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An Evaluation of the Primary Causative Factors Affecting Durability of Flow Diversion Simple Weirs in Muchinga Province in Zambia

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Abstract: The effectiveness of simple weirs and the ability of rural farmers to construct durable weirs are still areas of concern in rural areas in Zambia. The objective of this study is to investigate the factors contributing to the varying levels of durability of the simple weir structures used for the diversion of river flows. This study was conducted in 5 districts where 33 SWs located in similar geographical zones were analyzed for their longevity. The research delved into catchment and climatic variables, and the social and psychological perception of simple weirs. The study conducted interviews with key informants who were familiar with the use of SWs in 5 districts in Muchinga provinces between 26 December 2023 and 15 January 2024 using semi-structured questions. The findings of this study indicated that simple weirs constructed on relatively square-shaped catchments and narrow-shaped catchment areas were less vulnerable to damage and easy to operate and maintain. The study also found that climatic factors such as storm rainfall events had little impact on the operation and maintenance of these weirs in Muchinga province, as most sites are in the rainfall shadow while farmers` views about the structures varied from site to site. Overly, planning is necessary for implementing small or large irrigation structures.

Keywords: farmer-led small-scale irrigation; operation and maintenance; catchment characteristics; durability assessment; local material; farmer perception

1. Introduction

Irrigation technologies, whether large or small in scale, play an important role in improving and unblocking irrigation potential in rural sub-Saharan Africa (SSA) [1]. Irrigated agriculture at a small-scale level also referred to as farmer-led irrigation, has become an essential tactic for improving land and water productivity and providing opportunities for income generation, piecework, food security, and poverty reduction in many regions of the world [2,3]. Small-scale irrigation systems are increasingly strengthening the ability of rural farmers to respond to the development of irrigation opportunities in Asia and sub-Saharan Africa. Some of these community-based irrigation systems are designed and contend with pro-poor low-cost technologies that are easily implementable by farmers. Small-scale irrigation has been practiced in South Asia, where irrigation structures are constructed using local materials and applying traditional skills. This approach has been used by farmers in rural Nepalese villages for centuries, enabling them to irrigate their crops and sustain their livelihoods [4–7].

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The agricultural season profile of Zambia is divided into wet-season and dry-season agriculture, largely consisting of small-scale farmers, who are responsible for most of the country's agricultural output. In Zambia today, small-scale farmers make up approximately 90% of Zambia's agricultural producers [8]. These types of farmers are primarily subsistence producers of staple foods such as maize, beans, and cassava, with an occasional surplus for the household income need [9]. However, they are often vulnerable to extreme weather conditions, which severely impact their productivity and income, leading to food insecurity and poverty most of the year [10]. Furthermore, a historical drought in 2023/2024 farming season resulted in severe water stress for crops across most parts of Zambia. As a result, in 2024 some households were threatened with food insecurity.

It is for those reasons that small-scale irrigation activities are heightened across Zambia during the dry season occurring between April and December, especially in areas where rainfall cannot be relied upon [11]. By having such systems in place, small-scale farmers can have access to a reliable source of water, enabling them to produce crops throughout the year and significantly reduce their dependency on rain-fed cycles. This, in turn, boosts their productivity and income, leading to a better standard of living and improved food security for their families.

In most parts of Zambia, however, small-scale farmers often face the challenge of having limited resources to invest in small-scale water harvesting structures, which are essential for crop production [12,13]. Although Simple weirs (SWs) are perceived as rudimentary, the majority of the local small-scale farmers make use of them for optimum economic benefits [14]. This defuses the negating views. SWs have gained popularity in Luapula, Copperbelt, North-western, Central, Northern, and Muchinga, because of the struggles marginalized rural farmers go through to access water flow abundantly available for irrigation and the potential effect on enhancing small-scale irrigation. In most cases, SWs are constructed for immediate use during the period of transition from bucket irrigation to more improved river flow diversion structures such as masonry weirs.

SWs are typically constructed across a river to divert water flow for irrigation purposes during the dry season when water is scarce. The construction of SWs involves using locally available materials such as poles, thatch grass, brushwood, and soil from nearby riverbank. These materials are woven together to form a sturdy barrier that diverts water into channels that lead to agricultural fields downslope. SWs are cost-effective and easy to construct, making them an ideal choice for rural communities that lack access to modern irrigation systems. With the SWs system, farmers can grow a broad range of crops including green maize, watermelon, tomatoes, irrigated groundnuts, onions, and vegetables. Of late, this irrigation system has been attracted in other countries such as Uganda, Malawi, and Mozambique, apart from Zambia. As such, the promotion of SWs is becoming an essential part of sustainable development initiatives for small-scale farmers in the Southern Africa region [15,16].

Muchinga province is mostly (90%) rural and the majority (80%) depend on agriculture as their main source of livelihood [17]. Undaunted by the lack of assistance, small-scale farmers concentrate on building SWs to increase agricultural food production and ensure agriculture is practiced all year. The simplicity and low cost of this technology make it a viable option for farmers who may have limited resources and access to external support. In Zambia, the most commonly used materials for constructing SWs are forest round poles, thatch grass, and tree bark fiber. These materials are carefully selected, based on their availability, durability, and cost-effectiveness. Forest round poles are used as the main structural component for the weir. These poles are driven into the ground and arranged in a staggered manner to form a porous barrier. Thatch grass is then woven around the poles to create a more secure barrier. Finally, tree bark fiber is added to fill in any gaps in the weave, making the weir more watertight.

Currently, there are four basic types of SWs widely used for diverting river flows: simple single-line type weirs, simple double-line type weirs, simple incline type weirs, and trigonal type weirs. In Muchinga province, the commonly constructed types of simple diversion weirs are simple single-line weirs and simple double-line weirs [18]. This is because the region's rivers have small widths, making these types of weirs suitable for most of the catchment outlets.

