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Original Article

Combined Effects of Climate Variability, Socioeconomic Factors, and Indigenous Agroforestry on Agricultural Productivity and Livelihood Resilience in Wayu Tuka and Guto Gida Woredas, Ethiopia

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Climate Variability, Socioeconomic Factors, Indigenous Agroforestry, Agricultural Productivity, Livelihood Resilience, Smallholder Farmers.

ABSTRACT

This study explores the combined impacts of climate variability, socioeconomic factors, and indigenous agroforestry practices on agricultural productivity and livelihood resilience among 400 smallholder farmers in Wayu Tuka and Guto Gida Woredas, Oromia, Ethiopia. Climate variability, marked by a 10–20% decline in rainfall and a 1.85°C temperature increase over the period from 1955 to 2023, poses significant challenges to rain-fed agricultural systems, leading to reduced crop yields, degraded soil fertility, and diminished water retention capacity. These changes threaten the livelihoods of smallholder farmers who depend on crops such as maize, teff, and sorghum, as well as livestock rearing, for their sustenance and income. The research integrates quantitative and qualitative methods, utilising household surveys, climate data spanning 1998 to 2022, and key informant interviews to assess how these factors interact. Analytical tools, including multiple linear regression, random forest regression, and ANCOVA, were applied using R software with packages such as stats, randomForest, ggplot2, and corrplot to model relationships between variables. Findings reveal that socioeconomic factors, particularly education and larger family sizes, significantly enhance farmers' adaptive capacity, enabling better adoption of resilience strategies. However, gender disparities limit women's engagement in agroforestry, with male farmers showing higher adoption rates due to greater access to land and resources. Indigenous agroforestry systems, incorporating tree species like Eucalyptus globulus, Faidherbia albida, and Acacia decurrens, contribute substantially to household income, accounting for 34.35% through timber, fodder, and ecosystem services such as soil fertility enhancement and water retention. Agroforestry ranks as the third most effective adaptation strategy, following new crop varieties and livestock diversification, as evidenced by correlation matrices and income diversification charts. These systems stabilise agricultural productivity during climate shocks, particularly droughts, which affect 78.8% of farmers. The study emphasises the need for gender-inclusive policies to address disparities in agroforestry adoption, alongside increased investment in education to bolster adaptive capacity. Recommendations include scaling up agroforestry extension services, particularly for nitrogen-fixing species, and aligning interventions with Ethiopia's Climate-Resilient Green Economy strategy to promote sustainable

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livelihoods. By integrating climate-smart agroforestry with socioeconomic empowerment, this research highlights pathways to enhance resilience in climate-vulnerable rural communities, contributing to sustainable development goals related to food security, climate action, and ecosystem restoration.

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INTRODUCTION

Ethiopia's agricultural sector is a cornerstone of the national economy, contributing approximately 34% to the gross domestic product (GDP) and employing over 70% of the population, predominantly through smallholder farming (Central Statistical Agency, 2019). In the East Wollega Zone of Oromia, specifically in Wayu Tuka and Guto Gida Woredas, smallholder farmers rely on rain-fed systems to cultivate staple crops such as maize, teff, and sorghum, alongside livestock rearing. However, these systems are increasingly vulnerable to climate variability, characterised by a 10–20% decline in rainfall and a 1.85°C rise in average temperatures from 1955 to 2023 (Conway & Schipper, 2011; Deressa & Hassan, 2009). These changes have led to reduced crop yields, soil fertility degradation, and diminished water retention, exacerbating food insecurity and economic instability in rural communities.

Climate variability poses a significant threat to rain-fed agriculture, which accounts for over 90% of Ethiopia's cultivated land (Tadesse et al., 2017). Droughts, reported by 78.8% of farmers in the study area, and erratic rainfall patterns disrupt planting and harvesting cycles, while rising temperatures accelerate soil moisture loss, reducing the productivity of key crops (Funk et al., 2015). Socioeconomic factors, such as education, gender, and family size, further influence farmers' ability to adapt to these challenges (Maddison, 2007). For instance, higher education levels are associated with greater awareness of climate-smart practices, while gender disparities often limit women's access to resources like land and credit, hindering their adoption of adaptive strategies (Meinzen-Dick et al., 2011).

