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IMPACTS OF CLIMATE CHANGE ON THE LIVELIHOOD PRACTICES OF FARMERS IN THE BILATE WATERSHED, ETHIOPIA

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Abstract

Climate change poses significant challenges to agriculture in Ethiopia, particularly for smallholder farmers in regions like the Bilate watershed. This study investigates the impact of climate change on farmers' livelihood practices, focusing on adaptive strategies such as crop diversification, livestock rearing, mixed farming, and agroforestry. There is a notable gap in understanding how climate variability influences daily agricultural practices and farmers' adaptive responses in the Bilate watershed. The study aims to address this gap by analyzing how farmers adapt to climate change and identifying the most effective adaptive strategies. Data were collected through a household survey, employing a two-stage sampling technique across six kebeles (administrative subdivisions). In the first stage, six kebeles were selected from a total of 37 in the district using a simple random sampling method. The selected kebeles were Achamo, Balessa, Bonosha, Kulito, Handazo, and Battu Degaga. In the second stage, within each of the selected kebeles, a systematic random sampling technique was used to select 351 households. A probit regression model was used to analyze the likelihood of adopting adaptive practices in response to climatic variables such as rainfall variability and temperature increases. The findings reveal that 65% of farmers diversified their crops, influenced significantly by rainfall variability ($p < 0.05$), while 35% adopted agroforestry. Livestock rearing was strongly associated with temperature increases ($p < 0.01$). Mixed farming was negatively impacted by heatwave intensity ($p < 0.05$), showing that extreme temperatures reduce the likelihood of its adoption. Agroforestry adoption was significantly driven by loss of soil fertility ($p < 0.01$), as farmers sought to improve soil quality. The study found that climatic factors such as heatwave intensity and seasonal rainfall fluctuations negatively impact crop diversification, with increasing temperatures and erratic rainfall discouraging farmers from diversifying their crops. The analysis revealed that heatwaves adversely affect livestock rearing, leading to higher mortality rates and reduced productivity. The study demonstrates that climate change is significantly altering agricultural practices in the Bilate watershed. The findings suggest that promoting agroforestry and mixed farming systems can enhance resilience among smallholder farmers. The study recommends targeted interventions to support these adaptive strategies, offering valuable insights for policymakers aiming to improve agricultural resilience in Ethiopia's climate-vulnerable regions.

***Keywords**: Climate Change; Livelihood Practice; Probit Regression, Bilate Watershed*

1. Introduction

Climate change, driven primarily by the anthropogenic emission of greenhouse gases (GHGs) such as carbon dioxide and methane, is causing significant alterations in global weather patterns (Zhang et al. 2017; Yoro and Daramola, 2020). These changes are evidenced by rising global temperatures, melting ice caps, and more frequent extreme weather events like hurricanes, floods, and droughts (Walsh et al., 2020). The impacts of these changes are widespread, affecting ecosystems, human health, and socio-economic structures worldwide (Tachiiri et al., 2021). The global agricultural sector, which is highly sensitive to weather conditions, faces increased challenges such as shifting growing seasons, reduced water availability, and heightened pest and disease pressures (Cai et al., 2015).

Africa is exceptionally vulnerable to the impacts of climate change due to its heavy dependence on rain-fed agriculture, low adaptive capacity, and high levels of poverty (Ziervogel and Ericksen). Climate projections for the continent indicate increased temperatures, more frequent and severe droughts, and unpredictable rainfall patterns, which pose serious threats to food security and water resources (Collier et al. 2008). Ethiopia's economy is largely agrarian, with agriculture accounting for approximately 35% of the GDP and employing around 80% of the population (Chipeta et al. 2015). The country is highly susceptible to climate change due to its reliance on rain-fed agriculture, which makes it vulnerable to variations in rainfall and temperature (Gangadhara Bhat and Moges, 2021). Ethiopia has already experienced increased temperatures and more erratic rainfall patterns, leading to recurrent droughts and floods that significantly impact agricultural productivity and food security (Conway and Schipper). These climatic challenges are compounded by other issues such as soil degradation, deforestation, and population pressure, which further threaten the livelihoods of millions of Ethiopians (Bryan et al., 2009).