Despite the potential benefits of the SW technology, there is still a need to adapt it to different circumstances such as the catchment size and shape, rainfall intensity, and soil characteristics of river foundations. This is because the technology was developed based on indigenous knowledge, which may not be applicable in all situations. While some farmers have reported significant increases in their incomes because of irrigated crop production using SWs, others have encountered numerous challenges that have led to structural failures in the purpose. Among the notable challenges is the relatively short life span likely caused by weak foundation soils, flash floods, and erosion. SWs are vulnerable to flood damage, usually common during the rainy season [19,20]. As a result, currently, SWs are not a long-term solution for small-scale irrigation development.

Muchinga province has SWs that vary in their durability condition, with some lasting for more than two years while others fail within a year of construction. This suggests that the success of these structures is not solely dependent on their design or construction but also on their good management and maintenance. Therefore, effective management of these structures can overcome the challenges that cause issues in the operation and maintenance of some SWs.

SWs are specifically suited to subsistence small-scale irrigation farming and similarly have an important role to play in the transition to farming for profit [21]. It is for this reason that SWs have attracted the attention of Governmental Institutions (GIs) and Non-Governmental Institutions (NGIs) to promote and expand small-scale irrigation using SWs to farmers in new areas. This scenario has highlighted the need to study this relatively alternative irrigation practice because the technology is a novelty to many small-scale farmers. However, the effectiveness of such structures and the ability of rural farmers to construct durable weirs are still areas of concern. In addition, the use of low-cost solutions, which may appear attractive to micro-scale farmers, can be misleading and may be mistaken for subpar engineering.

SWs are one of the emerging and increasingly common technologies observed among small-scale farmers in northern Zambia. For a period of almost two decades now, SWs have been implemented in the remote areas of the northern provinces of Zambia. Some of the positive net benefit effects of SWs in such areas is the increase in year-round dry-season irrigation activities leading to an increase in crop production and saleable surplus and enhanced household income, especially among small-scale farmers. Despite SWs being one of the technologies that are paving the way for the advancement of small-scale irrigation in rural communities, farmers encounter several challenges in operation and maintenance [22]. The primary factors that have been affecting the operation and maintenance (O&M) of SWs at a community level include those assumed related to catchment size, catchment management, rainfall, runoff variables, and farmers` perceptions.

This study focused on the operation and maintenance (O&M) challenges of existing weirs in practical field scenarios [23]. The evaluation of these factors required consideration of a wide range of parameters associated with hydraulic facility structural failures [24,25]. However, this study only focussed on the factors that have a significant impact on durability, and the factors were selected based on two parameters; catchment variables and farmers` perception. The catchment landscape was chosen as it determines the amount of water that can be generated and stored in the weir and the size of the irrigation area that can be covered. The negating perception of the farmers has the potential to affect the operation, maintenance, and overall efficiency of the irrigation system. Therefore, the evaluation of these factors will provide valuable insights to farmers for the operation and maintenance of SWs [26].

2. Materials and Methods

Approximately 617 households, benefiting around 1,121 small-scale farmers covering 17 hectares were brought under irrigation with 35 SWs constructed by farmers for dry season irrigation (April to December) in 2023 in 7 districts of Muchinga province.

2.1. Estimation of the Sample Size

The Krejcie and Morgan table was used to estimate the sample size for this research [27,28]. A total of 33 SWs were selected out of 35 SWs. For each of the targeted sites in 5 districts, 50 farmers per site were selected resulting in the selection of 250 farmers in total.

2.2. Data Collection Approach

This study gathered both quantitative and qualitative data on the challenges faced by farmers in operating and maintaining SWs in 5 out of 8 districts of Muchinga province in Zambia. To achieve this, a combination of qualitative and quantitative methodologies was used. The study involved a cross-section of participants, including representatives from the Ministry of Agriculture (MoA), Water Resources Catchment Officers, the Meteorological Office, and farmers themselves.

Due to resource and time limitations, the study focused on five districts in Muchinga province where SWs were widely constructed by the farmers to divert rivers for irrigation. 33 SW sites were visited in the five districts for approximately 14 days. During this time, conducted physical assessments of the weirs and engaged with local agricultural extension officers and elite farmers to collect quantitative data. For the qualitative assessment, approximately 250 small-scale farmers in village irrigation schemes were interviewed. To ensure the accuracy of the data, local agricultural extension officers assisted with the interviews. In addition, the survey was conducted to gain a better understanding of the operational and maintenance issues related to SWs in the five districts studied. Semi-structured questionnaires were used to collect information on the operation and maintenance of these weirs. The survey included questions related to farmers' involvement in site selection and planning, their participation in building the weirs, and whether they were instructed on how to operate and maintain them.

2.3. Interviews and Focus Group Discussions

Key informants were interviewed at each SW site visited in 5 districts, district agricultural officers, and local farmer`s associations. The interviews were conducted between December 26, 2023, and January 15, 2024. Additionally, focus group discussions with selected farmers were organized at randomly selected sites to explore issues related to the O&M of SWs. At all sites, most farmers were actively involved in SW irrigation. The interviews were conducted to gather the perspectives, observations, and suggestions of the farmers regarding the challenges of operating and maintaining SWs.

2.4. Evaluation Workshop Discussions

To gather more information and field experience feedback regarding SWs, a two-day annual evaluation workshop was held between 11-13 January 2024 to organize discussions and interactions among farmer leaders, agricultural government officials, and irrigation technical personnel from six different regions including Muchinga province where SWs were being implemented. The focus of the discussion was on the challenges faced during the operation and the socio-economic impacts of SW technology. The plan and activities for promoting the technology of SWs were also discussed.

