

Soil, Runoff, and Nutrient Losses from Major Cropping Systems in the River Katonga Micro-Catchment of South-Central Uganda

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Abstract

This study determined the magnitude of soil, runoff, and nutrient losses under four major cropping systems, including annual crops, banana monocrop, coffee-banana intercrop, and grazing lands in the River Katonga Micro-Catchment, South-Central Uganda. Data were collected using the runoff plot approach. Runoff plots measuring 2 M × 20 m were installed on each cropping system in farmers' gardens, equipped with dividers and collection tanks. Three soil erosion conservation practices, comprising trenches, mulches, and grass bunds, were tested for the experiment. Trenches and grass bunds were tested on annuals; trenches and mulches were tested on both banana and coffee-banana systems; and only trenches were tested on grazing land. The experiment included a control practice for each cropping system. Each treatment and control was replicated three times. Runoff and soil loss were estimated for each rainfall event and aggregated on a seasonal basis, while nutrient (nitrogen (N), phosphorus (P), and potassium (K)) losses were estimated per season. Results show that soil, runoff, and nutrient losses significantly depended on soil erosion conservation practices and rainfall seasons for all the cropping systems ($p < 0.001$). The magnitude of soil and runoff losses was in the order of annual crops > grazing lands > banana > coffee-banana. Soil losses ranged between 22.08 and 22.84 t/ha, while runoff losses varied from 84.15 to 97.05 m³ under annual cropping systems. In banana fields, soil losses ranged from 20.83 to 22.32 t/ha, while runoff losses were between 74.1 and 95.11 m³. Coffee-banana intercropping recorded soil losses ranging from 19.47 to 22.15 t/ha and runoff losses between 70.08 and 90.24 m³. For grazing lands, soil losses ranged from 20.53 to 21.75 t/ha, with runoff losses varying between 76.07 and 95.57 m³. Nutrient losses also varied across cropping systems. Under annual crops, nitrogen losses ranged from 21.23 to 41.53, phosphorus from 0 to 22.89, and

potassium from 22.33 to 48.83 kg/ha. In banana cropping systems, nitrogen losses ranged from 10.17 to 32.71, phosphorus from 0 to 16.22, and potassium from 17.7 to 41.31 kg/ha. Coffee-banana systems recorded nitrogen losses between 0 and 40.46, phosphorus between 0 and 25.63, and potassium between 0 and 48.59 kg/ha. For grazing lands, nitrogen losses ranged from 13.37 to 24.4, phosphorus from 0 to 13.07, and potassium from 18.43 to 37.06 kg/ha. The study provides valuable data for sustainable agricultural land management in the Lake Victoria Basin region, highlighting the importance of erosion control practices in mitigating soil, runoff, and nutrient losses.

Keywords

Land Degradation, Lake Victoria Basin, Pollution Loading, Katonga, Uganda

1. Introduction

Soil erosion and nutrient loss are among the most persistent environmental threats in sub-Saharan Africa, contributing to land degradation, declining agricultural productivity, and long-term food insecurity [1] [2]. In Uganda, these issues are particularly pronounced in both highland and lowland catchments, including the Katonga Catchment, which drains into Lake Victoria. Within this landscape, the interaction between poor land-use practices, rapid population growth, and fragile ecosystems has accelerated soil degradation and nutrient depletion [3]-[5].

The River Katonga Micro-Catchment, situated in south-central Uganda, covers approximately 13,837 km² and is increasingly exposed to unsustainable land management practices, including deforestation, wetland encroachment, and intensive cultivation. These practices exacerbate soil erosion and contribute to sediment and nutrient loading in Lake Victoria, Africa's largest freshwater lake. The ecological and socio-economic significance of the lake is well documented: it supports millions of people through fishing, transportation, and water supply [6] [7]. However, sedimentation and nutrient runoff into the lake have intensified eutrophication, resulting in the proliferation of invasive aquatic species such as *Eichhornia crassipes* (water hyacinth), which further degrades water quality, reduces biodiversity, and disrupts fisheries [8] [9].

