Research Paper

Sustainability evaluation of a primary school rainwater demonstration project in Tanzania

Tulinave Burton Mwamila, Moo Young Han and Soyoon Kum

ABSTRACT

Water shortages are widely prevalent in developing countries, affecting lives of people including schoolchildren, who miss classes while fetching water for daily use. A typical case was that of Mnyundo Primary School in Tanzania, East Africa. A rainwater harvesting (RWH) system was then constructed because of easy adaptability of the technology. The purpose of this study is sustainability evaluation. The evaluation considered construction details, level of water supply service, potential for sustainability and replication. Coarse screen, first flush tank, and sedimentation tank were included for maintaining drinkable water quality through particle load reduction. The water level gauge incorporated enables easy monitoring of water usage, while the provided training and operational manual are a practical guide on system management for the users. Local labor, material and techniques used, are recommended for capacity building, sense of ownership, and cost reduction. Companies' involvement is encouraged by providing financial support to the schools as their corporate social responsibility. RWH is thus suggested as a sustainable alternative for drinking water supply.

Key words | community water supply, demonstration project, rainwater harvesting, sustainability, water supply service level

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BACKGROUND

Tanzania in eastern Africa is among the many African countries suffering greatly from water shortage. The problem is more severe in rural areas, where centralized piped water supply systems rarely exist. Surface water sources such as rivers and springs are highly depended on, but these sources are at high risk of contamination from the surrounding environment. Alternatively, groundwater has been highly promoted as a substitute, especially in rural areas. However, its quality and accessibility is largely controlled by geology (Smedley 2004) and in some areas, for example, in Mtwara and Dar es Salaam regions, the water may be accessed only at depths beyond 100 m, which has high cost implication considering borehole development and operation. Moreover, these water sources could be located far away from community households, thus demanding time and energy to access them, which results in reduced devotion to other economic activities. Tanzania's service level strategy is to ensure that any water point is used by a maximum of 250 persons at not more than 400 m from the furthest user, and 30 minutes time for a round trip to fetch water (MoWI 2008).

The issue of water scarcity affects schoolchildren who spend time fetching it, instead of using the time attending class programs. The authors visited Mnyundo Primary School, whose population is about 300 including students and staff. Prior to February 2013, the school did not have any water source within its vicinity, like many schools in rural areas. For many years, its students had to spend some of the school day looking for water to use in their school at distances of approximately 2 km. During the dry season, the water scarcity worsens and some of the students fail to attend school because they have to assist in fetching water for their home use.

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In Tanzania, a larger portion receives average annual rainfall ranging between 400 and 2,000 mm. Malesu *et al.* (2006), by using GIS, established that there is high potential for rainwater harvesting (RWH) in Tanzania including rooftop RWH. Nevertheless, it is still not commonly and reliably practiced in the country. In general, people are concerned about the initial cost of constructing the system. Often, however, they do not consider the daily cost they incur buying water from vendors, at least US$ 0.3 for 20 L gallon (at least 500 TZS for 20 L gallon), or the distance they have to walk to a surface water source. Although some people worry that water collected on a roof may be contaminated with bird waste, surface water is obviously at a higher risk of contamination from animal and human waste. As well, there are advancements in rainwater quality management with simple techniques for particle load reduction. Recently, the government under the water sector development program has been promoting RWH construction by demonstrations in communities utilizing cheaper alternative mechanisms including storage system types (MoW 2014).

In this paper, a successful school RWH demonstration project is introduced, and evaluated for sustainability from technical, social, and economic perspectives, and recommendations are given for adaptability into similar cases of water shortage.

PROJECT DESCRIPTION

The RWH project was constructed at the Mnyundo Primary School in Mtwara, a southern region of Tanzania (Figure 1(a)). The region has two main seasons, a warm humid rainy season that lasts from November to May, and a dry cool season that lasts from June to October, with annual average rainfall estimated at 1,055.6 mm (Figure 1(b)).