2.5. Geographical Location of Study Areas

2.5.1. Description of Muchinga Province

Zambia is administratively divided into 10 provinces. Muchinga one of the provinces geographically located in the northeast of the country comprises 8 district areas. The landscape of Muchinga Province is generally high and flat, stretching from the Central Province to the northern part of Zambia, Figure 1.

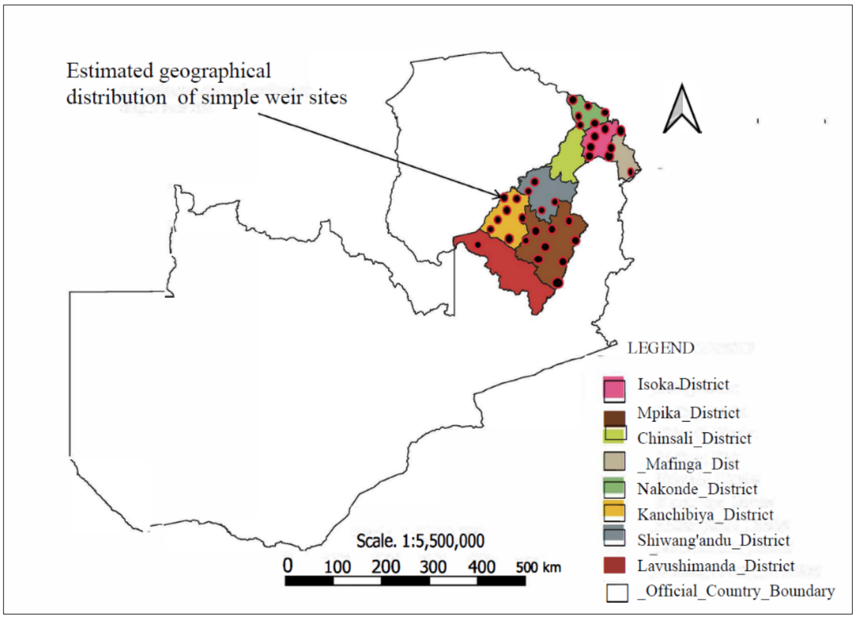

Figure 1. Map of Zambia showing the geographical location of Muchinga province. Source: ArcGIS 10.8.2., modified by Authors.

2.5.2. Climate and Hydrology

The climate of Muchinga province is characterized by a dry season that lasts from May to November. The rainy season normally between December and April reaches its peak in both duration and intensity between January and February. According to the meteorological data for the 2023/2024, period of this study, the mean annual rainfall was 125.9 mm, the mean annual maximum temperature was 24.9 °C, and the mean annual minimum temperature was about 14.24°C, [29] Figure 2. Muchinga province, located in the northern part of Zambia, is blessed with a diverse range of water bodies that provide an important lifeline for human communities in the region. The province boasts an extensive network of seasonal streams and perennial rivers such as Chambeshi, Lukulu, Luwalizi, Mwambwa, and Kalungu, which are vital for agriculture.

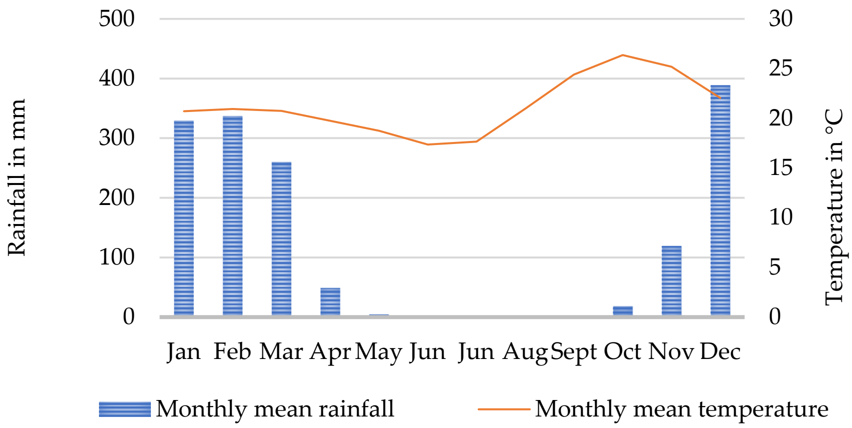

Figure 2. 10-year average monthly rainfall and temperatures of Muchinga province.

2.5.3. Description of Landforms for Muchinga Province

Muchinga province separates two major river drainages. The northern areas of Muchinga province consist of the Nyika Plateau, Makutu Plateau, and Mafinga mountains. While the eastern part of the province is drained by the Luangwa River (Luangwa valley), and eventually flows into the Zambezi River, and the western part of the province is drained by the Chambeshi/Luapula River network, subsequently flowing into the Congo River basin.

2.6. Catchment Surveys and Data Collection

Physical visits were conducted to the catchment sites, for survey, observations, and measurements. The information on the physical features (rivers, slopes, and areas) collected as a result of visits was combined with data from the analysis of satellite images collected by the Ministry of Agriculture in Zambia, land use planning unit. In addition to the above, the topographical maps (map scale, 1: 10,000) are appropriate for small-scale irrigation, and research plots) were used to identify the contours of the land and determine the elevation of various points in the catchment. This information was critical in helping to estimate the slope of the catchment, which is an important factor in understanding water flow and drainage patterns. Based on these tools, the size of the catchment was estimated by combining all the information gathered from the various sources mentioned.

Catchment landscape characteristics' numerical values were selected based on catchment vegetation cover conditions, predominant land uses, soil and drainage conditions, and catchment topography. The numerical values are summed up (catchment characteristic values). The combination of the aspects of catchment characteristic values, catchment shape, and catchment area (ha) assisted in estimating the run-off (m^3/s) for a specific catchment area, presented in Table 1.

