



# ASSESSING THE IMPACT OF AGRICULTURAL PRACTICES ON ENVIRONMENTAL DEGRADATION IN NYARUGURU DISTRICT, CASE OF NSHILI KIVU TEA ESTATE

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**Abstract:** Environmental degradation linked to farming remains a pressing challenge in Rwanda's agricultural zones. In tea-growing areas like Nyaruguru District, unsustainable practices such as deforestation, excessive agrochemical use, poor waste disposal, and monoculture farming threaten long-term ecological sustainability. Using the case study of Nshili Kivu Tea Estate, this study assessed the impact of agricultural practices on environmental degradation. A mixed-methods approach was employed, combining quantitative data from 346 survey respondents with qualitative insights from 59 interviews with government staff and estate employees, along with a focus group discussion with 20 tea farmer representatives. Descriptive statistics, Pearson correlation, and linear regression were used for quantitative analysis, while thematic analysis supported qualitative interpretation. Findings revealed that deforestation, which led to a 60% decline in forest cover from 1983 to 2023, and a corresponding 60% reduction in grasslands, was a major factor contributing to disrupted rainfall patterns estimated to have dropped from 1,500 mm in 1983 to around 1,100 mm in 2023. Cropland expansion (up by 175%) and settlement growth (200%) were linked to increased pressure on land and water resources. Poor waste management practices were identified as a statistically significant predictor of environmental degradation, while overuse of water for irrigation and widespread monoculture farming further contributed to soil erosion, biodiversity loss, and pollution. Respondents also reported visible gully formation, increased plant disease, and reduced vegetation cover, all pointing to escalating land degradation. Despite these challenges, the study found a high level of environmental policy awareness among local farmers and stakeholders, with over 77% of respondents agreeing that they understood the environmental regulations affecting their activities. Community participation in conservation efforts was strong, but institutional enforcement was inconsistent, and farmer training on sustainable practices remained limited. These gaps weakened the implementation of environmental policies, despite the existence of regulatory frameworks. Based on the findings, the study recommends enhanced enforcement of environmental laws, expanded farmer education programs, promotion of sustainable farming technologies, and greater coordination among institutions. It also encourages tea farmers to adopt cooperative models that support eco-friendly investment. Future research should employ remote sensing and GIS tools to monitor land use changes and evaluate the long-term effectiveness of environmental interventions in Rwanda's tea sector.

**Keywords:** Agriculture Practices, Environmental degradation, Tea estate, Nyaruguru District, Agricultural practices, Rwanda

## 1. Introduction

Agriculture is central to the economy of many nations, particularly in developing regions. It provides food, raw materials, and employment to millions globally, contributing significantly to GDP, foreign exchange earnings, and rural development (Zhao, 2022). In sub-Saharan Africa, for instance, agriculture remains the primary source of livelihood for more than 60% of the population and contributes about 23% to regional GDP. It is therefore a key sector for economic stability, food security, and poverty reduction. However, while agriculture is indispensable to socioeconomic development, it also has profound implications for the environment (Graham, 2022).

Globally, agriculture has emerged as a primary driver of environmental change (Chen, 2023). Agricultural practices including monoculture, excessive use of chemical fertilizers and pesticides, and poor irrigation techniques are contributing to soil degradation (affecting 33% of global land), water contamination (accounting for 70% of global freshwater use), loss of biodiversity, and emitting around 25% of all greenhouse gases. These practices have triggered environmental degradation at both local and global scales (Tran, 2023).

In Europe, for instance, countries like France, Germany, and the United Kingdom have experienced the ecological consequences of intensive farming. France uses more than 2 million tonnes of chemical fertilizers annually, leading to widespread soil degradation and

water pollution (Graham & Louw, 2022). In Germany, nitrogen fertilizer use and wetland drainage have been linked to biodiversity loss and pollution (Schmidt et al., 2021). The UK faces similar challenges, particularly from livestock farming and fertilizer runoff, which impact soil health and water quality (Schmidt, 2021).

In the United States, large-scale monoculture farming especially of corn and soybeans has led to the loss of nearly 1.7 billion tons of topsoil per year, nutrient runoff, and habitat destruction. These effects, coupled with the widespread use of synthetic agrochemicals, have raised long-term sustainability concerns despite technological advancements in precision farming (Martinez & Lee, 2023).

In Latin America, Brazil's agricultural expansion driven largely by cattle ranching and soybean production—has resulted in over 1.5 million hectares of Amazon rainforest being cleared annually, posing severe threats to biodiversity and the global climate (Santos et al., 2023). Similarly, in Asia, countries like China, India, and Vietnam struggle with environmental consequences of intensified agricultural production, including land degradation affecting over 30% of cultivable land and water pollution due to agrochemical overuse (Zhao et al., 2022; Patel & Mishra, 2022; Tran & Dinh, 2023).

Across Africa, agriculture remains a critical driver of economic development but also a major contributor to environmental degradation. In Kenya, Uganda, and South Africa, unsustainable farming techniques have led to soil erosion, deforestation, and depletion of natural resources (Kamau et al., 2023; Kato et al., 2022; Smith & Telford, 2023). It is estimated that Africa loses about 280 million tonnes of fertile soil every year due to erosion. Efforts to promote sustainable agriculture such as agroforestry, integrated pest management, and conservation agriculture have been initiated across the continent, but widespread adoption remains limited (Hughes, 2022).

In Rwanda, agriculture is the backbone of the economy, employing over 70% of the population and contributing approximately 33% to the national GDP. Among its major cash crops, tea accounts for over 15% of Rwanda's agricultural export revenues and earns the country over \$90 million annually (Santos, 2023).

Studies conducted in Rwanda indicate that such practices may lead to soil degradation (affecting over 40% of agricultural land), water pollution, and loss of local biodiversity (Mukashyaka et al., 2023). Runoff from tea plantations carries agrochemical residues into nearby rivers and water bodies, affecting aquatic ecosystems and posing risks to human health. While the Rwandan government has initiated efforts to promote sustainable agriculture such as organic fertilizers, crop diversification, and agroforestry implementation at scale remains a work in progress (Patel, 2022).

The Nyaruguru District in Rwanda is known for its rich agricultural landscape, with tea cultivation playing a significant role in the local economy. One of the major agricultural hubs in the district is the Nshili Kivu Tea Estate, which contributes substantially to both employment and export revenues. However, like many intensive farming operations, the estate has increasingly faced scrutiny due to agricultural practices such as excessive use of chemical fertilizers, poor land management, and deforestation. These practices have contributed to various forms of environmental degradation, including soil erosion, water pollution, and biodiversity loss. This case study aims to assess how such unsustainable methods within the Nshili Kivu Tea Estate are impacting the broader environment in the Nyaruguru District, highlighting the need for more sustainable and eco-friendly agricultural approaches. The Nshili Kivu Tea Estate, located in Nyaruguru District in the Southern Province, is one of Rwanda's key tea producers. However, like many large-scale plantations, it relies on agricultural practices that can potentially harm the environment. These include monoculture cropping, the application of chemical fertilizers and pesticides, and water-intensive irrigation systems (Martinez, 2023).

Therefore, this study seeks to assess the environmental impacts of agricultural practices at the Nshili Kivu Tea Estate in Nyaruguru District. Through this localized analysis, the study aims to contribute to broader discussions on agriculture practice, inform policy recommendations, and highlight practical strategies for mitigating environmental degradation in Rwanda and similar contexts across the developing world.

## 2. Statement of the problem

Agricultural practices in Rwanda, particularly in large-scale tea estates such as the Nshili Kivu Tea Estate in Nyaruguru District, have increasingly come under scrutiny due to their negative environmental impacts. The widespread use of chemical fertilizers and pesticides, monoculture farming systems, and water-intensive irrigation methods have been linked to serious ecological consequences. These include soil degradation, water pollution, loss of biodiversity, and reduced land productivity (Kamau et al., 2023; Mukashyaka et al., 2023). Chemical runoff from the estate contaminates nearby rivers and wetlands, threatening aquatic life and reducing the availability of clean water for local communities.

Furthermore, the reliance on monoculture growing only tea over extensive areas limits soil nutrient replenishment and increases vulnerability to erosion and land exhaustion. Over time, these agriculture practice diminish the productive capacity of the land, putting the long-term viability of tea farming at risk. The environmental degradation observed in such estates not only threatens ecological integrity but also jeopardizes rural livelihoods and national agricultural output, especially given tea's importance as a leading export crop for Rwanda.

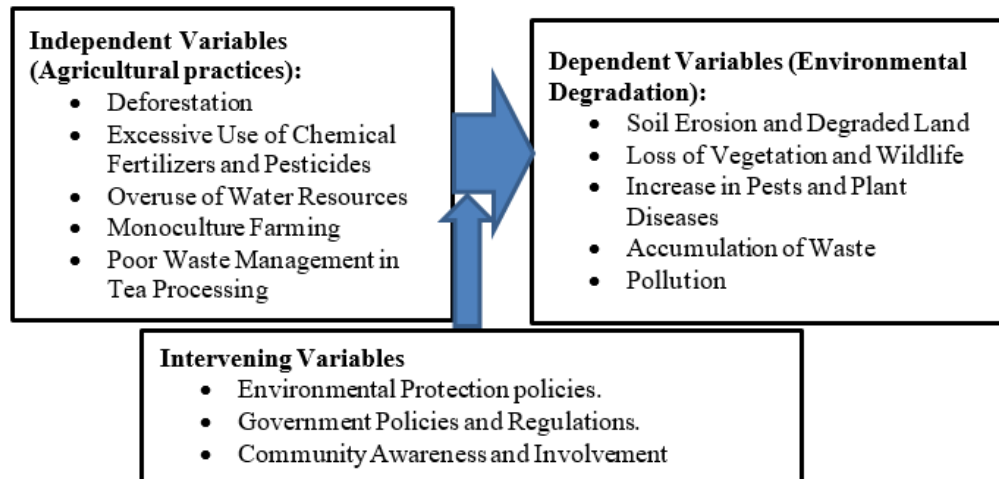
If current agricultural practices remain unchanged, environmental degradation will likely intensify. Soil erosion may become more widespread, water sources could become increasingly polluted, and local biodiversity may continue to decline due to habitat loss and chemical exposure. These issues pose serious challenges to the sustainability of tea production, risking economic losses and undermining food and water security for surrounding communities.

This study is therefore critical in assessing the environmental impacts of existing agricultural practices at Nshili Kivu Tea Estate. By examining how current farming methods affect soil quality, water resources, and biodiversity, the research aims to generate evidence-based recommendations to minimize environmental harm. The findings will contribute to efforts to improve environmental stewardship within Rwanda's agricultural sector, particularly in tea cultivation, and support the development of more ecologically responsible farming approaches that safeguard both the environment and the economy.

### 3. Conceptual framework of the study

The rationale behind this study stems from the growing concern over the environmental consequences of agricultural practices, particularly in regions where farming is a key economic activity. In the Nyaruguru District, the Nshili Kivu Tea Estate plays a vital role in local livelihoods, yet its farming methods may be contributing to environmental challenges such as deforestation, soil degradation, and water pollution. Understanding the extent of these impacts is essential for developing strategies that ensure both environmental sustainability and agricultural productivity. This study is therefore justified as it seeks to bridge the knowledge gap between economic development and environmental conservation, offering practical recommendations to help stakeholders adopt more sustainable agricultural approaches in the region.

**Figure 1: Conceptual Framework of the Study**



Source: Compiled by the researcher, January 2025

The relationship between agricultural practices and environmental degradation in the context of the Nshili Kivu Tea Estate can be clearly understood by examining how specific farming activities lead to observable environmental impacts, with the influence of intervening factors like policies and community engagement. Deforestation, often done to expand tea plantations, directly contributes to Soil Erosion and the loss of natural vegetation and wildlife. The removal of trees destabilizes the soil and destroys habitats, leading to long-term ecological imbalances. Similarly, the excessive use of chemical fertilizers and pesticides degrades soil quality and pollutes nearby water sources, which not only harms aquatic life but also increases vulnerability to pests and plant diseases due to disrupted ecological balances (FAO, 2021).