Compared to surface water, rainwater is free, safe, and less prone to contamination if properly managed. Capable of meeting the WHO drinking water standards, rainwater has been suggested as an alternative potable water source to piped system (Worm & Hattum 2006; Thomas & Martinson 2007; Rodrigo *et al.* 2009; Ndomba & Wambura 2010; Nguyen *et al.* 2013; Temesgen *et al.* 2015). The school is well suited for RWH, as it has five classroom buildings with iron roofs, each with an area greater than 100 m^2.

In February 2013, the RWH system (Figure 2) was constructed within a week at the Mnyundo School as a demonstration project. It utilized one classroom roof of 168 m^2, and two 5 m^3 plastic storage tanks. The project design and funding was provided by the Seoul National University Rainwater Research Centre (SNURRC) and the Korean Society of Civil Engineers (KSCE) as their Corporate Social Responsibility (CSR) activities. The project goal was not only to contribute rainwater as the main drinking water source for the school, but also for knowledge transfer, capacity building, and instilling a sense of ownership to local people.

Construction details

In this project, the materials used were sourced from local material suppliers, and local people under the supervision of the SNURRC mainly did the work. District water

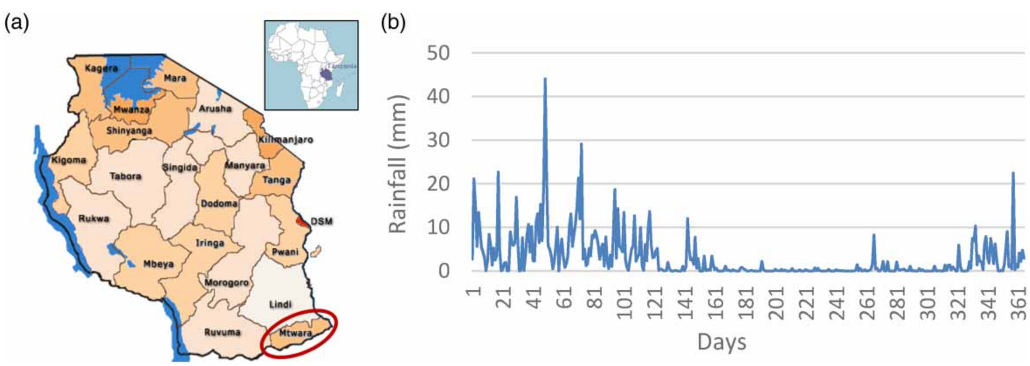

Figure 1 | (a) Location of the Mtwara Region in Tanzania (modified from PMORALG 2010) and (b) Mtwara average daily rainfall data for 2010–2014. Source: Tanzania Meteorological Agency.

