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Elevating the standard: a professionalized approach to community-based rainwater harvesting systems in Uganda

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Abstract: *Where water resources are limited, rainwater harvesting (RWH) can provide on-site access to improved water sources. Community institutions are uniquely positioned to benefit from RWH; advocates have encouraged the installation of community-based RWH systems as a way to ameliorate water supply insufficiencies in low-income settings. However, poor quality RWH system installations and insufficient attention to management support have resulted in sustainability challenges, necessitating a commitment to higher standards for community-based RWH. Spurred on by an iterative learning cycle and commitment to innovation, the Ugandan Water Project has achieved RWH system design, installation, and management practices that are well adapted to Ugandan institutions. By investing in a professional crew, high-quality materials, and post-installation support, the Ugandan Water Project has achieved 96 per cent functionality two years after installation. The professionalized approach that the Ugandan Water Project employs can be used as a model to guide future RWH system installations in Uganda and elsewhere.*

Keywords: rainwater harvesting, Uganda, community water supply, professionalization, sustainability

RAINWATER HARVESTING (RWH) HAS BEEN used to improve water access across a variety of economic settings, as well as in a range of climates (Chaplin and Legge, 2019). In particular, RWH has emerged as an important means of water supply in developing countries, most notably in communities lacking piped-water networks and groundwater sources (Baguma et al., 2010b; Thomas, 2014; Mwamila et al., 2015).

In general terms, RWH describes the practice of collecting and storing rainfall runoff (Chaplin and Leggee, 2019). RWH systems comprise three main components: a catchment area (e.g. a roof), a conveyance system (e.g. gutters and pipes), and a storage facility (e.g. a tank) (Arku et al., 2015). When rainwater is captured and stored on-site, it is considered safely managed and can be used for a variety of domestic uses, including drinking, at a low cost and without energy expenditure. Importantly,

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RWH systems can be affixed to homes and community buildings, eliminating the arduous and time-consuming task of fetching water off-site (Baguma et al., 2010b; Thomas, 2014).

According to Nijhof et al. (2010), community institutions are uniquely positioned to benefit from RWH: their large roofs afford significant rainfall capture area. In recent years, community-based RWH in low-resource settings has been discussed in the literature (Saboori et al., 2014; Mwamila et al., 2015, 2016a, b; Temesgen et al., 2015; Kim et al., 2016; Dao et al., 2017; Adugna et al., 2018). These authors write favourably of RWH at community institutions, promoting community-based RWH as a promising solution to water supply challenges. In fact, Kim et al. (2016) describe community-based RWH as the most innovative method to ameliorate water supply insufficiencies in Africa and Asia.

While several unique approaches to community-based RWH have been described in the literature, sustainability challenges attributed to poor quality installations, the absence of adequate funding, and a lack of appropriate management systems have also been outlined (Saboori et al., 2014; Mwamila et al, 2016a). To achieve sector-wide advancement in sustainability, the ongoing dissemination of successful methods is required. This paper adds to the community-based RWH conversation by describing the professionalized approach to community-based RWH employed by the Ugandan Water Project, an international development organization that implements innovative solutions to Uganda's water crisis.

As of March 2021, the Ugandan Water Project has installed more than 500 community-based RWH systems at schools, health centres, places of worship, and other community institutions in Uganda. Since 2008, the Ugandan Water Project has continuously improved its approach through an iterative learning cycle. This has resulted in a design that is well adapted to community-based institutions in Uganda, where two wet seasons produce rainfall between 1,000 mm and 2,000 mm per year in most regions (NEMA, 2016). While the Ugandan Water Project's methods are tailored to the Ugandan context, several advances in design, installation, and management can be extended to community-based RWH projects in other contexts.

Methods

The Ugandan Water Project's professionalized approach to community-based RWH expands beyond system installation to include both pre- and post-installation elements.

Pre-installation

Once community-based RWH system installation is confirmed, community leadership signs a memorandum of understanding (MOU) with the Ugandan Water Project. This MOU is a legally binding document that outlines the responsibilities, expectations, and outcomes for both parties. By signing the MOU, the community commits to making a series of contributions towards the installation, including local building materials, volunteer labour, and meals during installation.

