CLIMATE CHANGE AND VARIABILITY TRENDS AND SMALLHOLDER FARMERS' PERCEPTIONS IN THE JEMMA SUB-BASIN, UPPER BLUE NILE, ETHIOPIA

Abirham Cherinet[1*,2], Belay Simane[3], Abraham Mebrat Asmare[1]
and Tesemash Abebe[2]

[1]*Institute of Disaster Risk Management and Food Security Studies, Bahir Dar University, P.O. Box 79, Bahir Dar, Ethiopia*
[2]*Ethiopian Forestry Development, P.O. Box 33042, Addis Ababa, Ethiopia*
[3]*College of Development Studies, Addis Ababa University, P.O. Box 1176, Addis Ababa, Ethiopia*
**Corresponding author email: aberham2010@gmail.com*

Received: 28th May 2025, **Accepted:** 17th October 2025

ABSTRACT

Climate change and variability have significantly impacted smallholder and subsistence farmers in Ethiopia. The effectiveness of adaptation measures largely depends on how farmers perceive climate change and variability. Hence, understanding their perception and comparing it with long-term trends is crucial for designing appropriate responses. Thus, this study examined climate parameters and smallholder farmers' awareness of climate change in the Jemma sub-basin. A total of 366 households were randomly selected from highland, midland, and lowland kebeles. Quantitative and qualitative data were collected through household surveys, focus group discussions, and key informant interviews. Grided monthly precipitation and temperature data were obtained from the Ethiopian Meteorology Institute. The Mann–Kendall test and Sen's slope estimator were employed to examine the time series trends of rainfall and temperature. The MK trend test results revealed that yearly and summer season rainfall exhibit a non-significant increasing trend, while spring season rainfall shows a decreasing trend. The coefficient of variance shows that the monthly and spring season rainfall shows the highest variability (CV>30 %), while the annual rainfall shows less variability. Similarly, the mean annual, maximum, and minimum temperatures show an increasing trend. Consequently, about 83.47 % of highland, 91.54 % of midland, and 100 % of lowland respondents feel the temperature rise, and 44.62 %, 66.2 %, and 100 % of highland, midland, and lowland respondents recognized the decreasing rainfall trend, respectively. The analysis result reveals that age, gender, access to climate information, education, farming experience, and market access significantly influence perceptions of temperature and rainfall trends. Therefore, farmers' perceptions should be integrated into meteorological data analysis, and policymakers should consider these disparities when developing climate adaptation strategies.

Keywords: Climate variability, temperature trend, rainfall trend Mann-Kendall Test, coefficient of variation

INTRODUCTION

Climate change is one of the most pressing challenges of the 21st century, affecting ecosystems, economies, and societies worldwide (Abidoye & Odusola, 2015; IPCC, 2014). It is driven by both natural variability and human-induced greenhouse gas emissions, leading to shifts in temperature and precipitation patterns (Cavan & Hare, 2016). The increasing frequency of extreme weather events such as droughts and floods poses significant risks, particularly for vulnerable populations in developing countries. Compared to developed nations, developing countries face disproportionate impacts from climate change and extreme weather events because they have limited income opportunities and less adaptive capacity (Asfaw *et al.*, 2021; Likinaw, 2023). Smallholder farmers who heavily rely on natural ecosystems for agriculture in these countries are particularly susceptible to the impacts of climate variability (Abbas *et al.*, 2023; Dechassa *et al.*, 2017; FAO, 2017).

Ethiopia is highly vulnerable to climate change due to its dependence on rain-fed agriculture, which supports the livelihoods of millions (IPCC, 2007). Over the past few decades, the country has experienced rising temperatures and erratic rainfall, with reports indicating a 0.37 °C increase in temperature and a declining rainfall trend since the 1990s (Abebe, 2017; NMA, 2007). Even minor shifts in these climatic parameters can have profound effects on food production, exacerbating food insecurity and economic instability (Taye *et al.*, 2019; Tesfaye *et al.*, 2019). Agricultural productivity in Ethiopia has been directly impacted by climate variability. Historical drought events, such as the 1983/84 crisis, caused severe reductions in GDP (-9.7 %) and agricultural output (-21 %), highlighting the country's vulnerability. However, the effects of climate change are often regional or local and need to be examined on a case-by-case basis (IPCC, 2022). Studies on climate change trends and smallholder farmers' perception across Ethiopia's, revealing inconsistencies (Chemeda *et al.*, 2023; Debela *et al.*, 2015; Deressa *et al.*, 2011; Mekasha *et al.*, 2014; Mengistu *et al.*, 2014; Sorecha, 2017; Tamiru *et al.*, 2015). However, broad-scale assessments and inconsistencies of results affects the effective implementation of adaptation. In addition, perceived changes may not always reflect reality, and climatic events or trends may be misinterpreted or wrongly remembered for a variety of reasons. Therefore, it is necessary to assess and analyze farmers' perception of climate change and variability, and what climate data really shows.

The Jemma sub-basin, an agriculturally significant region (Mare *et al.*, 2024; Temeche *et al.*, 2021) and a major contributor to the Upper Blue Nile basin's water flow (Yilma & Awulachew, 2009), faces unique and compounded challenges. High population density (106 persons/km²) and poor land management practices have led to severe soil erosion, making the area highly susceptible to climate-related hazards (Tesso *et al.*, 2012). However, smallholder farmers in the Jemma sub-basin are facing climate change hazards and weather-related impacts. Over the past three decades, climate variability has been an issue with an increase in precipitation and temperature extremes (Worku *et al.*, 2018), which has a significant negative impact on crop production (Alemayehu & Bewket, 2016; Gonfa *et al.*, 2022). As a result, it is crucial to investigate

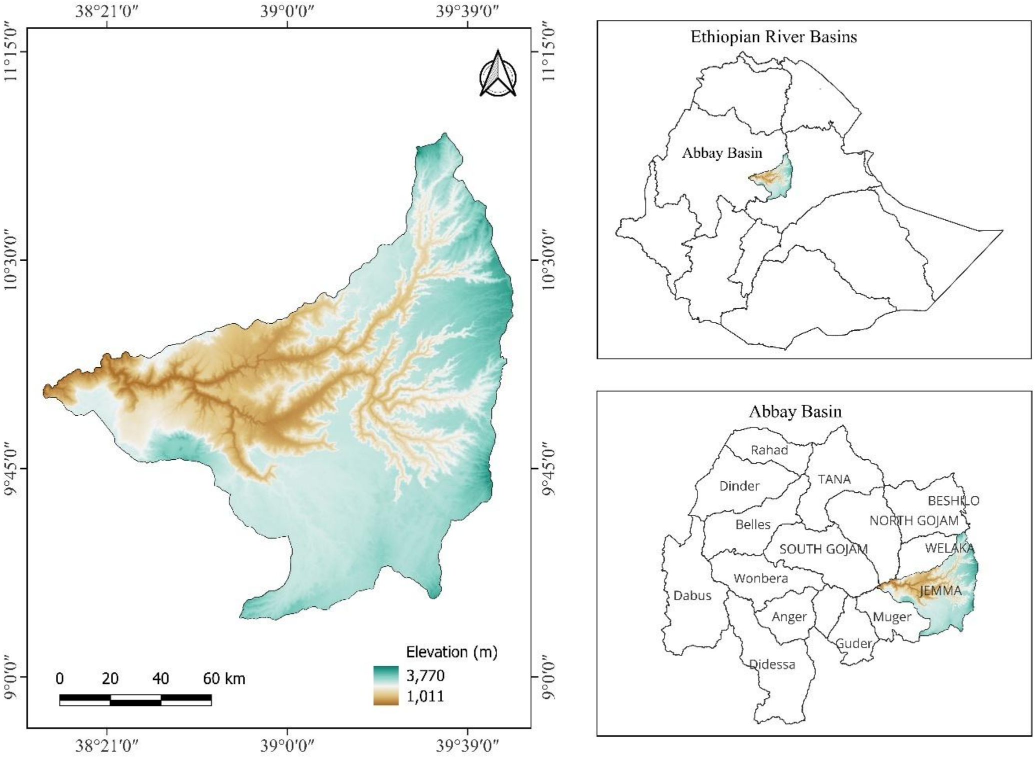
However, little attention has been paid to making comparisons with scientific meteorological data and information to establish the nexus and dynamics between scientific data and farmers' perceptions. Therefore, to address this gap, this study aims to conduct (i) a time series analysis of rainfall and temperature trends, and (ii) to analyze the smallholder farmers' perception of climate change and identify key determinants influencing their perception in the Jemma Sub-basin. We expected that climate change trend would vary across agroecological zones in the Jemma sub-basin as influenced by farmers' adaptation choices and institutional support. Also, we assumed that the barriers to climate change perception are not uniform across the agroecological zones of the study areas. The findings will provide valuable insights for policymakers and stakeholders to develop localized adaptation and mitigation strategies that enhance climate resilience in the region.

