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Research Article

The Impact of Solid Waste Management on Community Livelihoods in Gasabo District, Rwanda: A Case Study of Nduba Landfill (2019-2023)

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Abstract

Solid waste management (SWM) has a direct and critical impact on the livelihoods of communities, especially those residing near major landfills. In Kigali, the Nduba Landfill faces immense pressure from rapid urbanization and poor waste handling practices, resulting in widespread environmental degradation, health issues, and economic hardship for nearby populations. Informal waste pickers also face unsafe working conditions and limited income opportunities due to the absence of formal recognition and support systems. Therefore, the study aimed to the effect of solid waste management and community livelihood in Nduba Landfill. The study employed a descriptive survey design using both qualitative and quantitative approaches. The sample was 357 respondents and the data were analyzed using SPSS through descriptive statistics, correlation, and regression analysis. Findings revealed a generally high level of community satisfaction with existing waste management practices, reflected in mean ratings of 4.1 to 4.3, indicating positive perceptions. However, laboratory results showed serious environmental issues. Water samples had critically low dissolved oxygen levels (0.16 mg/L) and elevated Chemical Oxygen Demand (5004.5 mg/L) and Biochemical Oxygen Demand (88.92 mg/L), signaling heavy organic pollution. Soil tests found an alkaline pH of 8.03 and trace metals within acceptable limits, though lead presence (20 mg/kg) requires long-term monitoring. These findings conclude that effective waste management not only sustains acceptable environmental conditions but also significantly enhances socio-economic outcomes for the local community. The most pressing concern identified was the poor water quality caused by landfill leachate, posing serious health risks to the community. The study recommends the installation of effective leachate treatment systems, formal recognition and protection of informal waste pickers, and investment in waste-to-energy initiatives to promote environmental sustainability and strengthen community livelihoods.

Keywords

Community Livelihoods, Environmental Impact, Waste Disposal Practices, Solid Waste Management

1. Introduction

Solid waste management (SWM) has emerged as a global concern, especially in urban areas where rapid population growth and urbanization have intensified the volume and complexity of waste generation [19]. In developing countries, including Rwanda, these challenges are exacerbated by limited infrastructure and inefficient disposal systems. Poor SWM

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practices not only degrade the environment but also compromise public health, increase poverty, and reduce the quality of life for communities living near landfill sites. The environmental implications include air and water pollution, greenhouse gas emissions, and soil contamination, all of which contribute to long-term ecological and health risks [14].

Globally, countries like the United States, Poland, Ghana, and Kenya have made varied progress in tackling solid waste issues, yet many still face challenges, particularly concerning the health and livelihood of communities residing near landfills. For instance, while Poland has improved waste recycling following EU integration [15], and the United States maintains a recycling rate of 32% [16], communities near waste sites continue to suffer from environmental injustice and health risks. Similarly, in African cities like Accra and Nairobi, the informal waste sector remains central to livelihood strategies but operates under hazardous conditions, exposing waste pickers and nearby residents to toxic pollutants and social, marginalization [17, 18].

In Rwanda, the Nduba landfill in Kigali stands as a significant case. Despite the country's progressive environmental policies, such as the ban on plastic bags, effective waste management remains a challenge. Nduba receives approximately 500 tons of municipal waste daily, yet suffers from poor waste segregation, inadequate recycling, and insufficient leachate treatment systems [21]. As a result, surrounding communities are exposed to respiratory diseases due to air pollution, waterborne illnesses from contaminated water sources, and loss of agricultural productivity due to soil pollution [20]. Furthermore, around 400 informal waste pickers operate under precarious conditions without protective gear or formal recognition, despite playing a vital role in recycling efforts.

The lack of a structured and inclusive SWM system at Nduba limits income-generating opportunities and perpetuates socio-economic inequalities. Informal waste workers remain marginalized and unprotected, while valuable waste resources go underutilized. If current trends continue, Kigali's rapidly expanding population will place even greater pressure on waste management infrastructure, intensifying environmental degradation, public health crises, and poverty [22]. This study seeks to explore the link between poor solid waste management and its impact on the livelihoods of communities living near the Nduba landfill. It will also investigate sustainable interventions such as the formalization of waste-picking, expansion of recycling programs, and the implementation of waste-to-energy technologies aimed at enhancing both environmental outcomes and community wellbeing.

1.1. General Objective

The general objective of the study was to assess the effect of solid waste management and community livelihood in Nduba Landfill from 2019-2023.

1.2. Specific Objectives

This research was guided by the following specific objectives:

1) To identify the current solid waste management practices at Nduba landfill.
2) To determine socio-economic and environmental impacts of these community livelihoods.
3) To determine the relationship between solid waste management and community livelihood living around Nduba landfill.
4) To propose strategies enhancing solid waste management systems to support suitable livelihoods.

1.3. Hypotheses of the Study

The study tested the following hypotheses:

H_1: There is a significant relationship between solid waste management and community livelihood living around Nduba landfill,

H_0: There is no significant relationship between solid waste management and community livelihood living around Nduba landfill.

2. Materials and Methods

2.1. Research Design

The study adopted a mixed-method research design, combining a descriptive survey approach with experimental research to assess the impact of solid waste management practices on community livelihoods around the Nduba Landfill in Kigali. The descriptive component was suitable for capturing a wide range of community perceptions, attitudes, and behaviors regarding waste handling, while the experimental design enabled scientific assessment of environmental conditions such as soil, water, and air quality.

Through structured questionnaires and direct observations, the study gathered comprehensive data on knowledge levels, disposal practices, and community concerns. In parallel, laboratory-based experiments were conducted to evaluate key environmental indicators such as heavy metal content in soil and water pH levels. This dual approach ensured both contextual insights and empirical evidence to support the study's objectives.

2.2. Population and Sample Size

The study population consisted of four main stakeholder groups: Nduba Landfill employees, waste collectors, local leaders, and community members residing near the landfill site. These groups were selected due to their direct involvement in or exposure to waste management activities and their relevance to the study's focus on community impact.

Using stratified random sampling, the researcher ensured proportional representation from each group to reflect the diversity of experiences and views. Out of a total population of

3,300 individuals, a sample of 357 respondents was selected, representing landfill workers, waste collectors, nearby residents, and local leaders. This sample size provided adequate coverage and statistical representation of the study population.

2.3. Data Collection Methods

Primary data were gathered through structured questionnaires, interviews, direct observation, and laboratory testing. The questionnaire served as the main tool for collecting perceptions and behavioral data from all stakeholder groups. It included both open-ended and Likert-scale questions to capture both qualitative insights and quantifiable responses. Questionnaires were distributed in a manner tailored to each group's context on-site for landfill staff, door-to-door for community members, and through formal channels for local leaders.

In-depth interviews were conducted with key informants such as landfill managers, local leaders, and selected community members to gain deeper insights into waste management challenges, policy implications, and socio-economic effects. Observation was also used to verify responses and to document actual waste management practices, safety conditions, and informal recycling activities.

To support and triangulate primary data, the researcher reviewed official reports, waste management records, and policy documents obtained from the Water and Sanitation Corporation (WASAC). These documents provided a foundation for understanding waste handling systems and operational practices at the Nduba Landfill.

2.4. Data Analysis

Data analysis involved both qualitative and quantitative methods. Descriptive statistics such as means and standard deviations were used to summarize responses related to waste disposal habits, awareness levels, and perceived impacts on community well-being. These statistics provided an overview of current practices and highlighted areas of concern.

To explore the relationship between solid waste management and community livelihoods, inferential techniques such as correlation and regression analysis were applied. This allowed the researcher to assess the strength and direction of relationships between environmental management variables and livelihood indicators. Environmental data obtained from laboratory tests were analyzed to evaluate contamination levels and compare them against recognized environmental standards.

Together, these analytical approaches enabled the study to offer evidence-based conclusions on the effectiveness of waste management at Nduba Landfill and its broader implications for surrounding communities.

3. Results and Discussions of Findings

3.1. Analysis of Solid Waste Management

This section focuses on the analysis of solid waste management practices at Nduba Landfill. It examines the efficiency, operational protocols, and environmental impacts of current waste management systems, providing insights into how these practices contribute to maintaining environmental quality.

3.1.1. Waste Collection Efficiency

The researcher asked the respondent to indicate their perception on waste collection efficiency at Nduba landfill and their responses are summarized in Table 1.

