37
Total	116	100

CONCLUSION

The result revealed that there has been variability in temperature and rainfall, and coffee production in the study area has been decreasing over the last ten years (2009-2018). The annual rainfall amount has been decreasing over time. The regression analysis indicated that that only 4.4% of the total variation in coffee production can be explained by the amount of rainfall whereas about 3.1% of the total variation in coffee production was explained by temperature. Rainfall and coffee production tending a decline over the last ten years in Abe Dongoro district. Farmers' adaptation strategies in study areas included mulching to reduce evaporation (32.8%), terracing/contouring to avoid soil erosion and to improve soil fertility (6.9%), and planting shade trees to mitigate increased temperature due to direct sun ray effects (23.3%). Generally, the findings suggest that the trend analysis of rainfall and temperature indicated fluctuation in the study area contributing influence on coffee production. Further study may be required for better conclusive result

ACKNOWLEDGEMENTS

Wallaga University funding for this work is gratefully acknowledged by the authors.

DECLARATION OF COMPETING INTEREST

The authors declare no conflict of interest.

ETHICAL APPROVAL

This study does not involve any human or animal testing.

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