MATERIALS AND METHODS

Description of the Study Area

The Jemma sub-basin, located in the central highlands of Ethiopia, is one of the highest sub-basins of the Upper Blue Nile River basin. The sub-basin is located at 9° 0'0" - 11° 0'0" Northern latitude and 38°30' 0" to 41°0'0" Eastern longitude (Fig. 1). The sub-basin has a total area of ~15,803 km^2 and covers about 8-14 % of the total area and annual flow of the Upper Blue Nile Basin, respectively (Yilma & Awulachew, 2009). Administratively, the river basin intersects the Amhara and the Oromia Regional States of Ethiopia. According to the 2007 Ethiopian census, the population of the Jemma Sub-Basin was 1,605,876, with a growth rate of 1.7 and an average population density of 106 persons/km^2 (CSA, 2007). Assuming geometric population growth, the projected population of the Jemma sub-basin in 2025 is about 2,175,150, making the population density 144 persons/km^2. Crop cultivation and livestock rearing are the primary livelihoods for the residents.

Fig. 1: Map of the study area



Wheat, barley, teff, maize, and sorghum are the main crops cultivated in the Jemma Sub-Basin. The forest cover in the sub-basin is characterized by sparse woody vegetation, with Eucalyptus trees close to the villages. The sub-basin is characterized by uneven topography and dissected terrain where elevation varies over short distances and exhibits diverse agroecology ranging from cold, humid sub-Afroalpine to warm, sub-humid lowland areas. The Jemma Sub Basin receives annual rainfall ranging from 697 to 1475 millimeters. The mean annual temperature in the sub-basin is between 9 and 24 °C, and the elevation ranges from 1040 m to 3814 meters above sea level.

Sample Size and Procedures

Both probability and nonprobability sampling techniques were applied to select the required sample households in the study area. The research employs a multistage sampling technique to determine the study area, agroecological zones within the sub-basin, woredas[1], and Kebeles[2] within the selected agroecological zone, and individuals from each Kebele were involved in the data collection in various stages. First, we select Menz Mama, Siyadebirna Wayu, and Merhabete Woredas purposively from highland, midland, and lowland agroecology based on their dominant agroecological zones, demographics, and livelihood conditions. Secondly, Kebeles were clustered into the respective agroecological zones, and then three highland, two midland, and three lowland kebeles were selected randomly. Finally, 366 sample households were randomly selected based on a probability proportional to size sampling technique using Kothari's (2004) formula.

$$n = \frac{Z^2 * N * p * q}{e^2(N-1) + Z^2 * p * q} \tag{1}$$

Where n is the desired sample size, z is the value of the standard deviation (1.96), e is acceptable error (0.05), N is the total number of households in the selected AEZs $=7937$, p is the proportion of the target population estimated to have characteristics being measured (50 % is taken or 0.5), and q= 1-p. Then, p = 0.5, q = 0.5, considering a 95 % confidence level, the related standard normal deviation is z = 1.96, and the desired accuracy is at 0.05.

$$n = \frac{1.96^2 * 7937 * 0.5 * 0.5}{0.05^2(7937-1) + 1.96^2 * 0.5 * 0.5} = 366$$

We also used purposive sampling to identify and undertake 8 focus group discussions and 15 key informant interviews to gather qualitative information on corporate climate change perceptions.

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[1] *Woreda* refers to the fourth tier of government administration unit, which is closely equal to district.

[2] *Kebele* refers to the fifth tier of government administration unit.

Table1: Sample households in each agroecological zone in the Jemma sub-basin

Agroecology	Woredas	Altitude	Sample Kebeles	Household Heads	Sample households
Highland	Menze Mama	1577-3282	04	1053	49
			08	856	39
			010	721	33
Midland	Siyadebirna	1506-2827	Senketa	778	36
	Wayu		Motelemi	767	35
Lowland	Merhabete	1138-2469	Buyu	1350	62
			Geren	1162	54
			Arogenda	1250	58
Total			8	7937	366

Data Sources and Collection Methods

Both qualitative and quantitative data were collected from primary and secondary data sources. Primary data were collected from various individuals using household survey questionnaires, interviews with key informants, focus group discussions, and field observations. Secondary data is considered for the data triangulation by reviewing various documents from different sources, such as CSA, NMA, and research reports of relevant organizations operating in the study area. The secondary data sources were carefully reviewed for their accuracy, completeness, relevance, and complementarity with other sources used to achieve the study objectives and to reach valid conclusions. Long-term gridded (4 km by 4 km) climatic data (1981-2022) were used for the trend analysis, because station-based data have many missing values, poor quality, measurement errors, and a lack of continuous data (Mengistu & Lal, 2016). Gridded data is an integrated quality-controlled station data with locally calibrated satellite-derived data to fill spatial and temporal gaps. Previously, this method was also used for climate change trend analysis (Esayas *et al*., 2018).

Data Analysis Techniques

The quantitative information from interviews was analyzed using SPSS Version 23.0 statistical software. Whereas the qualitative data from FGDs, KIIs, and desk reviews were analyzed through a process of identifying patterns, themes, and meanings, then integrated with quantitative findings to provide a more comprehensive and contextually specific picture. Finally, the chi-square test was used to assess the association between independent variables and climate change indicators. Regarding the existence of long-term change for both rainfall and temperature indices, the Mann-Kendall (MK) trend test and Sen’s estimator were employed. The Mann–Kendall test is popularly used and not significantly influenced by the outliers occurring in the data series (Şen, 2014; Thapa *et al*., 2020). The MK test from the Zc value and trend from Sen’s slope (β) estimation was computed based on monthly, seasonal, and annual rainfall data from 1981 to 2022 in the Jemma Sub-basin. The Mann–Kendall trend test statistic *S* is computed as:

$$S=\sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\operatorname{sgn}\left(X_j-X_i\right) \qquad (2)$$

The time series *Xi* is ranked from i = 1, 2 … n-1, and Xj, which is ranked from j = i + 1, 2… n. Each of the data points Xi is taken as a reference point, which is compared with the rest of the data points Xj so that:

$$Sgn(X_j - X_i) = \begin{cases} +1 & if(X_j - X_i) > 0 \\ 0 & if(X_j - X_i) = 0 \\ -1 & if(X_j - X_i) < 0 \end{cases} \tag{3}$$

Xi and *Xj* are the annual values in years i and j (j>i). It has been documented that when the number of observations is more than 10 (n ≥ 10), the statistic 'S' is normally distributed with the mean and E(S) becomes 0 (Kendall, 1975). In this case, the variance statistic is given as:

$$Var(s) = \frac{n(n-1)(2n+5) - \sum_{t=1}^{m} t_1(t_1 - 1)(2t_1 + 5)}{18} \tag{4}$$

where n is the number of observations and ti are the times of the sample time series. The test statistic Zc is as follows:

$$Zc = \begin{cases} \frac{s-1}{\sigma} & if \quad S > 0 \\ 0 & if \quad S = 0 \\ \frac{s+1}{\sigma} & if \quad S < 0 \end{cases} \tag{5}$$

where Zc follows a normal distribution, a positive Zc and a negative Zc depict an upward and downward trend for the period, respectively. Sen's Slope estimation test computes the slope (i.e., the linear rate of change) and intercept according to Sen's method. The magnitude of the trend is predicted by Theil's (1950) and Sen's (1968) slope estimator methods. A positive value of β indicates an 'upward trend' (increasing values with time), while a negative value of β indicates a 'downward trend. Here, all data pairs of the slope (β) are computed using the Sen slope estimation technique (Sen, 1968). In general, the slope β between any two values of a time series x can be estimated from:

$$\beta = \frac{x_j - x_i}{j - i} \tag{6}$$

where xj and xi are data values at time j and k (j > i). A positive value of β indicates an increasing trend, whereas a negative value of β indicates a decreasing trend. The sign of β reflects the data trend direction, whereas its value indicates the steepness of the trend. The advantage of this method is that it limits the influence of missing values or outliers on the slope in comparison with linear regression. The coefficient of variation is used to evaluate the variability of rainfall data relative to its standard deviation and is normally presented as a percentage

$$cv = \frac{\delta}{\mu} \times 100 \tag{7}$$

where CV is the coefficient of variation; δ is the standard deviation and μ long-term mean rainfall. According to Hare 2020, the values of CV (<20) are considered less variable, (20– 30) moderately variable, and (>30) highly variable. To determine the deviations in rainfall variables from the average (961.85 mm) climate for the period 1981-2022, the anomaly of the rainfall variables was calculated (Fig. 3). Any deviation from the baseline, represented by the zero line, signifies the average rainfall over thirty years. The onset and offset of the main rainy season was analyzed using a Climate Data Tool (CDT) developed by International Research Institute (IRI).