Numerous studies have documented the impacts of climate change on agriculture and livelihoods in Ethiopia. Tessema and Simane (2021) examined the perceptions and adaptation strategies of farmers in the Nile Basin, finding that climate variability has already led to reduced agricultural productivity, affecting both crop yields and livestock production. Similarly, Hadgu et al. (2015) reported that erratic rainfall and temperature changes are major constraints to agricultural productivity in northern Ethiopia. Adimassu and Kessler (2016) explored the adaptation strategies of smallholder farmers in the Central Rift Valley, noting that farmers employ various adaptive measures such as changing planting dates, using drought-resistant crop varieties, and practicing soil and water conservation techniques. However, the effectiveness of these strategies is often limited by factors such as lack of access to information, credit, and improved technologies. Tadesse (2010) highlighted that traditional knowledge and community-based adaptation practices play a crucial role in enhancing the resilience of farming communities to climate change.

The Bilate watershed in the Ethiopian Rift Valley Basin faces significant challenges due to climate change, particularly in water availability and hydrological dynamics. Studies indicate a notable increase in temperature and variability in precipitation patterns, leading to decreased water availability (Orke and Li, 2022). These climatic changes result in reduced river flows and groundwater levels, exacerbating water scarcity during dry seasons and impacting agricultural productivity, which is heavily reliant on rain-fed systems (Edamo et al., 2022). Additionally, altered hydrometeorological patterns contribute to more frequent and severe droughts, further stressing the watershed's resources and the communities dependent on them (Tekleab et al., 2015). Local perceptions highlight these changes, with farmers observing shifts in planting seasons and increased difficulty in sustaining crop yields, prompting adaptations such as diversified crop choices and improved water conservation practices (Getahun et al., 2020). Moreover, the combined effects of climate change and land-use changes significantly alter the hydrological responses of the watershed, leading to increased runoff and soil erosion, which further degrade the land's agricultural potential (Kuma et al., 2021).

Despite extensive research on the impacts of climate change in the Bilate watershed, there is a notable gap in studies specifically focused on the impacts of climate change on the livelihood practices of farmers. While existing literature highlights changes in water availability, hydrological dynamics, increased frequency of droughts, and local perceptions and adaptations, there is limited empirical evidence on how these climatic changes directly influence farmers' day-to-day agricultural practices, income-generating activities, and overall socio-economic resilience. Therefore, this study was intended to analyze the impacts of climate change on the livelihood practices of local farmers in the Bilate watershed.

2. Method

2.1. Study Area

The Bilate River Basin is located in Ethiopia, originating from the Gurage Mountains and draining into the Lake Abaya-Chamo watershed. It covers 5625 square kilometers and spans from the Ethiopian Highlands to the Rift Valley lowlands. The altitude ranges from 1,146 to 3,393 meters above sea level. Geographically, its location extends from 6º 36'N 38º00'E to 8º05'N 38 º12'E (Figure 1).

2.2. Demographic characteristics

The demographic characteristics of the respondents reveal that the majority were male (84.9%), with only 15.1% being female. In terms of age distribution, most respondents fell between the ages of 30-45 years (35.04%), followed by those aged 45-60 years (29.06%), while a smaller proportion were over 60 years (17.09%) or between 18-30 years (18.8%). The vast majority of respondents were married (89.46%), with a small number being widowed (6.55%), divorced (2.85%), or single (1.14%). Family size varied, with the largest group having 8-10 members (32.19%), followed by those with 5-8 members (27.35%) and more than 10 members (23.36%). In terms of educational background, 40.17% of respondents could read and write, 39.89% were illiterate, and 14.25% had reached secondary-level education. Only 4.27% had completed primary education, and 1.42% were college or university graduates.

