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I will forever be grateful to my family (husband Yuda, son Jonathan and daughter Ruth), for their love, support, prayers, patience, critics, encouragement and for being with me.

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May our Lord Jesus and God bless you all abundantly and guide your ways always.

I am dedicating this research to my country Tanzania for sustainable water supply with Rainwater Harvesting.

Nomenclature

CSR – Corporate Social Responsibility

DSM – Dar es Salaam

DWEs – District Water Engineers

GoT – Government of Tanzania

GW/GWH – Groundwater/Groundwater Harvesting

LGA – Local Government Authority

MoW/MoWI - Ministry of Water/ Ministry of Water and Irrigation

NAWAPO – National Water Policy

NGOs – Nongovernmental Organizations

NWD – No Water Days

RUR – Rainwater Usage Ratio

RW/RWH – Rainwater/ Rainwater Harvesting

SNURRC – Seoul National University Rainwater Research Center

SW – Surface Water

TC – Total Coliform

TMA – Tanzania Meteorological Agency

VICOBA – Village Community Bank

WC – Water Committees

WD – Water Days

WSSR – Water Self Sufficiency Ratio

DISSERTATION ORGANIZATION

This dissertation consists of seven chapters as summarized in Figure 1. Chapter 1 introduces the study, offering a general description of water supply status in Tanzania specifically and in Africa as a whole, as well as research objectives and significance. Chapter 2 summarizes a collection of literature reviews, describing the trend in and status of RWH technology abroad and in Tanzania. Chapter 3 offers insight to innovative approaches that would boost sustainability potential of community-based RWH technology in Tanzania. Chapter 4 explains the role that RWH technology can have in improving household water supply practices in Tanzania. Chapter 5 offers an assessment on the potential for RWH technology in Tanzania. Chapter 6 maps out a way forward to sustainable water supply with RWH in Tanzania. Lastly, Chapter 7 gives overall conclusions of the study and recommendations for further work.

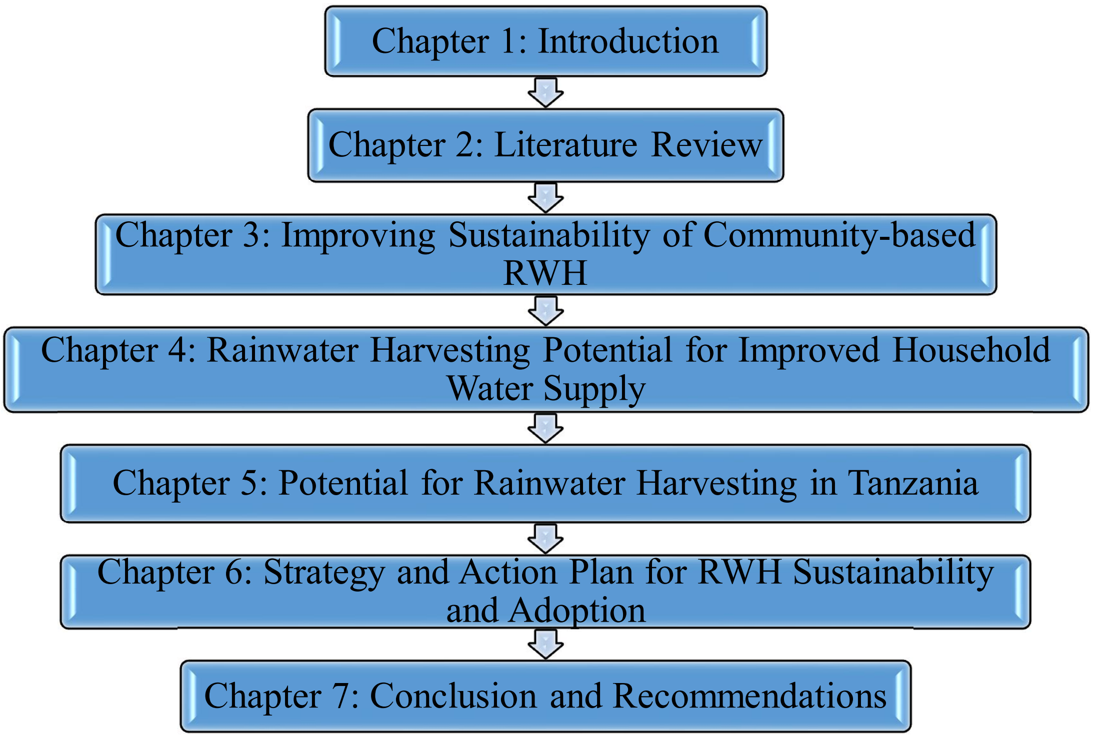


Figure 1: Dissertation structure

CHAPTER 1:

Introduction

1.1 Background

The continent of Africa comprises 54 countries, and 16% of the global population, wh ich makes it the second most populated continent (UN 2015). A third of the continent's popul ation, is living in a water scarcity situation. To address this, the Africa Water Vision 2025 wa s established, which highlighted that underdevelopment and low water resources usage in Afr ica was due to poor financing and technology but not inadequacy of available water resources. This has been reflected in its low withdrawal for its major water uses of agriculture, commun ity water supply and industry (only 0.7% and 3.8% of rainfall and internal renewable water re sources, respectively). However, poor spatial and temporal distribution of renewable freshwat er sources has also been identified as a challenge. Although improvement in rainwater (RW) conservation has been suggested among potential solutions (Malesu *et al.* 2006), it has not be en incorporated within the Vision' framework for action. In addition, it has not been consider ed in need of development among nonconventional resources. Rainwater harvesting (RWH) c an be incorporated with existing appropriate technologies, considering that it has low cost and is capable of performing with low technology and in a decentralized manner.

Tanzania is an east African country located between longitudes 29° and 41° east and latitudes 1° and 12° south (Figure 2), with a total area of 945,454 km^2. As of 2012, its population was 44.9 million (NBS 2013). The Tanzanian Development Vision 2025 targets high quality livelihood attainment for Tanzanians, and universal access to safe water is one of the Vision's goals. Having access to safe water affects other goals such as food self-sufficiency and security, poverty reduction, and improved health.

Even though Tanzania is recognized as a country with abundant annual renewable water resources of approximately 89 km^3 (MoW 2014a) and annual rainfall ranging from 400 to 2000 mm, the country still suffers water shortages. Low drinking water service coverage (within 400 m), which is 40% and 74% in rural and urban areas, respectively (NBS 2011), poor water quality, and malfunctioning water points are among the water problems.

Figure 2: Location map of Tanzania and its regions (Modified from PMORALG 2010)

Marobhe's review (2008) on Tanzanian water supply services through case studies at the urban and rural levels led to a number of revelations on the slow progress in supply coverage. For the urban case, the review cited poor technical maintenance leading to massive leakages and poor economic strategies resulting in increased dependence on external financial support. In the rural water cases, lack of skilled human resources and experienced local institutions, poor operation and maintenance of water points, and, in some areas, poor contribution to the water fund due to poor economic and an attitude that water should be free based on past governmental approaches, were stated. Dismally limited service coverage forces people to rely on unprotected sources, which risk their health. In terms of water quality, the main surface water (SW) quality concerns include color, turbidity, fluoride, and bacterial contamination, whereas groundwater (GW) quality concerns include isolated cases of fluoride, salinity, and iron. High salinity levels are usually found along the coastal areas due to saline water intrusion. High fluoride occurs more severely and widely within the rift zones in the north and southwest, and in the crystalline basement complex of the central plateau, with values greater than 8 mg/L in some areas (GCBP and SRK 2002, Smedley 2004, MoWI 2008). Moreover, as of 2014, only 54% of water points installed countrywide were functional (Figure 3). The other 7% were capable of functioning but needed repair first and 39% had malfunctioned. Over the years, the highest number of water points ever constructed was 23,751(considering all regions), within 2001 – 2010. Many factors, attribute to water point malfunctioning including poor operation and maintenance. Within Tanzania, Mtwara Region had the highest percentage of nonfunctioning water points at 62% (MoWI 2014).

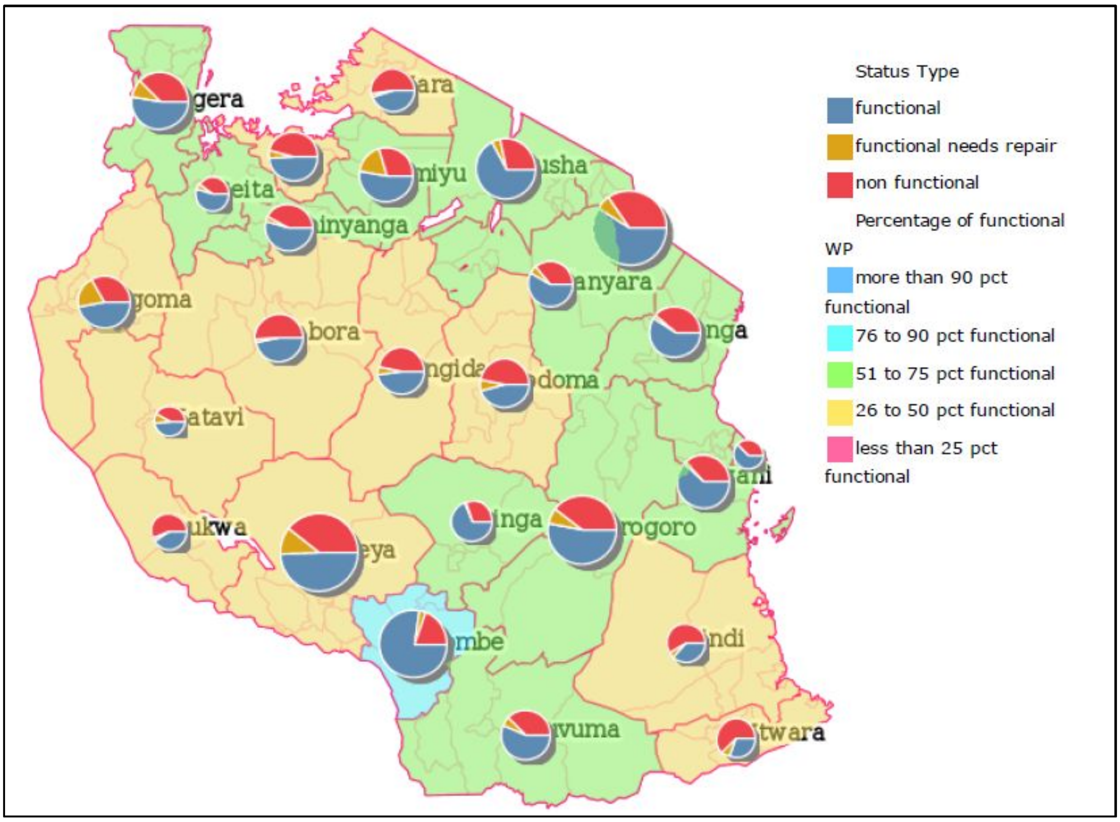


Figure 3: Water point status in the country (MoW 2014)

Water supply problems and barriers in Tanzania have been summarized from the technical, economic and social perspective (Table 1). Problems and barriers contribute to the degradation and hinder the progress, respectively, of the water supply service.

Table 1: A summary of problems and barriers of water supply in Tanzania

Perspective	Problems	Barriers
Technical	• Over and underutilization of water resources • Reliance on obsolete infrastructures • Inadequate management of water resources including catchment • Limited technical skills	• Non-uniform distribution of water resources in terms of time and space, quality and quantity • Topographical and climate variability • Limited climate change adaptation/restoration measures
Economical	• Inadequate water infrastructures • Limited funds for effective exploration of resources • Limited implementation of financial boosting strategies • Limited water revenue collection for infrastructure servicing • Illegal water abstractions	• Increased social-economic activities (domestic, industrial, agriculture, mining, livestock, power supply) • Limited financial and human resources/experts • Limited local technical support firms for adopted technologies • Increased water polluting activities
Social	• Limited awareness on potential alternatives to traditional water sources (springs, lakes, dams) • Limited implementation of water harvesting technologies • Water use conflicts (pastoralist vs farmers, hydropower vs irrigators)	• Population growth • Free water attitude • High installation cost for RWH technologies

In an effort to address daily water supply challenges, local citizen initiatives have included citizens developing their own water catchment systems by either digging wells or building crude RWH systems. Despite some reduction in water scarcity challenges, these sources are unreliable because they have low quality and insufficient quantity especially during the dry season, are victims of the whims of nature, and have infrastructures that may perform below standards.

In the past, the government has focused on developing large and centralized infrastructures for the management of water resources. These infrastructures have relied on rivers and reservoirs (natural and manmade), involving water capturing and purifying in large treatment centers and delivery through pipelines. However, this infrastructure has the challenges of requiring a huge support system for efficient performance, and coverage is limited mostly to urban areas.

A revised version of the national water policy (MWLD 2002) was introduced with the objective of developing a comprehensive framework for sustainable development and management of the nation's water resources. The main shortfall of the previous policy from 1991 was identified as the major reliance placed on the central government as the sole investor, implementer, and manager of the rural and urban projects and protector of water sources. In addition, new policy formation and revisions were prompted by poor performance of past water supply projects. A well-documented case occurred in 1971 when only 46% water service coverage resulted from the initiated 20 year rural water supply programme. Contributing factors to the poor performance were summed up as limited involvement of the beneficiaries, use of inappropriate technologies, use of a top-down approach, and lack of decentralization. Furthermore, water was regarded a freely supplied commodity. In a study that investigated 13 countries, included the USA and some African and South Asian countries, it was determined that an average of 30 – 40% of rural water projects failed due to similar reasons (Lockwood and Smits 2011). Hence, the aim of the current policy is to ensure full participation of beneficiaries in the planning, construction, operation, maintenance, and management of the community-based domestic water supply schemes.

As a result, community-based GW supply systems have been facilitated, including wells and springs. However, these also have challenges. Firstly, under current regulations a water point is constructed to serve domestic purposes of a population within 400 m, so some citizens will still have to walk this far. Secondly, the approach whereby village leaders had been responsible for maintaining water supply systems, in some cases, had made it difficult for villagers to use the water freely because it was being managed conservatively, undemocratically, and, at times in an ad hoc manner. Thirdly, the currently promoted management approaches, including water committees, community-owned water supply organizations, and water user groups need to be formalized and recognized under local government bylaws and national legislations for eligibility and empowerment. However, water shortages are likely to occur sporadically due to the overexploitation of the sources, water contamination, power interruptions, system malfunctioning, and/or a limited supply chain.

Therefore, new innovative ideas are required to solve the aforementioned challenges and to maintain the familiar community-based approach and decentralization. RWH fits these requirements, but its adoption as a water source is still limited in Tanzania, despite being clean, free of charge, and without territorial conflict. The major challenges of current RWH practices in Tanzania include, high investment cost, dry season insufficiency, quality maintenance, and system maintenance. Nevertheless, current advancement within the technical, social, and economic aspects can make rooftop RWH a better and more sustainable alternative technology. The proposed RWH technology can achieve the following:

- Under proper management and maintenance, the proposed RWH technology can supplement or replace the centralized, community based GW- and individual based-systems, and address their shortcomings.
- Water quantity can be estimated and predicted through modeling and monitoring strategies based on rainfall data, storage, and usage.
- Water quality can be safely maintained through simple treatment and maintenance measures.

- The harvesting system can be constructed and maintained easily at low cost by using local labor, materials and techniques.

Therefore, in this research, the potential of RWH to address current water supply challenges in Tanzania was explored through case studies at the community and household levels.

1.2 Research significance

In 2001, average annual water availability per capita was 2700 m^3, whereas, in 2012, it was 2000 m^3. A further decrease of 30% of the 2012 value, resulting in an average annual availability per capita of 1400 m^3 in 2025, is predicted due to population growth and water resources diminution (MoW 2014a). Therefore, the country is trending towards water stressed conditions and requires an inclusive resolution to avoid this projected outcome. Unlike the current water sources in the country, RW is freely available to everybody whenever it rains. However, RWH technology has a low adoption rate to date, and where it is practiced, challenges have been raised. Regardless, high decentralization potential of the RWH technology can empower individuals to address their own water challenges more conveniently, with proper management and guidance. During this research, the potential of RWH to address current water supply challenges was explored through a review of case studies in Tanzania.

1.3 Research objectives

The goals of this research were to:

1. Improve the sustainability of community-based RWH technology in Tanzania,
2. Establish RWH technology potential to improve household water supply practices in Tanzania,
3. Assess potential for RWH technology adoption in Tanzania, and

4. Propose an action and work plan for achieving sustainability and increased adoption in RWH technology in Tanzania.

CHAPTER 2:

Literature Review

2.1 Rainwater harvesting history

In terms of water harvesting and management, immense wisdom has existed in different countries since ancient times. Technologies, such as qanats, which are artificial underground water channeling systems installed up to 305 m below the Earth's surface, bring a continual stream of water to the Earth's surface for agricultural and domestic uses. The Persians used qanats more than 3,000 years (Mohsen *et al.* 2013). This technique later spread to northern African countries such as Egypt. Similar techniques were used in other countries, such as foggara in Libya, Tunisia, and Algeria and khettara in Morocco (Hydria 2009, UNESCO). Despite being in arid and semiarid sub regions with, at most, 10% of these areas receiving more than 300 mm of rainfall annually (FAO 2000), these techniques ensured sufficient water supply throughout the year. Thus, regardless of the rainfall quantity, RW can be harvested, and with proper management, it can contribute partially and/or fully to serving water demand.

Archeological evidence attests to the capture of RW as far back as 4,000 years ago, and the concept of RWH in China may date back 6,000 years. Ruins of cisterns built as early as 2000 B.C. for storing runoff from hillsides for agricultural and domestic purposes are still standing in Israel (Texas 2005). The world's first RW gauge known as Chuk-u-gi was invented in A.D. 1441 during the Chosun dynasty in Korea by King Sejong the Great. As a result, despite some destruction in the past, 250 years of rainfall records still remain (Han and Park 2009).

Indigenous knowledge also has existed in Tanzania for utilizing RW, especially for agricultural purposes. Water storage structures (known locally as ndiva) in Kilimanjaro Region (Figure 4), excavated bunded basins (known locally as majaluba) in the lake zone, and raised broad basins (known locally as vinyungu) in Iringa Region have been used to harvest RW. These systems have been sustainable for centuries due to their compatibility with local lifestyles, institutional patterns, and social systems (Mbilinyi *et al*. 2005). To develop sustainable RWH strategies, it is important to take into account and learn from what local people already know and incorporate, and build on this knowledge.

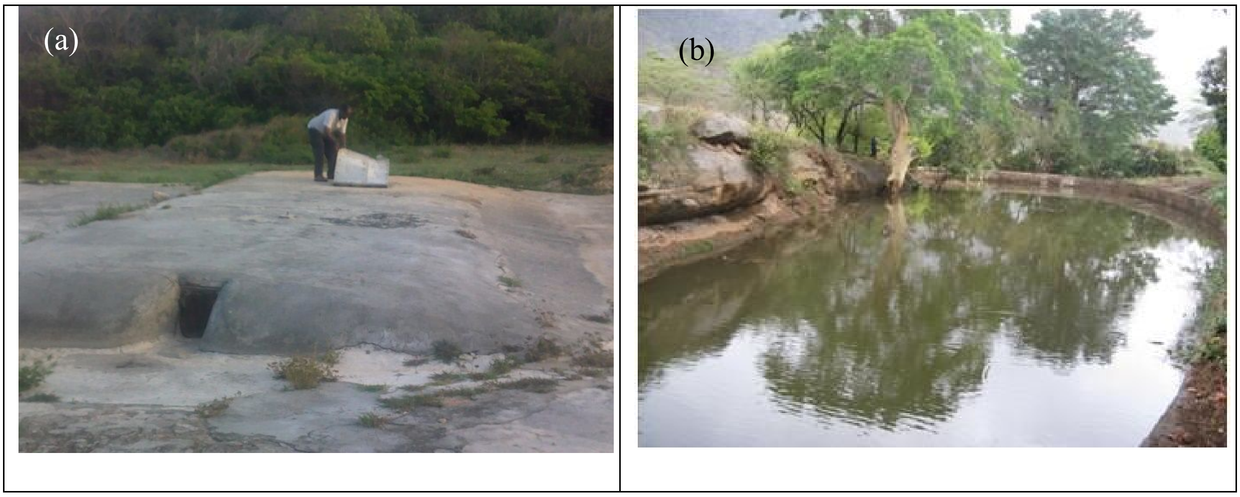


Figure 4: (a) Runoff harvesting into an underground reservoir in Pwani Region, and (b) open reservoir known as Ndiva in Kilimanjaro Region, Tanzania

2.2 Rainwater harvesting interventional roles

RWH has been suggested as a main component in the new water paradigm, which is an idea meant to help reverse the current trend in extreme weather effects due to climate change. The new water paradigm develops, utilizes, and supports overland RWH and conservation of RW in watersheds so that ecosystems can produce enough good quality water for human and wildlife needs; purify polluted water; reduce the risk of natural disasters like floods, droughts, and fires; stabilize the climate; strengthen biodiversity; and become a component of economically sustainable development programs (Kravcik *et al.* 2008). Thus, the need for promoting in situ and ex situ RWH interventions arises. In situ interventions include soil management strategies that enhance rainfall infiltration and reduce surface runoff, whereas ex situ interventions include RWH capture areas such as rooftops, road surfaces, rock catchments into external water storage areas such as storage tanks, and ponds (UNEP 2009). RWH interventions have been successful in upgrading societies, such as Gansu in China, and the Slovak Republic, that have experienced drought, flood, low annual precipitation, poor agricultural production, and poor domestic water supply (Zhu 2008, Kravcik *et al.*2012).

Furthermore, RWH can play both direct and indirect roles in achieving a number of the Millennium Development Goals (MDG), especially in areas of basic human needs and health (UNEP 2009). For instance, improved agricultural production can end poverty and hunger; increased water availability can improve gender equality; better domestic water supply and sanitation practices can improve the health of children; and enhanced ecosystem productivity, freshwater provisions, and GW recharging can improve environmental sustainability.

In the 2014 World Water Week, a group of scientists and experts made a declaration to United Nations General Assembly to add to any Hunger Goal a target on sustainable and resilient RW management. This is for improved food production aiming for an increase of over 50% in the yield of food per unit of RW through the adoption of sustainable watershed management practices at all scales (RWH declaration 2014).

Additionally, the sustainability potential of domestic RWH projects was shown through recent case studies in Tanzania, Ethiopia, and Vietnam (Nguyen *et al.* 2013, Mwamila *et al.* 2016, Temesgen *et al.* 2015). Furthermore, UN-Habitat (2005) has compiled a list of successful case studies of RWH from around the world for both domestic and agricultural purposes, which can serve as guides for future projects.0

2.3 Rainwater quantity potential

RW quantity sufficiency is determined by several factors including rainfall amount (I) and variance, catchment size (A), runoff coefficient (C) of a given catchment, demand of a served population, and storage size. The runoff coefficient has been studied for different kinds of roof catchments (Table 2). The runoff coefficient is meant to incorporate the effect of evaporation, infiltration, and any additional water loss. Additional loss can occur through spills and leaks resulting from poor positioning and/or sizing of gutters and/or pipes. Equation 2.1 is used to determine the volume of harvestable RW in a given period of time (Q_t), where t is the period of time and I_t is the direct precipitation on the given period of time. Equation 2.2 shows a typical mass balance of RW in a storage system, and its parameters are illustrated in Figure 5.

Table 2: Runoff coefficient proposed for different roofing types

Roof type	**Thomas&Martinson 2007**	**Worm&Hattum 2006**
Galvanised iron	>0.9	>0.9
Tile (glazed)	0.6-0.9	0.6-0.9
Asbestos	0.8-0.9	Not done
Organic (thatch, palm)	0.2	0.2
Aluminiun	Not done	0.8-0.9

$$Q_t = C \times I_t \times A \qquad (2.1)$$

$$V_t = V_{t-1} + Q_t - Y_t - O_t \qquad (2.2)$$

In situations of limited storage or catchment size and/or financial support, demand variation strategies are recommended for ensuring water quantity sufficiency even during the dry season (Thomas and Martinson 2007, Mwamila *et al.* 2015).

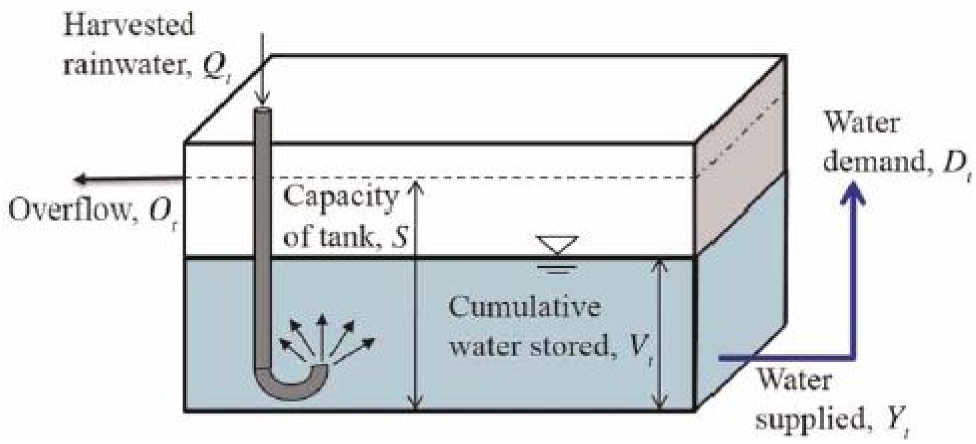


Figure 5: Schematic diagram of rainwater fluctuation in the tank (Nguyen and Han 2013)

Several researchers have developed models for optimal sizing of new storage tanks and assessment of old ones (Ndomba and Wambura 2010, Campisano and Modica 2012, Mun and Han 2012, Imteaz *et al*. 2012, Katambara 2013). Most of the analyses were performed with considerations of fixed demand throughout the year. However, during conditions of low demand, the system reliability (defined as the percentage of times when the demand is fully met) may be higher but with lower RW usage due to overflow losses. On the other hand, if higher demand is maintained then there is a smaller probability of saving water for meeting the dry season demand. Because of this and bearing in mind that, by nature, rainfall is usually variable. Nguyen and Han (2013) introduced a different approach, whereby the daily demand is varied in such a way that it cannot be lower or higher than the defined minimum and maximum demand values respectively. During the rainy season, the demand is increased to include the water in excess of the storage capacity, ensuring no overflow, whereas for the days when the cumulative water stored is less than the storage capacity, the demand should be minimal to allow the supply to last to cover the dry days. Nevertheless, in some cases, especially those with limited rainfall, considerations for dual water supply may be necessary for meeting the demand. This was the case for Cukhe, Vietnam, where the village had to rely on both RWH and groundwater harvesting (GWH) (Nguyen and Han

2013). Henceforth, it is good to note that rainfall, whenever it falls, can be managed to fully or partially serve the demand, and maximum RW utilization should be targeted.

Although shorter time interval data (e.g., daily rainfall data) is recommended for more accurate modeling results, it is much easier to access monthly rainfall data instead for most African countries due to factors including incompleteness (missing data) and high cost of daily data. Unfortunately, Zaag (2000) showed that monthly data tends to underestimate required storage capacity for a given reliability.

2.4 Rainwater quality potential

RW is valued for its purity, softness, and nearly neutral pH and because it is free from disinfection by-products, salts, minerals, and other natural and man-made contaminants (Texas 2005). RW quality tends to deteriorate as it is exposed to airborne residues, especially in industrial areas. RW quality may worsen depending on the condition of the collection and storage surfaces (Mayo and Mashauri 1991, Texas 2005, Lee *et al*. 2011). Roof type and condition affect the RW quality (WHO 2008), as does the roof location, where the RW may be exposed to wind, tree litter, the droppings of animals and birds, and microorganisms. Metal, concrete tile, and cool roofs, roofings, have been recommended as the best for RWH for domestic purposes, considering the physical, chemical, and microbiological effects, whereas asphalt shingles, green, thatched, and palm roofs are not recommended (Texas 2005, Thomas and Martinson 2007, Mendez *et al*. 2011, Lee *et al*. 2012, Amin *et al.* 2013). Chapman *et al.* (2006) argued that water from RW tanks is unlikely to cause chemically related health problems if consumed, but they warned against use of RW in hot water systems due high lead level detected. Salleh's (2009) article on lead contamination recommended removing the lead from the roof; covering the roof with lead-free paint; using a floating outlet, ion exchange filter, or concrete tank; or flushing out the pipes before drinking. Floating outlets take water from the surface circumventing the lead because, as a heavy metal, lead tends to sink. Concrete tanks keep the pH of the water alkaline, which causes lead to precipitate out of the water, unlike plastic tanks, which cause the water to have a lower pH, and therefore keep the lead soluble. Additionally, water treatment processes of flocculation, settlement, sorption and bio-reaction operate in RW storages and improves quality of stored RW (Coombes 2015).

Furthermore, Sanchez *et al.* (2015) in their extensive review of scientific and technical works on physicochemical and microbiological contamination of RW in urban areas, concluded that RW needed to be treated before drinking. They also proposed that the quality of RW harvested from roofs is the sum of three main stages: i) rainfall washes out the urban atmosphere and scavenges contaminants from aerosols, gases, and thin volatile particles; ii) catchment contamination due to the RW washing off particles settled on the roof and scavenging roofing materials; and iii) first flush, storage and plumbing system, where some physical processes can also improve RW quality. In their review, Gwenzi *et al*. (2015) had similar comments regarding rooftop harvested RW quality contamination. They highlighted that data availability on roof water quality from sub-Saharan Africa is limited, and data on the traditional roofing materials that are still used in developing countries is lacking. They pointed out on the need for studies linking RW quality from various roof types to disease outbreaks.

Over the years, several pretreatment and post treatment methods have been studied and recommended to ensure that the end user has no/low risk of contamination, as briefly discussed below.

2.4.1 Pretreatment methods

Coarse screen, first flush tank, and storage system design strategies are proposed to tactically offer pretreatment services in RWH practices. Moreover, it is recommended that tanks should be above ground or located at least 50 feet (15.24 m) away from animal stables if they are underground (Texas 2005).

2.4.1.1 Coarse screen

For capturing leaf litter and debris, a coarse screen may be placed along the gutter or in the downspout, contributing to reduced particle quantity into the first flush tank (Texas 2005, Worm and Hattum 2006, Martinson and Thomas 2007). The coarse screen needs frequent monitoring to prevent clogging. Having only screens/filters may be insufficient in significantly improving quality of RW (Amin *et al.* 2013).

2.4.1.2 First flush tank

The purpose of a first flush tank is to divert the initial rainfall. Previous researchers have proven the capability of a first flush tank in washing out most of the contaminants, both physicochemical as well as microbiological parameters, that are adhered to the roof (Texas 2005, Doyle 2008, Amin and Alazba 2011, Gikas and Tsihrintzis 2012, Amin *et al.* 2013). Several factors influence how to determine the effective size of the first flush tank volume including the slope and smoothness of the collection surface, intensity of the rain event, length of time between events which increases the amount of accumulated contaminants, and the nature of the contaminants themselves (Texas 2005). Based on field observations and laboratory experiments, Coombes (2015) discovered that a first flush device designed to capture the first 0.25 mm of roof runoff could remove 11% – 94% of dissolved solids and 62% – 97% of suspended solids from the first flush runoff into a RW tank, limiting the inflow of chemicals and metals. Generally, it seems that the quantity of a contaminant (dissolved and suspended material) will be halved (Table 3) with each additional millimeter of first flush that is diverted (Martinson and Thomas 2005, Thomas and Martinson 2007). An additional recommendation is to divert water if rainfall follows at least three dry days.

Table 3: Recommended first flush amounts (in mm rainfall) (Thomas and Martinson 2007)

Initial run-off turbidity (NTU)	Target turbidity (NTU)			
	50	**20**	**10**	**5**
50	0	1.5	2.5	3.5
100	1	2.5	3.5	4.5
200	2	3.5	4.5	5.5
500	3.5	4.5	5.5	6.5
1,000	4.5	5.5	6.5	7.5
2,000	5.5	6.5	7.5	8.5

2.4.1.3 Role of sedimentation

RW tank design considerations can also improve stored RW quality. This is due to enhanced sedimentation and biofilm development because of retention time, longer flow paths, and presence of internal walls/baffles (Amin *et al*. 2013). Han and Mun (2007) investigated the effect of retention time, distance between inlet and outlet, and water supply (access) level. They recommended that an adequate distance between the inlet and outlet would increase removal efficiency of particles because they will be settling as the water moves along the flow path. Han and Mun also showed that higher retention times resulted in significant reduction of particles. Hence, they recommended a retention time of more than 24 hours. Additionally, these researchers showed that accessing water at top layers resulted in water with lower particle concentrations, due to settling effect whereby particles tend to accumulate at levels close to the bottom. Amin *et al*. (2013) also found this to be true. Coombes *et al*. (2006) found that there was an accumulation of lead and iron in samples taken from the sludge at the bottom of tanks, supporting their assumption that contaminants settle at the bottom of tanks.

A calm inlet into the storage tank should be used to ensure minimum/no resuspension of already settled particles, and the RW should be drawn from near the water surface in the tank by using a floating suction device to avoid removing settled contaminants (Figure 6).

2.4.1.4 Role of biofilm

On the tank's inner wall and bottom surfaces, biofilm grows and adsorbs heavy metals, organics, and pathogens from the water (Amin and Alazba 2011). A study on biofilm development and performance in RW storage tanks concluded that a larger surface area to volume ratio contributes to improved microbiological quality (Kim *et al.* 2011). Moreover, Kim *et al*. (2012) studied the impact of using common construction materials (concrete, clay, and PVC) for RW tanks on biofilm development and attachment. They established that clay and PVC were favorable for the initial attachment of biofilm, but concrete provided a better support on a long-term basis. Concrete had the highest degree of roughness, resulting in greater surface area and hence a favorable site for colonization. Moreover, in an elemental analysis using high resolution ICP-MS, Coombes *et al*. (2006) saw an accumulation of metals including lead, zinc, copper, manganese, chromium, mercury, and arsenic in biofilms. Coombes (2015) further suggested that RW storages are bioreactors with biofilms at the water surface micro layer, on internal walls and at the bottom as sludge. He recommended that stored RW should not be drawn from the bottom 100 mm of the RW tank to maximize the quality of water by avoiding sludge disturbances. In addition, frequent cleaning of the RW storage tanks is not recommended to allow the biofilm to remain established and performing well. Furthermore, the pump inlet should be positioned above the potential biofilm growth area. Figure 6 illustrates technical innovations in RW storage tank design for enhancing particle removal.

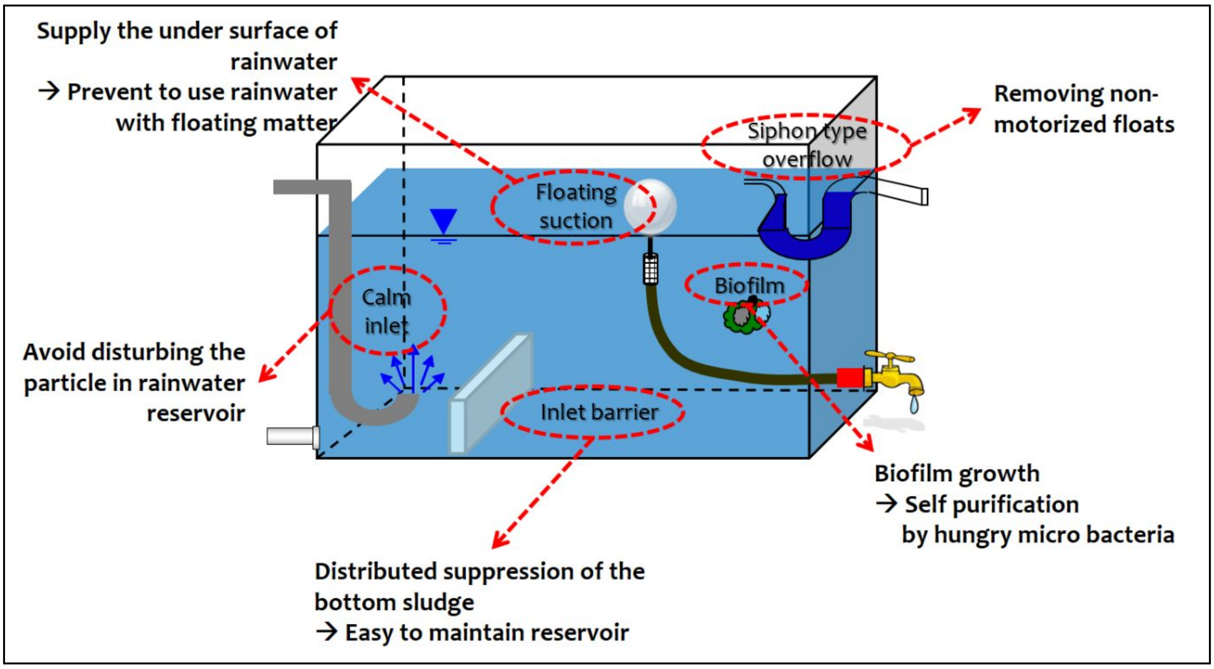


Figure 6: Technical innovation in particle removal from rainwater (Credit: Prof. M.Y. Han)

2.4.2 Posttreatment methods

Household water treatment may be applied to RW for more assurance of the user's health and safety. These treatments may include chemical disinfection; membrane, porous ceramic, or composite filters; granular media filters; solar disinfection (SODIS); UV light technologies; thermal technologies; and coagulation, precipitation, and/or sedimentation (WHO 2008). Each of these may have sustainability challenges considering treatment efficiency, technology cost, ease of use, time consumption, energy demand, and supply chain (Sobsey *et al*. 2008). SODIS and point-of-use chlorination have been suggested as low cost disinfection techniques for stored RW (WHO 2008).