RESULTS AND DISCUSSIONS

Demographic Characteristics of Sample Households

A total of 366 people participated in the study, with 84.7 % being male and 15.3 % from female-headed households (Table 2). Of the sampled households, about 25.7 % were illiterate, and 74.3 % could read and write. The mean age of the respondents was 50.75 years, with a standard deviation of 11.09. The minimum and maximum ages were 29 and 74, respectively. During the study period, 21.6 % were under 40 years of age, 59.8 % were in the range of 41–60 years, and 18.4 % were above 65 years (Table 2). Highland agroecology scored the highest average family size (5.74), followed by lowland and midland agroecologies. Smallholder farmers in the highland area hold relatively the highest landhold size and farm experience.

Table 2: Respondents' socio-economic and demographic characteristics

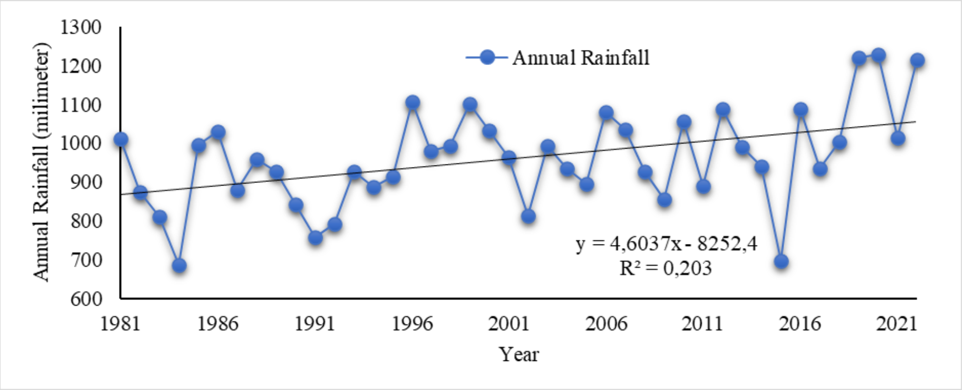
		Highland	Midland	Lowland	Total	Percentage
Sex	Male	102	66	148	310	84.7
	Female	19	11	26	56	15.3
Age	20-40	16	17	46	79	21.6
	41-60	79	40	121	219	59.8
	>61	26	12	30	68	18.6
Education	Illetirate	24	23	47	104	25.7
	Read and Write	97	48	127	262	74.3
Average family size		5.74	5.52	5.67		
Average farming experience		27.88	25.7	24.95		

Rainfall Analysis

Annual Rainfall Trend Analysis

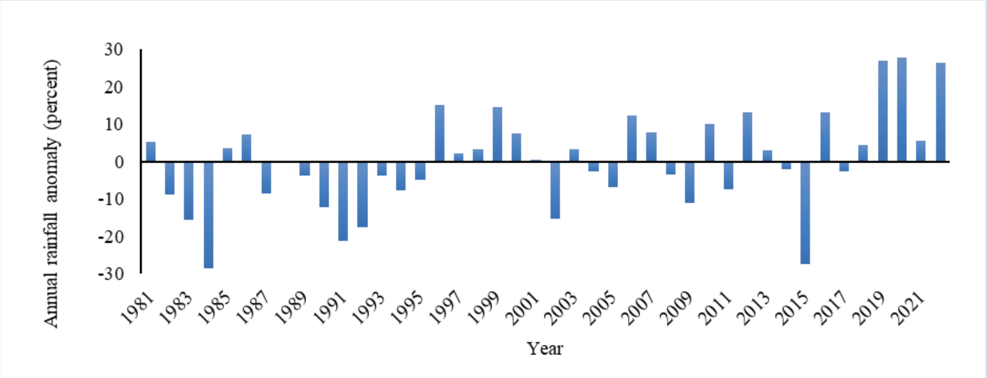
The result in Fig. 2 shows that over the past 42 years, the Jemma sub-basin has experienced varying levels of annual rainfall, with a minimum of 686.9 mm and a maximum of 1228.6 milimeter (mm). However, there has been a consistently increasing trend in annual rainfall from 1981 to 2022. Although rainfall fluctuated annually, the sub-basin received an average of 961.85 mm. Notably, there were years when the annual rainfall fell below the average, specifically in 1982, 1984, 1990, 1991, 1992, 2002, 2009, and 2015. However, the regression coefficients for the annual rainfall illustrated increasing trends at 0.203 mm/year. A study by Etana *et al.*, (2020) reported an average annual rainfall increase of 178 mm over the last decade in the midland region.

Fig. 2: Annual rainfall trend of Jemma sub-basin in the years 1981-2022



The annual rainfall anomaly results show that for the past 42 years (1981-2022), approximately 21 years, representing 50 %, were characterized by wet conditions due to rainfall exceeding the normal level. On the other hand, 20 years, representing 47.6 %, experienced lower than the average annual rainfall (Fig. 3). Whereas the rainfall condition for the year 1989 is equal to the established normal rainfall or the mean.However, these findings contradict previous studies, stated the presence of a considerable decrease in annual rainfall (Anteneh, 2022; Destaw, 2023; Teku & Eshetu, 2024).

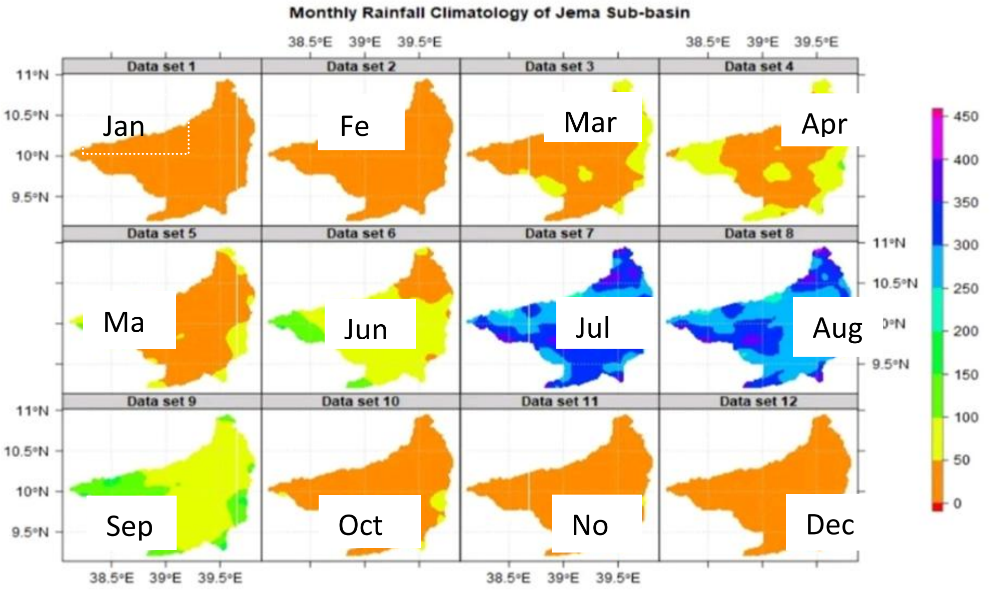
Fig. 3: Annual rainfall anomalies of the Jemma sub-basin



Monthly Rainfall Analysis

The monthly rainfall distribution of the Jemma sub-basin is shown in Fig. 4. The sub-basin received the highest maximum monthly rainfall in July (418.15 mm) in 2022 and 412.144 mm in August 1999, contributing 37.4 % and 34.46 % to the total rainfall in their respective years. On the other hand, November, December, January, and February received rainfall below 50 mm and were considered the driest months with the least contribution to the total annual rainfall. A research study conducted in southern Ethiopia revealed that July and August experienced the highest levels of monthly rainfall, accounting for roughly 15.7 % and 15.9 % of the total annual precipitation, respectively. In contrast, December and February recorded the lowest rainfall, accounting for approximately 1.3 % and 1.5 % of the yearly total, respectively. Additionally, the study identified a statistically significant upward trend in rainfall during September and November (Belay *et al.*, 2021).