Table 1. Catchment parameters used for estimating run-off (m^3/s).

Description of Catchment Landscape	Prevailing Catchment Characteristics	Assigned Value
Catchment slopes	flat slopes (0-1%)	5
	moderate slopes (1-5%)	10
	rolling slopes (5-8%)	15
	hilly, steep slopes (8-12%)	20
	mountainous slopes (< 12%)	25
Soil physical characteristics, drainage conditions	deep permeable soils (>90cm)	10
	shallow, semi-pervious soil (<60-90cm)	20
	shallow soil with underlying hard rock (<30cm)	30
	waterlogged soils	50
Catchment vegetation cover density, land uses	heavy grass cover	10
	moderate grass cover	15
	agricultural use	20
	bare catchment landscape	25

Source: Republic of Zambia, *The Mechanical Protection of Arable Land, A Guide to Agricultural Planning; Revised Edition;* Department of Agriculture: Lusaka, Zambia, 1977; pp. 67–118 [30]. Elaborated by Authors.

2.7. Riverbed Soil Properties Along Simple Weir Traverse Lines

Profiles of river foundations were obtained by augering along the transverse line at each site and laboratory soil assessment to establish the inherent nature of the undelaying soil profiles at all the SW sites. Soil samples from each weir site were taken for testing to confirm the field assessments and to verify the physical properties of the soils.

3. Results

3.1. Common Types of Simple Weirs Constructed by Farmers in Muchinga Province

As of January 2024, there were 22 SWs in functional and health condition, 9 damaged, and 2 neglected. The reasons for the abandonment in two places are shortage of water, vandalism of SW facilities, conflict, and disputes over water and land, crop pests, and disease infestation, and distant markets for irrigated crops.

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3.1.1. Single-line Weirs

This type of SW, shown in Figure 3, is built across narrow river channels to divert the flow of water. They consist of a single line of poles that span the width of the river, which are then woven together using thatch grass and clay soil. This weaving process is essential for ensuring water tightness and preventing any leakage that may compromise the structure's effectiveness. The poles used in constructing these weirs are usually sturdy and strong enough to withstand the force of the water. The weir can divert water to crop fields downstream, thus making it ideal for small-scale irrigation purposes [31].

Figure 3. Single line type of simple weir. Image by Authors.

3.1.2. Double-Line Weirs

Double-line weir types in Figure 4 are constructed by erecting two lines of poles approximately 1 meter high and 0.5 meters wide, across the river. The poles are grounded in the riverbed and connected by purlins for anchorage. The space between the two parallel lines of poles is filled with clay soil collected from surrounding areas where the weir is being constructed. Apart from using the double line for irrigation, this type of SW is also constructed for extra potential use as a crossing point by the farmers [32].

Figure 4. Double line type of simple weir. Image by Authors.

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3.2. Farmers` Social Perception of Simple Weirs

It was found that the total number of respondents across the Muchinga province was 60% (were males), and 40% (were females). 36% of the respondents (majority) in the age bracket between (31-40 years old) result shown in Table 2.

Table 2. Demographic data for farmers randomly selected for interviews from 5 districts.

Demographic Data and Information	District					Average
	Isoka, n=50	Nakonde, n=50	Mpika, n=50	Kanchibiya, n=50	Lavushimanda, n=50	
Marital status						
Single	18	21	17	12	17	17.0
Divorced	6	3	7	5	0	4.2
Widowed	5	2	4	1	3	3.0
Married	21	24	22	32	30	25.8
Gender						
Males	32	29	35	30	23	29.8
Females	18	21	15	20	27	20.2
Age group						
20-30	10	8	13	15	5	10.2
31-40	22	15	18	20	16	18.2
41-50	13	27	16	3	18	15.4
51-60	5	0	3	12	11	6.2

The study found that SWs were among the widely used traditional irrigation techniques in village irrigation schemes and community-based irrigation schemes at a proportional rate of 66% presented in Table 3.

Table 3. Types of irrigation technologies used by small-scale farmers in Muchinga province.

Common types of irrigation	Districts				
	Isoka	Nakonde	Mpika	Kanchibiya	Lavushimanda
Bucket Method	9	17	8	4	6
Simple weirs	25	28	31	39	42
Masonry/concrete weirs	10	3	7	1	1
Treadle pump	1	0	2	5	0
Gasoline pumps	5	2	2	1	1

The majority of the respondents were primary school dropouts with limited options for formal job opportunities. Only 11% of the respondents acquired tertiary education in training such as primary teaching, basic agriculture, and community development management, as shown in Table 4.

Table 4. Level of formal education.

Average education level	Districts				
	Isoka	Nakonde	Mpika	Kanchibiya	Lavushimanda
Primary school	21	35	36	41	27
Secondary school	15	5	14	5	23
Tertailly education	14	10	0	4	0

Figure 5 shows the frequency of willingness and collective participation in SWs management in the study revealing that the majority (79%) of respondents participated at least once in the maintenance of the structures. A summary of the findings depicted in Figure 6 reveals the frequencies

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of operation and maintenance (O&M) activities carried out between April and December. The willingness of farmers to participate in O&M of simple weirs varies from site to site. The study found that farmers who did not have their fields supplied with water from a simple weir intake were never willing to maintain the weirs.