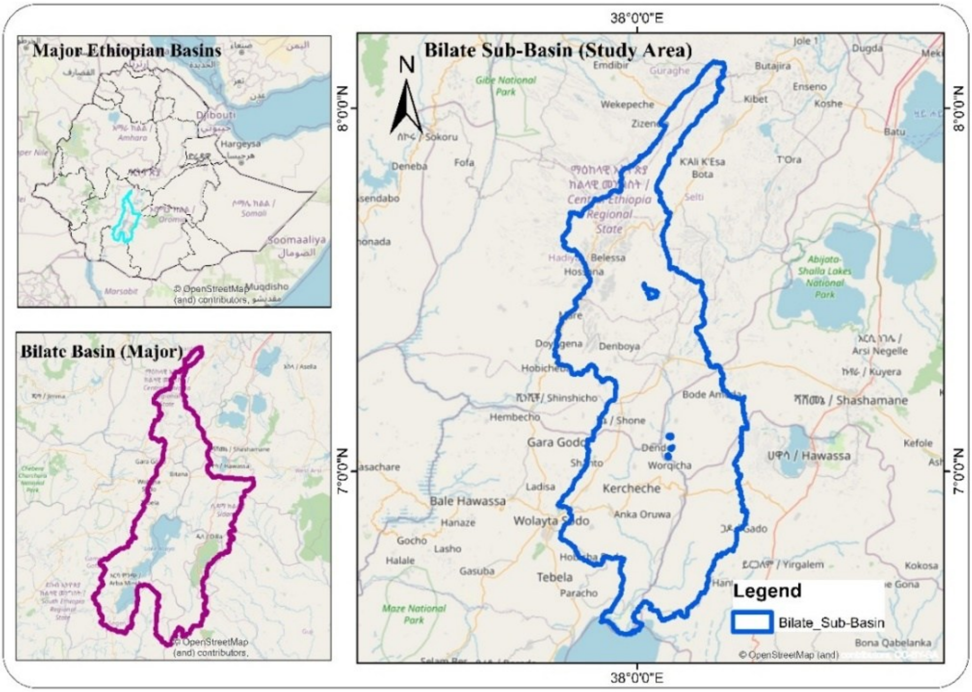

Figure 1: Location map of the study area

2.3. Research approach

In this study, a quantitative research approach was chosen to rigorously assess the impacts of climate change on the livelihood practices of farmers in the Bilate watershed, Ethiopia. This approach allows for objective measurement and statistical analysis of variables like crop diversification, livestock rearing, and adoption of agroforestry practices in response to climatic factors such as heatwaves, rainfall variability, and soil erosion rates. Through systematically quantifying these relationships, the study aims to provide robust insights into how climate change influences farmers' adaptive strategies and livelihood decisions in the Bilate watershed, contributing to evidence-based interventions and policy recommendations for enhancing agricultural resilience in similar contexts.

2.4. Data collection instruments

The research methodology employed a comprehensive and triangulated approach to gather data on climate change impacts and adaptation strategies among smallholder farmers in the Bilate watershed, Ethiopia. Utilizing a household questionnaire survey as the primary data collection tool ensured efficient gathering of information from a large and dispersed population within a defined timeframe, leveraging both closed and open-ended questions to capture a wide range of insights.

Table 1: Demographic characteristics of the respondents

Variables	Categories	Frequency	Percent
Sex	Male	298	84.90
	Female	53	15.10
Age	<18	0	0.00
	18-30	66	18.80
	30-45	123	35.04
	45-60	102	29.06
	>60	60	17.09
Marital status	Single	4	1.14
	Married	314	89.46
	Widowed	23	6.55
	Divorced	10	2.85
Family size	3-5	60	17.09
	5-8	96	27.35
	8-10	113	32.19
	>10	82	23.36
Educational level	Read and write	141	40.17
	primary level	15	4.27
	Secondary level	50	14.25
	college/university graduate	5	1.42
	Illiterate	140	39.89