Fig. 4: Monthly rainfall distribution climatology of the Jemma sub-basin



Seasonal Rainfall Analysis

The seasonal rainfall variability trends in the Jemma sub-basin illustrated in Fig. 5. The main rainy season, summer, occurs from June to September, while the spring (Belg) rainy season occurs from February to May. Most of the annual rainfall occurs during the Summer season (72 %) and the Spring season (16 %). The summer season rainfall showed a variability of 5.4323 mm/year, while the spring and winter seasons had a variability of -1.1885 and -0.0932mm/year, respectively. The negative and positive values indicate a decrease and an increase in rainfall distribution over the observed period, respectively. The MK test result revealed a non-significant change in yearly and summer rainfall, whereas the spring season rainfall decreased insignificantly (Table 3).

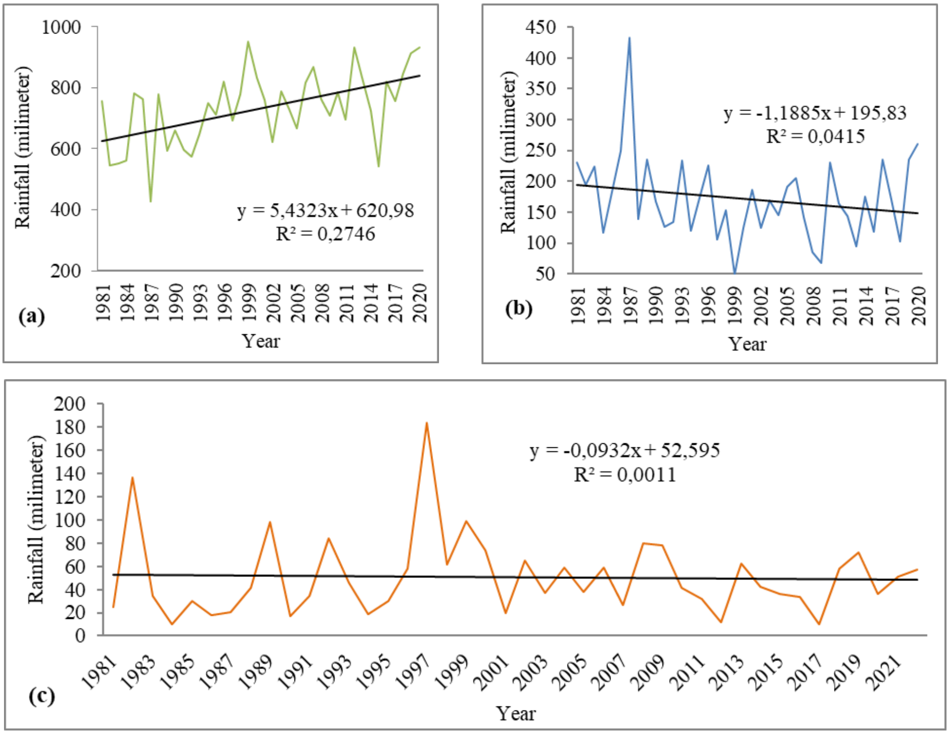
Table 3: Monthly & Seasonal rainfall trend test output for the Jemma sub-Basin (1981–2022).

Variable	Minimum	Mean	Maximum	SD	CV	MK test (p-value)	Slope (β)
January	0	11.46	37.82	10.61	92.52	0.63	-1.65
February	0	18.34	74.39	16.89	92.07	0.24	-6.65
March	0.32	49.53	169.94	35.76	72.19	0.57	-9.56
April	2.571	53.62	117.68	28.62	53.38	1.00	-2.59
May	0.39	47.13	155.99	33.67	71.43	0.85	9.23
June	9.10	66.04	164.65	39.58	59.93	0.19	14.64
July	86.17	293.54	418.15	76.92	26.2	0.12	41.54
August	115.49	289.35	412.14	52.58	18.17	0.11	20.66
September	39.32	94.7	189.07	30.2	31.89	0.84	-4.8
October	1.70	21.1	95.07	20.96	99.31	0.58	-3.14
November	0.05	9.69	49.68	13.03	134.52	0.09	2.41
December	0.06	8.17	66.07	11.57	141.63	0.08	-1.45
Spring(F MAM)	48.6	171.5	426	68.18	39.76	0.38	-0.82
Winter	9.862	50.59	183.28	34.39	67.81	0.04*	-0.92
Summer (JJAS)	61.09	702.8	953.07	178.84	16.55	0.02*	4.55
Annual	686.9	961.85	1228.6	125.3	13	0.15	40.33

MK is the Mann–Kendall trend test, β = Sen’s slope, SD = Standard Deviation; CV = coefficient of variation.* = indicate significant at $p < 0.05$.

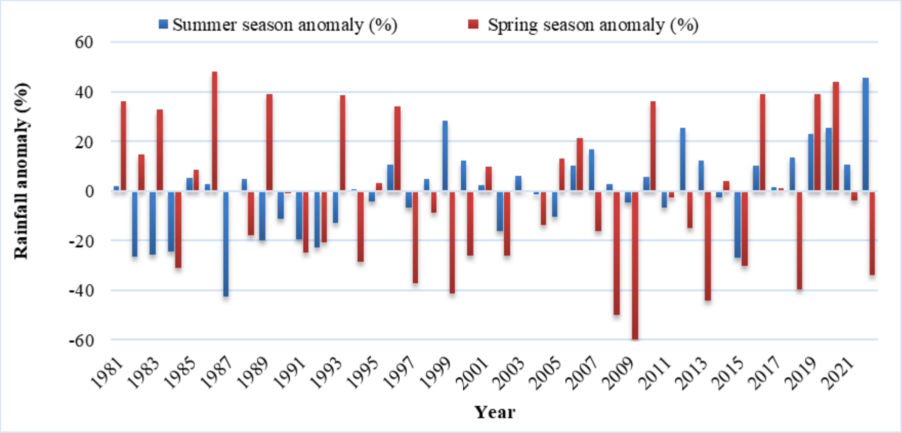
The coefficient of variation result of seasonal rainfall showed high variability, especially in the Belg season (CV>30 %) in the Jemma sub-river basin (Fig. 5). The highest monthly rainfall variability was observed in January, February, October, November, and December (CV>90 %). Previous studies also reported that the spring season is characterized by significant intra-seasonal variability in various regions of Ethiopia, leading to droughts and floods in different regions (Alemayehu *et al.*, 2017, Bekele-Biratu *et al.*, 2018 and Alemu & Bawoke, 2020). Such seasonal and inter-annual variability in rainfall could undermine farmers' ability to adapt to climate change and variability.

Fig. 5: Summer (a), spring (b), and winter (c) season rainfall variability of Jemma sub-basin (1981–2022).



For the seasonal rainfall anomaly analysis, the average rainfall was 168.6 mm for spring and 742.8 mm for summer, considered a baseline for 1981-2022. Any deviation from this established average climate indicates rainfall variability. The result signifies that the average spring season rainfall was above the average for 21 years and below for 18 years. Over the years, the rainfall in the summer season has been above the average for 22 years and below the average for 18 years. This data suggests a consistent rainfall pattern, with the average rainfall value being representative of the typical precipitation experienced during the summer season in the study area (Fig. 6).

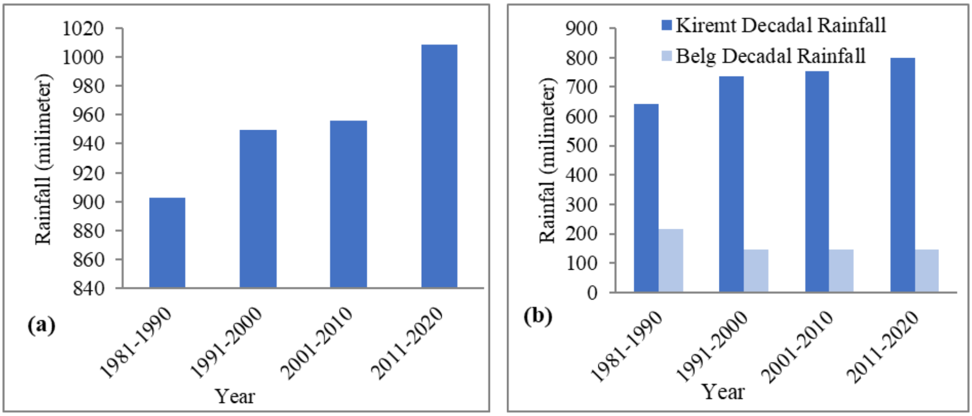
Fig. 6: Long-term seasonal rainfall anomaly of Jemma sub-basin (1981–2022)



