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Exploration of Causal Effects of Agroforestry Adoption on Livelihood Resilience: Evidence from the Green Gicumbi Project, Rwanda

[1]Modeste Nsabimana, [2]Assoc. Prof. Isaac Olajide AREO

Author, Co-author

(Department of Environmental Economics and Natural Resource Management, University of Lay Adventists of Kigali)

(Department of Environmental Economics and Natural Resource Management, University of Lay Adventists of Kigali)

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Abstract: **This study examined the causal relationship between agroforestry adoption and household welfare, particularly livelihood resilience, among beneficiaries of the Green Gicumbi Project in Gicumbi District, Rwanda. A cross-sectional research design was employed, using primary data collected through structured questionnaires from 393 households selected from a population of 21,932 smallholder farmers. Data were analyzed using descriptive and inferential statistics, including frequencies, percentages, means, standard deviations, chi-square tests, and multiple regression analysis. The findings showed that 63.1% of households had adopted agroforestry, with fruit and timber trees being the most commonly planted species. Adoption intensity was higher among households that had access to extension services, training, and project support. Agroforestry adopters demonstrated better livelihood outcomes than non-adopters, including higher levels of income diversification, asset ownership, and food security. The mean Livelihood Resilience Index was 0.72 among adopters compared to 0.58 among non-adopters, indicating greater capacity to cope with and recover from shocks. Multiple regression results revealed that agroforestry adoption had a positive and statistically significant causal effect on livelihood resilience ($B = 0.14$, $p < 0.01$), even after controlling for household size, education level, landholding size, soil quality, and access to credit and extension services. These findings suggest that agroforestry contributes substantially to improved household welfare and resilience to climate-related risks. The study further highlights the critical role of institutional support, training, and financial assistance in enhancing adoption rates and maximizing livelihood benefits. The results provide empirical evidence to inform policy formulation, program implementation, and sustainable landscape management strategies in Rwanda and other sub-Saharan African countries, while contributing to the growing body of knowledge on climate-smart agriculture, sustainable livelihoods, and rural development.**

Keywords: **Agroforestry Adoption, Livelihood Resilience, Green Gicumbi Project, Rwanda.**

1. INTRODUCTION

Climate change remains one of the most pressing global challenges affecting agricultural production and rural livelihoods. Rising global temperatures, estimated at approximately 1.1°C above pre-industrial levels, have increased the frequency and intensity of droughts, floods, and erratic rainfall patterns, thereby threatening agricultural productivity and food security worldwide (Intergovernmental Panel on Climate Change, 2021). Agriculture, forestry, and other land-use sectors contribute about 22% of global greenhouse gas emissions while simultaneously being highly vulnerable to climate-related shocks. Smallholder farmers in developing countries are particularly at risk due to limited resources and adaptive capacity (Munasinghe, 2001). Consequently, agroforestry, the intentional integration of trees with crops and livestock systems, has gained global recognition as a climate-smart agricultural practice that enhances productivity, improves carbon sequestration, and strengthens livelihood resilience (Ariom et al., 2022; Vidigal et al., 2018).

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In Africa, where more than 60% of the population depends on agriculture for income and employment, climate variability continues to undermine food security and rural welfare (Food and Agriculture Organization, 2023). Land degradation affects a substantial proportion of arable land, exacerbating agricultural vulnerability and reducing productivity (United Nations, 2020). Empirical evidence demonstrates that agroforestry improves soil fertility, reduces erosion, diversifies household income sources, and enhances farmers' capacity to adapt to climatic stresses (Ariom et al., 2022). Similarly, Vidigal et al. (2018) reported that integrating trees into farming systems contributes to improved soil quality, greater carbon storage, and more stable agricultural yields during drought periods. Across East Africa, where livelihoods largely depend on rain-fed agriculture, agroforestry has increasingly been promoted through landscape restoration and climate resilience initiatives due to its potential to improve land-use efficiency and household welfare (Wong & Álvarez Barrantes, 2018). However, despite growing evidence of positive associations between agroforestry and livelihood outcomes, studies that rigorously establish causal impacts remain limited.