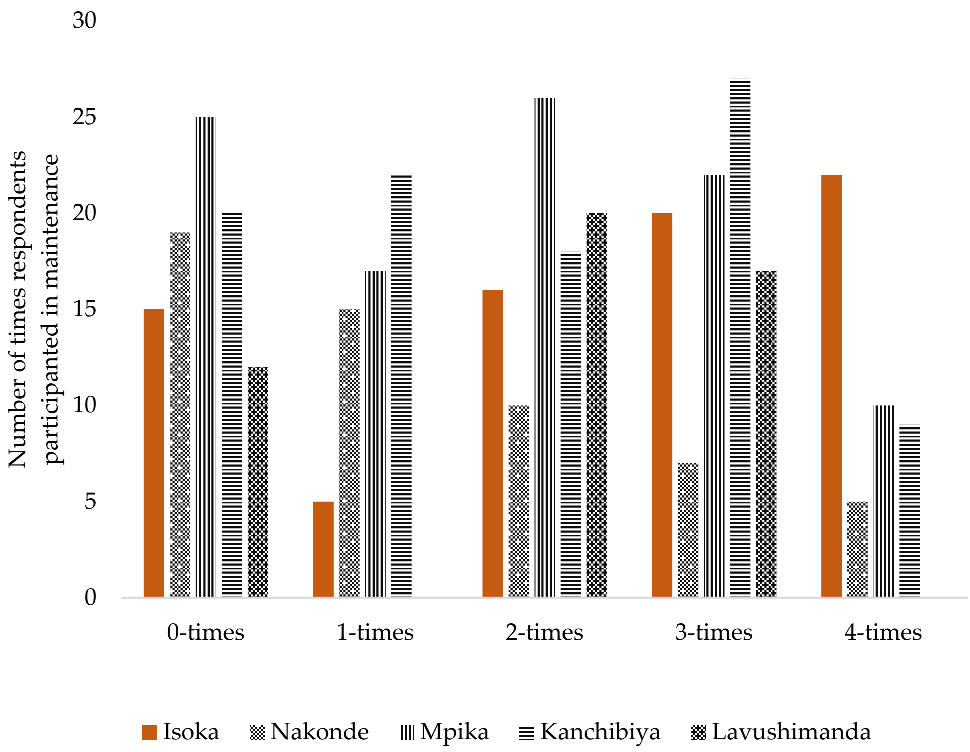

Figure 5. Participation profile of farmers in the maintenance of simple weirs in Muchinga province.

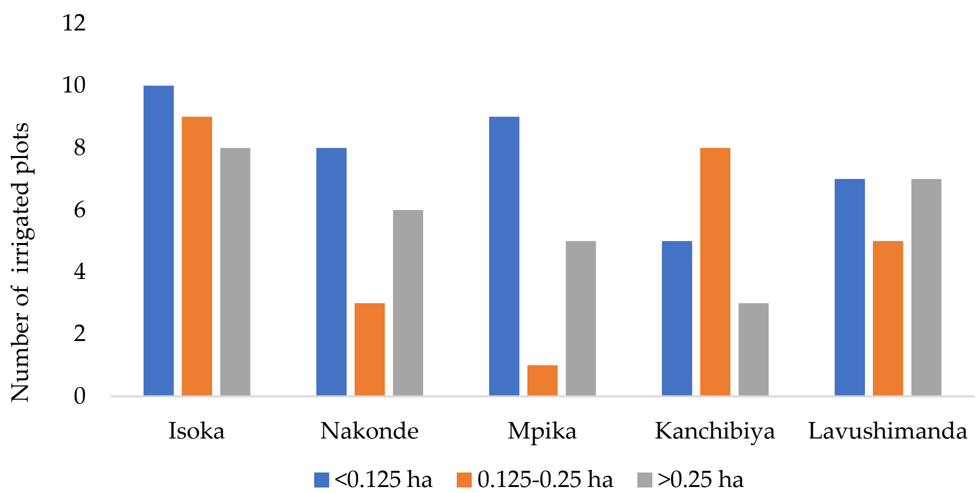

Figure 6. The average size of plots (ha) irrigated by small-scale farmers using low-cost irrigation Practices in Muchinga province.

As far as plot ownership by individual farmers is concerned, 48% of the respondents irrigated an area between 0.125 and 0.25 [33,34] ha as presented in Figure 6.

The respondents pointed out multiple reasons that have been affecting the O&M of SWs in the Muchinga province. The reasons assumed by the respondents across the region. The assumptions of

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the respondents were analyzed, and the findings on average were that (i) 27% of the farmers pointed out deforestation concerns,(ii) 24% Stated high rate of weirs breaking down, (iii) 19% mentioned the presence of permanent weirs in the catchment, (iv) 17% stated vulnerability to vandalism and bush fire damage, (v) 14% of the farmers were unaware of maintenance need (Figure 7).

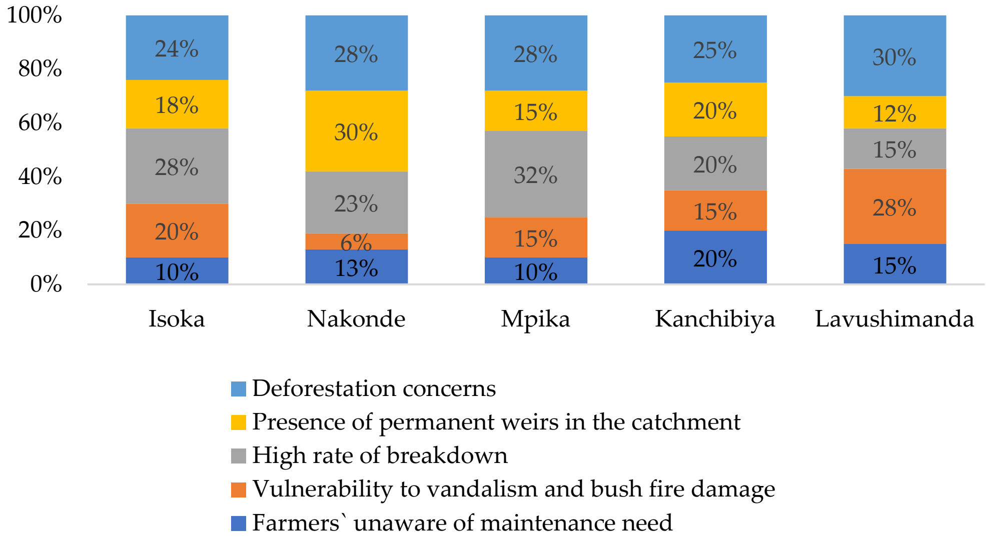


Figure 7. Farmers` perception affecting O&M of simple weirs.