Decadal Rainfall Analysis

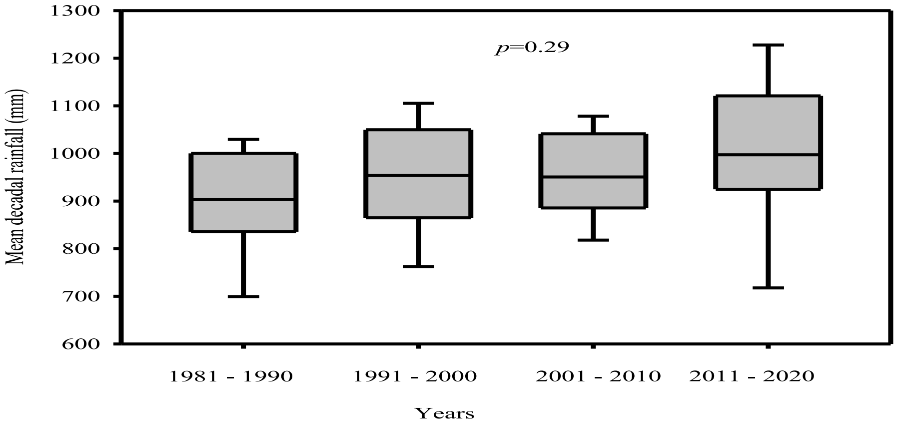
The decadal annual mean rainfall for 1981–1990, 1991–2001, 2002–2012, and 2013-2022 was recorded as 902.4 mm, 949.64 mm, 956.3 mm, and 1008.54mm, respectively. On average, the study area's annual mean decadal rainfall trend increases by about 26.53 mm of rainfall per decade during this period (Fig. 7a). These findings align with recent studies conducted in Ethiopia and the East African region (Bahaga *et al.*, 2019; Jury, 2010). In contrast, Stojanovic *et al.* (2022) found about a 6.5 mm rainfall reduction per decade in the northeastern area of Ethiopia between 1900 and 2016. The decadal seasonal rainfall analysis for the summer season shows an increasing trend (y = 48.685 and $R^2 = 0.9132$). In other words, the summer season rainfall increased by 39.255 mm/decade, while the spring season rainfall shows a decreasing trend (y = -21.63 and $R^2 = 0.6$), or 18.08 mm of rainfall decreased per decade (Fig. 7b).

Fig. 7: Average(a) and summer and spring season(b) decadal rainfall trend analysis



The box and whisker plot graph in Fig. 8 illustrates a clear and consistent upward trend in mean decadal rainfall from the 1980s to the 2010s, rising from approximately 800 mm to around 1300 mm. However, the annotation "p=0.29" indicates that this apparent increase is not statistically significant. The high p-value suggests that the observed trend is likely due to random variation rather than a conclusive long-term change in the rainfall pattern.

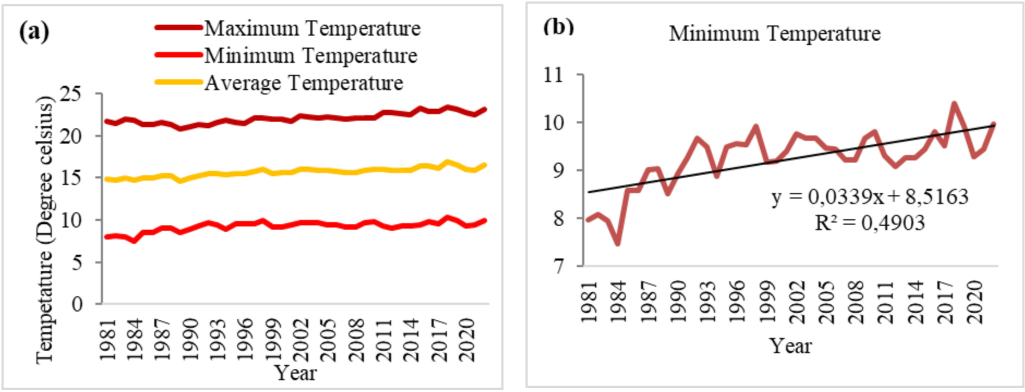
Fig. 8: The statistical analysis result (One-way) ANOVA on the mean decadal rainfall of the study area at p=0.05 level of significance

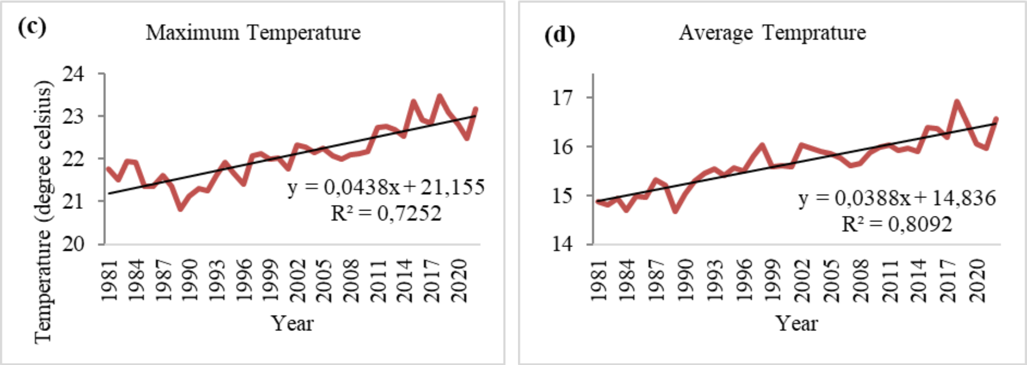


Temperature Trend Analysis

The mean annual minimum and maximum temperatures in the Jemma sub-basin for the last 42 years were 9.24 °C and 22.09 °C, respectively. The Sen's slope estimates for the minimum, maximum, and average temperatures from 1981 to 2022 in the Jemma sub-basin demonstrate an increasing trend. This is supported by the MK statistic (Z) results showing positive values (Table 4). The Sen's Slope estimator indicates a tendency for temperature increases, which, when combined with other factors, can contribute to extreme weather events. The rates of increase for mean annual, maximum, and minimum temperatures were 0.038 °C/yr, 0.044 °C/yr, and 0.039 °C/yr, respectively.

Fig. 9: Annual minimum, maximum, and average temperature of the Jemma sub-basin





(a) Minimum temperature, Average temperature, and Maximum temperature from 1981 to 2022, (b) Minimum temperature from 1981 to 2022, (c) Maximum temperature from 1981 to 2022, (d) Plot of average temperature from 1981 to 2022 for Jemma sub basin

The Mann-Kendall trend test of the minimum and maximum temperatures during the sspring and summer seasons showed insignificant increasing trendas p-value being greater than the significance level alpha 0.05 (Fig. 9). The results for both minimum and maximum temperatures during the winter and summer seasons also show an increasing trend (Table 4). The temperature rise, particularly during the main growing season (Summer), may have affected crop growth, development, and yield in the sub-basin. This is due to higher temperatures during the crop growing season, leading to increased evapotranspiration, resulting in greater water demand for the crops.

Table 4: Annual and seasonal temperature MK trend test of the Jemma sub-Basin

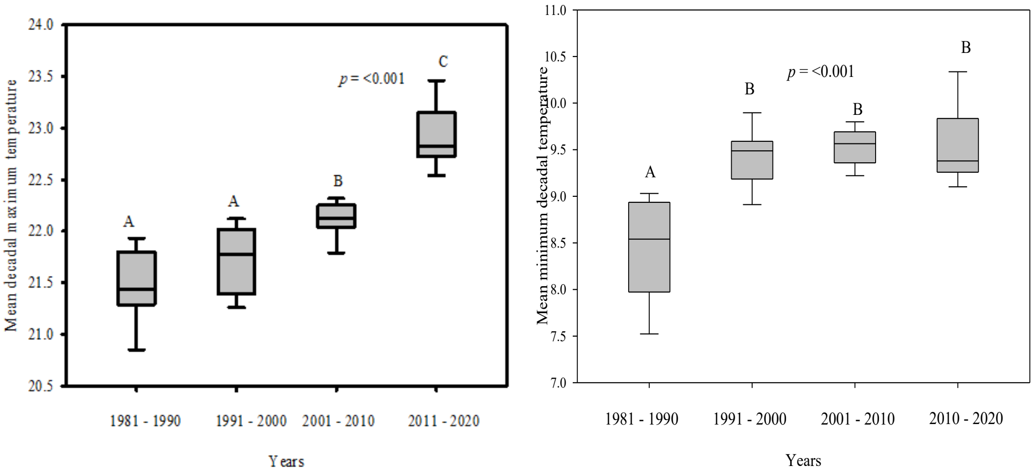
Variable	Min.	Mean	Max.	SD	CV	MK test/ p-value	Slope (β)
Tmin (Annual)	7.48	9.24	10.38	0.59	6.42	0.2	0.46
Tmax (Annual)	20.82	22.1	23.47	0.63	2.82	0.06	0.49
Tmin(Belg)	7.52	9.93	11.05	0.72	6.29	0.17	0.55
Tmin (Kremit)	8.39	9.95	11.16	0.63	7.22	0.12	0.58
Tmax (Belg)	21.41	23.4	24.99	0.91	2.74	0.07	0.76
Tmax (Kiremit)	20.19	21.16	22.8	0.68	3.2	0.07	0.42

MK is the Mann–Kendall trend test, β = Sen's slope, SD = Standard Deviation; CV = coefficient of variation. * = indicate significant at $p < 0.05$.