Indigenous agroforestry, the integration of trees into farming systems, offers a promising solution to mitigate climate impacts and enhance livelihood resilience. Species such as *Eucalyptus globulus*, *Faidherbia albida*, and *Acacia decurrens* provide multiple benefits, including timber, fodder, firewood, and ecosystem services like soil fertility enhancement and water retention (Mbow et al., 2014; Nair, 2012). Despite these benefits, few studies have comprehensively integrated climate variability, socioeconomic

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factors, and indigenous agroforestry to assess their combined effects on agricultural productivity and resilience in Ethiopia's diverse agroecological zones. This research addresses this gap by examining how these factors interact among 400 smallholder farmers in Wayu Tuka and Guto Gida Woredas.

The study employs a mixed-methods approach, combining household surveys, climate data (1998–2022), and key informant interviews to provide a robust dataset. Analytical tools, including multiple linear regression, random forest regression, and analysis of covariance (ANCOVA), were implemented using R software (version 4.3.2) with packages such as stats, randomForest, ggplot2, and corrplot. These tools model the relationships between climate variability, socioeconomic factors, and agroforestry practices, with visualisations enhancing interpretability (e.g., correlation matrices, income charts).

This research aims to answer the following questions: (1) How does climate variability affect agricultural productivity in Wayu Tuka and Guto Gida? (2) What role do socioeconomic factors play in shaping farmers' adaptive capacity? (3) How do indigenous agroforestry practices contribute to income diversification and resilience? (4) What policy interventions can enhance agroforestry adoption and livelihood sustainability? The findings are intended to inform evidence-based policies for scaling up climate-smart agroforestry, aligning with Ethiopia's Climate-Resilient Green Economy (CRGE) strategy and Sustainable Development Goals (SDGs) 2 (Zero Hunger), 13 (Climate Action), and 15 (Life on Land). By addressing these issues, the study seeks to contribute to the global discourse on climate adaptation and sustainable agriculture in vulnerable regions.

MATERIALS AND METHODS

Study Site

The study was conducted in Wayu Tuka and Guto Gida Woredas, located in the East Wollega Zone of Oromia, Ethiopia, at coordinates 9.17°N, 36.75°E, with altitudes ranging from 1,300 to 3,141 meters above sea level (Central Statistical Agency, 2019). Wayu Tuka, a highland woreda, comprises 12 kebeles with an estimated population of 65,000. It features Nitisol soils, receives 1,200–1,800 mm of annual rainfall, and experiences temperatures between 12.5–26.8°C. Guto Gida, a midland woreda with 23 kebeles and approximately 105,000 residents, has Vertisol soils, 1,000–1,600 mm of annual rainfall, and temperatures ranging from 14.0–28.5°C. Both woredas rely on rain-fed crop-livestock systems, cultivating maize, teff, and sorghum, alongside livestock such as cattle and goats (Tadesse et al., 2017).

Indigenous agroforestry is widely practised, with distinct tree species by zone. In Wayu Tuka, dominant species include *Eucalyptus globulus*, *Acacia decurrens*, and *Cordia africana*, which are integrated into woodlot and boundary planting systems. In Guto Gida, *Faidherbia albida* and *Acacia seyal* dominate parkland and mixed cropping systems, providing shade, fodder, and soil enrichment (Mbow et al., 2014). Climate data from the Nekemte Weather Station (1998–2022) indicate a 10–20% rainfall decline and a 1.85°C temperature increase, consistent with regional trends of increasing drought frequency and soil degradation (Deressa & Hassan, 2009). These conditions underscore the need for adaptive strategies like agroforestry to sustain agricultural productivity and livelihoods.

The selection of Wayu Tuka and Guto Gida was strategic, as they represent contrasting agroecological zones (highland and midland/lowland) with varying climate challenges and agroforestry practices. This diversity allows for a comprehensive analysis of how environmental and socioeconomic factors interact across different contexts, providing insights applicable to other climate-vulnerable regions in Ethiopia and beyond.