3.3. Runoff (m³/s) Estimation Based on Catchment Characteristics and Shape

Estimating the catchment run-off (m³/s) based on catchment values, shape, and area (ha) can be done by following these steps: Step 1: Choose the appropriate catchment values based on the prevailing catchment conditions, such as vegetation cover, type of soil and drainage, and predominant slope. Sum up the values that are presented in Table 1. Step 2: Decide on the appropriate catchment shape - whether it is square, rectangular, or narrow. Step 3: Finally, based on steps 1 and 2, estimate the catchment run-off using catchment conditions, area (ha), and shape, presented in Tables 5–7. The Water Resources Management Authority (WARMA) keeps a record of the catchment discharge over several years. They estimate the shape of the catchment by using topographic maps with square grids to determine the origins of a network of streams and rivers that discharge at a single outlet of the catchment.

Table 5. Estimated run-off(m3/s) based on 10-year rainfall events from the rectangular-shaped catchment.

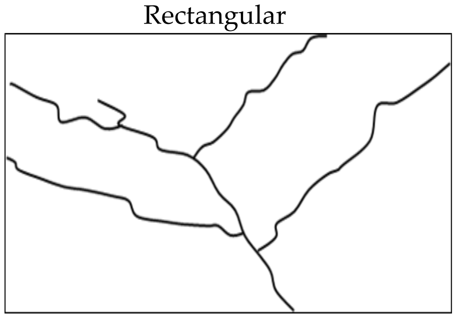
Catchment Area(ha)	Catchment Characteristic values									Catchment Shape
	35	40	45	50	55	60	65	70	75	Rectangular
	Average catchment run-off (m³/s)									
2	0.20	0.30	0.40	0.60	0.75	0.80	0.95	1.10	1.50	
2.5	0.19	0.27	0.30	0.35	0.45	0.55	1.05	1.50	1.80	
3.1	0.30	0.43	0.60	0.70	0.95	1.10	1.05	1.50	1.80	
5	0.50	0.60	0.90	1.10	1.40	1.60	1.90	2.10	2.40	
10	0.90	1.10	1.40	1.80	2.10	2.50	3.00	3.50	4.00	
15	1.40	1.80	2.10	2.50	3.00	3.60	4.30	5.00	5.80	
20	1.80	2.30	2.80	3.40	4.00	4.80	5.50	6.40	7.30	
30	2.30	2.90	3.60	4.50	5.50	6.60	7.90	9.10	10.50	
40	2.60	3.50	4.40	5.60	6.90	8.30	9.80	11.40	13.10	

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Table 6. Estimated run-off (m3/s)based on 10-year rainfall events from the square-shaped catchment.

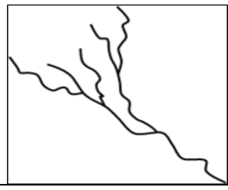
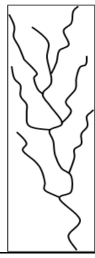
Catchment Area(ha)	Catchment Characteristic Values									Catchment Shape
	35	40	45	50	55	60	65	70	75	Square
	Average catchment run-off (m³/s)									
10	0.70	0.90	1.10	1.40	1.70	2.00	2.40	2.80	3.20	
20	1.40	1.80	2.20	2.70	3.20	3.80	4.40	5.10	5.80	

Table 7. Estimated run-off (m3/s) based on 10-year rainfall events from the elongated-shaped catchment.

Catchment Area(ha)	Catchment Characteristic Value									Catchment Shape
	35	40	45	50	55	60	65	70	75	Narrow and elongated
	Average Catchment run-off (m³/s)									
5	0.30	0.40	0.60	0.70	0.70	1.00	1.20	1.40	1.70	
10	0.60	0.70	0.90	1.10	1.10	1.60	1.90	2.20	2.60	
15	0.90	1.10	1.40	1.60	1.60	2.30	2.70	3.20	3.70	

3.4. Riverbed Soil Properties Characterization

Laboratory soil analyses of the soil samples from each site augered riverbed. The study found that 4 SWs, 2 sites in (Isoka 1 and Isoka 7), and 2 sites (Nakonde 2 and Nakonde 6), were constructed and anchored between depths 30-40 cm into the riverbed. The soil sample collected from the sites showed that the profiles for each site were predominantly sandy textured soil (> 70%). This scenario was the challenge exhibited by 5 SWs, (Kanchibiya 1, Kanchibiya 3, Kanchibiya 4, Kanchibiya 5, and Kanchibiya 7). Potentially, sandy, and silty soils in their natural form are weak and erodable. As a result, (27%), 9 out of 33 SWs of the total number of SWs experienced O&M challenges mainly caused by weak foundations. Tables 8–12 [35] show the soil properties.

Table 8. USDA soil classification and composition found on the riverbed with simple weirs for sites, Lavushimanda district.