The mean decadal maximum temperatures from 1981–1990, 1991–2001, 2002–2012, and 2013-2022 was 21.47 °C, 21.70 °C, 22.71 °C, and 22.92 °C, respectively. The box and whisker plot in Fig. 10 (a) shows a consistent and significant increasing trend in maximum temperature across the decades ($p < 0.001$). During the 1981–1990 and 1991–2000 periods, the mean maximum temperatures were relatively low and statistically similar. However, there was a noticeable increase in the mean temperature from 2001 to 2010 (group "B"), indicating a warming trend. The highest decadal maximum temperature was observed in the 2011–2020 period (group "C"), which is significantly higher than all previous decades. The interquartile ranges (IQRs) show that the variability of maximum temperature was relatively higher in the earlier decades (1981–2000) and became slightly narrower in the 2001–2010 decade, indicating more consistent temperature values during that period. In the 2011–2020 decade, the IQR widened again, reflecting an increase in both temperature level and variability.

The corresponding mean minimum temperatures also demonstrate a significant increasing trend. The box and whisker plot in Fig. 10 (b) reveals a clear and significant warming trend in minimum temperatures over the four decades from 1981 to 2020. The 1980s stand out as a distinctly cooler period, with a mean minimum temperature of 8.41 °C. A substantial shift occurred in the 1990s, as the mean jumped by over 1.0°C to 9.42 °C, marking a decisive break from the previous decade. This new, warmer regime persisted into the 21st century, with the 2000s and 2010s recording nearly identical mean minimum temperatures of 9.53 °C and 9.53 °C, respectively. This pattern indicates that the climate crossed a threshold in the 1990s, entering a new state characterized by consistently higher minimum temperatures. This suggests that while the climate has stabilized at a warmer level, it may also be becoming more unpredictable, with recent years showing wider swings in minimum temperatures around the elevated mean.

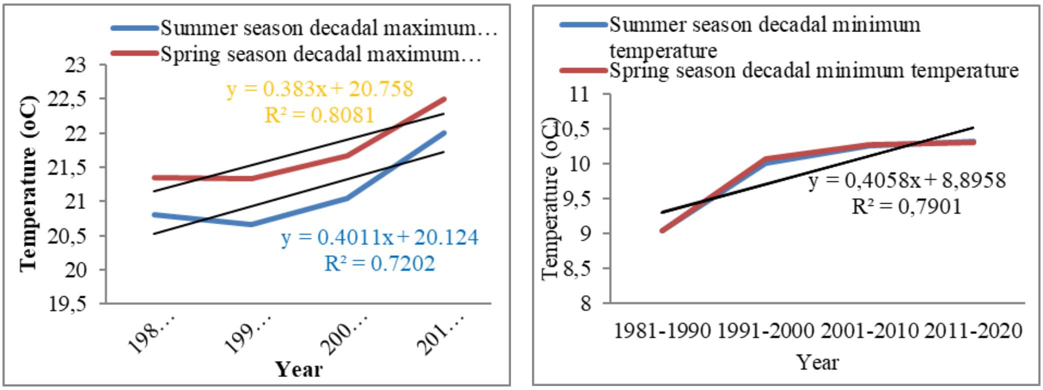
Fig. 10: The statistical ANOVA result on the mean maximum (a) and mean minimum (b) decadal temperature in the study area



(a) **(b)**

The decadal seasonal mean maximum and minimum temperatures also reflect a non-significant increasing trend (Fig. 11). The findings further revealed that the mean decadal maximum temperatures for spring and summer seasons increased by 0.38 °C ($R^2 = 0.8081$) and 0.4 °C ($R^2 = 0.7202$) per decade, respectively. The corresponding mean minimum temperatures for both the spring and summer seasons rose by 0.4 °C ($R^2 = 0.7$).

Fig. 11: Summer and spring seasons decadal maximum and minimum temperature



Smallholder Farmers' Perceptions of Climate Change

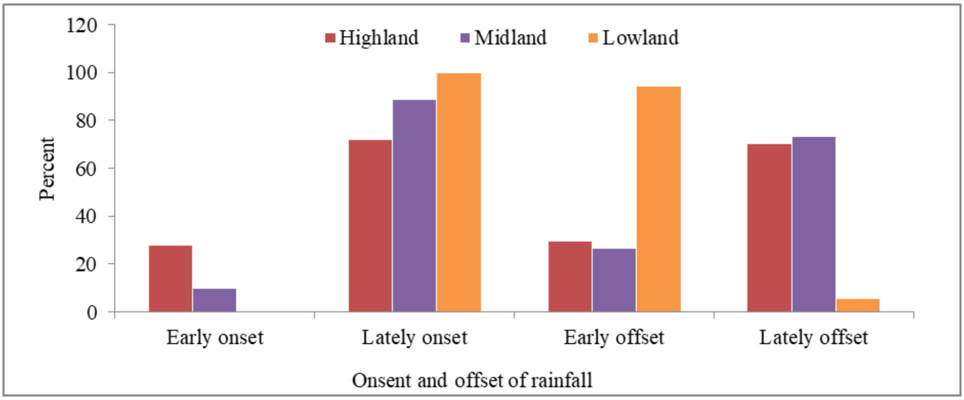
Understanding local people’s perceptions of climate change and variability is crucial to designing appropriate adaptation and coping strategies (Daba, 2018). Smallholder farmers in the study area had observed several indicators associated with climate variability. Of the interviewed respondents, 100 % of lowland and 66.2 % of midland area respondents recognized that the mean rainfall has decreased (Table 5). However, the meteorological data show an increasing rainfall trend over the last 42 years in the Jemma sub-basin. About 92.9 % of respondents perceived that the mean temperature of the area had increased over the past decades. The increasing temperature generally increases the water-holding capacity of the atmosphere, which leads to a change in precipitation patterns and an increase in atmospheric moisture (Devkota & Maraseni, 2014). Therefore, an increase in minimum temperature in the study area can be expected to cause an increase in unusual rainfall and damage.

Table 5: The percentage of respondents who realized the variations

Variables	Scale	Hiland (n□121)	Midland (n=71)	Lowland (n=174)	Total (n=366)	Chi square	*p* value
Rainfall	No change	6.61	15.49	0.00	5.2	140.4	0.000
	Increased	48.77	18.31	0.00	19.67		
	Decreased	44.62	66.2	100	75.13		
Temperature	No change	3.31	8.46	0.00	2.74	47.91	0.000
	Increased	83.47	91.54	100	92.89		
	Decreased	13.2	0.00	0.00	4.37		

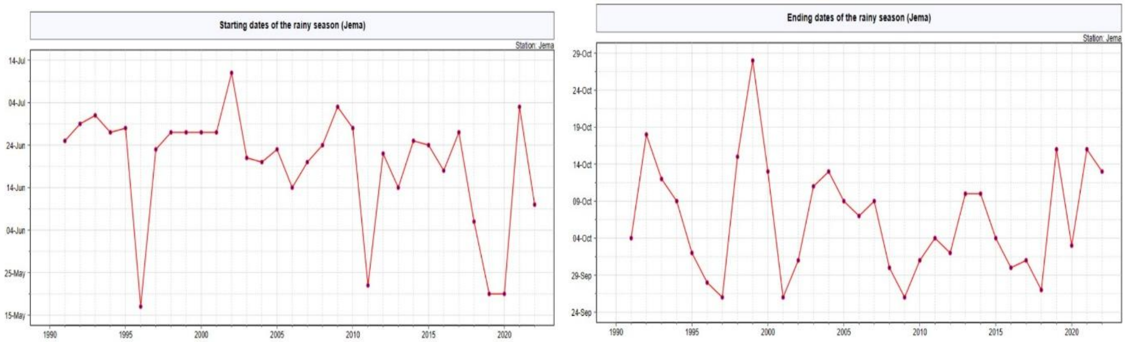
Regarding the onset and offset of the rainy season, about 100 % of lowland and 88.74 % of midland area respondents noticed the onset of the rainy season has shifted from the first week of June to the first week of Jully and the first week of July (Fig. 12). In addition about 94.25 % of lowland and 29.75 % of highland respondents perceive the cessation shifted from the 1st week of October to the last week of September in 2018. According to the focus group discussants in the lowland area, the rain comes after they saw, and the rain stops just as the crops start to grow. And it begins to rain after the crops have already been ruined.”