Precautions are needed for chlorination of RW harvested from asphalt shingles and green rooftops due to high concentrations of dissolved organic carbon, which could lead to high concentrations of disinfection by-products (Mendez *et al*. 2011).

The performance of SODIS was evaluated based on criteria including PET bottle condition and handling, sunlight exposure time, sunlight magnitude (temperature and radiation effects), turbidity level and pH of the RW, backing surface effect, and microbial regrowth (Amin and Han 2009a, b). A solar collector enhanced the efficiency of SODIS in microbial inactivation up to 30% (as a result of concentrated effects of sunlight radiation and synergistic effects of thermal and optical inactivation), ensuring complete disinfection in not only strong (irradiance range 650 – 1000 W/m^2) but also moderate (350 – 700 W/m^2) weather conditions. In addition, reflective surfaces were better than absorptive and simple surfaces. Furthermore, acidic condition of RW with turbidity levels less than 20 NTU showed better results. Food product use, such as lemon and vinegar as catalysts, enhanced the performance of SODIS and resulted in complete disinfection of RW even under weak weather conditions (100 – 400 W/m^2) with solar collectors (Amin and Han 2011). In their review of SODIS technology mechanisms, application, and adoption, McGuigan *et al*. (2012) acknowledged that SODIS is effective against almost all waterborne microbial pathogens, and it can reduce household finances by reducing fuel, morbidity, and illness-related costs.

Therefore, with low cost technology, RWH can provide high quality water for potable purposes as illustrated in Figure 7.

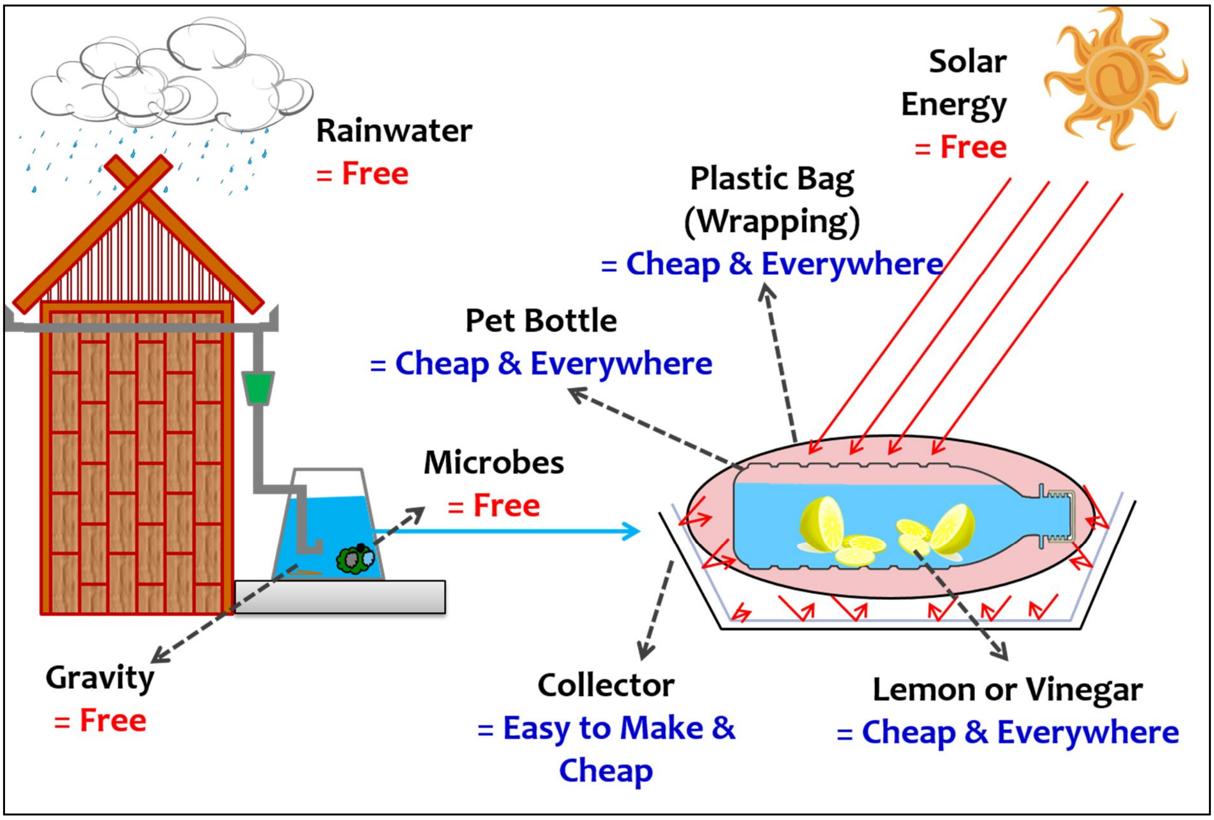


Figure 7: Rainwater harvesting with affordable technical innovations for enhanced water quality (Credit: Prof. M.Y. Han)

2.5 Rainwater harvesting system construction and maintenance

The greatest concern in considering RWH adoption at the household level is investment cost. Operation and maintenance costs are relatively low, but depending on the design and water supply methodology, it may be elevated. Thomas and Martinson (2007) offered an estimate of annual maintenance and labor costs as a fraction of total construction cost for various RW tanks, based on some country case studies (Table 4). In practice, labor time and overall cost varies with tank size. In addition, the maintenance workload would vary depending on the design quality and tank type and size. Frequent maintenance is inevitable for low quality designs, and larger tanks demand more work load, which could be in the form of material or labor demand. Hence, annual maintenance can be described simply as a fraction of the capital cost. Labor and maintenance costs would vary depending on design and country where the system was constructed. The estimations in Table 4 could serve as guidance for planning.

Table 4: Annual maintenance and labor cost as a fraction of total investment cost (Compiled from Thomas and Martinson 2007)

Tank type	Maintenance fraction (%)	Labor fraction (%)		
	Uganda	**Ethiopia (variable material cost & low labor cost)**	**Uganda (high material cost & low labor cost)**	**Sri Lanka (low material cost & medium labor cost)**
Drum	2	20	25	60
Moulded plastic	2	< 5	< 5	10
Thai jar	5	10	20	30
Open frame ferrocement	7	25	25	35
Plate	7	15	15	30
Pumpkin	7	35	25	50
Dome	10	35	35	60
Tarpaulin	10	20	20	33
Thatch	15	40	45	70
Tube	20	20	30	50
Mud	25	63	55	80

Research results are dependent on numerous factors, including material use and types and even beneficiaries' involvement in community projects, which could lower the cost. Microfinancing for individual RWH projects has been tried in Nepal (Nijhof and Shrestha 2010).

Thomas and Martinson (2007) offered strategies for cost reduction, which included tank shape optimization, workshop production, underground tank construction (subject to site specific condition), reduction in construction and material quality, land use reduction by increasing height to width aspect ratio, local labor and material usage, beneficiaries contribution in kind and selecting type of system with ease implementation (minimizing on time and labor). They also recommended mortar jars, ferro-cement, brick tanks, and lined underground tanks as they cost less when compared to metal, plastic, and concrete tanks.

From RWH projects conducted in rural Tanzania (Kihila 2014), it was determined that ferro-cement was relatively cheap in comparison to concrete and polyethylene tanks. Nega and Kimeu (2002) suggested some low cost designs and construction methods for RWH systems, based on cases conducted in Kenya and Ethiopia. They paid more attention to locally and naturally available materials such as clay.

Construction and design guidelines for different kinds of RWH storage tanks (including concrete, bricks, blocks, and rubble stones) were listed with their respective bills of quantities from projects conducted in Kenya (Petersen 2007) and could serve as a guide for replication considerations. Better yet, nongovernmental organizations (NGOs) and international organizations, such as WaterAid and Practical Action, have documented their RWH fieldwork experiences in developing countries in their online databases.

2.6 Rainwater harvesting in Tanzania

RWH in Tanzania is defined as a technology used for collecting and storing RW from land surfaces, rock catchments, or rooftops using simple techniques, such as jars and pots, and complex techniques, like charco dams (MoWI 2008). Assessment of University of Dar es Salaam staff houses' RWH cisterns suggested that RWH might be the best drinking water source in Tanzania, provided that health precautions are taken during collection, storage, and use (Mayo and Mashauri1991).

Although RWH is a familiar technology to most citizens, it has been practiced only at a low- level scale. It is common to find people aligning their buckets, pots, jars, basins, and drums under roof eaves during the rainy season, regardless of gutter presence or absence (Figure 8). However, the capacity of such items hardly lasts to the dry season.

Formally, RWH technology was introduced to the Government of Tanzania (GoT) by United Nations Development Programme in 1997 with tank construction and artisan training in some districts. The promotion continued under coordination by the Rural Water Supply Department of the Ministry of Water (MoW).

Figure 8: Harvesting rainwater from the roof at a household in Kilimanjaro, Region

In recent years, the GoT has been putting more emphasis on RWH promotion as an alternative water supply technology. A goal of the current national water policy (NAWAPO) for rural water supply is to increase water availability through RWH technologies. Emphasis is on the promotion of RWH through raising awareness and training and research enhancement (MWLD 2002). Moreover, the national strategy for growth and reduction of poverty for 2006 – 2015 (MoWI 2008) includes national water sector development strategies among its priorities, in which it sets out how the NAWAPO is to be implemented. It also describes the necessary institutional and legislative changes for effective implementation of the NAWAPO. In its strategies on water resources management, it acknowledges RWH as suitable among alternative resources and a viable option to meet increasing demands. It states that RWH needs development and promotion at household level, and for rural development.

The ongoing Water Sector Development Programme, which commenced in 2007 under joint financial support from the GoT, World Bank, and other partners, has incorporated RWH demonstration projects as a prerequisite in social service centers such as schools, dispensaries, and hospitals. Contractors have been directed to build three storage tanks (5000 L, 3000 L, and 1000 L) as a way of promoting RWH to local citizens with respect to their economic potential. The types of tanks being promoted include ferro-cement, mortar jars, and plastic tanks. By March 2014, 675 tanks had been constructed (WM 2014). By April 2015, 1,862 RWH tanks had been built in 931 villages, which is about 9.2% of villages in Tanzania based on the 2009 statistic of 10,165 villages total in Tanzania mainland (NBS 2011). Additionally, local government authorities (LGAs) have been mandated to pass by-laws that ensure incorporation of RWH infrastructures in new houses. This has been implemented by only 29 out of 168 LGAs as of May 2015.

NGOs, faith-based groups, and international organizations had been conducting RWH projects for years.

However, of the available types of water supply sources in the country, RWH is one of the least sought (Figure 9). Springs are the highest sought source type, followed closely by shallow wells, and then boreholes.

In conclusion, the pace of RWH adoption at the individual and community levels is still slow, with available systems performing below par. High investment cost seems to be the most challenging factor, followed closely by quality maintenance and the dry season. Well performing demonstration projects involving the government, the private sector, and local citizens are imperative at both the individual and community levels, as are strategy introduction and incorporation of recent innovations for resolving critical challenges in the technical, economic, and social aspects. This study offers guidance through assessment of RWH potential in Tanzanian case studies.

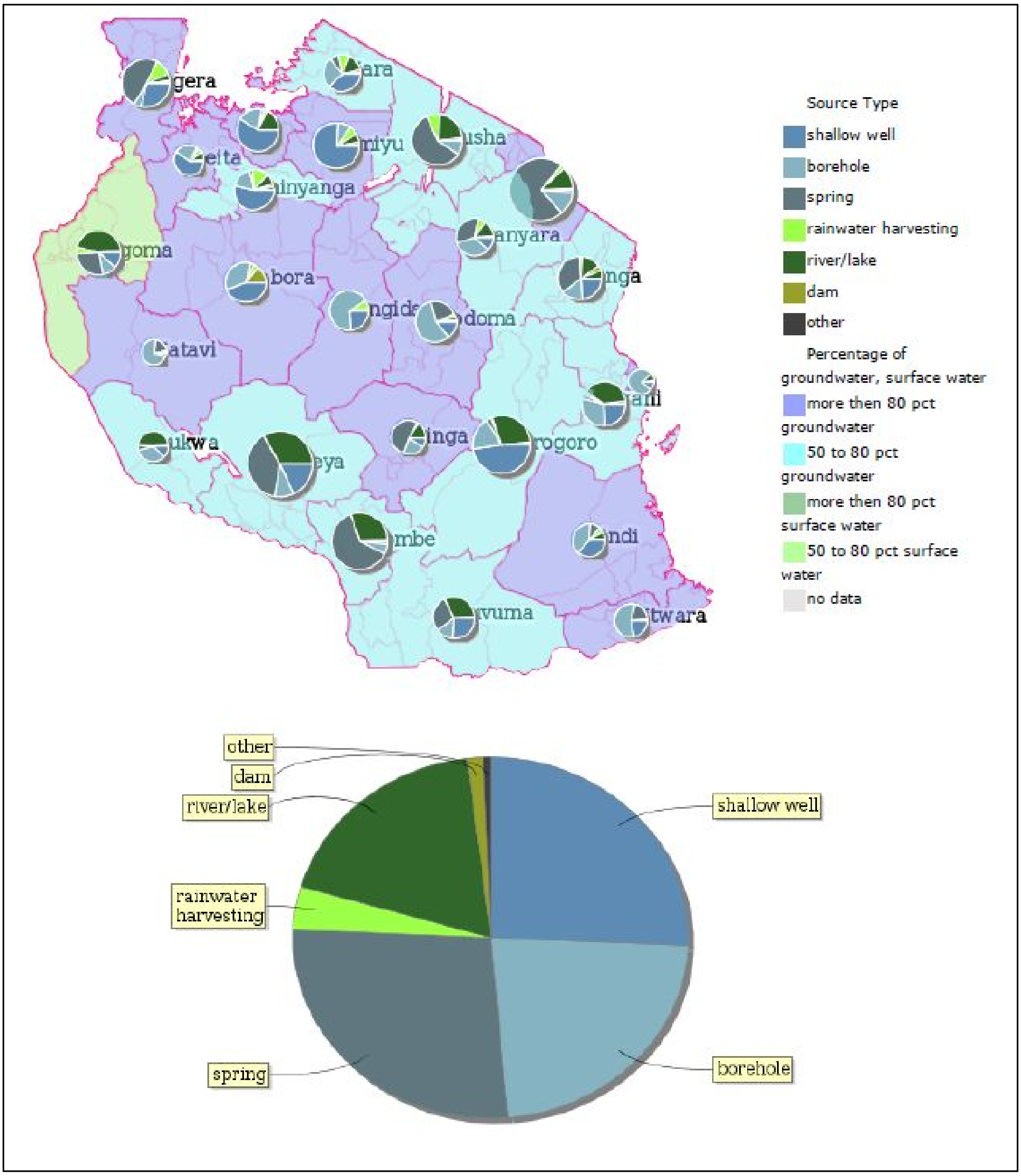


Figure 9: Water point source type adopted in the country (MoW 2014b)

2.7 Summary

RWH is imperative as a sustainable way of tackling water supply problems in Tanzania. With the knowledge that RWH has existed sustainably since ancient times, in situ and ex situ RWH interventions should be employed based on existing indigenous knowledge that is available within a given society. In addition, current scientific and social advances in research and practical application of RWH should be incorporated to ensure RWH quantity, quality, and construction maintenance. The goal should be focused more on collecting rainfall regardless of time and quantity. RW should be harvested and utilized to help meet water supply demand. However, because rainfall variation is site specific, it would be relevant to assess the potential of RWH as a sole source through modeling and case studies.

CHAPTER 3:

Improving Sustainability of Community-based Rainwater Harvesting

3.1 Introduction

Over the years in Tanzania, several RWH systems have been constructed at the community and individual levels. Most of the work at the community level has been facilitated and even sponsored by either NGOs, international organizations, or government entities. Unfortunately, there is still limited adoption of RWH technology, which can be linked to limited promotional strategies. Additionally, common technical, economic, and social problems of current RWH practices have been gathered from literature reviews as well as qualitative surveys and are compiled in Table 5.

Table 5: Common problems of current rainwater harvesting practices in Tanzania

Perspective	Problems
Technical	Insufficient quantity during dry season
	Poor water quality
	Low workmanship
	Lacking local data
Economical	Relatively high initial cost for individuals
	High cost of parts (material) due to immature market
Social	Water committees have limited capacity in project management
	No sense of ownership on freely donated system
	Rainwater is not included in educational programs
	Poor perception of rainwater due to lack of successful demo projects
	Limited restriction and justification for rainwater harvesting technology adoption

Technically, most RWH storage tanks have problems related to water quantity and quality. The variable/irregular nature of rainfall during the year has led to its categorization as an unreliable source, most specifically due to rainfall shortages during the dry season. In most areas, local rainfall data, which is an essential input data for establishing efficient designs, is quite expensive and not easily accessible. Water quality is affected by sediment accumulation, turbidity due to suspended particles, and even tiny visible insects. Furthermore, technical capacities for developing RWH systems are limited because of limited business opportunities and a lack of technical standards and guidelines. Occasionally, poor design becomes an obstacle to harvesting RW for consumption, with experiences of leakage, cracks, and infiltration by contaminants.

Economically, equipment and material costs are high. These initial costs of RWH systems are prohibitive for most individual households. On top of these, low workmanship quality partly contributed to an immature market for RW business.

Socially, due to poor water quantity and quality as well as a lack of successful RW demonstration projects, RWH is not highly prioritized as an alternative water supply source. Despite the demonstrations constructed within communities, there are no rules or regulations enforcing the adoption nor incentives. There is limited awareness of RWH best management practices. Free donations without any kind of reciprocation from beneficiaries results in reduced commitment to management of the provided system. Moreover, local WC have accessibility challenges to financial and technical support due to limited recognition within government bodies.

This research addressed the limitation of performance parameters for quantification of the dry season. Through the study three parameters were defined, namely no water days (NWD), rainwater usage ratio (RUR), and water level (WL). NWD are the days in a year when the storage system contain insufficient water to meet usage demands (Equation 3.1), the RUR is the percentage of harvested RW that has been consumed to meet demand (Equation 3.2), and WL displays the percentage of water level in the storage system (Equation 3.3).

$$NWD = 1 - \sum_{t=1}^{T} WD;\ \mathrm{WD} \rightarrow \mathrm{Y_t} = \mathrm{D_t} \qquad (3.1)$$

$$RUR = \frac{Water\ usage}{Total\ amount\ of\ rainfall} \times 100 = \frac{\sum_{t=1}^{T} Y_t}{\sum_{t=1}^{T} Q_t} \times 100 \qquad (3.2)$$

$$WL_{t-1} = \frac{V_{t-1}}{S} \times 100 \qquad (3.3)$$

where Q_t is the harvested RW runoff on the t^{th} day, V_{t-1} is the stored RW in the storage system at the beginning of the t^{th} day, D_t is the daily RW demand on the t^{th} day, Y_t is the RW supplied during the t^{th} day, WD is a day whose demand is fully met, WL_{t-1} is the water level percentage in the storage system at the beginning of the t^{th} day, T is number of days in a year and S is the storage capacity.

RWH demonstration project was conducted, within which innovative ideas were incorporated to solve the commonly identified problems in current RWH practices and ensure project sustainability (Mwamila *et al* 2016). For rural water supply services, Lockwood and Smits (2011) defined sustainability as an indefinite provision of a water service with certain agreed upon characteristics over time. The project and the approaches applied for ensuring technical, economic, and social improvement from current RWH practices are explained further in the following sections.

3.2 Rainwater harvesting project description at Mnyundo School

Demonstration projects are essential for promoting a technology, by exposing beneficiaries to the necessary parameters. The projects also increase awareness and offer guidance on the best way forward.

3.2.1 Site selection and description

The major case study took place in Mtwara, a region in southern Tanzania (Figure 2). The region's population was estimated at 1.27 million as of 2012 (NBS 2014), with 77% of those people living in rural areas (NBS 2013a). This region has the highest record of nonfunctional water points, estimated at 62% in 2014 with only 13% of the population supplied by functional water points (MoW 2014c). Commonly sought alternative water sources include rivers, streams, shallow wells, and RWH. RWH sources are limited to 0.7% of all water sources in the region (MoW 2014b).

Mtwara Region has two main seasons, a warm, humid rainy season that lasts from November to May, and a cool dry season that lasts from June to October. Average annual rainfall for this area is approximately 1000 mm (Figure 10) and is categorized as a unimodal rainfall regime.

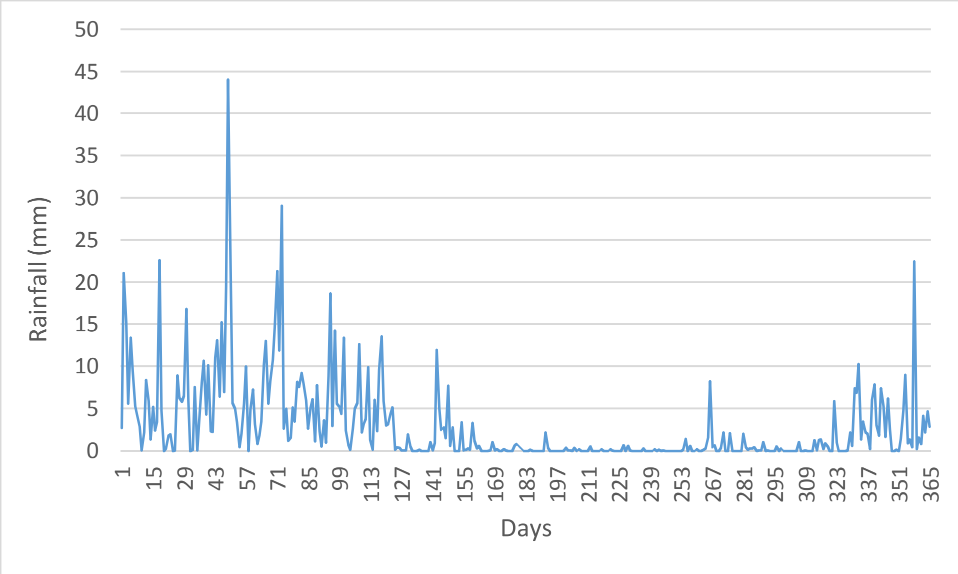


Figure 10: Mtwara Region average daily rainfall data for 2010 -2014 (Source: TMA)

The RWH project was conducted in February 2013 at Mnyundo Primary School, which is a typical rural public primary school that was established in 1966. The school population is 319 including 15 teachers. It had no water supply facility, thus students had to fetch water for school domestic uses from distances of approximately 1 to 2 km. Alternative sources included a shallow pumping system and a river. The main project goal was to establish RW as the main drinking water source for the school.

The school was chosen for the RWH demonstration project due to its standard roofing, conducive working environment, and high potential for technology promotion to the children, their families, and the teachers. There was high potential for interaction among many stakeholders who could serve as links to the project and technology. Most of all, improving water accessibility for the schoolchildren has a big impact on their education, allowing them more time to concentrate on their studies.

The RWH system was designed by Seoul National University team, and the construction was financed by the Seoul National University Rainwater Research Center (SNURRC) and Korean Society of Civil Engineers (KSCE) for US$3600. The labor and material costs accounted for 14% and 86%, respectively, of the total construction cost (Table 6). The system utilized one among five existing school buildings (Figure 11).

Table 6: Construction cost breakdown for the Mnyundo project

S/N	Item description	Total (TZS)	Total (US$)
1	Storage Tank and Gutter Profile System	3,170,500	1962.55
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**	**3600**

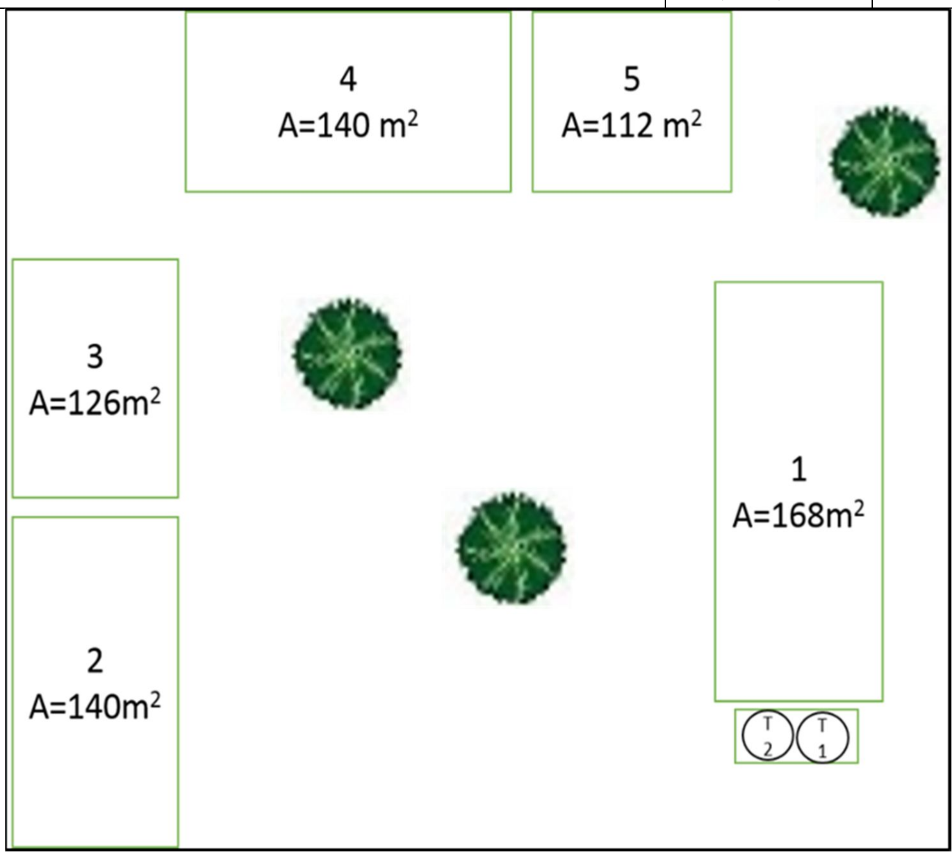


Figure 11: Layout plan sketch of Mnyundo Primary School in Mtwara Region

3.2.2 Rainwater harvesting system design

The school RWH system comprises six main parts as follows:

i) The collection system consists of a 168 m^2 corrugated iron roof.

ii) The delivery system uses PVC gutters and pipes.

iii) The treatment system consists of a coarse screen, first flush tank, and sedimentation tan k

iv) The storage system comprises two 5 m^3 plastic tanks, of which the first tank (Tank 1) serves as a sedimentation tank as well as storage.

v) Taps for supply, and as washout valve.

vi) A water level gauge for monitoring the system.

This is considered as an improved RWH system as shown in Figure 12, of which the plan and section views are shown in Appendix A.

Figure 12: Rainwater harvesting system at Mnyundo School, with treatment and monitoring components

A daily water balance model by Mun and Han (2012) was adopted using the cumulative water storage (Equation 2.2). The model was applied in a Microsoft Excel environment using the daily demand and usage conditions (Equations 3.4 and 3.5). This assessed the system performance and reliability (Equation 3.6) for a year under fixed demand conditions. Even though it is a day school, all days of the year were included because other activities occasionally occur on weekend days and holidays. Under the assumption that daily demand for drinking is 1 L/d for each of the 300 pupils (considering a range of 1 – 3 L daily drinking water consumption per person), 10 m^3 at an adopted *C* of 0.8 (iron roof) can result in 143 NWD with a RUR estimated at 50% (Figure 13). Considering WHO recommendations for drinking i.e., 2.5 – 3 L/person/d (Reed and Reed 2013), NWD reached 239, hence only 35% reliability but with a RUR of 97% (Figure 13).

For: $0 < V_t \leq S;\ V_t > S$

$$Y_t = D_t;\ O_t \geq 0 \tag{3.4}$$

For: $V_t < 0;\ V_t = 0$

$$Y_t < D_t;\ Y_t = V_{t-1} + Q_t;\ O_t = 0 \tag{3.5}$$

$$Reliability = \frac{Days\ fully\ served\ in\ a\ year}{Total\ days\ in\ a\ year} \times 100 = \frac{\sum_{t=1}^{T} WD_t}{T} \times 100 \tag{3.6}$$

where V_t is the cumulative RW stored in the storage system at the end of the t^{th} day, and O_t is the overflow amount on the t^{th} day.

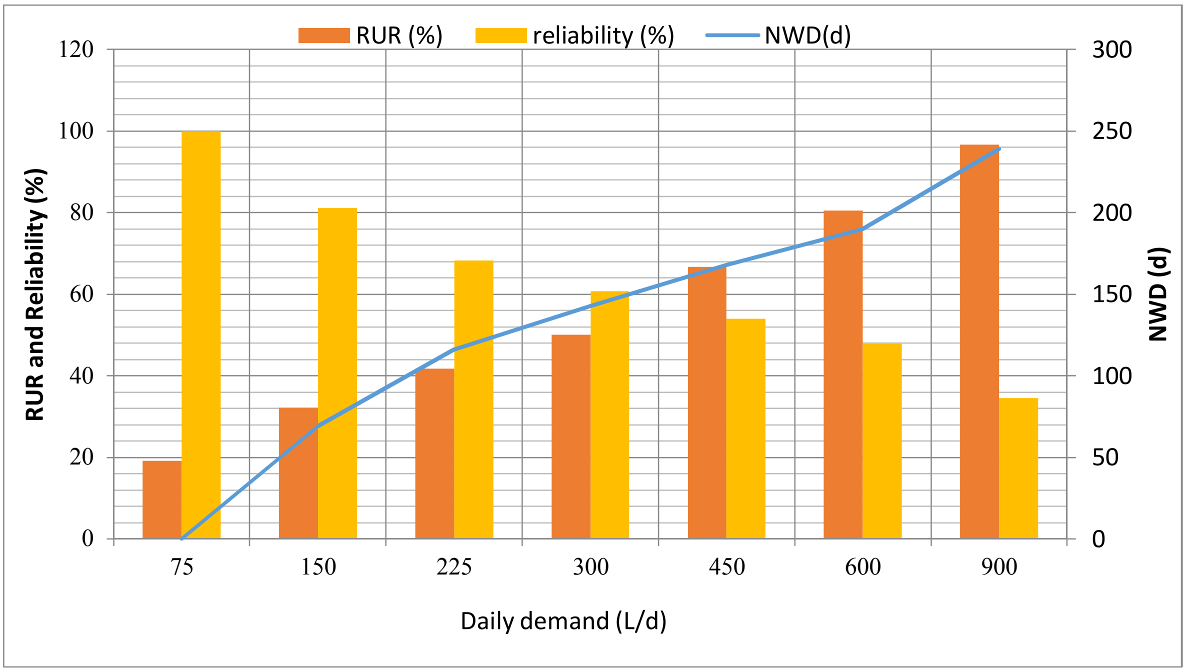


Figure 13: Reliability, rainwater usage, and number of no water days in a year, under fixed demand conditions

3.2.3 Success and challenges of current system

For this project, the materials used were sourced from local material suppliers, and local people mainly did the work with SNURRC supervision. District water engineers (DWEs) were involved in the project planning and supervision. Local techniques were adopted, as the location was rural with no electricity supply. All these approaches empower and boost the sense of ownership of the local people.

However, under the current conditions of system capacity, population, and rainfall data, the number of attained NWD was very high, thus requiring further efforts to reduce the number of NWD during the dry season. In addition, promotion of self-supply initiatives is important.

3.3 Technical improvement

Technical innovative ideas were incorporated within the system to improve quantity control as well as to provide palatable and safer water for drinking.

3.3.1 Rainwater quantity control

As most storage tanks are not transparent, it is difficult for users to monitor the WL while consumption is ongoing. In most cases, the users only realize the WL 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 WL 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 WL, a simple water level gauge was taped onto the outer tank wall (Figure 14a). 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 14b). 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 WL 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.

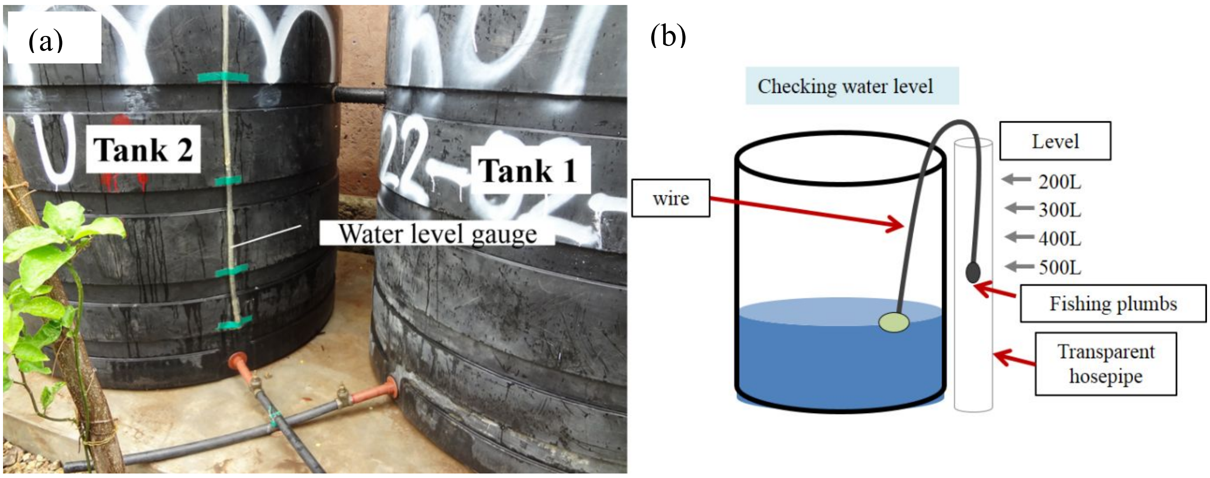


Figure 14: a) Water level gauge taped onto the supply Tank 2, and (b) the components of the water level gauge

3.3.2 Rainwater quality improvement

Impaired health due to poor access to safe water negatively affects educational outcomes (NBS 2011). Water quality is essential for ensuring good health, which is imperative for a country's development. To ensure good RW quality for the school, the treatment components of a coarse screen, first flush tank, and sedimentation tank were included in the system.

3.3.2.1 Coarse screen

Because 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. Users could then manually remove the large particles that are trapped. The screen can be made of several types of materials including plastic or metal (Figure 15a). For the school project, a plastic screen was used because of its high availability and low cost.

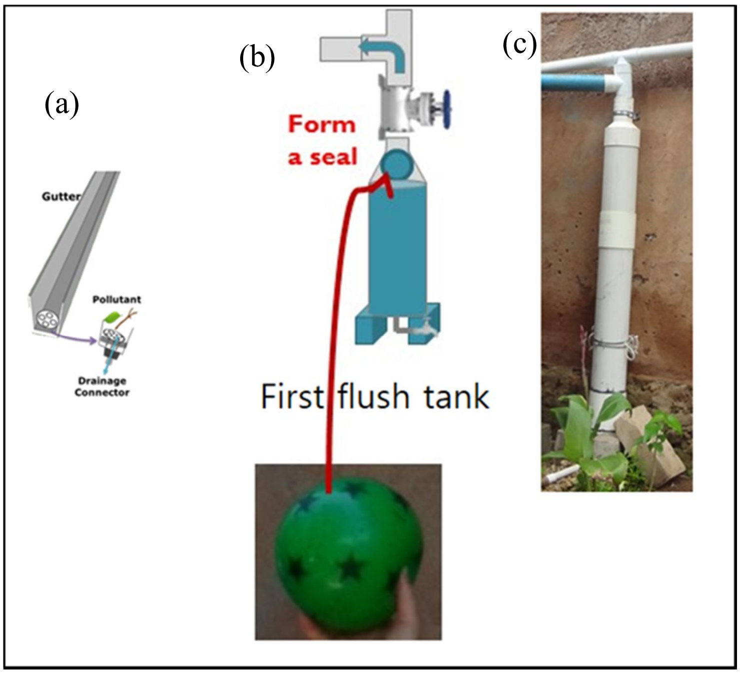


Figure 15: Illustrations of, (a) gutter screen, (b) first flush tank, and (c) the first flush tank at the Mnyundo School

3.3.2.2 First flush tank

The purpose of a first flush tank is to divert the initial rainfall that washes off most of the contaminants that have adhered to the roof. Once filled, the ball inside the first flush tank, having raised up with the increasing WL, will block the inlet, and then the incoming RW will flow into Tank 1 without any mixing (Figure 15b). In addition, a diversion mechanism that utilizes a valve is necessary (Figure 15b), which can be closed in case the flush tank has malfunctioned, thus avoiding any water wasting by diverting the RW straight into the Tank 1. Generally, contaminant quantity is halved with each additional millimeter of first flush (Table 3). For this project, the first flush tank is a PVC pipe with a diameter of 0.2 m and effective height of 2 m (Figure 15c). The tank is capable of collecting approximately 62 L from the 168 m^2 roof, which is approximately 0.5 mm of rainfall (assuming C of 0.8). Based on the rule stated above, the 100 NTU initial turbidity of the water moving into Tank 1 should decrease to 75 NTU. Once the rain stops, the first flush tank should be emptied by opening the brass ball valve connected to the 0.03 m pipe at the bottom of the tank.