Photo 1 Photograph of a completed RWH system installed by the Ugandan Water Project

Installation

Ugandan Water Project RWH systems comprise a 10,000-L Poly Fibre (U) Ltd polyethylene tank placed on a base, attached to an existing metal roof via a gutter system, equipped with a tap stand for water access. A completed system is pictured in Photo 1.

All personnel, tools, and off-site materials are transported using Ugandan Water Project vehicles and drivers. All building materials are procured in Uganda, with brick, sand, and stone sourced locally. Brick joints between 4 mm and 10 mm are standard for all masonry, and a cement mix-to-sand ratio of 1:2 is used. Installation is completed in less than two days using a professional four-person crew. On the first day of installation, the base is constructed and the fascia boards hung. The remainder of the installation is completed on the second day.

A technical drawing of the Ugandan Water Project's RWH system design is provided in Figure 1; technical details of the installation are outlined below:

- *Constructing the base*. The location of the tank is determined by the crew leader, in consultation with community leadership. The base is built with a circular brick outer wall and internal brick support walls, which divide the base into quadrants. The space between the walls is filled with hardcore and then small stones, which are levelled and finished with a cement pad.
- *Installing the tank*. On the second day of installation, after the base has cured, the tank is positioned atop the platform. An overflow hole is drilled near the top of the tank and an overflow pipe extending 60 cm from the tank is affixed.

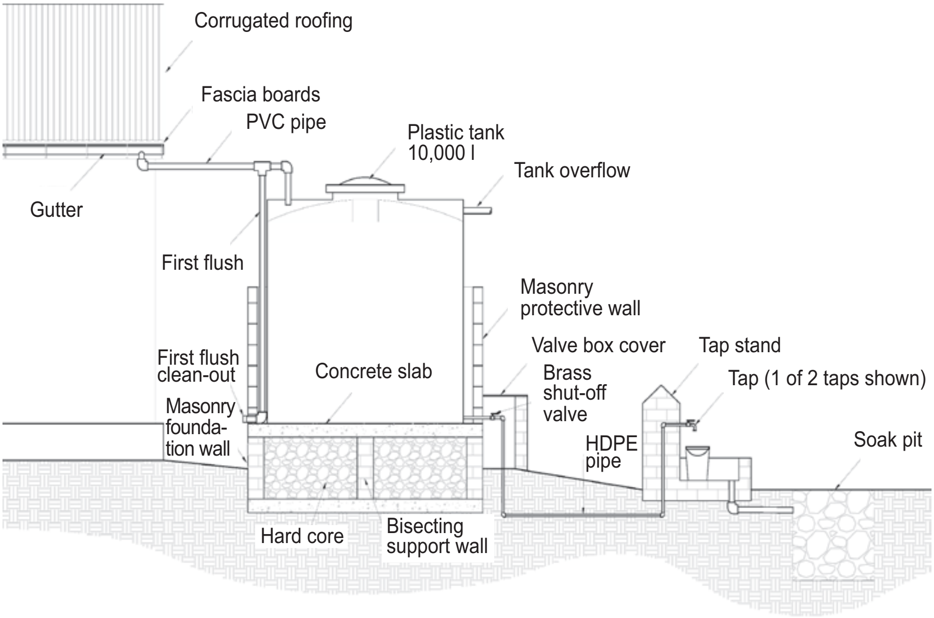

Figure 1 Technical drawing of the Ugandan Water Project's RWH system design

Approximately 5 cm above the base of the tank, an outlet hole is drilled and a shut-off valve fastened.

