Science Discovery Food
2026, Vol. 1, No. 3, pp. 111–116
https://doi.org/10.11648/j.sdf.20260103.12

Research Article

Assessing Climate Change Impacts on Coffee Production in Hai District, Tanzania: Evidence from Climate Data and Smallholder Farmers

Aden Mbuba*, Domic Lameck

Good Agricultural Practices Programme, Tanzania Coffee Research Institute (TaCRI), Moshi, Tanzania

Abstract

A study investigated the impact of climate change on coffee production on the slopes of Mt. Kilimanjaro by analyzing climatic and yield data trends over 30 years from 1989 to 2018. Meteorological data, including rainfall and temperature, were extracted from the Lyamungu meteorological station. Data on yield were collected through questionnaires, interviews, and focus group discussions with the farmer. Furthermore, data analysis was performed using SPSS version 12.0 and COSATAT for regression analysis, the results showed that total rainfall distribution remained relatively stable, though there were slight changes in trends, with long rain peaks becoming steeper. The mean maximum temperature exhibited significant variation over the years, averaging around 25°C, which is still within the optimal range for coffee cultivation. Notably, the temperature in 1997 deviated most from the mean, rising by almost 1°C. Despite these climatic fluctuations, coffee yield trends were not significantly affected. The study suggests that coffee production in Machame Mashariki ward has not yet been severely impacted by climate change. However, it recommends adaptive strategies such as mulching, trickle irrigation, and rainwater harvesting to mitigate potential future effects. This comprehensive assessment provides valuable insights into the resilience of coffee production to climatic variations on the slopes of Mt. Kilimanjaro.

Keywords

Climate Change, Coffee Production, Mt. Kilimanjaro, Meteorological Data, Yield Trends, Adaptive Strategies

1. Introduction

Coffee is one of the most internationally traded commodities, second only to petroleum oil [2, 10]. Globally, Brazil leads as the top producer and exporter of coffee, followed by Vietnam and Colombia [8]. In Africa, countries such as Uganda, Tanzania, Burundi, Rwanda, and Ethiopia rely heavily on coffee as a key commodity that significantly contributes to the livelihoods of millions of smallholder farmers [11]. The economic value of coffee production is predominantly driven by two species: *Coffea arabica L.* (Arabica coffee) and *Coffea canephora* (Robusta coffee) [14, 17]. Arabica accounts for approximately 70% of global coffee production, with Robusta contributing the remaining 30% [10]. Tanzanian coffee, particularly the washed Arabica variety, is renowned for its high quality and unique flavor profile. Ranked among the rare "Colombian Milds," Tanzanian coffee is often

*Correspondence: Aden Mbuba (adenmbuba@yahoo.com)

Received: 23 April 2026; **Accepted:** 17 July 2026; **Published:** 10 August 2026

blended with lower-quality varieties, such as ordinary milds, hard Arabicas, and Robustas, ensuring high demand that consistently outpaces supply [18]. However, the production and productivity of both Arabica and Robusta are highly dependent on favorable climatic conditions, such as optimal temperatures and sufficient rainfall, to achieve high yields and quality [13]. For instance, Arabica coffee thrives in temperatures ranging from 18°C to 21°C and annual rainfall between 1,200 mm and 1,800 mm while Robusta prefers temperatures of 24°C–30°C, rainfall of 2,000 mm, and altitudes around 800 meters [6].

Climate change poses significant challenges to coffee production, rising temperatures and decreasing rainfall adversely affect coffee flowering and fruiting, leading to reduced yields [9, 11]. Studies indicate that temperature plays a more critical role than precipitation in determining coffee's suitability for cultivation [1, 5, 15]. In Tanzania, increased nighttime temperatures and prolonged droughts have been identified as key factors negatively impacting coffee yields [20]. Projections suggest that for every 1°C rise in minimum temperature, coffee yields in Tanzania may decrease by approximately 140 kg per hectare annually [20]. Additionally, abiotic factors such as temperature and relative humidity have been found to exacerbate pest infestations, such as the Coffee Berry Borer, which further the leading pest-reducing coffee quality and quantity in the world [10].