3.3.2.3 Sedimentation tank

The RW is diverted from the roof downpipe (0.1 m diameter) to Tank 1 after the first flush tank is full (Figure 12). Tank1 has a capacity of 5 m^3. As the RW fills up the tank, the remaining particles settle down, as a function of the time spent by the RW in the tank. Other researchers support this settling concept (Han and 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 RW 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).

3.3.2.4 Water quality testing

To attain acceptable water quality, monitoring is essential, especially when the water will be used for drinking purposes. Tanzania mainland health statistics for 2006 reported diarrheal diseases among the major causes of morbidity and mortality and associated mainly with poor hygiene. Among notifiable diseases for Mtwara Region, dysentery had the most cases for all ages (HIRS 2008). In this study, water quality testing was performed to approve the RW quality.

i. Sample collection

Water samples were collected during the rainy season in the same day of April 2013 from the Mnyundo School RWH system, preferred water sources (river and borehole), and a nearby secondary school RWH system. Total rainfall for the month was 45.5 mm, which had been preceded by heavy rainfall in March amounting to 327.1 mm (NBS 2014). The samples were analyzed for physical, chemical, and microbiological quality (Table 7) at the University of Dar es Salaam's water quality laboratories. The secondary school RWH system comprises an underground ferro-cement 70 m^3 storage tank. The government constructed this system as part of a demonstration project. Unfortunately, the pump was not installed due to a shortage in funds; thereby the users had to access the water via bucket dipping. This introduces potential risk of the water being contaminated, depending on how the bucket is cared for. Borehole implies a shallow pumping system whose water was serving domestic needs, and a river water source for other uses. Both are communally shared.

ii. Test results

All of the samples, except the one from the Mnyundo primary school RWH system, had total coliform (TC) counts above the recommended standard values of both Tanzania and the WHO (Table 7). Utilizing open surface sources and unsterilized buckets in contained water sources in a nondecentralized manner are among the reasons that could have contributed to the high TC counts. TC counts are used to determine the vulnerability of a system to fecal contamination.

Table 7: Water quality results for samples from available water sources around Mnyundo School

S/N	Parameter	Sampling Source				Water Quality Standards	
		Mnyundo Pr. School RWHS	**Mtiniko Sec. School RWHS**	**River**	**Borehole**	**TZ**	**WHO**
1	pH	6.58	7.24	7.38	7.32	6.50–8.50	6.5–8.5
2	Total Dissolved Solids (mg/l)	18	47	790	830	1,000	1,000
3	Colour (Pt.Co)	2.50	1.5	33	7.0	15	15
4	Total Hardness (mg/l) as $CaCO_3$	8	16	250	270	500	200
5	Sulphate (mg/l)	2.0	6	84	90	400	500
6	Chloride (mg/l)	5.0	10	160	170	250	200–300
7	Sodium (mg/l)	1.50	1.8	10.30	18.70	200	200
8	Lead (mg/l)	0.034	0.024	0.036	0.114	0.05	0.01
9	Total Coliform No/100 mls)	Nil	10	200	250	Nil	Nil

Lead concentration seemed to prevail above WHO standard in samples from all the water sources, but below Tanzanian standard, except for the borehole water. This is likely due to lead based paints which could have been used on roof because it is an old school, leaching into RW. In addition, the surrounding environment can be contributing to these sources. In regard to surrounding environment as source of lead, of recent uranium mining activities were initiated in the Mtwara Region. Uranium is one of several elements known to decay to lead (Gitt 2015).

Most of the tested parameters were low for the samples from the two rooftop RWH systems, including carbonates, which indicates that the RW was soft. Thus, the RW stands out among the other sources.

In further comparison between the two rooftop RWH systems, the sample from the secondary school system had a slightly lower lead concentration. This can be related to the storage tank material contributing to an alkaline condition of the water, which causes the lead to precipitate out, whereas the lower pH in the plastic tank of the primary school's system allows more lead to be dissolved in the water, as was explained in an article by Salleh (2009). WHO (2008) states that the solubility of lead increases remarkably as the pH falls below 8 because of the substantial decrease in equilibrium carbonate concentration. To reduce lead's solubility in soft water, such as the RW (below 50 mg/l calcium carbonate), the optimal pH of approximately 8.0 – 8.5 should be maintained.

The concentration of lead should decrease in the accessed RW because of settling and biofilm processes, as was shown by Coombes *et al*. (2006).

3.4 Economic improvement

Innovative ideas were incorporated during the planning and implementation of the Mnyundo project with the goal of lowering the construction cost as well as promoting future replication potential.

3.4.1 Cost reduction strategies

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.

3.4.2 1C1C campaign

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 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 targeted community can participate through provision of labor and some percent cash or in-kind contribution. In the Mnyundo project, the total construction cost was US$3600 (Table 6) which is high for a rural school community to afford but is easily affordable by a company. The SNURRC donated the money to the school as their corporate social responsibility (CSR), thus reducing the financial load on the community. 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.

3.5 Improvement of social involvement

The Mnyundo School project also targeted on boosting beneficiaries' sense of ownership and empowerment for future operation and maintenance as well as replication. To improve social involvement, the following measures have been implemented on the demonstration project.

3.5.1 Maintenance manual

An operation and maintenance manual was prepared in Swahili (dominant official language of Tanzania) and English (Appendix B). The school received the Swahili version for operational guidance whereas 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.

3.5.2 Empowerment

Training was provided to the school community, as well as the villagers, during the project hand over. The system mechanism; proper management of the system components such as screen, gutter, and tank cleaning; and operation of first flush tank were explained. Any queries raised were addressed instantly.

The involvement of the local people in the demonstration project work ensured capacity building for conducting future similar work, and created opportunities for self-employment in masonry work with the knowledge gained from the project.

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.

3.6 Sociotechnical operational strategy to reduce number of no water days

Rainfall is variable by nature; hence, to maximize its potential in this study it was proposed that users adopt a variable demand approach. This is especially important because of the limitation in funding for financing additional systems, as was the case for Mnyundo School.

3.6.1 Water level gauge application

The strategy for the project includes water level monitoring by users prior to their deciding their daily demand which supports the proposed variable demand approach (Mwamila *et al*. 2015). The performance of this water level monitoring strategy was assessed by incorporating the newly defined parameter WL into the daily water balance model.

Equation 3.7 redefined the daily demand condition. Daily demand scenarios were introduced, defined, and incorporated into the model (Table 8).

$$D_t = f\,(WL_{t-1});\; WL_{t-1} = 0\% - 100\% \qquad (3.7)$$

Table 8: Current and proposed water level monitoring strategy scenarios

Description	Scenarios	Water Level (%)	Demand (L/d)	NWD (d)	RUR (%)
current scenario		0-100	300	143	50
proposed scenarios	1	>50	300	103	48
		≤50	150		
	2	>75	600	120	74
		≤75 and >50	450		
		≤50 and >25	300		
		≤25	150		
	3	>75	450	47	61
		≤75 and >50	300		
		≤50 and >25	150		
		≤25	75		
	4	>70	600	115	74
		≤70 and >30	300		
		≤30	150		

The analytical results indicated that Scenario 3 was the most favorable for reduction in NWD based on the decreasing trend in favorability as follows: Scenario 3→Scenario 1→Scenario 4→Scenario 2→current scenario (Table 8). In addition, the RUR for Scenario 3 is better than the current scenario, although it does not show the greatest improvement among the proposed scenarios. Figure 16 displays the water saving efficiency of Scenario 3. For example, the WL at the beginning of day 265 was 0%, but a demand of 75 L/d could still be accommodated. This is because of the occurrence of rainfall on that day, with the excess of the recommended demand, as based on the WL, being stored and distributed during the following dry days, 269 and 270. Additionally, there was an absence of water from days 246 to 253, which were dry days where previous rainfall savings were already depleted. These are considered typical cases. In actual practice, a designated individual checks the WL in the tank prior to collecting water for daily use and translates the WL reading into the recommended demand value.

In the absence of usage strategies, people tend to use water without regard to caution or planning and maintain constant usage habits even during the dry season. The recommended water level monitoring strategy can be applied to new and existing RWH system designs to ensure the elimination, or reduction, of NWD during the year.

Better yet, a printed guideline based on the preferred demand scenario can be attached to the storage tank close to the water level gauge (Figure 17). The simplification of these gui delines should encourage users to cooperate and adhere to the guidelines during the dry seaso n.

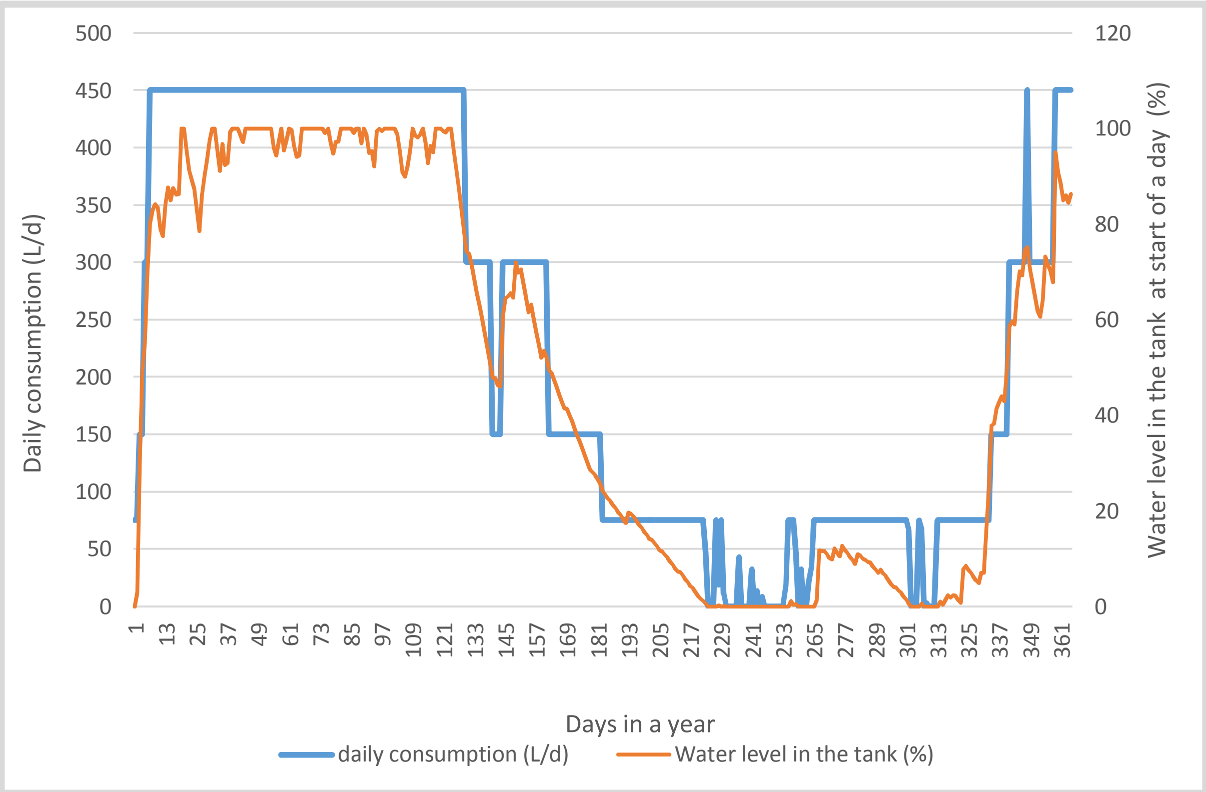
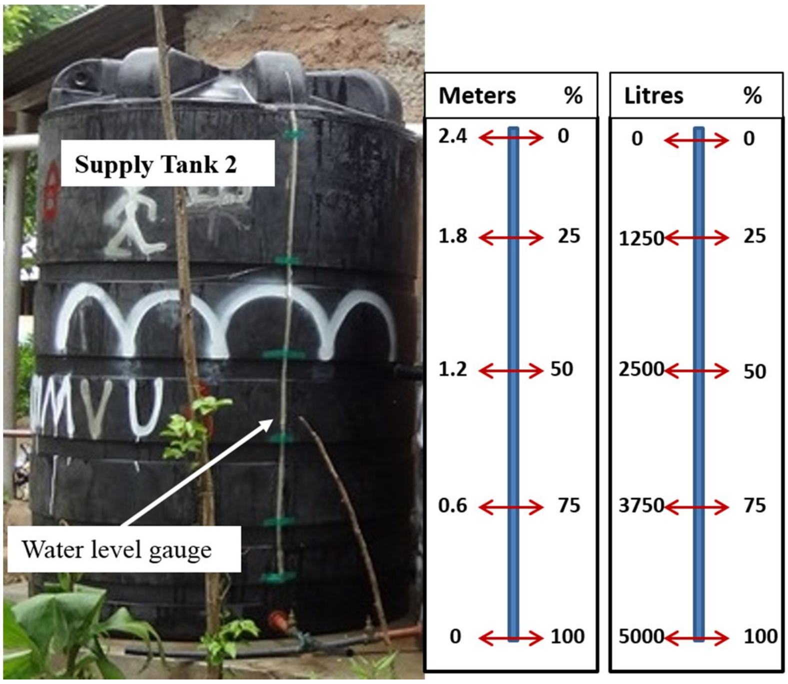


Figure 16: Scenario 3, expected daily consumption with respect to the water level in the tank at the beginning of the day



Scenario 3	
Water level (%)	Demand (L/d)
100 → 75	450
75 → 50	300
50 → 25	150
25 → 0	75

Figure 17: Application of the water level monitoring strategy

3.6.2 Strategy limitations

The success of the reduction in NWD strategy relies on all the skilled and unskilled users. Users are in charge and, thus, directly affect whether NWD are reduced. To reduce the number of NWD they experience, they should be flexible in their water use, at times limiting it to only basic needs such as drinking.

3.7 Socioeconomic strategies for self-promotion

Socioeconomic strategies, such as managing the financial implication and simultaneously enhancing sense of ownership and community spirit, are necessary for averting sustainability challenges; thereupon, eliminating or reducing reliance on external sources/donors. For Mnyundo School, both social and financial aspects were addressed with the goal to ensure improved daily demand and RW usage.

3.7.1 Boosting water supply

The school has the potential to boost its daily supply simply by relying on RWH, considering the school layout (Figure 11). There are more roofs to exploit as catchments, as only one was used during the project. This will increase the school's water self-sufficiency ratio (WSSR), which is the ratio of the amount of self-supplied water to total water use (Han and Kim 2007, Rygaard *et al*. 2011). The WSSR encourages reduction in reliance on external water sources, such as the rivers and streams, boreholes, and vendors.

Daily water balance models and conditions (Equations 2.2, 3.4, 3.5. and 3.7) were applied to determine the optimal RWH system, which is defined as one that would ensure zero NWD during the whole year. Similar basic analysis conditions were adopted, and both fixed and variable daily demand water level scenarios were considered (Table 9).

Table 9: Fixed and variable daily demand scenarios

Fixed		**Variable**		
ID	**Demand (L/d)**	**ID**	**Water Level (%)**	**Demand (L/d)**
F1	150	V1	>50	300
F2	300		≤50	150
F3	450	V2	>75	600
F4	600		≤75 and >50	450
			≤50 and >25	300
			≤25	150
		V3	>75	450
			≤75 and >50	300
			≤50 and >25	150
			≤ 25	75
		V4	>70	900
			≤70 and >30	600
			≤30	300

The current RWH system, under considerations of all daily demand scenarios cannot achieve zero NWD (Figures 18 and 19). The minimum number of NWD is 47 d, whereas the maximum RUR is limited to 88%. For approximately US$4,000 (two buildings' roofs including the current one), there is potential to achieve zero NWD for the F1 and V3 demand scenarios with 21 and 41% RUR respectively. A reasonable RUR and number of NWD are attainable with the utilization of two buildings for Scenario V2, 50% and 44 d respectively.

Nevertheless, it is possible even with a higher daily demand to achieve close to zero NWD if four or five buildings are utilized, but a counterplan that uses overflowing water will be needed to increase the RUR. If five buildings are used with Scenario V4, the number of NWD and RUR are 2 d and 40% respectively, whereas with Scenario F4, the number of NWD and RUR are 51 d and 33% respectively, with a cost of approximately US$18,000.

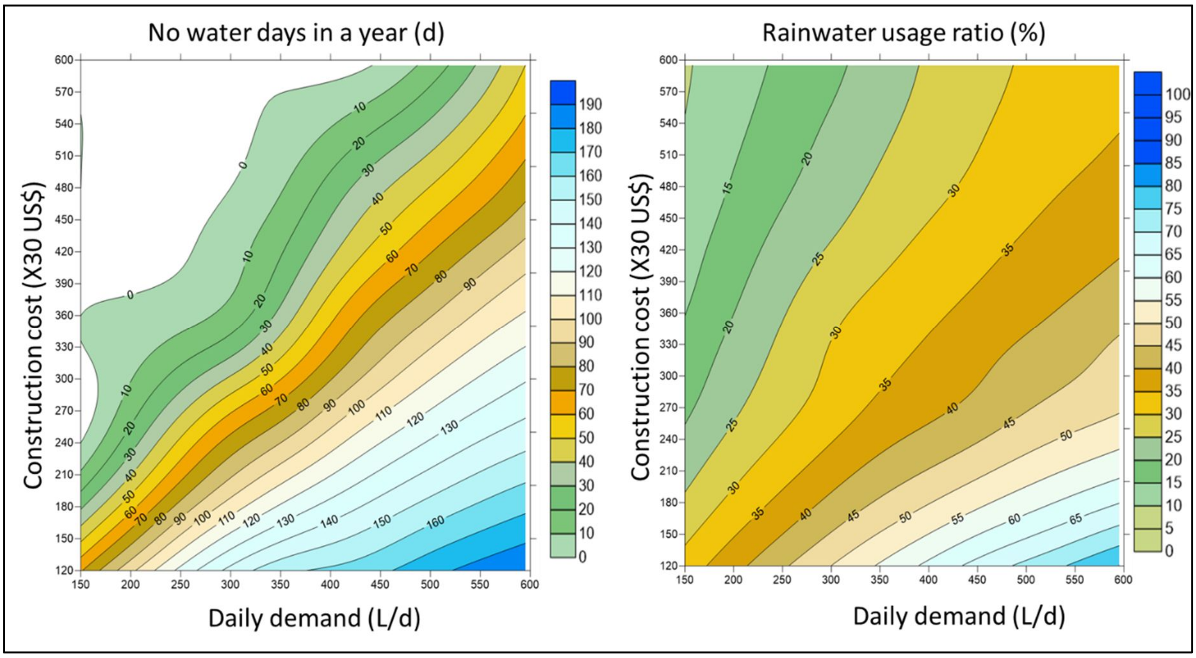


Figure 18: No water days and rainwater usage ratio, variation at different building considerations under fixed demand scenario

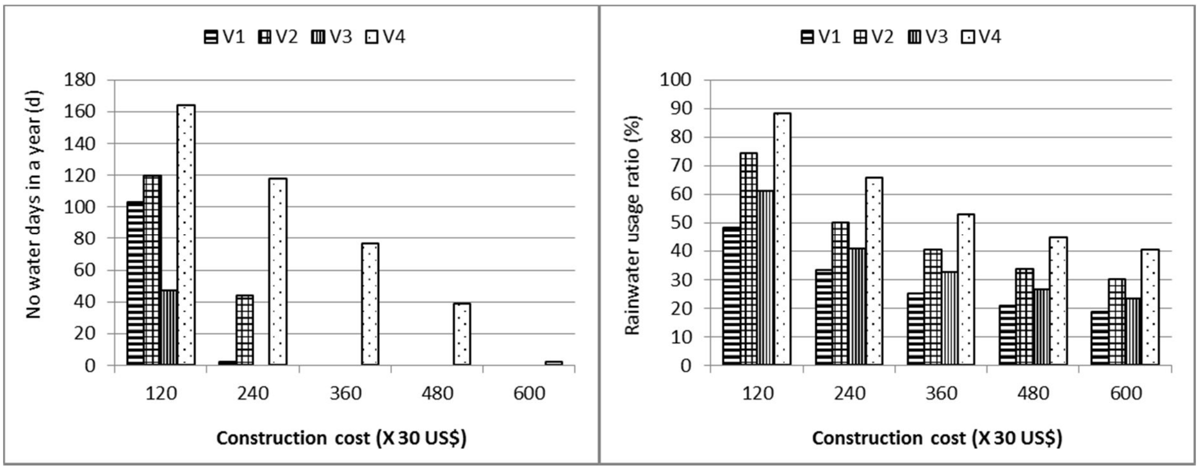


Figure 19: Number of no water days and rainwater usage ratio, variation at different building considerations under variable demand

3.7.2 Self-funding initiatives

Additional roof utilization comes with economic challenges, where most of the cost is attributed to the storage system (Table 6). The cost of utilizing two, three, four, or five buildings will require compounding duplication of the current system cost with each additional building (Figures 18 and 19). The same construction cost was assumed, regardless of the roof size, as they do not vary much in this case (Figure 11).

The beneficiaries can be sensitized into cost sharing through labor contributions, cash/in-kind contributions, and microfinancing. As they collaborate on the project, their sense of ownership and community spirit would be boosted. For the Mnyundo School project, the pupils are the main consumers of the water during school days; thus, it is logical to involve the parents/guardians when it comes to improving the welfare of the children.

Furthermore, the overflowing water from rainy days can be turned into an additional funding source for the school by transferring it to and storing it at other external facilities, and then during the dry season trading it to neighboring villagers.

3.7.2.1 Cash contributions

Considering equal division of the cost for an additional RWH system, and assuming a ratio of 1:1 of parent to pupil, each parent (totaling 300) should contribute approximately US$6 to cover the school's 50% of the construction cost (Table 10). Then, additional funding can be secured from government sectors or companies using the 1C1C campaign. This self-initiative likely would motivate potential donors to cooperate with the school and support the project.

Table 10: Cash contribution breakdown per participant, and percent total construction cost met

Contribution per user (TZS)	Contribution per user (US$)	Total contribution (US$)	% of 1 RWH system construction cost	% of 2 RWH system construction cost
10,000	6	1,747.03	49	24
7,500	4	1,310.27	36	18
5,000	3	873.52	24	12
3,000	2	524.11	15	7

3.7.2.2 In-kind contribution

Agriculture is the foundation of the Tanzanian economy, representing a source of livelihood for three quarters of the population as 76.3% of households are cultivating land (NBS 2011). Over 90% of the inhabitants of Mtwara District Council are employed in agriculture (PC and RC 1997). Therefore, it is reasonable to conclude that agricultural products could be used as in-kind contributions as a substitute for the cash contribution from the Mnyundo School community.

Common cash crops in the district include cashews, sesame, and groundnuts, whereas food crops include cassava, sorghum, paddy rice, maize, and cowpeas. Considering retail prices of these commodities, for equal in-kind contribution, the smallest crop quantity will be required from the sesame farmers (Table 11), with only 3.3 kg each from 20 families to cover 7% of the community's half of the total construction cost (Figure 20). The community's 50% of the construction cost for an additional system can be met by collecting 3643 kg of farm products.

Table 11: Common cash and food crops produced in Mtwara Region (PC&RC 1997, NBS 2011), their respective retail prices, quantity and potential construction cost contribution

Crops type	Price per kg (TZS)*	Price per kg (US$)**	Required min. quantity to be collected per family (kg)	Equivalent min. cash collected per family (US$)	Average number of families involved	Total equivalent cash contributed by all families(US$)
cassava	1,500	0.87	6.7	5.82	60	349.41
sorghum	1,000	0.58	10.0	5.82	20	116.47
paddy rice	550	0.32	18.2	5.82	50	291.17
maize	700	0.41	14.3	5.82	30	174.70
cow peas	1,500	0.87	6.7	5.82	20	116.47
cashewnuts	600	0.35	16.7	5.82	80	465.88
sesame	3,000	1.75	3.3	5.82	20	116.47
groundnuts	1,200	0.70	8.3	5.82	20	116.47
Overall total		**5.9**	**84.1**	**46.59**	**300**	**1,747.03**

*** Retail prices as of 31st December 2014 (Mwananyamala food market, Dar es salaam, TZ)**

**** Bank of Tanzania-foreign exchange rate as of 31st December 2014, 1US$ = 1,717.20**

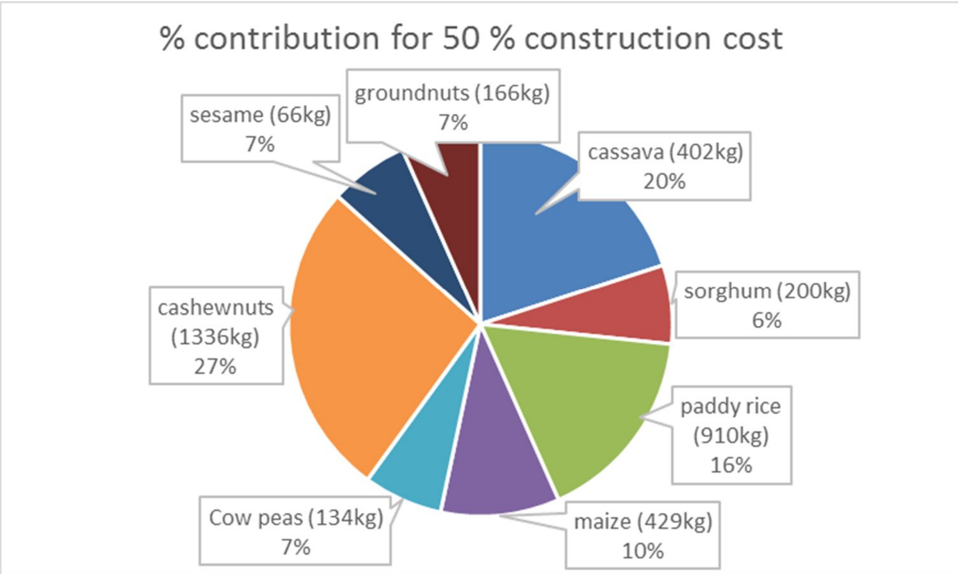


Figure 20: Commodity quantity and percent construction cost contribution

3.7.2.3 Labor contributions

Community members also can be sensitized to get involved during project implementation by donating labor, especially for less skilled jobs such as excavation and material mobilization. This is an alternative for those failing to contribute their share through cash or commodity means due to poverty. For the Mnyundo School RWH system, the labor cost was borne mainly (~80%) by skilled laborers, such as masons and engineers. A reduction from 14% to 4% of the total construction cost can occur through discount negotiation, with the mason being sourced from within the benefiting community and DWEs playing voluntary supervisory roles. This approach benefits the community with capacity building, knowledge transfer, and sense of ownership acquisition.

3.7.2.4 Community micro financing system

Many poor communities, since time immemorial, have been using a variety of indigenous microfinancing facilities to meet economic pressures. Some of these indigenous microfinance facilities include burial associations, rotating savings and credit associations, and lotteries in various forms. It is easy to apply traditional microfinance models to communities, as they are already accepted and practiced although not necessarily to modern economic standards (Kihongo 2005). In Tanzania, the national microfinance policy written in 2000 guides the establishment and operation of microfinance institutions (URT, 2000). In Tanzania, many microfinance institutions, including Promotion of Rural Initiative and Development Enterprises (PRIDE), Foundation for International Community Assistance (FINCA), and Dar es Salaam Community Bank (DCB), practice different models. However, the Village Community Bank (VICOBA) seems the most sympathetic with the poor (Kihongo 2005, SEDIT 2008, Ahlén 2012). It uses a down-top approach, and thus is fully owned by the target communities and raises the capital assets of poor and low-income people. VICOBA entails that after shares contribution by each member, which is recommended on weekly basis, then members borrowing and repaying with interest increases the capital basket. The annual accumulated interest can be used for entrepreneurial activities. Nijhof and Shrestha (2010) recommended microfinancing promotion to afford individual RWH projects based on their experience in Nepal.

Considering the Mnyundo School population (300), up to 15 VICOBA groups each with 4 cells comprising 5 people, can be established. At the end of the year, with at least 500,000 TZS (US$290) in accumulated interest from each group, the cost of an additional RWH system would be covered. At the same time, through individual borrowing, one can achieve personal economic gain and be able to afford a simple, individual RWH system. Thus, from such joint practices, personal as well as community gain and capital assets achievements can be expected.

3.7.3 Self-funding application by a neighboring school

Upon completion of the Mnyundo School showcase project, a cooperation agreement was made between LGA and the Mnyundo project donors. In June 2014, a similar RWH project was constructed at Namayakata Primary School (Figure 21), which is also located within the district. This school has 320 students, and a 140 m^2 roof was utilized and a 10 m^3 storage tank installed. The project funding mechanism was cofinancing (equal cost sharing) by the LGA and the Korean company, which used the project as their CSR. This upgraded the project funding management.

Figure 21: Namayakata Primary School pupils with their rainwater harvesting system

3.7.4 Proposed socioeconomic model

For the Mnyundo and Namayakata Primary Schools, there was limited social and financial involvement of the benefiting school community. A private entity was more in control at the Mnyundo project, whereas the Namayakata School project was more under the control of both private and public entities. This resulted in partial attainment of sense of ownership, limited awareness on technology management, delay in project implementation due to lengthy processes in terms of public sector funding, and limited access to local working data and incentives when the public sector is not involved.

For enhanced sustainability in water supply projects at the community level, the private sector and benefitted community should be fully involved economically, whereas the public and private sector and the benefitted community should be fully engaged in the social aspect of the project. The economic benefits of this model include CSR achievement, a good sense of ownership, and new synergistic business opportunities. Socially, the benefits include active participation of community members, increased technical know-how, better maintenance and system monitoring, and better access to local working data and incentives.

3.7.5 Strategy limitations

The strategy performance relies solely on the user's motivation, devotion, cooperation, and commitment to improve and sustain their water supply. They should establish and assign their own participative roles in the financing and operation plans and adhere to those roles. Government involvement is encouraged, though, to ensure that the strategy takes root and remains sustainable.

3.8 Conclusion

For the demonstration project at Mnyundo Primary School, it was possible to improve sustainability of RWH technology for meeting community water supply demand. This achievement has been elaborated on through technical, economic, and social perspectives.

In summary, for improvement of RWH practices in the country, solutions have been proposed to the common problems raised in earlier sections (Figure 22). With specific guidelines, standards, and regulations in place, the targeted technology potential can be achieved and adoption can be increased. Media involvement, training, and inclusion of technology basics in the curriculum can serve to boost technology awareness as well as empowerment. Social and financial strategies can allow users to afford their own systems with reduced reliance on donors and boost their sense of ownership, guaranteeing a system that is operated and maintained well.

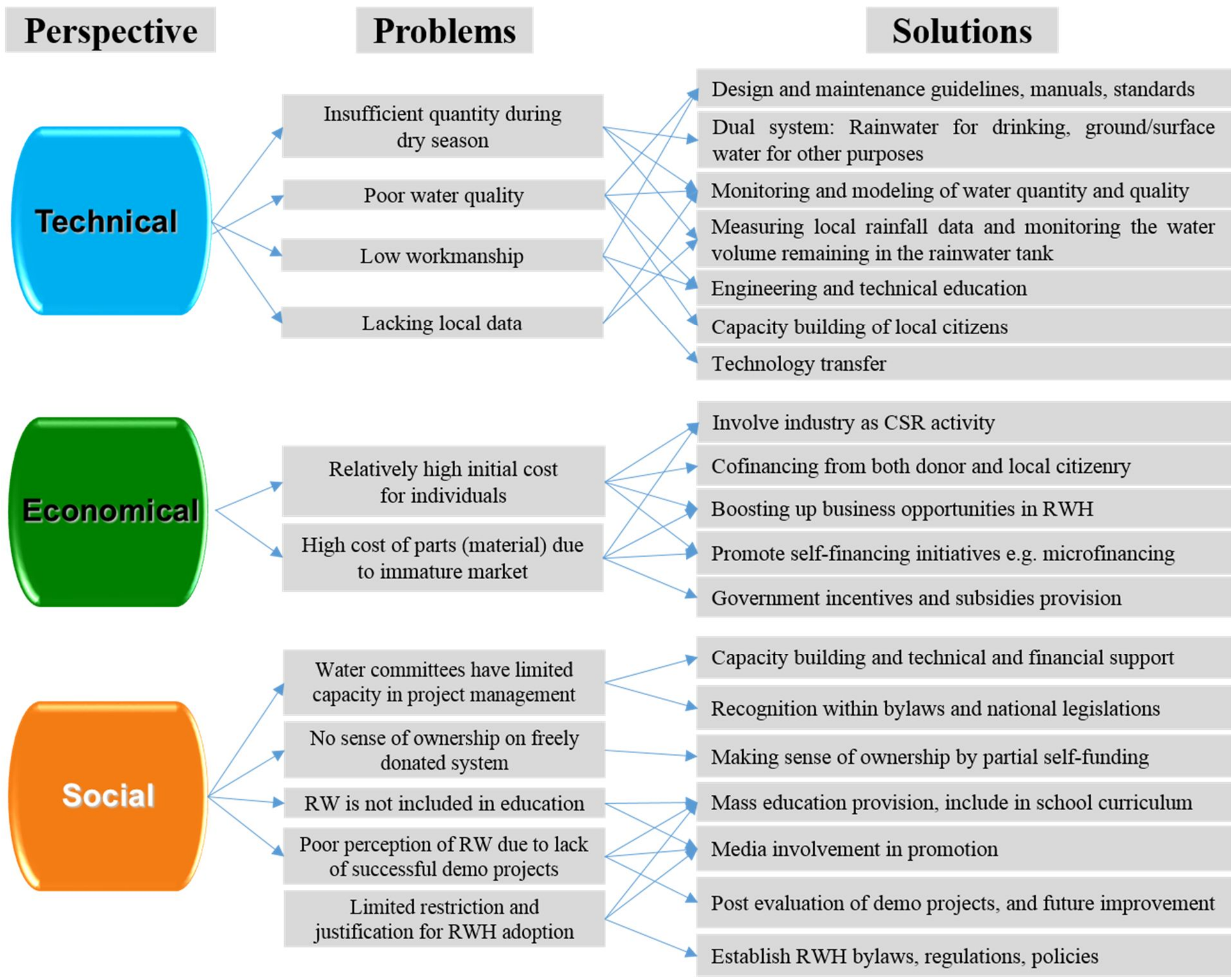


Figure 22: Common problems and proposed solutions for rainwater harvesting practice improvement in Tanzania

CHAPTER 4:

Rainwater Harvesting Potential for Improved Household Water Supply

4.1 Introduction

Household water supply practices in both rural and urban areas of Tanzania present several challenges, which can be classified under technical, economic, and social perspectives.

Technical challenges include limited connections to centralized water supply systems, frequent water rationing experiences as a result of limited performance of systems, and demand overload. Insufficient supply forces people to seek alternative sources, which may involve unprotected water sources and demanding hourly walks for some locations.

The household economy is at stake when water shortages occur. In most places, individuals in households resort to relying on water vendors. Small-scale vendors sell 20 L buckets that cost at least 300 TZS (US$0.175) from their bicycles or wheelbarrows. Large-scale vendors sell water from water boozers, at a cost of at least 80,000 TZS (US$46.59) for 10,000 L. In rural areas there is more reliance in the former.

Limited awareness on alternative means to address water supply challenges and limited knowledge on better management practices for upgrading indigenously adopted practices are social challenges.

Using a typical rural village in Tanzania as a case study, challenges of current household practices are discussed and recommendations are provided on better management practices for improved livelihood of the villagers.