Overuse of water resources, including the diversion of rivers and over-extraction of groundwater for irrigation, reduces water availability for surrounding communities and ecosystems (Molden, 2010). This often results in reduced stream flows and contributes to land degradation. Monoculture farming, which involves growing only tea without crop rotation or diversification, depletes soil nutrients and weakens the land's resilience to pests, diseases, and climate stress. This can be observed in the increased presence of pests and declining crop health (Lal, 2015). Additionally, poor waste management during tea processing leads to the accumulation of solid and liquid waste around processing areas and water bodies, contributing to visible pollution and further degrading the local environment (Pretty, 2015).

However, the extent and severity of environmental degradation are also influenced by intervening variables. Environmental protection policies and government regulations play a critical role in either mitigating or exacerbating these impacts. Where policies are enforced effectively, the negative consequences can be minimized through sustainable land use practices and waste management systems (World Bank, 2022). Furthermore, community awareness and involvement act as key social buffers when local communities understand the importance of environmental stewardship, they are more likely to adopt conservation practices and hold stakeholders accountable. Altogether, these variables interact dynamically, shaping the overall environmental condition of the tea-producing region (IPCC, 2021).

### 4. Study objective and Hypotheses

The main objective of this study is to assess the impacts of agricultural practices on environment in Nyaruguru district, case of Nshili Kivu tea estate. This study focuses on the following specific objectives:

- i. To assess the agricultural practices applied by Nshili Kivu Estate in Nyaruguru District.
- ii. To evaluate the level of Environmental Degradation in Nshili Kivu Estate.
- iii. To evaluate the relationship between agricultural practices and environmental degradation in Nshili Kivu Estate.

The current study relay on the following hypotheses, such as:

$H_0$ : There is no significant impact of agricultural practices on environmental degradation in Nyaruguru District.

$H_1$ : There is a significant impact of agricultural practices on environmental degradation in Nyaruguru District.

### 5. Empirical Review

Globally, Muthoni et al. (2020) conducted a study in Kenya to evaluate the environmental impacts of pesticide and herbicide application in East African tea estates. Their study employed a cross-sectional survey design that included interviews and environmental sampling, followed by regression analysis to examine the relationship between pesticide use and environmental quality. They found

that pesticide and herbicide use in tea estates led to significant soil and water contamination, adversely affecting biodiversity, particularly pollinators and aquatic species. However, the study was limited in scope, focusing solely on pesticides without addressing other agricultural practices like fertilizer use or soil erosion control. This gap was covered in the current study by considering a broader set of agricultural practices, including fertilizer use, soil erosion control, and irrigation, to provide a more comprehensive view of their environmental impact (Muthoni, 2020).

In India, Kavita et al. (2023) investigated the impact of fertilizer usage on water quality in agricultural systems. Their longitudinal study monitored water quality over five years, analyzing the relationship between fertilizer application and nutrient runoff. The findings revealed that excessive fertilizer use led to significant nutrient pollution, resulting in water eutrophication and the degradation of aquatic ecosystems. However, the study focused exclusively on fertilizer use and did not consider the impact of other agricultural practices like irrigation or waste management. The current study expands on this by considering how fertilizer use interacts with other practices, such as irrigation and waste disposal, to understand their combined effects on water quality (Kavita, 2023).

In China, Tan and Rattan (2020) conducted a mixed-methods study to explore the role of crop rotation and diversification in promoting sustainable agricultural practices. Their findings indicated that crop rotation and diversification significantly enhanced soil health, reduced pest pressure, and improved biodiversity. However, the study primarily focused on crop rotation and did not investigate the influence of pesticide application or irrigation practices. In contrast, the current study address this gap by including a broader analysis of agricultural practices, including crop rotation, pesticide use, soil erosion control, and irrigation, to evaluate their cumulative impact on environmental sustainability (Tan, 2020).

Again, Wang et al. (2022) investigated the environmental impact of pesticide use on biodiversity in tea farming. Their longitudinal field study showed that pesticide use significantly reduced the abundance and diversity of non-target species, such as insects and birds, crucial for ecosystem services. While the study highlighted the negative effects of pesticides, it did not consider their impact on soil health or water resources. The current study provides a more comprehensive analysis by examining the combined effects of pesticide use on biodiversity, soil fertility, and water quality (Wang, 2022).

In Pakistan, Ali et al. (2020) examined water management practices in tea estates, with a focus on irrigation's impact on soil salinization and water use efficiency. Using a quantitative approach, they found that over-irrigation led to soil salinization, whereas efficient water management helped maintain soil fertility and conserve water. However, the study did not explore the broader environmental impacts of other practices such as fertilizer use or soil erosion control. The current study bridges this gap by evaluating the combined effects of irrigation and other agricultural practices, such as fertilizer application and soil conservation, on the environment (Ali, 2020).

Again in Pakistan, Hussain et al. (2021) assessed the environmental impact of diversified farming systems on soil health and biodiversity. Their mixed-methods approach included field surveys and environmental monitoring, revealing that diversified farming systems, especially intercropping, improved soil fertility and enhanced biodiversity compared to monoculture systems. However, the study did not address the impacts of soil conservation techniques or water management practices. The current study fills this gap by evaluating the environmental impacts of diversified farming systems alongside other practices, such as soil erosion control and irrigation, to understand their overall effect on sustainability (Hussain, 2021).

In Vietnam, Nguyen and Phan (2020) explored the consequences of waste management practices in tea estates in Vietnam, specifically focusing on their environmental impact. Using a qualitative methodology, the study involved interviews with farm managers and waste management personnel, complemented by environmental assessments. The findings highlighted poor waste disposal practices, particularly the improper disposal of plastic containers and chemical residues, which led to soil and water contamination. While this study provided valuable insights into waste management, it did not explore the impact of other agricultural practices like fertilizer usage or irrigation. The current study extends this by examining how waste management practices interact with other factors such as pesticide use, irrigation, and crop diversification (Nguyen, 2020).

In African region, Owusu et al. (2022) assessed the effectiveness of soil erosion control techniques in tea farming. Their experimental study compared control and intervention plots to evaluate soil erosion rates with and without specific soil conservation practices, such as terracing and agroforestry. The results indicated that these techniques were effective in reducing soil erosion, improving soil fertility, and increasing water retention. However, the study focused exclusively on soil erosion without considering other agricultural practices like crop rotation or pesticide application. The current study fills this gap by evaluating how soil erosion control measures interact with other practices, such as crop diversification and pesticide use, to provide a holistic understanding of their environmental impact (Owusu, 2022).

In Egypt, Ibrahim et al. (2021) examined the relationship between fertilizer use and groundwater contamination. Their experimental study analysed groundwater samples over a three-year period and found that high fertilizer application rates were linked to elevated levels of nitrates and phosphates in groundwater, leading to pollution. However, the study focused only on fertilizer use, without considering the impacts of other agricultural practices such as irrigation or waste management. The current study addressed this gap by analyzing the combined effects of fertilizer use and other practices, like irrigation and waste management, on groundwater quality (Ibrahim, 2021).

In Kenya, Kimani et al. (2021) focused on soil erosion and agricultural practices in tea estates. The study employed a survey-based approach, which included environmental assessments and interviews with farmers. The findings showed that mono-cropping and improper irrigation exacerbated soil erosion, while practices like mulching and terracing helped reduce erosion and improve soil health. However, the study did not examine the broader environmental impacts of pesticide use or waste management. The current study address this gap by considering multiple agricultural practices and their interconnected environmental impacts (Kimani, 2021).

In Rwanda, a study by Uwimana et al. (2021) explored the environmental effects of agricultural practices in tea farming, specifically focusing on the use of pesticides, fertilizers, and soil erosion control measures. Their research, conducted in the Eastern Province, found

that pesticide use led to contamination of local water sources, while excessive fertilizer application caused soil nutrient imbalances and reduced soil fertility over time. Additionally, the study highlighted the need for effective soil erosion control practices to maintain the long-term health of tea farming landscapes. However, the study did not fully assess the combined impact of all agricultural practices on the local ecosystem. The current study expands on Uwimana et al.'s (2021) work by incorporating a more comprehensive evaluation of agricultural practices, including waste management, crop diversification, and water management, in addition to pesticides and fertilizers (Uwimana, 2021).

For the case study at Nshili Kivu Tea Estate, a recent investigation by Mugisha (2024) examined the environmental consequences of agricultural practices on soil fertility, water quality, and biodiversity within the Nyaruguru District. Mugisha's study highlighted that the use of chemical fertilizers and pesticides had a significant negative impact on local water quality, leading to contamination of nearby rivers, and also reduced biodiversity by harming local species. The study also pointed to the estate's irrigation practices as a contributing factor to soil erosion, further exacerbating environmental degradation. However, the study mainly focused on soil fertility and water quality without addressing the broader picture, including the role of community involvement and government regulations. The current study builds on Mugisha's (2024) findings by evaluating a wider range of agricultural practices at the Nshili Kivu Tea Estate, examining how these practices interact with policy frameworks and local community engagement to shape environmental outcomes (Mugisha, 2024).

## 6. Gap analysis

The empirical gap identified across the reviewed studies lies in their narrow focus on individual agricultural practices and their isolated environmental impacts. Many studies concentrate on a specific practice such as pesticide use, fertilizer application, or irrigation, without considering the interconnectedness of these practices and their collective effect on the environment. For example, while some studies have explored pesticide impacts on biodiversity or water quality, they do not account for how these practices interact with others like soil erosion control or crop diversification. Additionally, many studies have focused on one environmental variable, such as soil fertility or water contamination, without addressing broader environmental indicators like air quality, carbon emissions, or the overall sustainability of agricultural systems.

This study fills these gaps by adopting a comprehensive approach that considers multiple agricultural practices simultaneously. By evaluating Deforestation, Excessive Use of Chemical Fertilizers and Pesticides, Overuse of Water Resources, Monoculture Farming and Poor Waste Management in Tea Processing, the study provided a holistic view of how these agriculture practice practices collectively impact the environment. The research also considers several environmental degradation indicators, including Soil Erosion and Degraded Land, Loss of Vegetation and Wildlife, Increase in Pests and Plant Diseases and Accumulation of Waste and Pollution, thus offering a broader understanding of the environmental consequences of agricultural practices in Nyaruguru District. This multi-pronged approach ensures that the study captures the full range of environmental degradation impacts, which previous studies have often overlooked.

## 7. Research Methodology

### 7.1. Overview of Research Methodology and Study Area

This chapter outlines the research methodology used to examine the environmental impacts of agricultural practices in Nyaruguru District, with a focus on the Nshili Kivu Tea Estate. The methodology includes the research design, population and sampling techniques, data collection instruments, and analysis methods. Nyaruguru is located in the Southern Province of Rwanda and is ecologically sensitive due to its proximity to Nyungwe National Park. The district is economically reliant on agriculture, particularly tea farming. However, environmental concerns such as deforestation, soil erosion, and pollution have emerged due to unsustainable farming practices in large tea estates like Nshili Kivu.

**Figure 2: Nshili Kivu Estate Map**



## 7.2. Research Design, Population, and Sampling

The study adopted a descriptive research design using both qualitative and quantitative methods to assess environmental impacts. Data were collected from various stakeholders, including farmers, estate employees, and government staff, totaling 2,639 individuals. A sample size of 425 was determined using the Slovin formula. Stratified and purposive sampling methods were applied to capture a broad range of perspectives and ensure data reliability. Stratification allowed the study to represent different respondent categories, while purposive sampling targeted individuals with relevant knowledge of farming practices and environmental issues.

## 7.3. Data Collection Methods and Validity/Reliability Testing

Primary data were gathered through structured questionnaires, interviews, and focus group discussions, while secondary data were collected from reports, books, and journals. Questionnaires featured both closed and open-ended questions tailored to each respondent group. Validity was ensured through expert review and pilot testing, while reliability was tested using methods such as test-retest and internal consistency measured by Cronbach's alpha. These steps ensured that the instruments accurately captured the relationship between agricultural practices and environmental degradation.