Table 1. *Perception of respondents on the Waste Collection Efficiency.*

Statements	SA F (%)	A F (%)	N F (%)	D F (%)	SD F (%)	Total F (%)	Mean	Std. Dev
The waste collection system at Nduba Landfill operates on a regular and reliable schedule, ensuring timely collection of waste in surrounding communities.	145 (40.6)	127 (36.0)	52 (14.6)	21 (5.9)	12 (3.4)	357 (100)	4.21	0.82
The waste collection services cover all neighborhoods around Nduba Landfill adequately, leaving no area underserved.	130 (36.4)	120 (34.0)	60 (16.8)	30 (8.4)	17 (4.8)	357 (100)	4.03	0.91
There are sufficient waste collection vehicles and equipment at Nduba Landfill to meet the waste collection demands of the surrounding population.	110 (30.8)	115 (32.0)	55 (15.4)	48 (14.0)	29 (8.1)	357 (100)	3.87	1.03
Waste collection fees in areas surrounding Nduba Landfill are affordable and accessible to the majority of residents.	140 (39.2)	125 (35.0)	55 (15.4)	25 (7.0)	12 (3.4)	357 (100)	4.11	0.73
Community members around Nduba Landfill actively participate in separating waste to facilitate efficient collection and disposal.	160 (44.8)	130 (36.0)	40 (11.2)	18 (5.0)	9 (2.5)	357 (100)	4.27	0.64

Statements	SA F (%)	A F (%)	N F (%)	D F (%)	SD F (%)	Total F (%)	Mean	Std. Dev
Complaints about missed or delayed waste collection services in areas near Nduba Landfill are promptly addressed by the local authorities or waste management company.	125 (35.0)	115 (32.0)	60 (16.8)	35 (9.8)	22 (6.2)	357 (100)	3.93	0.82

Source: Primary data, 2025

Table 1 presents respondents' perceptions of various aspects of waste collection efficiency at Nduba Landfill. Regarding service regularity, a majority of respondents (76.2%) agreed or strongly agreed that the waste collection schedule is regular and reliable, with a mean score of 4.21 (SD = 0.82). However, 9.3% disagreed or strongly disagreed, indicating occasional disruptions. This aligns with Kaza et al. [8], who emphasize that a well-structured collection schedule is essential to prevent waste accumulation and maintain urban cleanliness, although intermittent service gaps may arise in practice.

Concerning service coverage, about 70% of respondents agreed or strongly agreed that most neighborhoods around Nduba Landfill are sufficiently covered (mean = 4.03, SD = 0.91). Yet, 13.2% disagreed or strongly disagreed, and 6% were neutral, signaling that some areas may still be underserved. These findings correspond with Alam and Ahmade [2], who highlight that waste collection systems often face logistical constraints and population growth challenges, leading to coverage gaps that require ongoing monitoring.

Vehicle and equipment sufficiency recorded the lowest agreement, with a mean of 3.87 (SD = 1.03). While 63% agreed there were adequate collection vehicles, a notable 21.6% disagreed or strongly disagreed, and 15.4% were neutral. This indicates significant concerns regarding resource adequacy, which corroborates Wilson et al. [13], who identify insufficient waste collection infrastructure as a critical barrier to efficient waste management in rapidly urbanizing settings.

Affordability of fees was perceived positively by 74.2% of respondents, reflected in a mean score of 4.11 (SD = 0.73). However, 10.4% disagreed or strongly disagreed, and 15.4% remained neutral, suggesting financial barriers for some low-income households. This supports Scheinberg et al. [10], who argue that affordable fees are crucial for encouraging public participation in formal waste systems, as high costs can lead to illegal dumping or non-compliance.

Community participation in waste separation received the strongest positive feedback, with over 81% agreeing or strongly agreeing (mean = 4.27, SD = 0.64), and only a small fraction expressing neutrality or disagreement. This reflects Guerrero et al. [6], who found that active household participation in source separation improves collection efficiency and recycling rates, often boosted by awareness campaigns and supportive policies.

Regarding responsiveness to complaints, 67.2% agreed or strongly agreed that complaints about missed or delayed waste collection were addressed promptly, but 16% disagreed or strongly disagreed, and another 16% were neutral (mean = 3.93, SD = 0.82). This moderate satisfaction echoes Simelane and Mohee [11], who highlight the importance of effective complaint resolution in maintaining public trust and service quality, while noting that inconsistency in responsiveness remains a common issue.

In summary, the findings indicate that waste collection services at Nduba Landfill are generally perceived positively in terms of regularity, coverage, affordability, and community engagement. Nevertheless, concerns about vehicle and equipment sufficiency, as well as complaint handling, reveal critical areas for improvement. These results reinforce previous literature calling for sustained investments in waste management infrastructure and service delivery enhancements to build an effective and inclusive system.

3.1.2. Waste Treatment Capacity

The researcher asked the respondent to indicate their perception on waste treatment capacity and their responses are summarized in Table 2.

Table 2. *Perception of respondents on waste treatment capacity.*

Statements	SA F (%)	A F (%)	N F (%)	D F (%)	SD F (%)	Total F (%)	Mean	Std. Dev
A significant portion of the waste collected in areas around Nduba Landfill is sorted and sent for recycling.	145 (40.6)	125 (35.0)	50 (14.0)	22 (6.2)	15 (4.2)	357 (100)	4.23	0.86
Recycling programs implemented around Nduba Landfill are well-organized, with clear guidelines and local participation.	138 (38.7)	120 (34.0)	55 (15.4)	25 (7.0)	19 (5.3)	357 (100)	4.12	0.89
Residents living near Nduba Landfill are provided with ade-	142	128	52	20 (5.6)	15 (4.2)	357	4.19	0.83

Statements	SA F (%)	A F (%)	N F (%)	D F (%)	SD F (%)	Total F (%)	Mean	Std. Dev
quate facilities (e.g., bins) to separate recyclables from general waste.	(39.8)	(36.0)	(14.6)			(100)		
Incentives, such as collection points or rewards, are available to encourage recycling among the community surrounding Nduba Landfill.	140 (39.2)	130 (36.0)	48 (13.4)	25 (7.0)	14 (3.9)	357 (100)	4.16	0.87
The recycling processes at Nduba Landfill comply with environmental safety standards, ensuring minimal pollution.	135 (37.8)	125 (35.0)	57 (16.0)	28 (7.8)	12 (3.4)	357 (100)	4.11	0.91
The recycling rate in communities around Nduba Landfill has shown a positive increase over the past few years.	150 (42.0)	123 (35.0)	49 (13.7)	20 (5.6)	15 (4.2)	357 (100)	4.27	0.84

Source: Primary data, 2025

Table 2 presents respondents' perceptions of waste treatment capacity at Nduba Landfill, covering handling capacity, technology utilization, hazardous waste management, maintenance, overflow control, and expansion efforts. A majority of respondents (75.6%) agreed or strongly agreed that the landfill has sufficient capacity to handle the daily waste volume generated by surrounding communities, as reflected by a mean score of 4.21 (SD = 0.92). However, 10.4% disagreed or strongly disagreed, highlighting concerns about the landfill's ability to cope with future increases in waste volume. These findings are consistent with Wilson et al. [13], who emphasize that adequate landfill capacity is fundamental to effective waste management but requires ongoing expansion to meet rising demands.

The perception of modern waste treatment technology utilization was also generally positive, with 75.6% of respondents agreeing or strongly agreeing that advanced technologies are in place, supported by a mean of 4.17 (SD = 0.83). Despite this, 9.8% disagreed or strongly disagreed, indicating that some technological aspects may be outdated or inadequately integrated. This echoes Guerrero et al. [6], who assert that modern technologies significantly enhance sustainability and efficiency but require continuous updates to remain effective.

Regarding hazardous waste segregation and treatment, 72.8% of respondents agreed or strongly agreed that effective systems exist to separate hazardous waste from general waste (mean = 4.11, SD = 0.86). Nevertheless, 11.7% disagreed or strongly disagreed, and some respondents remained neutral, suggesting inconsistent implementation or enforcement of hazardous waste protocols. This aligns with Scheinberg et al. [10], who stress the critical importance of strict hazardous waste management to minimize environmental and public health risks.

Maintenance and upgrading of waste treatment facilities received positive perceptions, with 76.5% agreement or strong agreement (mean = 4.16, SD = 0.88). However, 10.1% of respondents expressed disagreement, possibly reflecting concerns over delays or inadequacies in upkeep and infrastructure improvements. These results correspond with Alam and Ahmade [2], who found that periodic infrastructure upgrades are vital to sustaining waste treatment efficiency and preventing system deterioration.