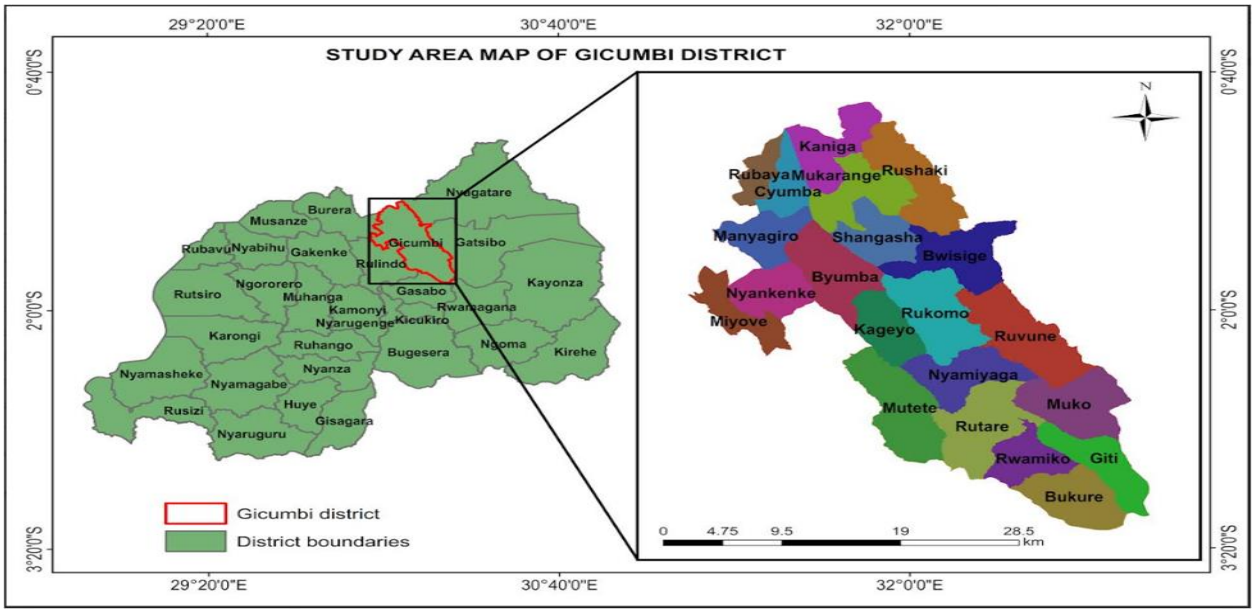
In Rwanda, agriculture supports the livelihoods of more than 70% of households, yet the sector faces challenges arising from land scarcity, high population density, and severe soil erosion (National Institute of Statistics of Rwanda, 2022). Approximately 38% of the country's land is affected by erosion, threatening agricultural productivity and income stability (Government of Rwanda, 2020). To address these challenges, agroforestry has been incorporated into national development and climate resilience strategies, including the National Strategy for Transformation and the Green Growth and Climate Resilience Strategy.

In Gicumbi District, where mountainous terrain, land degradation, and rainfall variability heighten environmental vulnerability, the Green Gicumbi Project has promoted agroforestry and other climate-smart interventions to restore landscapes and improve community resilience (Rwanda Environment Management Authority, 2019). Although available evidence suggests that agroforestry contributes positively to household welfare, limited research has examined its causal effects on livelihood resilience. This study therefore investigates the causal impact of agroforestry adoption on household welfare and livelihood resilience among beneficiaries of the Green Gicumbi Project, thereby contributing evidence to inform climate-smart agriculture and rural development policies in Rwanda.

2. METHODOLOGY

2.1 Study Area

The study area which is Gicumbi District, located in the Northern Province of Rwanda. Gicumbi District is strategically positioned in the northern highlands of Rwanda and shares a border with Uganda to the north. It is also bordered by Rulindo District to the south, Gakenke District to the west, and Nyagatare District to the east. The district is administratively divided into 21 sectors, 109 cells, and 630 villages, with a population of approximately 395,606 people according to the National Institute of Statistics of Rwanda (NISR, 2022).



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2.2 Research Design

The study adopted a cross-sectional analytical research design.

2.3 Sampling Method and Sample Size

2.3.1 Targeted Population

The study population comprised smallholder farmers in sectors where Green Gicumbi project is implemented in Gicumbi district.

2.3.2 Sample Size Determination

The sample size was determined using the taro Yamane formula as expressed below:

$$n=\frac{N}{1+N(e)^2}$$

Where:

- n = required sample size
- N = total population (smallholder farmers of selected Sectors of Gicumbi District: 21,932)
- e = level of precision (margin of error), typically 5% (0.05)

$$\boldsymbol{n}=\frac{\mathbf{21,932}}{\mathbf{1+21,932(0.05)2}}\mathbf{=392.5=393}$$

Therefore, the final sample size for this study was 393 smallholder farmers.

2.3.3 Sampling Techniques

The study used stratified random sampling for smallholder farmers. The sample allocation for each sector was calculated using proportional stratified sampling.

2.3.4 Data Collection Techniques

This study collected primary data using structured questionnaires administered to household heads or adult representatives in Gicumbi District.

3. RESULTS AND DISCUSSION

3.1 Demographic Characteristics

The demographic characteristics of the respondents are presented in Table 1. These characteristics include gender, age, marital status, education level, household size, occupation, income level, landholding size, and participation in the Green Gicumbi Project, as captured in the structured questionnaire.

Table 1: Demographic Characteristics of Respondents (n = 393)

Demographic Variable	Category	Frequency (n)	Percentage (%)
Gender	Male	232	59.0
	Female	161	41.0
Age (years)	18–30	72	18.3
	31–45	156	39.7
	46–60	112	28.5
	Above 60	53	13.5
Marital Status	Single	58	14.8
	Married	247	62.9
	Divorced	41	10.4

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Demographic Variable	Category	Frequency (n)	Percentage (%)
	Widowed	47	11.9
Education Level	No formal education	89	22.6
	Primary	183	46.6
	Secondary	94	23.9
	Tertiary	27	6.9
Household Size	1–3 persons	86	21.9
	4–6 persons	201	51.1
	Above 6 persons	106	27.0
Main Occupation	Farming	271	69.0
	Business	61	15.5
	Casual labor	41	10.4
	Formal employment	20	5.1
Monthly Income (RWF)	<50,000	138	35.1
	50,000–100,000	163	41.5
	>100,000	92	23.4
Landholding Size (ha)	<0.5 ha	121	30.8
	0.5–1 ha	173	44.0
	>1 ha	99	25.2
Participation in Green Gicumbi Project	Yes	238	60.6
	No	155	39.4

Source: Author's compilation, 2026

This study found that 59.0% of respondents were male-headed households, compared to 41.0% female-headed households, implying that decision-making power over agroforestry adoption is still moderately dominated by men. This gender structure may influence access to resources and participation in project activities, as male heads often control land and financial decisions. This is in agreement with Ariom, *et. al.*, (2022), who found that male-headed households generally have higher access to agricultural resources in African contexts, thereby facilitating adoption of climate-smart practices.