- *Hanging the conveyance system and first flush*. Extra-wide fascia boards (23 cm wide) are attached to the roof. Subsequently, heavy gauge, 14-cm PVC gutters are installed. To hang the gutters, plastic gutter supports are fastened to the fascia boards every 50 cm to achieve a gutter slope of at least 1 per cent. PVC downspouts pipes (8 cm diameter) connect the gutter system to the tank. Adjacent to the tank, a PVC pipe first flush system (8 cm diameter) runs towards the ground from a 'T' joint in the downspout. An elbow joint directs the first flush outwards at the base, where a robust removable end-cap with improved o-ring seals is attached. Systems are typically equipped with two first flush structures, one for each side of the roof.
- *Building the protective wall*. A protective brick wall is constructed around the tank and first flush. The wall is approximately 1.5 m tall, with approximately 12 cm of space between the tank and the wall to permit tank expansion when full. The wall is constructed so the first flush end-cap protrudes, protecting the pipe while permitting access to the cap. Similarly, drainage holes are built into the bottom of the wall using PVC pipe. A brick valve box is built into the wall around the outlet valve and secured with a lockable steel cover. The surface is plastered to provide a finished appearance.
- *Constructing the tap stand*. HDPE pipe (2.5 cm diameter) is run underground from the outlet valve to the tap stand, which is constructed 2 m to 10 m downhill from the tank. The tap stand is constructed using bricks, with plumbing embedded

within the masonry. The tap stand is equipped with two entirely brass taps and is large enough to accommodate two standard 20-L jerrycans. To prevent standing water, a drain connects the tap stand to an adjacent soak pit. The soak pit is 1.25 m to 1.5 m deep and wide, filled with hardcore, covered with heavy plastic sheeting, and topped with dirt. The tap stand is given a plaster finish. Hinged lockboxes that clip over the taps are provided.

- *Supplementary water filters*. Four Sawyer PointONE water filters are distributed with each installation. Filters are not affixed to the RWH system. Rather, they are housed separately on filter stands fabricated by the Ugandan Water Project.

Post-installation

After installation, training is completed. A Ugandan Water Project facilitator introduces the community to Sawyer PointONE water filters, with proper use and maintenance described and demonstrated. Next, RWH is discussed with community leadership and a community-appointed RWH system caretaker. Instructions include: cleaning the conveyance system and tank; emptying the first flush after each rainfall; system protection and security; water use and management; minor maintenance and part replacement.

Furthermore, the Ugandan Water Project completes site visits every six months for two years. Site visits facilitate ongoing relational touch-points and training reinforcement. When system repairs are required, facilitators commonly coach the community through part procurement and repairs. Visits also allow for project monitoring, enabling the Ugandan Water Project's iterative learning cycle.

Results

Ugandan Water Project RWH systems cost US$3,600. Materials account for approximately 44 per cent of expenses, with off-site materials (tank, gutters, hardware, plumbing, lumber) totalling three-quarters of those costs. Labour accounts for approximately 10 per cent of expenses, and just under 8 per cent goes towards freight, delivery, vehicles, and equipment. Supplementary water filter stations account for approximately 7 per cent of costs, with training and monitoring totalling slightly less than 12 per cent. The remaining expenses, approximately 20 per cent, are split between administrative costs, miscellaneous expenses, and variance.

The functionality of Ugandan Water Project RWH systems was assessed by Ugandan Water Project enumerators approximately two years after installation. Fully functional systems were those in good working condition and able to provide water according to the specifications in the original design. Non-functional systems were those that no longer provided water on a regular basis. A third category, functional but servicing recommended, was designated for systems that provided water on a regular basis but would benefit from minor repairs or maintenance.

The 100 most recent RWH systems installed by the Ugandan Water Project with a minimum of 640 operational days (1.75 years) were included in the analysis.

