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Original Research

Effects of Rainfall and Temperature Variability and Trends on Wheat Yield in Horro District, Horro Guduru Wollega Zone, Ethiopia

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Abstract

This research examined the fluctuations and patterns in precipitation and temperature between 1990 and 2025 and their impacts on wheat yield. Rainfall and temperature historical data acquired from NASA POWER and meteorological records, whereas wheat yield information for 2006–2025 sourced from the agricultural office. Furthermore, information was gathered from 145 randomly chosen wheat-producing households using questionnaires, key informant interviews, and focus group discussions. Descriptive statistics, Mann–Kendall trend evaluation, and Pearson correlation assessment applied to examine the data. The findings indicated upward patterns in maximum and minimum annual temperatures, with rates of about 0.031°C and 0.021°C each year, respectively. In comparison, yearly and seasonal precipitation displayed decreasing trends and significant fluctuations. Belg rainfall exhibited the highest variability (CV = 48.69%), followed by annual rainfall (26.20%) and Kiremt rainfall (18.43%). Wheat production showed a negative correlation with minimum temperature (r = −0.477, $p < 0.05$) and maximum temperature (r = −0.820, $p < 0.01$), whereas positive correlations were found with Belg rainfall (r = 0.823, $p < 0.01$) and Kiremt rainfall (r = 0.399, $p < 0.05$). Farmers noted rising temperatures, postponed rainfall start, premature end, and erratic rainfall patterns, which adversely impacted wheat yields. The results show that increasing temperatures along with decreasing and inconsistent rainfall are significant climatic factors affecting wheat yield in Horro District. Enhancing climate information, extension services, encouraging heat- and drought-resistant wheat varieties, and advancing soil and water management practices are crucial to boost wheat productivity and farmer resilience to climate variability.

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INTRODUCTION

Climate variability is one of the major issues impacting agricultural output and global food security, especially in developing nations (FAO, 2022; IPCC, 2023). The Intergovernmental Panel on Climate Change (IPCC, 2023) states that human-induced greenhouse gas emissions have led to a notable rise in global surface temperatures, causing alterations in precipitation patterns, a higher occurrence of extreme weather events, and escalating climate-related threats to agricultural systems. These climate changes significantly affect crop yields, especially in developing nations where farming relies largely on rainfall. Climate variability remains the pressing environmental challenge today and will persist as such in the future on a global scale (Deressa *et al*., 2025). The phrase climate change denotes a modification in the climate's condition that can be recognized by alterations in the average and/or variability of its characteristics and that lasts for a prolonged duration, usually decades or more (IPCC, 2021). It includes prolonged alterations in temperature, rainfall, atmospheric patterns, and other elements of the climate system stemming from both natural phenomena and human actions (IPCC, 2023).

Ethiopia heavily relies on agricultural sectors; agriculture mainly depends on rainfall and is extremely vulnerable to climate changes, which impacts national employment, food security, and rural livelihoods. Ethiopia is significantly impacted by climate change and variability, primarily due to human activities; agriculture accounts for about 43% of GDP, 90% of export revenues, and 80% of employment in the country. Thus, the nation's wheat output, an essential staple crop, is particularly susceptible to changes in rainfall and temperature, which directly affect its development, yield, and food security (Gebremariam *et al*., 2023). Ethiopia's population, however, surpasses 120 million, with the majority of the agricultural labor force consisting of smallholder farmers. These farmers experience decreasing wheat outputs because of erratic rainfall; extended dry periods, increasing temperatures, and severe weather phenomena like droughts and floods (Alemayehu *et al*., 2021). Recent research shows that rising temperatures, fluctuating rainfall, repeated droughts, and severe weather occurrences have negatively impacted agricultural output in various agroecological regions of Ethiopia (Abebe *et al*., 2023).

Yet, wheat production faces growing risks from climate variability, such as increasing temperatures, unpredictable rainfall patterns, and extended periods of dryness. These climatic pressures impact essential phases of wheat growth, shorten grain filling durations, heighten pest and disease occurrences, and ultimately lower yields (Alemu *et al*., 2022; Kassie *et al*., 2025). Recent research indicates that even small changes in seasonal rainfall and temperature can lead to a 10–15% decrease in wheat yields in highland regions, where the majority of wheat is grown (Bekele, 2021; Mulugeta *et al*., 2026). Nonetheless, Ethiopian farmers have traditionally utilized local coping mechanisms like crop diversification, early sowing, soil and water preservation, and agroforestry to mitigate climate-related threats (Mekonnen & Tadesse, 2019). Hence, combining local indigenous knowledge with scientific methods is crucial for the effective planning and formulation of suitable adaptation strategies.

The research area was chosen due to its significant potential for wheat cultivation, as wheat serves as a primary source of food and income both nationally and specifically in the study region. Nevertheless, no research has been carried out so far concerning this topic and within the study region. The study area is a significant producer of wheat in highland and midland regions that are predominantly impacted by climate variability. Being the main source of sustenance and income, more than 95% of Horro district's population relies on agriculture, with local farmers entirely reliant on rainfed crop cultivation.

Consequently, this research was carried out to address these gaps in the Western Ethiopia region to examine the impact of rainfall and temperature fluctuations on wheat yield. Consequently, the productivity of farmers' wheat has been fluctuating downward, resulting in food insecurity in the research region. Thus, comprehending the local aspects of climate variability (precipitation and temperature) is crucial for creating suitable adaptation strategies by enhancing the current local coping methods utilized by smallholder farmers. Nonetheless, the effects of climate change and variability on wheat production and farmers' adaptation strategies have not been thoroughly researched and recorded in the study region. This study aims to address this gap by examining the trends and variability of climate (rainfall and temperature) from 1990 to 2025 and its impact on wheat production. This study aimed to evaluate the impacts of climate variability, particularly fluctuations in rainfall and temperature patterns, on wheat yield. Additionally, the research analyzed historical patterns and present circumstances of climate factors to gain insights into their impact on wheat production in the region under investigation.