The effects of climate change have become increasingly apparent in recent years, drawing attention from stakeholders and the public alike [7, 12]. Since the early 1900s, both anthropogenic and natural factors have contributed to climate variability [3]. Accelerating weather changes have led to irreversible impacts on global ecosystems (Turner *et al.,* 2020). These shifts are often experienced as erratic weather patterns, including delayed rainy seasons, prolonged droughts, excessive rainfall causing floods, and extreme temperature fluctuations [4]. As a climate-sensitive perennial crop, coffee is particularly vulnerable to these changes. Drought and humid conditions not only reduce yields but also create environments conducive to pests like the Coffee berry borer and diseases such as Coffee leaf rust. Understanding the impact of climate change on coffee production is crucial for policymakers and farmers. Insights from such studies can inform agricultural policy reviews and help farmers adapt to mitigate production challenges.

However, limited studies have assessed the localized impacts of climate change on coffee production in Machame Mashariki Ward. Therefore, this study aims to examine the effects of climate change on coffee production in the Machame Mashariki ward of Tanzania's Hai district.

2. Material and Methods

2.1. Description of the Study Area

The study was conducted in Lyamungo village located in Hai District in Kilimanjaro Region. Furthermore, the Lyamungo village is located in Machame Mashariki Ward. The study area is located at latitude 03° 14 S” and longitude 37° 15 E” with elevation of 1268 m altitude above mean sea level (Map 1).

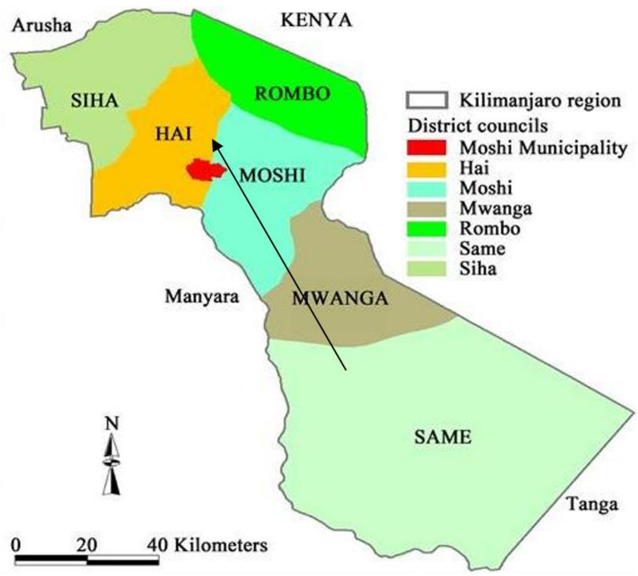

Figure 1. *Map of Kilimanjaro Showing the Relative Location of the Study Area.*

2.2. Research Design and Sampling Techniques

A cross-sectional research design was employed in this study, collecting data at a single point in time (Kothari, 2004). The sampling frame comprised smallholder farmers cultivating coffee. A simple random sampling procedure was utilized to select a total of 300 smallholder farmers from the sampling frame. The Global Positioning System (GPS) was used to mark the geo-references of each surveyed farm.

2.3. Primary and Secondary Data

The study utilized both primary and secondary data. Secondary data was gathered through the review of documents and reports. Primary data was collected using structured questionnaires, which included both closed and open-ended questions, to obtain information from a representative sample of farm households in the study area. The main data collected encompassed the socio-economic characteristics of farmers, farm and farming characteristics, access to farming resources, and sources of income. A pre-testing of the questionnaire was conducted to refine the tool before administering it for the interviews.

2.4. Key Informant Interviews

Key informant interviews were conducted with twenty selected individuals among coffee producers to gather qualitative data. A set of checklist questions guided these interviews. Key informants included TaCRI research officers, ward extension staff, local leaders from the ward, and primary cooperative leaders where coffee farmers sell their coffee. The collected information encompassed their opinions on climate change, serving to cross-check the data obtained during focus group discussions.

2.5. Focus Group Discussion

Checklist questions were also used to conduct focus group discussions (FGDs) with 20 members from each study site. These members were divided into four groups, each consisting of five members, with 1 or 2 females purposefully selected among coffee producers to facilitate the collection of qualitative data. The purpose of the FGDs was to capture in-depth information on coffee production and its related challenges, as well as to understand the farmers' perceptions of climate change.