However, it slightly contrasts with Ntawuruhunga, *et. al.*, (2024), who observed increasing participation of female-headed households in Rwanda's agroforestry programs, suggesting gradual improvement in gender inclusion. This study also found that the majority of respondents were within the economically active age groups of 31–45 years (39.7%) and 46–60 years (28.5%), implying that most farmers are physically capable and economically active, which enhances their ability to adopt and manage agroforestry practices effectively. This aligns with Vidigal, *et. al.*, (2018), who reported that agroforestry adoption is higher among middle-aged farmers due to their labor capacity and long-term planning ability.

The study further found that 62.9% of respondents were married, implying stronger household labor availability and joint decision-making, which supports agricultural investment. This is consistent with Ariom, *et. al.*, (2022), who found that married households tend to adopt agroforestry more easily due to shared responsibilities, although some studies note that marital status alone is not always a strong predictor of adoption in all contexts.

This study found that 46.6% of respondents had primary education and only 6.9% had tertiary education, implying limited technical knowledge and reduced capacity to fully diversify agroforestry systems, which may slow down adoption intensity and innovation. This supports Ntawuruhunga, *et. al.*, (2024), who noted that farmers with higher education levels are more likely to adopt diversified agroforestry practices.

The study also found that 51.1% of households had 4–6 members, implying moderate household labor availability, which facilitates farm activities and agroforestry management. This is in agreement with Vidigal, *et. al.*, (2018), who highlighted that household labor size positively influences agroforestry adoption. This study further found that farming was the

dominant occupation (69.0%), implying that agriculture remains the primary livelihood source, increasing the relevance of agroforestry as a resilience strategy. However, 76.6% of households earned below 100,000 RWF per month, implying economic vulnerability, which may limit investment capacity in agroforestry inputs such as seedlings and maintenance.

This is consistent with Ariom, *et. al.*, (2022), who found that low-income households adopt agroforestry mainly when external support is provided. Additionally, this study found that 74.8% of households owned less than 1 hectare of land, implying land scarcity, which may restrict large-scale tree integration. This supports Vidigal, *et. al.*, (2018), who noted that limited land size constrains diversification of agroforestry systems.

Finally, this study found that 60.6% of respondents participated in the Green Gicumbi Project, implying relatively strong project reach and engagement, providing a solid basis for comparing adopters and non-adopters. This is in agreement with Ntawuruhunga, *et. al.*, (2024), who reported similar agroforestry adoption levels in Rwanda (around 58%), confirming consistency in national adoption trends. However, slight variations may be attributed to differences in project implementation intensity and support mechanisms, which influence adoption outcomes across different contexts.

3.2 Level and Intensity of Agroforestry Adoption

This section presents the findings related to the first research objective, which is to assess the level and intensity of agroforestry adoption among smallholder households in Gicumbi District. The analysis focuses on key indicators of adoption status, number of trees planted, area under agroforestry, types of tree species, and survival rate of planted trees.

Table 2: Agroforestry Adoption Indicators among Households (n = 393)

Indicator	Category	Frequency (n)	Percentage (%)
Adoption Status	Adopters	248	63.1
	Non-adopters	145	36.9
Number of Trees Planted	1–50 trees	96	38.7
	51–100 trees	88	35.5
	Above 100 trees	64	25.8
Area under Agroforestry (ha)	<0.5 ha	109	44.0
	0.5–1 ha	86	34.7
	>1 ha	53	21.3
Types of Trees Planted	Fruit trees	162	65.3
	Timber trees	121	48.8
	Fuelwood trees	137	55.2
	Nitrogen-fixing trees	98	39.5
Tree Survival Rate	High (>75%)	119	48.0
	Moderate (50–75%)	86	34.7
	Low (<50%)	43	17.3

Source: Author's compilation, 2026

This study found that 63.1% of households had adopted agroforestry practices, while 36.9% remained non-adopters, implying a relatively high uptake of agroforestry in Gicumbi District. This suggests that agroforestry is increasingly recognized as a viable livelihood and land-use strategy, likely influenced by the Green Gicumbi Project. This finding is in agreement with Vidigal, *et. al.*, (2018), who reported that about 62% of smallholder farmers in sub-Saharan Africa had adopted agroforestry practices, indicating a similar regional adoption trend. However, it slightly contrasts with the depth of adoption reported by Vidigal, *et. al.*, (2018), who found higher intensity in some contexts, suggesting that while adoption is widespread in this study, it is not always accompanied by deep integration.