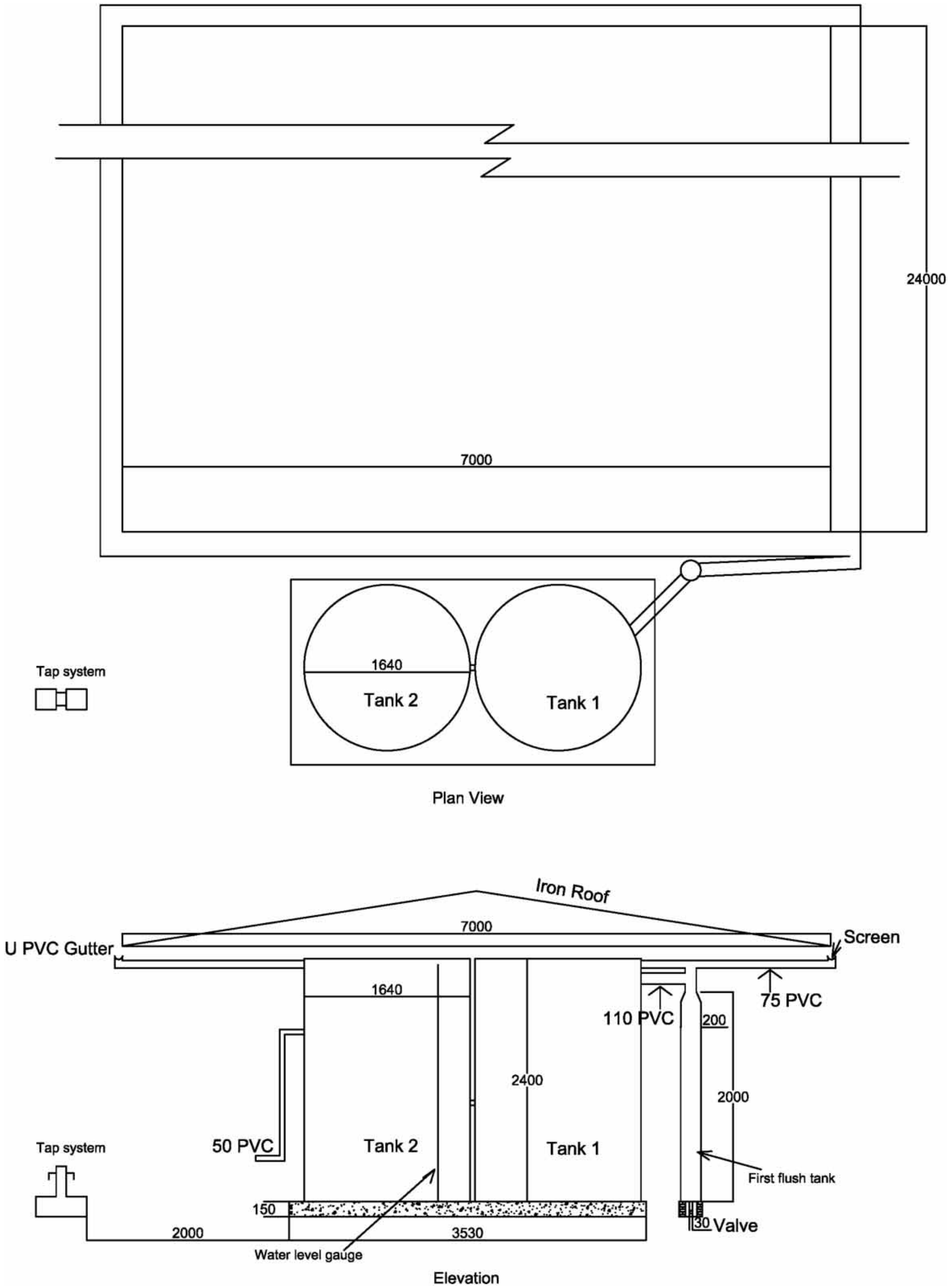

Figure 2 | Schematic of the RWH system at the Mnyundo Primary School, plan and elevation views, showing the treatment and monitoring components.

engineers (DWEs) were involved in the project planning and supervision. Local techniques were adopted, as the location was rural with no electricity supply.

The RWH system comprised six main parts (Figure 2). These are the collection system consisting of a 168 m^2 corrugated iron roof; delivery by PVC gutters and pipes; a treatment system consisting of a coarse screen, first flush tank, and sedimentation tank; storage system of two 5 m^3 plastic tanks, the first tank being used as a sedimentation tank as well as storage; the taps for supply and as washout valve; and lastly, the water level gauge for monitoring the system.

The total project cost was US$ 3,600, from which labor and material costs accounted for 14% and 86%, respectively (Table 1). Labor cost incorporates the masons and laborers involved during the mobilization and throughout the construction phase.