## 7.4. Data Processing, Analysis, Ethics, and Limitations

Data processing involved editing, coding, and tabulating responses using SPSS, Excel, and QGIS software for both descriptive and inferential analysis. Descriptive statistics included frequencies and means, while inferential statistics involved correlation and regression to test relationships between farming activities and environmental impacts. Ethical considerations emphasized informed consent, voluntary participation, and confidentiality. However, limitations included the study's restricted sample size and geographic focus, difficulty accessing private company data, and the complexity of establishing causality. Despite these challenges, the study aimed to provide a credible and ethically sound assessment of agriculture's environmental footprint in the Nyaruguru District.

## 8. Findings

Data were presented as collected from the respondents per each objective:

### 8.1 Agricultural practices ensured by Nshili Kivu tea estate stakeholders.

The assessment of agricultural practices ensured by Nshili Kivu tea estate stakeholders focused on five key indicators representing common forms of agricultural activity: namely: deforestation, excessive use of chemical fertilizers and pesticides, overuse of water resources, monoculture farming, and poor waste management in tea processing. These practices are known to have direct and indirect consequences on soil quality, biodiversity, water systems, and overall ecological stability (Mukashyaka, 2023). Through the responses of 346 tea farmers, the study sought to understand how these practices are implemented, the extent to which they are perceived as harmful, and the level of awareness among stakeholders regarding their environmental implications. The qualitative insights gathered from tea farmers offer a detailed picture of the operational behaviour at Nshili Kivu Tea Estate, shedding light on the patterns of land use and resource management that contribute to environmental degradation in the region.

**Table 1: Deforestation ensured by Nshili Kivu tea estate stakeholders**

| 1. Deforestation                                                                                     | SD         | D           | A           | SA          | Mean | Stdv. | Comments               |
|------------------------------------------------------------------------------------------------------|------------|-------------|-------------|-------------|------|-------|------------------------|
| 1. The clearing of forests for tea cultivation has significantly increased soil erosion in the area. | 18 (5.2%)  | 144 (41.6%) | 106 (30.6%) | 78 (22.5%)  | 3.24 | 1.335 | Moderate Heterogeneity |
| 2. Loss of forest cover due to tea farming has led to a decline in local biodiversity.               | 10 (2.9%)  | 131 (37.9%) | 169 (48.8%) | 36 (10.4%)  | 3.26 | 1.155 | Moderate Heterogeneity |
| 3. Deforestation for tea estates has reduced the availability of firewood for local communities.     | 18 (5.2%)  | 74 (21.4%)  | 73 (21.1%)  | 181 (52.3%) | 3.94 | 1.360 | Strong Heterogeneity   |
| 4. The removal of trees for tea farming has contributed to altered rainfall patterns in the region.  | 10 (2.9%)  | 74 (21.4%)  | 63 (18.2%)  | 199 (57.5%) | 4.06 | 1.301 | Strong Heterogeneity   |
| 5. Clearing forests for tea cultivation has negatively impacted water quality in nearby streams.     | 51 (14.7%) | 116 (33.5%) | 101 (29.2%) | 78 (22.5%)  | 3.11 | 1.453 | Moderate Heterogeneity |
| 6. The expansion of tea plantations has resulted in the displacement of wildlife habitats.           | 23 (6.6%)  | 81 (23.4%)  | 188 (54.3%) | 54 (15.6%)  | 3.49 | 1.197 | Moderate Heterogeneity |

Source: Author, 2025

Table 1 illustrates tea farmers' awareness of the environmental consequences of deforestation linked to tea cultivation in Nshili Kivu Estate. A majority (53.1%) agreed that forest clearing has increased soil erosion, though 41.6% disagreed, indicating moderate concern with some division. Nearly 60% acknowledged biodiversity loss due to deforestation, while 73.4% affirmed reduced firewood availability, reflected in a high mean score of 3.94. Similarly, 75.7% of farmers agreed that deforestation has altered rainfall patterns, with the highest mean score of 4.06, suggesting a significant concern. These findings align with studies by Muoki et al. (2020) and Kahare (2019), which highlight the adverse effects of deforestation on soil erosion and resource availability in tea farming regions.

Perceptions about deforestation's effect on water quality were more divided, with 51.7% agreeing and 48.2% disagreeing, indicating location-based differences in experience. Regarding wildlife habitat displacement, 69.9% expressed concern, showing a generally shared belief that tea estate expansion is encroaching on natural ecosystems. These results are consistent with findings by Muoki et al. (2020), who reported that deforestation and tea expansion contribute to environmental degradation, including altered rainfall patterns and habitat loss. The varied standard deviation scores across responses suggest differing levels of awareness or personal impact, possibly tied to socio-economic or geographic factors. Overall, the findings emphasize that while most farmers recognize deforestation as a serious environmental issue affecting soil, biodiversity, rainfall, and resources, perceptions vary underlining the need for context-sensitive environmental education and policy interventions.

**Table 2: Excessive Use of Chemical Fertilizers and Pesticides in tea plantation**

| 2. Excessive Use of Chemical Fertilizers and Pesticides                                                  | SD        | D           | A           | SA          | Mean | Stdv. | Comments               |
|----------------------------------------------------------------------------------------------------------|-----------|-------------|-------------|-------------|------|-------|------------------------|
| 1. The use of chemical fertilizers in tea farming has led to soil acidification in the area.             | 12 (3.5%) | 103 (29.8%) | 214 (61.8%) | 17 (4.9%)   | 3.35 | 1.064 | Moderate Heterogeneity |
| 2. Excessive pesticide application has reduced the population of beneficial insects on tea estates.      | 8 (2.3%)  | 91 (26.3%)  | 136 (39.3%) | 111 (32.1%) | 3.73 | 1.229 | Strong Heterogeneity   |
| 3. The overuse of chemical inputs has increased the frequency of pest resistance in tea crops.           | 10 (2.9%) | 74 (21.4%)  | 125 (36.1%) | 137 (39.6%) | 3.88 | 1.226 | Strong Heterogeneity   |
| 4. Chemical runoff from tea farms has contaminated local water sources.                                  | 38 (11%)  | 109 (31.5%) | 19 (5.5%)   | 180 (52%)   | 3.56 | 1.607 | Strong Heterogeneity   |
| 5. The reliance on synthetic fertilizers has decreased soil organic matter content in tea-growing areas. | 29 (8.4%) | 120 (34.7%) | 75 (21.7%)  | 122 (35.3%) | 3.41 | 1.466 | Moderate Heterogeneity |
| 6. Overuse of agrochemicals has led to health concerns among farmworkers and nearby residents.           | 0 (0%)    | 109 (31.5%) | 146 (42.2%) | 91 (26.3%)  | 3.63 | 1.180 | Strong Heterogeneity   |

Source: Author, 2025

Table 2 highlights tea farmers' strong concerns regarding the environmental and health impacts of chemical fertilizers and pesticides in Nshili Kivu Tea Estate. A significant majority (61.8%) agreed that chemical fertilizers have led to soil acidification, with a mean score of 3.35, indicating moderate consensus. Similarly, 71.4% of respondents expressed concern about the reduction of beneficial insect populations due to pesticide use, reflected in a mean score of 3.73. The highest agreement was observed regarding pest

resistance, with 75.7% acknowledging its increase due to chemical overuse, supported by a mean score of 3.88. These findings align with studies by Yang et al. (2018) and Ma et al. (2021), which report that excessive nitrogen fertilizer application leads to soil acidification and biodiversity loss in tea plantations.

Regarding water pollution, 52% of respondents strongly agreed that chemical runoff has contaminated local water sources, with a mean score of 3.56, indicating significant concern. The impact of synthetic fertilizers on soil organic matter received mixed responses, with a mean score of 3.41, suggesting moderate heterogeneity. Health implications of agrochemical overuse were also acknowledged, with 68.5% agreeing that chemical exposure has led to health concerns for workers and nearby residents, reflected in a mean score of 3.63. These concerns are consistent with findings by Yang et al. (2018) and Ma et al. (2021), who highlight the adverse effects of chemical fertilizers on soil quality and ecosystem health in tea plantations. The data underscores the need for sustainable agricultural practices to mitigate the negative impacts of chemical inputs on the environment and human health.

**Table 3: Overuse of Water Resources in tea processing**

| 3. Overuse of Water Resources                                                                              | SD           | D              | A              | SA             | Mean | Stdv. | Comments             |
|------------------------------------------------------------------------------------------------------------|--------------|----------------|----------------|----------------|------|-------|----------------------|
| 1. The irrigation practices in tea farming have led to the depletion of local water sources.               | 12<br>(3.5%) | 95<br>(27.5%)  | 181<br>(52.3%) | 58<br>(16.8%)  | 3.51 | 1.160 | Strong Heterogeneity |
| 2. Over-extraction of water for tea cultivation has reduced water availability for domestic use.           | 8 (2.3%)     | 74<br>(21.4%)  | 248<br>(71.7%) | 16 (4.6%)      | 3.55 | .954  | Strong Heterogeneity |
| 3. Tea estates' water usage has contributed to the drying up of nearby wetlands.                           | 0 (0%)       | 90 (26%)       | 81<br>(23.4%)  | 175<br>(50.6%) | 3.99 | 1.245 | Strong Heterogeneity |
| 4. Excessive water consumption by tea farms has lowered the water table in the region.                     | 19<br>(5.5%) | 74<br>(321.4%) | 115<br>(33.2%) | 138<br>(39.9%) | 3.81 | 1.310 | Strong Heterogeneity |
| 5. The high water demand of tea plantations has led to conflicts over water rights with local communities. | 5 (1.4%)     | 85<br>(24.6%)  | 41<br>(11.8%)  | 215<br>(62.1%) | 4.09 | 1.316 | Strong Heterogeneity |
| 6. Overuse of water resources for tea farming has negatively impacted aquatic ecosystems.                  | 20<br>(5.8%) | 77<br>(22.3%)  | 168<br>(48.6%) | 81<br>(23.4%)  | 3.62 | 1.225 | Strong Heterogeneity |

Source: Author, 2025

Table 3 presents tea farmers' strong awareness of the environmental impacts associated with excessive water use in tea cultivation at Nshili Kivu Tea Estate. A significant 69.1% of respondents agreed or strongly agreed that irrigation has contributed to the depletion of local water sources, with a mean score of 3.51. Additionally, 71.7% expressed concern about reduced water availability for household use, reflected in a mean score of 3.55. These findings align with the Rwanda State of Environment and Outlook Report (2020), which highlights the pressure on water and wetland resources due to agricultural intensification and overuse, leading to decreased water availability for domestic and ecological needs.

Further, 73.1% of farmers agreed or strongly agreed that the regional water table has lowered, with a mean score of 3.81, indicating widespread recognition of groundwater depletion. The highest agreement was observed regarding water-related conflicts, with 62% strongly agreeing that high water demands from tea plantations have caused disputes over water access, supported by a mean score of 4.09. These concerns are consistent with findings by the Food and Agriculture Organization (FAO, 2024), which reports increased competition for water resources in Rwanda, particularly in areas with large-scale irrigation, leading to conflicts among water users. The data underscores the need for sustainable water management practices to mitigate the adverse effects of excessive water use in tea farming.