4.2 Site description

Mtiniko is a village within Mtiniko Ward, which is among 28 wards located within the Mtwara rural LGA in Mtwara Region. Mtiniko ward has a population of approximately 7,423 as of 2012. The average household size in the region is approximately 4 (NBS 2014). Households around the Mtiniko village were investigated. Thatched roofs accounts for 80% of roof types, whereas only 20% are iron. A typical roof size is 18 m^2.

Individual efforts to address water supply challenges have led to a common practice of constructing open cemented ponds, which collect and store surface water runoff during the rainy season (Figure 23). The collected water is used mainly for domestic purposes. Similar practices are found in villages in different parts of the country.

Figure 23: Surface runoff harvesting into ponds at Mtiniko Village

4.3 Water supply challenges

Quantity and quality challenges of currently adopted practices affect the economy of the households, limiting opportunities for social empowerment of the village.

4.3.1 Technical challenges

Most dwellers in Mtiniko use the pond technology because it is a cheap and convenient way to address their water supply challenges. This is an indigenous technology, with limited expertise demand; however, water quantity and quality suffer when this technology is used.

4.3.1.1 Water quantity sufficiency

Because the pond is open, precipitation falls directly into the pond during the rainy season. Depending on the size of the pond and quantity of rainfall, RW loss during the rainy season will be mainly due to overflow only, whereas during the dry season, in addition to daily consumption, losses from evaporation are significant. Annual evaporation in the country is estimated at 2000 mm (Moges *et al.* 2003), which if divided equally among the 117 dry days of an average year (Figure 10), is approximately 17 mm. A low C of at most 50%, due to seepage into the catchment, further reduces quantity harvested from a given rainfall.

The daily water balance model, with modifications incorporating evaporation losses in case of an open pond (Equations 4.1, 4.2, 4.3, and 4.4), was applied to assess the pond performance during the year under fixed demand conditions. Previously defined daily demand conditions were adopted (Equations 3.4 and 3.5) as were the following basic conditions: population, 5; catchment size, 150 m^2; pond area, 12.6 m^2; and volume, 20 m^3. Evaporation was considered significant for those days when rainfall ≤ 2 mm and the C is 0.5.

$$V_t = Q_t + I_{tp} + V_{t-1} - E_{tp} - Y_t - O_t \quad (4.1)$$

$$Q_t = I_t \times A_c \times C \quad (4.2)$$

$$I_{tp} = I_t \times A_p \quad (4.3)$$

$$E_{tp} = E_t \times A_p \quad (4.4)$$

Where I_{tp} is the direct precipitation collected into the pond on the t^{th} day (m^3), E_t is the open water evaporation on the t^{th} day (mm), E_{tp} is the pond water evaporation on the t^{th} day (m^3), a nd A_p and A_c are area of the pond and catchment respectively (m^2).

Figure 24 illustrates the current pond performance reliability. The highest reliability is 81%, which was attained at a lower demand of 100 L/d, implying 70 NWD. The number of NWD will decrease as reliability increases.

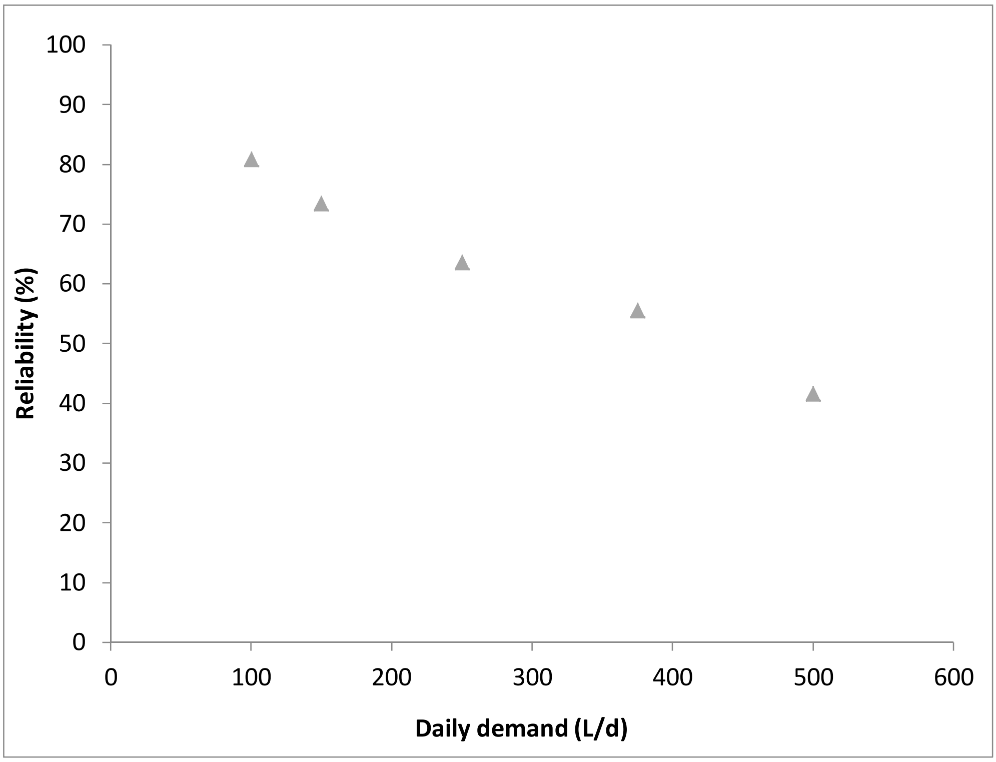


Figure 24: Reliability of uncovered pond under given fixed demand

4.3.1.2 Water quality concern

Even though the ponds are lined mostly with cement mortar, which helps with water quality, they are still open to uncontrolled activities on the catchment surface, allowing organic and inorganic contaminants to reach the pond. Firewood is the main source of energy in these rural areas hence affording water treatment by boiling is unlikely. On empty pond days, alternative water sources may include unprotected streams and rivers, but SW sources are at high risk of contamination due to uncontrolled public usage.

Algal growth was an obvious challenge at one site in Mtiniko village (Figure 23). This may have been promoted by the openness of the pond, exposing it to the sun and nutrients from the surroundings, which could easily find their way into the pond through wind effect and runoff from rainfall.

i. Sample collection

Water samples were collected from ponds in Mtiniko and Nanguruwe villages and a local RWH system. The samples, except for the pond at Mtiniko village, were collected and analyzed for physical, chemical, and microbiological quality at the Mtwara Zonal Water Quality Laboratory in October 2014. The Mtiniko village pond samples were collected and tested at the University of Dar es Salaam Water Quality Laboratory in April, 2013 (rainy season). In all the sources means of accessing water by users is through dipping bucket.

ii. Test results

Based on water quality results (Table 12), the pond at Mtiniko village failed the color test and had high TC counts, which were also measured in the samples from the other two villages. The causes for the high fecal and TC counts in the RWH tank could be caused by the dipping of an unsterilized rope and bucket to retrieve the water. High coliform counts, more specifically fecal coliforms, shows that the water poses a threat to the user's health and may be a contributing factor to high volume of diarrheal cases in the region.

Table 12: Water quality test results for samples from relied water sources within Mtwara District

S/N	Parameter	Sampling Villages (source type)			Standards	
		Mtiniko (Pond)	**Dinyecha (RWH tank)**	**Nanguruwe (Pond)**	**TZ**	**WHO**
1	pH	6.56	8.5	5.75	6.50–8.50	6.5–8.5
2	Total Dissolved Solids (mg/l)	90	75.7	72.6	1,000	1,000
3	Colour (Pt.Co)	24	0	7	15	15
4	Total Hardness (mg/l) as $CaCO_3$	30	8.1	5.6	500	200
5	Sulphate (mg/l)	13	1	24	400	500
6	Chloride (mg/l)	5.0	2.72	25.45	250	200–300
7	Sodium (mg/l)	2.6	0	1.2	200	200
8	Faecal coliform (No./100 mls)	Not tested	11	37	Nil	Nil
9	Total Coliform (No/100 mls)	165	27	270	Nil	Nil

4.3.2 Economic challenges

Because of insufficient quantity of water supply, villagers resort to alternative water sources, which often are not easily accessed, are inconvenient and have questionable water quality. Most often, women and children retrieve the water from these sources.

Water vendors also are sought, which is an expensive option and affordable by few. Considering the established 70 NWD in the case of lower demand value at 20 L/person/d for a family of 5, a 20 L bucket, sold at 400 TZS (US$0.23), will add up to 140,000 TZS (US$81.5) for a one-year's supply. This sum is high for individual households largely depending on rain-fed agriculture as their source of income.

4.3.3 Social challenges

Limited awareness of alternative water supply sources results in people staying with familiar traditional water sources, even if they have been performing below par with respect to quantity and quality. This is the case not only in Mtiniko village, where surface runoff water in ponds is relied on, but also in villages around the country where similar practices are used.

4.4 Strategies for improving water supply practices

Some strategies are suggested to mitigate the challenges of relying on a pond as a household main water supply source. The purpose of these strategies is to enhance harvested RW quantity sufficiency and quality, to ensure the user's good health as well as empowerment when handling their own water supply.

4.4.1 Technical considerations

Through innovative technical ideas, indigenous technology, such as ponds, can be upgraded to achieve sufficiency in quantity and acceptable quality, rather than abandonment of these technologies in favor of new technologies. Even if there is a need for a new technology, it should be used in addition to what is already familiar to the locals to ensure its sustainability.

4.4.1.1 Quantity sufficiency

Assessment was done comparing conditions of open and closed ponds through application of the daily water balance model. Figure 25 presents pond performance in regard to NWD and RUR. When comparing the current pond condition, which is open, to a condition where it is covered, at higher daily demand, the uncovered pond appeared to have lower NWD values than the covered ponds. This is due to the extra available RW from direct precipitation into the uncovered pond; thus, meeting the higher demand well. The limited RW in the covered pond fails to meet the higher demand. Nevertheless, at lower demand values, the dominating factor is the ability to save RW for drier days. This is where the covered pond is more effective because no additional loss due to evaporation occurs. The RUR is higher for the covered pond. However, even if covered, the pond cannot assure daily demand satisfaction throughout the year, unless the demand is limited to 100 L/d resulting in a 46% RUR.

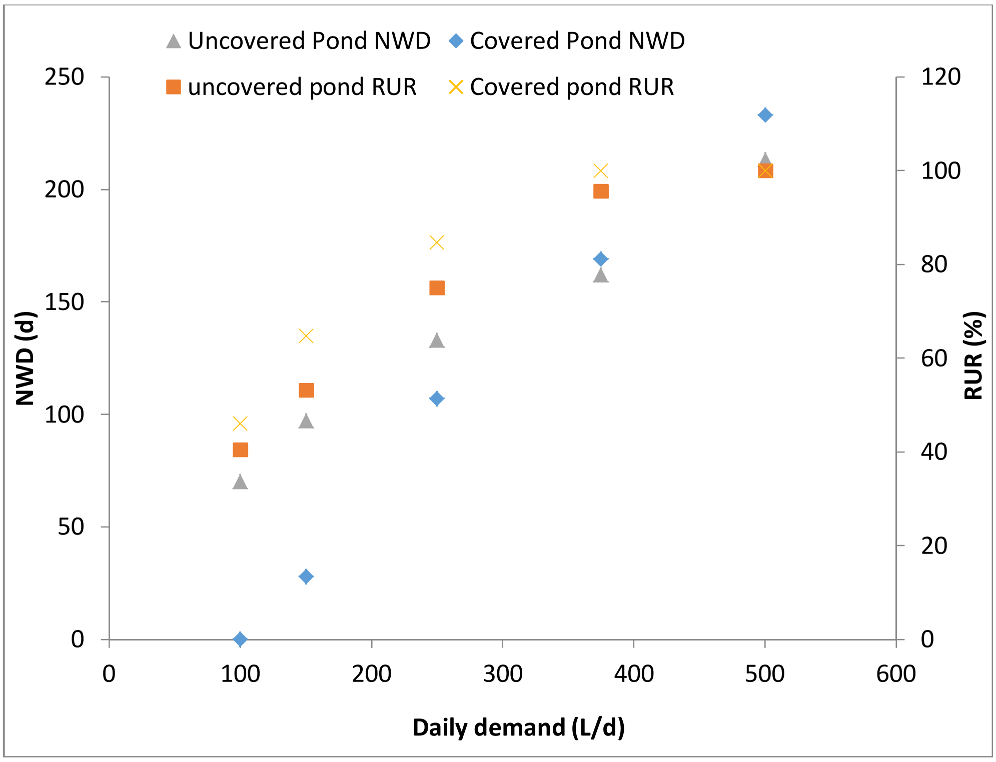


Figure 25: Performance comparison between covered and open pond

For ensuring sufficient demand satisfaction, not only is pond covering recommended but having a simple rooftop RWH system is as well. These can be relied on in a dual manner, with drinking water taken from the RWH system and pond water used for nonpotable purposes to address quality concerns (Figure 26). RWH systems are a possibility as most households in this village had at least one building with an iron roof, even if the walls were made of clay.

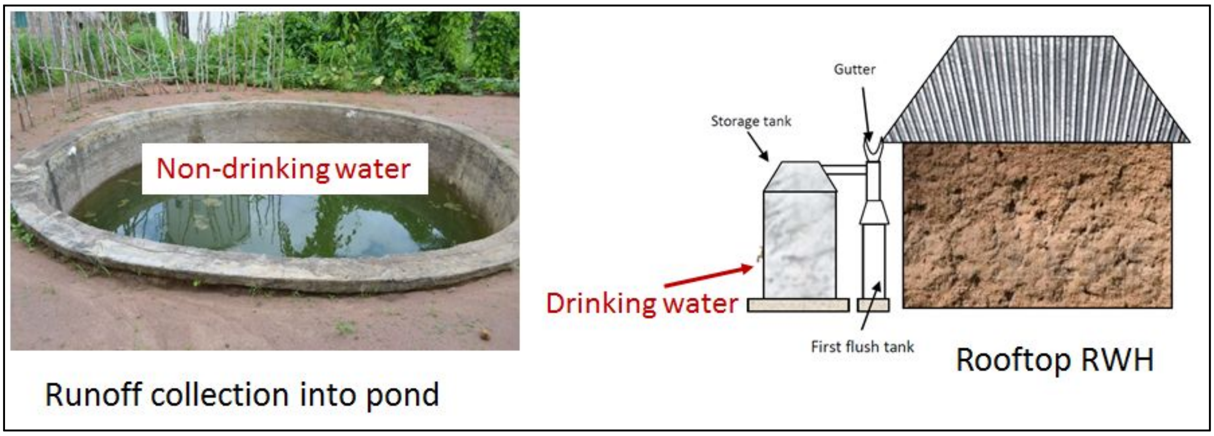


Figure 26: Proposed reliance on both surface and rooftop rainwater runoff collection

Further analysis was performed by utilizing the daily water balance model with modifications incorporating a water level monitoring strategy (Section 3.3.1). This was conducted to establish a good application strategy.

i. Reliance on covered pond

With pond capacity limited to 20 m^3 for a population of 5 and a C of 0.5 for a catchment size of 150 m2, variable daily demand scenarios were proposed as follows:

- Scenario 1: if WL > 50%, then demand is 150 L/d; else 100 L/d;
- Scenario 2: if WL > 50%, then demand is 200 L/d; else 100 L/d;
- Scenario 3: if WL > 70%, then demand is 375 L/d; else if WL > 30% but ≤ 70%, then demand is 250 L/d; else if WL ≤ 30%, then demand is 150 L/d

In reality, to monitor the WL one would have a graduated piece of wood for dipping into the pond and checking the levels prior to consumption.

Scenario 1 offers better pond performance with reliability, NWD, and RUR values of 100%, zero d, and 58% respectively (Figure 27). Overflow losses are limited at 31% of total rainfall harvested, while 11% of total rainfall harvested remains stored in the tank at the end of the year.

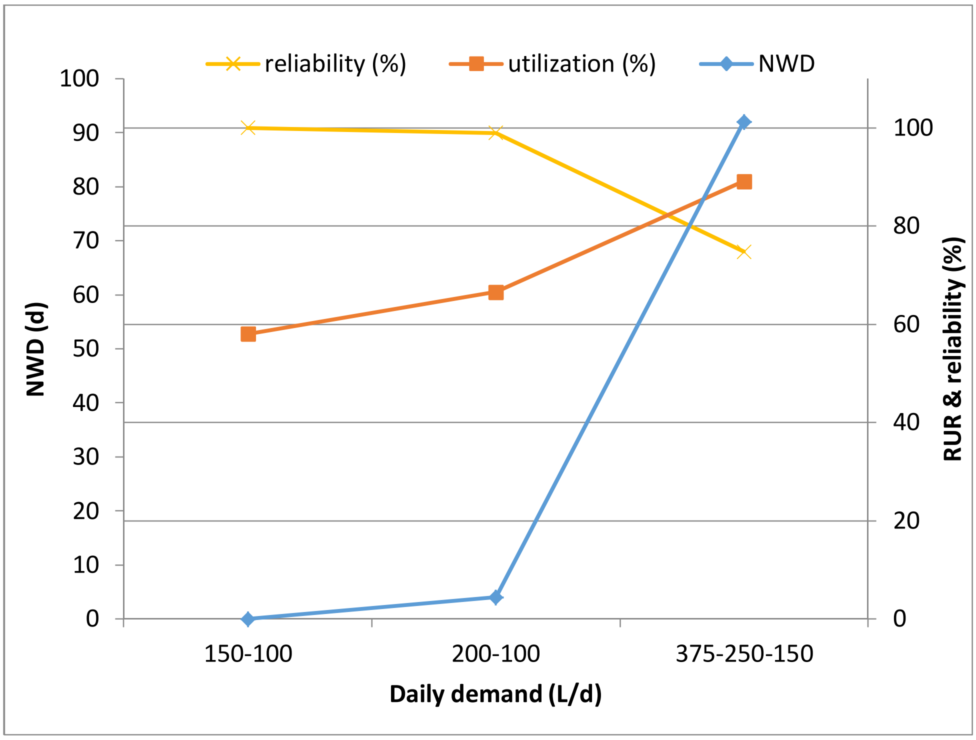


Figure 27: Covered pond performance assessment under variable daily demand scenarios

ii. Reliance on rooftop harvesting

The considered rooftop size was 18 m^2 with a *C* of 0.8. The storage capacities assessed were 0.5, 1, 1.5, 2.2, and 3.2 m^3 for a population of 5. Variable daily demand scenarios considered are as follows:

- Scenario 1: if WL > 50%, then demand is 15 L/d; else 10 L/d;
- Scenario 2: if WL > 70%, then demand is 25 L/d; else if WL is > 30% but ≤ 70%, then demand is 15 L/d; else if WL ≤ 30%, then demand is 10 L/d;
- Scenario 3: if WL > 75%, then demand is 37.5 L/d; else if WL > 50% but ≤ 75%, then demand is 25 L/d; else if WL > 25% but ≤ 50%, then demand is 15 L/d; else if WL ≤ 25%, then demand is 10 L/d;
- Scenario 4: if WL > 75%, then demand is 50 L/d; else if WL > 50% but ≤ 75%, then demand is 37.5 L/d; else if WL > 25% but ≤ 50%, then demand is 25 L/d; else if WL ≤ 25%, then demand is 15 L/d.

Despite having 100% reliability, Scenarios 1 and 2 have RURs lower than 50%, hence Scenario 3 shows better performance (Figure 28). For rooftop harvesting, increased storage size results in increased construction/purchasing cost regardless of the type of material used, therefore, 2.2 m^3 is the optimal solution. This storage capacity results in zero NWD and a RUR of 54% (Figure 29). Overflow losses are limited to 36% of total rainfall harvested.

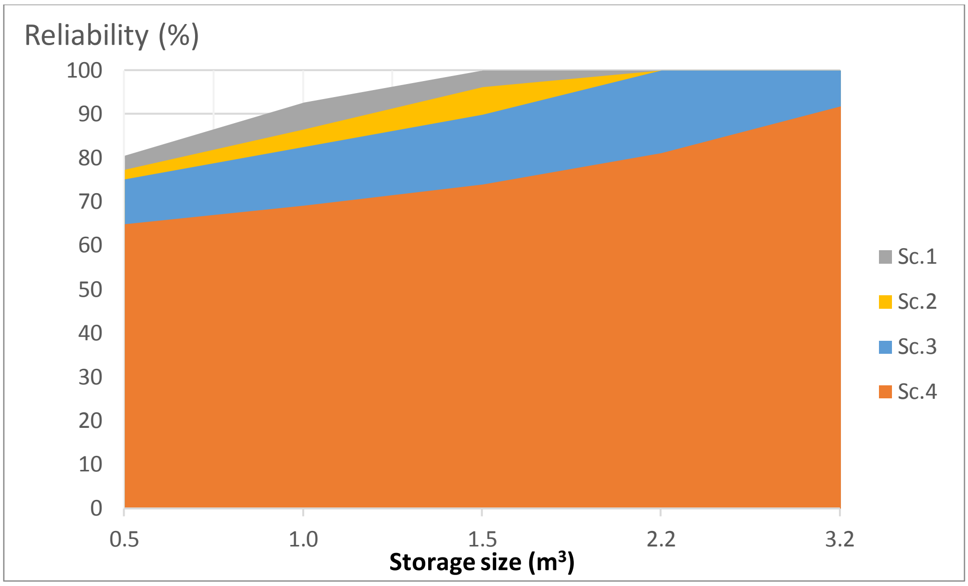


Figure 28: Reliability of various storage sizes at the proposed variable daily demand scenarios

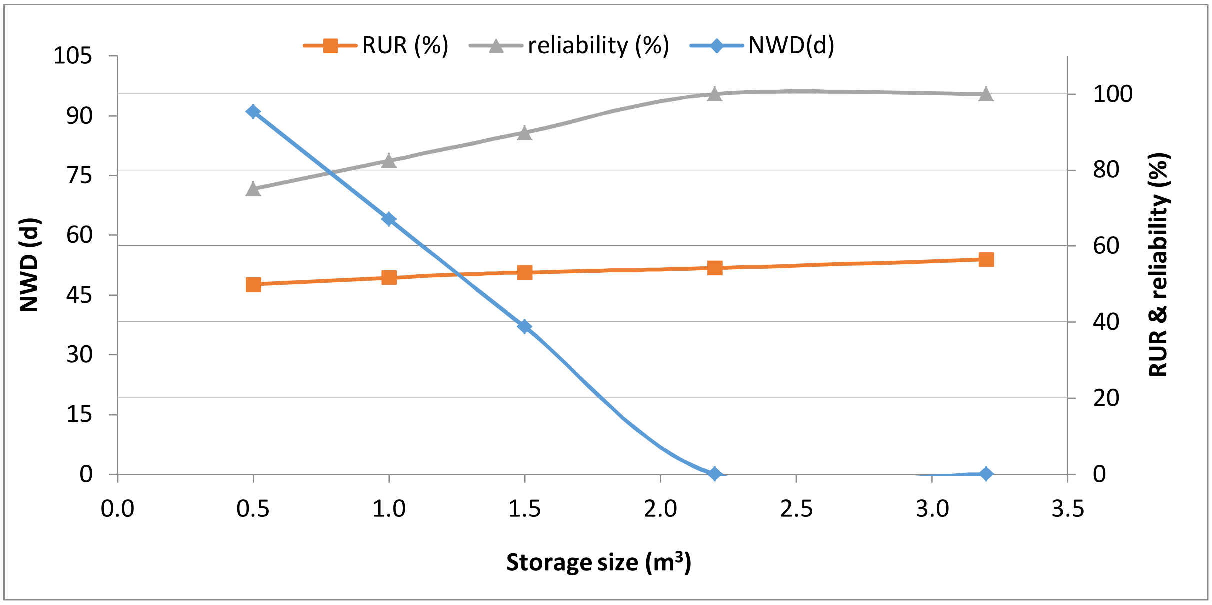


Figure 29: Rooftop harvesting performance at various storage sizes under demand scenario 3

iii. Dual supply reliance with both rooftop and surface runoff harvesting

For total demand satisfaction throughout the year, both harvesting techniques can be adopted to work as a dual water supply. Figure 30a shows that during the rainy season the locals can rely on rooftop water for both drinking and cooking with up to 37.5 L/d, whereas during the dry season, it would only be used for drinking purposes at 10 L/d. During the rainy season, the pond (Figure 30b) can source up to 150 L/d of water for meeting household demands other than drinking, but during the dry season the usage would be limited to 100 L/d. This combination strategy assure the locals that even on dry days there should be at least 2 and 20 L/person/d for drinking and nondrinking purposes, respectively, effectively raising their WSSR to 100%.

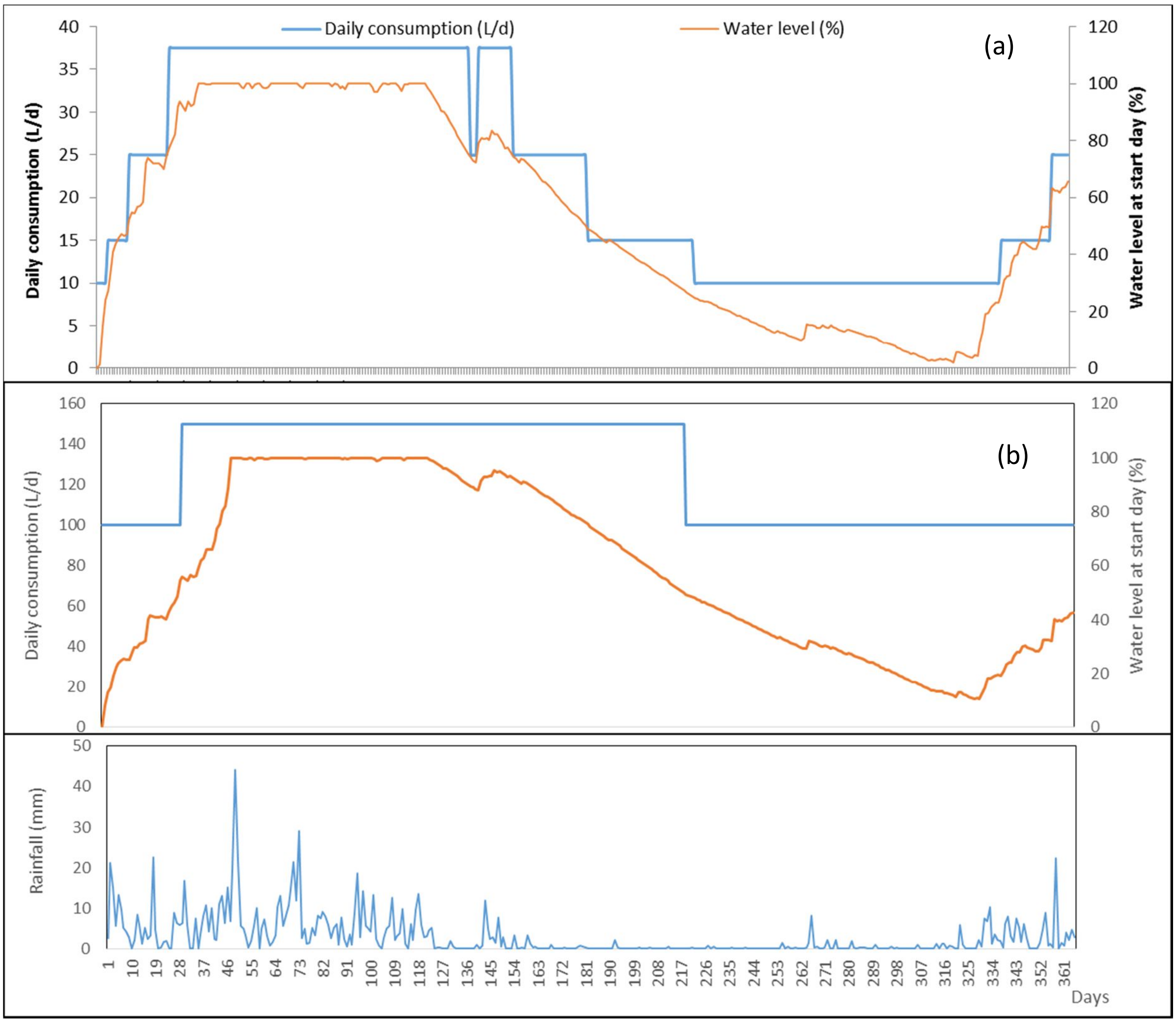


Figure 30: Recommended daily consumption in combined rooftop (a) and surface (b) runoff harvesting

4.4.1.2 Quality improvement

Allocating rooftop runoff water for drinking and surface runoff water from the pond for other household uses would help to address the quality concerns, which arise when pond water is used for drinking purposes.

Additionally, better pond and catchment management practices are recommended to ensure improved water quality into and out of the pond:

- With concern of maintaining low cost interventions as well as incorporating indigenous knowledge, ponds can be covered by imitating the thatching mechanism applied in roofing traditional houses. Locally available materials, such as palm tree leaves, coconut tree leaves, and sisal seedpods, can be used. This would result in limited sunlight exposure and prevention of dusty input.

- Allocation of a specific bucket for water collection from the pond is necessary, which should be kept in a clean place and its cleanness maintained. This would minimize contaminant input into the pond. Another alternative would be to introduce a mechanism for lifting water out of the pond using a rope and washer pump.
- Improved catchment management is necessary to control, not only human activities, but also the activities of other animals. Washing, farming, excretion activities, and poultry movement, if managed and allocated far from the catchment, would contribute to an improved quality of water entering the pond. Cementing the catchment would also improve the quality of the water entering the pond because the sediment load would be reduced. Most particles (organic and inorganic) tend to adhere to sediments, which often serve as the mode of transfer for the particles. With this reduction in sediment and, thus contaminant particles, an increase in quantity harvested will also occur due to an improved *C*.
- Fencing off the pond and, if possible, the catchment would improve water quality. A simple fence of tree branches can be effective. At Mtiniko village, some households had a similar kind of fencing. This would help keep dust away and act as an effective safety measure to protect young children from accidental drowning.
- A more advanced technique would be to include a filter material at the pond entry. The filter would need frequent cleaning to prevent clogging. A filter media incorporating processes of filtration and sedimentation prior to flow entry into pond would be even better (Figure 31). However, this requires engineering skills in structural design, sizing, and material selection.

- Bad algae, such as blue green and filamentous, can be controlled through the following approaches (Comas 2003):
    - ✓ Nutrient reduction: by managing activities within the catchment, such as relocating gardening activities thus limiting fertilizer runoff input
    - ✓ Physical removal: by using modified fish nets

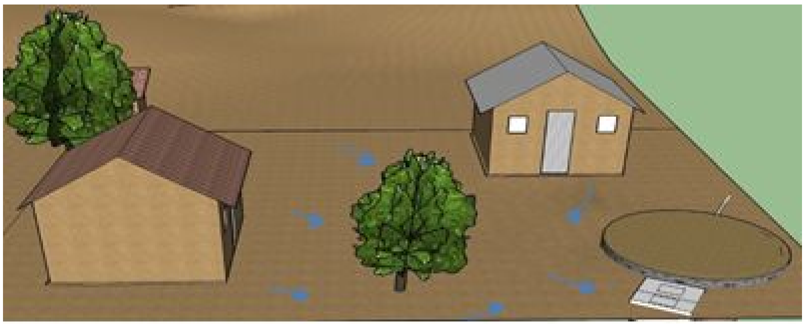


Figure 31: Schematic including pond media for filtering surface runoff into pond

4.4.2 Economic considerations

Improved household water supply, in this case with a dual supply, will result in an increased WSSR by reducing reliance on external water supply sources, including water vendors. In addition, safer water sources, such as rooftop RWH, reduce health impacts, which result from using unprotected water sources, and the cost implications from such.

For households with only thatched roofs, people can be encouraged to upgrade their thatched roof to iron roofing for RWH purposes. A roof catchment as small as 18 m^2 would be sufficient to meet drinking water demands of a household of 5. For technologies, such as mortar jar storage tanks (2.2 m^3), the construction cost can be limited at 1,000,000 TZS (US$582.3), through strategies of lowering reliance on external labor.

Self-financing initiatives, including microfinancing, individual business profit, and profit from the sale of farm products, can be applied to finance a simple household RWH supply system. The traditional kind of microfinancing, known as UPATU, also works well, whereby there is a revolving fund among members in a group, who are usually within the same income level, and one can save to accumulate the earned money or deposit it in a bank to collect interest. A simple loaning system also can be introduced by LGAs, as a financial support, with various options for qualifying for a loan, including a refund in cash and in-kind, interest rates lower than those found in banks, and criteria for setting extended grace periods.

Moreover, through knowledge gained during the demonstration projects, individuals can take charge of constructing their own systems, seek advice and supervision from local DWEs, and hire laborers only for highly skilled roles, thus lowering the construction cost.

4.4.3 Social considerations

Aiming to empower and boost individual capacity to tackle one's own water supply challenges, LGAs should routinely educate villagers about alternative decentralized water supply technologies such as RWH. This can take place during village meetings and through dramas. The LGAs should also offer close guidance during the system implementation. Self-initiative has a benefit of building capacity, boosting sense of ownership, and guaranteeing good operation and maintenance and reduced load on the government.

4.5 Conclusion

RWH has potential worthy of consideration as a household water supply source. In the Mtiniko village households, through modeling approaches, the locals can realize better ways of utilizing RW, even with limited rainfall quantity. RW may not necessarily serve as the sole water source, but it can be useful under dual supply conditions, with other water supplies including surface and GW sources. Having multiple convenient water sources boosts the household WSSR. In terms of quality, RW seems to be the best drinking water source. Available indigenous water supply approaches can be studied and improved upon to ensure good quality water. As a way forward, the GoT can invest in empowering individuals to address their own water supply challenges with RWH through increased awareness and technical and financial support strategies.

CHAPTER 5:

Potential for Rainwater Harvesting Technology in Tanzania

5.1 Introduction

A waffle type of water management is recommended to achieve self-sufficiency in water supply. This is a decentralized way of water management whereby each unit is responsible for collecting and managing water within its boundaries. For this type of management, RWH fits well.

Innovative strategies and techniques for improving and sustaining RWH practices in Tanzania have been introduced and discussed. The demonstration projects and case studies conducted in Mtwara Region are considered representative and typical of areas in Tanzania. Still, to apply the rooftop RWH technology effectively and sustainably, it is good to understand where exactly RWH can be applied to make full use of its potential. This is important when considering extending adoption of the technology throughout the country. The national water sector development strategy (MoWI 2008) on the service level has aims to provide a minimum of 70 L/person/d for consumers with household connections to a water supply system, a minimum of 25 L/person/d for consumers with yard connections to a water supply system, and 25 L/person/d through water points.

5.2 Annual rainfall statistics

Tanzania receives two major rainfall modals in the regions: unimodal from December to April in the southern, southwest central, southwest, and western part of the country and bimodal from October to December and March to May, in the north, northeast, and northern coast. A larger portion of the country receives annual rainfall in the range of 400 – 1200 mm.

There is an exception in the highlands and parts of the extreme south and west, where 1200 – 2000 mm, and sometimes more, can be experienced (Figure 32).

Considering the rainfall distribution statistics, it is safe to predict that RWH can serve as a water supply source. This would be possible in a dual manner with GW, springs, or a centralized system, and even as a sole source in some areas.

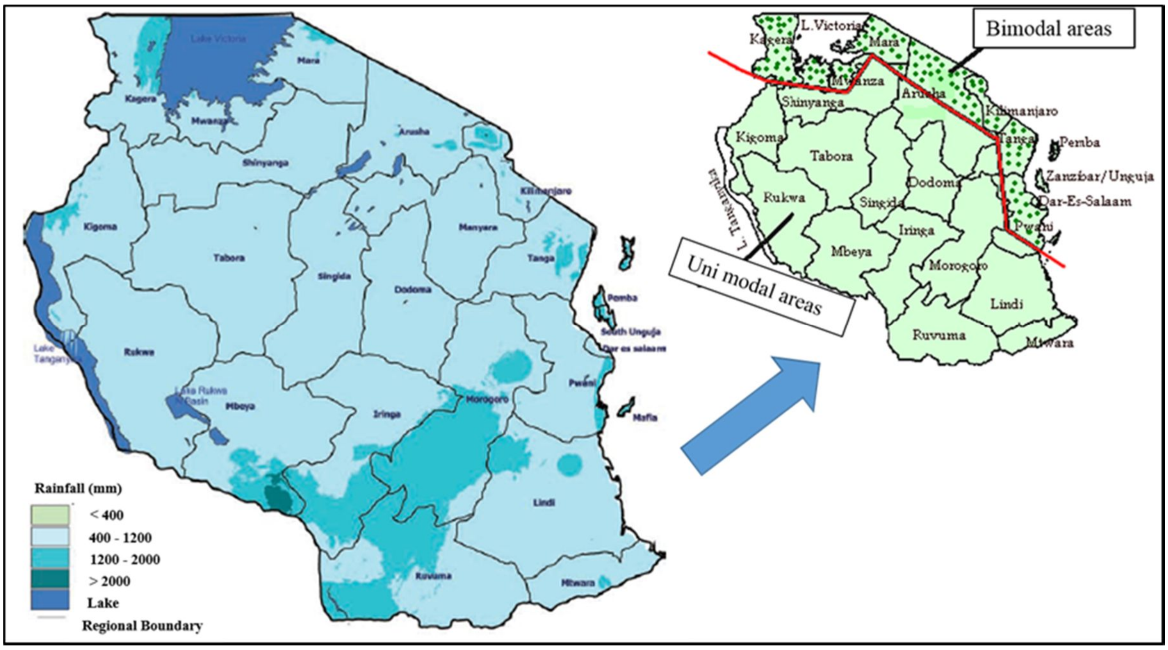


Figure 32: Tanzania annual rainfall distribution (Malesu et al. 2006) and rainfall regimes (FEWSNET 2005)

5.3 GIS based rainwater harvesting potential study

A geographic information system (GIS) has been recommended as a support that can help to identify RWH potential and feasibility in a specific area (Akvopedia 2015). The following datasets, on a broader perspective, are recommended as most relevant when accessible: population density, land use, access to other water source and aridity, annual rainfall, variation in rainfall, and soil drainage. The popularization of GIS usage has been due to the increased need for information in user friendly formats that can easily be updated, queried, managed, and utilized (Malesu *et al*. 2006).