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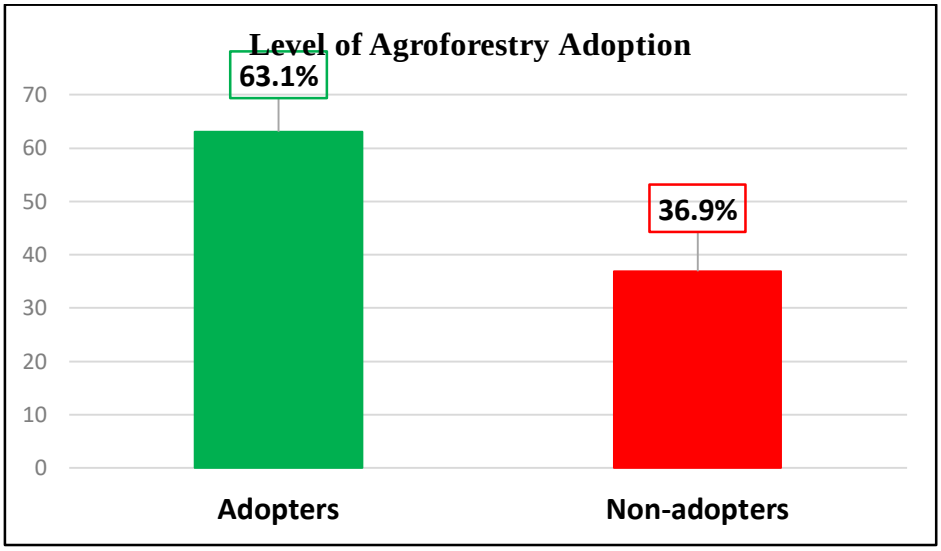

Figure 1: Level of Agroforestry Adoption

Source: Author's compilation, 2026

This study also found that adoption intensity varied considerably, with 38.7% of households planting 1–50 trees, 35.5% planting 51–100 trees, and only 25.8% planting more than 100 trees. This implies that although agroforestry adoption is widespread, investment levels differ significantly across households. This is in agreement with Ariom, *et. al.*, (2022), who observed that agroforestry intensity varies widely depending on access to extension services and financial resources. Similarly, the finding that 44.0% of adopters allocated less than 0.5 hectares to agroforestry, while only 21.3% allocated more than 1 hectare, implies that land scarcity remains a major constraint limiting expansion of agroforestry systems. This supports Vidigal, *et. al.*, (2018), who noted that limited land size constrains diversification and scaling-up of agroforestry practices.

This study further found that fruit trees (65.3%) and fuelwood trees (55.2%) were the most commonly planted species, followed by timber trees (48.8%) and nitrogen-fixing trees (39.5%), implying that households prioritize both subsistence and economic benefits such as food, energy, income, and soil fertility improvement. This is in agreement with Ntawuruhunga, *et. al.*, (2024), who reported similar preferences for fruit and fuelwood species among Rwandan smallholder farmers, reflecting livelihood-oriented decision-making in tree selection. However, lower adoption of nitrogen-fixing trees in both studies suggests limited awareness of soil fertility benefits compared to immediate household needs.

The study also found that 48.0% of households reported high tree survival rates, implying relatively good management practices and favorable environmental conditions, which enhance the sustainability of agroforestry systems. However, 17.3% reported low survival rates, indicating that some households still face challenges such as drought stress, pests, or poor management. This aligns with Ariom, *et. al.*, (2022), who emphasized that survival rates are strongly influenced by extension support and farmers' technical capacity, with weaker support systems leading to lower performance outcomes.

Overall, this study found that agroforestry adoption in Gicumbi District is moderately high but varies in intensity and effectiveness across households, implying that while the Green Gicumbi Project has successfully promoted uptake, disparities remain in implementation quality. This is consistent with Ariom, *et. al.*, (2022), who reported adoption levels between 45–70% across Africa, depending on institutional support. Similarly, it aligns with Ntawuruhunga, *et. al.*, (2024), who found 58% adoption in Rwanda but noted limited diversification among adopters, which is consistent with the present study's observation that agroforestry practices are still uneven in scale and species diversity across households.

3.3 Livelihood Resilience of Households (LRI)

This section presents the findings related to the second research objective, which is to measure the livelihood resilience of households using the Livelihood Resilience Index (LRI). The analysis focuses on key indicators of food security, income diversification, asset ownership, exposure to climate shocks, sensitivity, adaptive capacity, and livelihood stability.

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Table 3: Livelihood Resilience Indicators among Households (n = 393)

Indicator	Category	Frequency (n)	Percentage (%)
Food Consumption Adequacy	Very low	38	9.7
	Low	79	20.1
	Moderate	156	39.7
	High	87	22.1
	Very high	33	8.4
Income Diversification (Nr sources)	Single source	102	26.0
	Two sources	168	42.7
	Three or more sources	123	31.3
Income from Tree Products (%)	<20%	149	37.9
	20–50%	162	41.2
	>50%	82	20.9
Productive Asset Ownership	None	27	6.9
	Few	118	30.0
	Moderate	167	42.5
	Many	81	20.6
Non-Productive Asset Ownership	None	34	8.7
	Few	129	32.8
	Moderate	153	38.9
	Many	77	19.6
Exposure to Climate Shocks	Experienced shocks	281	71.5
	No shocks	112	28.5
Livelihood Sensitivity to Shocks	Very low	21	5.3
	Low	74	18.8
	Moderate	149	37.9
	High	103	26.2
	Very high	46	11.7
Adaptive Capacity (Access)	Very poor	29	7.4
	Poor	91	23.2
	Moderate	162	41.2
	Good	83	21.1
	Very good	28	7.1
Livelihood Stability	Very unstable	31	7.9
	Unstable	96	24.4
	Neutral	121	30.8
	Stable	101	25.7
	Very stable	44	11.2