2.6. Meteorological and Coffee Yield Data

Meteorological data were extracted from the Lyamungu meteorological station. The coffee yield data at Lyamungo were obtained from the Cooperative Union Centre were collected and evaluated as well.

2.7. Data Analysis

Data was analyzed using the Statistical Package for Social Science (SPSS) version 12.0 software. The assessed parameters included means, frequencies, and percentages. An assessment of weather trends, specifically rainfall, maximum, and minimum temperatures, was carried out for the slopes of Mt. Kilimanjaro over 30 years from 2001 to 2018. Data were analyzed using Excel, with regression analysis performed using the COSATAT package.

3. Results and Discussion

3.1. Rainfall

Rainfall patterns in Lyamungo Ward have shifted over the past years. Historically, the Masika rains occurred from February to May, and the bimodal Vuli rains from September to November. Recently, however, the Masika rains have shifted to March through June, while the Vuli rains now occur from October to December. These changes in the rainy season are likely due to climate change, which is attributed to human activities such as deforestation, bushfires, and other local practices. Despite these changes, the total annual rainfall, which exceeds 1000mm, remains suitable for coffee production in Lyamungu Ward. The average and total coffee yields for the period from 2001 to 2018 are depicted in Figure 2.

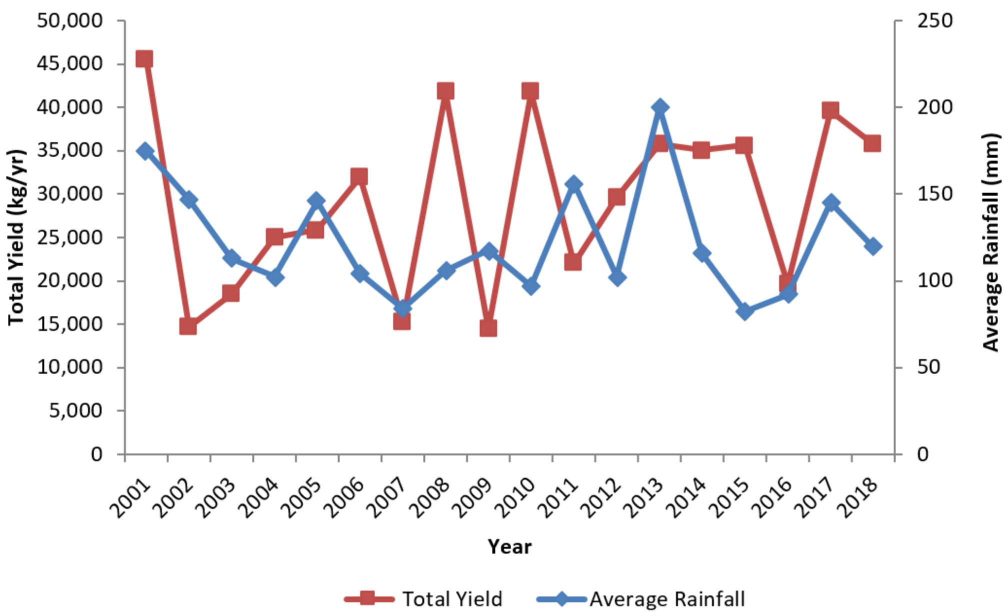

Figure 2. *Rainfall and Yield 2001-2018.*

3.2. Temperature

The mean maximum temperature (Figure 3) varied significantly over the years and periods, fluctuating around an average of 25°C, which is still suitable for coffee cultivation. The mean minimum temperature (Figure 3) also showed significant variation across different periods, with some periods experiencing deviations from the mean of 15°C, rising by almost 1°C. Among the parameters studied, the mean minimum temperature appeared to be the most indicative of climate change in the area. The average maximum and minimum temperatures of 25°C and 15°C, respectively, found in this study, are suitable for coffee production and currently do not pose a serious threat.