MATERIALS AND METHODS

Description of the Research Location: The research took place in the Horro district, located in the Horro Guduru Wollega Zone of Oromia, Ethiopia. The study area is situated geographically at a latitude of 9o30'0" N and a longitude of 37020'0" E, with elevations ranging from 1600m to 2800m above sea level. It is flanked by Horro Buluk and Abay Chomen to the east, Abe Dongoro to the west, Jardega Jarte to the north, and Jimma Geneti to the south. The district contains 11 rural Keble's. The capital city of the district is Shambu, situated 314 km west of Addis Ababa.

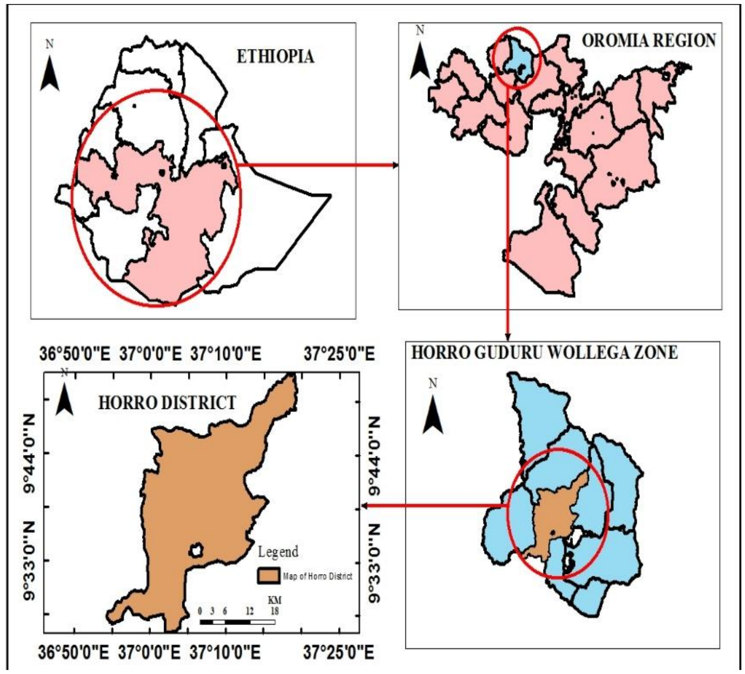

Figure 1: Map of the study area

Climate of the Study Area

The study area experiences significant and steady precipitation, varying between 1,500 mm and 2,700 mm each year. The primary rainy season, Kiremt, extends from June to September, with its peak in July and August, while a shorter season, Belg, takes place from February to April. In recent decades, significant climate changes have been observed in the Horro Guduru Wollega zone, akin to other areas in western and northwestern Oromia (unpublished HWAO data). Average temperatures differ with elevation, ranging from 12°C to 32°C. In WoynaDega (midland) regions (1,500 to 2,300 m), temperatures generally lie between 10°C and 15°C, while Kola (lowland) areas (1,000 to 1,500 m) are hotter, surpassing 20°C. The agro-ecological zones consist of Dega (20%), Woyna Dega (60%), and Kola (20%).

Topography and Soil type of the Study Area

Horro district has diverse topography, ranging from relatively flat and gently sloping areas to undulating landscapes, hills, mountains, and steep slopes, with elevations of approximately 1,500–2,800 m above sea level. Based on elevation, the district is broadly classified into Kola (lowland, <1,500 m), Woyna Dega (midland, 1,500–2,300 m), and Dega (highland, >2,300 m) agro-ecological zones. The major soil types include Nitisols, loam, clay-loam, black, and clay soils, with loamy and clay-loam soils being common. Topography and elevation influence soil formation, erosion, moisture availability, temperature, and crop suitability. The highland areas are generally cooler and favorable for wheat production, while the midland provides suitable conditions for diverse crops, and the lowland areas are relatively warmer and more exposed to moisture and heat stress. Thus, the variation in elevation, topography, and soil characteristics plays an important role in determining agricultural productivity and wheat production across Horro District (unpublished HWAO data).

Research Design

This research utilized a mixed-methods design that integrated quantitative and qualitative methods to evaluate the variability and trends of rainfall and temperature, as well as their impacts on wheat yield in the Horro District of the Horro Guduru Wollega Zone in Ethiopia. The quantitative aspect comprised the examination of historical rainfall and temperature records from 1990 to 2025 and wheat yield data spanning 2006 to 2025. The qualitative aspect is utilized to evaluate farmers' views on climate variability and its impact on wheat cultivation.

Sampling Technique and Sample Size Determination

A stratified random sampling method utilized to choose the representative sample from the entire kebeles administration and to reach the household level. These districts chosen as they are significant Wheat-producing regions and properly reflect the three agro-ecological zones of the research area. According to the agro-ecological classification of the district, the region divided into three agro-ecological zones: Highland (Dega), Midland (Woyna Dega), and Lowland (Kola) (unpublished HWAO (Horro Woreda Agricultural Office). One representative Kebele randomly chosen from each agro-ecological zone. Thus, Burkitu Abora was chosen from the highland region; Didibe Kistana from the midland region, and Rifenti Geber from the lowland region.

The sampling frame included all registered farm households that produce wheat in the chosen districts. A straightforward random sampling method used to choose sample households from the roster of wheat-producing farmers retrieved from the relevant district agricultural offices. The overall count of household heads engaged in wheat production within the chosen kebeles is 4458 (Four thousand four hundred fifty-eight) (unpublished HWAO). The necessary sample size calculated using the formula created by Kothari (2004) with a 95% confidence level and a 5% standard error. Accordingly, 145 household heads respondents as sample units selected for this research based on the above information; Proportional to sample size methods were applied to distribute the total sample size across the selected kebeles (Table 1).