Although the links between land degradation and poverty are well-established, the relationship is becoming increasingly cyclical in the Lake Victoria Basin. Declining soil fertility and agricultural yields drive farmers to overexploit already degraded lands, further accelerating erosion and environmental decline [10]-[12]. In the Katonga Catchment, these dynamics manifest in intensified food insecurity, decreasing household incomes, and increased vulnerability to climate variability [13] [14].

Despite broad recognition of soil erosion as a driver of land degradation in Uganda [3] [15]-[19], few studies have directly quantified soil, runoff, and nutrient

losses under actual field conditions for different cropping systems and management practices in the Katonga Micro-Catchment. Existing data tend to offer generalized estimates at regional or national levels [20] [21], which fail to capture the system-specific and context-dependent nature of erosion and nutrient dynamics. For example, while prior research has shown that annual cropping systems tend to lose more nutrients than perennial systems [3] [16] [19], there is limited field-based evidence on how specific land use types and management practices within the Katonga Micro-Catchment perform in terms of soil and water conservation.

Moreover, most past studies have either focused on soil loss or nutrient depletion independently, without examining their simultaneous occurrence alongside runoff despite the fact that all three are closely interlinked, especially under tropical rainfall regimes [1]. Similarly, off-site consequences, such as sedimentation in downstream water bodies and nutrient-driven eutrophication, have been widely acknowledged at global scales [22] [23], yet they remain under-investigated in Uganda's micro-catchment contexts, especially in relation to dominant agricultural systems and management practices.

This study presents original, system-specific data on soil, runoff, and nutrient losses from key cropping systems and management practices within the River Katonga Micro-Catchment, based on empirical field measurements. In contrast to previous studies, it integrates assessments of erosion, hydrological response, and nutrient depletion under contrasting land-use types and management practices. The findings provide new insights into which systems and practices are most vulnerable to soil, runoff, and nutrient losses, and which may offer more sustainable alternatives. This contribution is particularly relevant for designing targeted land management strategies, informing national soil conservation policies, and guiding interventions to reduce sedimentation and nutrient loading into Lake Victoria.

By addressing a critical knowledge gap on the biophysical performance of specific cropping systems and management practices in this under-studied region, the study contributes to the broader discourse on sustainable agriculture and land restoration in sub-Saharan Africa. It thus offers new and actionable evidence for researchers, policymakers, and practitioners working at the intersection of agriculture, environmental conservation, and water resource management.

2. Materials and Methods

2.1. Location and Description of the Study Area

The study was conducted in the Katonga micro-catchment, located in South-Central Uganda (**Figure 1**). This area was selected because it forms part of the larger River Katonga Basin, which plays a crucial role in maintaining the region's hydrological balance. Its linkage to Lake Victoria, Africa's largest freshwater body, makes it a key site for examining conservation practices that influence both the local and downstream water systems [5] [24] and for determining soil, runoff and nutrient losses from farmers' gardens associated with the main existing soil and water conservation (SWC) initiatives [25].

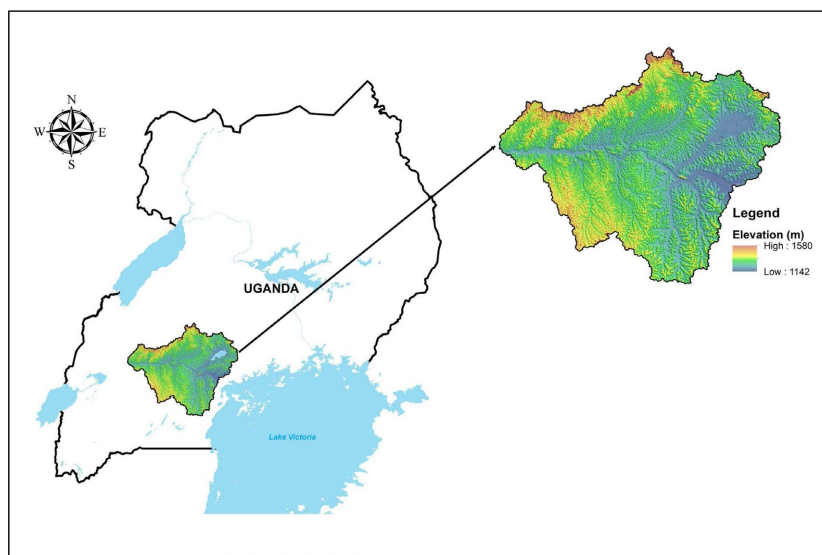


Figure 1. Map of the Katonga micro-catchment study area in south-central Uganda.