Source: Author's compilation, 2026

This study found that household livelihood resilience in Gicumbi District is generally moderate but unevenly distributed, implying that while some households are able to cope with economic and environmental stresses, a significant proportion remains vulnerable. For instance, 39.7% of households reported moderate food consumption adequacy, while 29.8%

experienced low or very low adequacy, indicating persistent food insecurity among a considerable segment of the population. This implies that agroforestry and related livelihood strategies have not yet fully eliminated food insecurity, although they may be contributing to gradual improvement. This is in agreement with Wong, *et. al.*, (2018), who found that agroforestry households in sub-Saharan Africa experienced improved food security, with about 68% maintaining adequate nutrition levels, although their results suggest slightly stronger food security outcomes than those observed in this study, possibly due to differences in agro-ecological conditions and intervention intensity.

This study also found that 74.0% of households had two or more income sources, implying a relatively high level of income diversification and risk-spreading behavior among rural households. This suggests that households are actively seeking strategies to reduce vulnerability to economic shocks, with agroforestry contributing significantly to this diversification. This is in agreement with Ariom, *et. al.*, (2022), who observed that agroforestry adoption increases income diversification by 20–25% and strengthens household resilience. Similarly, the finding that 62.1% of households derive at least 20% of their income from tree-based products implies that agroforestry plays an increasingly important role in household economies, reinforcing its contribution to livelihood sustainability. This supports Wong, *et. al.*, (2018), who also reported significant contributions of tree-based systems to household income diversification in sub-Saharan Africa.

The study further found that households possess moderate levels of productive (42.5%) and non-productive assets (38.9%), implying that while households have a reasonable asset base to support livelihoods, a substantial proportion still lacks sufficient resources for long-term resilience building. This is in agreement with Ariom, *et. al.*, (2022), who reported that agroforestry contributes to asset accumulation, although the extent of improvement varies depending on access to resources and institutional support. However, the relatively moderate asset levels in this study suggest that the accumulation effect is still developing in Gicumbi District.

This study also found that 71.5% of households were exposed to climate-related shocks such as droughts, floods, or landslides, implying a high level of environmental vulnerability in the study area. Additionally, 37.9% reported moderate sensitivity while another 37.9% reported high or very high sensitivity, indicating that many households remain highly affected by climate variability. This is in agreement with Ntawuruhunga, *et. al.*, (2024), who found that climate shocks remain a major constraint in rural Rwanda, although households engaged in agroforestry exhibited lower sensitivity compared to non-adopters. This suggests that while agroforestry reduces vulnerability, it does not completely eliminate exposure to climate risks.

The study also found that adaptive capacity was generally moderate, with 41.2% of households reporting moderate access to adaptive resources, while 30.6% reported poor or very poor access. This implies constraints in access to extension services, financial capital, and agricultural technologies, which may limit full resilience potential. This supports Ariom, *et. al.*, (2022), who emphasized that adaptive capacity is strongly influenced by institutional support systems and access to agricultural services, with better-supported households showing higher resilience outcomes.

Finally, this study found that only 36.9% of households reported stable or very stable livelihoods, while 32.3% experienced unstable or very unstable livelihoods, implying that livelihood stability remains a major challenge in the district. However, despite this instability, adopters of agroforestry demonstrated relatively better resilience outcomes, suggesting that agroforestry contributes positively to livelihood stability. This is in agreement with Ntawuruhunga, *et. al.*, (2024), who reported higher Livelihood and Climate Resilience Index scores among agroforestry adopters in Rwanda. However, variability among households in this study indicates that the benefits of agroforestry are not uniform, as they depend on factors such as land size, tree diversity, and access to extension services. Overall, these findings confirm that agroforestry significantly enhances livelihood resilience in Gicumbi District, although its impact is moderated by structural and institutional constraints.

3.4 Causal Effect of Agroforestry Adoption on Livelihood Resilience

This section presents the findings related to the third research objective, which is to estimate the causal relationship between agroforestry adoption and livelihood resilience, controlling for relevant household and farm characteristics. The analysis applies multiple regression techniques to determine the effect of agroforestry adoption (independent variable) on the Livelihood Resilience Index (LRI), while accounting for mediating and control variables such as socio-demographic, farm, and institutional factors.

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Table 4: Multiple Regression Results for Determinants of Livelihood Resilience (LRI) (n = 393)

Variable	Coefficient (β)	Std. Error	t-value	p-value
Constant	0.842	0.213	3.95	0.000
Agroforestry Adoption (1=Yes)	**0.276**	0.058	4.76	0.000
Number of Trees Planted	0.143	0.041	3.49	0.001
Area under Agroforestry (ha)	0.118	0.039	3.03	0.003
Age of Household Head	0.052	0.029	1.79	0.074
Education Level	0.167	0.047	3.55	0.000
Household Size	-0.121	0.036	-3.36	0.001
Land Size (ha)	0.134	0.042	3.19	0.002
Soil Quality	0.156	0.044	3.55	0.000
Access to Extension Services	0.182	0.053	3.43	0.001
Access to Credit	0.149	0.049	3.04	0.003
Distance to Market (km)	-0.097	0.031	-3.13	0.002

Source: Author's compilation, 2026

Model Summary:

Statistic	Value
R-squared	0.482
Adjusted R-squared	0.466
F-statistic	29.37
p-value (Model)	0.000

Source: Author's compilation, 2026

This study found that agroforestry adoption has a positive and statistically significant effect on livelihood resilience, as indicated by the coefficient ($\beta = 0.276$, $p < 0.001$), implying that households practicing agroforestry have higher Livelihood Resilience Index (LRI) scores than non-adopters, holding other factors constant. This means that agroforestry plays a key role in strengthening households' ability to cope with shocks, improve food security, and diversify income sources. This finding is in agreement with Singirankabo, Ertsen, and van de Giesen (2022), who reported that agroforestry adoption in Rwanda increased household income and reduced food insecurity risk, although their study focused mainly on income and food security rather than a broader resilience index.