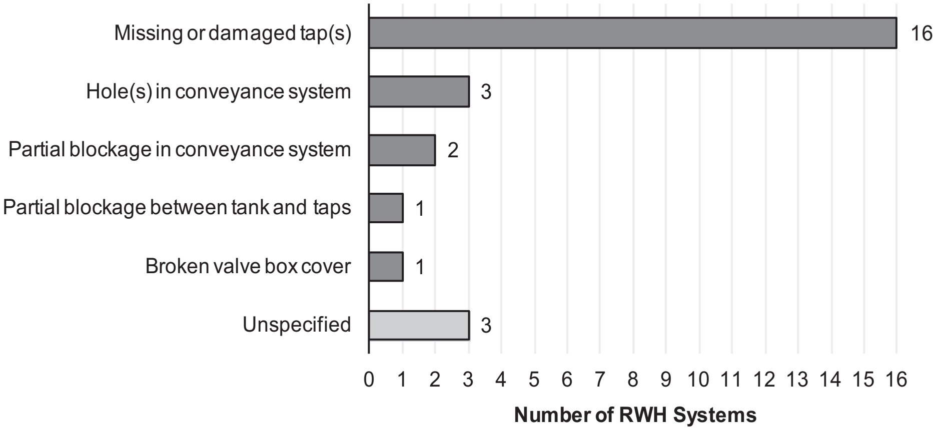

Figure 2 Reasons for RWH system servicing recommendations at two-year monitoring visit

The average number of operational days among the systems included was 742 (2.03 years), with the minimum operational time being 643 days (1.76 years) and the maximum 881 days (2.41 years). Of the 100 systems assessed, 70 were fully functional, 26 were functional with servicing recommended, and 4 were non-functional.

Reasons for servicing recommendations are summarized in Figure 2. Most notably, approximately 62 per cent (n=16) of servicing recommendations were made because of missing or damaged taps. The four instances of non-functionality involved a complete blockage in the conveyance system, severe damage to the first flush, a flooding incident that washed away the underground HDPE pipe, and a disassembled system that was being relocated by the community.

On average, community institutions with RWH systems installed by the Ugandan Water Project serve approximately 300 people. Most water users are day students or staff of the institution, who are only on-site during daytime hours.

Discussion

The Ugandan Water Project has professionalized its approach to community-based RWH, culminating in 96 per cent system functionality two years after installation. To achieve and maintain its high standard, the Ugandan Water Project has invested in a robust design, high-quality materials, and a professional crew. Furthermore, an iterative learning cycle facilitated by ongoing project monitoring has sparked several innovations that rise above common practice.

RWH system advancements begin at the base. The Ugandan Water Project's quadrant design with 4-mm to 10-mm brick joints and fortified cement mix is more robust than others. In Uganda, bases are commonly built with an outer brick wall, filled with dirt or stone, and topped with cement. These rudimentary designs are further weakened by builders using less robust cement mixes (commonly 1:5 cement mix to sand) and excessively large brick joints, which compromise the integrity of the structure. Furthermore, bases are commonly eroded by water that spills on them from the tank overflow. The Ugandan Water Project solves this problem by extending the overflow stream beyond the base using a 60-cm overflow pipe.

Innovations in the Ugandan Water Project's conveyance system are also worth noting. The Ugandan Water Project uses extra-wide 23-cm fascia boards to maximize gutter run while maintaining appropriate slope minimums. In Uganda, 15-cm fascia boards are common, and many gutters are hung without fascia boards. Consequently, gutter runs are truncated or slope minimums are not maintained. The 14-cm PVC gutters installed by the Ugandan Water Project also present advantages. Common steel gutters leak and rust, and 10-cm PVC gutters overflow or are overshot during heavy rains, reducing rainfall capture. Furthermore, the Ugandan Water Project prevents gutter failure by ensuring supports are affixed every 50 cm.

Given the nature of their construction, RWH systems can be subject to water theft, vandalism, and other damage. Of note, a study of RWH systems in Rakai, Uganda, documented polyethylene tanks being punctured by area residents attempting to steal water (Blanchard, 2012). Several elements of the Ugandan Water Project's design safeguard the system against similar threats. Most significantly, the protective wall shields the tank, first flush, and outlet valve. The wall is built with a 12-cm gap to permit tank expansion, drainage holes to prevent rainfall accumulation inside the wall, and a lockable valve box to secure the outlet. While many RWH system designs place taps at the tank itself (resulting in costly repairs or tank replacement when the vulnerable outlet is damaged), the Ugandan Water Project separates its taps from the tank. Damage at the tap stand can be easily repaired, and the outlet valve provides a back-up for controlling water flow. Tap lockboxes provide additional protection against theft and damage.