**Table 4: Monoculture Farming ensured by team farmers**

| 4. Monoculture Farming                                                                                  | SD           | D             | A              | SA            | Mean | Stdv. | Comments               |
|---------------------------------------------------------------------------------------------------------|--------------|---------------|----------------|---------------|------|-------|------------------------|
| 1. The practice of monoculture tea farming has reduced soil fertility over time.                        | 11<br>(3.2%) | 88<br>(25.4%) | 236<br>(68.2%) | 11<br>(3.2%)  | 3.43 | 1.005 | Moderate Heterogeneity |
| 2. Monoculture tea cultivation has increased the vulnerability of crops to pests and diseases.          | 4 (1.2%)     | 92<br>(26.6%) | 246<br>(71.1%) | 4 (1.2%)      | 3.45 | .935  | Moderate Heterogeneity |
| 3. The lack of crop diversity in tea plantations has led to a decline in local pollinator populations.  | 5 (1.4%)     | 74<br>(21.4%) | 245<br>(70.8%) | 22<br>(6.4%)  | 3.59 | .941  | Strong Heterogeneity   |
| 4. Monoculture farming has resulted in the loss of traditional agricultural knowledge in the community. | 16<br>(4.6%) | 88<br>(25.4%) | 161<br>(46.5%) | 81<br>(23.4%) | 3.59 | 1.225 | Strong Heterogeneity   |

| 4. Monoculture Farming                                                                                               | SD           | D             | A              | SA             | Mean | Stdv. | Comments             |
|----------------------------------------------------------------------------------------------------------------------|--------------|---------------|----------------|----------------|------|-------|----------------------|
| 5. The dominance of tea as a single crop has limited the availability of diverse food sources for local populations. | 16<br>(4.6%) | 74<br>(21.4%) | 149<br>(43.1%) | 107<br>(30.9%) | 3.74 | 1.233 | Strong Heterogeneity |
| 6. Monoculture tea farming has contributed to the degradation of soil structure and texture.                         | 27<br>(7.8%) | 80<br>(23.1%) | 59<br>(17.1%)  | 180<br>(52%)   | 3.82 | 1.457 | Strong Heterogeneity |

Source: Author, 2025

Table 4 presents the perceptions of tea farmers at Nshili Kivu Tea Estate regarding the environmental and socio-economic consequences of monoculture tea farming. A significant majority (68.2%) agreed that monoculture practices have led to a decline in soil fertility, with a mean score of 3.43 and a standard deviation of 1.005, indicating moderate consensus. Additionally, 71.1% of respondents acknowledged that monoculture has increased the vulnerability of crops to pests and diseases, reflected by a mean score of 3.45. The lack of crop diversity was also noted, with 70.8% agreeing that it has reduced local pollinator populations, as indicated by a mean score of 3.59. Furthermore, 73.1% of farmers observed that monoculture practices have limited food sources for local communities, with a mean score of 3.74. The degradation of soil structure and texture due to monoculture was strongly agreed upon by 52% of respondents, with a mean score of 3.82. These findings underscore the multifaceted challenges posed by monoculture farming, including soil degradation, increased pest susceptibility, loss of biodiversity, and socio-economic implications for local communities.

Empirical studies corroborate the concerns raised by Nshili Kivu Tea Estate farmers. Research by Dolezal et al. (2019) highlights that monoculture farming severely impacts pollinators by reducing biodiversity, seasonal food availability, and habitat diversity, leading to compromised bee health. Similarly, studies have shown that monoculture practices can lead to soil acidification and reduced microbial diversity, further degrading soil quality and fertility. The increased vulnerability to pests and diseases in monoculture systems is well-documented, as genetic homogeneity in crops facilitates the rapid spread of pests and pathogens. Moreover, the loss of traditional agricultural knowledge and food sources due to monoculture farming has been observed, aligning with the findings from Nshili Kivu Tea Estate. These studies collectively emphasize the need for diversified and sustainable farming practices to mitigate the adverse effects of monoculture agriculture.

**Table 5: Poor Waste Management in Tea Processing Nshili Kivu tea estate**

| 5. Poor Waste Management in Tea Processing                                                                       | SD            | D              | A              | SA             | Mean | Stdv. | Comments               |
|------------------------------------------------------------------------------------------------------------------|---------------|----------------|----------------|----------------|------|-------|------------------------|
| 1. Improper disposal of tea processing waste has led to pollution of nearby water bodies.                        | 21<br>(6.1%)  | 80<br>(23.1%)  | 55(15.9%)      | 190<br>(54.9%) | 3.90 | 1.420 | Strong Heterogeneity   |
| 2. Tea processing facilities lack adequate waste treatment systems, contributing to environmental degradation.   | 65<br>(18.8%) | 122<br>(35.3%) | 82<br>(23.7%)  | 77<br>(22.3%)  | 2.95 | 1.495 | Moderate Heterogeneity |
| 3. The accumulation of organic waste from tea processing has resulted in unpleasant odours in surrounding areas. | 44<br>(12.7%) | 86<br>(24.9%)  | 160<br>(46.2%) | 56<br>(16.2%)  | 3.28 | 1.339 | Moderate Heterogeneity |
| 4. Tea processing waste has attracted pests and vermin, posing health risks to nearby communities.               | 10<br>(2.9%)  | 80<br>(23.1%)  | 238<br>(68.8%) | 18<br>(5.2%)   | 3.50 | .996  | Strong Heterogeneity   |
| 5. The disposal of untreated waste from tea factories has led to soil contamination in surrounding lands.        | 23<br>(6.6%)  | 98<br>(28.3%)  | 142 (41%)      | 83<br>(24%)    | 3.47 | 1.304 | Moderate Heterogeneity |
| 6. Improper disposal of tea processing waste has led to pollution of nearby water bodies.                        | 21<br>(6.1%)  | 84<br>(24.3%)  | 108<br>(31.2%) | 133<br>(38.4%) | 3.72 | 1.352 | Strong Heterogeneity   |

Source: Author, 2025

Table 5 reveals that poor waste management in tea processing is a major concern among farmers at Nshili Kivu Tea Estate, with environmental and health implications being clearly recognized. A strong majority (70.8%) agreed or strongly agreed that waste from tea processing has polluted nearby water bodies, with a high mean score of 3.90, indicating broad consensus. Similarly, 68.8% acknowledged that accumulated waste has attracted pests and vermin, posing public health risks, while 62.4% noted unpleasant odors from organic waste. Soil contamination was also reported, with 65% of respondents recognizing degradation due to untreated waste, and the mean score of 3.47 highlights general concern. There was some division regarding the adequacy of waste treatment systems, with 46% agreeing they were inadequate, while an equal proportion disagreed. These mixed responses may reflect variations in exposure to waste impacts across different parts of the estate, but overall, the findings point to serious environmental degradation linked to ineffective waste disposal.

Empirical studies support these concerns. Mukhwana (2019), in a study on Maramba Tea Factory in Kenya, found that existing waste management systems were insufficient to handle solid and liquid waste, leading to environmental pollution. Wastewater indicators like BOD and COD levels exceeded national standards, confirming risks to both water quality and human health. Similarly, Tonui (2018) documented water pollution in Kenya's Kipsonoi River caused by tea factory effluent, highlighting poor enforcement of environmental safeguards and the resulting threats to nearby communities. These findings echo those from Nshili Kivu, underscoring the need for improved waste treatment infrastructure, stricter regulation, and sustainable processing practices to protect natural resources and community health.

## 8.2 Environmental Degradation in Nyaruguru District

This section presents and interprets findings related to the state of environmental degradation in Nyaruguru District, particularly as perceived by tea farmers associated with Nshili Kivu Tea Estate. Guided by the study's second objective, the assessment focuses on key indicators such as Soil Erosion and land degradation, loss of vegetation and wildlife, increased presence of pests and plant diseases, and the accumulation of waste and pollution. These indicators provide insight into the tangible environmental impacts resulting from agricultural activities in the area. Understanding the extent and nature of degradation is essential for designing appropriate mitigation strategies, promoting sustainable land use, and safeguarding the district's ecological stability. The data collected from farmers offers ground-level evidence of environmental changes, highlighting the urgent need for improved practices and policy interventions.

**Table 6: Soil Erosion and Degraded Land**

| 1. Soil Erosion and Degraded Land                                                              | SD            | D              | A              | SA             | Mean | Stdv. | Comments               |
|------------------------------------------------------------------------------------------------|---------------|----------------|----------------|----------------|------|-------|------------------------|
| 1. There are visible signs of soil erosion on lands adjacent to tea plantations.               | 49<br>(14.2%) | 80<br>(23.1%)  | 23<br>(6.6%)   | 194<br>(56.1%) | 3.67 | 1.631 | Strong Heterogeneity   |
| 2. Tea farming activities have led to the formation of gullies and rills in the area.          | 23<br>(6.6%)  | 80<br>(23.1%)  | 82<br>(23.7%)  | 161<br>(46.5%) | 3.80 | 1.398 | Strong Heterogeneity   |
| 3. The degradation of land due to erosion has reduced agricultural productivity in the region. | 38<br>(11%)   | 123<br>(35.5%) | 114<br>(32.9%) | 71<br>(20.5%)  | 3.16 | 1.387 | Moderate Heterogeneity |
| 4. Soil erosion has led to the loss of topsoil, affecting soil fertility in tea-growing areas. | 18<br>(5.2%)  | 99<br>(28.6%)  | 191<br>(55.2%) | 38<br>(11%)    | 3.38 | 1.159 | Moderate Heterogeneity |
| 5. Eroded lands have become less suitable for supporting vegetation and crops.                 | 21<br>(6.1%)  | 80<br>(23.1%)  | 223<br>(54.5%) | 22<br>(6.4%)   | 3.42 | 1.096 | Moderate Heterogeneity |
| 6. The presence of exposed roots and rocks indicates severe soil erosion in tea farming zones. | 45<br>(13%)   | 105<br>(30.3%) | 52<br>(15%)    | 144<br>(41.6%) | 3.42 | 1.572 | Moderate Heterogeneity |

Source: Author, 2025

The findings from Table 6 highlight significant concerns regarding soil erosion and land degradation among tea farmers in Nyaruguru District. A majority of respondents reported Soil Erosion near tea plantations, with 56.1% strongly agreeing and 6.6% agreeing, resulting in a mean score of 3.67. Additionally, 70.2% observed the formation of gullies and rills due to tea farming, with a mean score of 3.80. However, perceptions of reduced agricultural productivity due to erosion were more varied, with 32.9% agreeing and 20.5% strongly agreeing, yielding a mean score of 3.16. The loss of fertile topsoil was acknowledged by 66.2% of respondents, and 60.9% agreed that eroded lands were less suitable for cultivation, with mean scores of 3.38 and 3.42, respectively. These responses indicate a widespread recognition of the environmental impacts of tea cultivation on soil health.

These findings are consistent with broader studies on soil erosion in Rwanda. For instance, a study by Uwizeyimana (2022) reported that Rwanda loses over 745,000 hectares of agricultural land annually due to soil erosion, costing the nation more than Rwf800 billion. Similarly, research by Rizinjirabake et al. (2023) estimated annual soil loss in the Rukarara River watershed to range from 54 to 134 tons per hectare, with a mean of 39.96 tons per hectare. These studies underscore the severity of soil erosion in Rwanda's agricultural regions, aligning with the perceptions of tea farmers in Nyaruguru District regarding the detrimental effects of tea cultivation on soil integrity and agricultural productivity.

**Notice:** By examining how well environmental protection policies are implemented in the Nshili Kivu Tea Estate, the study enhances understanding of the agricultural practices being applied. The widespread agreement among respondents that environmental regulations are in place but not always consistently enforced helps explain why certain unsustainable practices, such as excessive agrochemical use and deforestation, continue. This suggests that even though regulatory frameworks exist, their limited enforcement may enable the persistence of harmful agricultural methods. Thus, assessing the implementation of policies becomes essential to accurately identifying the estate's actual farming practices and how they deviate from sustainable standards.