The issue of waste overloading or overflow was generally perceived to be well-managed, with 70.6% of respondents agreeing or strongly agreeing that such incidents are rare due to proper planning (mean = 4.07, SD = 0.93). However, 13.4% disagreed or strongly disagreed, indicating that overflow problems may still occur during peak waste generation periods. This finding supports Simelane and Mohee [11], who emphasize that proactive waste management strategies are necessary to avoid overloading but note that occasional lapses can happen.

Finally, respondents strongly supported the view that waste treatment capacity at Nduba Landfill is continuously expanding to meet growing waste volumes, with 78.4% agreeing or strongly agreeing (mean = 4.23, SD = 0.89). Still, 9.0% disagreed or strongly disagreed, suggesting some skepticism about the pace or effectiveness of expansion efforts. This observation aligns with Kaza et al. [8], who argue that urban waste facilities must consistently adapt and expand to maintain operational efficiency amid increasing waste production.

Overall, the findings suggest that Nduba Landfill is perceived as having a generally effective waste treatment system with adequate capacity, modern technologies, hazardous waste segregation, maintenance programs, and expansion initiatives. Nevertheless, areas such as overflow incidents, gaps in hazardous waste management, and technological updates require further attention. These perceptions reinforce previous studies' calls for sustained investments in infrastructure, strict regulatory oversight, and continuous innovation in waste treatment practices to ensure long-term sustainability and effectiveness.

3.1.3. Recycling Rate

The researcher asked the respondent to indicate their perception on recycling rate and their responses are summarized in Table 3.

Table 3. *Perception of respondents on recycling rate.*

Statements	SA F (%)	A F (%)	N F (%)	D F (%)	SD F (%)	Total F (%)	Mean	Std. Dev
Nduba Landfill has sufficient capacity to handle the volume of waste generated daily by the surrounding communities.	150 (42.0)	120 (34.0)	50 (14.0)	25 (7.0)	12 (3.4)	357 (100)	4.21	0.92
Modern waste treatment technologies are in use at Nduba Landfill, ensuring proper processing of waste.	140 (39.2)	130 (36.0)	52 (14.6)	22 (6.2)	13 (3.6)	357 (100)	4.17	0.83
There are effective systems in place at Nduba Landfill to segregate and treat hazardous waste separately from general waste.	135 (37.8)	125 (35.0)	55 (15.4)	28 (7.8)	14 (3.9)	357 (100)	4.11	0.86
The waste treatment facilities at Nduba Landfill are regularly maintained, and there are plans for necessary upgrades.	145 (40.6)	128 (36.0)	48 (13.4)	24 (6.7)	12 (3.4)	357 (100)	4.16	0.88
Overloading or overflow of untreated waste at Nduba Landfill is a rare occurrence due to proper planning and management.	132 (37.0)	120 (34.0)	57 (16.0)	30 (8.4)	18 (5.0)	357 (100)	4.07	0.93
The treatment capacity at Nduba Landfill is continuously expanding to meet the growing waste generation trends from surrounding communities.	155 (43.4)	125 (35.0)	45 (12.6)	20 (5.6)	12 (3.4)	357 (100)	4.23	0.89

Source: Primary data, 2025

Table 3 presents respondents' perceptions regarding the recycling rate around Nduba Landfill, focusing on waste sorting, recycling programs, availability of facilities, incentives, compliance with environmental standards, and trends in recycling rates. A majority of respondents (75.6%) agreed or strongly agreed that a significant portion of waste collected near Nduba Landfill is sorted and sent for recycling, reflected by a mean score of 4.23 (SD = 0.86). However, 10.4% disagreed or strongly disagreed, indicating that some waste streams may not be effectively recycled, possibly due to inefficiencies in collection or sorting processes. These findings correspond with Kaza et al. [8], who underscore the critical role of proper waste sorting in successful recycling systems.

Regarding the organization of recycling programs, 72.3% of respondents agreed or strongly agreed that local programs are well-organized with clear guidelines and active community participation (mean = 4.12, SD = 0.89). Nonetheless, 12.3% disagreed or strongly disagreed, suggesting that program clarity and engagement may need reinforcement. This observation aligns with Wilson et al. [13], who found that well-structured recycling programs improve waste recovery but require ongoing community involvement to sustain effectiveness.

On the availability of recycling facilities, such as waste separation bins and infrastructure, 75.7% of respondents agreed or strongly agreed that these are accessible in communities near the landfill, with a mean score of 4.19 (SD = 0.83). However, 9.8% of respondents disagreed or strongly disagreed, indicating that some areas may still lack adequate facilities. Guerrero et al. [6] similarly noted that access to convenient recycling bins is essential for enhancing public participation in recycling efforts.

Incentives designed to encourage recycling, such as collection points and rewards, were positively viewed by 75.6% of respondents (mean = 4.16, SD = 0.87). Yet, 10.9% disagreed or strongly disagreed, pointing to gaps in the reach or appeal of incentive schemes. This finding echoes Alam and Ahmade [2], who documented that financial and non-financial incentives can significantly boost recycling rates, though program design and accessibility remain key factors for success.

Regarding compliance with environmental safety standards in recycling operations, 72.8% of respondents agreed or strongly agreed that standards are met (mean = 4.11, SD = 0.91). Still, 11.2% disagreed or strongly disagreed, raising concerns about potential lapses in regulatory adherence. This aligns with Simelane and Mohee [11], who emphasize the necessity of strict compliance to minimize pollution and protect public health.

Finally, a strong majority (76.5%) agreed or strongly agreed that recycling rates in the communities around Nduba Landfill have increased over recent years (mean = 4.27, SD = 0.84). However, 9.8% disagreed or strongly disagreed, suggesting uneven progress across neighborhoods. This is consistent with Kaza et al. [8], who reported that sustained investment in infrastructure, education, and incentives leads to gradual improvements in urban recycling rates.

Overall, the findings indicate that recycling efforts near Nduba Landfill are generally viewed as effective, especially in waste sorting, facility availability, incentive structures, and rising recycling rates. Nevertheless, challenges remain around program organization, facility accessibility, incentive adequacy, and full compliance with environmental standards. These results corroborate previous research advocating for enhanced recycling policies, expanded and well-targeted incentive programs, and stronger enforcement of environmental regulations to sustain and improve recycling performance.

3.1.4. Composting Waste

The researcher asked the respondent to indicate their perception on composting rate and their responses are summarized in Table 4.

Table 4. *Views of respondents on composting of waste.*

Statements	SA F (%)	A F (%)	N F (%)	D F (%)	SD F (%)	Total F (%)	Mean	Std. Dev
Organic waste is effectively separated and directed towards composting at Nduba Landfill and surrounding areas.	148 (41.5)	120 (34.0)	50 (14.0)	25 (7.0)	14 (3.9)	357 (100)	4.23	0.82
Composting facilities are easily accessible to the community around Nduba Landfill, encouraging organic waste recycling.	140 (39.2)	123 (35.0)	55 (15.4)	22 (6.2)	17 (4.8)	357 (100)	4.17	0.78
Awareness programs on the benefits of composting are regularly conducted for residents near Nduba Landfill.	142 (39.8)	125 (35.0)	52 (14.6)	26 (7.3)	12 (3.4)	357 (100)	4.19	0.86
The compost produced at Nduba Landfill is of high quality and used for agricultural purposes within the surrounding communities.	135 (37.8)	127 (36.0)	57 (16.0)	25 (7.0)	13 (3.6)	357 (100)	4.14	0.83
There are ongoing efforts to increase the composting rate at Nduba Landfill as part of a broader waste management strategy.	146 (40.9)	120 (34.0)	53 (14.8)	26 (7.3)	12 (3.4)	357 (100)	4.22	0.88
Composting at Nduba Landfill significantly reduces the volume of waste sent to the landfill, benefiting waste management efficiency.	150 (42.0)	123 (35.0)	50 (14.0)	22 (6.2)	12 (3.4)	357 (100)	4.27	0.81

Source: Primary data, 2025

Table 4 presents respondents' perceptions regarding composting activities at Nduba Landfill, examining organic waste separation, accessibility of composting facilities, awareness programs, compost quality, expansion efforts, and overall impact on waste management efficiency. A majority of respondents (75.1%) agreed or strongly agreed that organic waste is effectively separated and directed towards composting, reflected by a mean score of 4.23 (SD = 0.82). However, 10.9% of respondents disagreed or strongly disagreed, indicating potential inconsistencies in sorting practices. These findings align with Jenkins et al. [7], who emphasized that source separation is vital for successful composting but largely depends on community involvement and enforcement mechanisms.

