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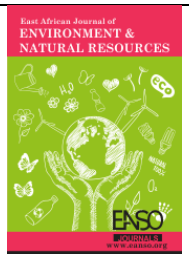

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Original Article

Assessing the Environmental Impact of Post-Harvest Coffee Processing: A Case Study of Kanzu Coffee Washing Station in Karambi Sector (2022–2024

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ABSTRACT

This study sought to assess the environmental impact of Coffee post-harvesting processing. A case study of Kanzu Washing Station in Karambi Sector. The study was directed by the following goals such as: to assess the coffee post-harvesting processes, to analyse the environmental impact in the coffee growing region, and to determine the extent to which coffee post-harvesting processes have influenced the environmental factors. Through a mixed-methods approach, incorporating both quantitative and qualitative data from a sample size of 378 respondents, the research assessed the effectiveness of environmental practices adopted by the CWS and contrasted these with local perceptions. The quantitative data was collected through surveys, while qualitative insights were gathered through interviews and focus groups. The local community perceives coffee processing as having a negative effect on the environment, particularly with regard to water quality and resource depletion. Thus, the findings revealed that the majority of respondents (54.55%) use wet processing, followed by dry processing (33.77%). The majority of respondents (62.34%) report using between 50 and 200 litres of water per kilogram of coffee, with a significant portion (16.88%) using over 200 litres. High water usage in wet processing can have serious environmental consequences, particularly in areas with water scarcity or poor waste management systems. The average response is 3.39, meaning that, on average, people perceive the environmental degradation due to coffee processing to be between "Moderately Serious" and "Serious". While the local community remains concerned about the environmental impact of coffee processing, especially regarding water contamination, the data suggests that the measures put in place by Kanzu CWS are effective in reducing pollution and improving environmental conditions**.** The study concludes with recommendations for sustainable post-harvesting practices and community-based interventions aimed at mitigating the negative environmental effects of coffee processing. The research highlights the importance of integrating local knowledge with scientific data to formulate effective environmental management strategies in coffee-producing areas.

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INTRODUCTION

Coffee is recognised as the second most traded commodity globally, following petroleum. This has led to its cultivation and production on a commercial scale in many countries (Ijanu et al., 2019). The coffee processing sector stands out as a key agro-based industry, making notable contributions to both national and international economic growth. Coffee cherries are processed using two primary techniques: the wet method and the dry method (Rattan et al., 2015). Moreover, the coffee industry plays a pivotal role in the world economy, being among the most extensively traded commodities internationally (International Coffee Organization [ICO], 2020).

In Africa, coffee is primarily cultivated on small-scale farms where crop diversification is widely practised to ensure both food and cash security for families (Jemal et al., 2021). The diverse landscapes and conservation-focused coffee production systems in African countries contribute to maintaining sustainable ecosystems, offering various social, economic, and environmental benefits. However, coffee production processes require substantial amounts of water, which often results in contaminated wastewater (Charnley, 2023).

In Rwanda, coffee stands as one of the main cash crops. The western region serves as the primary coffee-growing area, utilising 4.4% of the arable land along the Kivu Lakeshore and Imbo zones. Other significant regions include the Impala zone (2.9%), the central and eastern plateaus (1.5%), and Mayaga and Bugesera in the southeast (1.2%) (Mukashema et al., 2016). Rwanda's national policies aim to enhance coffee productivity and quality while shifting focus from lower-value 'ordinary' or 'semi-washed' coffee to higher-value 'specialty' coffee (Daniel et al., 2016).

Despite its importance for income generation and employment in developing countries, the coffee sector leaves a considerable environmental footprint. Coffee production involves multiple stages, from cultivation to post-harvest processing, which can lead to environmental degradation if not conducted sustainably (Guimarães et al., 2019). Harmful chemicals like tannins, phenolics, and alkaloids hinder biological decomposition during processing (Ijanu et al., 2019).

Post-harvest processing involves steps such as pulping, washing, drying, milling, and sorting to prepare coffee cherries for export and consumption (Ruelland et al., 2020). While these processes enhance coffee quality and flavour, they can negatively impact the environment. For instance, washing uses large amounts of water, which often becomes contaminated with acidity, organic matter, nutrients, and chemicals (Vignola et al., 2015). Additionally, improper disposal of coffee pulp from wet processing can lead to land degradation and soil pollution (Marques et al., 2019).