The micro-catchment is characterized by diverse bio-physical and socio-economic conditions, with crop-livestock mixed farming as the predominant agricultural system.

2.2. Socio-Economic and Biophysical Characteristics of the Katonga Micro-Catchment

According to [25] and [26], the Katonga micro-catchment spans an area of 2478 km² and receives an average annual rainfall ranging between 800 and 1300 mm. The altitude varies from 1108 to 1581 meters above sea level. The dominant soil types in the area include Acric Ferralsols, Luvisols, Gleyic Arenosols, Planosols, and Dystric Regosols, with soil pH values ranging from 4.5 to 6.8. The landscape is characterized by rocky outcrops and steep slopes and the land cover includes rainfed farmland, isolated central and local forest reserves, a wildlife reserve, wetlands, forest plantations and irrigated farmland. The dominant crops grown in the area are maize, bananas, beans, and coffee, while cattle, goats, and sheep are the primary livestock reared. However, agricultural productivity is low and declining due to land degradation, as the area is classified as highly degraded. Livelihood opportunities are limited, with most residents relying on rainfed subsistence farming, livestock rearing, and fishing, while tourism plays a minor role. The micro-catchment has a high population density, with a total population of 3,020,638 under 678,076 households. The distance to the district town ranges from 10 to over 30 km, and road infrastructure is poor, with bad roads limiting accessibility.

2.3. Methodology

The determination of soil, runoff, and nutrient losses from annuals, banana, coffee-banana, and grazing lands cropping systems was done using experimental approaches.

Treatments and control

Soil, runoff, and nutrient losses were determined using the runoff plot approach (Figure 2). A total of 33 runoff plots of 2 m × 20 m were demarcated on farmers' gardens in Ngando sub-county of the Butambala district and equipped with dividers and collecting tanks. Runoff transfer coefficients were estimated in the field using water and an accurate balance. Annual crops, banana, coffee-banana, and grazing lands cropping systems were used for the experiment. Annual crops were intercropped, banana was cultivated in monoculture, coffee and banana were also intercropped, and grazing lands were composed of a mix of grass and shrub, providing grazing for animals. Two soil erosion management practices were tested on annuals (trenches and grasses), banana monocrop (trenches and mulch), and coffee-banana intercrop (trenches and mulch), while only one practice (trenches) was tested on grazing lands. The experiment included a control practice for each cropping system. Each treatment and control was replicated three times. The experiment included a randomized complete block design with runoff plots installed on farmers' gardens.



Figure 2. Runoff plots established on farmers' gardens in the Katonga Micro-catchment.

Measured parameters

Measured parameters included soil, runoff, and nutrient losses. Runoff and soil losses were estimated for each rainfall event. Samples of collected runoffs were measured using a graduated cylinder, and total runoffs for the rainfall events were estimated by multiplying the collected runoff by the deviser's transfer coefficient. The collected runoff was thoroughly mixed, and a 100 ml sample was collected for sediment concentration determination in the laboratory. In the laboratory, sediment concentration was determined by filtration. Total soil loss for the rainfall event was determined by multiplying the total runoff volume by the associated sediment concentration. For a given season, the total runoff was computed as the sum of the different event runoffs. The same was done for soil loss. Plot composite soil samples were obtained by putting together sediment collected after each rainfall event for a given season. The composite samples were taken to the laboratory for N, P, and K analysis. N, P, and K were analysed using standard procedures

according to standard laboratory methods by [27]. Total N was analysed using the Kjeldahl digestion method. Available P was extracted using the Bray II method [28]. Exchangeable K⁺ cation was determined by a flame photometer. Total N and total available P were determined by multiplying their respective concentrations with the total season soil loss. Initial soil characterization was not included or conducted; however, soil texture and slope were visually consistent across plots.