In general, research has found that well-designed RWH systems provide relatively safe water with good physicochemical quality (Abbasi and Abbasi, 2011; Gwenzi et al., 2015; Hamilton et al., 2019). The primary concern is microbial contamination, which can be mitigated by proper design and cleaning. Contamination that persists can be resolved with water treatment.

To mitigate water quality issues, the Ugandan Water Project equips systems with a first flush to divert the first run-off from each rainfall. A unique aspect of the Ugandan Water Project's first flush design is its location, adjacent to the tank instead of attached to the catchment building. An independent study of the Ugandan Water Project's first flush showed that placement beside the tank minimizes turbulence at the downspout-first flush junction, thereby limiting the transfer of contaminants to the tank. In contrast, many Ugandan RWH systems are built without a first flush; those with one typically affix it to the catchment building. Furthermore, the Ugandan Water Project positions the tank outlet approximately 5 cm above the base of the tank, which prevents settled sediments from passing to the taps without requiring an additional sedimentation chamber. Beyond system design, community leaders and the caretaker receive training on system cleaning. Though not directly water-quality related, construction of the soak pit removes potential hazards by preventing standing water.

Point-of-use water filters are also provided to safeguard against persistent microbial contaminants. At community institutions, the Ugandan Water Project distributes Sawyer PointONE water filters, which employ gravity-driven hollow fibre membrane filtration (0.1 micron) and can be backflushed for reuse without regular replacement. While the Ugandan Water Project acknowledges that locally made ceramic and biosand filters of proven quality are available in Uganda, the flow rates of ceramic filters (0.3 to 2.5 L/hour) and biosand filters (0.5 to 2.0 L/hour) are significantly slower than those of Sawyer PointONE filters (32.8 to 46.5 L/hour) (CAWST, 2018). Given the relatively large volumes of drinking water required at community institutions, the Ugandan Water Project has opted to deploy higher capacity Sawyer PointONE filters.

The relative merits of different tank types are discussed elsewhere (Thomas and Martinson, 2007; Parker et al., 2012; Thomas, 2014). For several reasons, the Ugandan Water Project has elected to install prefabricated polyethylene tanks. In general, polyethylene tanks have a significantly longer lifespan than galvanized iron options and come with a manufacturer's guarantee. Compared to constructed tanks, they are faster to install and less prone to production defects that result in tank failure. Prefabricated tanks are also easier to clean, require less maintenance, and can be relocated. The Ugandan Water Project exclusively installs Poly Fibre (U) Ltd tanks, which are manufactured using the rotational moulding method; the Ugandan Water Project has found these tanks more durable than others produced using blow moulding.

There is extensive literature discussing the selection of optimal tank sizes, including a review by Thomas and Martinson (2007). While the Ugandan Water Project acknowledges these contributions, it does not optimize tank size site-by-site. Instead, 10,000-L tanks are standard. Though the notion of standardization runs contrary to the optimization discussions in the literature, standardization has several advantages. By reducing installation variability, the Ugandan Water Project has ensured quality production, streamlined supply chains, and achieved operational efficiency. While many constructed tanks can take a week or longer to install, a single four-person Ugandan Water Project crew commonly installs three RWH systems in a week.

When RWH systems are installed on premises and managed effectively, many institutions immediately climb from 'no service' or 'limited service' to 'basic service' on the Joint Monitoring Programme drinking water service ladder. While the improvements are clear, the Ugandan Water Project recognizes that a single 10,000-L system is often insufficient to satisfy all water-related needs of a community institution, particularly in the dry season. During periods of limited rainfall, it is common for institutions to reserve on-site rainwater for drinking, cooking, and washing, while procuring water for other uses from existing off-site sources. If on-site supplies are depleted despite these measures, it is possible to refill the tank using alternative means, such as by tanker-truck.