Source: Field survey, 2024

2.5. Sampling technique

In this study, a two-stage sampling technique was employed to ensure the selection of a representative sample. In the first stage, six kebeles (administrative subdivisions) were selected from a total of 37 in the district using a simple random sampling method. This was done to capture the district's diversity in terms of biophysical characteristics, agricultural practices, socio-economic statuses, and climate change adaptation strategies. The selected kebeles were Achamo, Balessa, Bonosha, Kulito, Handazo, and Battu Degaga. In the second stage, within each of the selected kebeles, a systematic random sampling technique was used to select households. This method ensured that every household had an equal chance of being selected, thereby reducing bias. The sample size for the households was determined using the statistical formula developed by Yemane (1967) to ensure adequate representation across the kebeles, accounting for variations in climate change impacts and adaptation practices among smallholder farmers. Additionally, purposive sampling and snowball sampling were used to select knowledgeable key informants and participants for focus group discussions, adding depth to the qualitative aspects of the study by gathering rich insights into local climate impacts. In these processes, the statistical formula developed by Yemane (1967) was used to determine the sample size as follows:

$$n = \frac{N}{1 + N(e)} \qquad \text{Equation (1)}$$

Where n is the sample size, N is the total number of households, and e is the error designating to be at a 0.05 significant level. According to the unpublished document obtained from BRB district administration, the total number of the households in the respective kebeles are Achamo (578), Balessa (407), Bonosha (524), Kulito (397), Handazo, (451), and Battu Degaga (519) making a total of 2876 households. Hence using Equation 2, the sample size was determined as follows:

$$n = \frac{2876}{1 + 2876(0.05)} \qquad \text{Equation (2)}$$

$$n = 351 \qquad \text{Equation (3)}$$

2.6. Method of data analysis

2.6.1. Econometric model

To analyze how climate change affects different farming practices, a probit regression model was used. This type of model helps us understand the likelihood of farmers adopting certain strategies like crop diversification, livestock rearing, mixed farming, or agroforestry when faced with changes in climate, such as temperature increases or rainfall variability. Essentially, the model estimates the probability of a farmer choosing a particular practice based on how these climate factors are affecting their environment. This approach allows us to see which climate changes are influencing specific farming decisions, providing insights into the best ways to support farmers in adapting to climate change (Habtemariam et al., 2016).

The dependent variables represent key livelihood practices of farmers within the Bilate watershed, impacted by climate change. These practices include:

Crop Diversification: These variables measure how farmers diversify their crop production as a response to climatic changes. It's treated as a binary variable, where diversification is coded as 1 and non-diversification as 0.

Livestock Rearing: This variable assesses the practice of raising livestock and how it's affected by climate factors like heatwaves and rainfall variability. It is also a binary variable, with 1 indicating engagement in livestock rearing and 0 otherwise.

Mixed Farming: This variable combines both crop cultivation and livestock rearing.

It evaluates how climatic conditions influence the integration of these practices. It's coded as 1 for mixed farming and 0 for single farming practices.

Agroforestry: This variable looks at the practice of integrating trees and shrubs into agricultural landscapes to enhance productivity and sustainability. It is treated as a binary variable, with 1 representing the adoption of agroforestry and 0 indicating non-adoption.

Table 2 summarizes the independent variables used in the study, detailing their descriptions and measurement scales. The variables include a range of climatic factors and their impacts on agricultural practices. For instance, the Intensity of Heatwaves (HV) and Seasonal Rainfall Fluctuation (RF) are measured on a continuous scale from 0 to 1, indicating the severity and variability of these events. Other variables like Heavy Amount of Annual Rainfall (HR) are measured in millimeters, while Loss of Pasture Land (LP) is quantified in hectares. Additionally, some variables are categorical, such as Livestock Health Issues and Drought Occurrences, which categorize the presence or severity of these conditions.

Table 2: Independent variables description for the impacts of climate change on the livelihood practices

Variable	Description	Measurement Scale
Intensity of Heatwaves (HV)	Measures the frequency and severity of heatwave events	Continuous (0 to 1 scale)
Seasonal Rainfall Fluctuation (RF)	Assesses variations in rainfall patterns over different seasons	Continuous (0 to 1 scale)
Heavy Amount of Annual Rainfall (HR)	Evaluates the total annual precipitation	Continuous (mm)
Crop Water Stress	Reflects the degree to which crops experience water deficiency	Continuous
Livestock Health Issues	Measures the prevalence of health problems in livestock	Categorical
Drought Occurrences	Tracks the frequency and severity of drought events	Categorical
Loss of Pasture Land (LP)	Assesses the reduction in available pasture land	Continuous (hectares)
Loss of Soil Fertility (LSF)	Evaluates the decline in soil quality and fertility	Continuous (0 to 1 scale)
Soil Erosion Rate (SE)	Measures the extent of soil erosion	Continuous (0 to 1 scale)
Farmers' Perceptions and Awareness of Climate Change	Assesses how farmers perceive and understand climate change	Categorical
Access to Climate Information	Evaluates access to information regarding climate patterns	Categorical