Data analysis

Analysis of Variance (ANOVA) was used for mean separation at $p \leq 0.05$ in GenStat 16th edition. The statistical separation of means among treatments was obtained where applicable using the least significant difference (LSD) test at the 0.05 significance level.

3. Results

3.1. Soil, Runoff, and Nutrient Losses from Major Cropping Systems in the River Katonga Micro-Catchment

The major cropping systems of the Katonga micro-catchment included annual crops, banana monocrop, and coffee intercropped with banana and grazing lands.

3.1.1. Soil and Runoff Losses from Major Cropping Systems

Soil and runoff losses for both MAM season (long rainy) and SON season (short rainy) are presented in **Figure 3** and **Figure 4**, respectively. Soil and runoff losses significantly depended on soil erosion practices and rain seasons ($p < 0.001$). These soil and runoff losses were in the order annuals > rangelands > banana > coffee-banana for both seasons and for all practices.

Annuals-based cropping system

Soil loss was relatively highest under the control, followed by grass bunds and trenches for both seasons. A similar trend was observed for runoff. The short rains season (SON) tended to have relatively higher value of soil and runoff losses for all practices. Soil loss under the control varied between 22.74 and 22.84, 22.65 and 22.82 t/ha under grass bunds and 22.08 and 22.48 t/ha/season under trenches, depending on seasons. Runoff was also highest under the control, followed by grass bunds and trenches for both seasons. Runoff ranged between 88.82 and 97.05 under the control, 87.63 and 96.44 under grass bunds and 84.15 and 95.81 m³/ha/season under trenches (**Figure 3** and **Figure 4**).

Banana-based cropping system

Soil loss was relatively higher under the control, followed by trenches and mulch for both seasons. A similar trend was observed for runoff. The short rains season (SON) tended to have relatively higher values of soil and runoff losses for all practices. Soil loss under the control varied between 21.68 and 22.32, 21.11 and 22.04 t/ha under trenches, and 20.83 and 21.64 t/ha/season under mulch, depending on seasons. Runoff was also the highest under the control, followed by trenches and mulch for both seasons. Runoff ranged between 75.9 and 95.11 under the control, 75.08 and 93.99 under trenches, and 74.1 and 92.21 m³/ha/season under mulch (**Figure 3** and **Figure 4**).

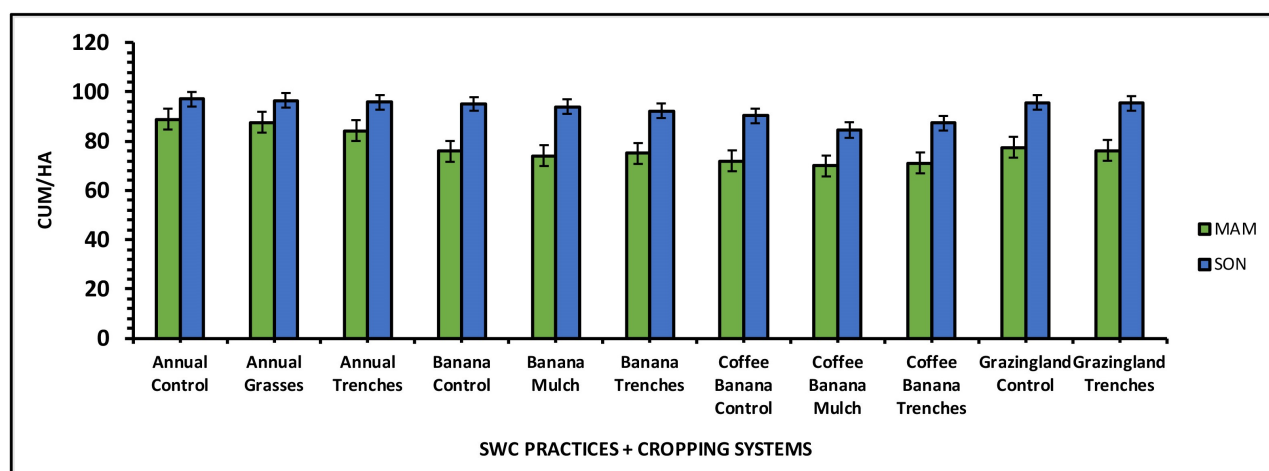


Figure 3. Runoff losses under major cropping systems in the Katonga micro-catchment.