For nine African countries, including Tanzania, a GIS-based study on RWH potential was conducted (Malesu *et al*. 2006). This was a joint project between United Nations Environmental Programme and the International Centre for Research in Agroforestry with the purpose of developing GIS thematic data of the potential for RWH in Africa in spatial domains. Domains were established as indicators of suitability of the following RWH interventions: rooftop RWH, surface runoff from open surfaces with storage in pans/ponds, flood-flow harvesting from watercourses with storages in sand/subsurface dams, and in situ soil water storage systems. The GIS database was developed using ArcGIS and ArcView software utilizing both vector and raster (gridded) available databases. The database comprises baseline thematic maps and composite processed maps, developed using mapping criteria including:

- Rainfall data: The available continent-wide spatial data used was mean annual rainfall. Areas with rainfall of 400 – 1200 mm were considered as most optimal to have huge incremental benefits from RWH.
- Land slope: Elevation models with 90 m resolution digital were used, accommodating continent-wide and country scales. Slope steepness was determined using GIS analyses and used to show areas preferable for runoff harvesting from open areas.
- Population density: Africa-wide digital data on population from Food and Agriculture Organization Corporate Statistical Database (FAOSTAT) was used, and the developed classification scheme allowed for one household per km^2 as minimum population density for RWH.

5.3.1 Feedback on rooftop rainwater harvesting potential for Tanzania

For rooftop RWH, Malesu *et al*. (2006) assumed that all areas have potential for rooftop RWH as long as annual rainfall is at least 200 mm, there is a presence of settlement, and the population > 10 persons/km^2. Input spatial data were classified as follows:

a) Rainfall (mm): Desert 0 – 200; low 200 – 400; medium 400 – 1200; high > 1200

b) *C*: 0.8

c) Population (persons/km^2): Low < 10; medium 11 – 100; high > 100

For rooftop domain, Malesu *et al*. (2006) established that harvestable RW for the medium rainfall, high population (MR/HP) rooftop domain, ranges from 115.6 to 346.8 km^3 and occupies 38.3% of the country area (Figures 33 and 34).

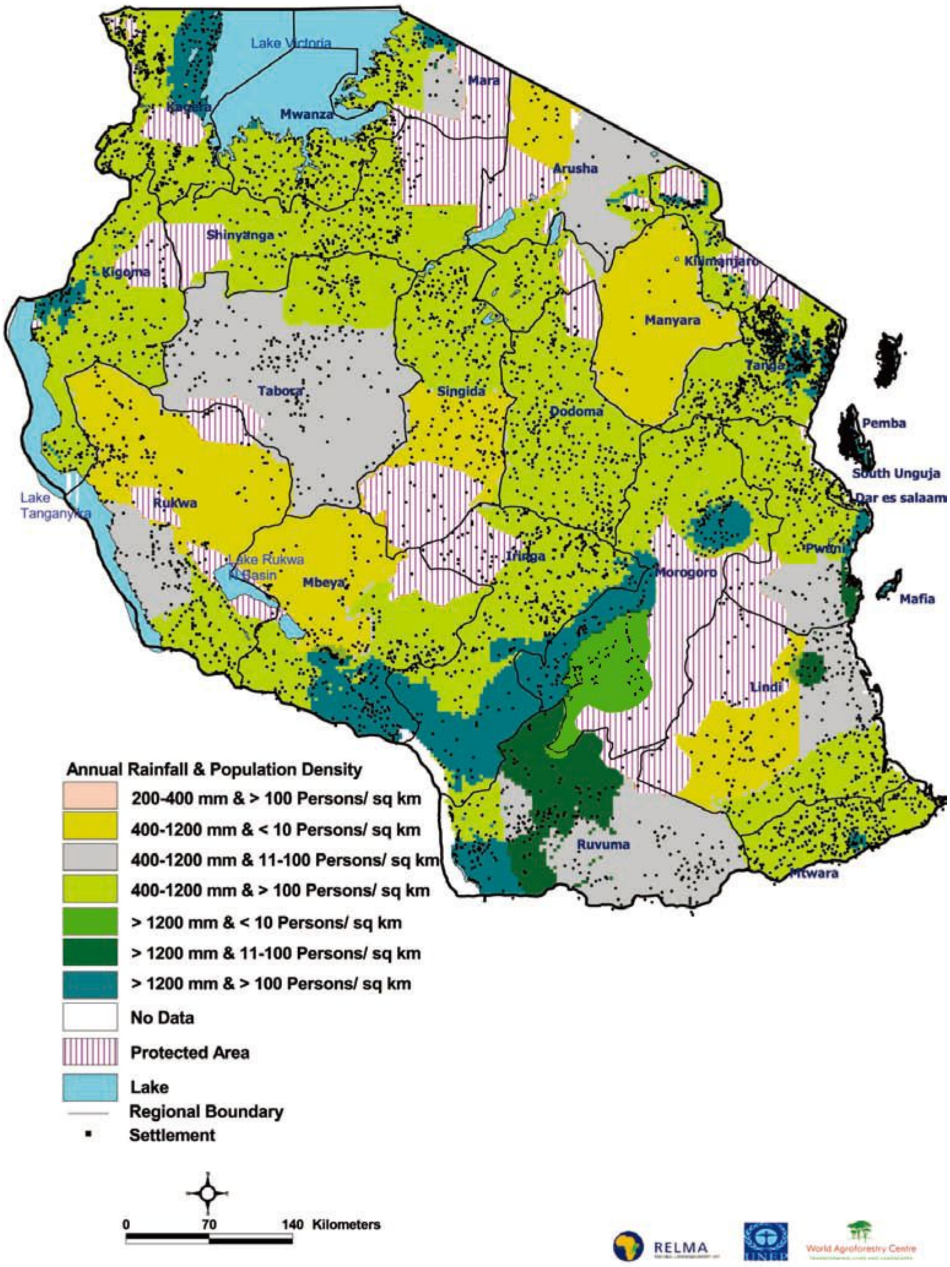


Figure 33: Development domains for rooftop rainwater harvesting in Tanzania (Malesu et al. 2006)

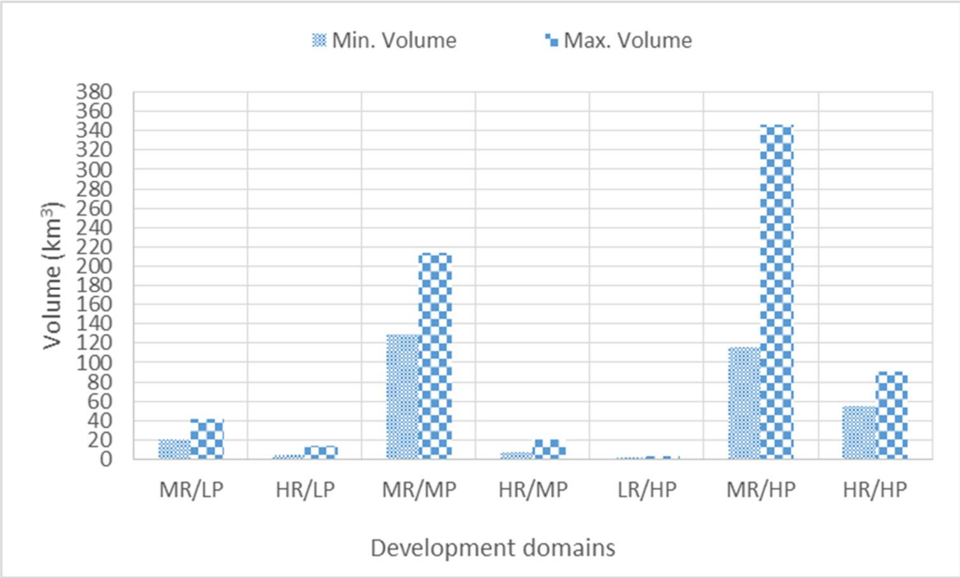


Figure 34: Maximum and minimum volume of harvestable rainwater (Modified from Malesu et al. 2006)

5.3.2 Rainwater harvesting potential for selected regions in Tanzania

Further specific analysis can be performed based on the established maximum and minimum potential harvestable RW values (Figure 34). These limits can serve in predicting the best considerations for RWH, whether as a sole source or in duality with other sources.

5.3.2.1 General overview

Consider the following data for the larger area of the country (MR/HP): minimum har vestable RW, 115.6 km^3; annual rainfall, 400 mm; population per km^2, 3,133 (which is the hig hest of all regions and sixty times the average population density in the country i.e., 51 (NBS 2014)); and *C*, 0.8.

$$Q_t = I_t \times A \times C; A = \frac{Q_t}{I_t \times C} = \frac{115.6}{0.4 \times 10^{-3} \times 0.8} = 361{,}250 \text{ km}^2$$

3,133 people – 1 km^2; how many people in 361,250 km^2?

$$= \frac{3{,}133 \times 361{,}250}{1} = 1{,}131{,}796{,}250 \text{ people}$$

1 km^3 = $1X10^{12}$ L; how many liters per person per year, if 115.6 km^3 per 1 B people?

$$= \frac{115.6 \times 10^{12} \times 1}{1{,}131{,}796{,}250} = \frac{102{,}138.53 \text{ L}}{\text{person}} / \text{year}$$

If RW is equally distributed, how much will each person have per day?

$$= \frac{102{,}138.53}{365} = 279.83 \text{ L/d}$$

Considering a similar approach, on the upper level of annual rainfall of 1200 mm, consumption is estimated at 839.49 L/person/d.

In general, despite lacking incorporation of seasonal variation (shorter interval rainfall data) and socioeconomic factors, this still provides a good platform in support of promoting rooftop RWH for tackling current water challenges in Tanzania.

5.3.2.2 Dar es Salaam Region

Dar es Salaam (DSM) is the administrative, commercial, industrial, and transportation center of Tanzania and has a population of approximately 4.4 million, which is the highest population of all the regions (NBS 2014). It lies in the southeastern part of the country (Figure 2). Functional water points meet 3.99% of full coverage (MoW 2014a), which is the lowest of all the regions in the country.

Rwehumbiza *et al*. (2000) challenged a study conducted in 1997 on augmentation of the DSM water supply for failing to incorporate rooftop RWH among solutions proposed. The main water source for the city, the Ruvu River, was supplying below expectations due to excessive water losses estimated at 53%. An analysis was performed based on the mean annual rainfall for DSM of 1095 mm. RWH was designed to meet 30% of water demand with 30% of the rainfall from the rainy season. This would result in partial utilization of the Ruvu River supply system, thus providing time for maintenance and reducing energy costs. It was established that roof catchments would need to be installed in approximately 700,000 residential houses, which seemed possible because most new houses already had good gutter systems.

i. Data collected

A more specific GIS study was conducted for the city of DSM on assessing potential for RWH interventions including rooftop RWH (UNEP 2006). The established potential volume of water that can be harvested from buildings was 5,029,491 m^3 for an area of 5,374,249 m^2 as displayed in the map in Appendix C. Catchment characteristics, such as different types of roofing materials and roof slopes, were not included as input for the projected RWH potential.

ii. Analytical results

Considering recent statistical data (NBS 2014), the population density of DSM is estimated at 3,133 persons/km^2. Hence, approximately16,838 people would occupy 5.374 km^2. The established RW quantity harvested will be able to serve as follows:

$$= \frac{5{,}029{,}491}{16{,}838} = \frac{\frac{298.7\ \text{m3}}{\text{person}}}{\text{year}} = \frac{818.4\ \text{L}}{\text{person}}/\text{day}$$

This shows a very high potential of RWH for addressing persistent water supply challenges in the city.

5.3.2.3 Dodoma Region

Dodoma, officially the national capital of Tanzania, hosts the national assembly. This capital city lies in the eastern central part of the country (Figure 2) and has a population of approximately 2.1 million with population density estimated at 50 persons/km^2 (NBS 2014). Functional water points meet 16.95% of full coverage (MoW 2014a). Average annual rainfall in the capital city is approximately 400 mm.

i. Data collected

Figures 33 and 34 show that the Dodoma Region is within MR/HP domain, hence minimum harvestable volume is estimated at 115.6 km^3, and population density is considered to be 200 persons/km^2 (four times the density established in the 2012 census).

ii. Analytical results

$$Q_t = I_t \times A \times C; A = \frac{Q_t}{I_t \times C} = \frac{115.6}{0.4 \times 10^{-3} \times 0.8} = 361{,}250 \text{ km}^2$$

200 people – 1 km^2; how many people in 361,250 km^2?

$$= \frac{200 \times 361{,}250}{1} = 72{,}250{,}000 \text{ people}$$

1 km^3 = 1X10^{12} L; how many liters per person per year, if 115.6 km^3 per 72 M people?

$$= \frac{115.6 \times 10^{12} \times 1}{72{,}250{,}000} = \frac{1{,}600{,}000 \text{ L}}{\text{person}}/\text{year}$$

If the RW is equally distributed, how much will each person have per day?

$$= \frac{1{,}600{,}000}{365} = 4{,}383.56 \text{ L/d}$$

From a general perspective, this shows a very high potential of RWH to address persistent water supply challenges in the region.

5.3.2.4 Arusha Region

Arusha, in the northern part of the country (Figure 2), is a global tourist destination, center of the northern Tanzanian safari circuit, and among the developed regions of the country. It has a population of approximately 1.7 million with a population density estimated at 45 persons/km^2 (NBS 2014). Functional water points meet 43.2% of full coverage (MoW 2014a). Average annual rainfall in Arusha is approximately 900 mm.

i. Data collected

Figures 33 and 34 show that Arusha Region is within MR/MP domain, hence minimum harvestable volume is estimated at 128.5 km^3, and population density is considered to be 45 persons/km^2 (as established in the 2012 census).

ii. Analytical results

$$Q_t = I_t \times A \times C; A = \frac{Q_t}{I_t \times C} = \frac{128.5}{0.9 \times 10^{-3} \times 0.8} = 178{,}472 \text{ km}^2$$

45 people – 1 km^2; how many people in 178,472 km^2?

$$= \frac{45 \times 178{,}472}{1} = 8{,}031{,}250 \text{ people}$$

1 km^3 = $1X10^{12}$ L; how many liters per person per year, if 128.5 km^3 per 8 M people?

$$= \frac{128.5 \times 10^{12} \times 1}{8{,}031{,}250} = \frac{16{,}000{,}019.92 \text{ L}}{\text{person}} /\text{year}$$

If the RW is equally distributed, how much will each person have per day?

$$= \frac{16{,}000{,}019.92}{365} = 43{,}835.67 \text{ L/d}$$

From a general perspective, this shows a very high potential for RWH to address water supply challenges in this region.

5.4 Rainwater harvesting technology adoption in households

As stated in a 2012 human settlement survey of the Tanzanian mainland, 61.9% of households had modern roofs, which includes iron sheets, tiles, and concrete, whereas the rest of the households still utilized either grass, thatch, or mud (NBS 2013a). As a majority of the roofs are harvestable, there is room for advocating rooftop RWH adoption in households within Tanzania. Representative household cases within unimodal and bimodal regimes in Mtwara and DSM Regions, respectively, were considered. Modeling was applied to determine the contribution RWH adoption would have on meeting annual water demand.

Basic conditions and assumptions included: average household size, 5; roof size, 60 m^2; *C*, 0.8; storage, 5 m^3. Daily rainfall data were used, Figures 10 and 35, for the Mtwara and DSM (average annual rainfall is 991.6 mm) Regions, respectively. All days of the year were considered, that is 365, and fixed and variable daily demand were both applied. Fixed demand from 10 to 120 L/person/d, and scenarios for variable daily demand are as shown in

Table 13. In addition, what is required to serve in the RW scarce days is addressed as supplement (Equation 5.1).

$$\text{Supplement (\%)} = \frac{\sum_{t=1}^{T} D_t - Y_t}{\sum_{t=1}^{T} D_t} \times 100 \qquad (5.1)$$

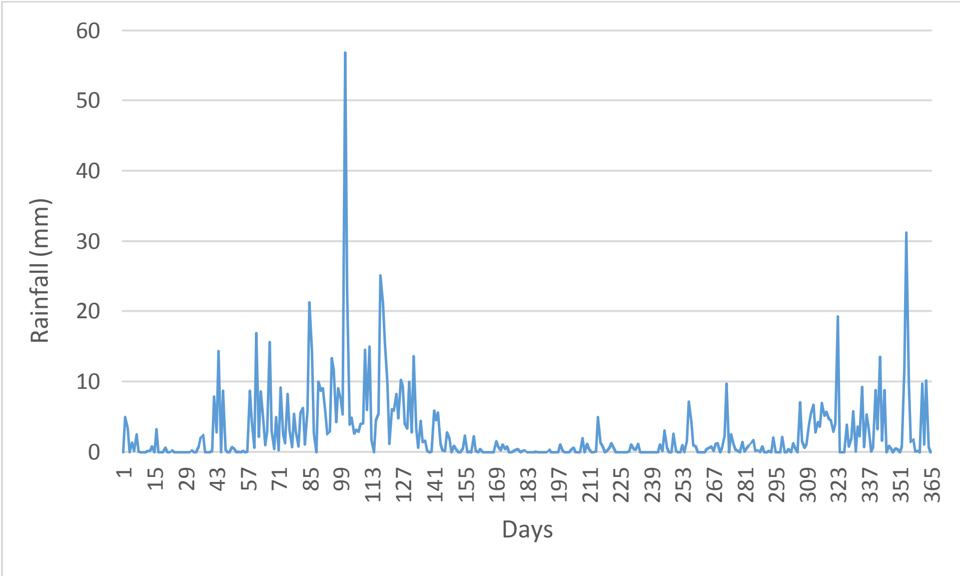


Figure 35: DSM Region average daily rainfall data for 2010 - 2014 (Source: TMA)

Table 13: Water level monitoring demand scenarios, and performance results for DSM and Mtwara households

Scenarios	**Water Level (%)**	**Demand (L/p/d)**	**DSM house**			**Mtwara house**		
			NWD (d)	**RUR (%)**	**Supplement (%)**	**NWD (d)**	**RUR (%)**	**Supplement (%)**
1	>70	50	174	83	36	165	85	35
	≤70 and >30	40						
	≤30	30						
2	>70	100	236	99	52	213	100	49
	≤70 and >30	70						
	≤30	50						
3	>70	70	200	94	44	189	95	42
	≤70 and >30	50						
	≤30	40						

5.4.1 Bimodal regime case study

For the household in DSM, with 70 L/person/d, RW would meet 37% of annual water demand, with 100% RUR. The demand would be fully served in 92 d, or approximately 3.1 months (Figure 36 and 37). For variable demand approach, at Scenario 3, RW would meet 56% of annual water demand with 94% RUR. The demand would be fully served in 165 d, or approximately 5.5 months (Table 13 and Figure 38).

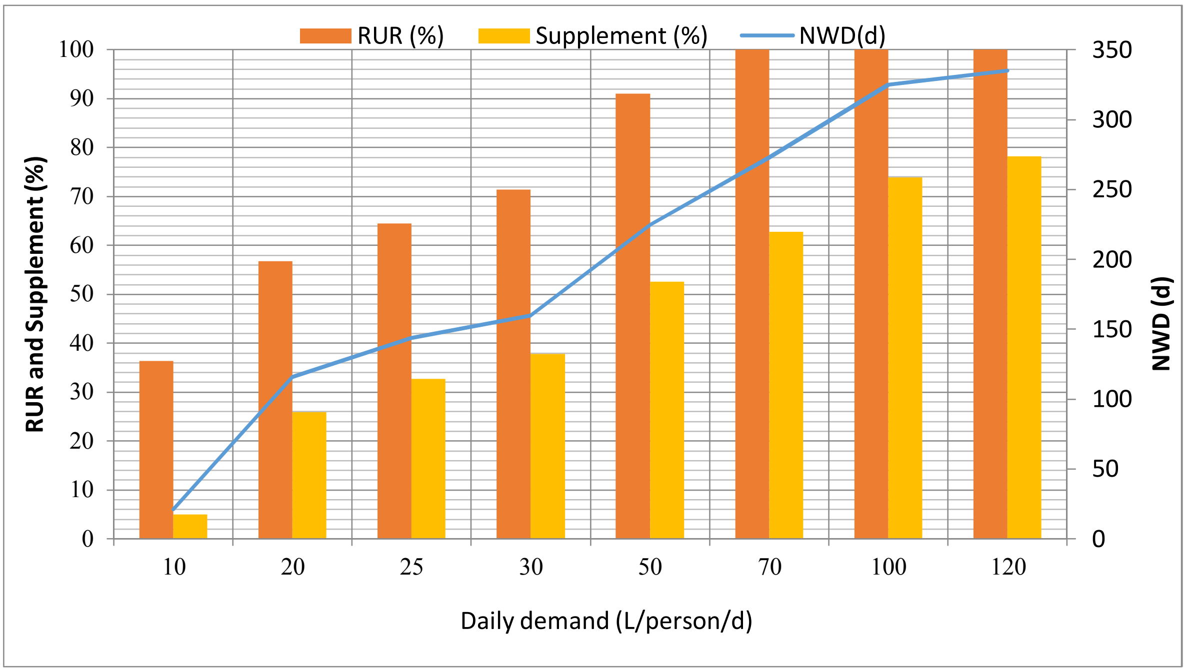


Figure 36: Storage performance assessment, and required supplement under fixed demand for the DSM household

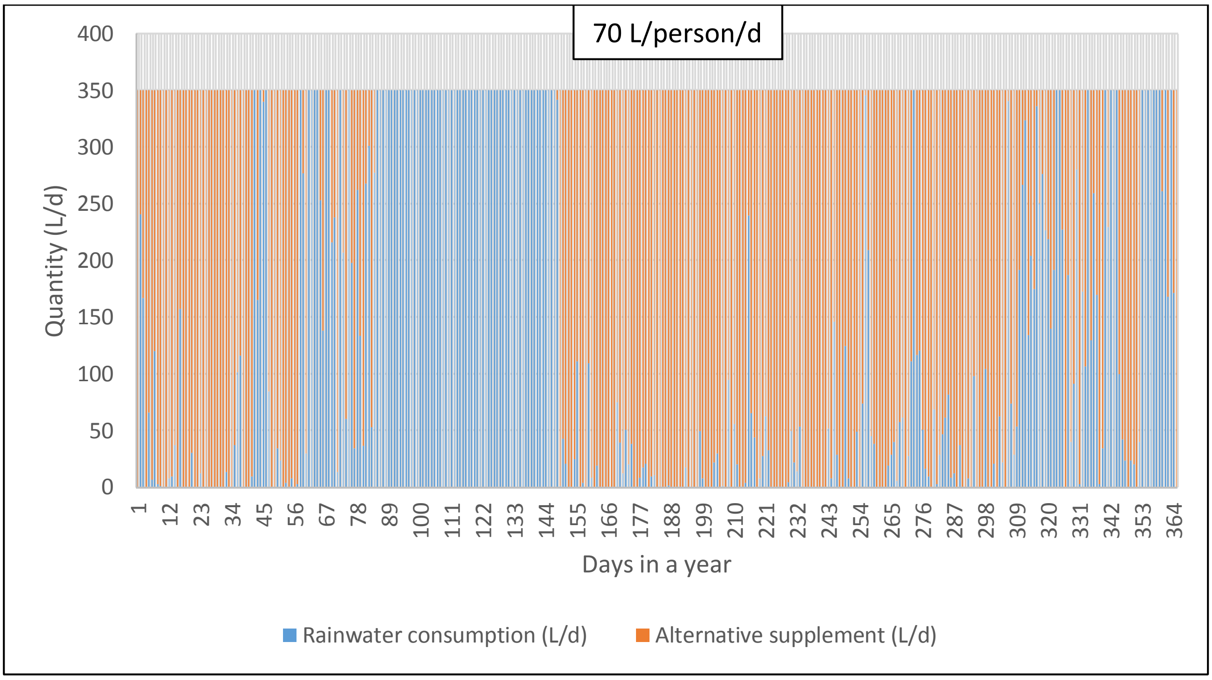


Figure 37: Daily rainwater consumption, and alternative supplement for the DSM household at 70 L/person/d

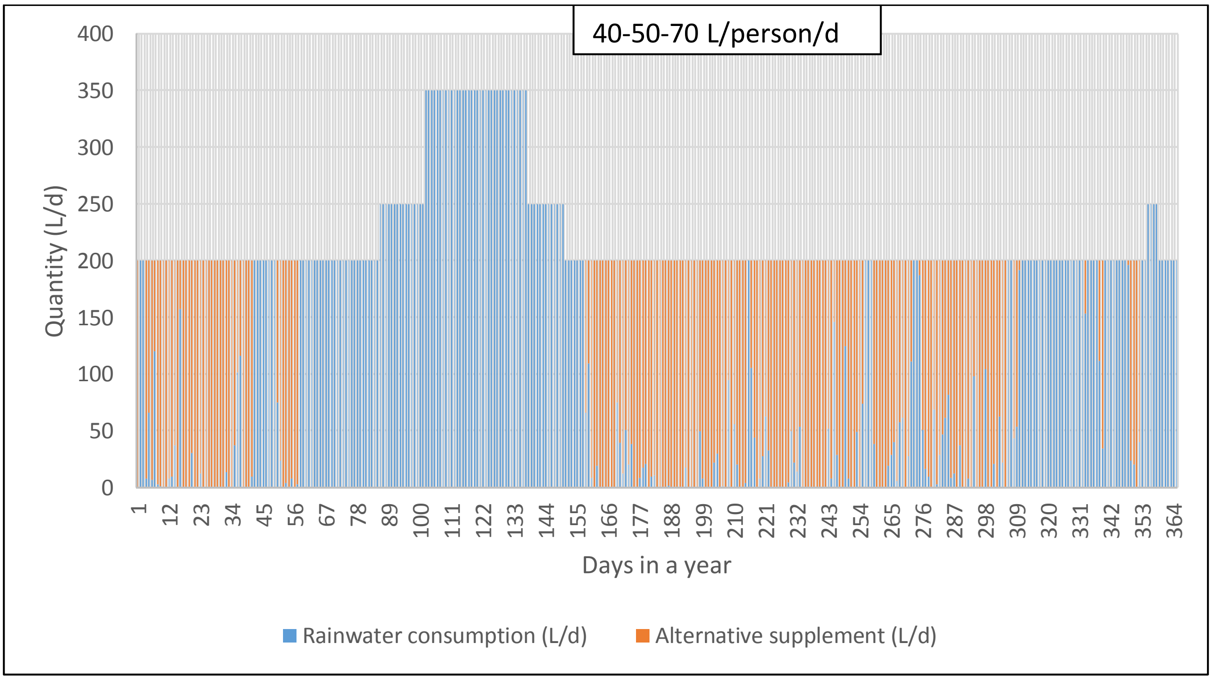


Figure 38: Daily rainwater consumption, and alternative supplement for the DSM household at Scenario 3

5.4.2 Unimodal regime case study

For the household in Mtwara, with 70 L/person/d, RW would meet 40% of annual water demand, with 100% RUR. The demand would be fully served in 115 d, or approximately 3.8 months (Figure 39 and 40). For the variable demand approach, at Scenario 3, RW would meet 58% of annual water demand with 95% RUR. The demand would be fully served in 176 d, or approximately 5.9 months (Table 13 and Figure 41).

In both the bimodal and unimodal case studies, the RW scarce days can be served with available alternative safe sources. However, for increased harvested RW quantity, investment in larger catchment and storage size, would contribute to reduced RW scarce days.

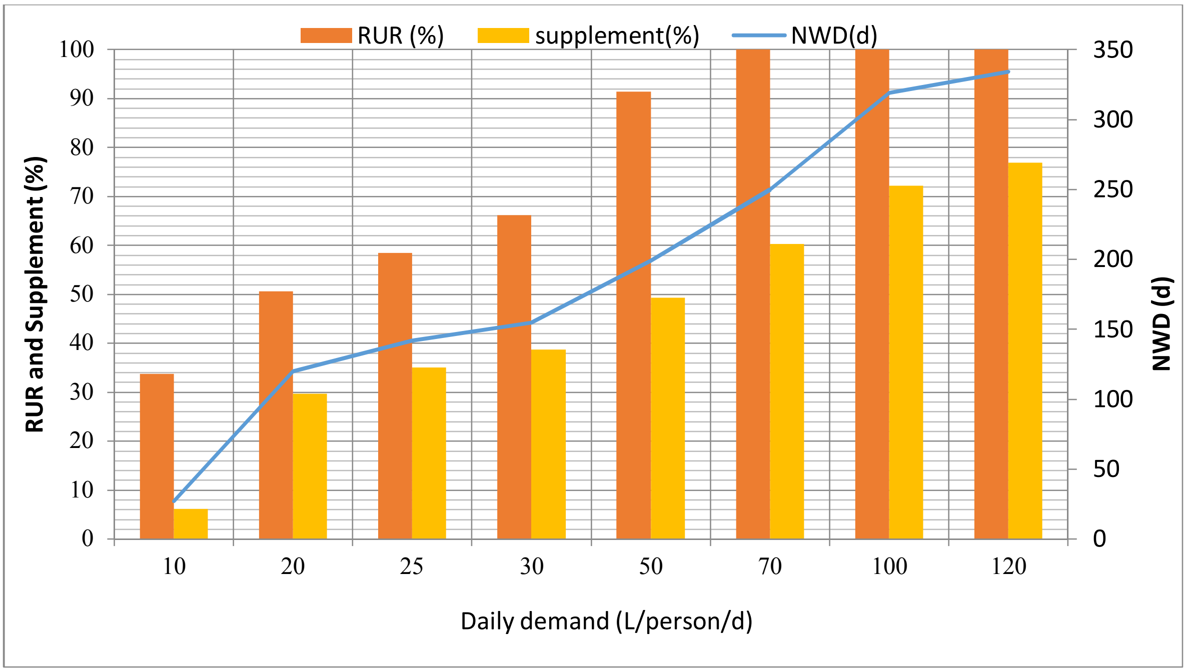


Figure 39: Storage performance assessment, and required supplement under fixed demand for the Mtwara household

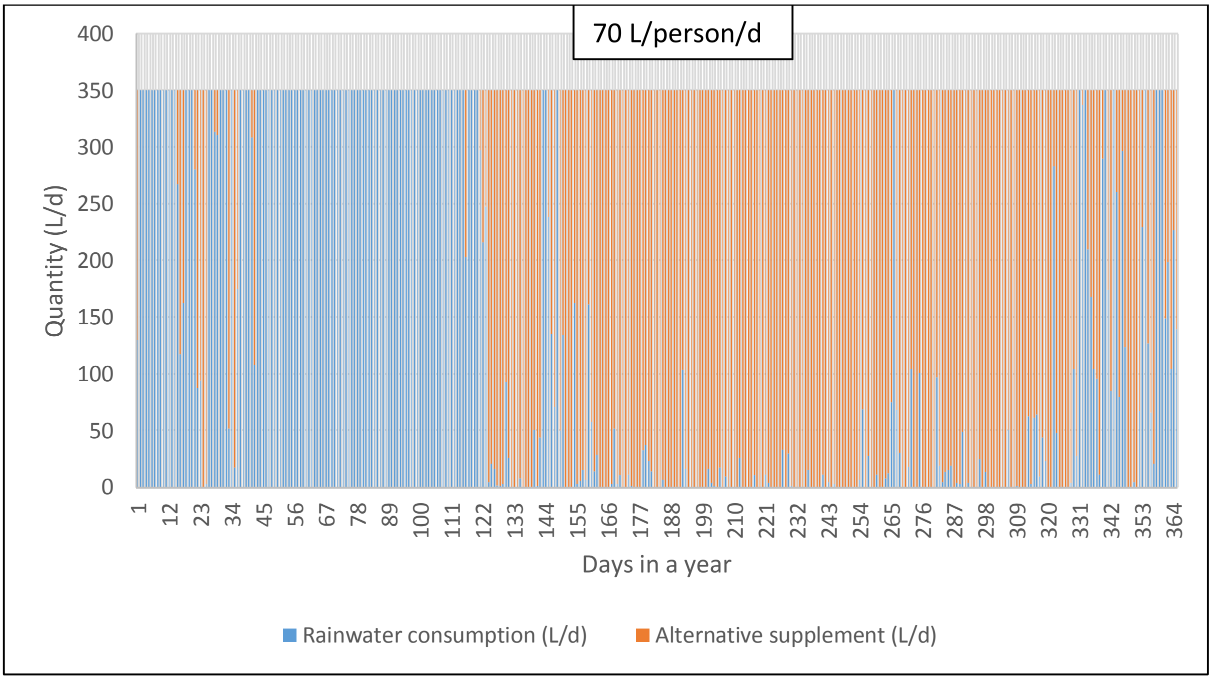


Figure 40: Daily rainwater consumption, and alternative supplement for the Mtwara household at 70 L/person/d

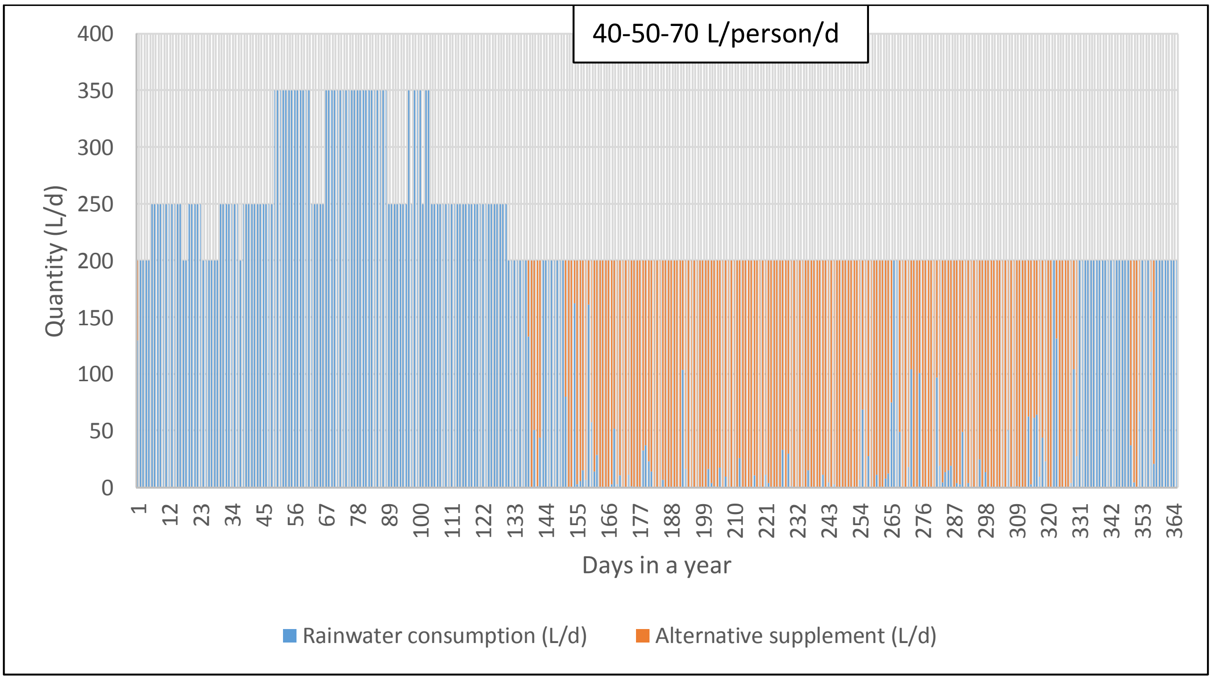


Figure 41: Daily rainwater consumption, and alternative supplement for the Mtwara household at Scenario 3

5.5 Rainwater harvesting technology adoption in institutions

Institutions, such as universities, colleges, and industries, and commercial buildings in the current era of increased challenges to water supply need to be proactive by adopting decentralized means of securing sufficiency in water supply and management, such as RWH.