Table 1. Selected Households

Kebeles	Agro Ecology	Total population	Number of HH of kebele	Number of HHs of selected	Percentage (%)
Burkitu Abora	High land	4547	1516	49	33.8
Didibe Kistana	Midland	5349	1828	60	41.4
Rifenti Geber	Lowland	3343	1114	36	24.8
	Total	**13239**	**4458**	**145**	**100%**

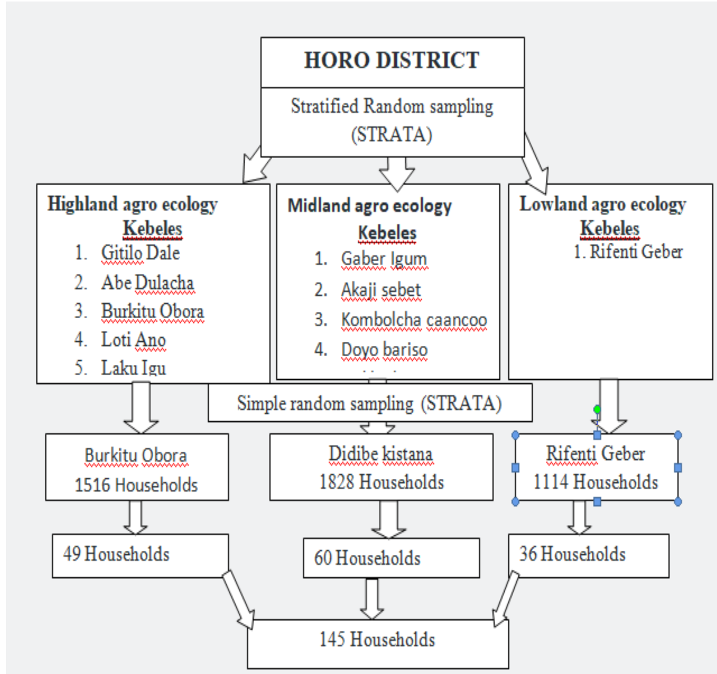

Figure 2. Represent sampling procedure and sample size for each kebele

In order to generate the necessary data for this research work, both primary and secondary sources of data have been used. The primary sources of data gathered through questionnaires, interviews and focus group discussion (FGDs) from the targeted population. Climate data include daily, monthly and annual rainfall (mm), minimum and maximum temperature (ºC) used for this study were obtained from NASA power data access viewer and Shambu Meteorological agency, recorded from 1990 to 2025, time series. Wheat yield in (kuntal) was collected for 20 years (2006 to 2025) from (Unpublished HWAO, 2025).

Questionnaire

Close ended and open-ended questions were prepared by researchers and conducted to households selected to get data about perception of local farmers about climate variability, its effects on their wheat production and adaptations practices of climate change.

Key informant interview (KII) and Focus group discussion (FGD)

Key informant interview as one of data collection methods carried out with knowledgeable and experienced experts from the word's agricultural office and DAs. The interview was carried out with a total of 10 key informants: 3 development agents (one from each kebele), 6 elder informants (two from each kebele) and 1 district crop office experts.

A focus group discussion was held with both female and male farmers representing different age groups and different education level selected from each sampled kebeles. A total of 6 focus group discussions was conducted (two FGDs in each kebele; with four participants in each focus group discussions). During the focus group discussion, the perception of farmers about climate change in the area and the change in temperature and occurrence of extreme events were given an emphasis. A participant in focus group discussions also discussed adaptation strategies being undertaken by households to the existing climate variability and change of their locality. In order to achieve the study, it was trying to interconnect sample community's responses with the actual observation and took pictures of important observations, which are actually put as exhibits to support findings.

Method of Data Analysis and Presentation

The data collected through questionnaire, FGDs and interview was analyzed using both qualitative and quantitative methods after the raw data of daily rainfall and temperature were captured in to Microsoft excel 2010 spreadsheet and processed (coded, edited and organized) to generate relevant information. Quantitative and qualitative data was organized, sorted, edited, coded and analyzed using a Statistical Package for Social Sciences (SPSS) version 20.0 computer software and Microsoft-Excel 2007 program. Quantitative data generated from structured questionnaire was analyzed by using Descriptive statistics such as frequencies, percentage, means, standard deviations and tables were used to summarize and present the result.

Trend Analysis

Man-Kendall test is a technique based on the Kendall statistics has been introduced to test for randomness against trend in climatologically time series. The non-parametric Mann Kendall test was used to detect monotonically time series trended climatic factors (temperatures and rainfall). Its statistical value (S-score) indicates that the capacity of the climate system to the long-term change of climatic factors. Therefore, Mann-Kendall trend test applied to detect the presence of trends in the rainfall and temperature records for Horro districts. A Pearson's correlation coefficient analysis was performed to determine the correlation between Wheat yield and selected climate variables.

RESULTS

Socio-demographic Profile of Respondents: From the 145 household heads surveyed, 109 (75.2%) were male and 36 (24.8%) were female. In terms of age distribution, participants under 30 years made up 9.6%, individuals aged 31–40 years accounted for 13.8%, whereas 36.6% and 40.0% fell into the age groups of 41–50 years and over 51 years, respectively. The findings show that most farmers are in their middle and older age groups. Regarding marital status, 84.8% of participants were married, while 12.4% were widowed, and 2.8% were divorced. The prevalence of married households aligns with results from recent research in rural Ethiopia, where heads of married households typically account for over 80% of respondents. Likewise, as observed through key informant interviews and Focus Group Discussions (FGDs), the study region experienced significant impacts from temperature and rainfall variability and changes (see figures 2 and 3). The educational background of participants showed that 40.7% were illiterate, while 24.1% had participated in non-formal or adult education programs. Just 18.6% had finished primary education, whereas 6.9% had achieved secondary education, 6.9% had obtained preparatory education, and 2.8% had pursued university and college/higher education. These results suggest a comparatively low level of formal education within farming households in the research region (Table 2).

