Research article

Simple Weir Types and Their Prospects for Small-Scale Irrigation Development in Northern Zambia

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Receive 19 January 2023 Accepted 8 May 2023 (*Corresponding Author)

Abstract In Zambia, simple weir technology is increasingly gaining popularity as an alternative method for river water diversion among rural small-scale farmers. The now widely-adopted technology was first introduced in the Northern Province region of Zambia to promote small-scale irrigation in local communities. These small-scale facilities are constructed across the width of the river using forest materials such as poles, twigs, thatching grass, and tree bark strips. These types of irrigation structures produce an adequate head of water enough for the diversion of water from the river into a canal conveying water for irrigation. However, simple weirs that farmers have been constructing with forest materials are observed to experience challenges such as breaching, and often break down and collapse within six to seven months. Therefore, the objective of this research was to investigate the characteristics of simple weirs constructed by farmers on a self-help basis for community-based small-scale irrigation schemes in the Luapula, Muchinga, and Northern Province regions of Zambia. We observed the simple weirs constructed before the start of irrigation season (May) and simple weirs built in the operational phase (May-November) and we characterized simple weirs as 1) single-line weir, 2) inclined weir, 3) trigonal weir, and 4) double-line weir. The results show an improvement in the irrigated area by small-scale farmers since the introduction of simple weirs. The findings revealed that challenges that were often encountered on the simple weirs were not solely caused by river flooding, but also by compromises in the construction, inconsistencies in maintenance, and lack of measures to sustain and protect the weirs. It was also observed that simple weirs in operation were regularly maintained and repaired during the irrigation season. Despite the challenges farmers were experiencing with the simple weirs, farmers persistently conducted maintenance activities, replaced worn-out poles and thatching grass and de-silted before the start of the irrigation season.

Keywords simple weir types, small-scale irrigation, river water diversion, arid land

INTRODUCTION

Most of the smallholder farmers live in rural areas in sub-Saharan Africa (SSA) and constitute about 70% of the continent's population in the bracket of poor people (Sakaki and Koga, 2013). This group of farmers is viable, but marginalized and vulnerable since they entirely depend on seasonal rainfall for their agricultural activities. Rainfed farming practiced by small-scale rural farmers produces a low agricultural yield that is frequently influenced by weather-induced changes. The problems associated with rainy season farming are numerous and not limited to 1) farming within 3-4 months in which to produce enough food crops to last up to the following harvest and 2) during the dry season, there is a prevalent shortage of fresh and nutritious crops**.** Based on the mentioned challenges, smallholder irrigation is promoted in SSA as a strategic intervention to enhance agricultural production, productivity, and farm household incomes (Osewe et al., 2020). To accelerate smallholder irrigation development in rural areas in SSA, low-cost irrigation technologies like river diversion simple weirs have been widely promoted for gravity irrigation. One of the gravity irrigation methods that has become popular in rural areas in SSA is river water diversion. The Southern Africa region is cited with a potential irrigable area of more than 3 million hectares (Xie et al., 2021) for river water irrigation schemes.

Simple weirs have been used in establishing community irrigation schemes in rural areas in Southern African countries such as Malawi, Mozambique, and Zambia (Lautze et al., 2017). In the northern region provinces of Zambia, small-scale local farmers construct simple weirs on the rivers in the dry season (May-November). The simple weir irrigation technology has increasingly become one of the irrigation methods among smallholder irrigation farmers in the rural areas in Zambia (Luapula, Muchinga, and Northern provinces) (Colenbrander et al., 2012). This is because simple weirs are community demand-driven technologies, relatively cost-effective, and adaptable to rural environments with the potential for gravity irrigation (suitable topography and surface flowing rivers). In Zambia, surface water from rivers and springs are the primary sources of water accessed by farmers for small-scale irrigation. Farmers have been accessing irrigation water using manually operated technologies like watering cans, buckets, and 20-25ltr plastic containers. However, this type of irrigation has less impact on the irrigated area expanded and irrigation production. Simple weirs have been introduced to develop small-scale irrigation in Zambia. The simple weir irrigation technology has attracted the attention of the majority of small-scale farmers in the rural area.