METHODOLOGY

Basic condition for RWH system performance analysis

Average daily rainfall data was used in the analysis (Figure 1(b)). Adopting a runoff coefficient of 0.8 for the iron roof (Thomas & Martinson 2007), the analysis was done for a population of 300. Even though it is a day school, all days of the year were included because other activities occasionally occur on weekend days and holidays. A simple daily water balance model by Mun & Han (2012) was adopted using the cumulative water storage (Equation (1)). Equations (2) and (3) represented daily demand and usage conditions.

$$V_t = V_{t-1} + Q_t - Y_t - O_t \quad (1)$$

D_t is a fixed value

Table 1 | Cost breakdown of the Mnyundo school RWH demonstration project construction

S/N	Item description	Total (TZS)	Total (US$)
1	Storage tank and gutter profile system	3,170,500	1,962.55
2	First flush tank system	114,060	70.60
3	Foundation and base slab construction	1,008,000	623.96
4	Tap water system	284,000	175.80
5	Material transportation	420,000	259.98
6	Labor cost	820,000	507.58
Grand total		5,816,560	3,600

$$\begin{aligned}&\text{For: } 0 < V_t \le S;\ V_t > S\\&Y_t = D_t;\ O_t \ge 0\end{aligned} \quad (2)$$

$$\begin{aligned}&\text{For: } V_t < 0;\ V_t = 0\\&Y_t < D_t;\ Y_t = V_{t-1} + Q_t;\ O_t = 0\end{aligned} \quad (3)$$

where V_t is the cumulative rainwater stored in the tank (L) after the end of the t^{th} day, V_{t-1} is the stored rainwater in the tank (L) at the beginning of the t^{th} day, Q_t is the harvested rainwater (L) on the t^{th} day, O_t is the overflow amount (L) on the t^{th} day, D_t is the daily rainwater demand (L) on the t^{th} day, Y_t is the rainwater supplied (L) during the t^{th} day, and S is the capacity of the rainwater tank (L).

No water days (NWD) and rainwater usage ratio (RUR) parameters introduced by Mwamila et al. (2015) were used for quantification of dry season and realization of RWH system efficiency (Equations (4) and (5)). NWD are the days in a year when the storage system contains insufficient water to meet usage demands, and the RUR is the percentage of harvested rainwater that has been consumed to meet demand.

$$\text{(i) NWD} = 1 - \sum_{t=1}^{T} \text{WD};\ \text{WD} \rightarrow \text{Y}_t = \text{D}_t \quad (4)$$

$$\text{(ii) RUR} = \frac{\text{Water usage}}{\text{Total amount of rainfall}} \times 100 = \frac{\sum_{t=1}^{T} \text{Y}_t}{\sum_{t=1}^{T} \text{Q}_t} \times 100 \quad (5)$$

SUSTAINABILITY CONSIDERATIONS

For rural water supply services, sustainability has been defined as an indefinite provision of a water service with certain agreed characteristics over time (Lockwood & Smits 2011). With that in mind, in this study it has been discussed by considering factors which indicate the likelihood of the service continuing to be provided over time.

Water supply service levels

This investigates the targeted outcome of the service being rendered, and efforts applied to maintain it.

Water quality

To attain acceptable water quality, monitoring is essential, especially when the water will be used for drinking purposes. Water samples from the RWH tanks and other preferred water sources (river and borehole) were analyzed for physical, chemical, and microbiological quality (Table 2) at the University of Dar es Salaam's water quality laboratories. All of the samples, except the one from the Mnyundo School RWH system, had total coliform counts above the recommended standard values of both Tanzania and the WHO (Table 2). By consuming such contaminated water, cases of diarrhea and other symptoms are inevitable, incurring medical costs, which further affect the economy of already poor families.

Water quantity and reliability

This is a day school, thus consumption of water is within class hours (8 am to 3 pm) and the RWH system is for drinking only in a supervised manner. The actual demand per day is considered 1 L/person. Reliability of the system at this demand is 61%, which shows its ability to supply the intended demand. It is calculated as the ratio of the number of days when the intended demand is fully met by the rainwater supply to the total number of days in the year. However, the NWD is high at 143 with RUR of 50%

Table 2 | Water quality test results for samples from available water sources around Mnyundo school (April 2013)