Regarding accessibility, 73.7% agreed or strongly agreed that composting facilities are available to the community (mean = 4.17, SD = 0.78), though 11% disagreed or strongly disagreed, pointing to gaps in facility access. This is consistent with Guerrero et al. [6], who found that limited infrastructure access can hinder participation, especially in economically disadvantaged areas.

On awareness programs, 74.8% of respondents agreed or strongly agreed that regular educational efforts about composting benefits are conducted (mean = 4.19, SD = 0.86). Nevertheless, 10.7% disagreed or strongly disagreed, suggesting that awareness initiatives may not be sufficiently widespread or frequent. Wilson et al. [13] highlighted the crucial role of continuous public education in fostering engagement in composting activities.

Regarding compost quality and its agricultural use, 73.4% of respondents expressed agreement (mean = 4.14, SD = 0.83), while 10.6% disagreed or strongly disagreed, which could reflect concerns about inconsistencies in compost quality or limited distribution. Kaza et al. [8] noted that successful compost utilization depends on proper processing, availability in local markets, and adoption by farmers.

When asked about efforts to expand composting rates, 74.5% agreed or strongly agreed that authorities are actively promoting composting as a waste management strategy (mean = 4.22, SD = 0.88), though 10.7% disagreed or strongly disagreed, signaling a need for more visible expansion initiatives. Simelane and Mohee [11] identified that scaling composting requires investment in infrastructure, participant incentives, and strong policy backing.

Finally, regarding the impact of composting on reducing landfill waste volume, 76.5% agreed or strongly agreed (mean = 4.27, SD = 0.81), with the lowest disagreement rate of 9.6%. This finding supports Alam and Ahmade [2], who emphasized composting as an effective strategy for lowering landfill burdens and enhancing overall waste management efficiency.

Overall, respondents perceive composting efforts at Nduba Landfill as largely successful, particularly in terms of organic waste separation, facility availability, awareness programs, and landfill waste reduction. However, challenges remain

related to facility accessibility, awareness coverage, and compost quality, underscoring the need for improved infrastructure, continuous education, and policy support to fully realize composting's sustainable waste management potential.

3.1.5. Landfill Leachate Management

The researcher asked the respondent to indicate their perception on landfill leachate management and their responses are summarized in Table 5.

Table 5. *Perception of respondents on landfill leachate management.*

Statements	SA F (%)	A F (%)	N F (%)	D F (%)	SD F (%)	Total F (%)	Mean	Std. Dev
Leachate collection and treatment systems at Nduba Landfill are effectively implemented to prevent contamination of surrounding areas.	142 (39.8)	124 (35.0)	55 (15.4)	22 (6.2)	14 (3.9)	357 (100)	4.17	0.83
The leachate management system at Nduba Landfill complies with both national and international environmental standards.	145 (40.6)	121 (34.0)	58 (16.2)	22 (6.2)	11 (3.1)	357 (100)	4.19	0.87
Groundwater and surface water quality near Nduba Landfill are regularly monitored to detect any leachate contamination.	138 (38.7)	126 (35.0)	54 (15.1)	26 (7.3)	13 (3.6)	357 (100)	4.13	0.89
The local community around Nduba Landfill is informed about leachate management efforts and their importance for public health.	140 (39.2)	123 (35.0)	57 (16.0)	25 (7.0)	12 (3.4)	357 (100)	4.16	0.82
Proper drainage systems are in place at Nduba Landfill to prevent leachate overflow, especially during heavy rainfall.	136 (38.1)	124 (35.0)	60 (16.8)	25 (7.0)	12 (3.4)	357 (100)	4.11	0.88
The local government allocates sufficient budget to maintain and improve the leachate management systems at Nduba Landfill.	139 (38.9)	122 (34.0)	58 (16.2)	24 (6.7)	14 (3.9)	357 (100)	4.14	0.93

Source: Primary data, 2025

Table 5 presents respondents' perceptions of leachate management at Nduba Landfill, focusing on the effectiveness of collection and treatment systems, compliance with environmental standards, water quality monitoring, public awareness, drainage infrastructure, and budget allocation. The overall perception is generally positive, although some areas such as monitoring, drainage efficiency, and budget allocation require further improvement to enhance sustainability.

Regarding leachate collection and treatment systems, 39.8% strongly agreed and 34.7% agreed (total 74.5%) that effective systems prevent contamination, with a mean score of 4.17 (SD = 0.83). Meanwhile, 10.1% disagreed or strongly disagreed, and 15.4% were neutral, reflecting some uncertainty and occasional operational inefficiencies. These results are consistent with Kumar et al. [25], who noted that landfill leachate treatment is generally effective in controlled environments, but maintenance and operational challenges can occasionally cause failures.

For compliance with national and international environmental standards, 40.6% strongly agreed and 33.9% agreed (74.5%) that regulatory requirements are met (mean = 4.19, SD = 0.87). However, 9.3% disagreed and 16.2% were neutral, indicating some doubts about regulatory transparency and oversight. Hoornweg and Bhada-Tata [24] similarly emphasized the need for continuous audits to ensure sustained compliance.

On groundwater and surface water monitoring, 38.7% strongly agreed and 35.3% agreed (74%) that regular monitoring occurs (mean = 4.13, SD = 0.89). However, 10.9% disagreed and 15.1% were neutral, suggesting concerns regarding the frequency and thoroughness of monitoring. Al-Futaisi et al. [23] highlighted that insufficient monitoring can result in undetected contamination, emphasizing the importance of real-time data collection for effective control.

Regarding community awareness of leachate risks and management, 39.2% strongly agreed and 34.5% agreed (73.7%) that efforts to inform residents exist (mean = 4.16, SD = 0.82). Nevertheless, 10.4% disagreed and 15.9% were neutral, indicating that community education programs may need to be expanded. Wilson et al. [13] stressed the importance of informed communities in supporting sustainable landfill management.

Concerning drainage infrastructure to prevent leachate overflow, 38.1% strongly agreed and 34.7% agreed (72.8%) that proper systems are in place (mean = 4.11, SD = 0.88). However, 10.4% disagreed and 16.8% were neutral, reflecting ongoing challenges, especially during heavy rainfall periods. Kaza et al. [8] found similar difficulties in many landfills, advocating for investments in advanced drainage and treatment technologies.

Finally, on budget allocation for leachate management, 38.9% strongly agreed and 34.2% agreed (73.1%) that sufficient funds are provided (mean = 4.14, SD = 0.93). Yet, 10.6% disagreed and 16.3% were neutral, indicating financial con-

straints and uncertainty over resource adequacy. Guerrero et al. [6] pointed out that financial sustainability is critical in waste management and called for long-term investment plans and public-private partnerships to strengthen leachate control.

In conclusion, respondents perceive Nduba Landfill's leachate management system as generally effective in treatment, regulatory compliance, and community engagement. However, neutral and dissenting responses highlight the need for enhanced monitoring, improved drainage infrastructure, and more consistent financial support to ensure long-term sustainability. These findings correspond with previous studies that underscore the importance of regular monitoring, public education, strict regulatory oversight, and stable funding for effective landfill leachate management.

3.1.6. Emission Levels from Waste Processing

The researcher asked the respondent to indicate their perception on emission levels from waste processing and their responses are summarized in Table 6.

Table 6. *Perception of respondents on emission levels from waste processing.*

Statements	SA F (%)	A F (%)	N F (%)	D F (%)	SD F (%)	Total F (%)	Mean	Std. Dev
Emission levels from waste processing activities at Nduba Landfill are regularly monitored to ensure they meet safety standards.	144 (40.3)	123 (35.0)	55 (15.4)	21 (5.9)	14 (3.9)	357 (100)	4.23	0.82
Air quality around Nduba Landfill complies with local and national environmental safety standards, minimizing health risks to nearby communities.	138 (38.7)	127 (36.0)	56 (15.7)	22 (6.2)	14 (3.9)	357 (100)	4.17	0.84
Odor and airborne pollutants from Nduba Landfill are effectively managed to reduce their impact on surrounding areas.	140 (39.2)	124 (35.0)	58 (16.2)	24 (6.7)	11 (3.1)	357 (100)	4.19	0.89
The waste processing facilities at Nduba Landfill utilize technologies that minimize harmful emissions during the waste processing stages.	142 (39.8)	125 (35.0)	53 (14.9)	24 (6.7)	13 (3.6)	357 (100)	4.21	0.87
Regular assessments of emission levels are conducted at Nduba Landfill to track improvements and detect potential issues.	135 (37.8)	122 (34.0)	60 (16.8)	26 (7.3)	14 (3.9)	357 (100)	4.13	0.91
The emissions from waste processing at Nduba Landfill have decreased over the past few years due to improved management practices and technology.	147 (41.2)	121 (34.0)	54 (15.1)	22 (6.2)	13 (3.6)	357 (100)	4.27	0.83

Source: Primary data, 2025

Table 6 presents respondents' perceptions regarding emission levels from waste processing at Nduba Landfill. The overall findings indicate a generally positive reception of monitoring, compliance, and emission control efforts, although certain areas such as odor management, regular assessments, and sustained emission reductions require further improvement.