Table 2. Sex, age, Family Size and Marital status of respondents

Variables		**F**	**Percent (N= 145)**
Sex	Male	109	75.2
	Female	36	24.8
Age in year	Below 30	14	9.6
	31-40	20	13.8
	41-50	53	36.6
	Above 51	58	40.0
Family Size (members)	1 to 3	26	17.9
	4 to 7	52	35.9
	8 to 10	45	31.0
	11 to 15	18	12.4
	Above 15	4	2.8
Marital Status	Married	123	84.8
	Divorced	4	2.8
	Widowed	18	12.4
	Non-educated	59	40.7
Educational Level	Adult education	35	24.1
	Attended primary school	27	18.6
	High school	10	6.9
	Preparatory school	10	6.9
	Higher institution	4	2.8
	Non-educated		75.2

Land holding and average distance from the respondents

In the present study, the majority of respondents (93.1%) reported owning agricultural land, while only 6.9% indicated that it was landless. But by rented and benefit share they produce wheat. The findings further revealed that 45.5% of households owned between 2 and 4 hectares of land, making it the dominant landholding category in the study area. In contrast, 27.6% of households possessed less than 1 hectare, 15.9% owned between 4 and 6 hectares, and only 4.7% had more than 6 hectares of agricultural land. These results suggest that although most households have access to farmland, landholding sizes vary considerably among farmers. Regarding the distance of farmland from homesteads, the survey results indicated that 42.8% of households cultivated plots located 1–2 km from their homes, representing the largest proportion of respondents (Table 3).

Table 3. Landholding and distance of farm in KM from their homestead

Variables	**Frequency**	**Frequency**	**Percent (N=145)**
Landhonding	landless	9	6.2
	<1hac	40	27.6
	2-4 hac	66	45.5
	4-6 hac	23	15.5
	>6 hac	7	4.8
Average distance from farms	1-2km	62	42.8
	3-4km	50	34.5
	5-6km	25	17.2
	6-7km	8	5.5

Source: own Survey, 2025

Institutional Factors: The findings show that a majority of surveyed households, 86.9%, had access to agricultural extension services, while

13.1% did not, which offer various activities like training and demonstration trials that can either boost or reduce wheat production. Additionally, approximately 79.3% had access to climate information, whereas 20.7% did not. These services enhance understanding of emerging agricultural technologies and environmental changes, shaping farmers' views and choices regarding wheat production technology. Access to credit is essential for resource-limited farmers, allowing them to invest in agricultural technologies and management practices that improve farm returns on wheat production. Of the respondents, 29% indicated they had access to credit services, whereas 71% did not (Table 4).

Table 4: Sampled households' access to institutional information

Variable	Responses	Frequency	Percentage
Access to extension services	Yes	126	86.9
	No	19	13.1
Access to Climate Information	Yes	115	79.3
	No	30	20.7
Access to Credit Service	Yes	40	29.0
	No	103	71

Agricultural Practice and Farming System of the Respondents

The majority of respondents (66.2%) engaged in crop rotation, while approximately 19.3% practiced mono cropping. They lack experience in mixed cropping or integrating one or more farming systems across three agro-ecological zones. Survey results indicate that 95.2% of participants engage in Rainfed agriculture, while merely 4.8% have recently implemented irrigation agriculture (Figures 3 and 4).

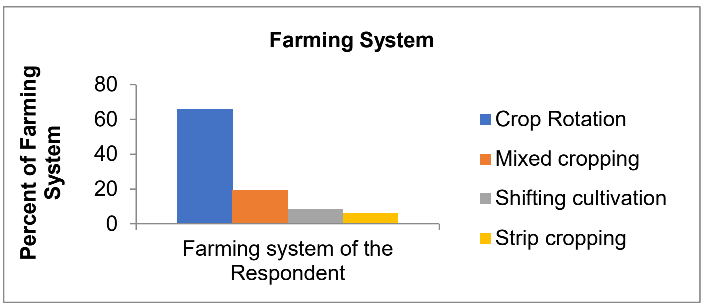

Figure 3. Graphical representation of farming system of respondents

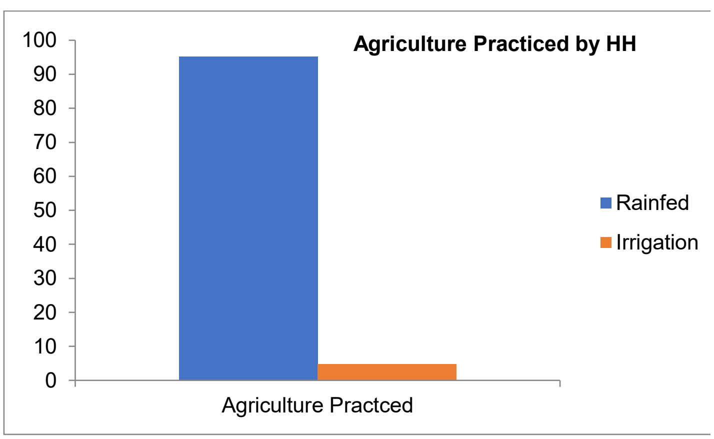

Figure 4. Graphical representation of agricultural practice of respondents

Farmers' perceptions of rainfall and temperature variability in the study area

As studied, about 33.8% and 45.7% of the respondents perceived an increment in the level of rainfall and temperature respectively while about 13.1% and 7.6 % of the respondents had perceived a reduction in the level of the rainfall and temperature respectively (Table 5).

Table 5. Farmer's perception of climate variability in study area

Variables		Frequency	Percent (N=145)
Farmers Perception	Decrease in Rainfall	11	17.6
	Increase in rainfall	19	933.8
	Increase in Temperature	49	645.7

Variability in the Timing of Rain Observed by Farmers in the Horro District

The farmers' observations of climate variability in timing of rain in the study area identified as in Table 6, show that mostly about 60 of the respondents (41.4%) said that rainfall comes and goes early. Similarly, about 38 of the respondents (26.2%) of the total identified specific patterns in timing of rainfall comes early and goes late while 47 of the respondents (32.4%) responded as it comes late and goes early. The remaining 32.4% of respondents revealed that there are changes in timing rainfall came late and goes early. On the other hand, 41.4% of the respondents perceived the timing of rainfall comes and going early (table 6).

Table 6. Table Indicator of climate variability (rainfall and temperature) in the timing of rain

Variables		Frequency	Percent
Indicator of Climate Variability	Comes early and goes late	38	26.2
	Comes late and goes early	47	32.4
	Comes and goes early	60	41.4

Trend of Annual Rainfall and Temperature Variability of the Study Area

The study area exhibited considerable fluctuation, according to an analysis of yearly rainfall data from 1990 to 2025. There were significant variations over time, with rainfall levels ranging from a low of 816.06 mm in 2002, the driest year, to a high of 2,648.32 mm in 1996, the wettest year. The rainfall variability was further demonstrated by the average annual rainfall of 1,710.75 mm over this time, with a standard deviation of 448.2 mm. An 8.6 mm annual drop in rainfall was found by trend analysis, indicating a slow reduction in the availability of rainfall. Furthermore, 16 of the 36 years (44.5%) had annual rainfall below the long-term average, indicating that drier years are becoming more common (see Figure 7).