However, most of the simple weirs constructed by farmers themselves do not continue functioning throughout the irrigation season as many of them are either breached, partially destroyed, or washed away and needed to be either repaired, rehabilitated, or reconstructed after the annual floods. Farmers claim that, based on their experiences with simple weirs, the contributing factors to the challenges experienced include high peak discharges, weakness of structures, small canal intake, and excessive accumulation of sediment particles upstream of the weirs. Since the introduction of simple weirs as an alternative method of irrigation in the northern region of Zambia a decade ago, to date little information has been disseminated on the performance and challenges of these types of small-scale irrigation facilities.

OBJECTIVE

To explore the prospects of the simple river water diversion weirs constructed by local communities for small-scale irrigation in the northern region of Zambia by 1) characterizing the simple weirs structures, construction, and materials 2) studying the challenges of simple weirs, 3) assessing the effectiveness of simple weir maintenance during and before the irrigation seasons, and 4) assess the impact of the simple weir on small-scale irrigation development.

METHODOLOGY

Study Area and Data Collection

The study was conducted in Zambia's northern provinces shown in Fig.1. Geographically, Zambia lies in the tropics at an elevation of 1,200m above sea level with a sub-tropical climate due to its

latitude and high-altitude location. The climate in Zambia is characterized by three distinctive seasons all year, dry and hot (August to November), dry and cool (May to August), and a wet rainy season (December to April). Zambia is divided into three agroecological zones with Zone III, covering the northern region of Zambia, receiving the highest amount of rainfall between 1,000 mm to 1,500 mm per year (Brigadier et al., 2015). The rainy season increases both in intensity and duration from the southern region to the northern region. In Zambia's northern region, surface flowing water is sufficient to support dry-season irrigation.

Fig. 1 Location of Luapula, Muchinga, and Northern Provinces in Zambia

The collection of primary data was conducted through discussions and interviews with agricultural extension officers, farmer groups, and simple weir users. The study reviewed the literature on small-scale irrigation development, focusing on low-cost irrigation technologies in rural areas in Zambia. The primary data used in this study was collected from 55 sites in three provinces. The study area was clustered into three provinces and 55 simple weirs were randomly selected from Luapula province 22 sites (72 participants), Muchinga province 15 sites (31 participants), and Northern province 18 sites (69 participants). 172 simple weir users participated in the discussion in Table 1. The data was collected between August 20th and November 30th, 2022.

Table 1 Location of simple weir sites, number of simple weirs, and users who participated

Province	Number of simple weirs and sites	Number of simple weir users who participated
Luapula	22	72
Muchinga	15	31
Northern	18	69
Total	55	172

Simple Weirs Small-Scale Irrigated Agriculture

During the seven-month dry season, small-scale farmers resort to irrigation to supplement rain-fed agricultural production. Vegetable growing is the common system of agriculture between May and December in rural areas in Zambia. This type of agriculture during the period is the principal livelihood for the majority of the people in the region. Crops that are produced using simple weir irrigation include cabbage, tomatoes, onions, watermelons, carrots, and Irish potatoes. These crops are generally irrigated and widely cultivated on sites supplied with river water diverted by simple weirs.

RESULTS AND DISCUSSIONS

Characteristics of the Simple Weir Types

In Zambia, simple river water diversion structures are usually constructed of simple materials of poles, thatch grass, and clay soil bunds (Food and Agriculture Organization, 2014). Although simple weirs are generally constructed for one irrigation season, they are viable facilities. Farmers are usually advised to dismantle the weirs as a coping strategy to flood damage and store material to avoid depletion of forest for the reconstruction in the following irrigation season. Figure 2 shows four simple weir types that are conventionally used for irrigation and are part of improved methods for small-scale irrigation (Bekele et al., 2006).