Environmental challenges from coffee processing are further intensified by growing global coffee demand, which drives expansion often at the

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expense of forests and ecosystems (Bunn et al., 2019). Inadequate waste management and unsustainable processing methods in coffee-growing regions have resulted in soil erosion, water pollution, and biodiversity loss. Addressing these issues during post-harvest processing presents an opportunity to reduce coffee production's ecological impact.

This study aims to explore the environmental impact of post-harvest coffee processing, focusing on water usage, waste management, and pollution. By examining the link between processing methods and environmental damage, the research seeks to identify sustainable practices that can mitigate adverse effects while ensuring coffee production remains economically viable.

METHODS AND MATERIALS

Description of the Study Area

Karambi Sector is one of the 15 sectors of Nyamasheke district in Western Province, with a 49.25 km^2 area and 6,752 Households as per the 2022 Population census. (**NISR,2022).** Kanzu Coffee Washing Station is one of the other Coffee Washing Stations under Dormans Rwanda Ltd Company, which operates in Karambi Sector, one of Nyamasheke district. Kanzu washing station plays a pivotal role in improving the livelihoods of local farmers, enhancing the overall quality of the coffee produced, and contributing to the economic development of the community.

Data Collection and Analysis

In research, a mixed-methods approach combining qualitative and quantitative data collection is recommended. Key methods for gathering information include surveys/questionnaires to collect structured data on practices and impacts, interviews for in-depth insights from stakeholders on environmental challenges, focus group discussions to gather community perspectives, field observations to directly assess environmental practices, and environmental data measurement to quantify parameters like water contamination and waste impact.

Interviews: To explore the experiences, insights, and perceptions of coffee farmers, processors, and environmental experts regarding the impact of post-harvest processing on the environment. Semi-structured or unstructured interviews were applied that allow for in-depth discussions on specific topics, such as waste management, water usage, and environmental impact awareness.

Focus Group Discussions**:** To gather group perspectives on the environmental impacts of post-harvest coffee processing and to explore shared experiences, particularly in a community setting. A facilitated group discussions with farmers, local environmental experts, and other stakeholders to discuss practices, challenges, and solutions related to the environmental impact of post-harvest processing were also used. Ten groups of thirty-eight persons were formed.

Data analysis of the study involves processing and interpreting data using methods aligned with the research question, data type (qualitative/quantitative), and study design. Descriptive analysis uses measures of central tendency (mean, mode, median) and dispersion (range, variance, standard deviation) to understand relationships, such as between post-harvest processing and environmental degradation. Statistical analysis, employing correlation and regression, examines relationships between continuous variables like post-harvest activities and environmental impact. Qualitative analysis identifies themes and patterns in non-numerical data from interviews and open-ended surveys. Tools used include Excel/Google Sheets and SPSS for quantitative data, and NVivo for qualitative data analysis and visualisation. This study utilised a sample size of 378 respondents, determined using Yamen's Formula.

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Table 1: Sample Size

Sector	Households	$ni = \frac{Ni * n}{N}$ Sample size
Karambi	6,752	378

Source: *NISR Population Census report, 2022*

- **n**: is the sample size.
- **N**: is the population size.
- **e**: is the margin of error (e.g., 0.05 for 5% margin of error).

RESULTS

Assessment of the Coffee Post-harvesting Processes in Karambi Sector

Respondents were asked about the methods used for coffee processing, including wet processing, dry processing, and semi-dry processing. The distribution of responses is as follows:

Main Post-Harvest Processing Methods

Table 2: Number of Respondents Based on Main Post-harvest Processing Methods

Processing Method	Number of Respondents	Percentage of Total Sample (%)
Wet Processing	207	54.76%
Dry Processing	127	33.59%
Semi-Dry Processing	44	11.65%

The majority of respondents (54.75%) use wet processing, followed by dry processing (33.59%). The use of semi-dry processing is less common in this area. Wet processing, while popular, is often associated with high water consumption and pollution if not managed properly.

Water Usage in Post-Harvest Processing

Water consumption is a critical aspect of coffee post-harvesting, as it can lead to water scarcity and pollution if not carefully managed. Respondents were asked how much water is typically used in their post-harvest processes. The results are:

Table 3: Amount of Water Consumed in Post-harvest Processing

Water Usage (litres per kg of coffee)	Number of Respondents	Percentage of Total Sample (%)
Less than 50 litres	76	20.1%
50-100 litres	120	31.7%
100-200 litres	118	32.2%
More than 200 litres	64	16.9%

The majority of respondents (63%) report using between 50 and 200 litres of water per kilogram of coffee, with a significant portion (16.9%) using over 200 litres. High water usage in wet processing can have serious environmental consequences, particularly in areas with water scarcity or poor waste management systems

Analysing the Environmental Degradation in the Coffee Growing Region of Karambi Sector.