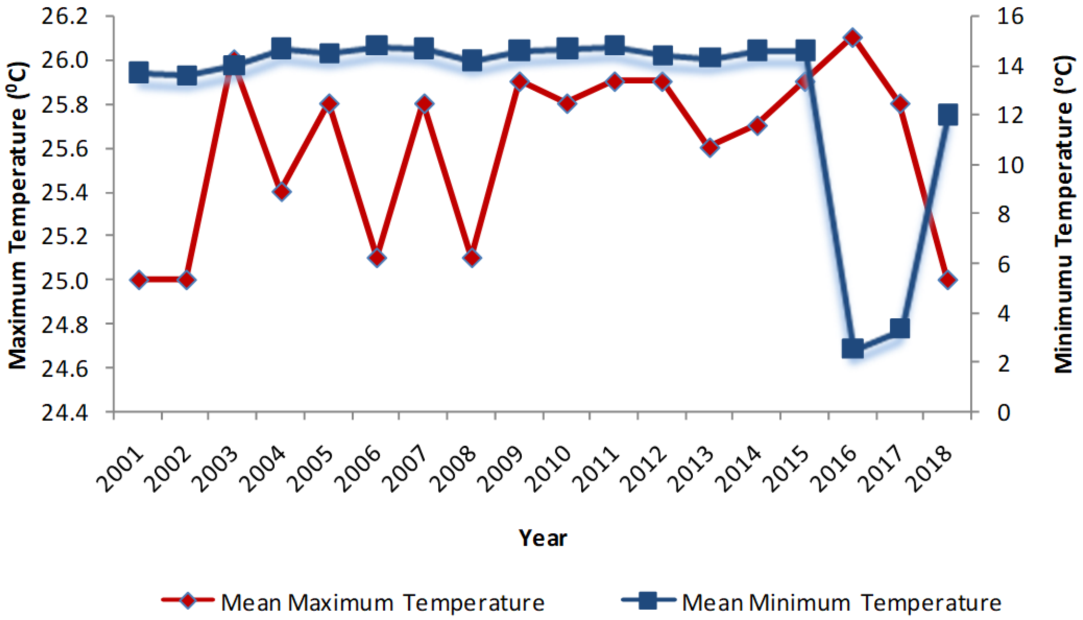

Figure 3. *Mean max and min temperatures 2001-2018.*

3.3. Coffee Yield

In the past, the coffee harvest season ran from August to October each year, with each coffee tree yielding 1 kg of parchment. However, the harvest season has shifted to June through November, and the yield per tree has decreased from 1 kg to 0.25 kg of parchment. These changes in the harvest season and yield may be attributed to climate change. The average annual yield is 29,414 kg, with a maximum yield of 45,614 kg in 2001 and a minimum yield of 14,397 kg in 2009 as shown in Figure 4.