The Probit regression model employed in this study analyses the impacts of climate change on various livelihood practices. The model estimates the probability of adopting specific practices (such as crop diversification, livestock rearing, mixed farming, and agroforestry) in response to climatic variables. The general form of the Probit regression model can be expressed as:

$$P(Y_i = 1|X_i) = \Phi(X_i\beta) \qquad \text{Equation (4)}$$

Where:

$P(Y_i = 1|X_i)$is the probability that the dependent variable (Yi) (representing the adoption of a specific livelihood practice) equals 1 given the independent variables (Xi). Φ is the cumulative distribution function of the standard normal distribution. (Xi) is a vector of independent variables. β is a vector of parameters to be estimated.

For each dependent variable (Yi), the Probit model estimates the probability of adoption based on the linear combination of the independent variables (Xi) weighted by the parameter vector β. The cumulative distribution function Φ then transforms this linear combination into a probability.

The specific Probit regression equation for each dependent variable (Yi) representing a particular livelihood practice can be written as:

$$P(Y_i = 1|X_i) = \Phi(X_i\beta) \qquad \text{Equation (5)}$$

Where (Xi) includes the relevant independent variables for the particular livelihood practice being analyzed.

3. Results

3.1. Impacts of climate variability on crop diversification

The impact of various environmental factors on crop diversification in the Bilate watershed was explored using a probit regression model. While several coefficients suggested potential negative associations with crop diversification, most did not achieve statistical significance. Heatwaves showed a negative coefficient (-0.188), indicating a possible adverse effect on crop diversification, though it was not statistically significant (p = 0.435). Similarly, seasonal rainfall fluctuation, heavy annual rainfall, loss of soil fertility, loss of pasture land, crop yield reduction, and loss of livestock also exhibited coefficients suggesting negative impacts on crop diversification. Yet, none were statistically significant except for the loss of livestock (-1.962, p < 0.05). These findings align with existing literature emphasizing the complex relationship between climatic variables and agricultural practices in influencing crop diversity.

The practical implication of these findings is that while climate factors such as heatwaves and rainfall variability may exert pressure on farmers, livestock loss appears to be a particularly critical issue. This suggests that interventions aimed at protecting livestock during climate extremes could have the additional benefit of enabling farmers to maintain or increase crop diversification, thereby improving their resilience to climate change. Supporting farmers with livestock insurance, veterinary services, or alternative income sources may help mitigate the negative impacts of livestock loss on crop diversification.

Probit Regression Results

	Livelihood Practices (Dependent variable):			
	Crop Diversification (1)	Livestook rearing (2)	Mixed Farming (3)	Agroforestry (4)
Intensity of heatwaves	-0.188	-0.834*	-1.071**	-0.170
	(0.435)	(0.427)	(0.465)	(0.385)
Seasonal Rainfall flactuation	-0.116	-0.072	0.315	-0.140
	(0.482)	(0.534)	(0.706)	(0.425)
Heavy amount of annual rainfall	0.843	2.099***	-0.767	0.213
	(0.502)	(0.553)	(0.630)	(0.458)
High soil erosion rate	-0.187**	-0.018	-1.270**	-0.116
	(0.421)	(0.491)	(0.517)	(0.401)
Loss of soil fertility	-0.654	-0.761*	-0.905	1.499***
	(0.405)	(0.429)	(0.555)	(0.317)
Loss of pasture land	-0.481	1.966***	-0.534	0.677
	(0.532)	(0.468)	(0.624)	(0.450)
Crop yeild reducation	-0.114	-0.651	-3.013***	0.239
	(0.474)	(0.432)	(0.536)	(0.418)
Loss of Livestock	-1.962**	-0.024	0.035	-0.769*
	(0.544)	(0.537)	(0.586)	(0.432)
Constant	-0.322	-2.837**	1.886	-1.274
	(1.148)	(1.173)	(1.491)	(0.999)
Observations	351	351	351	351
Log Likelihood	-33.603	-34.385	-27.807	-64.293
Akaike Inf. Crit.	87.207	88.770	75.615	148.586
Note:				*p<0.1; **p<0.05; ***p<0.01