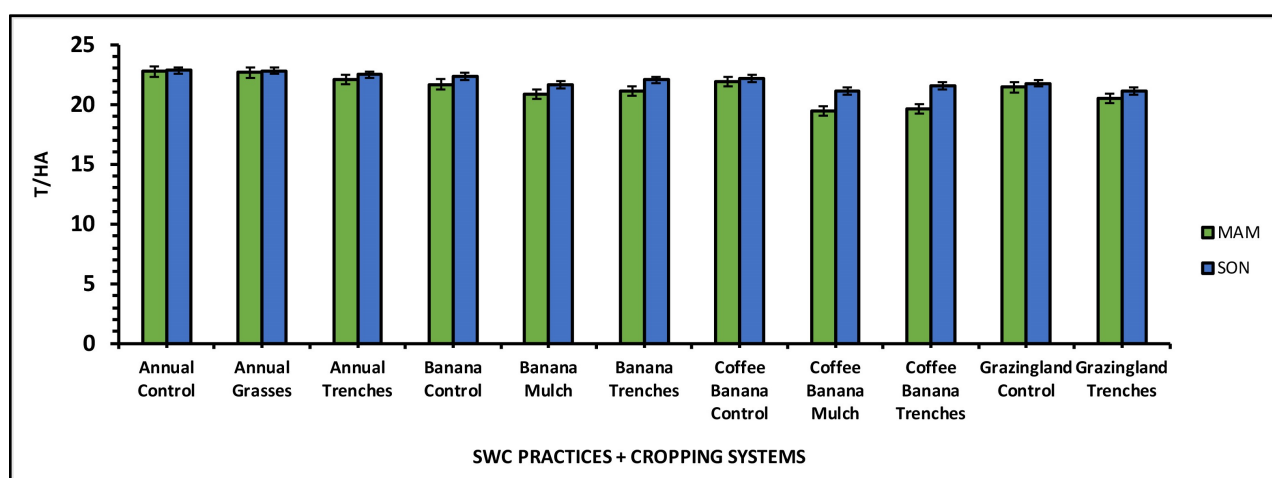


Figure 4. Soil losses under major cropping systems in the Katonga micro-catchment.

Coffee and banana-based cropping system

Soil loss was relatively higher under the control, followed by trenches and mulch for both seasons. A similar trend was observed for runoff. The short rains season (SON) tended to have relatively higher values of soil and runoff losses for all practices. Soil loss under the control varied between 21.87 and 22.15, 19.63 and 21.57 under trenches, and 19.47 and 21.13 t/ha/season under mulch, depending on seasons. Runoff was also highest under the control, followed by trenches and mulch for both seasons. Runoff ranged between 71.93 and 90.24 under the control, 71.17 and 87.34 under trenches, and 70.08 and 84.53 m³/ha/season under mulch (Figure 3 and Figure 4).

Grazing-based cropping system

Soil loss was relatively higher under the control compared to trenches for both seasons. A similar trend was observed for runoff. The short rains season (SON) tended to have relatively higher values of soil and runoff losses for both practices. Soil loss under the control varied between 21.42 and 21.75 and between 20.53 and 21.12 t/ha/season under trenches, depending on seasons. Runoff was also higher

under the control compared to trenches for both seasons. Runoff varied between 77.48 and 95.57 under the control and between 76.07 and 95.38 m³/ha/season under trenches (Figure 3 and Figure 4).