Fig. 12: Perceived variation in seasonal onset and offset by the respondents



The Climate Data Tool (CDT) result also shows, there is high inter-annual variability, indicating that the ending date of the rainy season varies significantly from year to year (Fig. 13). For instance, the earliest endings occurred in 1998, 2009, and 2018, where the rainy season ended in late September. While late endings were recorded during 1999 and 2000, the season extended from October 24–26. The variability in ending dates indicates unstable rainfall distribution, which can affect: crop maturity and harvest timing, water resource availability, pasture regeneration and soil moisture maintenance.

Fig. 13: Variation in seasonal onset and offset



According to the key informants, comparing the current climate to that of the past 30 to 40 years, it is apparent that there has been a significant shift in distribution, timing, and amount, making the cropping period unpredictable. For example, since 2019, there has been an extended delay in the exit period, and there was high rainfall in November, December, and January as well, especially in the highland area. In line with these findings, late onset and early cessation of rainfall was observed in different parts of the country (Aniye *et al.*, 2024; Teshome *et al.*, 2021). Erratic rainfall, with late onset and early cessation identified as major climatic factors affecting crop production (Asfaw *et al.*, 2018; Degefu & Bewket, 2014; Shiferaw *et al.*, 2014).

Farmers' Perception on Indicators of Climate Change

The most commonly used indicators of climate change by the farmers are listed in Table 6. The result shows that about 73.5 % of highland, 35.22 % of midland, and 41.9 % of lowland households perceived the incidence of flooding is increasing through time. In addition, 47.11 % of highland, 69.01 % of midland, and 100 % of lowland respondents have reported increasing drought trends in the past decades. Regarding the distribution, 98.27 % of lowland participants perceived that the rainfall distribution is erratic, and the area doesn't get enough rain from the same community. The key informant interviews and focus group discussants emphasized that there was a regular rainfall distribution on both annual and seasonal bases. But now, the distribution patterns have dramatically changed and have become difficult to predict, evidenced by the late-onset and early cessation of the main rainfall season, erratic nature of rainfall, high temperature during winter (*Bega*), and devastating frost during autumn (*Meher*), all of which were seen in the three agroecological zones alternatively. In addition, 83.5 % of highland respondents perceived that the prevalence of pests and diseases increases in their locality from time to time. The occurrence of climate extremes such as flooding, drought, and strong winds was the direct outcome of climate change (Abebe *et al.*, 2019; Tesfahunegn *et al.*, 2016; Gelete & Gichamo, 2019).

Table 6: People's perception on climate change indicators in Jemma sub-basin (N=366)

Indicators	Scale	Percentage of respondents who realized the variations					
		Hiland (n□121)	Midland (n=71)	Lowland (n=174)	Total (n=366)	Chi square	P value
Rainfall distribution	No change	12.40	0.00	0.00	4.10	97.5	0.000
	Uniform	34.71	23.95	1.73	16.94		
	Erratic	52.89	76.05	98.27	78.96		
Frequency of floods	No change	5.78	0.00	4.60	4.10	77.1	0.000
	Increased	73.55	35.22	41.90	51.10		
	Decreased	20.66	64.78	53.40	44.80		
Drought frequency	No change	23.14	1.42	0.00	7.93	131.4	0.000
	Increased	47.11	69.01	100	76.50		
	Decreased	29.75	29.57	0.00	15.60		
Occurrence of frost	No change	19.83	2.83	1.72	8.20	71.3	0.000
	Increased	35.53	40.84	26.50	32.20		
	Decreased	44.63	56.33	71.80	59.80		
Prevalence of pests and diseases	No change	3.30	8.45	1.16	3.28	13.7	0.08
	Increased	83.48	66.20	79.90	78.40		
	Decreased	13.22	25.35	18.90	18.30		

Determinants of Perception of Climate Change

Table 7 presents the results of the ordered logistic regression examining determinants of households' perception of temperature and rainfall trends. The model includes socio-demographic factors (gender, age, education, and farming experience) and access-related variables (training, market, climate information, and extension services). For temperature perception, age and access to climate information are significant predictors, while gender, education, farming experience, market access, and extension are not significant. For rainfall perception, gender, age, education, farming experience, market access, and access to climate information are all significant. Positive coefficients indicate a higher likelihood of perceiving increasing trends, whereas negative coefficients suggest a tendency to perceive decreasing or normal trends. The chi-square and probability values show that the rainfall perception model fits the data well ($Chi^2 = 51.663$, $p < 0.001$), while the temperature perception model is marginally significant ($Chi^2 = 15.279$, $p = 0.054$).

Gender: Gender is significantly associated with rainfall trend perception (positive coefficient), indicating that respondents of the reference gender are more likely to perceive rainfall as increasing. For temperature, the effect is not significant.

Age: According to Deressa *et al.* (2011) perception will increase when the age of a household increases. In line with these arguments, the findings show that, age is positively associated with both temperature and rainfall trend, suggesting older respondents are more likely to perceive an increase in temperature and rainfall.

Education Level: Less-educated citizens have lower levels of scientific knowledge than more-educated citizens (Hoekstra *et al.*, 2024; Achterberg *et al.*, 2017). The educational level of farmers is directly linked to their perception of climate change and variability. Farmers with higher education levels have opportunities to get information from schools, environmental clubs, and other sources of information. The result revealed, education has a negative effect on rainfall perception in the model, meaning more educated respondents are less likely to perceive rainfall as increasing. For temperature, the effect is not significant. These results suggest that education may foster critical evaluation of variable climate signals rather than overreliance on anecdotal experience.

Farming Experience: According to Amadou *et al.* (2015), farmers with high experience are likely to perceive climate change. The result showed that farming experience negatively affects rainfall perception. Suggesting that experienced farmers are less likely to perceive rainfall as increasing. But, the result showed that farming experience does not have a significant influence on the temperature trend perception.

Access to Market: Market places serve as a source of information. Results from the ordered logistic regression model indicate that access to the market negatively affects rainfall perception, suggesting that households with better market access are less likely to perceive rainfall as increasing. This may reflect access to alternative livelihoods, irrigation, and technologies that buffer climate impacts. These studies highlight the role of economic access in shaping climate perception.

Access to Climate Information: Access to climate information positively affects temperature perception but negatively affects rainfall perception. Households receiving climate information are more likely to perceive increasing temperature but less likely to perceive increasing rainfall, reflecting greater awareness of global warming and moderated interpretation of variable rainfall data. The result confirm that climate information shapes both perception and response strategies in rural households.

Table 7: Determinants of households' perception on temperature and rainfall trend from ordered logistic regression model

Independent variables	Perception on temperature trend				Perception on rainfall trend			
	Coef.	St.Err.	t-value	p-value	Coef.	St.Err.	t-value	p-value
Gender	-.548	.661	-0.83	.407	1.005	.384	2.62	.009***
Age	.903	.548	1.65	.099*	1.123	.39	2.88	.004***
Education level	.118	.533	0.22	.825	-.785	.35	-2.24	.025**
Farming Experience	-.024	.029	-0.82	.411	-.082	.02	-3.99	0.000***
Access to training	.49	.531	0.92	.356	-.034	.341	-0.10	.921
Access to market	.77	.544	1.41	.157	-.694	.344	-2.01	.044**
Access to climate information	1.674	.565	2.96	.003***	-.911	.33	-2.76	.006***
Access to extension	-.307	.494	-0.62	.534	.179	.309	0.58	.562
cut1	-2.746	1.274			-5.109	.856		
cut2	4.556	1.337			-3.15	.82		
Number of obs	365				365			
Chi-square	15.279				51.663			
Prob > chi2	0.054				0.000			

Note: ****,* ** *and* * *presents 1%, 5% and 10% significance levels, respectively.*

Comparing Farmers' Perceptions of Climate Change with Meteorological Data

Individual's perception of climate change is highly personal, place-based, and influenced by several factors. Farmer perceptions of climate change varied considerably and were not systematically consistent with the direction and significance of climate trends calculated from the observational record. In this regard, like any farmer in the country, farmers in the study area believe the climate has changed. The study results shows that about 83.47 % of highland, 91.54 % of midland, and 100 % of lowland respondents perceived the increasing trend of temprature. The meteorological data also in lime with the smallholder farmers perception, indicated the mean annual, maximum, and minimum temperatures of the study area have increased by 0.038°C/yr, 0.044°C/yr, and 0.039°C/yr, respectively.