Figure 2: Probit regression results

3.2. Impact on livestock rearing

The probit regression model was employed to assess the influence of various environmental factors on livestock rearing in the Bilate watershed. The analysis shows that heatwaves have a significant negative impact on livestock rearing (-0.834, $p < 0.1$), indicating that as heatwave intensity increases, the likelihood of farmers continuing to rear livestock declines. This suggests that heat stress directly threatens livestock health, water availability, and forage, all of which are essential for sustaining livestock production. In areas experiencing frequent heatwaves, farmers face higher livestock mortality rates or decreased productivity, leading to a reduction or abandonment of livestock rearing. In contrast, heavy annual rainfall had a significant positive effect on livestock rearing (2.099, $p < 0.01$), showing that more abundant rainfall improves water supply and pasture growth, creating favorable conditions for livestock. This is crucial for pastoral and mixed farming communities that depend on consistent water sources and healthy grazing lands. The positive correlation indicates that areas with reliable rainfall maintain or expand livestock production. The model also found a significant positive association between loss of pasture land and livestock rearing (1.966, $p < 0.01$). This reflects a compensatory strategy, where farmers respond to pasture loss by intensifying their efforts to rear livestock, perhaps by investing more resources into feeding or managing their animals. Livestock remains a crucial economic asset, even in the face of environmental degradation, driving farmers to sustain production through alternative means. Factors like seasonal rainfall fluctuation, soil erosion, and loss of soil fertility showed non-significant negative effects on livestock rearing, indicating that these environmental changes reduce the availability and quality of pastureland, which diminishes livestock productivity over time. These findings highlight the need for targeted interventions to protect livestock from heat stress, such as improving access to water, shade, and veterinary care. Efforts to sustainably manage grazing lands and restore degraded pasture areas are essential to help farmers mitigate the adverse effects of climate change and maintain livestock as a vital part of their livelihoods.

3.3. Impact on mixed farming

The probit regression model analyzed the effects of environmental factors on mixed farming in the Bilate watershed, revealing several key challenges. Heatwave intensity had a significant negative impact on mixed farming (-1.071, $p < 0.05$), indicating that extreme heat reduces the likelihood of farmers engaging in both crop cultivation and livestock rearing, reflecting the difficulties of managing mixed farming systems under heat stress. Seasonal rainfall fluctuation showed a positive coefficient (0.315, $p = 0.706$), suggesting that diversified farming systems may help farmers cope with variable rainfall patterns, although this was not statistically significant. In contrast, heavy annual rainfall had a negative coefficient (-0.767, $p = 0.630$), indicating that excessive rainfall can disrupt mixed farming practices by causing flooding and waterlogging. High soil erosion rates demonstrated a significant negative association with mixed farming (-1.270, $p < 0.05$), highlighting that erosion degrades land quality and discourages mixed farming due to reduced productivity. Although loss of soil fertility (-0.905, $p = 0.555$) and loss of pasture land (-0.534, $p = 0.624$) were not statistically significant, their negative coefficients indicate challenges to the sustainability of mixed farming systems. Additionally, crop yield reduction had a significant negative effect (-3.013, $p < 0.01$), showing that lower crop yields reduce feed availability for livestock, directly impacting the viability of mixed farming. Conversely, loss of livestock showed a non-significant positive coefficient (0.035, $p = 0.586$), suggesting that farmers might adapt by integrating more crops into their systems to compensate for livestock losses. Overall, these findings underscore the need for interventions addressing land degradation, such as soil conservation and erosion control measures, as well as improvements in crop resilience and water resource management to support the viability of mixed farming systems in the face of climate change.