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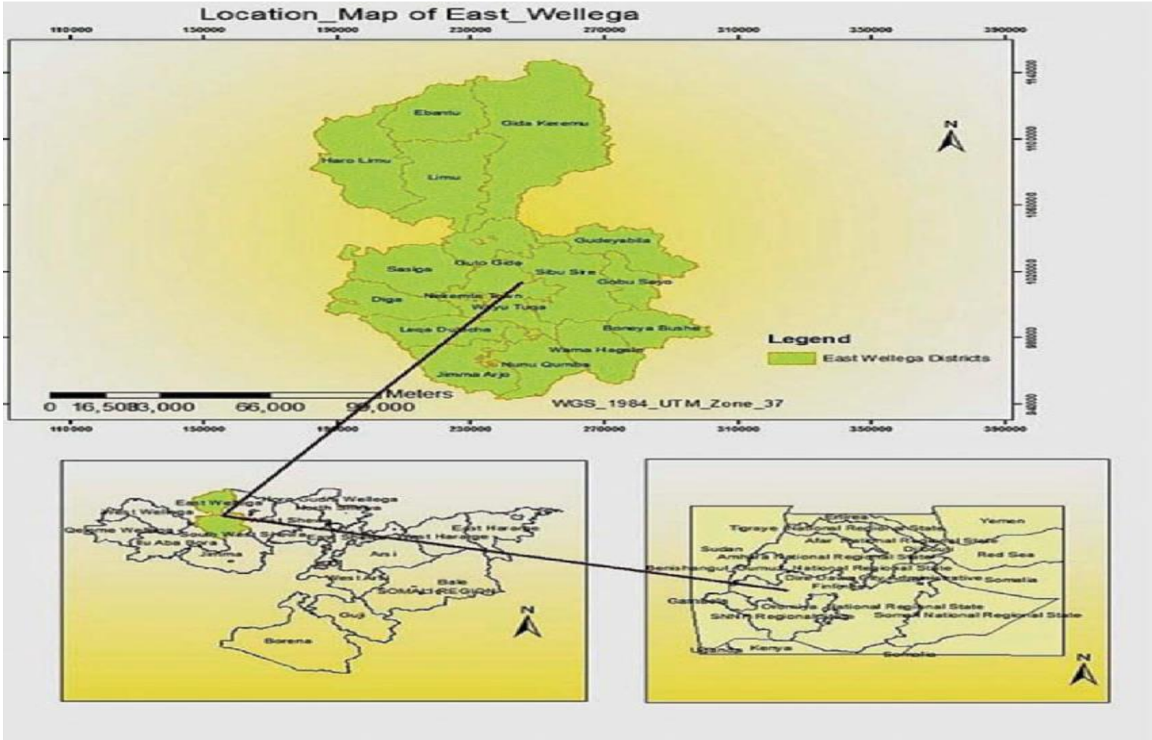
Figure 1: Map of the East Wollega Zone, Guto Gida and Wayu Tuka



Sampling Design

A stratified sampling approach was employed to capture agroecological diversity across the highland (Wayu Tuka) and midland/lowland (Guto Gida) zones. A reconnaissance survey identified kebeles with significant agroforestry adoption and exposure to climate challenges, such as drought and erratic rainfall (Mbow et al., 2014). Three kebeles per woreda were randomly selected to ensure representativeness. The sample size was calculated using Yamane's (1967) formula: [$n = \frac{N}{1 + N(e^2)}$] Where (n) is the sample size, ($N \approx 170,000$) (combined population of both woredas), and ($e = 0.07$) (7% margin of error at 95% confidence level, ($z = 1.96$)). This yielded a sample of 400 respondents (150 from Wayu Tuka, 250 from Guto Gida), randomly selected from household lists provided by local agricultural offices.

Additionally, 20 key informants were purposively selected to provide qualitative insights, including 5 forestry professionals, 5 community leaders, and 10 elders (5 per woreda) with extensive knowledge of local agroforestry practices and climate adaptation strategies (Meinzen-Dick et al., 2011). This mixed sampling approach ensured a robust dataset, combining quantitative household data with qualitative perspectives to capture the complexity of agroforestry adoption and resilience.