3.1.2. Nutrient Losses from Major Cropping Systems

Table 1 shows nutrient losses under different practices and across seasons. Nutrient losses were significantly affected by practices and seasons ($p \leq 0.001$). The interaction between seasons and practices was also significant for nutrient losses. Nutrient losses were in the order annuals > grazing lands > banana > coffee-banana for both seasons and all practices.

Table 1. Nutrient losses under different practices and across seasons.

Land use practice (s)	MAM season (March-April-May)			SON season (September-October-November)		
	N (Kg/ha)	P (Kg/ha)	K (Kg/ha)	N (Kg/ha)	P (Kg/ha)	K (Kg/ha)
Annual Control	26.21	1.88	32.68	41.53*	22.89*	48.83*
Annual Grasses	28.33*	11.65*	37.29*	39.68*	20.74*	45.99*
Annual Trenches	21.23	0.00	22.33	37.41*	20.62*	45.56*
Banana Control	10.17*	0.00	17.7*	32.37	14.86*	39.01*
Banana Mulch	10.2*	0.00	20.51	27.54*	11.66	34.05
Banana Trenches	23.16	2.59	26.2	32.71	16.22	41.31
Coffee-Banana Control	14.74*	0.00	22.38	25.26*	9.49*	32.76
Coffee-Banana-Mulch	0.00*	0.00	0.00*	29.7*	16.23	39.11*
Coffee-Banana-Trenches	7.55*	0.00	12.81*	40.46*	25.63*	48.59*
Grazingland Control	24.4	4.87	26.33	22.99*	13.07	37.06
Grazingland Trenches	13.37*	0.00	18.43*	21.41*	9.67*	33.87
lsd	4.342	4.155	4.055			

*: Significant differences between nutrient losses, lsd: least significant difference at $\alpha = 5.0\%$.

Annuals-based cropping system

Trenches tended to have relatively low amounts of N, P, and K losses compared to other technologies for both the short and long rainy seasons ($p < 0.05$). There was no P loss (0.00 Kg/ha) for plots with trenches during the long rain season. The short rain season (SON) tended to have relatively higher values of nutrient losses for all practices.

Banana-based cropping system

Trenches tended to have relatively higher amounts of N, P, and K losses compared to other technologies for both the short and long rainy seasons ($p < 0.05$). There was no P loss (0.00 Kg/ha) on both plots with mulch and the control during the long rain season. The short rain season (SON) tended to have relatively higher values of nutrient losses for all practices.

Coffee-banana based cropping system

Trenches tended to have a relatively higher amounts of N and K losses and a similar or equal value of P loss compared to other technologies for the long rainy season ($p < 0.05$). Trenches also had relatively higher amounts of K, N and P losses compared to other technologies in the short rain season ($p < 0.05$). There was no P loss (0.00 Kg/ha) for plots with mulch, trenches and the control during the long rain season. There were also no N and K losses (0.00 Kg/ha) recorded for plots with mulch during the long rain season. The short rain season (SON) tended to have relatively higher values of nutrient losses for all practices.

Grazing-based cropping system

Plots with trenches tended to have relatively low nutrient losses (N, P and K) in both seasons ($p < 0.05$). There was no P loss (0.00 Kg/ha) for plots with trenches during the long rain season. The short rain season (SON) tended to have relatively higher values of nutrient losses for all practices.