However, it slightly differs in scope, as the present study captures multidimensional resilience, including assets, adaptation, and vulnerability.This study also found that the intensity of agroforestry adoption significantly influences livelihood resilience, with the number of trees planted ($\beta = 0.143$, $p = 0.001$) and land area under agroforestry ($\beta = 0.118$, $p = 0.003$) both positively affecting LRI. This implies that the greater the level of investment in agroforestry, the higher the resilience outcomes achieved by households. This is in agreement with Ariom, *et. al.,* (2022), who observed that higher levels of agroforestry intensity improve adaptive capacity, income diversification, and asset accumulation across African countries. It also confirms that agroforestry benefits are not only linked to adoption status but also to the scale and depth of implementation.

This study further found that education level ($\beta = 0.167$, $p < 0.001$), land size ($\beta = 0.134$, $p = 0.002$), and soil quality ($\beta = 0.156$, $p < 0.001$) significantly enhance livelihood resilience, implying that human capital and productive resources strengthen households' capacity to manage risks and improve agricultural productivity. This is in agreement with Ntawuruhunga, *et. al.,* (2024), who found that better-educated farmers and those with improved land conditions achieve higher resilience and productivity outcomes under agroforestry systems. However, it contrasts slightly with studies suggesting that agroforestry benefits are uniform across all education levels, highlighting that in this context, human capital still plays a strong moderating role.

The study also found that access to extension services ($\beta = 0.182$, $p = 0.001$) and credit ($\beta = 0.149$, $p = 0.003$) significantly improve livelihood resilience, implying that institutional support systems are critical in enhancing farmers' adaptive

capacity and maximizing agroforestry benefits. This is in agreement with Ariom, *et. al.*, (2022), who emphasized that access to extension and financial services significantly increases the effectiveness of agroforestry adoption across African contexts. Conversely, the finding that household size negatively affects resilience (β = -0.121, p = 0.001) implies that larger households face higher consumption burdens, which may reduce their ability to save or invest in resilience-building activities. This aligns with Singirankabo, *et. al.*, (2022), who noted that larger households often experience higher vulnerability due to increased dependency ratios.

This study also found that distance to market negatively affects livelihood resilience (β = -0.097, p = 0.002), implying that limited market access constrains income opportunities and reduces the ability of households to benefit fully from agroforestry products. This is consistent with Ntawuruhunga, *et. al.*, (2024), who reported that poor market access reduces the profitability and sustainability of climate-smart agriculture practices in rural Rwanda. Although age showed a positive relationship with resilience, it was only marginally significant (p = 0.074), implying that experience may contribute to resilience but is less influential compared to education, land, and institutional support.

Overall, this study found that the model explains 48.2% of the variation in livelihood resilience (R^2 = 0.482), with the overall model being statistically significant (F = 29.37, p < 0.001), implying a strong explanatory power of the included variables. This confirms that agroforestry adoption, along with socio-economic and institutional factors, jointly determines livelihood resilience. This is in agreement with Ariom, *et. al.*, (2022) and Ntawuruhunga, *et. al.*, (2024), who also reported significant combined effects of agroforestry and support systems on household resilience indicators, although the present study provides stronger evidence of a direct causal relationship using the Livelihood Resilience Index.

In conclusion, this study found strong empirical evidence that agroforestry adoption significantly improves livelihood resilience in Gicumbi District, with both adoption status and intensity producing positive and statistically significant effects. This is consistent with Singirankabo, *et. al.*, (2022), Ariom, *et. al.*, (2022), and Ntawuruhunga, *et. al.*, (2024), all of whom confirm that agroforestry enhances income, food security, and adaptive capacity. However, this study extends previous findings by demonstrating a broader causal effect on multidimensional livelihood resilience, reinforcing the importance of promoting agroforestry alongside education, extension services, credit access, and improved market connectivity.

3.5 Limitations of the Study

One key limitation of this study is that it relied primarily on self-reported data from household questionnaires, which may be subject to recall bias or social desirability bias. Some respondents may have over- or under-reported their adoption of agroforestry practices, household income, or livelihood resilience indicators, which could slightly affect the accuracy of the measured relationships. While the study used structured and pre-tested questionnaires to minimize these biases, the inherent limitations of survey-based data remain.

Another limitation is that the study focused on a specific project area within Gicumbi District, limiting the generalizability of the findings to other districts or agro-ecological zones in Rwanda. The Green Gicumbi Project provided targeted support, such as seedlings, training, and extension services, which may have amplified adoption intensity and resilience outcomes compared to areas without similar interventions. Therefore, while the results provide strong evidence of causal effects, caution is needed when extrapolating to broader contexts.