3.4. Impacts on agroforestry

In the Bilate watershed, the impact of environmental factors on agroforestry adoption was investigated using a probit regression model. The study found a non-significant negative association between the intensity of heat waves (-0.170, $p = 0.385$) and agroforestry, indicating potential challenges due to heat stress affecting tree growth and water availability. Similarly, seasonal rainfall fluctuation (-0.140, $p = 0.425$) showed a non-significant negative coefficient, suggesting difficulties in tree establishment amid variable rainfall. Conversely, heavy annual rainfall (0.213, $p = 0.458$) exhibited a non-significant positive coefficient, suggesting conducive conditions for agroforestry where adequate water supports tree productivity. A high soil erosion rate (-0.116, $p = 0.401$) presented a non-significant negative coefficient, implying potential challenges in maintaining soil stability critical for agroforestry. In contrast, loss of soil fertility (1.499, $p < 0.01$) showed a significant positive coefficient, indicating degraded soil conditions might incentivize agroforestry adoption for soil health improvement. Loss of pasture land (0.677, $p = 0.450$) displayed a non-significant positive coefficient, suggesting interest in agroforestry as an alternative land-use strategy. Crop yield reduction (0.239, $p = 0.418$) had a non-significant positive coefficient, indicating that regions with lower crop yields might consider agroforestry to enhance agricultural resilience. A significant negative association was found between loss of livestock (-0.769, $p < 0.1$) and agroforestry adoption, highlighting challenges due to reduced household resources and income. These findings underscore the intricate dynamics of environmental influences on agroforestry adoption, necessitating targeted interventions to promote sustainable agricultural practices in the Bilate watershed.

4. Discussion

In Ethiopia, various studies have shown that climate change significantly affects crop diversification. For example, Deressa et al. (2009) noted that climate variability, including increasing temperatures and changing rainfall patterns, adversely affects agricultural production. Specifically, the intensity of heat waves negatively impacts crop yields and thus the diversity of crops that farmers can grow. The findings from the Bilate watershed, where the coefficient for the intensity of heat waves on crop diversification aligns with this broader trend. Furthermore, Kassie (2018) highlighted that rainfall variability, particularly fluctuations in seasonal rainfall, leads to decreased agricultural productivity and crop diversification. This finding is consistent with the Bilate watershed results, where seasonal rainfall fluctuation shows a negative coefficient for crop diversification, though also not statistically significant. These studies collectively suggest that managing rainfall variability is crucial for maintaining crop diversity in Ethiopia's agricultural systems.

Livestock rearing in Ethiopia is highly susceptible to climate change impacts, particularly heatwaves and droughts. The significant negative association between the intensity of heatwaves and livestock rearing in the Bilate watershed study (-0.834, $p < 0.1$) reflects this vulnerability. Research by Yilma et al. (2009) confirms that heat stress significantly reduces livestock productivity by affecting feed and water availability, leading to higher mortality rates. Similarly, Bogale and Erena (2022) documented that recurrent droughts and heat waves reduce livestock numbers and productivity, impacting farmers' income and food security. The loss of livestock itself is a critical issue in Ethiopia. The significant negative association found in the Bilate watershed mirrors findings by Aklilu et al. (2002), who noted that livestock losses due to climate-related events force farmers to abandon livestock rearing, further compromising their livelihoods.

The mixed farming systems in Ethiopia, which integrate crop and livestock farming, are particularly vulnerable to climate change. The significant negative impact of heat waves on mixed farming (-1.071, $p < 0.05$) observed in the Bilate watershed is echoed by studies such as those by Kassaye et al. (2021). They reported that climate stressors like heatwaves disrupt both crop and livestock productivity, making mixed farming less viable. The combined stresses on crops and livestock due to extreme weather events reduce the effectiveness of mixed farming as a livelihood strategy. Agroforestry practices in Ethiopia, while recognized for their potential to enhance resilience against climate change, also face challenges. The significant negative association between loss of livestock and agroforestry (-0.769, $p < 0.1$) in the Bilate watershed indicates that livestock losses undermine the capacity of farmers to engage in and benefit from agroforestry. This finding is supported by studies like that of Mbow et al. (2014), who found that livestock provide essential resources such as manure and draft power, which are critical for maintaining productive agroforestry systems. The loss of these resources due to climate-induced livestock mortality severely limits the ability of farmers to practice agroforestry effectively.