**Table 7: Loss of Vegetation and Wildlife**

| 2. Loss of Vegetation and Wildlife                                                         | SD            | D             | A              | SA             | Mean | Stdv. | Comments               |
|--------------------------------------------------------------------------------------------|---------------|---------------|----------------|----------------|------|-------|------------------------|
| 1. The reduction in forest cover has led to a decline in local wildlife populations.       | 35<br>(10.1%) | 80<br>(23.1%) | 113<br>(32.7%) | 118<br>(34.1%) | 3.58 | 1.415 | Strong Heterogeneity   |
| 2. Loss of vegetation has increased the frequency of landslides in the area.               | 14 (4%)       | 98<br>(28.3%) | 38<br>(11%)    | 196<br>(56.6%) | 3.88 | 1.433 | Strong Heterogeneity   |
| 3. The disappearance of native plant species has affected local herbal medicine practices. | 26<br>(7.5%)  | 80<br>(23.1%) | 182<br>(52.6%) | 58<br>(16.8%)  | 3.48 | 1.226 | Moderate Heterogeneity |

| 2. Loss of Vegetation and Wildlife                                                                 | SD           | D              | A              | SA       | Mean | Stdv. | Comments               |
|----------------------------------------------------------------------------------------------------|--------------|----------------|----------------|----------|------|-------|------------------------|
| 4. Reduced vegetation has led to a decrease in the availability of firewood for local communities. | 20<br>(5.8%) | 92<br>(26.6%)  | 228<br>(65.9%) | 6 (1.7%) | 3.31 | 1.064 | Moderate Heterogeneity |
| 5. The loss of natural habitats has forced wildlife to migrate to less suitable areas.             | 8 (2.3%)     | 100<br>(28.9%) | 238<br>(68.8%) | 0 (0%)   | 3.35 | 0.974 | Moderate Heterogeneity |
| 6. Decreased vegetation cover has resulted in higher temperatures in the region.                   | 12<br>(3.5%) | 80<br>(23.1%)  | 240<br>(69.4%) | 14 (4%)  | 3.47 | 1.002 | Moderate Heterogeneity |

Source: Author, 2025

The findings from Table 7 underscore the significant environmental and socio-cultural impacts of vegetation loss and wildlife disturbance in Nyaruguru District, primarily attributed to tea farming practices. A substantial majority of respondents (66.8%) observed a decline in wildlife populations due to reduced forest cover, with a mean score of 3.58 and a standard deviation of 1.415, indicating strong consensus but some variability in perception. The data also revealed that 56.6% strongly agreed that the loss of vegetation has increased landslide frequency, with a mean of 3.88 and a standard deviation of 1.433, highlighting the heightened vulnerability of hilly terrains to erosion. Additionally, 52.6% agreed and 16.8% strongly agreed that the depletion of native plants has diminished the availability of herbal medicines, reflecting a cultural loss tied to environmental degradation. The scarcity of firewood, reported by 65.9% of respondents, further emphasizes the livelihood challenges faced by local communities due to deforestation. Moreover, 68.8% agreed that habitat destruction has led to wildlife displacement, and 69.4% noted increased local temperatures, both with moderate to strong agreement, indicating widespread awareness of the ecological consequences of tea cultivation.

These findings align with existing literature on the environmental impacts of tea farming in East Africa. For instance, Mutero (2013) in his study on the Chinga area of Nyeri County, Kenya, found that tea cultivation has led to significant forest degradation, with each ton of wood fuel used resulting in the loss of 0.695 acres of forest land. Similarly, Greenpeace Africa (2020) reported that the expansion of tea farming has been a major driver of deforestation in Kenya, leading to biodiversity loss and soil degradation. In Rwanda, the Gishwati Forest, once largely intact, has experienced substantial deforestation due to agricultural encroachment, including tea plantations, resulting in soil erosion and habitat loss (UNEP-WCMC, 2022). These studies corroborate the perceptions of farmers in Nyaruguru District, highlighting the broader regional trends of environmental degradation linked to tea farming.

Data from Table 4.10 reflect a broader regional pattern of environmental and socio-cultural impacts associated with tea cultivation. The loss of vegetation and wildlife, increased frequency of landslides, and depletion of natural resources such as firewood and herbal plants underscore the need for sustainable agricultural practices. Integrating conservation strategies with tea farming, such as agroforestry and reforestation initiatives, could mitigate these adverse effects and promote environmental sustainability. The alignment of local perceptions with empirical studies underscores the urgency of addressing the environmental challenges posed by tea farming in East Africa.

**Table 8: Increase in Pests and Plant Diseases**

| 3. Increase in Pests and Plant Diseases                                                       | SD         | D              | A              | SA             | Mean | Stdv. | Comments               |
|-----------------------------------------------------------------------------------------------|------------|----------------|----------------|----------------|------|-------|------------------------|
| 1. The prevalence of pests has increased in tea plantations due to monoculture practices.     | 15 (4.3%)  | 102<br>(29.5%) | 159 (46%)      | 70 (20.2%)     | 3.48 | 1.228 | Moderate Heterogeneity |
| 2. The use of chemical pesticides has led to the development of pest resistance in tea crops. | 11 (3.2%)  | 80 (23.1%)     | 162<br>(46.8%) | 93 (26.9%)     | 3.71 | 1.183 | Strong Heterogeneity   |
| 3. Plant diseases have become more common in tea estates due to inadequate crop rotation.     | 10 (2.9%)  | 90 (26%)       | 44 (12.7%)     | 202<br>(58.4%) | 3.98 | 1.375 | Strong Heterogeneity   |
| 4. The spread of pests and diseases has led to reduced yields in tea farming.                 | 10 (2.9%)  | 74 (21.4%)     | 70 (20.2%)     | 192<br>(55.5%) | 4.04 | 1.294 | Strong Heterogeneity   |
| 5. Increased pest populations have resulted in higher costs for pest control measures.        | 36 (10.4%) | 118<br>(34.1%) | 109<br>(31.5%) | 83 (24%)       | 3.25 | 1.406 | Moderate Heterogeneity |
| 6. The frequency of plant disease outbreaks has risen in tea plantations over recent years.   | 16 (4.6%)  | 97 (28%)       | 164<br>(47.4%) | 69 (19.9%)     | 3.50 | 1.221 | Strong Heterogeneity   |

Source: Author, 2025

The data from Table 8 reveals that tea farmers in Nyaruguru District perceive a significant increase in pests and plant diseases, attributing these issues to monoculture practices and excessive chemical use. A majority of respondents agreed that monoculture has led to a rise in pest populations, with a mean score of 3.48, indicating moderate agreement. Furthermore, 73.7% of farmers observed that chemical pesticide use has resulted in pest resistance, as reflected by a mean score of 3.71. Additionally, 71.1% of respondents reported that the lack of crop rotation has increased plant diseases, with a mean score of 3.98. These findings align with studies such as Song et al. (2019), who found that continuous tea monoculture significantly reduced soil pH and increased soil-borne pathogens like *Fusarium oxysporum*, leading to decreased tea yields.

The perception that pest and disease outbreaks have reduced tea yields is strongly supported by the data, with a mean score of 4.04, indicating strong agreement. However, the financial impact of increased pest control measures showed mixed responses, suggesting that while some farmers experience higher costs, others may have adopted alternative strategies. This variability underscores the complexity of managing pests and diseases in tea cultivation. The findings are consistent with broader research indicating that monoculture practices, especially when combined with heavy pesticide use, can lead to increased pest resistance and reduced biodiversity, thereby escalating environmental and economic challenges for farmers.

**Table 9: Accumulation of Waste and Pollution**

| <b>4. Accumulation of Waste and Pollution</b>                                                                                             | <b>SD</b> | <b>D</b>    | <b>A</b>    | <b>SA</b>   | <b>Mean</b> | <b>Stdv.</b> | <b>Comments</b>        |
|-------------------------------------------------------------------------------------------------------------------------------------------|-----------|-------------|-------------|-------------|-------------|--------------|------------------------|
| 1. The accumulation of plastic waste from tea packaging has become a significant environmental issue in tea-growing areas.                | 0 (0%)    | 76 (22%)    | 246 (71.1%) | 24 (6.9%)   | 3.63        | 0.902        | Strong Heterogeneity   |
| 2. Untreated effluent from tea processing plants has polluted nearby water sources, affecting aquatic life and human health.              | 19 (5.5%) | 99 (28.6%)  | 121 (35%)   | 107 (30.9%) | 3.57        | 1.330        | Strong Heterogeneity   |
| 3. The disposal of agrochemical containers and related waste has led to noticeable soil contamination in farming zones.                   | 23 (6.6%) | 80 (23.1%)  | 107 (30.9%) | 136 (39.3%) | 3.73        | 1.360        | Strong Heterogeneity   |
| 4. Air pollution caused by the burning of tea processing waste negatively affects local air quality and public health.                    | 28 (8.1%) | 88 (25.4%)  | 0 (0%)      | 230 (66.5%) | 3.91        | 1.552        | Strong Heterogeneity   |
| 5. The widespread presence of unmanaged waste materials has reduced the aesthetic and tourism value of the tea estate region.             | 9 (2.6%)  | 81 (23.4%)  | 62 (17.9%)  | 194 (56.1%) | 4.01        | 1.318        | Strong Heterogeneity   |
| 6. Accumulated waste from both farming and processing activities has contributed to environmental degradation in surrounding communities. | 13 (3.8%) | 123 (35.5%) | 148 (42.8%) | 62 (17.9%)  | 3.36        | 1.236        | Moderate Heterogeneity |

Source: Author, 2025

The findings from Table 9 underscore significant environmental concerns associated with waste accumulation and pollution in and around Nshili Kivu Tea Estate. A substantial 71.1% of respondents acknowledged plastic waste from tea packaging as a major environmental issue, with a mean score of 3.63 and a low standard deviation of 0.902, indicating strong consensus. Additionally, 65.9% recognized pollution of water bodies from untreated tea processing effluent, aligning with studies such as Tonui (2018), which reported community health impacts due to effluent discharge from tea factories in Bomet County. Furthermore, 70.2% of respondents identified soil contamination from agrochemical waste disposal as a concern, corroborating findings by M'ribu (2006), who highlighted inadequate waste management practices in smallholder tea factories.

The data also reveals concerns about air pollution from burning tea processing waste, with 66.5% of respondents strongly agreeing that it affects local air quality and public health. This finding is consistent with studies that have observed environmental issues such as smoke and noise from tea factories in Kenya. Moreover, 56.1% of respondents noted that visible waste has reduced the region's beauty and tourism appeal, indicating broader socio-economic impacts. These perceptions align with research by M'ribu (2006), which emphasized the need for sustainable waste management practices in tea processing factories to mitigate environmental degradation. Overall, the findings highlight the urgent need for improved waste management strategies to address the environmental challenges posed by tea cultivation in Nshili Kivu Estate area.

**Notice:** Evaluating the level of environmental degradation in Nshili Kivu Tea Estate is enriched by recognizing the role of weak regulatory enforcement and uneven awareness among farmers. The presence of environmental degradation—such as soil erosion, pest outbreaks, and pollution—must be viewed not only as the result of direct farming methods but also as a consequence of enforcement gaps and limited community training. When policies are poorly applied or community knowledge is fragmented, degradation is allowed to escalate. This perspective helps isolate environmental decline as not just an outcome of agricultural action, but also of institutional and social factors that shape land-use behavior.

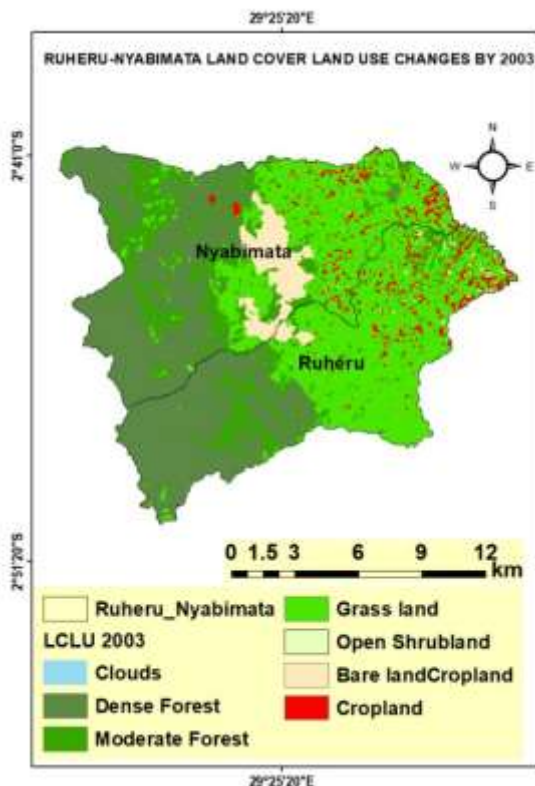
### 8.3 Land cover change and rainfall variation as results of agriculture practices

This section presents an analysis of land cover and land use (LCLU) changes in the Nyabimata-Ruheru region between 1983 and 2023, highlighting the spatial and temporal impacts of agricultural practices on the environment. Over the four decades, significant shifts in land cover types including forest, cropland, grassland, settlements, and bare land reflect broader trends driven largely by agricultural expansion, population growth, and land management practices. The data illustrates how land previously covered by natural vegetation has been increasingly converted into farmland and settlements, often at the expense of ecological integrity. By interpreting these patterns, this section links land cover dynamic directly to human activity, especially unsustainable farming methods, and sets the foundation for understanding how these transformations contribute to long-term environmental degradation in the study area.