As a representative case, the Nelson Mandela Institute of Science and Technology (NMAIST), located in Arusha Region, was considered. This institution is one in a network of African institutions of science and technology in sub-Saharan Africa (NMAIST 2011). It is an ideal site, even though it was recently established. It has potential for growth because of its goal of developing world class science, engineering, and technology. Hence, this can serve as a showcase for other related organizations within and outside the country.

5.5.1 Current water supply status

The main water supply for the Institute's population comes from GWH from boreholes located on campus. The water from the boreholes is pumped to and stored in two elevated storage tanks, each having a capacity of 90 m^3, located approximately 3.5 km from the campus. From there, the water is gravity fed throughout the campus, which includes administration offices, laboratories, classrooms, dormitories of MSc. students, and houses of PhD students and staff.

However, the water for the houses is currently supplied in a rationing manner, arranged throughout morning and evening hours. Also, the quality of the GW is somewhat compromised by high concentrations of fluoride (F^-), with values of 2.9 and 2.7 mg/L in samples collected from the two boreholes utilized by the Institute (water quality analysis by Arusha Regional Water Laboratory in 2010).

Almost all the buildings have gutters installed and quality roofs that are either galvanized or tiled, but none are outfitted with a RWH system. An underground RWH system with a capacity of 800 m^3 was constructed within the laboratory complex and connected to harvest from 62% of the roof (2887.4 m^2). Unfortunately, it is not in full operation due to leakages.

As the population is expected to grow to its full potential of approximately 1000, the current source does not seem sustainable, especially if no extra effort to ensure aquifer recharge is implemented. Furthermore, there are high and continuous operational costs due to the energy consumption by pumping to the distantly located storage tanks. Additionally, regarding water quality, the WHO (2011) states that elevated fluoride intake in the range of 3 – 6 mg/L can have serious health effects such as skeletal fluorosis.

5.5.2 The role of rainwater harvesting technology

The daily water balance model was applied under fixed and variable daily demand conditions to assess and determine the potential storage capacity for RWH from the buildings on the NMAIST campus. Applicable details of the buildings are summarized in Table 14.

Table 14: Summary of available NMAIST buildings' details

Building	Catchment size (m^2)	Runoff coefficient	Population size	Suggested storage (m^3)
MSc. hostel A&B	3510.8	0.8	231	100
Administration complex	3701.6	0.8	300	100
Laboratory complex & Student center	5683.9	0.93	500	200 of 800
PhD house	124	0.8	10	5
Staff house	144	0.8	10	5

5.5.2.1 Assumptions and conditions

Average daily rainfall data for 2000 – 2014 were utilized (Figure 42). The available 800 m^3 storage size was considered to collect RW from roofs of the laboratory complex and student center, which is situated nearby. All 365 days of the year were considered. When underground RW storage is proposed, a raised tank size is suggested, assuming the design load of the available roofs can accommodate it. A raised tank size would affect pumping frequency. Otherwise, local conditions should be the basis for decisions on tank size and location. Whenever possible, GW and RW should be partitioned because the qualities of the two are different. If that is not possible, the GW should be added after the RW supply is exhausted. In practice, water supply can be adjusted to offer additional water to hostel and houses during the weekend for such tasks as washing clothes and cleaning up, as it is expected that during weekdays students and staff spend most of their time working in classrooms, offices, laboratories, and the student center.

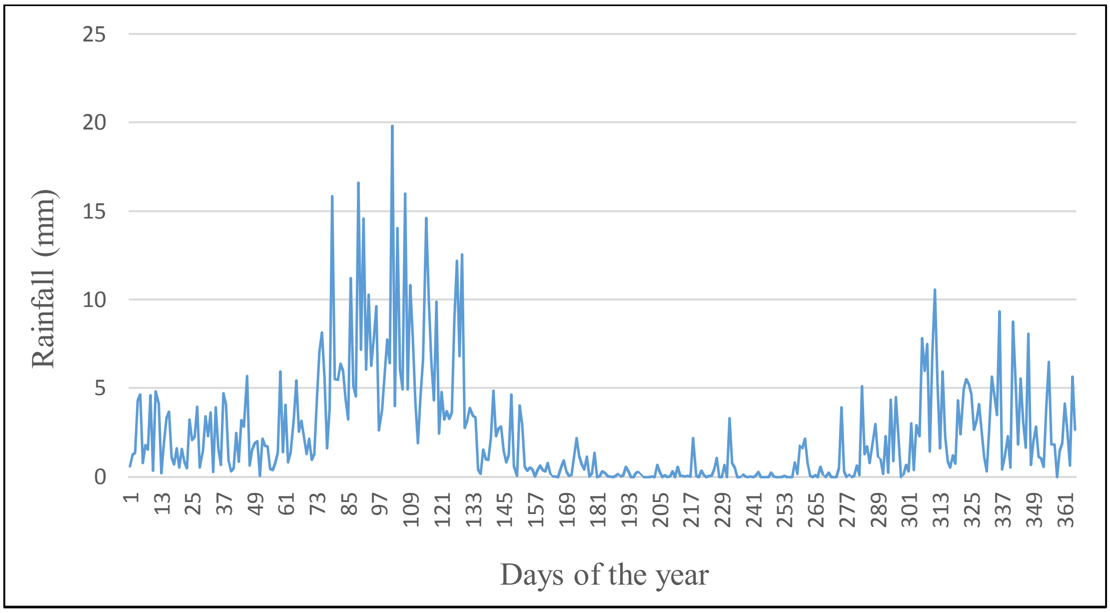


Figure 42: Arusha average daily rainfall data for 2000 - 2014 (Source: Pangani Basin Water Office)

5.5.2.2 MSc. blocks A and B

Considering a 100 m^3 underground storage tank into which RW would flow by gravity, GW supplementation would cover 59% of the annual demand at 70 L/person/d. At this amount, a 94% RUR would occur and RW would be expected to fully meet the demand in 77 d, or approximately 3 months (Figure 43). The GW supplementation would be highest from June to October, whereas April would be fully served by RW (Figure 44). From the underground tank, RW should be pumped to a raised tank of at least 50 m^3, which would be better placed on the roof, so that it can supply the rooms by gravity and with good pressure.

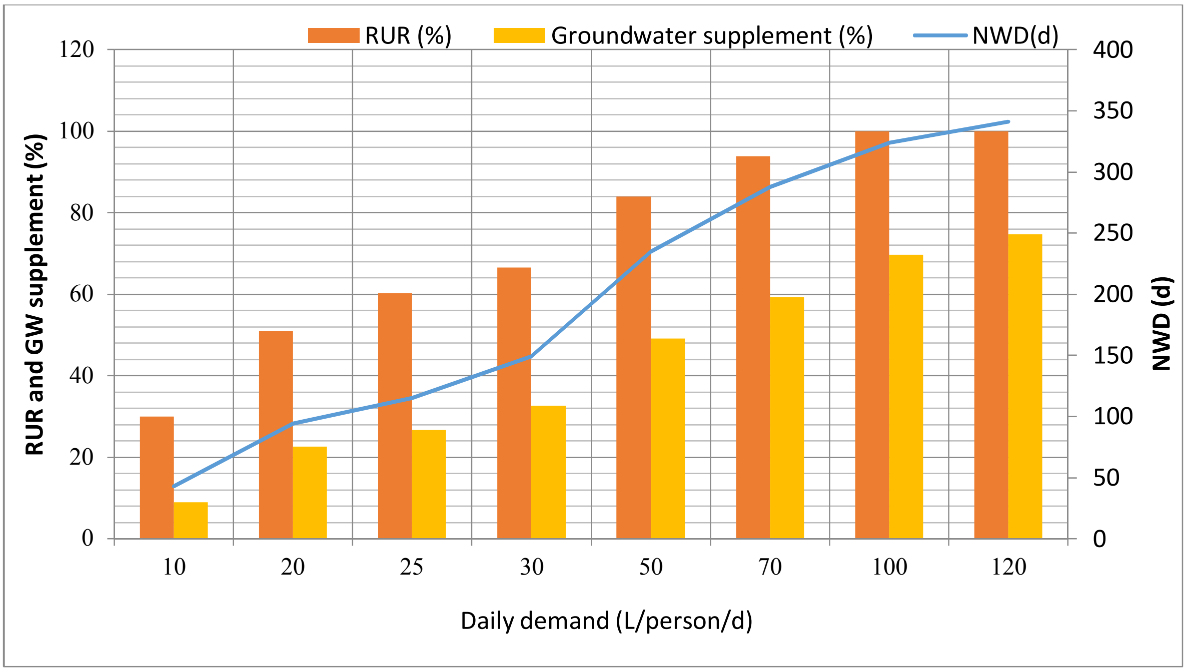


Figure 43: Storage performance assessment, and required groundwater supplement under fixed demand for the MSc blocks

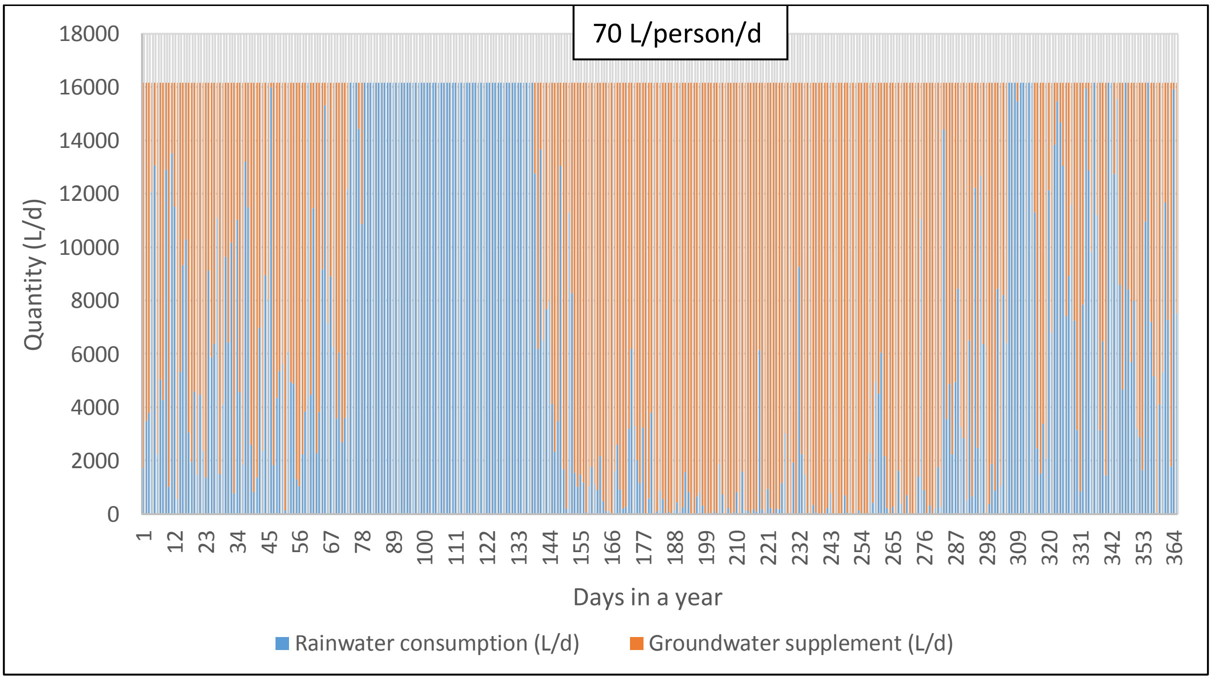


Figure 44: Daily rainwater consumption, and groundwater supplement for the MSc. blocks at 70 L/person/d

5.5.2.3 Administration complex

An underground storage tank of 100 m^3 was considered into which RW would flow by gravity. GW supplementation would cover 56% of the annual demand at 50 L/person/d. For this amount, a 90% RUR would occur and RW would be expected to fully meet the demand in 96 d (Figure 45), or approximately 3.2 months. The GW supplementation would be highest from June to October, whereas April would be fully served by RW (Figure 46). From the underground tank, RW should be pumped to a raised tank of at least 50 m^3, which would be better placed on the roof, so that it can supply the rooms by gravity and with good pressure.

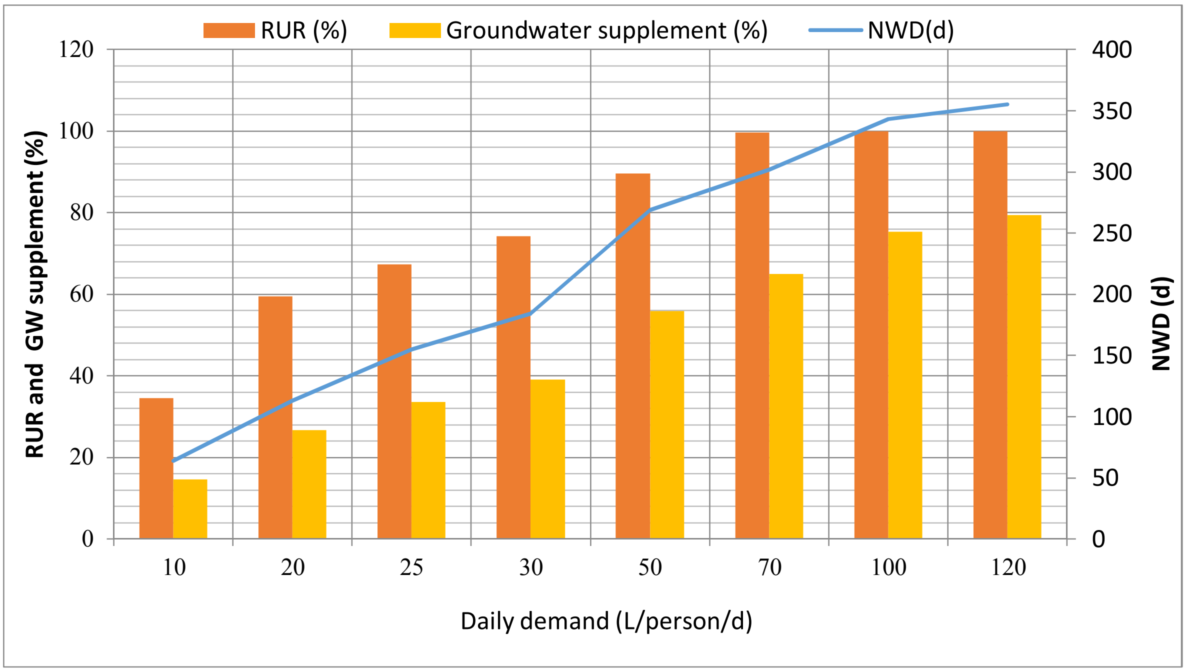


Figure 45: Storage performance assessment, and required groundwater supplement under fixed demand for the Administration complex

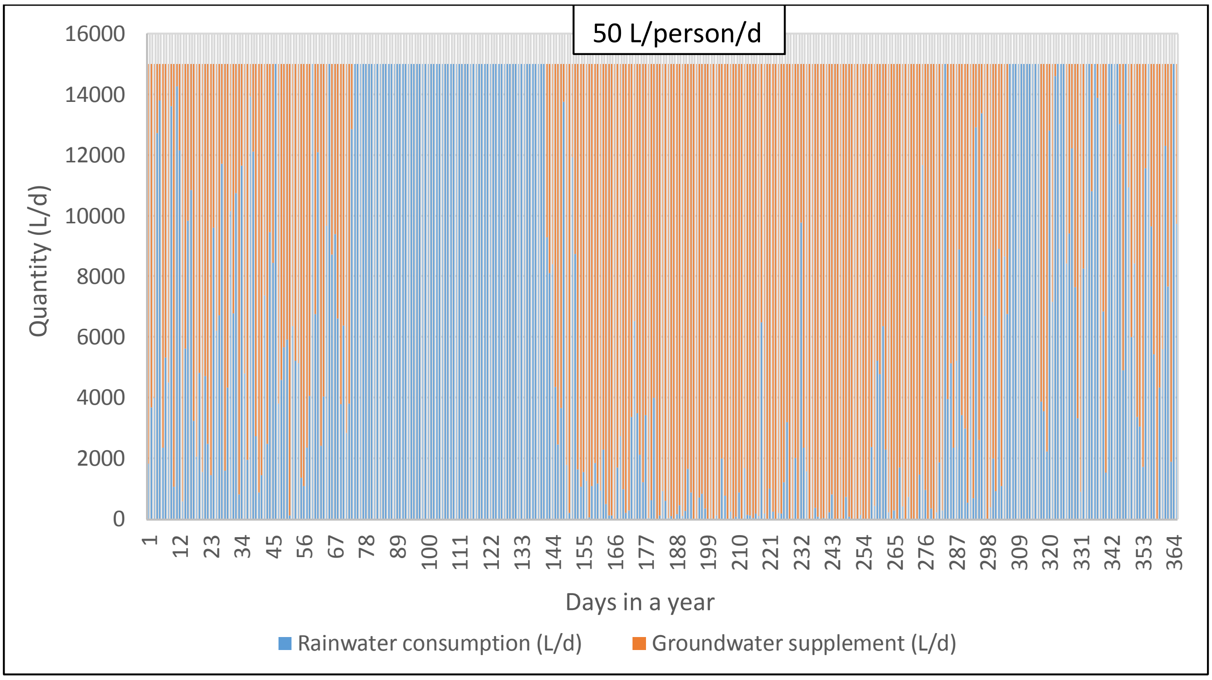


Figure 46: Daily rainwater consumption, and groundwater supplement for the Administration complex at 50 L/person/d

5.5.2.4 Laboratory complex and student center

For the laboratory complex and student center, the goal was to utilize 200 m^3 out of the available 800 m^3 underground storage tank for RW storage, which can be repaired to attain its full capacity. This tank should be partitioned, and GW would be stored in 600 m^3 as a backup supply for the campus. Into the 200 m^3 section of the underground storage tank, RW would flow by gravity. GW supplementation would cover 54% of the annual demand at 50 L/person/d. For this amount, a 88% RUR should occur, and RW should fully meet the demand in 104 d (Figure 47), or approximately 3.5 months. The GW supplementation would be highest from June to October, whereas April would be fully served by RW (Figure 48). From the underground tank, RW should be pumped to a raised tank of at least 50 m^3, which would be better placed on the roof, so that it can supply the rooms by gravity and with good pressure.

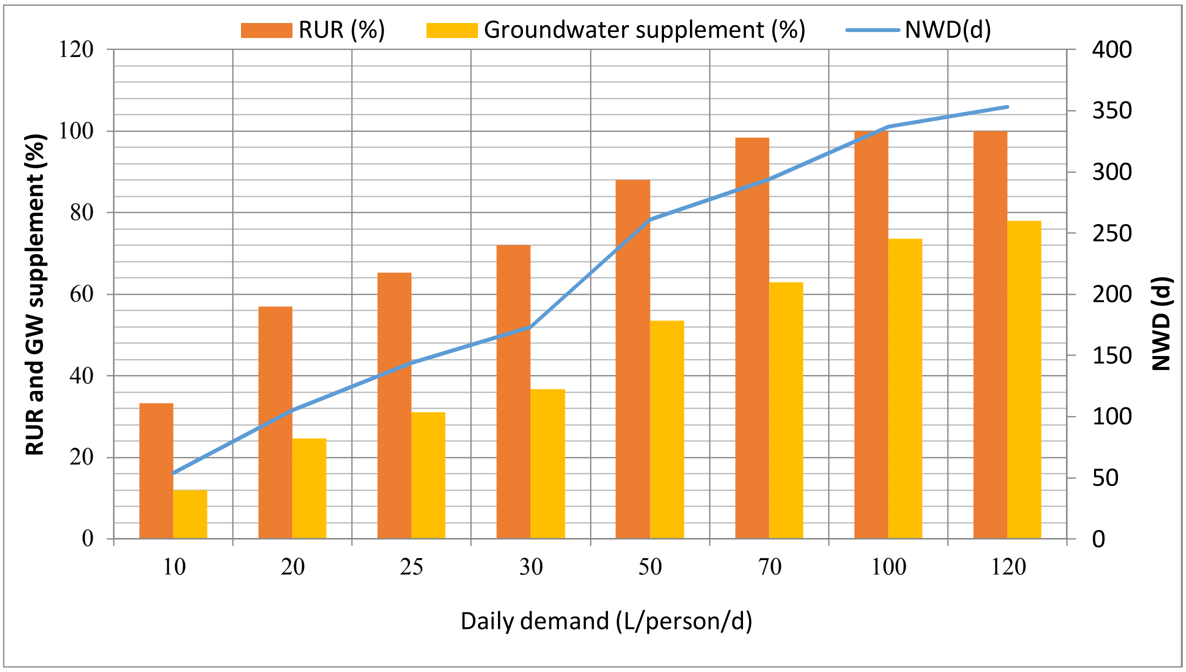


Figure 47: Storage performance assessment, and required groundwater supplement under fixed demand for the Laboratory complex and student center

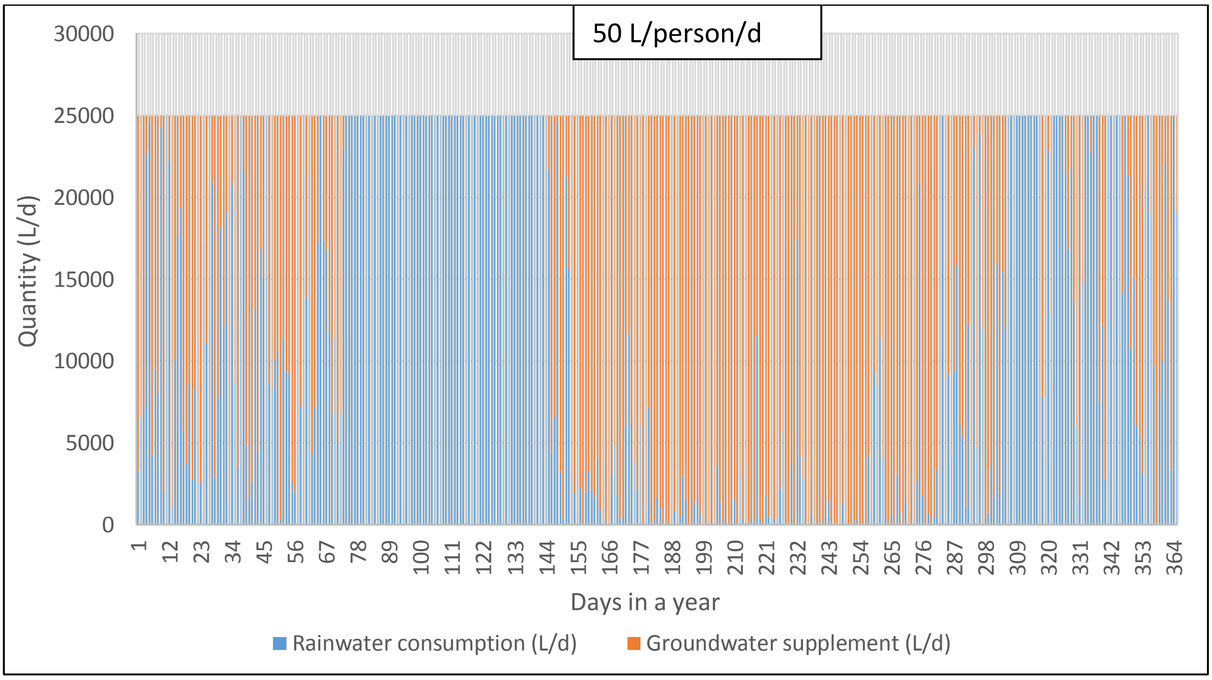


Figure 48: Daily rainwater consumption, and groundwater supplement for the Laboratory complex and student center at 50 L/person/d

5.5.2.5 PhD and staff houses

Currently there are approximately 25 PhD and 16 staff houses, each designed to accommodate two families, thus sharing a roof. It is assumed that each house accommodates 5 people. In this case, RW should flow by gravity into an above ground tank of 5 m^3, from which a gravity supply system is recommended. Variable demand conditions were considered (Table 15) because as it is within a household, it should be under the control of the family members. With the incorporation of a water level gauge, water usage can be monitored closely and adjusted accordingly. A tank this size can be constructed/installed by the house occupants themselves and paid for by the two families instead of them relying on college support. This is a good strategy as it will instill a sense of ownership and assure good operation and maintenance of the system. Apart from supplementing RW, GW will also supply additional water quantity.

Table 15: Water level monitoring demand scenarios and performance results for PhD and Staff houses

Scenarios	Water Level (%)	Demand (L/p/d)	PhD houses			Staff houses		
			NWD (d)	RUR (%)	GW (%)	NWD (d)	RUR (%)	GW (%)
1	>70	50	186	89	35	164	84	31
	≤70 and >30	40						
	≤30	30						
2	>70	100	274	100	53	254	100	48
	≤70 and >30	70						
	≤30	50						
3	>70	70	233	98	44	209	93	40
	≤70 and >30	50						
	≤30	40						

i. PhD houses

For the PhD houses in Scenario 3, GW supplementation would cover 45% of the annual demand, a 98% RUR would occur, and RW should fully meet the demand in 132 d (Table 15), or approximately 4.4 months. The GW supplementation would be highest from June to September, whereas April would be fully served by RW at 70 L/person/d (Figure 49).

ii. Staff houses

For the staff houses in Scenario 3, GW supplementation would cover 40% of the annual demand, a 93% RUR would occur, and RW should fully meet the demand in 156 d

(Table 15), or approximately 5.2 months. The GW supplementation would be highest from July to September, whereas April would be fully served by RW at 70 L/person/d (Figure 50).

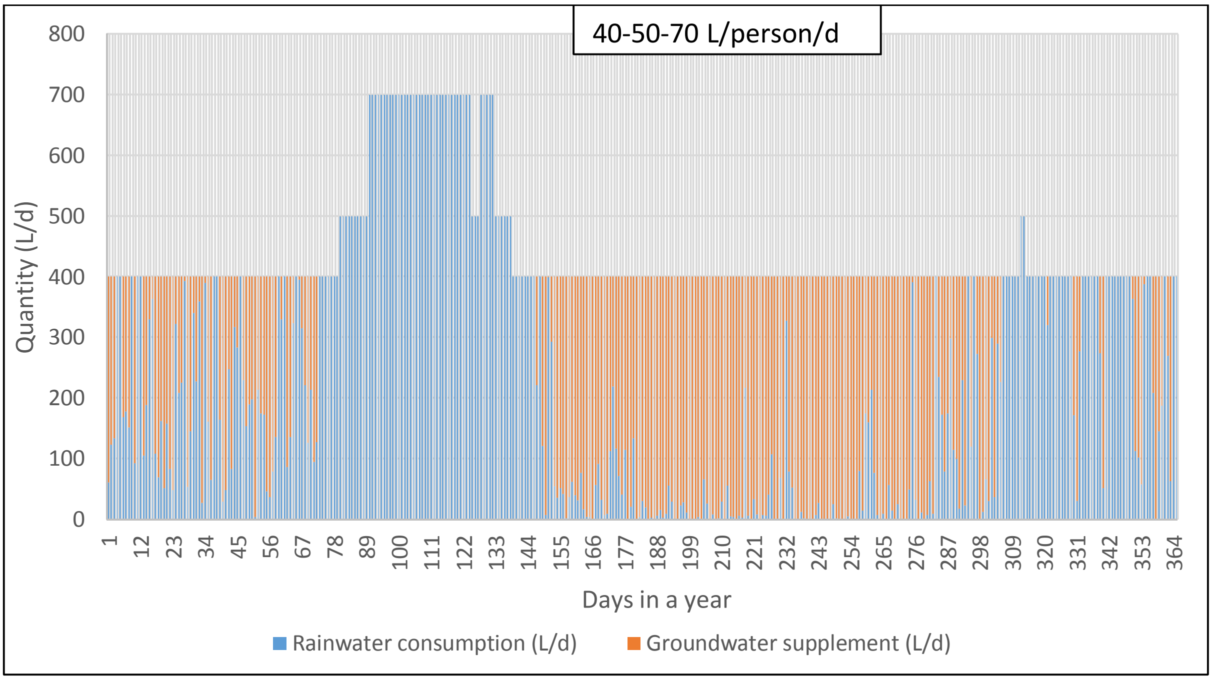


Figure 49: Daily rainwater consumption, and groundwater supplement for the PhD houses at Scenario 3

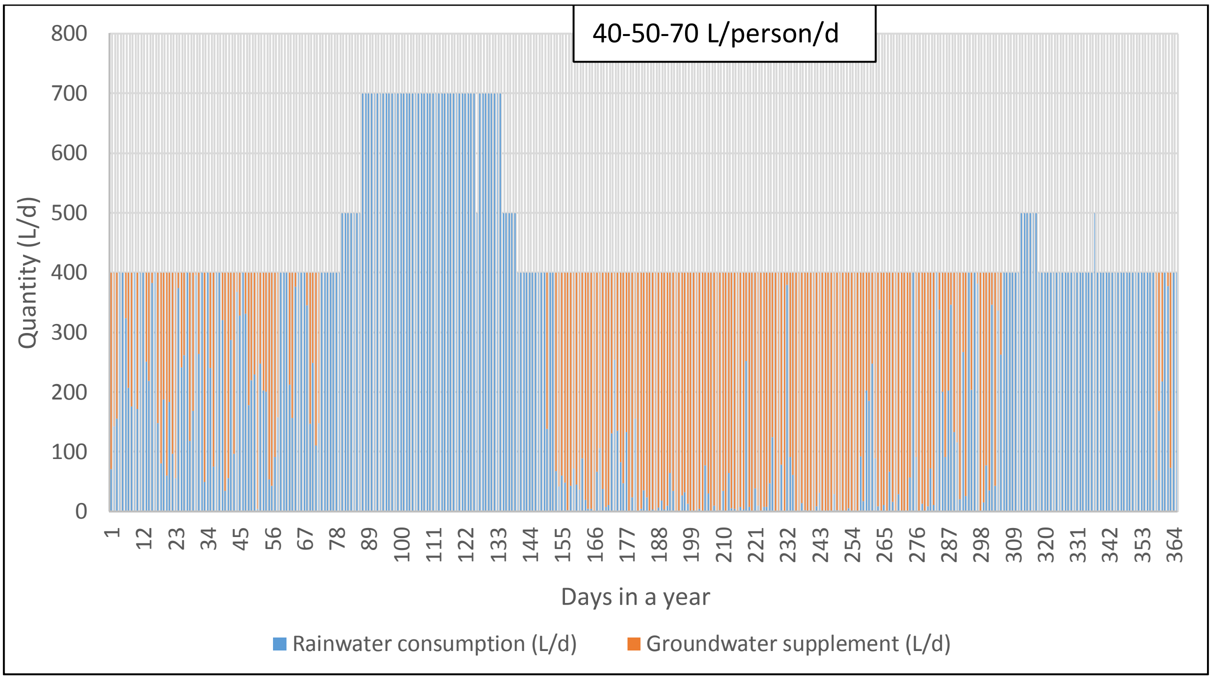


Figure 50: Daily rainwater consumption, and groundwater supplement for the staff houses at Scenario 3

5.6 Practical factors for adopting rainwater harvesting technology in Tanzania

Technically, as rooftop harvested RW is not easily subjected to topographical and geological influences like GW and SW sources, its quality can easily be maintained and monitored through increased user awareness and adoption of simple pretreatment mechanisms, and where necessary, post treatment mechanisms. Based on rainfall seasons, RW quantity can be predictable and user's consumption adapted to fluctuate accordingly.

Economically, in comparison to other alternative sources such as GW, RWH is much cheaper, more so when considering operation costs where a gravity system may be applied. For instance, harnessing GW sources in the Mtwara district costs approximately 160,000 TZS (US$93) per m (VAT exclusive), which includes processes of mobilization and demobilization of staff and equipment, drilling works, pumping tests, and water quality testing and excludes pump costs and geophysical surveys. In DSM region, the cost for similar processes is approximately 100,000 TZS (US$58) per m. Pump supplying and installation may cost approximately US$2240 (this may raise depending on the type of pump sought, for this case a submersible SP 1828 with a motor and control box were considered) and geophysical surveys cost approximately US$145, all VAT exclusive. Even though in some parts of the country the water table is high, allowing simple hand pumps to be used, in other parts of the country, the water table is very low. This includes DSM and Mtwara, where water can be accessed at depths beyond 100 m. Additionally, there would be operation and maintenance costs involving submersible pumps. These costs are quite high for a typical family, whether in rural or urban areas.

Socially, reliance on RW is familiar to many in Tanzania, both in rural and urban areas. For years, people have collected RW during the rainy season. With the current increasing challenges to water supply, it seems necessary for RWH technology to be promoted further. It should be easier to convince people to adopt the technology and simultaneously train them in better management practices for technology sustainability.

In the long run, RWH can replace, or work hand-in-hand with already established available water sources within households and communities. As well, it can serve to preserve GW sources from overutilization, hence prolonging their life span.

5.7 Technical design guidelines for better rainwater harvesting practice

There are some challenges with regard to current approaches in RWH system design and construction for domestic purposes, considering water quantity sufficiency and quality maintenance. In most case, the absence/misallocation of components can contribute to poor quality of RW accessed from the tank and improper sizing of the system can result in inadequate RW usage or prolonged emptiness.

5.7.1 Rainwater harvesting system components

Lacking a coarse screen/filter prior to water access into the storage tank would contribute to much unwanted material entering the tank. This has been a complaint of many RWH system users. In most cases, a first flush tank is not included, hence after a prolonged dry season all the dirt adhering to the roof is washed into the storage tank when the rainy season begins. In some above ground tanks, the outlet tap is located very close to the bottom of the tank, which would contribute to the accessed water getting mixed up with deposited sediments/particles. The design of collection chamber matters as well, which when improperly constructed, can lead to water stagnation that favors mosquito breeding. These shortcomings have been observed in designs and projects approved by MoW (Figure 51 and Appendix D).

Figure 51: Rainwater harvesting system at a dispensary in Rukwa Region, Tanzania

Essentially a RWH system should comprise the following systems: collection, which includes the roof and gutter; delivery, which includes pipes and down pipes; treatment, which includes a coarse filter, first flush tank, and calm inlet; storage, which includes a tank or jar; supply, which includes taps and an overflow pipe; and monitoring, which includes a water level gauge. A maintenance manual should be provided to guide system management. For better water supply practices, recommendations have been offered on RWH system components (Table 16).

Table 16: Recommendations on rainwater harvesting system components for better practice

S/N	Facility	Recommendations
1	Coarse screen	• For filtration of coarse material carried on by runoff water. • With approximately 5 mm mesh openings, larger particles are expected to be filtered out. • It can be located anywhere within the system, on gutter, on or in downpipe and on storage tank.
2	First flush	• For deviation of initial rainfall (at least 1 mm) with high concentration of particles previously adhering on the roof • It should be located prior entry into the storage tank • Automatic flush tank for easier management • Comprising a ball inside for preventing recontamination, and a valve for diversion in case of malfunctioning
3	Calm inlet	• For minimizing resuspension of already settled sediments in the tank, as newly introduced rainwater flows in • An extension of the downpipe into the storage tank
4	Vent pipe	• For aerating the storage tank, and preventing anaerobic conditions favoring decomposition of washed in matter
5	Inlet barrier/buffer	• For inhibiting passage of particles towards the outlet, and enhancing particle settlement • It can be useful in large and rectangular RWH tanks
6	Drain pipe	• For discharging dirty water during tank clean up
7	Outlet	• It should be located at least 100 mm above tank bottom to prevent water contamination with the deposited sludge
8	Collection chamber	• It should allow water to seep or drain away quickly, instead of stagnating into clear/mud water pools
9	Water level gauge	• For guiding in monitoring water level in the storage tank • It can be attached on the supply tank surface

Additionally, in case of calm inlet application in a tank system (Figure 52), to maximize the potential of water, standard arrangement of overflow should be avoided (Figure 53a), whereby water is simply thrown from the top of the tank, as the top water would be the cleanest. Instead, an inflow exclusion is recommended. This entails that the entrance/overflow pipe blocks incoming water from mixing with water stored at the top of the tank and channels it to the overflow exit, if the tank is full (Figure 53b). This is recommended as the best arrangement for tanks of less than 2 m^3.