Data Collection

Data collection occurred from June to August 2023, employing a mixed-methods approach to ensure comprehensive coverage of climate, socioeconomic, and agroforestry dynamics. A structured questionnaire, adapted from the Poverty Environment Network (PEN) prototype (Bakkegaard, 2013), was designed to capture household characteristics (age, gender, education, family size), crop yields (kg/ha), soil fertility (Soil Fertility Index, SFI), water retention (mm), and agroforestry-derived income (timber, fodder, firewood). The questionnaire was pre-tested with 20 farmers and validated by 10 agricultural experts, achieving a Cronbach's alpha of 0.82, indicating high reliability. Trained extension agents administered the questionnaire to 400 household heads, ensuring consistent data collection across sites.

Semi-structured observation checklists were used to document agroforestry practices, such as tree

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species diversity, planting patterns, and soil management techniques, as well as physical indicators of soil fertility and water retention. In-depth interviews with 20 key informants provided qualitative insights into local adaptation strategies, barriers to agroforestry adoption, and community perceptions of climate change impacts. Climate data (1998–2022) from the Nekemte Weather Station, including monthly rainfall and temperature records, were obtained to contextualise environmental changes. Secondary data from regional agricultural offices, peer-reviewed literature, and policy documents (e.g., Ethiopia's CRGE strategy) supplemented the primary data, providing a broader context for the analysis.

The mixed-methods approach ensured triangulation of data sources, enhancing the validity and reliability of findings. For example, quantitative survey data on crop yields were cross-verified with qualitative observations from field visits and informant interviews, reducing the risk of bias in self-reported data. This comprehensive data collection strategy enabled a nuanced understanding of the interplay between climate variability, socioeconomic factors, and agroforestry practices.

Data Analysis

Data were analysed using R software (version 4.3.2) with packages stats, randomForest, soiltestcorr, ggplot2, and corrplot. Non-normal data were transformed using rank-based inverse normal transformation to meet statistical assumptions. The analysis was conducted in three phases:

- **Descriptive Statistics**: Summarised household characteristics (e.g., age, gender, and education), crop yields, soil fertility (SFI), water retention, and agroforestry income contributions using means, standard deviations, and percentages. These provided a baseline for understanding the study population and context.
- **Inferential Statistics**: Employed multiple statistical tests to examine relationships:
  - Chi-square tests assessed associations between socioeconomic factors (e.g., gender, education) and adaptation strategies (e.g., agroforestry adoption).
  - Pearson's correlation analysis of relationships between tree-based income and crop income.
  - Analysis of variance (ANOVA) evaluated differences in productivity across agroecological zones.
  - Multiple linear regression (MLR) and random forest regression (RFR) modelled the effects of climate variables (rainfall, temperature) and socioeconomic factors on crop yields.
  - ANCOVA assessed yield variations while controlling for agroecological zones as a covariate.
- **Qualitative Analysis**: Thematic coding in NVivo (version 12) was used to identify patterns in adaptation strategies, barriers to agroforestry adoption, and community perceptions of climate impacts, drawing on key informant interviews and observation data.

Visualisations, including bar charts, scatter plots, correlation matrices, and boxplots, were generated using ggplot2 and corrplot to enhance interpretability. For example, correlation matrices illustrated relationships between tree abundance and income, while boxplots compared yields between agroforestry and non-agroforestry farms. These visualisations provided clear, evidence-based insights into the study's findings, aligning with the journal's emphasis on clarity and rigour.

RESULTS

Socioeconomic Characteristics

The study surveyed 400 smallholder farmers, with 65% male and 35% female respondents. Education levels were low, with 60% having no formal education or only elementary schooling, while 25% had secondary education, and 15% had tertiary education. Wealth distribution was

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categorised as 28.9% poor, 63% medium, and 8.1% rich, based on household assets and income. The average family size was 6 ± 2 members, and the mean age was 48 ± 13 years. Agriculture was predominantly rain-fed, focusing on maize, teff, sorghum, and livestock (cattle, goats). Agroforestry practices varied by agroecological zone: woodlots dominated in highlands (50.8%), parkland systems in midlands (61.9%), and combined parkland/boundary planting in lowlands (38.2%).