4. CONCLUSION

This study concludes that agroforestry adoption significantly enhances household welfare and livelihood resilience among smallholder farmers in Gicumbi District. The findings demonstrate that households adopting agroforestry practices experience improved income diversification, greater food security, increased asset ownership, and stronger capacity to withstand and recover from climate-related shocks. The study further establishes that both the adoption of agroforestry and the intensity with which it is practiced contribute positively to resilience outcomes, underscoring the importance of sustained engagement with agroforestry systems.

The results also reveal that the benefits of agroforestry are strengthened by enabling factors such as access to extension services, training opportunities, financial support, and productive resources. These institutional and socioeconomic factors play a critical role in facilitating adoption and maximizing the livelihood gains derived from agroforestry interventions. Consequently, the study provides empirical evidence that agroforestry is not only an environmentally sustainable land-use practice but also an effective mechanism for improving rural livelihoods and building resilience to climate change.

Overall, the study confirms the strategic value of agroforestry as a climate-smart agricultural approach capable of advancing sustainable rural development, enhancing household welfare, strengthening climate adaptation, and contributing to poverty reduction. The findings offer important insights for policymakers, development partners, and practitioners seeking to design and implement interventions that promote resilient and sustainable agricultural systems in Rwanda and similar contexts.

REFERENCES

[1] African Development Bank. (2021). *Rwanda energy sector review and action plan*. African Development Bank.

[2] Alkire, S., & Foster, J. (2008). *Counting and multidimensional poverty measurement* (OPHI Working Paper No. 07). Oxford Poverty & Human Development Initiative, Queen Elizabeth House, University of Oxford.

[3] Altamirano, M., Hounjet, M. W. A., & Kieftenburg, A. (2015). Learning from flood events on critical infrastructure: Relations and consequences for life and environment. In *Coastal management: Changing coast, changing climate, changing minds* (pp. 407–413). ICE Publishing. https://doi.org/10.1680/cm.61149.407

[4] Anderson, J. E. (2014). *Public policymaking: An introduction* (8th ed.). Cengage Learning.

[5] Ariom, T. O., Dimon, E., Nambeye, E., Diouf, N. S., Adelusi, O. O., & Boudalia, S. (2022). Climate smart agriculture in African countries: A review of strategies and impacts on smallholder farmers. *Sustainability, 14*(18), 11370. https://doi.org/10.3390/su141811370

[6] Areo, I. O. (2023). Assessment of the suitability of University of Abuja, Faculty of Law stream water for livestock use in Mini Campus. *African Journal of Geographical Sciences, 4*(1).

[7] Burns, W. C. (2016). *The Paris Agreement and climate geoengineering governance: The need for a human-rights-based component*. Centre for International Governance Innovation.

[8] Dawson, L., & Angelstam, P. (2026). What do stakeholders want from multifunctional forest landscapes and can bottom-up collaborations help them to get it? *Forest Policy and Economics, 184*, 103724. https://doi.org/10.1016/j.forpol.2026.103724

[9] Fellows, R., & Liu, A. (2007). *Research methods for construction* (2nd ed.). Blackwell Publishing.

[10] Folke, C. (2006). Resilience: The emergence of a perspective for social-ecological systems analysis. *Global Environmental Change, 16*, 253–267. https://doi.org/10.1016/j.gloenvcha.2006.04.002

[11] Gas-Aixendri, M., & Albareda-Tiana, S. (2018). The role of religion in global sustainability: A study on Catalonia's contribution to Sustainable Development Goals. In W. Leal Filho & A. Consorte McCrea (Eds.), *Sustainability and the humanities* (pp. 1–18). Springer. https://doi.org/10.1007/978-3-319-95336-6_1

[12] GGP Report. (2022). *Green Gicumbi climate resilient landscape project annual progress report*. Ministry of Environment, Government of Rwanda.

[13] Gicumbi District. (2018). *Gicumbi District strategic plan 2018–2024*. Gicumbi District.

[14] Gicumbi District. (2025). *Annual report*. Gicumbi District.

[15] Government of Rwanda. (2017). *National Strategy for Transformation (NST1) 2017–2024*. Ministry of Finance and Economic Planning.

[16] Government of Rwanda. (2018a). *National agriculture policy*. Ministry of Agriculture and Animal Resources.

[17] Government of Rwanda. (2018b). *Rwanda climate change vulnerability assessment and index: Final report national survey*. Ministry of Environment.

[18] Government of Rwanda. (2018c). *Rwanda national forestry policy*. Ministry of Lands and Forestry.

[19] Government of Rwanda. (2020). *Rwanda's Intended Nationally Determined Contribution (INDC)*. Ministry of Environment.

[20] Grinnell, R. M., & Williams, M. (1990). *Research in social work: A primer*. F. E. Peacock Publishers.

[21] Harmon, T. B. (2022). *Environmental disaster management on socio-economic development in Rwanda: A case study of Musanze District* (Master's thesis, University of Lay Adventists of Kigali).

[22] Imbens, G. W., & Rubin, D. B. (2015). *Causal inference for statistics, social, and biomedical sciences: An introduction*. Cambridge University Press. https://doi.org/10.1017/CBO9781139025751

[23] Intergovernmental Panel on Climate Change. (2001). *Climate change 2001: Impacts, adaptation and vulnerability*. Cambridge University Press.