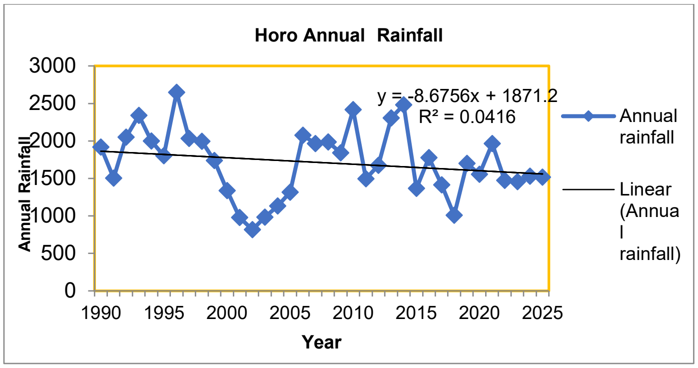

Figure 7. Annual rainfall trend of the study area

Seasonal Rainfall Variability and Trend Analysis

Analysis of seasonal rainfall during the period 1990–2025 revealed substantial start annual variability in both the Belg and Kiremt rainfall seasons. Among the 36 years analyzed, Belg and Kiremt rainfall were below their long-term averages for 17 and 15 years, respectively, indicating frequent occurrences of seasonal rainfall deficits. Kiremt rainfall ranged from 559.7 mm to 1951.22 mm, with a mean of 1315.57 mm, and a standard deviation of 242.40 mm. Belg rainfall exhibited a wider relative fluctuation, varying between 95.99 mm and 572.9 mm, with a mean of 286.41 mm and a standard deviation of 139.44 mm. Trend analysis further showed a declining tendency in both rainy seasons with Kiremt rainfall decreasing by 3.62 mm year^{-1} and Belg rainfall decreasing by about 3.37 mm year^{-1} over the study period. The decline trend in Kiremt rainfall could be the main cause for decreasing of annual rainfall because Kiremt rainfall contributes the largest share of annual rainfall and supports the main cropping season in Ethiopia (Figure 8).

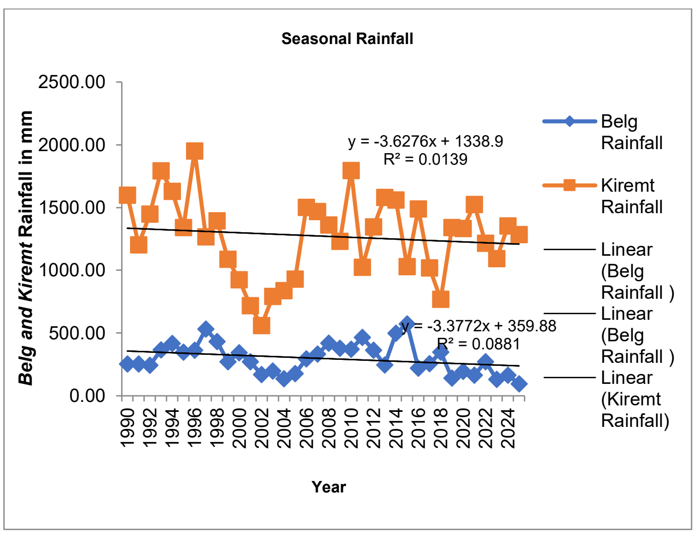

Figure 8: *Kiremt* and *Belg* rainfall trends of the study area

The coefficient of variation analysis further demonstrated that Belg rainfall (CV = 48.69%) was highly variable, whereas annual rainfall (CV = 26.20%) and Kiremt rainfall (CV = 18.43%) were moderately variable. This indicates that Belg rainfall is considerably less reliable than Kiremt rainfall and contributes more to seasonal climate uncertainty. Wheat growth depends heavily on the timing, amount, and distribution of rainfall during the growing season. Increased rainfall variability can lead to delayed planting, moisture stress during critical growth stages, reduced yields, and greater production uncertainty.

Table 7. Coefficient of Variance

Rainfall	Mean Rainfall (mm)	CV (%)
Annual	1 7 1 0 . 7 5	26.20
Kiremt		18.43
Belg		48.69

Annual Temperature Variability

Annual temperature variation is typically assessed by observing daily, monthly, and yearly maximum and minimum readings. The Bega period is the warmest time of year, while the Kiremt season is the coolest. The hottest year was 2003, recording a temperature of 36.01°C in May, and the coldest year was 1999, which saw 22.12°C in July. The yearly average maximum temperature in Horro District varied from 26.57°C in 1991 to 30.98°C in 1997. Trend analysis also revealed a rising rate of approximately 0.031°C annually over the last thirty years, demonstrating a steady warming trend in the research area (Figure 9 and Table 7).

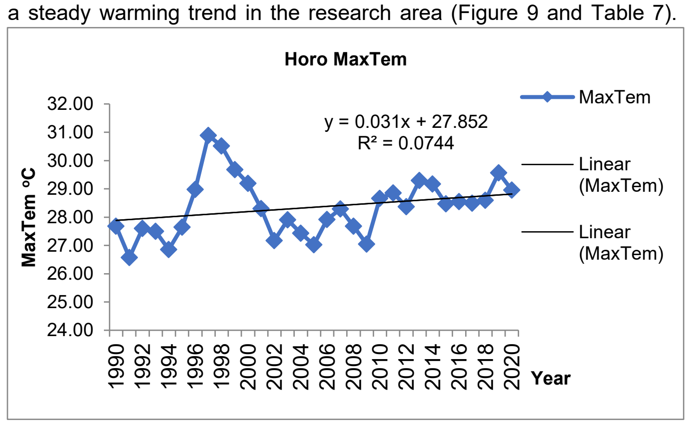

Figure 9. Trends of annual maximum temperature

As illustrated in Figure 10, the average yearly minimum temperature in the research area varied between 10.88°C and 12.97°C throughout the study duration. The minimum values noted in 1994 and 1999 were 22.51°C and 22.12°C respectively, whereas the maximum values observed in 2003 and 2024 were 36.01°C and 35.54°C respectively. This could be attributed to climate change caused by human actions such as fossil fuel combustion and ozone layer degradation; the warming trend observed in this study correlates strongly with wider regional and national data that show a consistent rise in nighttime temperatures, which is exacerbating climate stress in agricultural systems. In general, the rising pattern of 0.021°C annually in minimum temperature indicates that the study region is undergoing slow yet steady warming that could have lasting effects on wheat cultivation.