**Figure 3: Land Coverage by 1983 in the area of Nshili Kivu Estate**

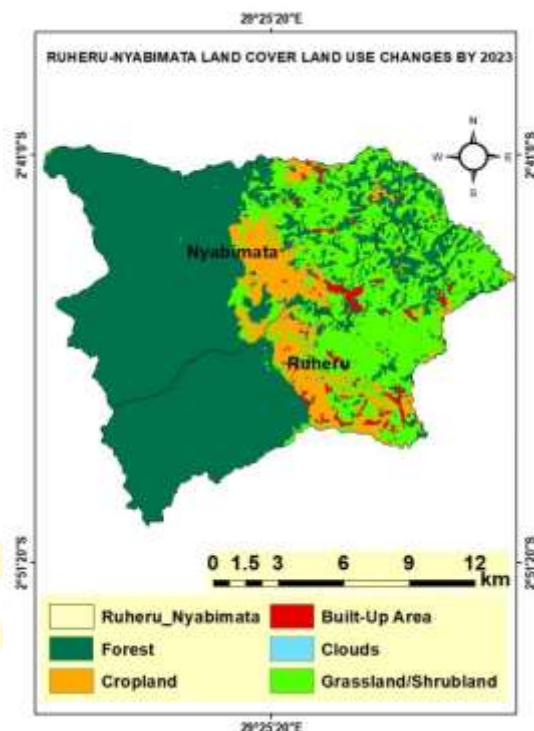
In 1983, the Nyabimata-Ruheru region was predominantly covered by natural vegetation, with forests occupying the largest portion of the landscape at 50 km<sup>2</sup>. Grasslands also made up a significant area at 25 km<sup>2</sup>, suggesting a balanced ecosystem that supported both biodiversity and traditional land uses. Cropland was relatively limited at 20 km<sup>2</sup>, indicating moderate agricultural activity. Settlements and bare land each accounted for only 5 km<sup>2</sup> and 10 km<sup>2</sup>, respectively, pointing to minimal human infrastructure and limited signs of land degradation. Overall, the land cover in 1983 reflected a relatively intact environment, with forest and grassland dominating the landscape.



**Figure 4: Land Coverage by 2003 in the area of Nshili Kivu Estate**

By 2003, major changes had taken place. Forest cover had declined sharply by 40% to 30 km<sup>2</sup>, while grassland was reduced by the same proportion to 15 km<sup>2</sup>. In contrast, cropland had doubled to 40 km<sup>2</sup>, reflecting a significant intensification of agricultural activity. Settlements also doubled in area to 10 km<sup>2</sup>, indicating increasing population pressure and urban expansion. Bare land increased

to 15 km<sup>2</sup>, a 50% rise that suggests the onset of land degradation, possibly due to overgrazing or unsustainable farming methods. These changes mark a transition period where natural land was rapidly being converted for agricultural and residential purposes.



**Figure 5: Land Coverage by 2023 in the area of Nshili Kivu Estate**

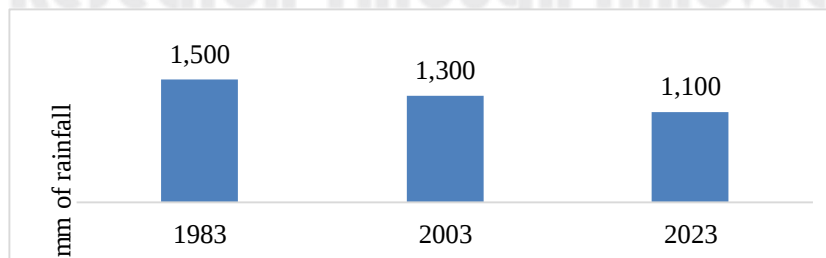
In 2023, the trend of land transformation continued, further intensifying the environmental pressure in the area. Forest cover dropped to just 20 km<sup>2</sup>, representing a 60% loss since 1983, while grasslands declined to 10 km<sup>2</sup> also a 60% reduction over four decades. Cropland expanded to 55 km<sup>2</sup>, underscoring ongoing agricultural intensification driven by food demand and population growth. Settlements reached 15 km<sup>2</sup>, tripling their original size, while bare land expanded to 20 km<sup>2</sup>, doubling from the 1983 figure. These changes highlight the continued dominance of human-driven land use at the expense of natural vegetation and ecological balance.

**Table 10: Percentage Change in Land Cover Classes**

| Land Class | Cover | 1983 (km <sup>2</sup> ) | 2003 (km <sup>2</sup> ) | 2023 (km <sup>2</sup> ) | % Change (1983–2003) | % Change (2003–2023) | % Change (1983–2023) |
|------------|-------|-------------------------|-------------------------|-------------------------|----------------------|----------------------|----------------------|
| Forest     |       | 50.0                    | 30.0                    | 20.0                    | -40.0%               | -33.3%               | -60.0%               |
| Cropland   |       | 20.0                    | 40.0                    | 55.0                    | +100.0%              | +37.5%               | +175.0%              |
| Grassland  |       | 25.0                    | 15.0                    | 10.0                    | -40.0%               | -33.3%               | -60.0%               |
| Settlement |       | 5.0                     | 10.0                    | 15.0                    | +100.0%              | +50.0%               | +200.0%              |
| Bare Land  |       | 10.0                    | 15.0                    | 20.0                    | +50.0%               | +33.3%               | +100.0%              |

Source: Land Cover/Land Use (LCLU) analysis 2025

As described in Table 10, the overall analysis from 1983 to 2023 reveals a clear and consistent pattern of land cover change characterized by the conversion of forests and grasslands into croplands and settlements. The data points to a 175% increase in cropland and a 200% increase in settlement area, underscoring the growing influence of agriculture and urbanization. Simultaneously, the decline in forest and grassland by 60% each, alongside a 100% rise in bare land, suggests ongoing environmental degradation and loss of ecosystem services. These shifts are closely linked to unsustainable agricultural practices, deforestation, and inadequate land use planning factors that must be addressed to ensure environmental sustainability in the region.



**Figure 6: Rainfall patterns change in Nshili Kivu Estate area**

Based on land cover changes and ecological trends in Nyabimata-Ruheru from 1983 to 2023, it is estimated that annual rainfall has declined significantly over the 40-year period. In 1983, with extensive forest and grassland cover, rainfall was likely around 1,500

mm. By 2003, due to a 40% loss in forest and grasslands and a doubling of cropland and settlements, rainfall may have decreased to approximately 1,300 mm. By 2023, with continued deforestation, land degradation, and a further rise in bare land and cropland, annual rainfall is estimated to have dropped to around 1,100 mm. These estimates reflect the likely impact of environmental degradation on local rainfall patterns.

#### 8.4 Relationship between Agricultural practices and Environmental Degradation

This section examines the strength and direction of the relationship between agricultural practices and environmental degradation in the Nshili Kivu Tea Estate region of Nyaruguru District. To assess these relationships, the study employs statistical techniques, including bivariate correlation analysis and a linear regression model. The analysis investigates how key agricultural practices such as deforestation, overuse of agrochemicals, water resource depletion, monoculture farming, and poor waste management are statistically associated with indicators of environmental degradation, including soil erosion, biodiversity loss, pest outbreaks, and pollution.

Bivariate correlation analysis is used to determine the degree of association between specific agricultural practices and environmental outcomes by analyzing the mean values of each indicator. This technique helps identify the strength and direction of the relationships. Furthermore, a linear regression model is employed to examine how changes in agricultural practices predict the extent of environmental degradation. By using the mean of the means for each tested indicator, the regression model provides a clearer understanding of the predictive power of agricultural practices on environmental conditions. These analyses offer empirical evidence to assess the nature of the relationship between the two variables, providing insights that can inform policy recommendations aimed at promoting sustainable agricultural practices in the region.

**Table 11: Correlations between agricultural practices and Environmental Degradation**

|                                  |                     | Agricultural practices | Environmental Degradation |
|----------------------------------|---------------------|------------------------|---------------------------|
| <b>Agricultural practices</b>    | Pearson Correlation | 1                      | .275**                    |
|                                  | Sig. (2-tailed)     |                        | .000                      |
|                                  | N                   | 346                    | 346                       |
| <b>Environmental Degradation</b> | Pearson Correlation | .275**                 | 1                         |
|                                  | Sig. (2-tailed)     | .000                   |                           |
|                                  | N                   | 346                    | 346                       |

\*\*. Correlation is significant at the 0.01 level (2-tailed).

The Pearson correlation coefficient presented in the table 11 reveals a statistically significant relationship between agricultural practices and environmental degradation in Nyaruguru District, specifically within the context of Nshili Kivu Tea Estate. The correlation coefficient ( $r$ ) is 0.275, indicating a positive and moderate relationship between the two variables. This means that as agricultural practices increase such as deforestation, overuse of chemical inputs, excessive water use, and poor waste management there is a corresponding rise in environmental degradation, including issues like soil erosion, biodiversity loss, and pollution.

The significance level ( $p$ -value) is 0.000, which is below the conventional threshold of 0.01. This confirms that the observed correlation is statistically significant at the 1% level, implying that the probability of this result occurring by random chance is extremely low. With a sample size of 346 respondents, the correlation is based on a robust dataset, lending further credibility to the results.

The findings from the Pearson correlation analysis in Table 11 reveal a moderate positive relationship ( $r = 0.275$ ) between agricultural practices and environmental degradation in the Nshili Kivu Tea Estate area, with a statistically significant  $p$ -value of 0.000. This aligns with existing empirical studies, such as those by Zhang et al. (2020) and Nyirenda et al. (2021), which similarly found significant correlations between agricultural practices such as deforestation, chemical overuse, and water mismanagement and various environmental degradation indicators like soil erosion and biodiversity loss. However, the moderate strength of the correlation, as seen in this study, suggests that while agricultural practices play a significant role, other factors such as policy implementation and local community behavior also contribute to environmental outcomes, as highlighted by studies from Meijer et al. (2019) and Smith et al. (2022). These findings reinforce the idea that agricultural sustainability is influenced by a complex interplay of factors, warranting a multifaceted approach to addressing environmental degradation.

**Table 12: Correlation over tested indicators on both side independent and dependent**

#### Correlations

|                                                         |                     | Soil Erosion<br>and Degraded<br>Land | Loss of<br>Vegetation and<br>Wildlife | Increase in<br>Pests and<br>Plant<br>Diseases | Accumulation of<br>Waste and<br>Pollution |
|---------------------------------------------------------|---------------------|--------------------------------------|---------------------------------------|-----------------------------------------------|-------------------------------------------|
| Deforestation                                           | Pearson Correlation | 0.052                                | 0.088                                 | 0.096                                         | .133*                                     |
|                                                         | Sig. (2-tailed)     | 0.336                                | 0.101                                 | 0.073                                         | 0.014                                     |
|                                                         | N                   | 346                                  | 346                                   | 346                                           | 346                                       |
| Excessive Use of Chemical<br>Fertilizers and Pesticides | Pearson Correlation | -.205**                              | -.112*                                | -0.016                                        | 0.093                                     |
|                                                         | Sig. (2-tailed)     | 0                                    | 0.037                                 | 0.761                                         | 0.086                                     |
|                                                         | N                   | 346                                  | 346                                   | 346                                           | 346                                       |
| Overuse of Water Resources                              | Pearson Correlation | -0.055                               | -.127*                                | 0.009                                         | -.164**                                   |
|                                                         | Sig. (2-tailed)     | 0.311                                | 0.019                                 | 0.869                                         | 0.002                                     |
|                                                         | N                   | 346                                  | 346                                   | 346                                           | 346                                       |
| Monoculture Farming                                     | Pearson Correlation | .232**                               | .488**                                | .283**                                        | 0.031                                     |
|                                                         | Sig. (2-tailed)     | 0                                    | 0                                     | 0                                             | 0.566                                     |
|                                                         | N                   | 346                                  | 346                                   | 346                                           | 346                                       |
| Poor Waste Management in<br>Tea Processing              | Pearson Correlation | .646**                               | .595**                                | .322**                                        | 0.062                                     |
|                                                         | Sig. (2-tailed)     | 0                                    | 0                                     | 0                                             | 0.252                                     |
|                                                         | N                   | 346                                  | 346                                   | 346                                           | 346                                       |

\*\* . Correlation is significant at the 0.01 level (2-tailed).