Regarding rainfall, about 100 % of the respondents in lowland, 66.2 % of midland and 44.62 % of highland respondents have perceived rainfall decreases over the last three decades.perceived that rainfall is decreasing Some of the mentioned reasons for their perception of the long-term decrease in rainfall were day-to-day experiences with rainfall variability, increasing dry spells, time shifts in the onset and offset of rainfall, and its distribution rather than on average quantities of annual rainfall. The MK test result shows that, the annual and summer season rainfall of the study area increased over the past decades, whereas the spring season rainfall shows a decreasing trend. This inconsistency is attributed to the fact that they mainly focus on the distribution, timing, and effectiveness of rainfall rather than total annual amounts. According to the key informants' perceptions about precipitation is influenced by their own beliefs and expectations as well as experience related to their agronomic practices.

DISCUSSION

The effectiveness of adaptation strategies depends on how smallholder farmers perceive climate change and their responses to it. Therefore, assessing long-term climate trends and smallholder farmers' perceptions of climate change and variability is essential to identify vulnerable ecosystems, improve land-use planning, bolster ecosystem resilience, and develop suitable adaptation strategies for achieving a sustainable landscape in the long run. The Mann–Kendall trend test revealed that both the seasonal and annual average temperatures and rainfall increase in the Jemma subbasin. For instance, the regression coefficients for the annual rainfall illustrated increasing trends by 0.203 mm/year. The perception results show that about 44.62 %, 66.2 %, and 100 % of highland, midland, and lowland respondents recognized the decreasing rainfall trend, respectively. Such kinds of results were also found in a different part of the country (Cherinet & Mekonnen, 2019; Megersa *et al*., 2022; Tessema & Simane, 2021).

The summer season rainfall also showed a variability of 5.4323 mm/year, while the spring and winter seasons had a variability of -1.1885 and -0.0932 mm/year. Several studies also indicated an increasing trend of winter, summer, and annual rainfall in most agroecological zones of Ethiopia, while spring rainfall showed a decreasing trend in a greater number (Asfaw *et al*., 2018; Belay *et al*., 2019; Gashaw *et al*., 2023; Yona *et al*., 2024). However, the spring season rainfall is crucial for local farmers as it determines their preparation and planting activities in the study area. In kiremt, a significant increasing trend in mean rainfall of those seasons may have affected crop production. In contrast, Asfaw *et al*., (2018) and Addisu *et al*. (2015) found a statistically significant downward trend in the summer season. In terms of the onset and offset of the rainy season, all the interviewed farmers indicated the presence of long-term change in the study area's start and end of the rainy season. However, in the last three years, there has been an extended delay in the exit period, and there was high rainfall in November, December, and January as well, especially in the highland agroecology of the study area.

Regarding the temperature, both the mean annual, maximum, and minimum temperatures show an increasing trend. About 83.47 % of highland, 91.54 % of midland, and 100 % of lowland respondents perceived that temperatures have risen. The warming trend of temperatures in the study area affects the agricultural demand for water and the smallholder farmers' overall performance. The result also revealed that both minimum and maximum temperature increases were recorded in the spring and summer seasons, but the difference was insignificant. These positive and rising trends of temperatures were reported in different parts of Ethiopia (Degefu & Bewket, 2014; Esayas *et al.*, 2018; Habtemariam *et al*., 2016; Worku *et al*., 2018). The observed temperature increase has significant implications for agriculture, water resources, and public health. Previous studies show that higher temperatures can lead to increased evapotranspiration, reduced soil moisture, and more frequent heat waves, all of which can adversely affect crop yields and water availability (Tadese *et al*., 2020; Tessema *et al*., 2021).

However, the positive trend of average annual rainfall contradicts the household perceptions in the study area and periods. This inconsistency is attributed to the fact that they mainly focus on the distribution, timing, and effectiveness of rainfall rather than total annual amounts. For instance, even if total rainfall remains relatively constant, delayed onset, early cessation, or poor intra-seasonal distribution can severely affect crop production and lead farmers to perceive rainfall as declining (Belay *et al*., 2017; Daba, 2018). Farmers' perception of rainfall and the climate trend can be affected by several social, economic, demographic, and institutional factors (Mengistu *et al*., 2014). The finding shows, gender is significantly associated with rainfall trend perception. Studies in Southern Ethiopia highlighted that male and female farmers perceive climate variability differently because of differences in workload, exposure to climatic events, and access to information (Gashaw *et al.*, 2023). Together, these studies suggest that social norms, roles, and access to information explain gendered differences in perceiving rainfall trends. Age is also one of the significant determining factors of climate change perception. The study finding shows that age is positively associated with both temperature and rainfall trend, suggesting older respondents are more likely to perceive an increase in temperature and rainfall. Similar to this finding, a study in central Ethiopia shows that older farmers were likely to perceive climate change (Daniel, 2018). These studies reinforce the idea that age is a strong predictor of subjective climate perception among rural households.

The result further revealed that, educated respondents are less likely to perceive the increasing rainfall trend. This is potentially due to the reason that education may foster critical evaluation of variable climate signals rather than overreliance on anecdotal experience. In contrast, a study result by Aniye *et al.* (2024) in the Gassera District, farmers with higher educational attainment were more aware of significant temperature and rainfall changes than those with lower education levels. Access to climate information significantly affects smallholder farmers' perception of temperature and rainfall in the study area. Similar findings in Ethiopia indicate that access to meteorological information strongly influences perception of temperature and rainfall trends (Daniel, 2018).

The model result shows, farming experience negatively affects rainfall perception. Some studies indicate experience increases climate change perception, while others find experienced farmers are more conservative in judging rainfall declines without long-term data (Daniel, 2018). In general, the findings show farmers’ perceptions cannot merely depend on the actual climate conditions and changes in climate parameters. Nevertheless, high agreement between perception and instrumental records strengthens the reliability of indigenous knowledge as a complementary climate indicator. The convergence of observed climate trends and farmers’ perceptions underscores the urgency of climate adaptation.

CONCLUSION

The trend analysis results indicated the presence of climate variability or change in the Jemma sub-basin over the past 42 years. Both annual and Kiremit rainfall showed increasing trends, but a decreasing trend was observed in the Belg season rainfall. The coefficient of variation revealed moderate inter-annual variability of annual rainfall in the study area. However, there was greater variation in seasonal rainfall between years. Several farmers in the study area were also aware of the late onset and early cessation of rains. Additionally, both minimum, maximum, and annual temperatures of the study area showed an increasing trend. Regarding the perception results, about 83.47 % of highland, 91.54 % of midland, and 100% of lowland respondents perceived that temperature has increased, while 93.33 % of respondents in the lowland recognized a decreasing trend of rainfall. Overall, it was found that smallholder farmers’ perceptions of changes in temperature and seasonal rainfall over the years aligned with scientific historical data. However, the total annual rainfall trend contradicts farmers' perception, possibly because farmers give much more importance to the intra-annual variability of rainy season characteristics, such as rainfall intensity and distribution, than to the total annual rainfall. The study highlights that households' perceptions of climate trends are influenced by socioeconomic status and access to resources. Age and education play pivotal roles in shaping these perceptions. The result shows that older individuals and those with higher education levels are more likely to perceive increasing temperature and rainfall trends. Access to climate information also significantly impacts households' perception, particularly concerning temperature. The study recommends integrating farmers’ perceptions into meteorological data analysis, improving access to climate information, especially for households with limited education and older individuals, developing and promoting gender sensitive adaptation strategies, and improving infrastructure to enhance their resilience to climate variability and change.

ACKNOWLEDGMENTS

The authors would like to thank the Ethiopian Meteorological Institute (EMI) for providing past climate data of the study area free of charge. We also thank the respondents and experts at both the Woreda and Kebele levels for their kind responses.

CONFLICT OF INTEREST

The authors declare that they have no competing interests.

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