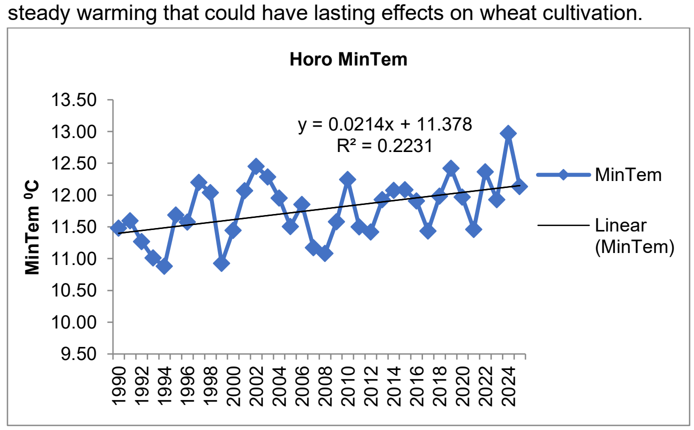

Figure 10. Trends of annual minimum temperature

Seasonal Temperature Variability and Trend Analysis

In this research, the Kiremt minimum temperature varied between 11.48°C and 14.59°C, whereas the Belg minimum temperature fluctuated from 7.61°C to 14.28°C, demonstrating a distinct warming trend throughout the study duration. Trend analysis also indicated a steady rise in seasonal minimum temperature, with annual rates of approximately 0.023°C for Belg and 0.0232°C for Kiremt during the last thirty years (Figure 11).

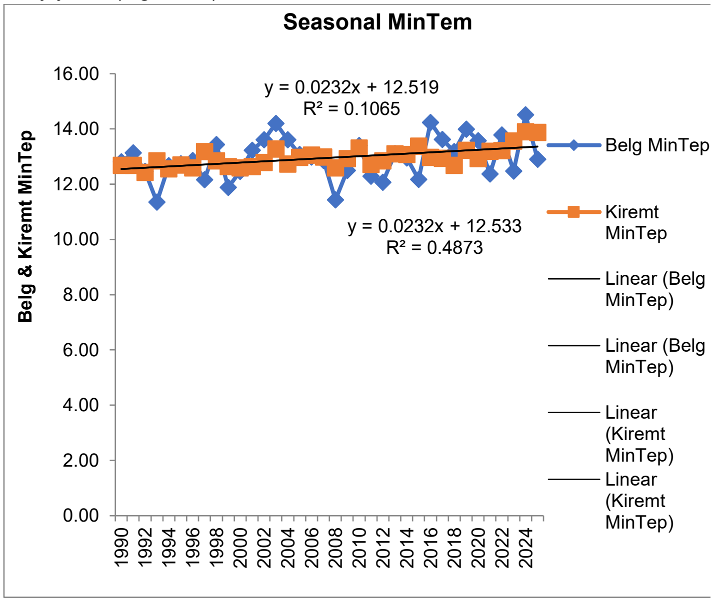

Figure 11. Seasonal Belg and Kiremt minimum temperature variability (1990-2025).

Trend analysis also indicated a rising trend in seasonal maximum temperature, reporting increases of approximately 0.066°C annually for Belg and 0.0428°C yearly for Kiremt during the last thirty years. The noted increase in maximum temperature variability during the Kiremt season relative to Belg aligns with recent research indicating that seasonal temperature variability is rising in the highland agro-ecologies of the region due to intricate interactions among elevation, land use changes, and regional climate factors. This variability leads to unpredictable growing conditions, heightened pest and disease threats, and diminished effectiveness of wheat growth mechanisms. Consequently, the results indicate that the increase in maximum temperature is a significant climatic constraint impacting wheat productivity, potentially due to heightened evapo-transpiration and increased water stress affecting wheat yield (Figure 12).

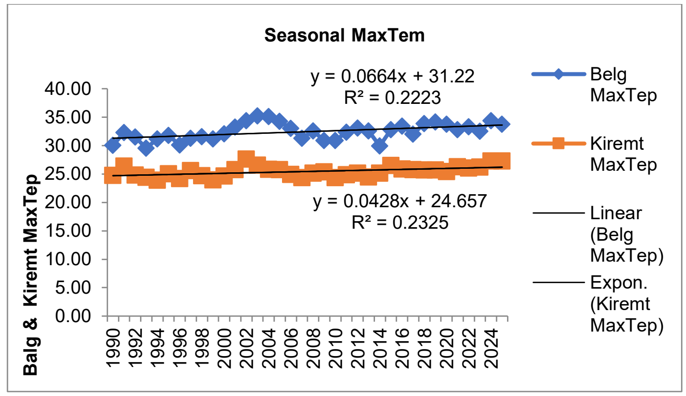

Figure 12. Seasonal *Belg* and *Kiremt* maximum temperature variability for the study area (1990-2025).

Trend evaluation of Seasonal Belg and Kiremt maximum temperature fluctuations in the study area indicated values of 0.232°C and 0.222°C, respectively, revealing a rising trend in seasonal maximum temperatures, with annual increases of approximately 0.066°C for Belg and 0.0428°C for Kiremt over the last thirty years. The noted increased variability of maximum temperature in the Kiremt season relative to Belg. This variability leads to inconsistent growth conditions, heightened pest and disease challenges, and diminished efficiency in wheat production (Figure 12).