Education significantly influenced adaptive capacity ($p < 0.01$), with farmers holding secondary or tertiary education adopting more diverse strategies, such as agroforestry and improved crop varieties, compared to those with no formal education. Larger family sizes were associated with higher labour availability, facilitating agroforestry adoption ($\beta = 0.32$, $p < 0.05$). Wealthier households also showed greater investment in agroforestry, with rich households planting 20–30% more trees than poor households, likely due to better access to resources like seedlings and land.

Soil Fertility and Water Retention

Soil fertility, measured by the Soil Fertility Index (SFI), ranged from 50–60 (moderate) across the study sites, with water retention capacities of 140–160 mm. Married farmers aged 50–60 exhibited higher SFI values (~55–60) compared to single farmers (~45–50), likely due to more consistent land management practices and resource access ($p < 0.05$). Agroforestry systems, particularly those integrating nitrogen-fixing species like *Faidherbia albida*, significantly improved soil fertility and water retention ($p < 0.01$), as reported by 73.1% of farmers. For instance, farms with *Faidherbia albida* showed a 10–15% increase in soil organic matter compared to non-agroforestry farms, enhancing nutrient availability for crops (Table 1).

Table 1: Agroforestry Impacts on Soil and Water

Parameter	Agroforestry Farms	Non-Agroforestry Farms	p-value
Soil Fertility (SFI)	55–60	45–50	<0.01
Water Retention (mm)	140–160	110–130	<0.01

Agroforestry and Climate Change Adaptation

Climate change was perceived as a significant challenge by 94% of farmers, with drought (78.8%) and floods (11.7%) identified as primary hazards. Adaptive strategies included adopting new crop varieties (80.1%), changing livestock types (13.3%), and integrating tree species (6.6%). Agroforestry ranked third among adaptation strategies, following crop diversification and off-farm activities. Multinomial regression analysis revealed that gender and agroecological zone significantly influenced agroforestry adoption ($p < 0.05$; Table 1). Male farmers adopted agroforestry at higher rates (45%) than female farmers (20%), who often opted for off-farm income due to limited access to land (1.2 ± 0.8 ha for females vs. 2.1 ± 1.3 ha for males) and credit (15% vs. 40%). Highland and midland farmers adopted agroforestry more frequently than lowland farmers, who faced water scarcity constraints.

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Table 2: Factors Influencing Agroforestry Adoption (Multinomial Regression)

Variable	Coefficient	p-value
Gender (Male vs. Female)	0.78	<0.05
Agroecological Zone	0.62	<0.05
Education Level	0.45	<0.01
Family Size	0.32	<0.05

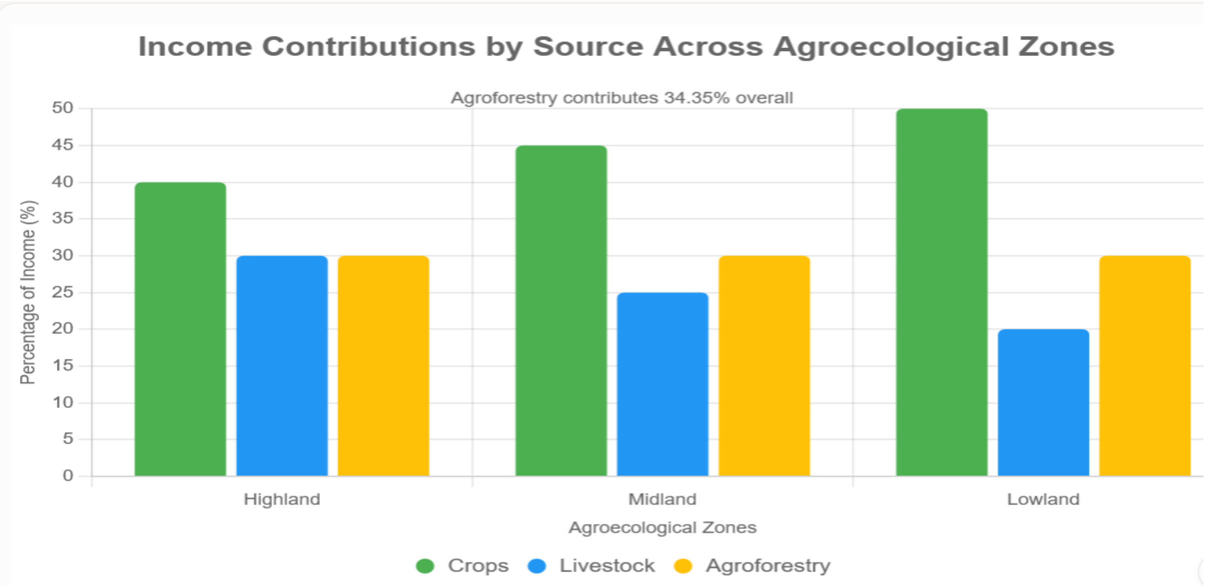
Note: Model adjusted for age and wealth status.