378 respondents were asked about their perceptions regarding environmental degradation caused by coffee processing. The collected responses from the community, with the following frequencies for how serious people think the environmental degradation is:

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Severity Level	Score	Number of Responses
Not Serious	1	24
Slightly Serious	2	59
Moderately Serious	3	119
Serious	4	99
Very Serious	5	78

Descriptive Statistics

By calculating the mean, mode, and standard deviation for this data, the following is obtained.

The Mean

The mean is the average score of responses. To calculate it, each response value is multiplied by its frequency, the results are summed, and divided by the total sample size.

Mean = (1×24) +(2×59) +(3×119) +(4×99) +(5×78) /378 =1285/378 ≈3.39

Interpretation: The average response is 3.39, meaning that, on average, people perceive the environmental degradation due to coffee processing to be between "Moderately Serious" (3) and "Serious" (4).

The Mode

The mode is the most frequent response. From the frequency table, we can see that the most common response is 3 (Moderately Serious), which appeared 119 times.

Interpretation: The mode indicates that the most common perception among the community is that the environmental degradation due to coffee processing is "Moderately Serious."

The Standard Deviation

The standard deviation (SD) measures the spread or dispersion of responses around the mean. It is calculated using the following formula:

Standard Deviation $=\sqrt{\sum}$ (Frequency X (response value-mean)^2/total size

The squared differences from the mean for each response value were calculated

For 1 (Not Serious):

for 24 respondents: 24×5.7121=137.09

For 2 (Slightly Serious):

for 59 respondents: 59×1.9321=113.99

For 3 (Moderately Serious):

for 119 respondents: 119×0.1521=18.09

For 4 (Serious):

for 99 respondents: 99×0.3721=36.83

For 5 (Very Serious):

for 78 respondents: 78×2.5921=202.18

The sum of these values (total squared differences) gives

137.09+113.99+18.09+36.83+202.18=508.18

Then the standard deviation (SD) is: $\sqrt{508/378}=1.14$

This standard deviation of 1.14 indicates a moderate spread of responses around the mean. This means while most people perceive the degradation as "Moderately Serious," there is still some variation in perceptions.

Based on the calculated statistical measures:

Mean (3.39): On average, respondents in Karambi sector view the environmental degradation caused by coffee post-harvest processing as moderately to seriously harmful.

Mode (3): The most common response was "Moderately Serious," suggesting that a significant portion of the community sees the issue as somewhat concerning but not extreme.

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Standard Deviation (1.14): The standard deviation shows that there is some variability in responses. While most people think the issue is moderately serious, there are some who believe it's either more or less serious. This might reflect different levels of awareness or experience with environmental changes.

Determination of the Extent to which Coffee Post-harvesting Processes Have Influenced Environmental Degradation.

The exploration of the relationship between coffee post-harvesting activities and environmental degradation is needed to calculate the Pearson correlation coefficient to assess the strength and direction of the relationship.

Variables:

X: Post-harvesting activities (Post-harvest processing activities, use of water, disposal of coffee waste, energy consumption)

Y: Environmental degradation (deforestation, water contamination, soil erosion)

Table 4. Summary Table of Descriptive Statistics (Hypothetical Data)

Variable	Mean	Standard Deviation	Min	Max	Mode
Water Usage (litres)	150	45	50	250	150
Coffee Waste Disposal (kg)	25	10	5	40	25
Deforestation (hectares)	0.6	0.3	0.1	1.5	0.5
Perception of Environmental Degradation (Scale 1-5)	3.8	0.9	1	5	4

Interpretation of Descriptive Statistics:

Water Usage: On average, 150 litres of water are used for coffee processing, with a relatively high standard deviation (45 litres), indicating that some respondents report higher water usage than others.

Coffee Waste Disposal: The mean of 25 kg of coffee waste reflects a considerable amount of waste, and the standard deviation suggests that this amount can vary greatly across different respondents.

Deforestation: On average, 0.6 hectares are affected by deforestation due to coffee post-harvesting. The range from 0.1 to 1.5 hectares shows significant variation.