Effect of Temperature and Rainfall Variability on Wheat Production

Respondents identified climate variability as a major constraint impacting wheat production, suggesting that farmers are significantly susceptible to fluctuations in temperature and rainfall patterns. Participants indicated that rising climate variability impacts wheat production by causing inconsistent rainfall patterns, temperature changes, and alterations in the timing of seasonal rain, all of which can interfere with the typical phenological growth of wheat. Focus group discussions indicated that farmers have noticed a reduction in the duration of the rainy season, a delay in the start of rainfall, and a rise in irregularity in rainfall patterns. These alterations are especially harmful to wheat cultivation since the plant needs sufficient and evenly spread rainfall during both the vegetative and reproductive phases to attain maximum growth and yield. As a result, variations in the timing, quantity, and distribution of rainfall can negatively impact wheat growth and ultimately decrease wheat yield. The study also identified that 44.8% of respondents perceived a highly decreased productivity in annual wheat production associated with rainfall and temperature variability, while 40.7% reported decreasing wheat yield per hectare (Table 8).

Table 8: Major effects of climate variability on wheat production ranked by respondents

Variables	Reduced productivity		Reduced yield		Increased diseases and pests		Reduced seeding area	
Degree/level explain	NR	%	NR	%	NR	%	NR	%
A	65	44.8	59	40.7	51	35.2	43	29.7
B	52	35.8	45	31	62	42.8	52	35.8
C	18	12.4	32	22	28	19.3	28	19.3
D	10	6.9	9	6.2	4	2.8	22	15.2
Total (N=145)								

N=Number, NR =Number of respondents

Note: A stands for highly decreased; B stands for moderately decreased; and C stands for low decrement and D stands for extremely very low decrement

Pearson's Correlation Analysis between the Wheat Yield and Climate Variability

Based on Table 9, the Pearson correlation analysis indicates that minimum temperature has a negative association with wheat yield, suggesting that increases in minimum temperature may adversely affect wheat productivity for the period 2006–2025 shows statistically significant relationships between climate variability and wheat productivity. The results indicate that wheat yield has a significant negative relationship with minimum temperature (r = −0.477*) and a strong negative relationship with maximum temperature (r = −0.820**). In contrast, wheat yield shows a statistically significant positive relationship with Belg rainfall (r = 0.823**) and Kiremt rainfall (r = 0.399*). The strong negative correlation between maximum temperature and wheat yield is consistent with recent agronomic and climate impact studies in Ethiopia and similar agro-ecological regions (Table 9).

The positive but relatively weaker relationship between Kiremt rainfall and wheat yield suggests that rainfall during the main growing season is also important for wheat productivity. However, unlike moderate and well-distributed rainfall, excessive or poorly distributed Kiremt rainfall may negatively affect production through waterlogging, delayed harvesting, and increased incidence of crop diseases. These factors may explain the comparatively weaker correlation observed between Kiremt rainfall and wheat yield. Overall, the findings presented in Table 9 suggest that temperature and rainfall are important climatic determinants of wheat productivity in the study area. Increasing minimum and maximum temperatures tend to exert negative effects on wheat yield, whereas rainfall generally has a positive influence, although its effect depends strongly on its amount, timing, and distribution across the growing seasons.

Table 9. Correlation Coefficient between wheat yield and Climate Parameters

Parameters		Minimum Temperature	Maximum Temperature	Belg Rainfall	Kiremt Rainfall	N=20
Minimum Temperature	r	1				
	Sig.	-				
Maximum Temperature	r	.467*	1			
	Sig.	.019	-			
Belg Rainfall	r	-.431*	-.883**	1		
	Sig.	.029	.000	-		
Kiremt Rainfall	r	.062	-.481*	.505*	1	
	Sig.	.397	.016	.012	-	

*Correlation is significant and **Correlation is significant at the 0.01 level, r= correlation

DISCUSSION

The results show that most of the surveyed households were led by males, with a significant portion of the respondents being middle-aged and older farmers. This trend indicates that farming decisions in the research area are mostly dominated by male heads of households and seasoned farmers. The dominance of male-headed households aligns with observations from western Ethiopia, where over 70% of surveyed households indicated being male-led, mirroring the dominant gender hierarchy in rural agricultural societies (Abebe *et al*., 2023; Tesfaye & Seifu, 2023). The significant percentage of middle-aged and older farmers might also have crucial effects on wheat production and climate adaptation. Farmers who have spent more years in agriculture are more prone to possess knowledge about local weather patterns, crop management methods, and indigenous adaptation techniques. This experience can improve their skill in identifying variations in rainfall and temperature and reacting with insights learned from past climate occurrences. This rationale aligns with research indicating that agricultural experience and gathered local insight affect farmers' views on climate variability and their choices to implement adaptation strategies (Alemayehu & Bewket, 2017; Asfaw *et al*., 2021).

Educational achievement is another significant element that could impact farmers' capability to react to climate-related shifts in wheat production. The results indicate that restricted access to formal education continues to pose a challenge for agricultural progress and efficient adaptation to climate change in the research area. Farmers with less education might encounter limited chances to access, comprehend, and utilize information related to enhanced agricultural technologies, climate data, and different crop management methods. This might diminish their ability to react efficiently to shifting rainfall patterns and other climatic pressures impacting wheat production, as indicated by the studies of Belay *et al*. (2022) and Mekonnen *et al*. (2023).

On the other hand, greater levels of education can enhance farmers' capacity to comprehend climate data, assess different technologies, and make well-informed production choices. As stated by Belay *et al*. (2022) and Tessema *et al*. (2022), knowledgeable farmers are consequently more inclined to embrace enhanced crop varieties, soil and water conservation practices, and climate-resilient agricultural technologies. The allocation of land ownership also offers significant understanding of the production circumstances in the study region. The comparatively larger landholdings found in the sampled households, in contrast to the typically small farm sizes reported on a national scale, could give some farmers more flexibility to distribute land across various crops and implement soil and water management techniques. Nonetheless, the ongoing division of agricultural land poses a possible limitation to sustainable production. The rise in population and heightened demand for land resources have led to smaller farm sizes and land fragmentation in numerous regions of Ethiopia. This fragmentation may restrict economies of scale, make farm management more challenging, and diminish farmers' ability to invest in sustainable long-term land-management practices (Berhanu & Fekadu, 2023).