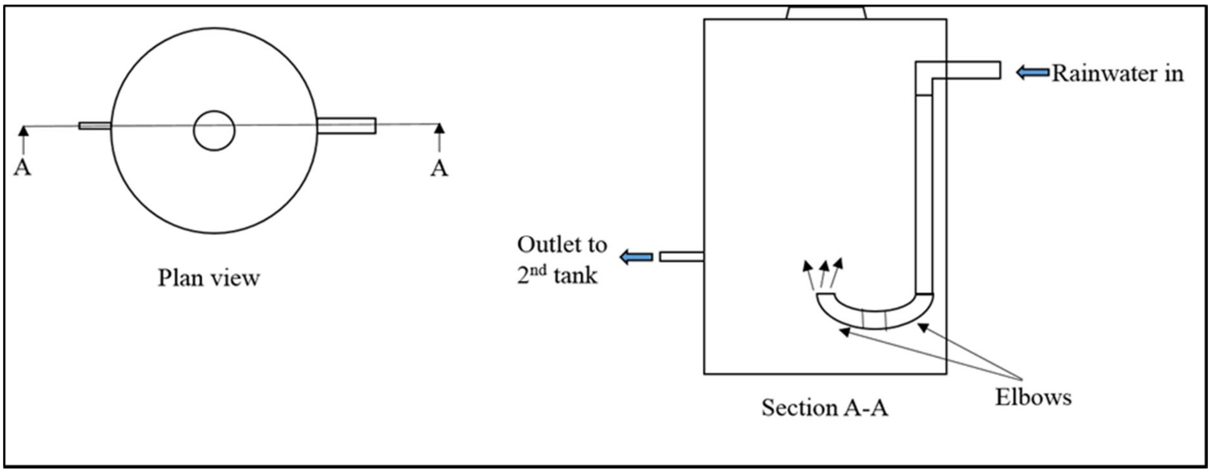


Figure 52: Calm inlet application in a rainwater harvesting system

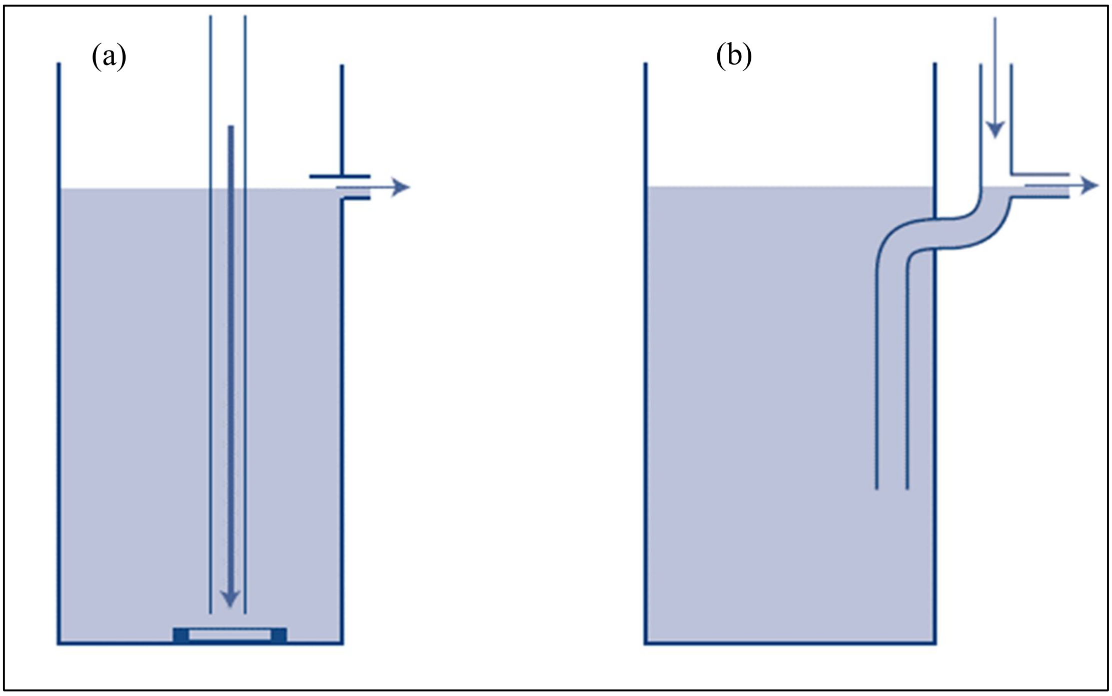


Figure 53: (a) Standard arrangement of an overflow pipe, and (b) the inflow exclusion design (Thomas and Martinson 2007)

5.7.2 Rainwater harvesting system size estimation

Several approaches are usually considered in sizing storage system in Tanzania, including those based on demonstration projects showcases, practical experience, and available fund. Common calculation approaches base on dry days in a year and on roof capacity. Whereas data type commonly utilized are monthly data, and reason for preference include easy accessibility and affordability.

5.7.2.1 Storage tank sizing

The two commonly adopted methods in estimating tank size requirements, (a) based on dry months hence dry days, (b) based on a given roof capacity and average annual rainfall data, have been assessed and compared with results from a daily water balance model (c).

i. Basic data and conditions considered

Population = 5; Daily demand (L/person/d) = 10; Roof size (m^2) = 18; Annual rainfall (mm) = 1055.6; Dry days = 117; C = 0.8; Mtwara daily rainfall data (Figure 10).

a) Based on dry months:

   Storage = Population X Demand X Dry days

b) Based on roof capacity and average annual rain data:

   Storage = Roof size X Annual rain X Runoff coefficient

c) Daily water balance model under fixed demand condition (Equations 2.2, 3.4, and 3.5).

ii. Analytical results

The compiled results are 5.9, 15.2, and 6 m^3 from a, b, and c approaches, respectively. From the daily water balance model, the maximum storage size recommended 6 m^3**,** would serve at a reliability of 80%, resulting in 74 NWD and 99% RUR (Figure 54).

Thus, under the given condition of available rainfall and demand, approach b overestimates the storage size requirement, implying that the tank will stay empty in most time of the year (Figure 54). In addition, Imteaz *et al.* (2011) elaborated that it was unrealistic to use average annual data in storage performance assessment as it does not capture the variation during the year. For approach a, overestimation may result considering dry days occurring within the rainy season, whose demand maybe fully met by the stored RW. While underestimation may result considering rainy days with RW insufficient to meet the demand.

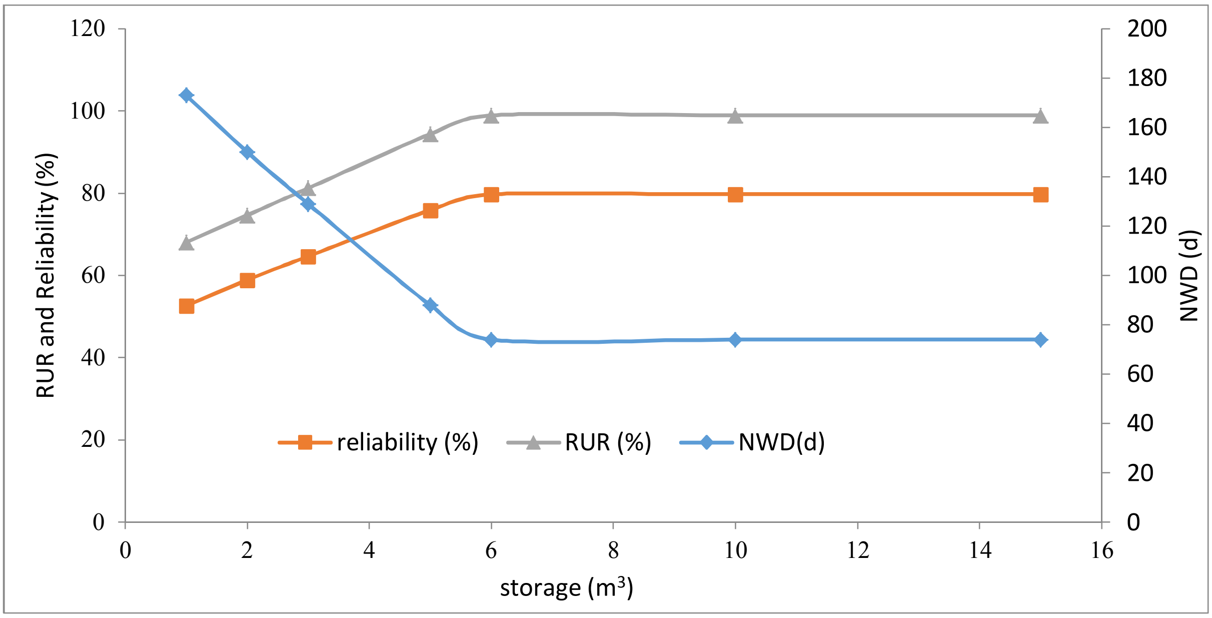


Figure 54: Daily water balance model application in storage tank size estimation

5.7.2.2 Data type usage

The reliance on monthly data for size estimation, has a shortfall in the sense that it fails to capture the variability of rainfall that occurs during the year. Zaag (2000) while introducing his RW storage simulation tool applied on African case studies, argued and showed that monthly data severely underestimates required storage capacity. This is also supported in this study (Figure 55) by utilizing similar conditions. Monthly data shows higher reliability for similar storage size, which would be misleading in actual situations. For instance, at 1 m^3, there is 19 NWD difference between monthly and daily data result; hence, upon reliance on monthly data, users can find themselves without sufficient water on those extra days.

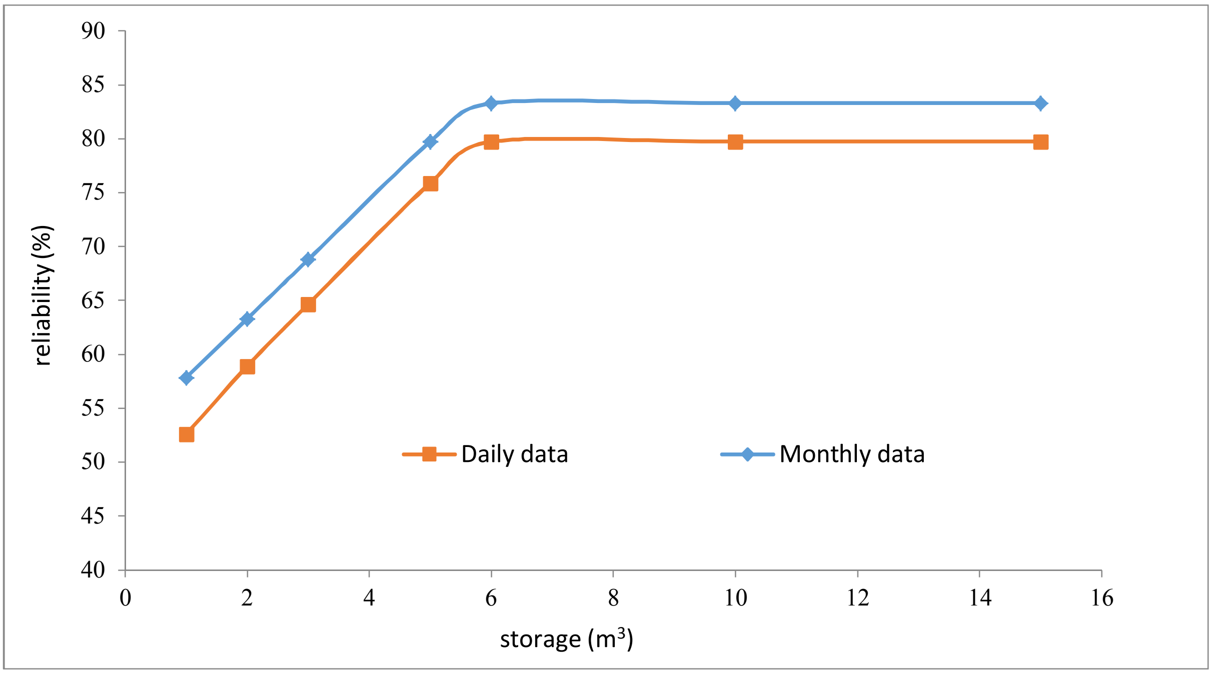


Figure 55: Monthly vs daily data usage in storage size estimation

5.7.3 Rainwater harvesting system performance assessment tool

A RW modeling tool has been developed, incorporating the innovative ideas introduced within this work and considering the above challenges on available tools and approaches.

5.7.3.1 Significance of the tool

This tool incorporates monthly and daily data as well as fixed and variable daily demand, thus giving a user a wide range of options based on what he can access or afford at a given time. This will be a good guide for engineers and practitioners, both in Tanzania and in Africa as a whole. Users will be able to make better decisions concerning storage size for a given set of RW catchment conditions. Better design judgment is expected with the utilization of this tool in RWH project design.

5.7.3.2 Components and targets of the tool

The tool has been established, utilized under excel environment and coded and run in mat lab environment. Incorporation of a user interface is underway to improve its application. The respective flowchart is attached in appendix E.

i. Input data

As input, the tool requires the following: population size, catchment size, *C*, proposed storage size, annual rainfall data (daily/monthly and single/several years), demand and WL scenarios (daily/monthly). Governing equations include the previously introduced Equations 2.2, 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, and 3.7, which have been varied respectively to represent the kind of data used, i.e., monthly or daily data.

ii. Output data

From the above input data, we expect the following output: the number of days when demand is fully and not fully met, the RW usage ratio in a year, tank performance reliability, and the number of times during the year that the given tank will be refilled. Additionally, a graphic display of daily/monthly consumption variation against initial water level percentage in the tank is expected.

5.7.3.3 Sample study

The community case study of Mnyundo School (Chapter 3) was considered, and its basic data input into the model. For both monthly and daily data conditions, fixed demand of 450 L/d was used and variable daily demand scenario considered was as follows: if WL > 75%, then demand was 450 L/d; if WL > 50% but ≤ 75%, then demand was 300 L/d; if WL > 25% but ≤ 50%, then demand was 150 L/d, and; if WL ≤ 25%, then demand was 75 L/d.

Monthly data misleads regarding required storage size to achieve a certain reliability (Figures 56, 57, 58, and 59). Thus, the NWD is overrated by a factor of 1.3 and underrated by a factor of 1.1, under variable and fixed demand, respectively, compared to results from daily data input. Higher NWD values are observed under fixed demand conditions. Under fixed demand, NWD values are 168 and 150 from daily and monthly data usage, respectively, whereas under variable demand, NWD are 47 and 61 from daily and monthly data usage, respectively.

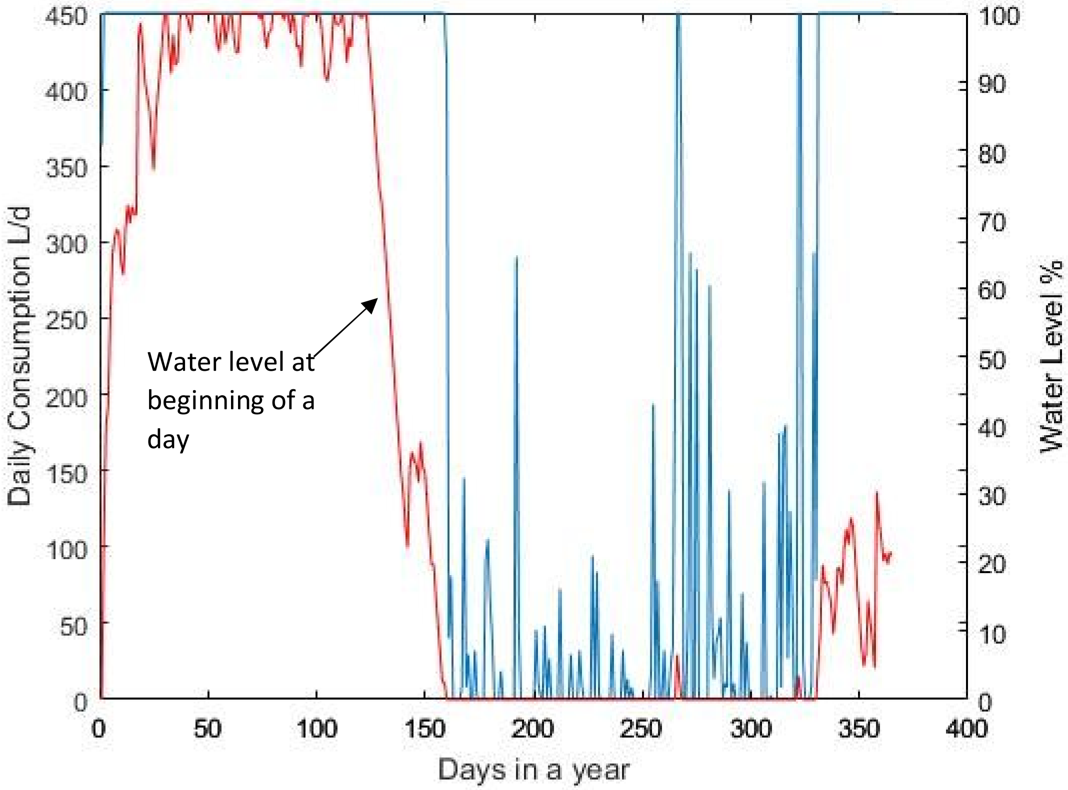


Figure 56: Daily consumption variation with water level under fixed demand condition

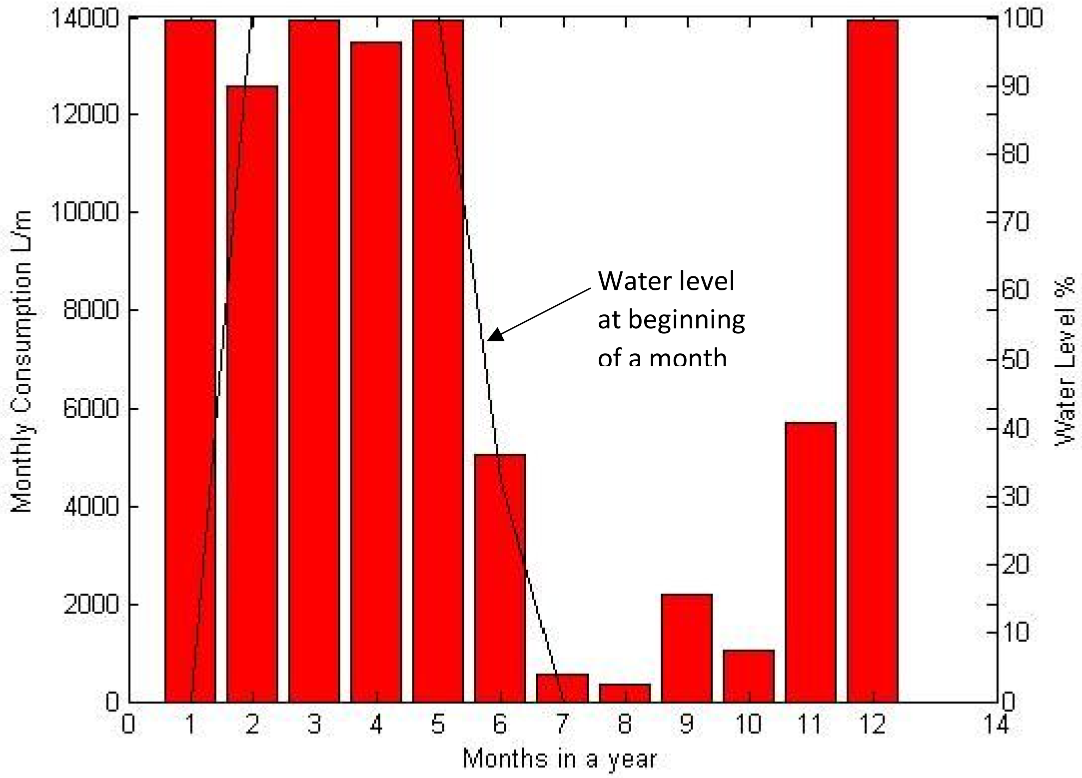


Figure 57: Monthly consumption variation with water level under fixed demand condition

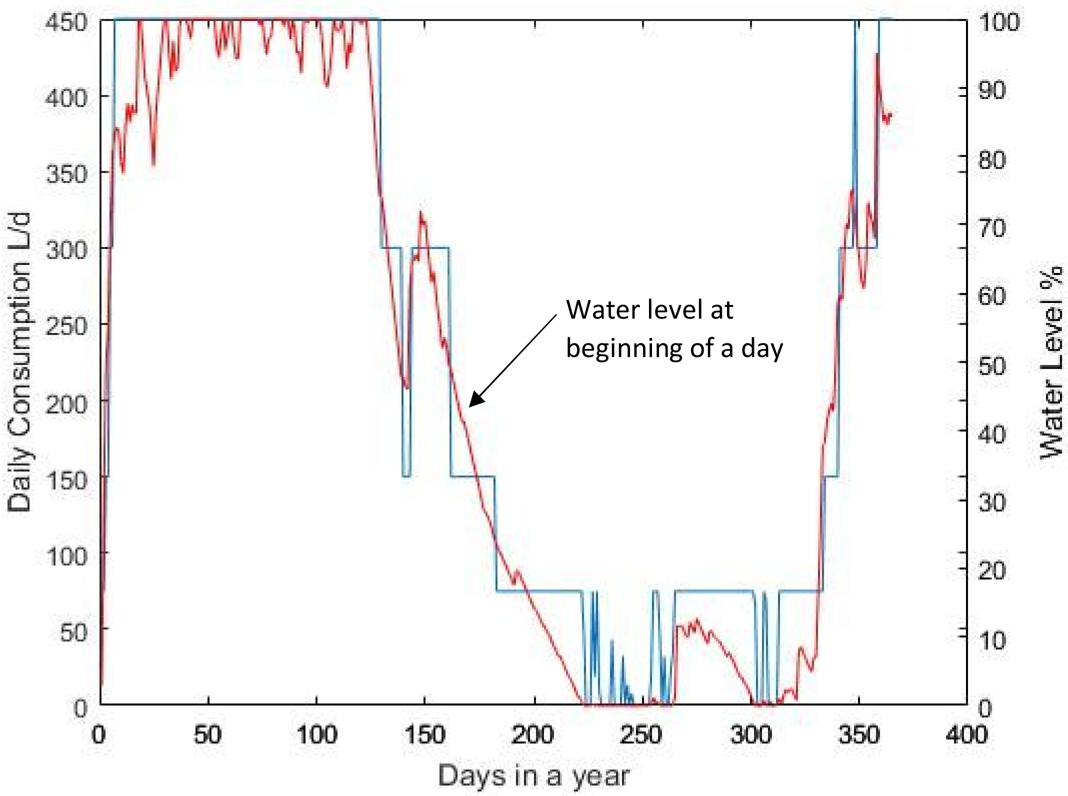


Figure 58: Daily consumption variation with water level under variable demand condition

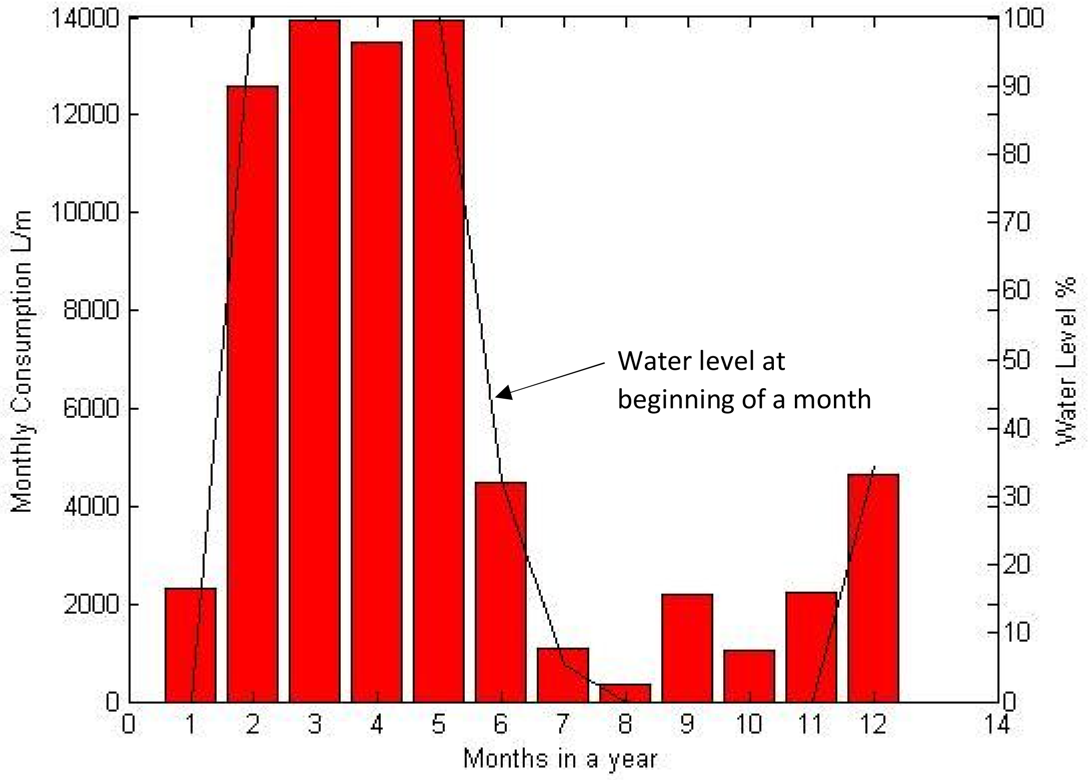


Figure 59: Monthly consumption variation with water level under variable demand condition

5.7.3.4 Verification

In the near future, this tool's results are to be compared against annual monitoring of actual RWH system in the field, for further improvement.

5.8 Proposed water conservation practices

Application of water efficient technologies is recommended in institutional buildings (Yudelson 2010), which may include waterless or low flow urinals, high efficiency toilets (HETs) that use less water while flushing, and low flow faucets and shower heads. Inclusion of water meters would also assist in water use management. However, sensitization of the public is essential to achieve the desired judicious usage of water. Incentives could be offered to those opting to install water-conserving devices in their homes. This should also be considered in ongoing residential and commercial construction projects (such as those by the National Housing Corporation and National Social Security Fund). Such water control measures can be incorporated, if not already considered in the plans. In addition, RWH facilities, such as gutters, for decentralized water supply can be implemented.

The reuse of greywater as flushing water, service water, irrigation, and even GW recharge, is recommended. This category of wastewater constitutes 3/4 of domestic wastewater by volume but has low concentrations of pathogens, chemical organic matter, nitrogen, potassium, and phosphorus (Otterpohl *et al.* 2002, Otterpohl 2003). Its quality can be improved through biological treatment using membrane bioreactors, activated sludge, rotating bio contactors, and constructed wetland, among others (Baykal and Giresunlu 2013).

The common practice of mixing wastewater with storm water/rainfall runoff ought to be modified because wastewater in most cases is far too polluted. Moreover, instead of the conventional practice of quickly draining rainfall from our premises, for the health of watersheds and water cycle restoration, the practice of retaining RW much longer should be adopted. At present, there are several low impact designs (LID) recommended as best management practices (BMPs) for storm water quantity and quality management. These would lead to increased water availability for domestic and nondomestic uses, as well as environmental sustenance. These BMPs include bio filters, rain gardens, ponds, road water harvesting, and green roofs.

5.9 Conclusion

RWH technology has good potential for addressing water supply challenges in Tanzania, especially considering its distribution and magnitude within the country. Analytical interpretation of GIS study results has demonstrated the good potential of rooftop RWH, even for highly populated areas. RWH can be relied on even when rainfall is as low as 400 mm/yr. In addition, it can be used in tandem with other available water supply sources, as has been shown for the case of households and NMAIST institute, where through RWH adoption more than 35% of annual demand (at least 40 L/person/d) could be met. Technical guidelines have been offered with recommendations on RWH components for better maintenance and management practices. A RWH system performance assessment tool has been introduced for utilization by all practitioners within the country. This tool offers guidance on better system design and helps to eliminate/minimize the problems of over-complicated and over-simplified design. Henceforth, rooftop RWH technology adoption needs to be extended to the entire country. In conjunction, water conservation practices should be adopted.

CHAPTER 6:

Strategy and Action Plan for Rainwater Harvesting Sustainability and Adoption

6.1 Introduction

RWH has the potential to provide sustainable water supply in Tanzania, if adequately managed. From this study, it has been established that RWH technology is capable of serving sustainably in a decentralized manner. For this vision to mature, identifying and establishing a roadmap is necessary. This should include means by which adoption can be extended through increased awareness, acceptance, and usage. Hence, the establishment of an action and work plan is proposed for sustainability in water supply using RWH technology. These should be derived from the SWOT (strengths, weaknesses, opportunities, and threats) of the current status in the technology adoption in the country.

6.2 Rainwater harvesting promotional strategies in other countries

The successes and failures of other countries can serve as stepping-stones for Tanzania in progressing towards increased RWH technology adoption. Countries like Germany, Japan, Korea, India, Australia, and Thailand have embraced RWH technology in efforts to enhance water availability for domestic and nondomestic uses, to reduce energy demand as well as for environmental sustenance.

6.2.1 Rainwater harvesting regulations in other countries

By March 2015, the cabinet of Japan approved wider usage of RWH in new buildings constructed by state government or administrative agencies (JFS 2015). In USA, in addition to voluntary effort, some states and municipalities are choosing to establish rules related to

RWH. Rules, ordinances, building codes, and homeowner association covenants nationwide run the gamut from requiring RWH systems on new construction to prohibiting tanks as an eyesore (Texas 2005). In addition, the city of Seoul in South Korea announced a new regulation in December 2004 to enforce the installation of a RWH system for purposes including flood mitigation and water conservation. By 2010, RW regulations were implemented in 23 local governments (Lee *et al* 2010, Han *et al* 2009). In Belgium, national legislation requires all new construction to have RWH systems for the purposes of flushing toilets and external water uses. The purpose of this legislation is twofold: 1) to reduce the demand for treated water and the expansion of the water supply infrastructure; and 2) to collect and use RW instead of surcharging storm water management systems (Brussels 2015). In Australia, five state governments have taken active steps to ensure that newly constructed houses are designed and built with the latest energy and water efficient designs and products, which includes RWH facilities. Germany collects rain taxes for the amount of impervious surface cover on a property that generates runoff to local storm sewers (Rainwaterharvesting.org). In Berlin, the fee charged is currently €1.84/m^2/year (Berlin 2010). In India, too, many cities have mandatory rules on RWH application (Rainwaterharvesting.org1).

6.2.2 Incentives and subsidies provision approach

The state of Texas in USA offers financial incentives for RWH systems. A Senate bill of the 77th Legislature exempts RWH equipment from sales tax and allows local governments to exempt RWH systems from advalorem (property) taxes (Texas 2005). As of April 2011, 208 municipalities in Japan were implementing subsidy programs for the installation of facilities for storing or filtering RW, of which 179 were providing subsidies for RW tanks. Sumida Ward was the first ward in Tokyo to promote the utilization of RW. For residents wanting to install a RW tank with a capacity of less than 1,000 L, the city would subsidize half the cost of the tank (up to 40,000 yen), including installation costs (JFS 2014). In Queens, Australia, a rebate of up to $1500 is offered for purchase and installation of home RW storages (Rainwaterharvesting.org). In Brussels, there is a municipal bonus granted for installation, repair or replacement of a RW system (up to €500, on a system of minimum capacity of 2000 L) (Brussels 2015).

6.3 Water resources regulations in Tanzania

Despite its portrayed high potential for contributing to improved water supply status in the country, no RWH manual, guidelines or regulations exist for guiding and enforcing the practice to date. The water utilization (general) regulations section 41 (2) (EWURA1997) does not acknowledge RWH among water sources, listing springs, streams, swamps, natural lakes, rivers, dams, charcos, shallow wells and boreholes in basins/catchments as water sources. Also, the 3rd edition of the Design Manual for Water Supply and Waste Water Disposal (MoWI 2009), which is used as a reference by most practitioners (consultants, contractors, etc.), has mainly focused on centralized systems, and it only includes RWH as a GW source type. However, the Water Resources Management Act No. 11 of 2009, on page 366 (Figure 60), gives citizens the right to establish personal RWH system for domestic purposes within their premises.

> wells in any area as may be prescribed in Regulations by the Minister.
>
> **Right to rainwater harvesting or use of recycled water**
>
> **12.**–(1) The owner or occupier of any land may construct any works for rainwater harvesting or for recycling of used water other than in a river or stream and abstract and use the water so conserved or recycled for domestic purposes without a Water Use Permit issued under this Act.
>
> (2) Notwithstanding the generality of subsection (1), no works for the purpose of rainwater harvesting shall have the capacity greater than the capacity prescribed in regulations by the Minister.

Figure 60: Right to rainwater harvesting activities as stipulated in the Water Resources Management Act no. 11 of 2009

UNEP (2009) recommends establishing enabling policies and cost-sharing strategies, including the provision of subsides along with technical know-how and capacity building for

RWH promotion. UN-Habitat (2005) states that the need for a policy framework for water harvesting systems arises even though the systems are ancient, mainly because the prevailing policy statements do not address the issue. They further recommend that, to promote urban water harvesting, policies should include a mix of incentives and penalties and that such policy initiatives should be strengthened further through legislation.

Specific guidance and restrictions are necessary so as to ensure that the necessary technology is speedily adopted and is able to meet its goals. For RWH technology to take significant effect in the country and for its full potential to be exercised, guidelines and regulations recognizable at national level are vital.

A practical regulation in Tanzania would need to incorporate: design and implementation standards, financial strategies, specification of government role through subsidies and incentives, and clarity on penalties, punishments, and charges to defectors.

6.3.1 Existing water related policies and strategies in Tanzania

The current water policy (MWLD 2002) has the promotion of the utilization of RWH technologies among its goals for rural water supply development. The national water sector strategy (MoWI 2008) acknowledges that RWH can play a role in offsetting water shortages. It supports rural development policy, which states that the central government will create an environment conducive to private sector participation in the development of RWH technology appropriate for rural areas. Additionally, it states that water resources management legislation will be reviewed with a goal of having a strong and effective legal and regulatory framework in place for the sustainable management of water resources. In addition, water resources legislation strategies will include promulgating new legislation and regulations to provide for future water resources management. It also sets out to prepare plans and promote introduction of suitable development technologies including RWH, introduce systems of regulating alternative supply sources and to prepare design guidelines based on minimum service levels. This offers a platform for initiating the establishment of RWH regulation for the country.

6.3.2 Rainwater harvesting bylaws

As a new institutional framework for water resources management, municipal and district councils have been given the mandate to formulate bylaws concerning water supply and sanitation (MoWI 2008). Recently, the establishment of RWH bylaws was initiated by the government. This is a good start even though the progress is slow. By May 2015, only 29 out of 168 LGAs had established the bylaws.

Typical bylaws (Appendix F), require house designs and construction implementations to include components for RWH system for approval by the LGA. In addition, it enforces a fine of at least 300,000 TZS (US$ 175) or construction termination until amendments are done.

More effort and follow up is needed to encourage not only the formulation but also the implementation of the established bylaws.

6.4 Water related institutions

For development and sustainability of a given technology, engaging in respective research is paramount. In the case of RWH, establishing a RW research center or a broader spectrum water research center is necessary. For years, a number of agricultural research centers have been active in the country, unlike water-specific ones. As a way forward, to sustain, develop, and address prevailing water supply challenges, it seems significant to propose the establishment of a water research center as a standalone entity, because water is equally important for one's welfare.

6.4.1 The purpose for the center

At the moment, there are few water research oriented centers in the country, with available universities limited within the scope of their departments, dissertation time frames, and donors' goals. Thus, an intensive research center with continuing upgradable water related research themes interlinked with daily practices of people is required.

The center should focus on innovations that are relevant to the nation's people and the environment, with roots in indigenous knowledge for sustainability and easy adoption by all classes of people. As Mbilinyi *et al*. (2005) stated, to develop sustainable RWH strategies, it is important to take into account, and learn from, what local people already know and do, and build on it.

RW should be the main subject, since it is the source of all water bodies. Thus, addressing issues related to its quality, quantity, maintenance, linkages with available water bodies, and its role in environmental sustenance, climate/weather extremes, and the water cycle should be focused on.

6.4.2 The scope and affiliations for the center

The proposed center for better impact and quick penetration into the community can begin in affiliations with existing reputable colleges or institutions or MoW. In the long run, its targeted stakeholders should be ministries, universities, the industrial sector, the private sector, and individuals as well. Involvement with the industrial and private sectors will secure funding and enhance reliance on research feedback for industrial growth. National and international recognition can also be attained through affiliations with colleges and government authorities.

The center should focus on both basic and applied research, targeting water supply challenges, and should involve innovations on quantity, quality, financing, management, maintenance, and include not only advanced technology but also indigenous knowledge.

There is a wealth of knowledge among communities in Tanzania, which have been sustainable for years and recently ignored/abandoned. Marobhe *et al*. (2007) studied locally available seeds commonly applied in clarifying water for drinking and cooking in rural districts of the Singida Region. Through traditional methods, turbidity removal efficiency of 83 to 90% could be achieved. Higher performance can be guaranteed with intense scientific research. Hence, indigenous knowledge can be studied and expanded upon for enhanced efficiency in the current world of advancement in science and technology.

The proposed center can incorporate entrepreneurial aspects for self-sufficiency, operating as a training center facilitating growth among youth and providing education regarding research skills. Thus, it can foster the next generation of innovators as well as initiating, facilitating and contributing to water related policies and regulations formulation.