4. Discussion

Soil and runoff losses from annuals, banana, coffee-banana, and grazing land cropping systems are moderate and very low. These soil and runoff losses were in the decreasing order of magnitude of annuals > rangelands > banana > coffee-banana for both seasons and for all practices. Nutrient losses are generally very high and relatively lower under coffee-banana compared to other cropping systems. Soil and water management practices effects were highly significant during the period of experimentation for soil, runoff, and nutrient losses under all the different cropping systems ($p < 0.001$). The short rains season (SON) tended to have relatively higher values of soil, runoff, and nutrient losses for all practices under all cropping systems. The observed moderate soil loss and very low runoff across the different cropping systems in the Katonga Micro-Catchment align with previous research findings indicating that the intensity of these losses is influenced by land use type and soil and water management practices [15]. The decreasing order of soil and runoff losses, indicating annuals > rangelands > banana > coffee-banana, suggests that cropping systems with more permanent vegetation, such as coffee-banana systems, are more effective in controlling soil erosion. This pattern can be attributed to differences in vegetation cover, root density, and surface roughness, which collectively reduce runoff velocity and enhance water infiltration [29] [30]. The significantly higher soil, runoff, and nutrient losses during the short rainy season (SON) compared to the long rains (MAM) reflect the increasing rainfall intensity and variability reported by [31]. Increased rainfall intensity during SON results in greater surface runoff and higher soil detachment rates, which amplify erosion and nutrient depletion. This seasonal variation underscores the importance of adapting soil conservation measures to changing climatic patterns to mitigate erosion risks effectively. Despite the moderate classification of soil loss [32] [33] in the study area, the values remain lower than those recorded in similar agroecological zones [3] [15] [34]-[36]. The lower soil and runoff losses

in this study may be attributed to several factors, including the relatively gentle slope (11%) compared to the steeper gradients (16 - 49%) reported in previous studies [34] [35] [37]. Slope gradient is a critical determinant of erosion rates, as steeper slopes increase runoff velocity and soil detachment [38]. The lower runoff observed in this study, particularly under coffee-banana systems, may also be explained by the high infiltration capacity of the experimental soils. Rapid infiltration reduces surface water accumulation, thereby limiting runoff generation and soil loss [39] [40]. The presence of organic matter in soil enhances water retention, stabilizes soil aggregates, and reduces susceptibility to erosion [41] [42]. This suggests that soils in the study area may have favorable physical properties that mitigate erosion, despite seasonal variations in rainfall intensity. The effectiveness of soil and water conservation practices in reducing soil, runoff, and nutrient losses across all cropping systems was statistically significant ($p < 0.001$). This finding is consistent with previous research demonstrating the importance of adopting erosion control measures to mitigate soil degradation [43]-[45]. The presence of well-maintained conservation structures such as trenches, mulches, and grass bunds may have contributed to the observed reductions by intercepting runoff, promoting water infiltration, and minimizing soil displacement. The relatively lower nutrient losses under coffee-banana systems highlight the role of permanent vegetation in nutrient retention. Agroforestry systems such as the coffee-banana system are known to enhance nutrient cycling through organic matter inputs, deep nutrient retrieval, and reduced surface runoff [46] [47]. This indicates that promoting integrated cropping systems with perennial components can be an effective strategy for reducing nutrient depletion and maintaining soil fertility. Moreover, the observed variation in soil and runoff losses across different studies may also be attributed to differences in climatic conditions, particularly rainfall erosivity. The study area's climate may exhibit higher rainfall erosivity compared to regions where previous studies were conducted [3] [48] [49]. Higher rainfall erosivity increases the kinetic energy of raindrops, leading to greater soil detachment and transport [50].

5. Conclusion and Recommendations

The major cropping systems in the Katonga Micro-Catchment include annual-based, banana-based, coffee and banana-based, and grazing lands-based cropping systems. Soil loss was generally moderate, while runoff was very low in all the cropping systems. The reduction in soil, runoff, and nutrient losses due to soil and water conservation practices was significant. Nutrient losses were generally high in all the major cropping systems and varied from one practice to another under annuals, banana, coffee-banana, and grazing lands.

These results highlight the need for site-specific conservation strategies that account for slope, soil type, and climatic variability. Future research should focus on long-term monitoring of soil and water conservation practices and their impacts on soil quality, crop productivity, and climate resilience. There is a need to evalu-

ate the economic feasibility and farmer adoption rates of these practices to ensure sustainable land management in the Katonga Micro-Catchment and similar environments.

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Authors' Contributions

Wivine Matabaro Adidja: conceptualized the study, designed the experiment, supervised fieldwork, and led data collection, analysis, interpretation, discussion, full manuscript writing, and revising the paper critically for intellectual content. Twaha Ali Basamba and Joseph Sekkandi: Supervision of the PhD study. All authors consent to publish.

Disclosure Statement

The authors report that there are no competing interests to declare.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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