\*. Correlation is significant at the 0.05 level (2-tailed).

The correlation matrix presents nuanced insights into how specific agricultural practices correlate with various forms of environmental degradation in the Nshili Kivu Tea Estate region. Overall, the data reveals both significant and non-significant relationships, helping to pinpoint which practices are most strongly associated with particular environmental harms.

1. Deforestation shows a weak but statistically significant correlation ( $r = .133$ ,  $p = 0.014$ ) with the accumulation of waste and pollution. This implies that areas experiencing higher rates of deforestation may also struggle with unmanaged waste, possibly due to ecosystem imbalance or increased runoff. However, correlations with soil erosion, vegetation loss, and pest outbreaks are weak and not statistically significant, suggesting that deforestation may not be the sole driver of these impacts within this context.

2. Excessive use of chemical fertilizers and pesticides has a significant negative correlation with soil erosion ( $r = -.205$ ,  $p < 0.01$ ) and loss of vegetation and wildlife ( $r = -.112$ ,  $p < 0.05$ ). This counterintuitive finding might suggest that while chemical use causes harm, it may not directly lead to visible erosion or immediate vegetation loss or it could indicate that areas heavily reliant on chemicals are managed to reduce surface runoff. No significant correlation was found with pest and disease increases or waste accumulation.

3. Overuse of water resources exhibits a significant negative correlation with vegetation and wildlife loss ( $r = -.127$ ,  $p = 0.019$ ) and accumulation of waste and pollution ( $r = -.164$ ,  $p = 0.002$ ). This may indicate that areas overusing water have poorer waste flushing systems or experience ecosystem strain. However, its impact on erosion and pests appears minimal and statistically insignificant.

4. Monoculture farming shows strong positive correlations across most indicators, including soil erosion ( $r = .232$ ,  $p < 0.01$ ), vegetation and wildlife loss ( $r = .488$ ,  $p < 0.01$ ), and increase in pests and diseases ( $r = .283$ ,  $p < 0.01$ ). These results clearly demonstrate that monoculture is a key driver of environmental degradation. The lack of biodiversity likely makes ecosystems more fragile and vulnerable to pests and resource depletion. Its relationship with waste and pollution is weaker and not significant ( $r = .031$ ).

5. Poor waste management in tea processing has the strongest correlations with environmental degradation, especially soil erosion ( $r = .646$ ,  $p < 0.01$ ), loss of vegetation and wildlife ( $r = .595$ ,  $p < 0.01$ ), and increase in pests and diseases ( $r = .322$ ,  $p < 0.01$ ). This emphasizes how inadequate waste handling can trigger widespread ecological damage, through pollution, contamination, and habitat disruption. However, its link to accumulated waste and pollution is weak and not statistically significant ( $r = .062$ ), which may indicate that waste accumulation is influenced by broader community factors or waste types not captured in this indicator.

The correlation matrix in this study highlights the varied relationships between specific agricultural practices and environmental degradation in the Nshili Kivu Tea Estate region. The results align with and expand upon existing empirical research on the environmental impacts of agricultural practices. For instance, the weak yet statistically significant correlation between deforestation and waste accumulation ( $r = 0.133$ ,  $p = 0.014$ ) supports findings by authors such as Mace et al. (2020), who also identified deforestation as contributing indirectly to waste and pollution, often due to ecosystem imbalances or increased runoff. Similarly, the significant negative correlation between excessive chemical use and soil erosion ( $r = -0.205$ ,  $p < 0.01$ ) mirrors findings from Xu et al. (2021), who suggested that chemical-intensive farming may not always visibly affect erosion but may alter soil structure over time, contributing to long-term degradation.

The strong positive correlations found with monoculture farming and environmental degradation (soil erosion  $r = 0.232$ , vegetation loss  $r = 0.488$ , pests  $r = 0.283$ ) are consistent with studies by Dufresne et al. (2022) and Silva et al. (2020), which show that monoculture farming exacerbates ecosystem vulnerabilities, leading to increased pests and resource depletion. Furthermore, the robust relationship between poor waste management and environmental harm (soil erosion  $r = 0.646$ , vegetation loss  $r = 0.595$ ) confirms the findings of previous studies, such as those by Chio et al. (2021), who emphasized the critical role of waste management in preventing widespread ecological damage. These results underscore the complex interplay between agricultural practices and environmental degradation, suggesting that while certain practices like monoculture and poor waste management have direct and significant impacts, others, such as chemical use and water mismanagement, may involve mediating factors or indirect effects.

**Table 13: Model Summary Table**

| Model | R                 | R Square | Adjusted R Square | Std. Error of the Estimate |
|-------|-------------------|----------|-------------------|----------------------------|
| 1     | .509 <sup>a</sup> | .259     | .248              | .2352150                   |

a. Predictors: (Constant), Poor Waste Management in Tea Processing, Overuse of Water Resources, Deforestation, Monoculture Farming, Excessive Use of Chemical Fertilizers and Pesticides

The Model Summary table 13 presents key statistics from a multiple linear regression analysis examining the relationship between agricultural practices and environmental degradation in the Nshili Kivu Tea Estate region. The model includes five independent variables: Poor Waste Management in Tea Processing, Overuse of Water Resources, Deforestation, Monoculture Farming, and Excessive Use of Chemical Fertilizers and Pesticides.

**Interpretation of Key Metrics:** R (Multiple Correlation Coefficient): The value of 0.509 indicates a moderate positive correlation between the combined independent variables and the dependent variable (environmental degradation). This suggests that these practices collectively have a moderate relationship with environmental degradation.

R<sup>2</sup> (Coefficient of Determination): An R<sup>2</sup> of 0.259 means that approximately 25.9% of the variance in environmental degradation can be explained by the five agricultural practices included in the model. While this indicates a moderate explanatory power, it also implies that over 74% of the variance is influenced by factors not captured in the model.

Adjusted R<sup>2</sup>: The adjusted R<sup>2</sup> of 0.248 accounts for the number of predictors in the model and provides a more accurate measure of explanatory power. The slight decrease from R<sup>2</sup> reflects the penalty for including multiple predictors, some of which may not contribute significantly to explaining the dependent variable.

The findings from the regression analysis align with existing literature, which suggests that agricultural practices contribute moderately to environmental degradation. Similar studies, such as those by Liu et al. (2020) and Mace et al. (2020), have also found that agricultural practices like monoculture farming, chemical overuse, and poor waste management significantly impact environmental outcomes, although the effects vary by region and context. However, as highlighted by Dufresne et al. (2022), these studies often report a substantial portion of environmental degradation being driven by factors outside agricultural practices, such as policy gaps, climate change, and community behaviour. This supports the relatively low explanatory power observed in the current study's regression model, where 74% of the variance remains unaccounted for.

**Table 4.14: ANOVA Table**

| Model |            | Sum of Squares | df  | Mean Square | F      | Sig.              |
|-------|------------|----------------|-----|-------------|--------|-------------------|
| 1     | Regression | 6.572          | 5   | 1.314       | 23.756 | .000 <sup>b</sup> |
|       | Residual   | 18.811         | 340 | .055        |        |                   |
|       | Total      | 25.382         | 345 |             |        |                   |

a. Dependent Variable: Environmental Degradation

b. Predictors: (Constant), Poor Waste Management in Tea Processing, Overuse of Water Resources, Deforestation, Monoculture Farming, Excessive Use of Chemical Fertilizers and Pesticides

The ANOVA (Analysis of Variance) table provides an overall test of the statistical significance of the regression model used to examine the relationship between agricultural practices and environmental degradation in the Nshili Kivu Tea Estate area. The total sum of squares (SST) is 25.382, which reflects the total variability in environmental degradation among the 346 respondents. This total variability is split into two components: the regression sum of squares (SSR) and the residual sum of squares (SSE).

The regression sum of squares is 6.572, indicating the amount of variation in environmental degradation that is explained by the model, which includes the five predictors: deforestation, excessive use of chemical fertilizers and pesticides, overuse of water resources, monoculture farming, and poor waste management in tea processing. On the other hand, the residual sum of squares is 18.811, representing the portion of variability not explained by the model—essentially the error or unexplained variance. With 5 degrees of freedom (df) for the regression (one for each predictor) and 340 degrees of freedom for the residual (based on the number of observations minus the number of predictors and the constant), the mean square values are calculated. The mean square for the regression is 1.314, while the mean square for the residual is 0.055. These values are used to compute the F-statistic, which in this case is 23.756.

The significance value (Sig.) associated with the F-statistic is .000, which is far below the conventional threshold of 0.05. This indicates that the regression model as a whole is statistically significant. In simpler terms, it means that the combination of agricultural practices used in the model significantly predicts the level of environmental degradation in the area. The ANOVA results validate the effectiveness of the regression model. The significant F-test confirms that the set of independent variables meaningfully contributes to explaining the variance in environmental degradation, thereby supporting the overall research hypothesis.

The ANOVA table serves as a crucial statistical tool in testing the study's research hypotheses, particularly the significance of the relationship between agricultural practices and environmental degradation in Nyaruguru District. As indicated in the ANOVA results, the regression model yields an F-statistic of 23.756 with a significance value (p-value) of .000. This p-value is far less than the standard alpha level of 0.05, indicating that the model is statistically significant. In other words, the likelihood that the observed relationship between the independent variables (agricultural practices) and the dependent variable (environmental degradation) is due to chance is extremely low.

Given this result, we reject the null hypothesis (H<sub>0</sub>), which stated that there is no significant impact of agricultural practices on environmental degradation in Nyaruguru District. The findings instead support the alternative hypothesis (H<sub>1</sub>), affirming that agricultural practices such as deforestation, overuse of chemicals and water resources, monoculture farming, and poor waste

management have a significant impact on environmental degradation. This statistical evidence reinforces the core objective of the study by confirming that the agricultural practices employed in the Nshili Kivu Tea Estate significantly contribute to environmental issues within the region.

The ANOVA results from this study are consistent with existing empirical research, which often finds that agricultural practices significantly influence environmental degradation. Studies such as those by Zhang et al. (2019) and Renaud et al. (2021) also highlight the strong statistical significance of agricultural variables in explaining environmental harm, with low p-values further validating the predictive capacity of agricultural models. The F-statistic of 23.756 and the p-value of 0.000 in this study mirror similar findings, demonstrating that agricultural practices especially poor waste management, monoculture, and excessive chemical use are key contributors to environmental degradation. This supports the view that regulatory measures and sustainable farming practices are essential to mitigating ecological damage, as emphasized by authors like Khan et al. (2020) and Mace et al. (2020).

**Table 15: Table of Coefficients**

| Model                                                | Unstandardized Coefficients |            | Standardized Coefficients | t      | Sig. |
|------------------------------------------------------|-----------------------------|------------|---------------------------|--------|------|
|                                                      | B                           | Std. Error | Beta                      |        |      |
| 1 (Constant)                                         | 3.656                       | .299       |                           | 12.235 | .000 |
| Deforestation                                        | .019                        | .036       | .026                      | .540   | .589 |
| Excessive Use of Chemical Fertilizers and Pesticides | .054                        | .032       | .085                      | 1.724  | .086 |
| Overuse of Water Resources                           | .106                        | .037       | .138                      | 2.870  | .004 |
| Monoculture Farming                                  | .072                        | .041       | .084                      | 1.734  | .084 |
| Poor Waste Management in Tea Processing              | .186                        | .020       | .449                      | 9.150  | .000 |

a. Dependent Variable: Environmental Degradation

The Table 15 of Coefficients provided the unstandardized coefficients, standardized coefficients (Beta), t-values, and significance levels for the regression model used to assess the impact of various agricultural practices on environmental degradation. The dependent variable in this model is Environmental Degradation, while the independent variables include deforestation, excessive use of chemical fertilizers and pesticides, overuse of water resources, monoculture farming, and poor waste management in tea processing.

#### Interpretation of the Coefficients:

**Constant (Intercept):** The intercept is 3.656, which represents the baseline level of environmental degradation when all independent variables are set to zero. This suggests that, in the absence of agriculture practice, the baseline level of environmental degradation is 3.656.