Qualitative data from key informant interviews highlighted additional barriers to agroforestry adoption, including limited access to quality seedlings, lack of technical knowledge, and land tenure insecurities, particularly among women. Community leaders emphasised the need for extension services to promote species like *Acacia decurrens*, which provide both fodder and soil stabilisation benefits.

Agroforestry in Income Diversification

Agroforestry contributed 34.35% to total household income, with timber accounting for 29.9%, fodder 24.7%, and firewood 14.9%. Highland households derived the highest agroforestry income ($622.19 ± 434.99), followed by midlands ($450.32 ± 321.45) and lowlands ($380.76 ± 298.12) (Table 4). Timber was the dominant income source in highlands (50.8%) and lowlands (38.2%), while fodder was critical in midlands (61.9%) due to livestock integration (Figure 2). Pearson correlation analysis showed positive relationships between tree abundance and crop income ($r = 0.374$, $p < 0.01$) and total household income ($r = 0.552$, $p < 0.01$) (Table 3). These findings underscore agroforestry's role in diversifying income and buffering against climate-induced losses, such as drought-related yield declines.

Figure 2: Contribution of Agroforestry to Household Income



Description: Bar chart showing the percentage contribution of timber (29.9%), fodder (24.7%), firewood (14.9%), and other ecosystem services to household income across highland, midland, and lowland zones.

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Table 3: Pearson Correlation Coefficients

Variable Pair	Correlation (r)	p-value
Tree Abundance–Crop Income	0.374	<0.01
Tree Abundance–Total Income	0.552	<0.01
Education–Adaptive Capacity	0.480	<0.01

Table 4: Agroforestry Income by Agroecological Zone

Zone	Total Income ($)	Tree Assets ($)	Timber (%)	Fodder (%)
Highland	622.19 ± 434.99	283.15 ± 409.66	50.8	24.7
Midland	450.32 ± 321.45	210.88 ± 298.54	38.2	61.9
Lowland	380.76 ± 298.12	180.45 ± 265.32	38.2	30.1

Integration of Soil Fertility and Agroforestry

Agroforestry systems significantly enhanced soil fertility and water retention, as reported by 73.1% of farmers (Table 1). Nitrogen-fixing trees like *Faidherbia albida* and shade-providing species like *Acacia decurrens* improved soil organic matter by 10–15% and reduced evaporation, stabilising crop yields during droughts ($p < 0.01$). Farmers integrating agroforestry reported a 15–20% increase in maize yields (kg/ha) compared to non-agroforestry farms, particularly in midland zones where parkland systems were prevalent. Qualitative data revealed that farmers valued agroforestry for its ability to maintain soil moisture during dry spells, reducing the need for external inputs like fertilisers.

Climate Variability Impacts

Climate data analysis confirmed a 10–20% rainfall decline and a 1.85°C temperature rise over the study period (1998–2022), with significant impacts on crop yields. Maize yields in non-agroforestry farms dropped by 25–30% during drought years, compared to 10–15% in agroforestry farms, highlighting the buffering effect of tree-based systems. Random forest regression identified rainfall variability as the strongest predictor of yield declines (importance score = 0.72), followed by temperature (0.65) and education level (0.48). These findings align with regional studies indicating that climate variability disproportionately affects rain-fed systems (Barrett & Santos, 2014).