(1) Single-line weir: It consists of a single line of wooded poles constructed across the width of a river. This weir type is suitable for rivers which are wider and shallower. It is recommended on hard riverbed foundations.

(2) Inclined weir: This weir has one main pole placed horizontally across the width of a river and supported by riverbanks of relatively the same height. It is recommended on rivers which are slightly deeper and

(3) Trigonal weir: The weir consists of several tripod stands constructed with round poles. The tripod stands are aligned across the width of the river to form a weir. This weir type is suitable on rocky riverbeds.

(4) Double-line weir: This weir type has two parallel lines of poles constructed across the river, spaced at 0.2-0.5 m. The space between the parallel lines is filled with clay soil to minimise water loss by seepage.

Fig. 2 Characterization of simple weir types and constructions methods: (1) single-line weir, (2) inclined weir, (3) trigonal weir, (4) double-line weir

Single-Line Weir

Single-line simple weirs are constructed using round forest poles (0.8-0.1 m diameter) and adult wrist-size bundles of thatch grass (Fig. 2-1). A single row of poles is embedded vertically into the riverbed across the width of a river. According to available data, the intra-spacing of poles ranges between 0.5 to 1 meter from each other across the river. The wooden poles are connected by purlins tied across using tree bark strips. The weir is reinforced at the base of the pole line by ramming clay soil. Thatching grass is used to reduce water seeping through the weir. The weir causes the water level to rise upstream and diverted into the canal off-taking on its upstream side.

Inclined Weir

The inclined weir is constructed where the narrow and straight river section has a good formation of riverbanks on both sides and relatively the same height. One pole (0.2-0.3 m diameter) is used as a cross member where slanted poles (about 0.1 m in diameter) are supported (Fig. 2-2). The cross-member pole is placed horizontally across the river to the preferred flood height and anchored by the riverbanks. The slanted fixed poles are approximately inclined at 60^0 angles to the river flow. The slated poles are connected using the purlins and covered with thatching grass to minimize water loss downstream. Clay soil is compacted at the base to provide anchorage and reduce seepage. The water rises above the historical flood level and is diverted into the canal conveying irrigation water.

Trigonal Weir

This type of weir is recommended on riverbeds with stones or hard rock foundations. A single tripod is constructed using 3 by 2 m (approximately) long poles and tree bark strips. The three poles are connected at the top of one end. The front with two long poles covered with thatch grass faces upstream, the other pole shunts downstream to provide stability. Several tripods are constructed and later aligned in a single line across the river to form a weir (Fig. 2-3). Water is prevented from being lost through seepage using the thatching grass. Depending on the width of a river two or more tripods can be erected across. During the rainy season, the tripods are removed from the river channel and stored for use in the following irrigation period.

Double-Line Weir

The double-line weir has two parallel rows of round poles placed vertically into the riverbed (Fig. 2-4). The space between the two parallel rows of poles across the river is approximately 0.2 to 0.5 meters (Food and Agriculture Organization (FAO), 2015). The space between the two rows of poles is filled with clay soil to reduce water loss through leakage. The double-line weir impounds flowing river water in a small earth pond formed upstream. Water is diverted from the ponds and supplied downstream to the fields. The double-line weir can also be used as a fishpond. Apart from diverting water for irrigation, the double-line weir can also be used as a crossing point.