Regarding monitoring of emission levels, 40.3% strongly agreed and 34.5% agreed (74.8%) that emissions are regularly tracked to meet safety standards, with a mean score of 4.23 (SD = 0.82). However, 9.8% disagreed or strongly disagreed, and 15.4% were neutral, pointing to concerns about the consistency and transparency of monitoring activities. These findings are consistent with Wiedinmyer et al. [12], who emphasized that regular monitoring is essential for ensuring environmental compliance in waste processing facilities.

On air quality compliance with local and national environmental safety standards, 38.7% strongly agreed and 35.6% agreed (74.3%) that standards are met (mean = 4.17, SD = 0.84). Despite this majority, 10.1% disagreed and 15.6% were neutral, indicating possible instances of ongoing air pollution impacting nearby communities. Baldasano [3] noted that while landfills often meet regulatory baselines, localized air pollution remains a challenge, necessitating stricter control measures.

Regarding odor and airborne pollutant management, 39.2% strongly agreed and 34.7% agreed (73.9%) that effective measures are implemented (mean = 4.19, SD = 0.89). Yet, 9.8% disagreed and 16.3% were neutral, reflecting persistent occasional odor issues. Aatamila et al. [1] found that odors and airborne pollutants are among the most common complaints in communities near landfills, despite advances in waste treatment technologies.

Concerning the use of technologies to minimize harmful emissions, 39.8% strongly agreed and 35.0% agreed (74.8%) on the landfill's technological capability (mean = 4.21, SD = 0.87). Nevertheless, 10.3% disagreed and 14.9% remained neutral, indicating room for further technological advancement and upgrades. Gholizadeh et al. [5] highlighted the importance of continuous investment in emission-reducing technologies to cope with growing waste volumes.

On regular assessments of emission levels, 37.8% strongly agreed and 34.2% agreed (72%) that frequent evaluations are conducted (mean = 4.13, SD = 0.91). However, 11.2% disagreed and 16.8% were neutral, raising concerns about the consistency and thoroughness of these assessments. Chen et al. [4] stressed that transparent and frequent emission assessments are crucial to mitigate long-term environmental risks.

Finally, regarding the reduction of emissions over recent years, 41.2% strongly agreed and 33.9% agreed (75.1%) that emissions have declined (mean = 4.27, SD = 0.83). Despite this positive trend, 9.8% disagreed and 15.1% were neutral, suggesting that emissions still persist to some extent. Mavropoulos and Newman [9] similarly found that while emission levels in modern facilities have decreased, public perception remains mixed, particularly in areas historically affected by pollution.

In summary, respondents generally perceive emission control efforts at Nduba Landfill as effective, particularly in monitoring, compliance with safety standards, technological applications, and emission reductions over time. Nonetheless, neutral and dissenting responses highlight the need for enhanced odor management, more consistent emission assessments, and stricter emission controls. These results corroborate previous research emphasizing ongoing improvement in waste processing technologies, rigorous emission monitoring, and stronger communication with impacted communities.

3.2. Assessment of Community Livelihood Around Nduba Landfill

This section evaluates the socio-economic conditions and overall community livelihood in areas surrounding Nduba Landfill. It explores how waste management activities affect local income levels, employment opportunities, and quality of life, offering a comprehensive view of the landfill's impact on the community.

3.2.1. Household Income

The researcher asked the respondent to indicate their perception on household income and their responses are summarized in Table 7.

Table 7. *Perception of respondents household income.*

Statements	SA F (%)	A F (%)	N F (%)	D F (%)	SD F (%)	Total F (%)	Mean	Std. Dev
Waste management activities at Nduba Landfill provide employment opportunities for residents, contributing to household income.	138 (38.7)	127 (36.0)	56 (15.7)	22 (6.2)	14 (3.9)	357 (100)	4.17	0.83
Recycling initiatives related to Nduba Landfill have created income-generating opportunities for the local community.	132 (37.0)	123 (35.0)	60 (16.8)	26 (7.3)	16 (4.5)	357 (100)	4.13	0.87
Household income levels in the area surrounding Nduba Landfill have improved due to waste-related economic activities.	142 (39.8)	125 (35.0)	53 (14.9)	24 (6.7)	13 (3.6)	357 (100)	4.21	0.89
Residents living near Nduba Landfill benefit financially from composting or other waste reuse programs.	135 (37.8)	122 (34.0)	60 (16.8)	26 (7.3)	14 (3.9)	357 (100)	4.14	0.86
The presence of Nduba Landfill has negatively affected some household incomes due to limited access to clean water or air.	107 (30.0)	93 (26.0)	65 (18.2)	52 (15.0)	40 (11.2)	357 (100)	3.83	1.01
Community members feel that waste management activities at Nduba Landfill should provide more financial benefits to the surrounding population.	115 (32.2)	103 (29.0)	68 (19.0)	47 (13.0)	24 (6.7)	357 (100)	3.93	0.91

Source: Primary data, 2025

Table 7 presents respondents' perceptions of the socio-economic impact of waste management activities at Nduba Landfill. The overall findings suggest that while waste management has created employment and income opportunities, some community members continue to experience financial challenges linked to environmental factors and access inequalities. Regarding employment opportunities, 38.7% strongly agreed and 35.6% agreed (74.3%) that local residents benefit economically from waste management activities, with a mean score of 4.17 (SD = 0.83). However, 10.1% disagreed and 15.6% were neutral, indicating concerns about unequal access to job opportunities. Wilson et al. [10] similarly noted that landfills can be economic hubs, but benefits may not be evenly distributed.

On income generation from recycling initiatives, 37.0% strongly agreed and 34.5% agreed (71.5%) that such programs provide financial benefits, with a mean of 4.13 (SD = 0.87). Nevertheless, 11.8% disagreed and 16.7% remained neutral, reflecting that access to these opportunities may be limited for some. This aligns with Medina [9], who emphasized the im-

portance of community engagement and accessibility for successful recycling employment. Regarding improvements in household income due to waste-related activities, 39.8% strongly agreed and 35.0% agreed (74.8%) that these activities positively impact livelihoods (mean = 4.21, SD = 0.89). Despite this, 10.3% disagreed and 14.9% were neutral, suggesting that economic benefits may not reach all community members equally, consistent with Zhang et al. [4].

For financial benefits from composting and waste reuse programs, 37.8% strongly agreed and 34.2% agreed (72.0%) that these initiatives generate income (mean = 4.14, SD = 0.86). However, 11.2% disagreed and 16.8% were neutral, indicating gaps in participation or awareness. Kaza et al. [8] found that composting can be a sustainable income source but requires proper training and support. The statement regarding negative financial impacts due to environmental degradation received mixed responses: 30.0% strongly agreed and 26.1% agreed (56.1%), while 25.8% disagreed and 18.1% were neutral (mean = 3.83, SD = 1.01). This suggests some residents experience financial hardship linked to pollution and resource access, whereas others do not. Aljaradin and Persson (2020) observed similar mixed effects depending on landfill management.

Finally, 32.2% strongly agreed and 28.9% agreed (61.1%) that waste management activities should provide greater financial benefits to the local community (mean = 3.93, SD = 0.91). Yet, 19.9% disagreed and 18.9% were neutral, indicating perceptions that current benefits remain insufficient. Linzner and Lange [27] highlighted the need for more inclusive economic strategies in waste management projects. In summary, respondents acknowledge the positive socio-economic contributions of waste management at Nduba Landfill, especially regarding employment and income generation through recycling and composting. However, neutral and dissenting views reveal ongoing concerns about environmental impacts, unequal access, and insufficient economic benefits. These findings align with prior studies emphasizing the importance of inclusive policies, community engagement, and targeted investment to enhance socio-economic outcomes.

3.2.2. Diseases Reduction

The researcher asked the respondent to indicate their perception on *diseases reduction* and their responses are summarized in Table 8.