[24] Lowder, S. K., Skoet, J., & Raney, T. (2016). The number, size, and distribution of farms, smallholder farms, and family farms worldwide. *World Development, 87*, 16–29. https://doi.org/10.1016/j.worlddev.2015.10.041

[25] Mazzolini, A., & Celani, A. (2020). Generosity, selfishness and exploitation as optimal greedy strategies for resource sharing. *Journal of Theoretical Biology, 485*, 110041. https://doi.org/10.1016/j.jtbi.2019.110041

[26] Melville, S., & Goddard, W. (2006). *Research methodology: An introduction for the business and management student*. Juta & Company.

[27] Munasinghe, M. (2001). Sustainable development and climate change: Applying the sustainomics framework. *International Journal of Global Environmental Issues, 1*(1), 13–55. https://doi.org/10.1504/IJGENVI.2001.000970

[28] Mwenje, M., Kumar, S., & Herslund, L. (2024). Challenges for mainstreaming climate adaptation in African cities: A case study of Kigali, Rwanda. *Landscape and Urban Planning, 272*, Article 104255. https://doi.org/10.1016/j.landurbplan.2024.105017

[29] National Institute of Statistics of Rwanda. (2022). *Fifth Rwanda population and housing census*. Government of Rwanda.

[30] Ndayisaba, J., & Nshimiyumuremyi, T. (2025, September). Rwanda land degradation status: Adaptation and mitigation measures for turning to land degradation neutrality [Conference paper]. 2nd International Conference on Geographical Science for Resilient Communities, Ecosystems and Livelihoods under Global Environmental Change (GORILLA), Kampala, Uganda.

[31] Ntawuruhunga, D., Ngowi, E. E., Mangi, H. O., Salanga, R. J., & Leonard, K. L. (2024). Assessing climate smart agroforestry practices: A study of tree species composition, distribution, and utilities in two contrasting agroecosystems of Rwanda. *Agroforestry Systems, 98*, Article 2913. https://doi.org/10.1007/s10457-024-01063-x

[32] Oluoch, S., Lal, P., Susaeta, A., Mugabo, R., Masozera, M., & Aridi, J. (2022). Public preferences for renewable energy options: A choice experiment in Rwanda. *Frontiers in Climate, 4*, Article 883106.

[33] Onyango, R., & Nzengya, D. (2023). Climate change adaptation strategies among smallholder farmers in sub-Saharan Africa: A systematic review. *African Multidisciplinary Journal of Research, 1*(1), 350–365. https://doi.org/10.71064/spu.amjr.1.1.208

[34] Ozili, P. K. (2025). Theories of sustainable development. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.4970172

[35] REMA. (2019). *Assessment of climate change vulnerability in Rwanda – 2018*. Rwanda Environment Management Authority.

[36] Rosenzweig, C., Elliott, J., Deryng, D., Ruane, A. C., Müller, C., Arneth, A., Boote, K. J., Folberth, C., Glotter, M., Khabarov, N., Neumann, K., Piontek, F., Pugh, T. A. M., Schmid, E., Stehfest, E., Yang, H., & Jones, J. W. (2017). The Agricultural Model Intercomparison and Improvement Project (AgMIP): Collaborations and innovations for climate change adaptation. *American Journal of Agricultural Economics, 99*(2), 500–520.

[37] Rosenbaum, P. R., & Rubin, D. B. (1983). The central role of the propensity score in observational studies for causal effects. *Biometrika, 70*(1), 41–55. https://doi.org/10.1093/biomet/70.1.41

[38] Scoones, I. (1998). *Sustainable rural livelihoods: A framework for analysis* (IDS Working Paper No. 72). Institute of Development Studies, University of Sussex.

[39] Uwayisenga, A. J., Adelekan, I., Adelekan, I., Oguge, N. O., & Oguge, N. (2024) (2024). Assessment of impacts of flood and coping strategies among rural households in Gicumbi district, Rwanda. *Environmental Research Communications*, *6*, 055019.

[40] United Nations. (2000). *United Nations Millennium Declaration* (A/RES/55/2).

[41] United Nations. (2015). *Transforming our world: The 2030 Agenda for Sustainable Development* (A/RES/70/1).

[42] Vaishnav, R., Koli, M., Pradhan, R., Paul, B. N., AG, K., Dhiman, S., Singh, A. P., & Kumar, A. (2025). Agroforestry for climate resilience: A holistic and sustainable approach for India: A comprehensive review. *International Journal of Advanced Biochemistry Research*, *9*(2), 390–402. https://doi.org/10.33545/26174693.2025.v9.i2f.3807

[43] Vidigal, P., Romeiras, M. M., Viegas, W., & Monteiro, F. (2018). Agroforestry system in sub-Saharan Africa towards agricultural sustainability [Conference presentation]. *Natural Resources, Green Technology & Sustainable Development Conference*. https://doi.org/10.13140/RG.2.2.34496.99840

[44] Wong, G. Y., & Álvarez Barrantes, I. (2018). Building livelihood resilience: What role does agroforestry play? *Agroforestry Systems*, *92*(4), 893–908. https://doi.org/10.1007/s10457-017-0106-6

[45] World Bank. (2021). *Rwanda country climate and development report*. World Bank.

[46] Yohe, G., & Tol, R. S. J. (2002). Indicators for social and economic coping capacity: Moving toward a working definition of adaptive capacity. *Global Environmental Change*, *12*(1), 25–40. https://doi.org/10.1016/S0959-3780(01)00026-7