		Sampling source			Water quality standards	
S/N	Parameter	Mnyundo Pr. School RWHS	River	Borehole	TZ	WHO
1	pH	6.58	7.38	7.32	6.50–8.50	6.5–9.5
2	Total dissolved solids (mg/L)	18	790	830	1,000	1,000
3	Color (Pt.Co)	2.50	33	7.0	15	15
4	Total hardness (mg/L) as $CaCO_3$	8	250	270	500	200
5	Sulfate (mg/L)	2.0	84	90	400	500
6	Chloride (mg/L)	5.0	160	170	250	200–300
7	Sodium (mg/L)	1.50	10.30	18.70	200	200
8	Total coliform No/100 mL)	Nil	200	250	Nil	Nil

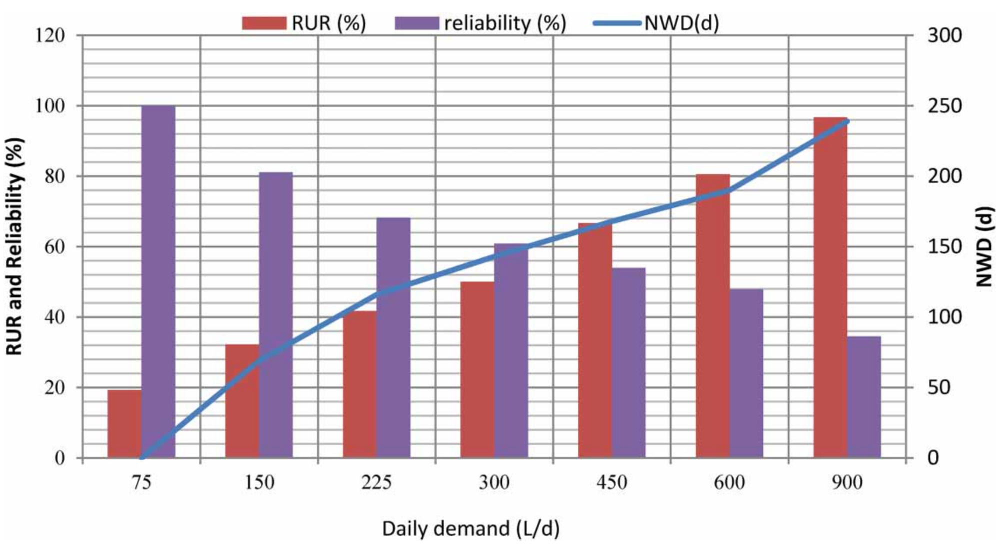

Figure 3 | Reliability, rainwater usage, and number of NWD in a year, under fixed demand conditions.

(Figure 3). Considering WHO recommendations for drinking water, i.e., 2.5–3 L/person/d (Reed et al. 2013), NWD reached 239, hence only 35% reliability but with a RUR of 97% (Figure 3).

Lower demand values would ensure higher reliability values but lower RUR due to overflow losses. Thus, the need arises to adapt the strategy of varying daily demand with respect to available water level to achieve good reliability relative to RUR (Mwamila et al. 2015).

Accessibility

The distance traveled and time spent for the previous practices to obtain water for use in the school were significant (approximately 2 km and more than 1 h, respectively), whereas now the water source is more convenient and easily available to the school for the students and teachers.

Potential for sustainability

The project sustainability potential is assessed from the technical, economic, and social perspectives.

Technical aspect

(i) Rainwater quality maintenance

Potential contaminants to the harvested rainwater include dusty particles, fecal matter from birds, and tree litter falling on rooftops. The treatment components in the RWH system (Figure 2) were included for rainwater quality maintenance as discussed below.

(a) Coarse screen

Since the dry season precedes the rainy season, dust particles, bird droppings, and leaf litter often are adhered to the roof. As the rain falls on the roof, it washes off and mixes up the contaminants, some of which will be filtered out depending on the size of the mesh openings of the screen on the gutter. The screen can be made of several types of materials including plastic or metal. For the school project, a plastic screen was used because of its high availability and low cost. Users could then manually remove the large particles that are trapped as was demonstrated during training.