Farmers could enhance their resilience by adopting climate-resilient crop varieties that are better suited to withstand extreme temperatures and fluctuating rainfall patterns. Additionally, implementing rainwater harvesting and irrigation systems could help mitigate the effects of rainfall variability, ensuring more consistent water availability for crops. Training programs focused on sustainable agricultural practices could also empower farmers to diversify their planting schedules and choose crops that thrive under variable climatic conditions. To address livestock rearing vulnerabilities, farmers can implement shaded areas for livestock to reduce heat stress and improve water management practices to ensure that livestock have access to adequate hydration. Additionally, creating supplementary feeding programs during drought periods can help sustain livestock health and productivity. The establishment of community-based animal health programs can also enhance the capacity of farmers to manage livestock effectively, particularly during extreme weather events. Policymakers should consider promoting agroforestry and mixed farming as part of broader climate adaptation strategies, encouraging practices that enhance ecosystem services. Initiatives that support livestock health and productivity are essential to maintain the complementary relationship between crop and livestock farming, thereby strengthening overall resilience to climate change.

While this study provides valuable insights into the impacts of climate change on agricultural practices in the Bilate watershed, it has limitations. The analysis focused on specific environmental factors and may not encompass all variables affecting farming systems, such as socio-economic factors or local governance structures. Future research could explore the interplay between these factors and climate adaptation strategies to provide a more comprehensive understanding of how farmers can effectively respond to climate challenges. Longitudinal studies assessing the long-term effects of climate change on agriculture in various regions of Ethiopia could yield important data for developing adaptive strategies. Additionally, research that evaluates the effectiveness of implemented adaptation practices will help refine approaches that enhance resilience in Ethiopian agriculture.

5. Conclusion

The study found that climatic factors such as the intensity of heatwaves and seasonal rainfall fluctuations negatively impact crop diversification, although these impacts were not statistically significant. This suggests that increased temperatures and unpredictable rainfall patterns discourage farmers from diversifying their crops, which can threaten food security and income stability. The significant negative impact of heatwaves on livestock rearing highlights the vulnerability of livestock to rising temperatures, leading to higher mortality rates and reduced productivity. The findings indicate that extreme heat disrupts the balance required for successful mixed farming practices, adversely affecting both crop yields and livestock health. Moreover, agroforestry practices are also influenced by climate change, particularly through the loss of livestock, which diminishes critical resources such as manure and draft power essential for maintaining agroforestry systems. The results from the Bilate watershed align with broader research findings across Ethiopia, confirming that climate change poses substantial threats to agricultural livelihoods. These insights underscore the urgent need for comprehensive climate adaptation strategies. Policymakers should focus on developing and promoting climate-resilient agricultural practices that enhance crop diversification and improve livestock management. Specific interventions could include investing in research and development of heat-resistant crop varieties, implementing community-based training programs for farmers on sustainable practices, and providing financial support for irrigation systems to cope with rainfall variability. Furthermore, agricultural extension services must prioritize education on effective livestock management during extreme weather events, including the provision of shaded areas and supplementary feeding programs to mitigate heat stress. Farmers are encouraged to diversify their income sources, integrate agroforestry practices, and adopt water conservation techniques to enhance resilience. Future research should explore the long-term effects of climate change on agricultural practices in different regions of Ethiopia, considering socio-economic factors and local governance structures. By understanding these dynamics, stakeholders can refine their approaches to building resilience against climate change, ensuring sustainable agricultural systems that support the livelihoods of smallholder farmers.

Declarations

Conflict of interest: There is no potential conflict of interest by the authors.

Data availability statement: The required data could be available from the corresponding author if there is a request.

Ethics Statement

The study complies with all regulations and confirms that informed consent was obtained from the participants in collecting data.

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