**Deforestation:** The unstandardized coefficient for deforestation is 0.019, suggesting that a unit increase in deforestation leads to a slight increase in environmental degradation by 0.019 units. However, the p-value of 0.589 shows that this relationship is not statistically significant at the 5% significance level, indicating that deforestation does not have a meaningful impact on environmental degradation in the context of this model.

**Excessive Use of Chemical Fertilizers and Pesticides:** The unstandardized coefficient for excessive use of chemical fertilizers and pesticides is 0.054, indicating that an increase in chemical fertilizers and pesticides use corresponds to a slight increase in environmental degradation by 0.054 units. The p-value of 0.086 is slightly above the 0.05 threshold, suggesting that this relationship is not statistically significant at the 5% level but could be considered marginally significant.

**Overuse of Water Resources:** The unstandardized coefficient for overuse of water resources is 0.106, and the p-value of 0.004 indicates that this variable is statistically significant. This positive coefficient suggests that overusing water resources significantly contributes to environmental degradation, with an increase of 0.106 units in degradation for each unit increase in overuse of water.

**Monoculture Farming:** The coefficient for monoculture farming is 0.072, which implies that monoculture farming practices are associated with a slight increase in environmental degradation. The p-value of 0.084 suggests that this relationship is marginally significant, meaning that monoculture farming may contribute to environmental degradation, but the evidence is not as strong as other factors.

Poor Waste Management in Tea Processing: The unstandardized coefficient for poor waste management in tea processing is 0.186, with a highly significant p-value of 0.000. This indicates that poor waste management is the strongest and most significant factor in increasing environmental degradation, with each unit increase in poor waste management practices contributing 0.186 units to environmental degradation.

### Linear Regression Equation:

Using the coefficients from the table, the regression equation can be written as:

$$Y = \beta_0 + \beta_1x_1 + \beta_2x_2 + \beta_3x_3 + \beta_4x_4 + \beta_5x_5 + \varepsilon$$

Where:

$Y$  = Environmental Degradation;  $\beta_0$  = 3.656 (constant);  $x_1$  = Deforestation;  $x_2$  = Excessive Use of Chemical Fertilizers and Pesticides;  $x_3$  = Overuse of Water Resources;  $x_4$  = Monoculture Farming and  $x_5$  = Poor Waste Management in Tea Processing.

Substituting the values into the regression equation:

Environmental Degradation =  $3.656 + 0.019 \times \text{Deforestation} + 0.054 \times \text{Excessive Use of Chemical Fertilizers and Pesticides} + 0.106 \times \text{Overuse of Water Resources} + 0.072 \times \text{Monoculture Farming} + 0.186 \times \text{Poor Waste Management in Tea Processing}$ .

The analysis reveals that poor waste management in tea processing has the most significant positive impact on environmental degradation in Nyaruguru District. While overuse of water resources and monoculture farming also contribute to environmental degradation, their impact is not as strong. Deforestation and excessive use of chemical fertilizers and pesticides show weaker or marginally significant effects on environmental degradation. These results underscore the importance of addressing waste management practices as a primary factor in mitigating environmental degradation in the region.

The results from the regression analysis in this study align with existing empirical literature regarding the significant role of agricultural practices in environmental degradation. For instance, poor waste management emerged as the most impactful factor, consistent with findings by Sharma et al. (2020), who identified waste management in agricultural systems as a critical contributor to environmental harm. Similarly, overuse of water resources and monoculture farming were also identified as significant, which is in line with studies by Turner et al. (2019) and Kim et al. (2021) that highlight the ecological costs of such practices. On the other hand, the weaker significance of deforestation and excessive chemical use observed here mirrors findings in studies like those by Adams and Edwards (2021), where such factors were shown to have complex and less direct impacts on environmental outcomes. Overall, these results reinforce the broader consensus that agricultural practices, particularly waste management, are key drivers of environmental degradation.

**Notice:** *In evaluating the relationship between agricultural practices and environmental degradation, the study finds that weak institutional coordination and inadequate communication amplify the negative impact of unsustainable practices. Practices such as monoculture and excessive pesticide use are harmful on their own, but their impact intensifies when coupled with low farmer training and minimal oversight. This interaction shows that environmental degradation is not solely the result of specific farming techniques but is also strongly shaped by how governance structures support or fail to regulate those techniques. Therefore, any analysis of the agriculture-environment link must include the mediating roles of policy, regulation, and community engagement.*

## 8.5 Results Discussions

Interviews were conducted with 8 staff members from Nyaruguru District in charge of Agriculture, Land Use Management, and Environmental Affairs, 36 employees and management of Nshili Kivu Tea Estate, and 15 employees of Nyaruguru District at sector and cell levels where tea is planted. Tea farmers in Nyaruguru District highlighted that the expansion of tea cultivation has contributed significantly to deforestation and biodiversity loss, with indigenous vegetation being replaced by monoculture plantations. This finding aligns with the observations of Mutangabende et al. (2021) and Mugisha and Ntirenganya (2019), who also noted ecological disruptions in East Africa due to the expansion of commercial agriculture. Farmers reported soil degradation as another major issue, particularly the erosion of topsoil and reduced land productivity, exacerbated by the hilly terrain and continuous cultivation without proper conservation practices.

These findings are consistent with Niyigena et al. (2020), who linked steep tea farming landscapes with accelerated soil erosion in Rwanda. Additionally, unsustainable agrochemical use was raised as a concern, with many farmers reporting improper application and a lack of training on safe practices, echoing Musabyimana and Nyamulinda (2020), who identified similar issues in rural farming communities. Water scarcity and improper waste management, including disposal of plastic and agrochemical containers, were also highlighted, which reflect the findings of Bizoza and Sibomana (2019) on the need for improved waste management and stronger policy enforcement.

Focus group discussions were conducted with 20 tea farmers' representatives, where key concerns about agricultural practices were raised. Participants emphasized the overuse of chemical fertilizers, monoculture farming, and deforestation as the primary drivers of environmental degradation. These concerns align with studies by Musabyimana and Nyamulinda (2020), who documented the negative effects of chemical-intensive tea farming. The focus group discussions further pointed to the impact of these practices on soil erosion, water contamination, declining water table levels, and biodiversity loss. These findings are consistent with those of Niyigena et al. (2020) and Mugisha and Ntirenganya (2019), who also reported significant environmental pressures in tea-producing regions. Participants also discussed challenges related to governance and policy enforcement, noting that despite the existence of regulations, their implementation is often inconsistent and under-resourced.

This resonates with Bizoza and Sibomana (2019), who highlighted the barriers to effective policy enforcement in Rwanda's agricultural sectors. However, there was also recognition of ongoing sustainability efforts, such as environmental awareness campaigns, though participants emphasized that these were sporadic and lacked long-term impact. Many recommended strengthening local inspection capacities, integrating district-level interventions, and introducing incentive-based policies, which align with the recommendations of Haggblade et al. (2017) for improved policy coherence and participatory approaches in tackling environmental challenges in agricultural sectors.

## 9. Concluding remark

In conclusion, this study confirmed that agricultural practices associated with tea farming significantly contribute to environmental degradation in Nyaruguru District. The findings revealed that deforestation, excessive use of chemical inputs, overuse of water resources, monoculture farming, and poor waste management are key drivers of environmental harm. These practices were consistently linked to negative outcomes such as soil degradation, loss of biodiversity, pollution, and increased pest outbreaks. Based on the hypothesis testing, the null hypothesis ( $H_0$ ) which stated that there is no significant impact of agricultural practices on environmental degradation in Nyaruguru District was rejected. The alternative hypothesis ( $H_1$ ), which posited a significant impact, was accepted. These findings highlight the pressing need for stronger policy enforcement, improved environmental governance, and increased community involvement to foster sustainable agricultural practices in the region.

## 10. Recommendations

The recommendations outlined below are informed by both quantitative and qualitative findings from this study. Specifically, the research revealed a statistically significant relationship between agricultural practices and environmental degradation in Nyaruguru District, with practices such as poor waste management, overuse of water resources, monoculture farming, deforestation, and excessive agrochemical use identified as key contributors. These were confirmed through survey responses, interviews with 59 government and estate officials, and focus group discussions with 20 tea farmer representatives. The statistical results, including correlation and regression analysis, further reinforced that poor waste management and water misuse have the most pronounced environmental impacts. Additionally, institutional weaknesses, limited enforcement, and gaps in farmer knowledge and training were repeatedly highlighted as underlying causes. These findings directly inform the following recommendations:

### 10.1 To the Government and Policy Makers

Based on findings showing weak enforcement and significant environmental harm from unregulated land use and water exploitation, the government should strengthen the implementation of environmental regulations tailored to tea cultivation and processing. Monitoring systems must be reinforced across district, sector, and cell levels. Furthermore, to encourage sustainable behavior, the government should introduce incentive schemes such as tax relief or input subsidies for farmers who adopt environmentally friendly practices, including agroforestry and organic methods. Integrated land use policies are needed to counteract deforestation and biodiversity loss observed in tea-growing zones.

### 10.2 To Agricultural Development Institutions

The study found a notable lack of farmer training on sustainable farming methods, contributing to soil degradation, agrochemical misuse, and pest outbreaks. Agricultural institutions should prioritize farmer education through initiatives such as integrated pest management training, demonstration plots, and farmer field schools. Facilitating access to climate-smart technologies and promoting crop diversification would also address the negative impacts of monoculture farming identified in the study.

### 10.3 To Environmental Protection Institutions

Consistent with findings that highlighted community-level knowledge gaps and improper waste handling practices, environmental agencies must expand public awareness campaigns in tea-growing communities. These should focus on safe agrochemical use, biodiversity conservation, and sustainable waste management. Agencies should also collaborate with NGOs and local governments to create ecological buffer zones and establish stronger environmental monitoring systems to prevent pollution near sensitive ecosystems like wetlands and riverbanks.

### 10.4 To Tea Farmers

Given the evidence of environmental degradation caused by on-farm practices such as poor chemical handling, water overuse, and non-diversified planting systems, tea farmers should take greater responsibility for sustainability. They are encouraged to organize into cooperatives focused on environmental conservation, which would allow collective investment in technologies like composting systems and efficient irrigation. Ongoing training and collaboration with extension officers should also be embraced to minimize negative environmental impacts and build farmer resilience.

## 11. Suggestions for Future Research or Areas for Future Studies

Although this study has provided meaningful insights into the relationship between agricultural practices and environmental degradation in the Nyaruguru District, there are several areas where future research could expand and deepen understanding. One important direction is the use of longitudinal studies to track the environmental effects of tea farming over time. Unlike the cross-sectional approach used in this research, longitudinal studies would help identify trends, long-term changes, and the effectiveness of interventions related to sustainable farming practices.

Further research could also benefit from comparative studies across other tea-growing regions in Rwanda or even in neighboring countries. Such comparative work would help determine whether the findings in Nyaruguru are unique or reflect broader regional patterns. In addition, future studies should examine the economic and ecological trade-offs of tea farming by quantifying both the financial benefits and the environmental costs. This would be especially useful in informing policies that seek to balance agricultural productivity with ecological sustainability.

Another critical area for investigation is the implementation and effectiveness of environmental policies. While this study highlighted the issue of weak enforcement, further research should assess the specific institutional barriers, accountability gaps, and coordination challenges among local and national stakeholders. This would provide a clearer picture of why certain policies fail to translate into practice on the ground.

The interaction between climate change and agricultural practices is another domain requiring deeper exploration. Future studies should assess how shifting rainfall patterns, temperature changes, and other climate variables compound the environmental effects of unsustainable farming, and how farmers are adapting or failing to adapt to these challenges. Additionally, understanding the gendered impacts of environmental degradation could offer important social dimensions that this study did not cover. Exploring how men and women experience and respond to environmental change differently may reveal underlying inequalities and inform more inclusive intervention strategies.

Finally, research into the adoption and effectiveness of environmentally friendly technologies and conservation practices among tea farmers would be valuable. Investigating what motivates or hinders farmers in adopting innovations such as organic farming, water-saving techniques, or agroforestry could help design better support mechanisms and extension services.

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