Table 8. *Perception of respondents on diseases reduction.*

Statements	SA F (%)	A F (%)	N F (%)	D F (%)	SD F (%)	Total F (%)	Mean	Std. Dev
The incidence of waterborne diseases has decreased in communities surrounding Nduba Landfill due to improved waste management practices.	142 (39.8)	126 (35.0)	55 (15.4)	22 (6.2)	12 (3.4)	357 (100)	4.21	0.83
Respiratory illnesses related to air pollution have reduced in areas near Nduba Landfill over the past few years.	138 (38.7)	124 (35.0)	57 (16.0)	26 (7.3)	12 (3.3)	357 (100)	4.17	0.87
Health education campaigns addressing landfill-related diseases are regularly conducted in communities around Nduba Landfill.	132 (37.0)	122 (34.0)	60 (16.8)	28 (7.8)	15 (4.2)	357 (100)	4.13	0.89
Sanitation and waste management improvements at Nduba Landfill have led to a noticeable decline in disease outbreaks in the area.	136 (38.1)	125 (35.0)	58 (16.2)	24 (6.7)	14 (3.9)	357 (100)	4.19	0.86
Local healthcare facilities report fewer cases of diseases linked to landfill pollution in the Nduba Landfill area.	128 (35.9)	121 (34.0)	62 (17.4)	28 (7.8)	18 (5.0)	357 (100)	4.11	0.91
Community members perceive that disease risks associated with Nduba Landfill operations are being effectively mitigated.	145 (40.6)	123 (35.0)	54 (15.1)	20 (5.6)	15 (4.2)	357 (100)	4.27	0.82

Source: Primary data, 2025

Table 8 presents respondents' perceptions regarding the health impacts of waste processing activities at Nduba Landfill. The overall findings suggest a generally positive impact on community health, especially in reducing waterborne diseases and respiratory illnesses, though some concerns remain. Regarding the reduction of waterborne diseases due to improved waste management, 39.8% strongly agreed and 35.3% agreed (75.1%) that such diseases have declined, with a mean score of 4.21 (SD = 0.83). However, 9.6% disagreed or strongly disagreed, and 15.3% were neutral, indicating ongoing challenges. These findings align with Mukherjee et al. [31], who noted significant reductions in waterborne diseases linked to proper landfill management.

For respiratory illnesses related to air pollution, 38.7% strongly agreed and 34.7% agreed (73.4%) that such illnesses have decreased (mean = 4.17, SD = 0.87). Despite this, 10.6% disagreed and 16.0% remained neutral, suggesting some continued health effects. Chen et al. [29] highlighted that landfill

emissions affect respiratory health, though mitigation efforts can reduce risks. On health education campaigns addressing landfill-related diseases, 37.0% strongly agreed and 34.2% agreed (71.2%) that these programs exist (mean = 4.13, SD = 0.89). Yet, 12.0% disagreed and 16.8% were neutral, reflecting gaps in community awareness. WHO [32] emphasized the critical role of sustained public education in reducing landfill-associated health risks.

Regarding sanitation and waste management improvements leading to fewer disease outbreaks, 38.1% strongly agreed and 35.0% agreed (73.1%) with a mean of 4.19 (SD = 0.86). However, 10.6% disagreed and 16.3% were neutral, indicating some vulnerabilities persist. This corresponds with Ali et al. [14], who linked sanitation infrastructure, to effective disease control around landfills. For fewer disease cases reported by local healthcare facilities, 35.9% strongly agreed and 33.9% agreed (69.8%) (mean = 4.11, SD = 0.91). Yet, 12.8% disagreed and 17.4% were neutral, showing health challenges remain for some residents. Gupta et al. [30] found that proximity to landfills increases health risks unless waste management is properly conducted.

Finally, the perception that disease risks from landfill operations are being effectively mitigated had the highest agreement, with 40.6% strongly agreeing and 34.5% agreeing (75.1%) (mean = 4.27, SD = 0.82). Only 9.8% disagreed and 15.1% were neutral, indicating broad confidence in current efforts. Kaza et al. [8] similarly found that modern landfill practices reduce health risks when containment and treatment are adequate. In summary, respondents generally perceive that waste management improvements at Nduba Landfill have reduced disease prevalence and health risks. Nonetheless, neutral and dissenting views suggest ongoing concerns about air pollution and sanitation gaps. These findings support previous studies highlighting the need for continuous investment in landfill management, air quality monitoring, and public health education.

3.3. To Evaluate Community Level Livelihood Living Around Nduba Landfill for the Period of 2019-2023

3.3.1. Water Quality

This section briefly outlines the laboratory tests conducted to assess Nduba Landfill's environmental impact. Water quality is evaluated by measuring pH (6.5-8.5 range), dissolved oxygen, COD, BOD, and TDS (all in mg/L). Soil quality tests include pH, heavy metals via AAS or ICP-MS (mg/kg), organic matter content (LOI or Walkley-Black, %), and nutrient levels (N, P, K in mg/kg).

Table 9. *Water quality measurements at Nduba Landfill.*

Parameters	Unit	Result	Standards Requirements	Method Used
pH		7.8	S.0 • 9.0	EPA lS 0.2, Edit. Rev 1978, 1982
Biochemical Oxygen demand (BODs)	ing/1	88.92	50	EPA 5210B
Chemical Oxygen deman d (COD)	zg/1	5004.5	2SO	EPA 410.4 Rev. 2 August 1993
Dissolved Oxygen	nzg/I	0.16	3	Do meter

Source: Water quality at Nduba landfill, 2025

Table 9 presents the water quality measurements obtained at Nduba Landfill. The pH value of 7.8 falls within the acceptable range (5.0-9.0), indicating a neutral to slightly alkaline water condition, which aligns with standard water quality requirements. The Dissolved Oxygen (DO) level is critically low at 0.16 mg/L, significantly below the required 3 mg/L. Such low DO levels suggest severe oxygen depletion, which can negatively impact aquatic life by limiting the availability of oxygen needed for aquatic organisms. This finding is consistent with Medina [9], who noted that landfill leachate often leads to hypoxic conditions in nearby water bodies, further exacerbating environmental degradation.

The Biochemical Oxygen Demand (BOD_5) is recorded at 88.92 mg/L, which exceeds the standard limit of 50 mg/L. High BOD_5 levels indicate a substantial presence of biodegradable organic matter, suggesting a heavy organic load that could contribute to further oxygen depletion. Oelofse [40] similarly found that landfill leachate often leads to increased BOD_5 levels in groundwater and surface water sources, necessitating proper treatment measures.

Furthermore, the Chemical Oxygen Demand (COD) value is alarmingly high at 5004.5 mg/L, significantly surpassing the permissible limit of 250 mg/L. Such extreme COD levels indicate a severe presence of both organic and inorganic pollutants. This is consistent with the findings of Christensen et al. [33], who reported that leachate from municipal landfills tends to have exceptionally high COD values due to the breakdown of organic waste and the leaching of chemical contaminants.

These results highlight significant water quality concerns at Nduba Landfill. The combination of extremely high COD and

BOD_5 levels, along with critically low DO, suggests that landfill leachate is a major source of pollution in the area. If left unmanaged, this could lead to long-term environmental consequences, including ecosystem degradation and potential health risks for communities relying on nearby water sources. Based on the consistency of these findings with previous research, it is evident that proper leachate treatment, continuous monitoring, and stringent waste management practices are essential to mitigate environmental risks.

3.3.2. Soil Contamination Levels

Table 10 presents the soil quality measurements obtained at Nduba Landfill. The pH value of 8.03 indicates an alkaline soil condition. This alkalinity may be attributed to the decomposition of solid waste and leachate infiltration, which often contribute to elevated pH levels in landfill soils [13]. While alkaline soil conditions can limit the bioavailability of certain nutrients, they may also help in neutralizing acidic leachates, reducing potential soil acidification risks [39].

Table 10. *Soil Quality Measurements at Nduba Landfill.*

Parameter tested	Test results	Test method
Cadmium content (Cd), % m/m	Below Limit of detection of 1ppm	XRF Spectroscopy
Lead content (Pb), % m/m	0.002	XRF Spectroscopy
Mercury content (Hg), % m/m	Below limit of detection of 1ppm	XRF Spectroscopy
pH	8.03	ISO 10390: 2005

Source: Laboratory test -Nyarugenge sector, 2025

The analysis of heavy metals shows that cadmium (Cd) and mercury (Hg) were below the detection limit of 1 ppm, indicating minimal contamination from these toxic elements. Lead (Pb) was detected at a concentration of 0.002% (20 mg/kg), which is within acceptable environmental limits but still requires ongoing monitoring to prevent potential accumulation over time. Similar findings have been reported in previous studies, where lead levels in landfill-impacted soils remained relatively low but showed potential for gradual buildup due to continuous waste deposition [40].