(b) First flush tank

The purpose of this tank is to divert the initial rainfall, which is expected to wash out most of the contaminants adhered to the roof. Once filled, the ball inside having risen up will block the passage and incoming rainwater will continue into Tank 1 without any mixing. Generally, it is considered that the contaminant quantity will be halved with each additional millimeter of first flush (Thomas & Martinson 2007). In this project, the first flush tank is a PVC pipe with a diameter of 0.2 m and effective height of 2 m. It is capable of collecting approximately 62 L from the 168 m^2 roof, which is approximately 0.5 mm (assuming 0.8 runoff coefficient) of rain. Based on the rule stated above, the 100 NTU initial turbidity of the water moving into Tank 1 will decrease to 75 NTU. Once the rain stops, this tank should be emptied as trained by opening the brass ball valve connected to the 0.03 m pipe positioned at its bottom. A member of the school is assigned for the task.

(c) Sedimentation tank

The rainwater is diverted from the roof downpipe (0.1 m diameter) to Tank 1 after the first flush tank is full (Figure 2). Tank 1 has a capacity of 5 m^3. As the rainwater fills up the tank, the remaining particles settle down, as a function of the time spent by the rainwater in the tank. Other researchers support this settling concept (Han & Mun 2007). In this design, the pipe is connected 1 m from the tank bottom, so that once settled, water from Tank 1 will go to Tank 2. Nevertheless, particles such as silt, bacteria, and clay can be carried into Tank 2. The rainwater can be resettled in Tank 2 before the finished water is accessed through the tap located approximately 2 m away from the tanks. Withal, at the inner wall and tank bottom surfaces, biofilm will grow and remove pathogens and/or organic materials that might have entered from the roof (Kim et al. 2012).

(ii) Rainwater quantity control

As most storage tanks are not transparent, it is difficult for users to monitor the water level while consumption is ongoing. In most cases, the users only realize the water level has decreased when water stops flowing out of the tap, which is too late. Alternatively, an individual had to climb up the tank and check the water level by opening the tank cover. This is risky, considering young children may have to perform this task in the absence of capable adults.

To monitor the water level, a simple water level gauge was taped onto the outer tank wall (Figure 4(a)). The gauge was made by tying a fishing plumb to the bottom and a ball to the top of a wire, which had a length equal to the height of the tank. The wire set up was inserted into a transparent hosepipe (Figure 4(b)). The gauge functions based on a buoyancy mechanism, whereby high upward pressure occurs when the tank is full, pushing the ball upwards and the plumb down to the bottom of the hosepipe. As the tank empties, the upward pressure decreases and the ball starts to sink, pulling the plumb upwards. This allows users to monitor the water level safely. With this simple technology, users will know when to adjust their demand to save more water for future use once the rainy season is over or to prevent overflow loss during the rainy season. Figure 5(a) shows children accessing rainwater to meet their demand.

Economic aspect

The approach of securing local material, labor, and techniques, as well as relying on local material suppliers, reduces the total cost. Individual users manufacturing some materials, such as screens by using the remains of unused plastic buckets or wire mesh, can reduce the cost even further. The water level gauge attached to the tank was designed simply and assembled from cheap and locally available material including transparent hosepipe, fishing plumbs, and wire.

To address the RWH system cost, an innovative fund raising program was adopted. The program is based on the 1C1C campaign recently introduced by SNURRC that