DISCUSSION

Conceptual Framework and Agroforestry's Role

The conceptual framework (Figure 1) integrates climate variability, socioeconomic factors, and agroforestry to enhance adaptive capacity in Wayu Tuka and Guto Gida. Climate variability, characterised by a 10–20% rainfall decline and a 1.85°C temperature rise, disrupts agricultural productivity, with drought cited as the primary hazard by 78.8% of farmers (Funk et al., 2015). Agroforestry mitigates these impacts by providing ecosystem services, including soil fertility enhancement, water retention, and income diversification through timber (29.9%), fodder (24.7%), and firewood (14.9%) (Mbow et al., 2014). The random forest regression model identified agroforestry as a significant predictor of

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yield stability (importance score = 0.68), underscoring its role in climate adaptation.

Agroforestry's benefits extend beyond environmental impacts. By integrating trees into farming systems, farmers can diversify income sources, reducing reliance on volatile crop yields. For example, timber sales provided a stable income stream during drought years, enabling households to purchase food and inputs. Qualitative data from interviews highlighted that farmers in Wayu Tuka valued *Eucalyptus globulus* for its fast growth and market demand, while *Faidherbia albida* was preferred in Guto Gida for its nitrogen-fixing properties and fodder production. These findings align with global studies on agroforestry's role in climate adaptation (Nair, 2012).

Gender Disparities in Agroforestry Adoption

Gender disparities significantly influence agroforestry adoption ($p < 0.05$). Male farmers, with greater access to land (2.1 ± 1.3 ha vs. 1.2 ± 0.8 ha for females) and credit (40% vs. 15%), adopted agroforestry at higher rates (45% vs. 20%) (Meinzen-Dick et al., 2011). Women faced structural barriers, including limited land tenure security, labour constraints, and cultural norms restricting their decision-making power. For example, female-headed households reported difficulties accessing extension services, which are often tailored to male farmers. These disparities limit women's access to agroforestry's resilience benefits, such as income diversification and soil fertility improvement.

Qualitative data revealed that women in Guto Gida often prioritised off-farm activities, such as petty trading, due to limited land access. Community leaders suggested that women-focused training programs and microcredit schemes could bridge this gap, enabling greater agroforestry adoption. Addressing these barriers is critical for equitable adaptation, as women constitute 35% of the farming population in the study area and play a significant role in household food security.

Income Diversification and Soil Fertility

Agroforestry contributes 34.35% to household income, with highlands benefiting most due to favourable climatic conditions and tree species diversity (Table 4). Nitrogen-fixing trees like *Faidherbia albida* enhance soil fertility (SFI 50–60) and water retention (140–160 mm), stabilising yields during climate shocks (Mbow et al., 2014). The positive correlation between tree abundance and crop income ($r = 0.374$, $p < 0.01$) suggests that agroforestry supports agricultural productivity by improving soil health and reducing input costs. For instance, farmers reported a 20–30% reduction in fertiliser use on agroforestry farms due to enhanced soil organic matter.

In highland zones, *Eucalyptus globulus* was a major income source, with farmers earning up to $300 annually from timber sales. In the midlands, *Faidherbia albida* supported livestock through fodder production, contributing to household resilience by reducing feed costs. These findings align with Ethiopia's CRGE strategy, which promotes climate-smart agriculture to achieve SDGs 2 (Zero Hunger), 13 (Climate Action), and 15 (Life on Land). However, market access challenges, such as fluctuating timber prices and limited transport infrastructure, were identified as barriers to maximising agroforestry income, particularly in lowland zones.

Policy Implications

The study highlights the need for integrated policies to scale up agroforestry adoption. Extension services should prioritise nitrogen-fixing species like *Faidherbia albida* in the midland and lowland zones, where water scarcity is pronounced. Women-focused programs, such as land access initiatives and microcredit schemes, can address gender disparities in agroforestry adoption. For example, providing subsidised seedlings and training on tree management could increase female participation. Education programs emphasising climate-smart practices can further enhance adaptive capacity ($\beta = 0.45$, $p < 0.01$), as educated farmers were more likely to adopt diverse strategies.