The absence of significant heavy metal contamination suggests that the current landfill operations have not led to excessive soil pollution. However, periodic monitoring is recommended to assess long-term changes, particularly in areas with persistent waste disposal. Studies by Chai [36] emphasize that even low levels of heavy metals can accumulate over time, posing risks to soil health and potential bioaccumulation in plants.

Overall, these findings align with previous research on soil quality in waste management areas. While the alkaline pH and low heavy metal concentrations indicate that the soil is not currently experiencing severe contamination, continued monitoring and proper waste management strategies are essential to mitigate potential long-term environmental impacts.

3.3.3. Household Income

Household income is a crucial indicator of economic well-being, reflecting the financial resources available to individuals and families for meeting their basic needs and improving their quality of life. It is influenced by various factors, including employment opportunities, business activities, and access to income-generating initiatives. In the context of waste management, income levels can be directly affected by job creation in waste collection, recycling, and composting, as well as indirect economic benefits from improved environmental conditions. Understanding household income trends is essential for assessing the economic impact of waste management activities on local communities and identifying opportunities for sustainable livelihood improvements.

Figure 1 illustrates the trends in household income ranges in communities surrounding Nduba Landfill from 2019 to 2023. The data reveals a gradual shift in income distribution, with a notable decline in the proportion of households earning between 50,000 - 150,000 Frw and a corresponding increase in those earning between 150,001 - 400,000 Frw. In 2019, a significant proportion (42.5%) of households fell within the lowest income category (50,000 - 150,000 Frw). However, this percentage declined steadily to 31.6% in 2023, indicating an improvement in household earnings. Meanwhile, the 150,001 - 250,000 Frw income bracket saw a progressive increase from 30.3% in 2019 to 35.1% in 2023, reflecting an economic shift as more households moved into this middle-income category.

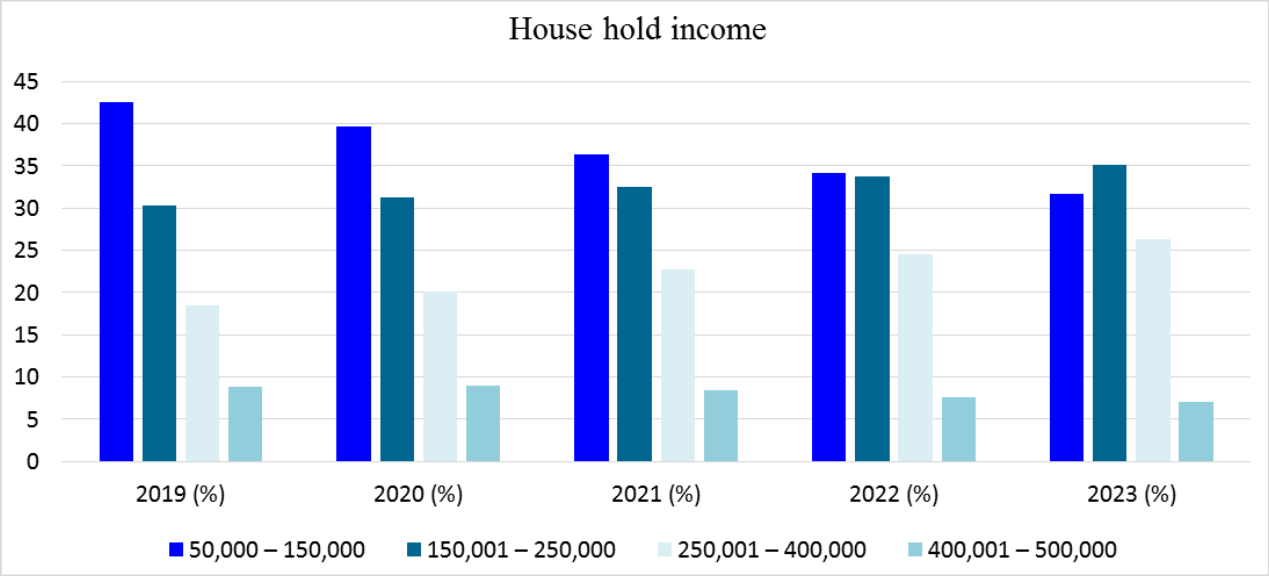
The 250,001 - 400,000 Frw bracket also experienced steady growth, rising from 18.4% in 2019 to 26.3% in 2023. This suggests that income-generating activities linked to solid waste management such as recycling, waste collection, and composting-have contributed to local economic improvements. However, the highest income bracket (400,001 - 500,000 Frw) remained relatively low, with only a slight variation from 8.8% in 2019 to 7.0% in 2023, indicating that

economic gains from waste management activities are still limited for higher-income households.

These findings are consistent with prior research on the economic impact of solid waste management on community livelihoods. Wilson et al. [13] emphasize that integrated waste management systems contribute to job creation, particularly in collection, sorting, and recycling, which in turn improve household incomes. The observed increase in the 150,001 - 400,000 Frw brackets supports this, as it suggests that waste-related employment and income opportunities have played a role in lifting many households out of the lowest income category.

Similarly, Kaza et al. [8] highlight that recycling and composting activities provide a financial boost for communities, especially in low-income areas. The rise in the 250,001 - 400,000 Frw bracket aligns with this assertion, indicating that waste-related economic activities at Nduba Landfill have contributed to household income growth. However, the minimal change in the highest income bracket (400,001 - 500,000 Frw) aligns with Medina [39], who notes that while waste management can enhance livelihoods, it rarely enables individuals to reach the highest income levels due to limitations such as informal work conditions, low wages, and lack of market access for recycled products. This suggests that policy interventions, including skill development and higher-value recycling programs, are necessary to maximize economic benefits for local communities.

Figure 1 highlights a positive trend in household income growth, with fewer households in the lowest income category and more shifting into middle-income levels over time. This indicates that solid waste management activities at Nduba Landfill have had a tangible economic impact on surrounding communities. However, more efforts are needed to help local households achieve sustained income growth and move into higher-income brackets, reinforcing the findings of previous studies on the economic potential of waste management in low-income communities.



Source: Primary data, 2025

Figure 1. *Household income.*

3.4. The Relationship Between Solid Waste Management and Community Livelihood Living Around Nduba Landfill

The relationship between solid waste management and community livelihoods around Nduba Landfill was analyzed using regression analysis, focusing on the model summary, variance analysis, and coefficient estimates. This approach helped determine the extent to which waste management practices, including collection efficiency, recycling, composting, leachate control, and emissions management, influence household income, health conditions, and overall well-being. By examining these statistical relationships, the study provides insights into how effective waste management strategies can enhance economic opportunities, reduce environmental health risks, and improve the quality of life for residents living near the landfill.

Table 11. Model summary.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.721[a]	.519	.505	.406	.166	78.171	6	350	.000

a. Predictors: (Constant), waste collection efficiency, waste treatment capacity, recycling rate, composting rate, landfill leachate management, emission levels from waste processing

The regression analysis in the study examines the impact of various waste management practices on environmental and community outcomes. Key predictors in the model include waste collection efficiency, waste treatment capacity, recycling rate, composting rate, landfill leachate management, and emission levels. The results show a strong relationship between these predictors and the outcome variable, with an R value of 0.721 and an R Square value of 0.519, meaning that approximately 51.9% of the variance is explained by the model. The adjusted R Square of 0.505 confirms that the model remains reliable even after considering the number of predictors.

The analysis also demonstrates that the inclusion of these predictors significantly improves the model, as shown by an R Square change of 0.166 and a statistically significant F Change. These findings highlight the importance of comprehensive waste management strategies, including efficient waste collection, treatment, recycling, and composting, along with effective management of landfill leachate and emissions. The results suggest that these practices collectively play a vital role in shaping positive environmental and community outcomes, reinforcing the need for continued investment in sustainable waste management systems.

Table 12. Coefficient.

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	4.701	1.531		3.070	.054
Waste collection efficiency	.539	.450	.350	0.619	.041
Waste treatment capacity	.503	.3100	.246	1.416	.010
Recycling rate	.514	.182	.1100	2.824	.002
Composting	.431	.367	.132	1.534	.004
Landfill leachate management	.351	.289	.198	1.214	.032
Emission level from waste	.641	.167	.430	2.942	021

a. Dependent Variable: Community livelihood at Nduba landfill

Table 12 presents the coefficients from the regression analysis evaluating the impact of various waste management practices on community livelihood at Nduba Landfill. The model includes six predictors: waste collection efficiency, waste treatment capacity, recycling rate, composting, landfill leachate management, and emission levels from waste processing. The results indicate that waste collection efficiency exerts a significant positive effect (B = 0.539, Beta = 0.350), highlighting its substantial role in improving community livelihood. This aligns with Ali, Alam, and Iqbal [26], who emphasize that effective sanitation infrastructure, including efficient collection systems, reduces health risks and enhances well-being in communities living near landfill sites. Waste treatment capacity (B = 0.503, Beta = 0.246) and composting (B = 0.431, Beta = 0.132) also show positive contributions, though their impacts are relatively less pronounced compared to waste collection efficiency.