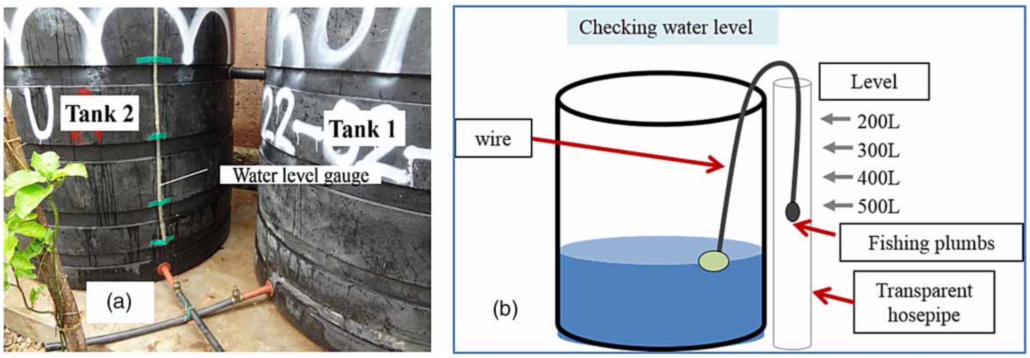

Figure 4 | (a) Water level gauge taped onto the supply Tank 2 and (b) illustrations of water level monitoring with the gauge.

Figure 5 | (a) Mnyundo students collecting rainwater for daily use and (b) Namayakata Primary School students with their RWH system.

aims to involve private sectors. The 1C1C stands for one company (1C) helping one community (1C), which in this case, is by donating a RWH system. The SNURRC donated the money to the school as their CSR. A contribution like this by a company to a social service center assures them recognition for their role in the development of the community and country, at large.

Considering system operation, some yearly expenses are expected covering minor repair costs, which are to be handled by the school community under DWE's office support.

Social aspect

An operation and maintenance manual was prepared in Swahili (dominant official language of Tanzania) and English (see Supplementary Information (available in the online version of this paper)). The school received the Swahili version for operational guidance whereas Ministry of Water (MoW) officials received the English version for replication and adoption reference for future projects. The manual contained all the necessary details of the RWH system with simple illustrations and explanations of the use and operation of the system. Furthermore, it included the contact details of the district and MoW's officials for consultation in case of any shortfalls with the system.

The SNU team provided training to the school community, as well as the villagers residing close to the school, during the day of the project hand over. The system mechanism, i.e., proper management of the system components such as screen, gutter, and tank cleaning, and operation of the first flush tank were explained. Any queries raised were addressed instantly.

The involvement of the local people in the demonstration project work ensures capacity building for conducting future similar work, and creates opportunities for self-employment in masonry work with the knowledge gained from the project. In addition, this has the potential to motivate sense of ownership for the given project hence guaranteeing good operation and maintenance.

Potential for replication

Construction work fully involved local people through labor, which has the potential for capacity building and technology transfer for an individual and community's sake as well. Future replication is possible by making use of local retailers and experienced masons.

This project investment cost (Table 1) may be high for a government-owned service center without extra income generating activities. However, this is a one-time cost, followed by operational costs that are minimal, approximately US$ 80 a year for minor repairs. There are no ongoing energy costs as a gravitational flow system is used. Regardless, for social service-oriented centers like schools and hospitals, company donations have been suggested for covering the construction costs as part of their CSR initiatives as was the case in this project.

In June 2014, a similar RWH project was constructed at the Namayakata Primary School in the same district (Figure 5(b)). The school has 320 students, and a 140 m^2 roof was used. This work was handled by the community themselves. The funding mechanism was co-financing (equal cost sharing) by the district office, and the Korean company which used the project as their CSR.

CONCLUSION

A RWH demonstration project was constructed at the Mnyundo Primary School in Tanzania, which like many schools in rural areas, suffered from water shortage. The system has been evaluated for sustainability in technical, economic, and social aspects.

By incorporating a coarse filter, first flush tank, sedimentation tank, and a water level gauge, which are simple to handle, manage, and reproduce, a better water supply service level was ensured in comparison to currently relied upon distant sources. The quality of accessed rainwater is improved with particle load reduction, quantity is controllable through water level monitoring, and the source is convenient.

Through financially supporting the initial investment cost, the system was made affordable. Company involvement, as CSR, is encouraged for improving water availability in social service centers. Also, local material, labor, and techniques reduce the cost even further and offer the potential for replication under local supervision.

Socially, capacity building and a sense of ownership was instilled through familiarization training, full involvement of the beneficiaries with labor contributions, and operation and maintenance manual provision.