District and Site Identification Number	Sample Location Depth(cm)	Organic Matter (%)	Sandy SoilParticles (%)	Silt Soil Particles (%)	Clay Soil Particles (%)
Lavushimanda 1	0-25	3.60	10.16	20.74	65.50
	25-50	1.76	12.34	18.90	67.00
	50-75	1.00	17.32	9.68	72.00
Lavushimanda 2	0-25	3.25	20.55	26	50.20
	25-50	1.20	6.10	26.90	65.80
	50-75	0.40	22.32	9.14	68.14
Lavushimanda 3	0-25	4.20	14.50	20.40	60.90
	25-50	1.50	5.20	17.85	75.45
	50-75	0.10	29.66	9.74	60.50
Lavushimanda 4	0-25	5.50	11.16	17.74	65.60

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	25-50	2.10	8.76	20.24	68.90
	50-75	1.40	13.36	9.74	75.50

Table 9. USDA soil classification and composition found on the riverbed with simple weirs for sites, Nakonde district.

District and Site Identification Number	Sample Location Depth(cm)	Organic Matter (%)	sand Soil Particles (%)	Silt Soil Particles (%)	Cay Soil Particles (%)
Nakonde 1	0-25	2.20	61.16	20.40	16.24
	25-50	1.76	76.76	16.60	4.88
	50-75	0.10	68.32	22.74	8.84
Nakonde 2	0-25	3.60	70.1	16.65	9.65
	25-50	0.76	76.76	12.52	9.96
	50-75	1.00	76.32	12.50	10.18
Nakonde 3	0-25	1.50	61.16	15.60	21.74
	25-50	0.60	66.76	10.55	22.09
	50-75	0.10	76.32	15.20	8.38
Nakonde 4	0-25	2.10	61.16	14.50	22.24
	25-50	0.15	76.76	16.80	6.29
	50-75	0.00	72.32	12.52	15.16
Nakonde 5	0-25	4.50	71.10	13.25	11.15
	25-50	2.10	56.65	15.90	25.35
	50-75	0.10	76.32	12.55	11.03
Nakonde 6	0-25	0.50	72.60	12.80	14.10
	25-50	0.30	78.05	15.60	6.05
	50-75	0.10	76.25	18.20	5.45

Table 10. USDA soil classification and composition found on the riverbed with simple weirs for sites, Mpika district.

District and Site Identification Number	Sample Location Depth(cm)	Organic Matter (%)	Sand Soil Particles (%)	Silt Soil Particles (%)	Clay Soil Particles (%)
Mpika 1	0-25	4.20	21.16	4.45	70.19
	25-50	3.50	16.76	19.16	60.58
	50-75	2.00	15.30	7.60	75.10
Mpika 2	0-25	5.00	27.30	2.50	65.20
	25-50	3.10	22.60	4.30	70.00
	50-75	1.50	20.30	9.83	68.37
Mpika 3	0-25	0.50	27.30	1.32	70.88
	25-50	0.20	25.60	3.70	70.50
	50-75	0.10	25.30	9.20	65.40
Mpika 4	0-25	3.27	25.50	2.65	68.58
	25-50	3.00	24.60	2.32	70.08
	50-75	2.40	18.50	13.30	65.80
Mpika 5	0-25	3.65	29.27	8.48	58.6
	25-50	2.74	25.25	1.03	70.98
	50-75	3.25	27.93	8.04	60.78
Mpika 6	0-25	2.76	15.32	9.24	72.68
	25-50	4.43	15.73	7.34	72.50
	50-75	3.5	27.93	7.79	60.78
Mpika 7	0-25	2.6	25.32	3.10	68.98
	25-50	4.43	26.73	8.49	60.35

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	50-75	4.2	27.93	2.62	65.25
Mpika 8	0-25	3.4	27.93	4.17	64.50
	25-50	1.75	35.32	2.03	60.90
	50-75	1.45	16.70	9.5	72.35

Table 11. USDA soil classification and composition found on the riverbed with simple weirs for sites in, Kanchibiya district.

District and Site Identification Number	Sample Location Depth(cm)	Organic Matter (%)	Sand Soil Particles (%)	Silt Soil particles (%)	Clay Soil Particles (%)
Kanchibiya 1	0-25	3.25	27.93	35.04	33.78
	25-50	2.76	35.32	35.23	26.69
	50-75	2.43	66.73	12.54	18.30
Kanchibiya 2	0-25	3.25	27.93	35.04	33.78
	25-50	2.76	35.32	35.23	26.69
	50-75	2.43	66.73	12.54	18.30
Kanchibiya 3	0-25	3.25	27.93	35.04	33.78
	25-50	2.76	35.32	35.23	26.69
	50-75	2.43	66.73	12.54	18.30
Kanchibiya 4	0-25	3.25	27.93	35.04	33.78
	25-50	2.76	35.32	35.23	26.69
	50-75	2.43	66.73	12.54	18.30
Kanchibiya 5	0-25	3.25	27.93	35.04	33.78
	25-50	2.76	35.32	35.23	26.69
	50-75	2.43	66.73	12.54	18.30
Kanchibiya 6	0-25	3.25	27.93	35.04	33.78
	25-50	2.76	35.32	35.23	26.69
	50-75	2.43	66.73	12.54	18.30
Kanchibiya 7	0-25	3.25	27.93	35.04	33.78
	25-50	2.76	35.32	35.23	26.69
	50-75	2.43	66.73	12.54	18.30

Table 12. USDA soil classification and composition found on the riverbeds with simple weirs for sited, Isoka district.