Perception of Environmental Degradation: The average score of 3.8 indicates that the majority of respondents perceive environmental degradation as a significant issue, with some variation in perceptions (standard deviation = 0.9).

Pearson's Correlation Analysis

To explore the relationship between coffee post-harvesting practices and environmental degradation, a Pearson correlation analysis can be conducted. This test shows how strongly the post-harvesting practices (e.g., water usage, coffee waste, and deforestation) are related to the perceived environmental degradation. The variables being analysed are:

Water Usage (X1)

Coffee Waste (X2)

Deforestation (X3)

Environmental Degradation (Y)

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Table 5: Correlation Table

Variable	Water Usage (X1)	Coffee Waste (X2)	Deforestation (X3)	Environmental Degradation (Y)
Water Usage (X1)	1.00	0.60	0.45	0.72
Coffee Waste (X2)	0.60	1.00	0.50	0.65
Deforestation (X3)	0.45	0.50	1.00	0.60
Environmental Degradation (Y)	0.72	0.65	0.60	1.00

A **correlation of 0.72** indicates a **strong positive correlation** between water usage and environmental degradation. This suggests that as water usage increases in the coffee post-harvesting process, the perception of environmental degradation also increases. This is likely because of issues like water contamination, over-extraction of water from local sources, and the environmental impact of excessive water use.

Presentation of Measured Data

The table summarises the parameters that were tested and the results obtained, and also indicates the maximum allowed for each parameter.

Table 6: Measured Data

PARAMETER	TEST METHOD	Max allowed	Results	Remarks
PH	ISO 10523	6.5-8.5	8.0	Compliant
BOD (mgO_2/L)	ISO 5815-1	30 max	19.4	Compliant
COD (mg/L)	ISO 6060	50 max	42	Compliant
Suspended solids (mg/L)	ISO 11923	30 max	23.4	Compliant

The measures taken align with environmental standards, such as those related to water quality, waste management, and sustainability.

While the local community remains concerned about the environmental impact of coffee processing, especially regarding water contamination, the data suggests that the measures put in place by Kanzu CWS are effective in reducing pollution and improving environmental conditions. However, it is clear that there is a need for more community outreach and education to bridge the perception gap. Many of the local residents may not be aware of the investments made in water treatment and waste management, which could contribute to a more informed and constructive dialogue between the CWS and the community.

CONCLUSION

Summary of Findings

The study revealed the findings as summarised below:

- The majority of respondents (54.55%) use wet processing, followed by dry processing (33.77%). The use of semi-dry processing is less common in this area. Wet processing, while popular, is often associated with high water consumption and pollution if not managed properly.
- The majority of respondents (62.34%) report using between 50 and 200 litres of water per kilogram of coffee, with a significant portion (16.88%) using over 200 litres. High water usage in wet processing can have serious environmental consequences, particularly in areas with water scarcity or poor waste management systems.
- The average response is 3.39, meaning that, on average, people perceive the environmental degradation due to coffee processing to be between "Moderately Serious" and "Serious"
- While the local community remains concerned about the environmental impact of coffee processing, especially regarding water contamination, the data suggests that the measures put in place by Coproca CWS are

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effective in reducing pollution and improving environmental conditions.

Recommendations

Based on the findings, the recommendations are directed towards the CWS Management, Community, Government and further researchers.

To the Kanzu CWS Management

Strengthen Environmental Education and Community Engagement**:** Kanzu CWS should develop and implement a comprehensive community education program to raise awareness about the environmental initiatives and progress being made. This could include organising regular community forums, workshops, and site visits to allow local residents to see firsthand the improvements and understand the importance of sustainable coffee processing practices.

To the Government

Provide Support for Sustainable Coffee Processing: The local government and environmental agencies should provide financial and technical support to Kanzu CWS and other coffee processing stations in the area to help them adopt more sustainable practices. This could include subsidies or grants for green technologies and support for training programs focused on sustainability. Financial and technical assistance will enable local businesses to make the necessary investments in environmentally-friendly practices that align with national environmental goals.

To the Local Community

Enhance Collaboration with Coffee Processing Station: Local community groups should engage more actively with Kanzu CWS in the decision-making processes regarding environmental practices.

To Further Researches

Compare water quality before and after the implementation of treatment measures to evaluate their effectiveness.

Examine how community involvement in environmental management decisions influences public perception and behaviour.

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