Finally, using schools as locations for RWH demonstration projects allows the possibility of higher future impact by affecting the younger generation and surrounding community. Therefore, for sustainable solutions to water shortages similar work is encouraged.

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REFERENCES

Han, M. Y. & Mun, J. S. 2007 Particle behaviour consideration to maximize the settling capacity of rainwater storage tanks. *Water Science & Technology* **56** (11), 73–79.

Kim, M., Ravault, J., Han, M. Y. & Kim, K. 2012 Impact of the surface characteristics of rainwater tank material on biofilm development. *Water Science & Technology* **66** (6), 1225–1230.

Lockwood, H. & Smits, S. 2011 *Supporting Rural Water Supply Moving Towards A Service Delivery Approach.* Practical Action Publishing Ltd, Rugby, UK.

Malesu, M., Khaka, E., Mati, B., Oduor, A., Bock, T. D., Nyabenge, M. & Oduor, V. 2006 *Mapping the Potential of Rainwater Harvesting Technologies in Africa: A GIS Overview on Development Domains for the Continent and Nine Selected Countries.* Technical Manual No. 7. World Agroforestry Centre (ICRAF), Netherlands Ministry of Foreign Affairs, Nairobi, Kenya.

MoW 2014 Randama ya mpango na bajeti ya wizara ya maji kwa mwaka 2014/2015- Fungu 49. *[Ministry of Water Budget Memorandum for Financial Year 2014/2015; Vote 49]*, Ministry of Water (MoW), Dar es Salaam, Tanzania.

MoWI 2008 *National Water Sector Development Strategy – 2006 to 2015*, Ministry of Water and Irrigation. Available at: http://maji.go.tz/sites/default/files/u12/natinalwaterstrategy1.pdf.

Mun, J. S. & Han, M. Y. 2012 Design and operational parameters of a rooftop rainwater harvesting system: definition, sensitivity and verification. *Journal of Environmental Management* **93** (1), 147–153.

Mwamila, T. B., Han, M. Y. & Ndomba, P. M. 2015 Tackling rainwater shortages during dry seasons using a socio-technical operational strategy. *Water Science & Technology: Water Supply* **15** (5), 974–980.

Ndomba, P. M. & Wambura, F. J. 2010 Reliability of rainwater harvesting systems in suburbs. A case study of changanyikeni in Dar es Salaam, Tanzania. *Nile Basin Water Science & Engineering* **3** (3), 72–85.

Nguyen, D. C., Dao, A. D., Kim, T. I. & Han, M. Y. 2013 A sustainability assessment of the rainwater harvesting system for drinking water supply: a case study of Cukhe village, Hanoi, Vietnam. *Environmental Engineering Research* **18** (2), 109–114.

PMORALG 2010 Prime Minister's Office Regional Administration and Local Government. Tanzania. Available at: http://www.pmoralg.go.tz/lginformation/perfmap1.php (accessed 13 June 2015).

Reed, B., Shaw, R. & Chatterton, K. 2013 *Technical Notes on Drinking Water, Sanitation and Hygiene in Emergencies.* WHO/WEDC, Loughborough, UK.

Rodrigo, S., Leder, K. & Sinclair, M. 2009 *Quality of Stored Rainwater Used for Drinking in Metropolitan South Australia.* Research, 84. E.P.M. Monash University, Melbourne, Victoria, Australia.

Smedley, P. 2004 *Groundwater Quality: Tanzania.* British Geological Survey, Nottingham, UK.

Temesgen, T., Han, M. Y., Park, H. & Kim, T. I. 2015 Design and technical evaluation of improved rainwater harvesting system on a university building in Ethiopia. *Water Science and Technology: Water Supply* **15** (6), 1220–1227.

Thomas, T. H. & Martinson, D. B. 2007 *Roofwater Harvesting: A Handbook for Practitioners.* IRC International Water and Sanitation Centre, Delft, The Netherlands.

Worm, J. & Hattum, T. V. 2006 *Rainwater Harvesting for Domestic Use.* Agromisa Foundation and CTA, Wageningen, The Netherlands.

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