District and Site Identification Number	Sample Location Depth (cm)	Organic Matter (%)	Sand Soil Particles (%)	Silt Soil Particles (%)	Clay Soil Particles (%)
Isoka 1	0-25	3.00	71.60	20.40	5.00
	25-50	2.76	75.60	16.90	4.74
	50-75	2.10	76.32	12.50	9.08
Isoka 2	0-25	4.20	61.60	15.80	18.40
	25-50	1.80	56.76	25.80	15.64
	50-75	0.50	67.32	26.50	5.68
Isoka 3	0-25	1.20	70.50	15.50	12.80
	25-50	0.70	65.15	16.90	17.25
	50-75	0.20	66.25	24.50	9.05
Isoka 4	0-25	2.20	75.10	12.45	10.25
	25-50	0.76	58.75	35.20	5.29
	50-75	0.70	75.20	13.55	10.55
Isoka 5	0-25	5.50	76.20	14.52	3.78
	25-50	3.50	65.80	18.50	12.20
	50-75	2.10	76.32	15.85	5.73

Isoka 6	0-25	6.20	60.80	18.50	14.50
	25-50	4.70	72.70	12.20	10.40
	50-75	1.40	76.32	15.25	7.03
Isoka 7	0-25	0.20	61.00	13.50	25.30
	25-50	0.10	78.50	14.75	6.65
	50-75	0.00	76.32	18.50	5.18

4. Discussion

4.1. Social Perception of Simple Weirs

According to this study, farmers had a perception that local materials were only intended for the rural poor, which posed a significant challenge to the operation and maintenance of simple weirs. The study also revealed that farmers from different districts who were implementing SWs for irrigation had varying opinions regarding the technology. Some farmers expressed their satisfaction with the technology, as provided a reliable source of water for their crops, which led to increased productivity and income. Others were fairly dissatisfied with the technology as it slowly contributed to deforestation by harvesting forest poles mainly used for construction. On the other hand, some farmers expressed their concerns regarding conflicts arising due to the use of SWs. They mentioned that water disputes were common in their communities, and the technology did not address this issue. Additionally, some farmers reported that bushfires and vandalism posed a significant risk to the weirs, leading to costly repairs.

4.2. Analysis of the Effect of Catchment Characteristics and Different Shapes on Run-off Yield

The study investigated the durability of (SWs) in Muchinga province, there were noticeable differences in the resilience of SWs constructed on different catchment shapes. Specifically, SWs built on rectangular-shaped catchments were found to be more vulnerable to damage caused by high flow generation and discharge than those constructed on narrow or square-shaped catchments. The study attributed this difference in durability to several factors, including catchment degradation, inherent catchment slope, soil type, and drainage conditions. For instance, rectangular-shaped catchments tend to have a larger surface area, which means that they can generate and discharge more water than narrow or square-shaped catchments. As a result, SWs constructed on rectangular-shaped catchments may experience more significant stress and damage due to the increased water flow. Furthermore, the inherent slope of a catchment can also play a role in the durability of an SW. Catchments with steeper slopes tend to accelerate runoff, which can increase the likelihood of SW damage. Soil type and drainage conditions can also impact the durability of SWs, as some soils may be more prone to erosion.

4.3. Assessment of Riverbed Soil Properties

During the construction of SWs, it is essential to ensure that the riverbed has specific characteristics that enable the structures to function effectively. These characteristics include stability, imperviousness, fair bearing capacity, and ease of work. This study has shown that the type of soil texture that the riverbed is composed of can significantly affect the performance of SWs. The study found that SWs constructed on sandy and silty soil textures were more prone to damage and wash-away during floods than those built on riverbeds made up of clay-textured soils. This is because clay soils have a higher cohesiveness and lower permeability, which makes them more resistant to erosion and able to withstand the pressure of water flow. Therefore, when constructing SWs, it is crucial to consider the soil texture of the riverbed to ensure that the structures are built on a stable and resilient foundation that can withstand the forces of nature.

5. Conclusions

A rapid assessment of 33 SWs, constructed by small-scale farmers in 5 districts, was conducted to establish the contributing causes affecting the durability. The study examined characteristics of catchments, climate variables, and the perceptions of farmers regarding SWs constructed by small-scale farmers in the province.

SWs in Muchinga province have been observed and also identified from the discussion with farmers. The major hindrances faced by farmers in managing SWs: (i) lack of conducting semi-detailed feasibility studies; (ii) inadequate assessment of the catchment where SWs are intended to be constructed;(iii) negating views of farmers on materials used for construction of SWs; (iv) lack of knowledge and experience in regular maintenance of SWs.

The results of the study demonstrated that catchment characteristics and climate variables play a significant role in the O&M of SWs. Another factor that has been highlighted to affect the management of SWs is the negative attitude of farmers towards maintaining these structures, especially during the off-irrigation season. By conducting this study, problems have been identified that play a crucial role in the sustainability and longevity of SWs [36]. However, with appropriate due diligence before the implementation and development of SW construction, increasing the O&M can be achieved [37].

The purpose of this study is to investigate and identify the causes that impact the O&M of SWs in Muchinga Province of Zambia. The findings show that most of the problems affecting the O&M of SWs are due to a lack of consideration of the catchment shape and an inadequate understanding of the riverbed's inherent soil profile. To address these challenges, it is recommended that farmers should have a good knowledge of the landscape where SWs are to be constructed. This will help farmers select the appropriate design for a particular landscape and prevailing climate. It is also suggested that farmers should seek expert advice on catchment shape, riverbed soil stability, and the type of SW before implementing any small hydraulic structure.

These findings suggest that catchment shape, slope, soil type, and drainage conditions are important factors to consider when designing and constructing stormwater systems to ensure their long-term durability. The study highlights the need for a comprehensive understanding of the social, economic, and environmental factors that affect the successful implementation of SWs for irrigation. By addressing these factors, farmers can maximize the benefits of the technology and promote sustainable small-scale irrigation practices.

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