Analysis of Reasons for Adoption of Simple Weirs for Irrigation

Information and farmers' experiences in Figs. 3 and 4, were collected from different sites between 2014 and 2017. Figure 3 summarises the reasons farmers expressed about the simple weir as a technology for irrigation. The findings of this study included exploring the motivation and interest of the local farmers in simple weir irrigation. The results show multiple reasons presented in Fig. 3 for using simple weirs for small-scale irrigation development. The responses presented are based on the information collected from the farmers. It was found that about 26% of the population of small-scale farmers using simple weirs stated easy construction, and 19% mentioned the use of local materials of forest products like poles and thatch grass in the construction of simple weirs as a motivating factor. 15% of simple weir users' interest in simple weir was about enhancing household livelihood while 14% of the farmers stated agricultural activities throughout the year, a vital reason (Bjornlund et al., 2019). About 13% of the farmers expected improvement in the area irrigated while other farmers stated a reduction in manual labor required to lift water for irrigation from the source to the crops. The reasons given by farmers for adopting simple weirs for irrigation purposes substantially varied. These responses were noted during the site visits and interviews. The responses farmers advanced according to (Colenbrander et al., 2012) represent the solutions seen by farmers as most promising for developing low-cost irrigation systems in rural areas. According to the responses of the farmers interviewed, easy construction, livelihood diversification, and increasing land under irrigation have been the basis for adopting simple weirs in the northern region of Zambia.

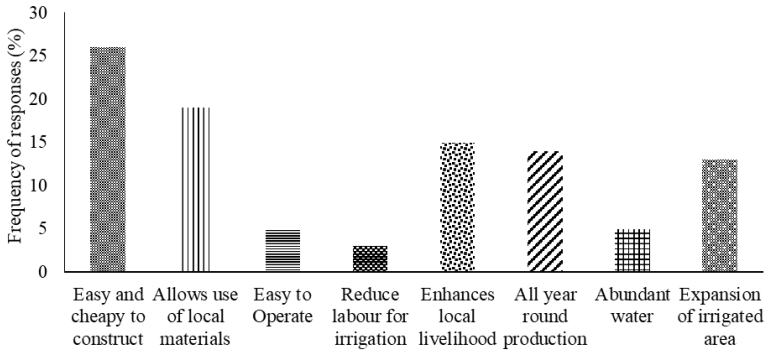

Fig. 3 Farmers' responses on the adoption of simple weirs

Analysis of the Attributing Factors to Stagnant Development of Small-Scale Irrigation and Low Adoption of Simple Weirs in the Northern Region

Figure 4 summarises the responses of the farmers from the study sites with simple weirs used for irrigation in the northern region province of Zambia. The responses varied with 18% of the farmers stating weir breaching challenges, 17% of the farmers expressing weir leakages as their concern, and 27% of the farmers mentioning high labour demand for repair and maintenance as challenges (Dakpalah et al., 2018). While 5% of the farmers stated deforestation as more poles are required to be harvested for construction from the forest. Fig. 4 Farmers' responses collected from simple weir sites.

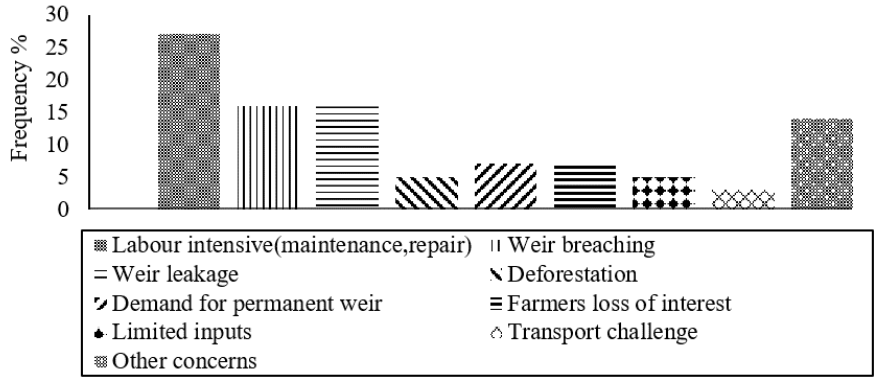

Fig. 4 Farmers' responses collected from simple weir sites

Analysis of the Maintenance Activities of Simple Weirs by Farmers

Figure 5 shows the flood damage control strategy farmers practice at the end of the irrigation period (December). Based on the observation during the site visits, it was observed that about 7% of the total number of weirs were deliberately dismantled, 47% partially dismantled and 50% of the total number of the weirs remained un-dismantled. Though dismantling of weirs during the off-season is recommended as a flood damage control measure, it is not implemented on all simple weirs because weirs are sometimes used to divert river water to supplement rainfall during dry spells.