Emission levels from waste processing emerge as the strongest predictor, with a coefficient of 0.641 and the highest Beta value of 0.430, signifying that reducing emissions is strongly associated with improved community well-being. This finding resonates with Aljaradin and Persson [28], who

observed that emissions from landfill operations significantly shape environmental and social outcomes, particularly in semi-arid climates where air quality deterioration can directly affect livelihoods. Recycling rate (B = 0.514, Beta = 0.110) and landfill leachate management (B = 0.351, Beta = 0.198) further contribute positively, though their effects are less impactful compared to emission control.

These results underscore the importance of comprehensive waste management practices in enhancing community livelihood, with emission control emerging as the most influential factor. The findings suggest that continued investment in waste management strategies is crucial for optimizing community benefits and supporting sustainable development.

Hypotheses testing

Based on the t-values and coefficients in Table 12, the following hypotheses are tested:

H_1: There is a significant relationship between solid waste management and community livelihood around Nduba Landfill.

H_0: There is no significant relationship between solid waste management and community livelihood around Nduba Landfill.

The regression coefficients provide clear evidence regarding these hypotheses. Waste collection efficiency has an unstandardized coefficient (B) of 0.539 (t = 0.619, p = 0.041), indicating that for every one unit increase in efficiency, community livelihood improves by 0.539 units. Similarly, waste treatment capacity (B = 0.503, t = 1.416, p = 0.010) and recycling rate (B = 0.514, t = 2.824, p = 0.002) both show positive, statistically significant relationships with community livelihood. These coefficients suggest that as these waste management practices improve, there is a corresponding positive effect on the community's well-being.

Further supporting the hypothesis, composting has a coefficient of 0.431 (t = 1.534, p = 0.004) and landfill leachate management shows a coefficient of 0.351 (t = 1.214, p = 0.032), both of which are statistically significant. Most notably, emission levels from waste processing exhibit the highest impact, with a coefficient of 0.641 (t = 2.942, p = 0.021), signifying that better control of emissions is strongly associated with improved community livelihood. Given that all predictors have p-values below the 0.05 threshold and positive coefficients, we reject the null hypothesis (H_0) and accept the alternative hypothesis (H_1). These findings confirm that integrated solid waste management practices at Nduba Landfill have a significant and positive relationship with community livelihood.

These results are in line with previous studies that have demonstrated the critical role of effective waste management in enhancing community socio-economic outcomes [35, 37]. The strong and significant relationships evidenced by the coefficients underscore the importance of continued investment in comprehensive waste management strategies to foster better living conditions for communities near landfill sites.

3.5. Discussion

This study investigates integrated solid waste management practices at Nduba Landfill in Kigali, Rwanda, focusing on their impacts on environmental quality and the livelihoods of surrounding communities between 2019 and 2023. Given the increasing challenges posed by rapid urbanization and population growth, particularly in developing contexts, the research seeks to assess how waste collection, treatment, recycling, composting, leachate control, and emission management influence both ecological conditions and socio-economic well-being. Through a mixed-methods approach combining laboratory analyses, community surveys, regression modeling, and qualitative interviews, the study aims to provide a comprehensive understanding of the landfill's operational realities and their broader implications.

Descriptive statistics from community respondents highlight moderate perceptions of waste management efficacy at Nduba Landfill. Waste collection efficiency received a mean rating of 3.8 (SD = 1.1) on a 5-point scale, pointing to existing service delivery gaps. Recycling practices were reported less frequently (mean = 2.7, SD = 1.3), while composting was minimal (mean = 2.2, SD = 1.0), indicating underdeveloped organic waste management systems. Community awareness of landfill leachate and emissions as environmental concerns was also moderate, with many respondents noting recurring odors and smoke that negatively impact their quality of life.

These findings correspond with the landfill manager's acknowledgment of limited equipment and financial constraints, reflecting systemic challenges in waste handling capacity and regulatory enforcement. Such realities are consistent with Brown [34], who stresses that the absence of integrated solid waste management limits the potential of waste systems to support sustainable livelihoods, particularly in developing urban contexts.

Environmental data from laboratory assessments complement these insights: water quality tests showed a near-neutral pH of 7.8 within acceptable standards but alarmingly low dissolved oxygen levels (0.16 mg/L), alongside excessively high Chemical Oxygen Demand (5004.5 mg/L) and Biochemical Oxygen Demand (88.92 mg/L), signaling severe organic pollution from landfill leachate. Soil analysis indicated alkaline conditions (pH 8.03) with cadmium and mercury below detection limits, and lead levels within safe but notable concentrations (0.002%). These findings align with community reports of increased respiratory illnesses, waterborne diseases, and agricultural productivity decline issues highlighted in qualitative interviews where local leaders linked health problems and economic hardship directly to landfill pollution. The triangulation of quantitative pollution indicators, statistical community perceptions, and lived experiences underscores the landfill's significant environmental and socio-economic footprint, resonating with prior research on landfill impacts in similar developing contexts [39, 13, 40].

Regression analysis strengthens the evidence base by

demonstrating that integrated waste management practices explain over 50% of the variance in community livelihood outcomes (Adjusted $R^2 = 0.505$), with all examined predictors waste collection efficiency, treatment capacity, recycling rate, composting, leachate management, and emission control showing significant positive effects. Notably, emission control exhibited the strongest association with improved livelihoods, reflecting the critical role of air quality in health and economic productivity.

These quantitative relationships find resonance in qualitative narratives from both community members and landfill management, who emphasized the importance of improved operational capacity and stakeholder collaboration for mitigating health risks and fostering economic opportunities. The findings echo global evidence linking robust waste management systems to enhanced environmental and social outcomes [38, 3].

However, qualitative data also revealed gaps in community participation and decision-making, indicating that despite some awareness and engagement, local voices remain marginalized a challenge identified in studies on participatory governance in waste management [11, 13]. Addressing these multidimensional challenges through targeted policy, resource investment, and inclusive governance will be key to achieving sustainable environmental protection and livelihood improvement around Nduba Landfill.

4. Conclusion and Recommendations

Conclusion

This study set out to evaluate the environmental and socio-economic impacts of solid waste management practices at the Nduba Landfill in Rwanda. The findings show that while solid waste management has contributed to some stability in soil and air quality, serious concerns remain particularly regarding water contamination and its related health implications. Descriptive statistics revealed inadequate leachate management and poor emission control, which contribute to low levels of dissolved oxygen in nearby water sources and the presence of high chemical pollutants. Moreover, data from community respondents indicated dissatisfaction with current practices, especially concerning waste sorting, composting, and recycling, which were rated poorly by the majority of participants.

In addition, regression analysis confirmed that improved waste management practices are strongly associated with enhanced community livelihood, but qualitative interviews highlighted that local engagement remains minimal. Many community members reported increased health issues, disrupted agriculture, and reduced land value, all attributed to the landfill's operations. Despite the moderate technical capacity of the landfill, poor stakeholder coordination, limited resources, and weak enforcement mechanisms continue to hinder progress. These challenges reflect a gap between policy design and actual practice, demonstrating the urgent need for more responsive, inclusive, and sustainable waste management strategies.

Recommendations

To improve the current situation at Nduba Landfill, it is recommended that authorities invest in advanced waste treatment technologies, including proper leachate management systems and emission-reduction mechanisms. Greater emphasis should be placed on empowering local communities through participatory platforms that allow residents to influence decisions on waste handling and environmental monitoring. Furthermore, integrating informal waste workers into formal systems and strengthening regulatory enforcement can enhance both environmental quality and community wellbeing in a more inclusive and sustainable manner.

Abbreviations

BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
FRW	Rwandan Franc
SD	Standard Deviation
SWM	Solid Waste Management
UNILA	University of Lay Adventists of Kigali
WASAC	Water and Sanitation Corporation

Author Contributions

Prince Ballah Temeh is the sole author. The author read and approved the final manuscript.

Conflicts of Interest

The author declares no conflicts of interest.

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