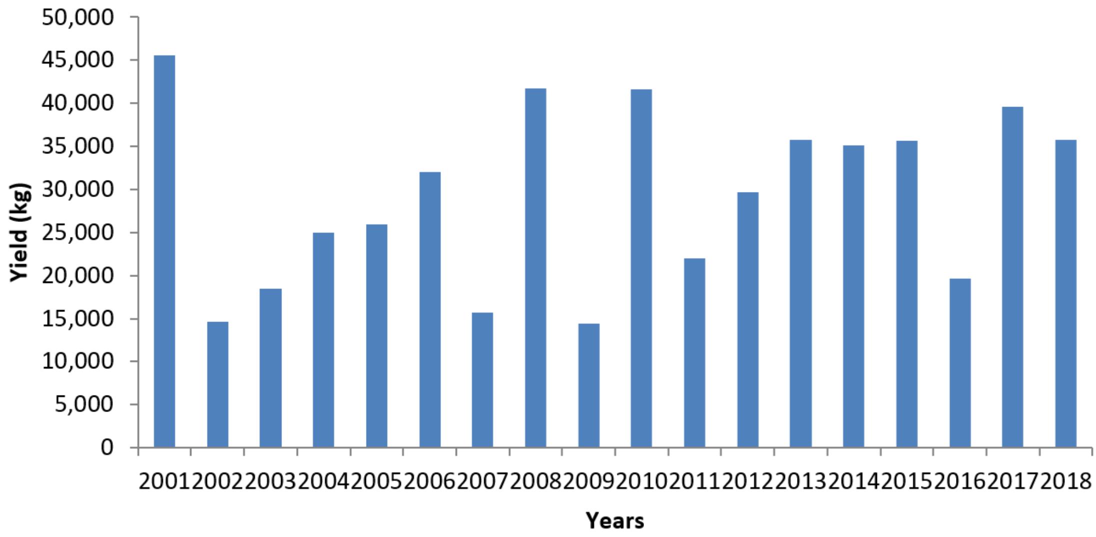

Figure 4. *Coffee yield for the period 2001 to 2018 in Machame Mashariki ward.*

3.4. Variation of Yield, Rainfall, Means Max, and Means Min over the Study Period

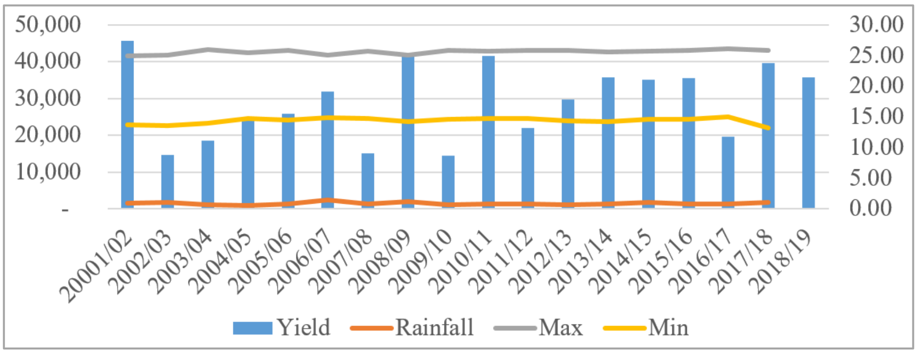

Figure 5. *Variation of yield, rainfall, means max, and means min over the study period.*

Figure 4 shows the variations in parchment yield over the study periods illustrated in the data. The highest yields were recorded in 2001/02 and 2010/11. This finding challenges the observation by [16] that climate change could lead to increased coffee production if pest and disease challenges are mitigated.

3.5. Regression Model Between Coffee Yields and Climatic Factors

The regression model between coffee yields and climatic factors is indicated in Table 1.

Table 1. *Regression model between coffee yields and climatic factors.*

Model	B	T	sig
Rainfall	0.56	1.72	0.098
T.max	-1.33	-.33803	0.935
T.min	122.42	0.275	0.785
Constant	2492.7	0.12	0.906

R^2= -1.33 F=122.42

The model in this table interprets the regression coefficient for linear relationships. The sign of a regression coefficient indicates whether there is a positive or negative correlation between each independent variable. In the table, B stands for the Beta coefficient, T stands for the t-value, F stands for the function, R stands for the regression formula, and SIG stands for the significance level.

The regression model (Table 1) relating coffee yields to the three climatic variables studied found no significant relationship at the 0.05 level. Only rainfall would be significant if the level were extended to 0.1. The expected negative relationship with maximum temperature and positive relationship with minimum temperature were observed. This implies that yield is not solely a function of climate; other factors, such as soil physical and chemical properties and crop management levels, as cited by [19], also play important roles.

4. Conclusion and Recommendation

This study analyzed long-term climate trends and their relationship with coffee yields in Machame Mashariki Ward. The findings indicate that trends in rainfall and temperature were highly irregular and did not significantly impact coffee yields. It was determined that coffee production in Machame ward has not yet been adversely affected by climate change. Total annual rainfall did not show significant variation over the study periods, although its distribution has slightly changed, with long rain peaks becoming steeper. The mean maximum temperature showed significant variation but remained stable at around 25°C, which is still within the normal range for coffee cultivation. While there are observable changes in climatic patterns, these have not yet posed a serious threat to coffee yields in Machame Mashariki. However, continuous monitoring and adaptive strategies are essential to mitigate potential future impacts of climate change on coffee production.

Abbreviations

SPSS Statistical Package for Social Science

Author Contributions

Aden Mbuba: Data curation, Formal Analysis, Writing – original draft

Domic Lameck: Data curation, Methodology, Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

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