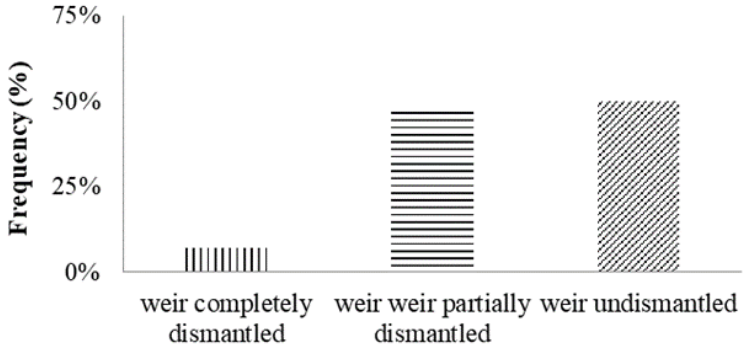

Fig. 5 Maintenance activities carried out on simple weirs by farmers

Simple Weir Impacts in Promoting Small-Scale Irrigation in Northern Region

Figure 6 refers to the period between 2014-2016, in which 876 hectares were brought under irrigation using simple weirs. In 2014, 2015, and 2016, the land expanded for irrigation in hectares was 292, 214.6, and 369.4 respectively. In 2016, there was a significant increase in the area brought under irrigation largely due to farmers' increasing interest in simple weirs and farmer-to-farmer knowledge sharing and skill transfer (Japan International Cooperation Agency (JICA), 2017).

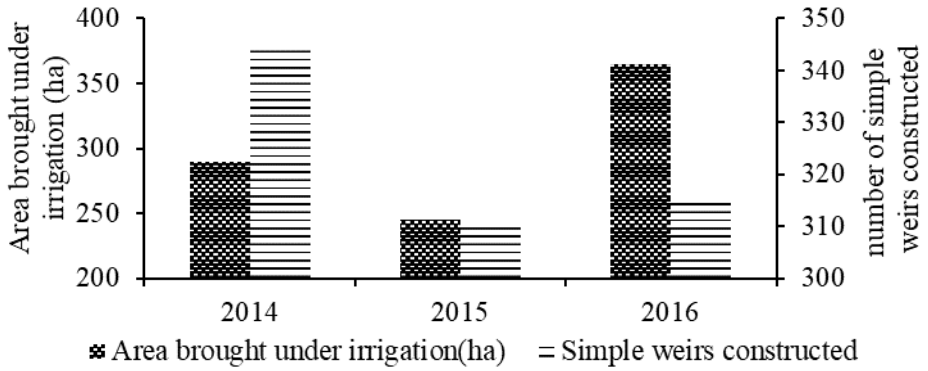

Fig. 6 Number of hectares irrigated by diverting river water using the corresponding number of simple weirs

CONCLUSION

This study focused on the simple weirs that have been introduced in the northern region of Zambia. Simple weirs characterized by four types single, line, double line, inclined, and trigonal weirs are increasingly becoming popular in small-scale irrigation development in the northern region rural areas in Zambia. The use of simple weirs to divert river water for irrigation is relatively ''new'' in Zambia. The use of locally available materials of forest materials and the need to supplement household income and food requirements has motivated the majority of small-scale farmers in the northern region to engage in dry season irrigation (May-December). Despite the promising results in enhancing irrigation water accessibility, there are still some structural challenges with simple weirs. This study suggests the need for improvement in the construction and selection of construction materials for simple weirs.

ACKNOWLEDGEMENTS

The authors would like to thank the Ministry of Agriculture staff in Luapula, Muchinga, and Northern provinces of Zambia for their contributions to this study. Furthermore, we would like to thank the International Platform for Dryland Research and Education of Tottori University and are also grateful to Japan International Cooperation Agency for its support.

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