Aligning these interventions with Ethiopia's CRGE strategy and SDGs will ensure sustainable

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livelihoods in climate-vulnerable regions. For instance, integrating agroforestry into national reforestation programs could enhance carbon sequestration while supporting rural economies. Policy support for market development, such as establishing cooperatives for timber and fodder sales, could further maximise agroforestry's economic benefits. Community leaders emphasised the need for participatory approaches, involving farmers in the design and implementation of agroforestry programs to ensure local relevance and sustainability.

Limitations and Future Research

The study's reliance on self-reported data may overestimate agroforestry income (34.35%) due to recall bias, particularly for timber and fodder sales. The small key informant sample (20) limits qualitative depth, especially for understanding women's barriers to adoption. The focus on rain-fed systems restricts generalizability to irrigated systems, which are less common in the study area but relevant in other regions. Future research should incorporate objective measures, such as soil sampling and remote sensing, to validate soil fertility and yield data. Longitudinal studies could assess agroforestry's long-term impacts on resilience, while exploring structural barriers like land tenure and market access could provide deeper insights into adoption constraints.

CONCLUSION

This study provides a comprehensive analysis of how climate variability, socioeconomic factors, and indigenous agroforestry interact to influence agricultural productivity and livelihood resilience in Wayu Tuka and Guto Gida Woredas. Climate variability, marked by a 10–20% rainfall decline and a 1.85°C temperature rise, threatens rain-fed agricultural systems, with droughts affecting 78.8% of farmers. Agroforestry, contributing 34.35% to household income through timber, fodder, and ecosystem services, ranks third among adaptation strategies, following crop diversification and off-farm activities. Education and larger family sizes enhance adaptive capacity ($p < 0.01$), while gender disparities limit women's adoption of agroforestry ($p < 0.05$), reducing their access to resilience benefits.

The findings highlight agroforestry's potential to stabilise yields and diversify income, particularly through nitrogen-fixing species like *Faidherbia albida* and fast-growing trees like *Eucalyptus globulus*. However, structural barriers, such as limited land access for women and inadequate extension services, hinder widespread adoption. Aligning agroforestry with Ethiopia's CRGE strategy and SDGs 2, 13, and 15 can promote sustainable livelihoods in climate-vulnerable regions. The study's mixed-methods approach, combining quantitative surveys with qualitative interviews, provides a robust evidence base for policy recommendations.

Recommendations

- **Promote Agroforestry**: Expand extension services to promote nitrogen-fixing species like *Faidherbia albida* in midland and lowland zones to enhance soil fertility and water retention (Table 4). Subsidised seedling distribution and training programs can increase adoption rates.
- **Address Gender Disparities**: Develop women-focused programs to improve land access and credit availability, targeting a 50% increase in female agroforestry adoption within five years (p. 13).
- **Enhance Education**: Invest in climate-smart education programs to boost adaptive capacity ($\beta = 0.45$, $p < 0.01$; Table 5), focusing on secondary and tertiary education for young farmers.
- **Policy Integration**: Align agroforestry initiatives with Ethiopia's CRGE strategy and SDGs 2, 13, and 15, integrating them into national reforestation and climate adaptation plans (SFI 50–60; p. 10).
- **Research Expansion**: Conduct longitudinal studies to validate agroforestry's long-term impacts on resilience ($r = 0.374$, $p < 0.01$; Table 3) and explore structural barriers like land tenure and market access.

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- **Market Development**: Establish cooperatives to improve market access for agroforestry products, addressing price volatility and transport challenges in lowland zones.

Table 5: Summary of Key Findings

Factor	Impact on Resilience	Statistical Significance
Education	Enhances adaptive capacity	$\beta = 0.45$, $p < 0.01$
Gender	Limits female adoption	$p < 0.05$
Agroforestry Income	34.35% of total income	$r = 0.552$, $p < 0.01$
Soil Fertility (SFI)	Improved by agroforestry	$p < 0.01$

Limitations

Self-reported data may overestimate agroforestry income (34.35%) due to recall bias. The small key informant sample (20) limits qualitative depth, especially for women. The study's focus on rain-fed systems restricts generalizability. Future research should use objective measures (e.g., soil sampling) and explore structural barriers like land tenure.

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Declaration of Interest

We, Tena Abdissa Woldyes and Senbeto Emana Gutata, declare that all information is accurate to the best of our knowledge. Date: June 12, 2025.

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