The gap between farmers' residences and their farming fields is another element with possible effects on wheat output and climate adaptation. Longer distances enhance the time and effort needed to access farmland and can elevate transportation expenses (Gizachew *et al*., 2023). These obstacles can postpone crucial agricultural tasks, such as land preparation, planting, weeding, applying fertilizers, and implementing soil and water conservation efforts. Holds in these operations can become especially challenging during inconsistent rainfall scenarios, as farmers frequently must perform field tasks during a limited period of favorable weather and soil conditions. This discovery aligns with the findings of Gebremedhin *et al*. (2021) who indicated that increased distances between residences and agricultural land may hinder prompt farm management.

Additionally, the closeness of agricultural land to the home might promote increased investment in climate adaptation and sustainable land management according to (Orkaido, & Gashure, 2026). Farmers with fields near their residences can observe their crops more often, react swiftly to developing weather and crop issues, and lower the labor and transport expenses tied to farm operations. As a result, families residing close to agricultural land might be more capable of implementing climate-smart farming technologies and funding soil and water conservation methods. This aligns with the results of Asfaw *et al*. (2022) and Tessema *et al*. (2024), suggesting that reduced monitoring and management expenses linked to proximate farmland can enhance farmers' readiness and ability to invest in sustainable agricultural practices. The socioeconomic traits of households, such as the gender and age of heads, level of education, farming experience, size of landholdings, and distance from homes to farm plots, significantly influence wheat production and farmers' ability to adapt to climate changes.

In the study region, declining rainfall trends and rising rainfall variability in numerous areas have led to heightened production risks for smallholder farmers regarding wheat yield. Multiple research efforts carried out in western Ethiopia have similarly recorded rainfall patterns. For example, Tufa *et al*. (2022) found a decrease in annual rainfall and an increase in rainfall variability in the Oromia Region. The increased variability seen in Belg rainfall relative to Kiremt rainfall aligns with the findings of Ayalew *et al*. (2022), who indicated that Belg rainfall shows greater temporal variability than Kiremt rainfall because of its significant sensitivity to large-scale atmospheric circulation patterns. Similarly, the reduction in Kiremt rainfall noted in this study aligns with observations from western Ethiopia, where diminishing Kiremt rainfall has been associated with lower soil moisture levels and decreased wheat yield (Mekonnen *et al*., 2023).

Climate factors, especially rainfall and temperature, exhibited significant annual variations in the research region from 1990 to 2025. Rainfall variability was greater during the Belg season compared to the Kiremt season. This result aligns with Tadesse *et al*. (2022), who indicated that Belg rainfall variability surpassed 40% in various regions of Ethiopia, whereas Kiremt rainfall variability typically remained under 25%. In a similar manner, Belay *et al*. (2022) discovered that Belg rainfall exhibited the greatest coefficient of variation among Ethiopia's primary rainfall seasons, rendering it especially susceptible to climate fluctuations and drought. These variations introduce unpredictability in agricultural strategies and may adversely impact wheat yields, especially in rain-dependent farming systems.

The temperature assessment additionally showed a distinct warming trend in the research region. The typical yearly minimum temperature rose by around 0.021°C annually throughout the research period, signifying ongoing warming. This result aligns with Asfaw *et al*. (2022), who noted yearly temperature rises of 0.02–0.05°C annually in northwestern Ethiopia, and possibly, Gebremariam *et al*. (2023), who recorded notable increases in maximum and minimum temperatures in western Oromia. Likewise, Tadesse *et al*. (2023) noted rising minimum temperatures in the Ethiopian highlands and associated this warming with decreased crop productivity and heightened vulnerability of rain-fed agriculture. National climate evaluations also reveal substantial rises in maximum temperatures throughout Ethiopia (Gizachew *et al*., 2023).

Rising temperatures significantly affect wheat production. Elevated temperatures can boost evapotranspiration, speed up crop growth, reduce the grain-filling duration, and heighten heat stress, especially during the flowering and grain-filling stages. These impacts can decrease biomass growth and grain development, ultimately leading to reduced wheat production. The effect is particularly intense in rain-fed situations, where heat stress frequently coincides with insufficient or erratic rainfall (IPCC, 2021; IPCC, 2022; FAO, 2022). The results from focus group discussions additionally reinforce the noted climatic patterns. Farmers observed a reduction in the length of the rainy season, late start of rainfall, premature ending of rain, and greater unpredictability in rainfall distribution. These findings align with meteorological evaluations that show alterations in the timing of rainfall beginning and ending in Ethiopia, especially in the Kiremt season, potentially reducing the effective duration for crop growth (IPCC, 2021). The findings suggest that the region under study is witnessing rising temperatures and more variable rainfall patterns. These alterations present considerable threats to wheat production by elevating moisture and heat stress, while also diminishing the stability of crop yield and growth. Consequently, enhancing farmers' access to climate data, advocating for heat- and drought-resistant wheat varieties, reinforcing soil and water conservation, and broadening climate-smart agricultural methods are crucial approaches for sustaining wheat yields amid shifting climatic circumstances.

CONCLUSION

The research finds that climate fluctuations have greatly impacted wheat yield in Horro District between 1990 and 2025. The findings indicate a distinct increase in both minimum and maximum temperatures, whereas precipitation has turned more erratic and has generally decreased, especially during the Belg and Kiremt seasons. Rising temperatures adversely impacted wheat yield, while sufficient and evenly distributed rainfall positively influenced productivity. Farmers reported late rainfall onset, premature termination, and rising irregularity in rainfall, corroborating the noted climatic patterns. In general, fluctuations in climate represent a significant risk to wheat yields in the research region. Enhancing access to climate data, drought- and heat-resistant wheat varieties, extension services, and climate-smart practices for soil and water management is vital for maintaining wheat production and boosting food security.

Availability of data and Material

The corresponding author can provide the raw data that was gathered and used to support the study's conclusions upon reasonable request.

Conflict of Interest

The authors declare that there is no conflict of interest concerning this manuscript.

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