At institutions requiring additional water resources, the Ugandan Water Project commonly installs multiple RWH systems to better satisfy demand. The modular nature of this approach offers secondary benefits: Additional systems can be added as funding becomes available and, if one system fails, water can still be accessed from the others.

Early in 2021, the Ugandan Water Project commissioned an independent study of programme impact. This investigation, which employed qualitative methods, confirmed that some institutions served by Ugandan Water Project systems would benefit from additional RWH tanks to satisfy dry-season demand. Overall, however, water users held Ugandan Water Project systems in high regard. Water users reported RWH system installation leading to several positive outcomes, including time and cost savings, increased water security, improved academic performance, better health outcomes, and overall advances in quality of life. Leaders at community institutions noted that training and technical assistance provided by the Ugandan Water Project supports proper system management and that robust system design contributes to longevity.

Mwamila et al. (2016a) suggest that low-quality design and poor construction can contribute to several RWH deficiencies. The Ugandan Water Project's professional approach overcomes these shortfalls, delivering a robust and reproducible product with minimal operating costs. Small details – such as ensuring the Ugandan Water Project crew is equipped with proper tools to make structures appropriately plumb, level, and square – contribute significantly to the quality of the installation. Though it sounds rudimentary, it is not uncommon for Ugandan builders to work without these tools. Beyond construction, the Ugandan Water Project also elevates its approach by investing considerable resources into community training focused on system management, a critical element that typically receives insufficient attention (Baguma et al., 2010a; Kim et al., 2016).

The Ugandan Water Project acknowledges that investment in quality comes at a price: installation costs $3,600, which is significant. This cost, however, is comparable to RWH systems reported in similar contexts. For example, Mwamila et al. (2016b) present an identical cost for a similar RWH system in Tanzania. It is worth noting that the Ugandan Water Project's costs also include pre- and post-installation elements, transportation, administrative overhead, and water filters; these costs are not always included in reports elsewhere. While donors fund the majority of the Ugandan Water Project's installation costs, communities are required to contribute in-kind with materials and unskilled labour. Community institutions are also responsible for operation and maintenance expenses, which are typically paid from institutional revenue. At the discretion of institutional leadership, water fees are charged to select user groups in some communities. Overall, this funding approach is similar to other community-based RWH financing schemes described in the literature (Kim et al., 2016; Mwamila et al., 2016b).

While this approach to community-based RWH is the culmination of 12 years of refinement, the Ugandan Water Project believes further improvements are possible and worth pursuing. As one example, the Ugandan Water Project is re-exploring the installation of insect-resistant screens on tank inlets and outlets, which were previously discontinued because of sustainability challenges. Furthermore, the Ugandan Water Project is not completely satisfied with the durability of its current brass taps. Though the organization has experimented with several tap types and found the current model most robust, the search for more durable yet readily available options continues. Other innovations, such as a self-draining first flush (Thomas and Martinson, 2007) or a basic water-level gauge (Mwamila et al., 2016b) could be incorporated. Presently, the Ugandan Water Project is field testing a tank wash-out, which it plans to incorporate on all future installations.

Conclusions

The Ugandan Water Project's professionalized approach to community-based RWH, spurred on by an iterative learning cycle and commitment to innovation, has culminated in sustainable design, installation, and management practices that are well adapted to Ugandan institutions. The methods employed by the Ugandan Water Project can guide future community-based RWH system installations in Uganda, and several advancements can be extended to contexts beyond Uganda.

Ultimately, the professionalized approach to community-based RWH employed by the Ugandan Water Project can be viewed as a model for sector-wide advancement. The Ugandan Water Project has achieved and maintained its high standard through investment in a robust design, high-quality materials, and a professional crew. By standardizing its installation process, the Ugandan Water Project has ensured quality production, streamlined supply chains, and achieved operational efficiency. Furthermore, investment in community training and a commitment to post-installation support has culminated in strong community management systems.

In Uganda and elsewhere, a commitment to higher standards for community-based RWH is required. Improved approaches, such as those modelled by the Ugandan Water Project, should be adopted as national standard practice and promoted among implementers.

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