6.4.3 Proposal for research center establishment

As mentioned, the involvement of a reputable, preferably existing, university or college is recommended. A survey of the relevant stakeholders can identify the demand and gaps at the national level. A proposal can be drafted, incorporating the scrutinized mission, vision, description of functions, goals and targets, organization chart, budget, and available opportunities in human, social, and financial assets. With a proposal in place, funds can then be sourced for the realization of the center. Consulting and involving both local and international private sector stakeholders will be necessary to address the financial aspect.

6.5 Community and individual financial stability and support

The HESAWA program in the 1980s in the lake zone regions, had key elements, including local ownership demonstrated through cost sharing, a new concept at the time. The program's goal was to contribute to the welfare of the rural population through the supply of drinking water. Additionally, Water User Groups were established in 1997 for the purpose of ownership and management of water facilities, thus transferring power from village government to the users themselves. While evaluating the program, Rautanen *et al.* (2006) declared that the deep rooted belief that water should be free also undermined sustainability of their funded projects.

Recently, Water User Groups, WC, and Community Owned Water Supply Organizations have been greatly promoted for handling the operation and maintenance of established community projects through the mobilization of funds.

Involving individuals and community at large is essential for water supply project sustainability. The financial challenges faced by previous water supply projects can serve as lessons in the understanding of the roles of different investors in relation to the performance of the projects and the accountability of the beneficiaries.

Therefore, the role of beneficiaries should be increased through various strategies in order to overcome the challenge posed by the cost of RWH construction and also to eliminate the free water attitude and instill a sense of ownership, which would ensure project sustainability in the long run. In Korea, the Seoul Metropolitan Government passed a regulation facilitating the combined financial efforts of the local government, the Donor Company, and volunteer citizens for RWH projects (Han and Park 2009).

6.5.1 Self-supply initiatives

Self-supply has been explained as a low cost approach to service delivery, initiated by individual families or groups. It was supported by promoting RWH in rural areas of Thailand (Lockwood and Smits 2011). Self-supply initiatives can serve as a motivator to external support from the government and the private sector as well, upon seeing internal efforts to improve the standard of living. Moreover, it reduces the reliance on government support. Systems financed under self-supply initiatives have the potential for better maintenance and management. These may include, cofinancing, cash/in-kind contributions, labor contributions, and microfinancing.

6.5.2 1C1C campaign

In community RWH projects, the involvement and cooperation of the public sector, the community and the private sector is essential. Each entity involvement has a beneficial impact on the project implementation and sustainability. Companies within a good setup can perform a 1C1C campaign as a CSR activity and gain recognition by the community and the public. This would cause the effective dissemination of technology, and address financial constraints.

6.5.3 Government incentives and subsidies

Clearly stipulated government roles are essential in ensuring implementation of given advocated technology in community.

In Tanzania, in an effort to boost agricultural production and the livelihood of rural households, the GoT has been offering farmers subsidies on seeds and fertilizers (Baltzer and Hansen 2011, Malhotra 2013). Further, the Tanzania Social Action Fund (TASAF) is implementing a productive social safety net, whose subcomponent is conditional cash transfer that targets poor and vulnerable families (TASAF 2015). The conditions imposed are those of health and education compliance. This started with a pilot case study covering the districts of Bagamoyo, Chamwino and Kibaha, but with long-term plans of nationwide implementation.

Water is a basic need for all people without which nothing can survive even health and education will be impacted. It is proposed that efforts similar to those towards agriculture improvement be directed by the GoT towards promoting RWH. Alternatively, RWH can be incorporated as a condition in the TASAF program. People can be advised to use some of the funds provided to install a simple RWH facility for meeting the drinking and cooking demands of the family. A favorable deal/tender can be secured with an engineering company/industry to produce cost effective storage tanks for such a project with TASAF. This would ensure that health is not jeopardized, thereby also impacting education through increased school attendance. Further, with healthy bodies and a relaxed mind, more energy can be invested in economic activities, including agriculture.

Additionally, the GoT can subsidize tank purchase/construction, which has been acknowledged as the most costly part of the system, or even consider offering tax exemption on RWH supply facilities.

6.6 Community-based demonstration project plan

Demonstration projects for promoting given technologies are necessary but strategies are required to ensure their acceptability, be instilled in people and change their mindset, acquire their ownership, and be within their comfort zone. A demonstration project should serve as a model for promotional plans.

From a practical point of view, demonstration projects for RWH technology are imperative. Therefore, focusing on successful promotion of RWH technology, demonstration projects need to be planned well. Considering a typical case of rural communities in Tanzania, several parameters need to be addressed in the demonstration project. These parameters include RW quantity modeling for sizing storage tank, RW quality maintenance, construction procedures, system operation and maintenance, system financing techniques, market allocation for RW components, and adoption strategies through awareness in adults and children. These are further discussed below.

6.6.1 Training and capacity building

Prior and post demonstration projects, seminars and workshops on RWH technology components should be conducted for DWEs and technicians because these are the core supervisors of villages. In addition, specific training should be provided for local community members. This would ensure consistency in the design and application of RWH technology within the country.

6.6.1.1 Engineers and technicians

Essential components for a RWH system should be clearly defined, and design procedures including criteria for sizing gutters, down pipes, first flush tank, and storage tank should be introduced in a stepwise manner. In addition, basic knowledge on the role of roof size, inclination, and type in the sizing of various RWH systems components should be provided.

Instead of the current trend of relying on annual average rainfall or making decisions based on roof capacity, dry days demand, or available funds; RW quantity modeling incorporating rainfall variation should be introduced. This approach would enable accurate assessment of the performance of a storage tank before its construction. To address the limitation in rainfall data accessibility, localization of rainfall monitoring facilities can be considered. For instance, by having rain gauges in schools, even students can participate in record keeping.

Standards, guidelines, and manuals can be improved, modified, and developed through exchange of ideas, know-how, and field experiences during such gatherings.

6.6.1.2 Local community

New techniques in RWH should be introduced to local communities in a stepwise manner. Air time should be provided to the community for sharing their existing knowledge, serving as a stepping stone for training.

Based on available knowledge, challenges can be explored and advanced techniques can be introduced. This can include usage strategies for water quantity management, water quality management, simple treatment mechanisms, and consumption tracking. In addition, people should be made aware of various individual as well as community financing techniques that can enable them to afford a RWH system. Training on the best operating method and simple maintenance methods should also be provided.

More skills and knowledge would be acquired by community members through full participation in actual construction work, through donating labor or employment as laborers.

6.6.2 Construction and maintenance empowerment

It is important to involve the beneficiaries from the initial stages, including site selection, market allocation for purchasing required materials, and mobilization of construction materials. During construction, beneficiaries can be involved through labor provision under supervision of trained engineers and technicians. In this manner, capacity building as well as a sense of ownership would be guaranteed.

Post construction, operation and maintenance can be delegated to established WC in case of community-based projects. The committee can oversee the entrepreneurial aspect of the project as well as ensure proper maintenance. It would be more convenient to formalize established committees, make them recognizable under the local government bylaws, or even under the national legislation and policy. This will increase the member's accountability and their eligibility to technical as well as financial assistance from the local government.

Moreover, a physical and simplified operation and maintenance manual should be prepared and provided to users as a guide.

6.6.3 Adoption and awareness promotion

From a demonstration project in a selected village, reports should be drafted addressing the pros and cons experienced. In addition, repetitive post evaluation of the project performance status, and beneficiaries' perception should be conducted, and knowledge applicable for incorporation into extension processes should be identified. Technical and economic efforts as well as social efforts involving the media, individual mindset, and culture and tradition should be considered in attempts on extension.

Individual mindset can be changed through incorporation of related information in education systems and in playing areas and parks for children, which can be have associated themes. Media, involving newspapers, radio, television, website, blogs, mobile phones, posters, banners, flyers, and brochures, is usually considered a powerful tool to convey information to a large crowd within a short time. A successful demonstration project can serve as an example, being included in media as evidence of a successful technology application.

6.7 Conclusion

There is much to learn from other countries with respect to the adoption of RWH technology, for which attempts have including knowledge dissemination, provision of subsidies and incentives, as well as exemption in taxes have been made. As a way forward for Tanzania, a roadmap comprising action and work plan (Appendix G) has been prepared and is offered towards adoption and implementation of RWH technology at individual and community levels. It addresses issues that have been affecting sustainability of water supply projects including ownership, maintenance, cost implication, enforcement, research and development, empowerment, and awareness.

CHAPTER 7:

Conclusion and Recommendations

7.1 Conclusions

RWH is a technology that, apart from having ancient roots, fits into most world traditions. It has shown the potential for sustainability even in recent applications, including a case study in a Tanzanian primary school. A demonstration project was conducted at Mnyundo Primary School in the Mtwara Region, a place originally lacking water supply facilities. Recent technical, economic, and social innovations, including quantity modeling and the use of treatment and monitoring components, were incorporated to boost sustainability. Moreover, through the application of simple sociotechnical and socioeconomic strategies, the school can achieve water sufficiency during the dry season, maintain good water quality, and be empowered to manage and maintain their system. Hence, RWH technology can be a sustainable water supply source for communities in Tanzania.

At the household level, as a result of limited water supply, local citizens tend to make their own systems for water collection and storage, but these are usually faced with the challenges of insufficient quantity and low quality. This was also the case for households in Mtiniko village of the Mtwara region. Through this research, it was established that water supply practices can be improved with RWH technology to safely and sufficiently meet the demands of users in households. As a way forward, each citizen should be educated towards addressing their own water supply challenges through the adoption of RWH technology in a decentralized manner, including strategies for fundraising, water usage, operation, and maintenance. A dual approach involving runoff, SW, or GW is suggested where rainfall is insufficient to effectively meet the demand.

RWH technology has good potential considering the distribution and magnitude of rainfall in the country, both as the sole of water supply source and in combination with another source. Through analytical interpretation of a study of RWH potential using GIS, it was established that rooftop RWH technology has a high potential to tackle water supply challenges throughout the country. Households as well as private and government organizations/institutions should adopt the suggested decentralized approaches, including RWH, to boost their water supply sufficiency and conserve water. Considering discussed cases of RWH adoption in households and institutions, RW can service over 35% of the annual demand, at least 40 L/person/d. Furthermore, recommendations on RWH components have been provided for better practical management of the system. Moreover, a modeling tool for storage size estimation has been developed, which would serve to guide practitioners for better design judgment.

It is obvious that the increased adoption of RWH in other countries has been impacted by the establishments of national standards, regulations, manuals and increased reliance on research feedback. In Tanzania, current RWH promotion efforts by the government and the private sector are still not adequate. The pace of establishing RWH bylaws in LGAs is slow, so more effort is required at the national level. These should include establishment of RWH regulations with clear incentives, subsidies, as well as penalties for misconduct and threats to the environment. In addition, water research centers should be established, incorporating available indigenous knowledge and recruiting both the young and the experienced in order to address the ongoing water supply challenges using RWH technology. Also, financial strategies that include self-supply initiatives, such as microfinancing, cost sharing, and the involvement of 1C1C campaigns for community cases, should be emphasized in order to empower and enable users to address their own water supply challenges. The government should also get involved through the provision of incentives and subsidies. Furthermore, prior to technology dissemination, well-planned demonstration projects involving local people from the planning stage through the implementation stage are of great importance. Providing training to boost awareness of the technology application and incorporating lessons from past shortcomings is also important.

Finally, with the goal of sustainability in water supply using RWH technology, an action and work plan has been prepared and is proposed. Through the implementation of this action plan, RWH technology can be developed, sustained, embraced, promoted, and enforced to serve efficiently.

7.2 Recommendations

The government RWH promotion strategy in urban and rural areas should include investment in raising the awareness of citizens as well as capacity building, the provision of incentives and subsidies, the establishment of legislation for enforcing the adoption, and investment in water resources research work as well as the establishment of a center. This is essential to sustain RWH technology through addressing prevailing and upcoming challenges.

An action plan for RWH technology promotion is necessary and its implementation should be overseen. Simultaneously, current practices detrimental to water resource management within the country should be identified and changed.

Modeling tools incorporating the nature of rainfall variation should be applied in RWH system design and performance assessment for good practical application. Moreover, in practicing RWH, water quality monitoring is essential through repetitive sampling and quality testing.

7.3 Recommendations on Africa Water Vision 2025

The African water vision 2025 should consider incorporating RWH technology among the interventions for addressing water scarcity during implementation of the vision. As highlighted in the vision, water supply challenges within the continent are mainly due to finances and technology, and not inadequacy of available water resources. RWH has been declared as low cost and capable of performing with low technology in a decentralized manner. Hence, it qualifies as a potential solution for African water supply challenges. RWH technology, through the adoption of in situ and ex situ interventions, can address some of the 10 identified key challenges faced by the water sector in Africa. It can address the challenges of water supply and sanitation, food and energy security, environmental sustenance and the ecosystem, climate variability, and serve in reversing man-made water quantity and quality problems.

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http://practicalaction.org

Mnyundo primary school rainwater harvesting project video link: http://www.youtube.com/watch?v=Bmco0bP2Kqw

APPENDICES

Appendix A: Mnyundo Primary School rainwater harvesting system drawing

Appendix B: Operation and maintenance manual (Swahili and English version)

Appendix C: GIS based rainwater harvesting potential map for Dar es Salaam city

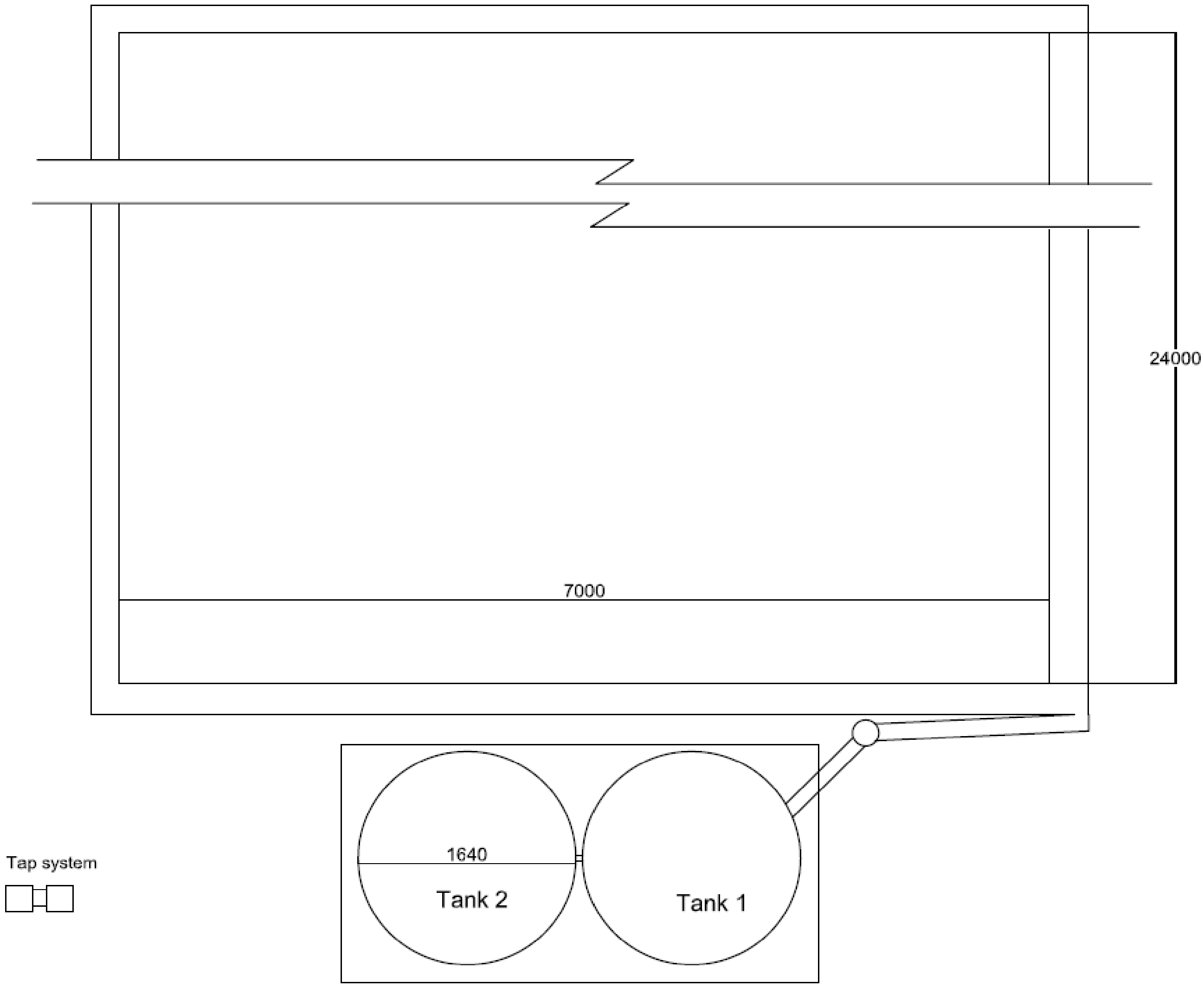
Appendix D: Rainwater harvesting system engineering design drawing

Appendix E: Flowchart for the rainwater harvesting system performance assessment tool

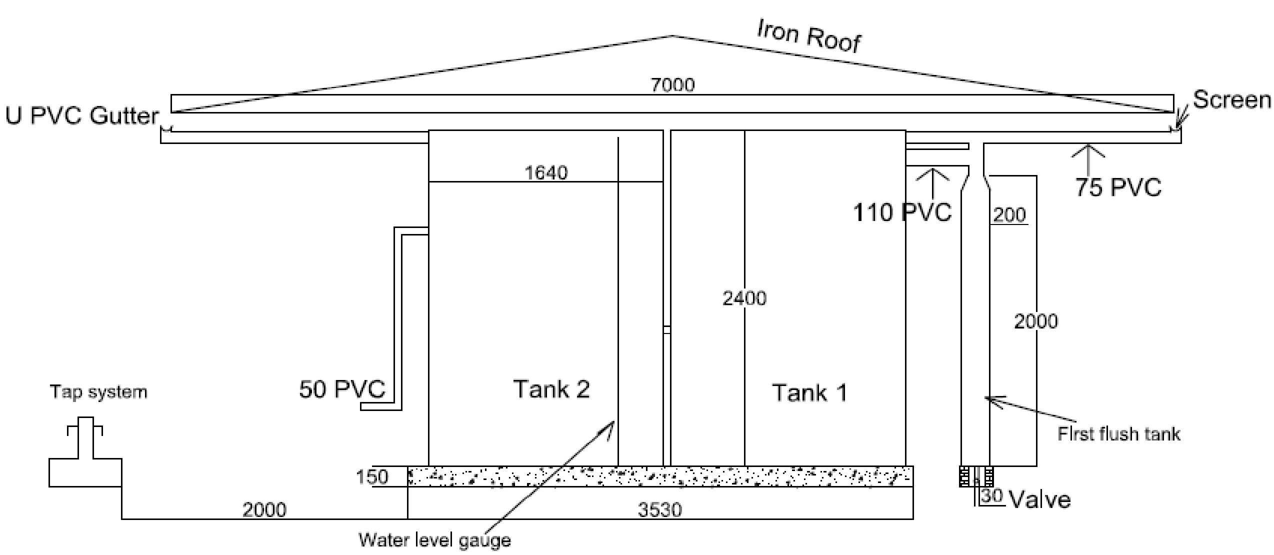
Appendix F: Rainwater harvesting bylaw prepared by a local government authority

Appendix G: Action plan and work plan for sustainable water supply with rainwater harvesting

Appendix A: Mnyundo Primary School rainwater harvesting system drawing



Plan View

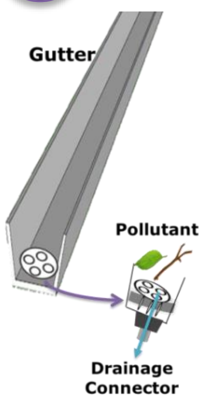


Elevation

Appendix B: Operation and maintenance manual (Swahili and English versions)

Mwongozo wa Utunzaji wa Mfumo wa Uvunaji wa Maji ya Mvua

1 Kingamaji na kiungo cha kupitisha maji



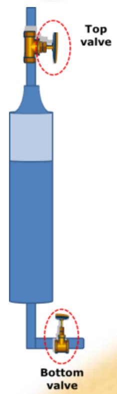
- **Kazi yake**

Maji ya mvua yanakusanywa katika kingamaji na kutiririkia ndani ya tanki la kuchuja maji ya mwanzo kupitia kwenye kiungo cha kupitisha maji

- **Matunzo**

Kila baada ya miezi 6 ondoa uchafu unaotuama juu ya kingamaji kama vile **majani n.k.**

2 Tanki la kuchuja maji ya kwanza



- **Kazi yake**

Tanki hili hukusanya yale maji ya mvua ya mwanzo kutua juu ya paa, ambayo mara nyingi huwa yamechanganyika na vumbi na uchafu mwengineo unaokuwa umegandia kwenye paa kabla ya mvua kuanza kunyesha.

- **Matunzo**

Baada ya mvua kuacha kunyesha, tafadhali fungua bomba la chini ili kuyaruhusu maji yaliyokusanywa kwenye tanki hili kutoka. Maji haya yanaweza kutumika kwa shughuli mbadala kama za umwagiliaji wa bustani.

- **Tahadhari!!**

1. Inapokuwa tanki hili halifanyi kazi ipasavyo kama vile linavuja au limepasuka, basi laweza tumika kwa kuendeshwa na mtu.
2. **Mvua inaponyesha, fungulia bomba la juu halafu ulifunge baada ya mvua kunyesha kwa dakika 5**
3. Wakati huo wote **bomba la chini** linakuwa **limefungwa.**

❖ Mahali: Shule ya Msingi Mnyundo, Mtwara , Tanzania
❖ Tarehe: 22. Feb. 2013

3 Tanki la kuhifadhia Maji

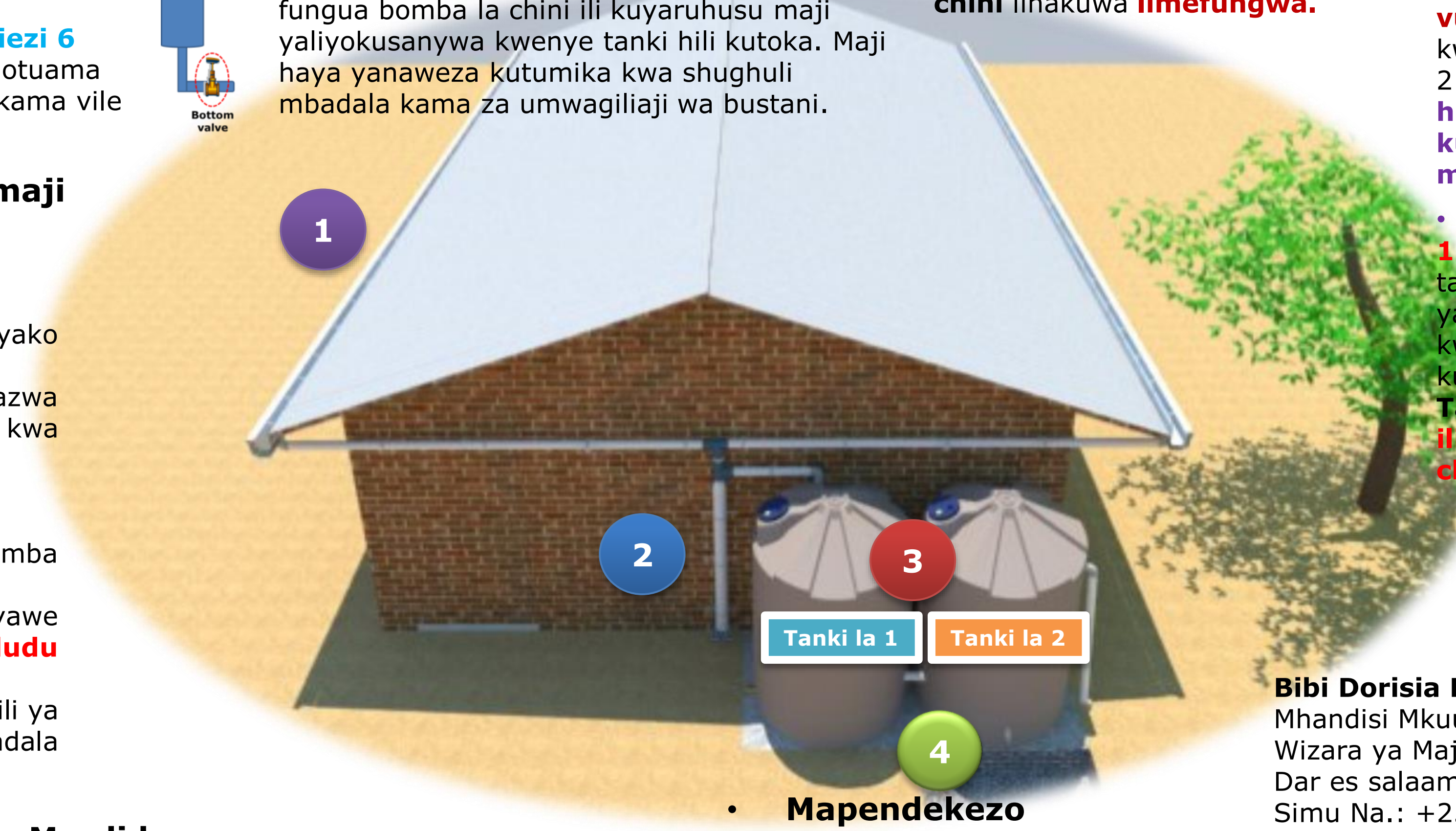
- **Kazi yake**

1. Yako matanki mawili, **La kwanza** ni **kwaajili ya kutunza maji na kuchuja vumbi** na maji ya mvua yanayotunzwa kwenye **tanki la pili ni ya ubora zaidi**
2. **Maji haya yaliyohifadhiwa humu hufaa kwa matumizi ya kunywa, kupikia na shughuli nyinginezo za majumbani.**

- **Matunzo**

1. Wakati wote chota maji toka kwenye tanki la pili, na wakati wa dharula maji yanaweza kuchotwa kwenye tanki la kwanza kupitia kibomba cha chini cha kusafishia.

Tanki lisafishwe kila baada ya miezi 6 ili kuondoa uchafu unaoganda kwa chini



4 Sehemu ya kuchotea maji

•**Kazi yake**
•Hapa ni mahali pa kukalisha ndoo yako wakati wa kukinga maji.
•Sehemu hii kitako chake kimejazwa kokoto kwa ajili ya kupitisha maji kwa urahisi kuingia ardhini

•**Matunzo**
1. Ili maji yatoke zungusha bomba kwenda upande wa kulia
2. **Mazingira** ya sehemu hii yawe masafi wakati wote ili **kuzuia wadudu kuzaliana**
3. **Kokoto** zilizotandazwa ni kwa ajili ya kuruhusu maji kupenya ardhini badala ya kutuama
4. **Kokoto** hizi **zisichezewe**

- **Mawasiliano zaidi**

Bw. John Msengi
Mhandisi wa Maji wa Halmashauri
Halmashauri ya Mtwara Vijijini
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- **Maelezo mafupi kuhusu Mradi huu**

Nia:
Kusaidia kupunguza tatizo la upatikanaji wa maji safi katika shule ya msingi Mnyundo, wilayani Mtwara

Upeo wa Mradi:
Walengwa: Wanafunzi na wafanyakazi wa shule hii ya msingi (makadirio ni watu 300, na wa kuanzia umri wa miaka 6 kwenda juu)
Mfumo wa ukusanyaji maji: Paa (Eneo – 168 mita za mraba); kingamaji
Mfumo wa usafishaji wa mwanzo: Chujio; Tanki la kuchuja maji ya kwanza
Mfumo wa usambazaji: Mabomba
Mfumo wa kuhifadhi maji: Tanki za plastiki **2** zenye ujazo wa lita 5000

Malengo:
-Kupunguza tatizo la ukosefu wa maji safi kwa watoto wa shule
-Kuleta mabadiliko kwenye maendeleo ya afya na elimu ya wanafunzi kwa kurahisisha upatikanaji wa maji
-Kuwepo kwa mazingira mazuri ya kusoma kwa wanafunzi, kwa kuchangia kupunguza tatizo la upatikanaji wa maji

- **Mapendekezo**

▪ Wakati wa msimu wa mvua maji yanayokusanywa yanaweza tumika kwa shughuli zote za maju mbani. Maji yatachotwa toka kwenye tanki la pili kwanza, na tanki la kwanza litatumika kwa dha rula tu.

Zingatia yafuatayo kabla ya kipindi cha kiangazi:
•Kuanzia mwezi **Mei** epuka kutumia maji ya kwenye tanki kama mvua bado zinanyesha
•Tumia, kusanya na tunza maji yanayomwagika baada ya tanki kujaa

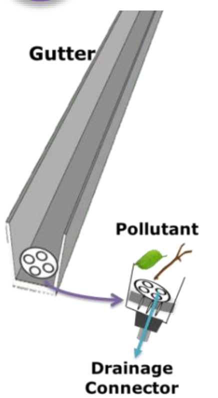
Wakati wa kiangazi:
•Wakati wote soma usawa wa maji kwenye mita ili kujua kiasi cha maji kilichopo
•Maji yatumike kwa uangalifu sana, mfano kipimo cha maji kwa siku kisizidi lita 2 kwa mtu mmoja
•Maji yatumike kwa matumizi ya kunywa tu
•Baada ya masomo kuisha bomba lifungwe
•Inapotokea hitilafu yoyote Mhandisi wa Maji wa Halmashauri aarifiwe

- **Imefadhiliwa na:**

NRF National Research Foundation of Korea · KMTC · Rain for all · BEOM HAN Engineering & Architects

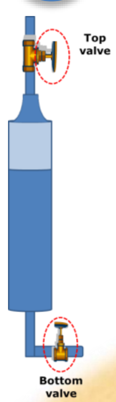
Maintenance Manual for Rainwater Harvesting System

1 Gutter and Drainage connector



- **Function**
  Rainwater is **collected** in gutter and **flows** into first flush tank through Drainage connector.
- **Maintenance**
  Remove pollutants, such as leaves from the gutter **once in 6 months**

2 First Flush Tank



- **Function**
  First flush tank collects the first rainwater that's polluted by contaminants which have been present on the roof prior to the beginning of the rainfall
- **Maintenance**
  After rainfall has stopped , please **open the bottom valve** to release water stored in this tank.

- **Caution!!**
  1. When the tank doesn't work, for example, the tank is leaking or is broken, you should operate the system manually.
  2. When it rains, open the top valve and close it **after 5 minutes** of rainfall.
  3. During the procedure, **the bottom valve** should be **closed**.

❖ Location: Mnyundo Primary School Mtwara , Tanzania
❖ Date: 22. Feb. 2013

3 Storage Tank

- **Function**
  1. There are two storage tank, **1^{st} tank** is for **storage and sedimentation** purposes and in **2^{nd} tank** stored **rainwater is of better quality**
  2. Stored water can be used for **drinking, cooking and other domestic purposes**
- **Maintenance**
  1. At all times collect water from **2^{nd}** tank and only incase **of emergency** water should be collected from **1^{st}** tank through the drain pipe
  2. Once in 6 months, please open the **drainage valve** and clean to remove settled substances.

4 Chamber

•**Function**
People can use water in the chamber and Chamber floor is composed with gravel which can absorb water

•**Maintenance**
1. The **tap** should be **rotated clock wisely** to release water and vice versa
2. The chamber surroundings should be kept clean at all times so as to avoid creating breeding areas for pathogens
3. Gravel bed underneath the chamber are for easy drainage of spilling water from water collection containers.
4. The **gravels** should not be tampered with

- **Contact People**

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Principal Engineer
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Mr Goyagoya Mbena
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- ## Description of the project

Purpose:
To contribute to improvement in water availability for domestic purposes for a Primary School community in Mtwara a Southern Region of Tanzania

Scopes:
Targeted users: Students and staff of Mnyundo Primary School (approx. 300 people, from age 6 upwards)
Collection system: Roof size (168 sqm); Gutters
Prior treatment system: Coarse filter; First flush tank
Distribution system: Down pipes, Inlet pipes, overflow pipe, water tap, drain pipes
Storage system: Two 5000 litres plastic tanks

Goals:
-Reduce the load that a young child is forced to carry when clean water is lacking
-Contribute to improved health of students
-Impact on improved education level of the students
-Contribute to provision of a comfortable learning environment for young students

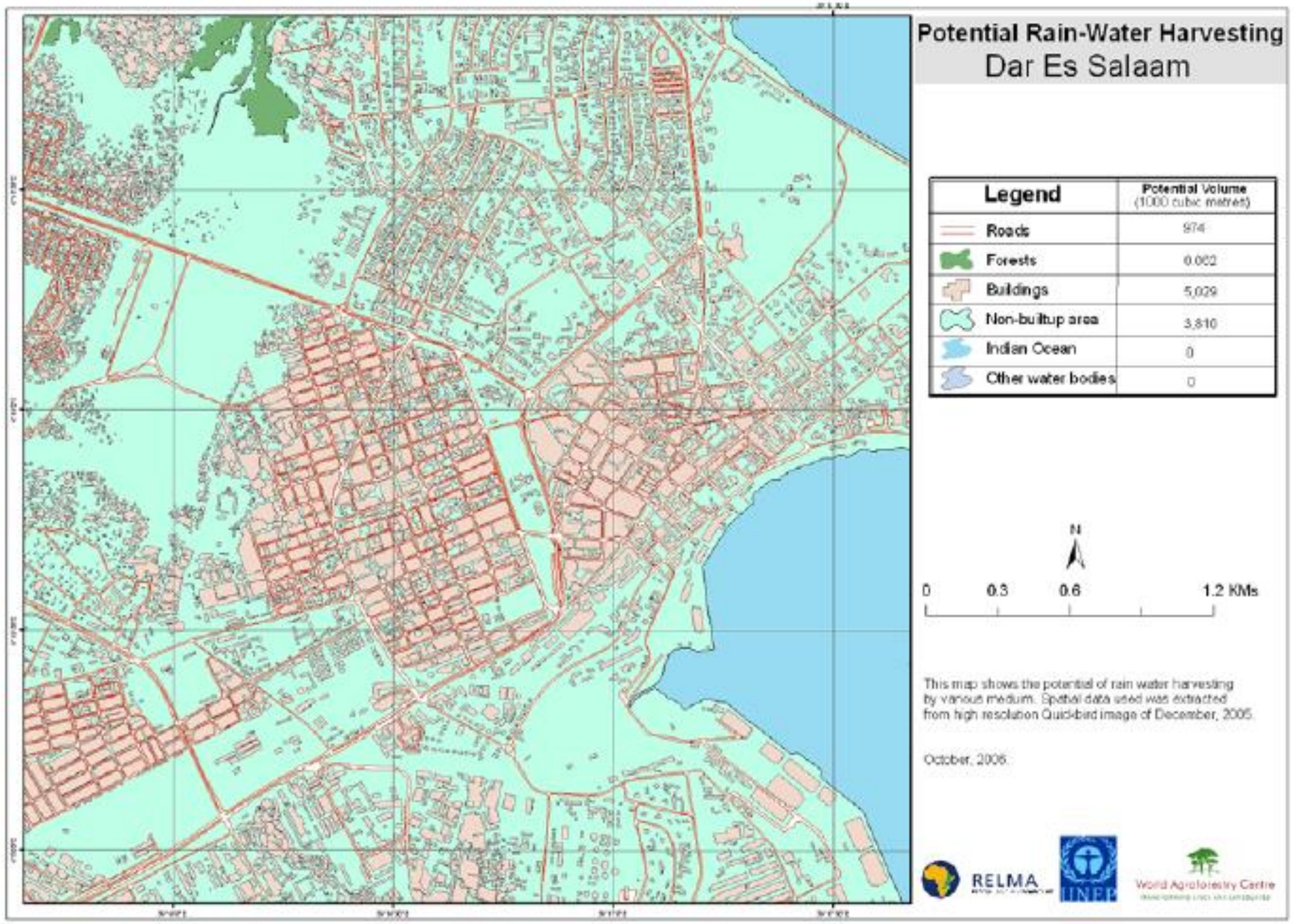
- ## Recommendations

- During the **rainy season** stored water can be tasked for all **domestic uses 2^{nd}** tank is used first, but **1^{st}** tank maybe used directly only incase of emergency
- Prior to the beginning of the **dry season** observe the following:
  - ✓ From month of **May** avoid using stored water if it is still raining
  - ✓ Use, collect and store **overflow water**
- During **dry season**:
  - ✓ Always observe the **water level meter**
  - ✓ Limit **water usage per person per day to a minimum value** such as 2 L
  - ✓ Limit water usage to only **drinking purposes**
  - ✓ After **school hours the tap should be kept locked**
- Incase of any **problem** the **District Water Engineer** should be **informed**

- **Sponsored by**

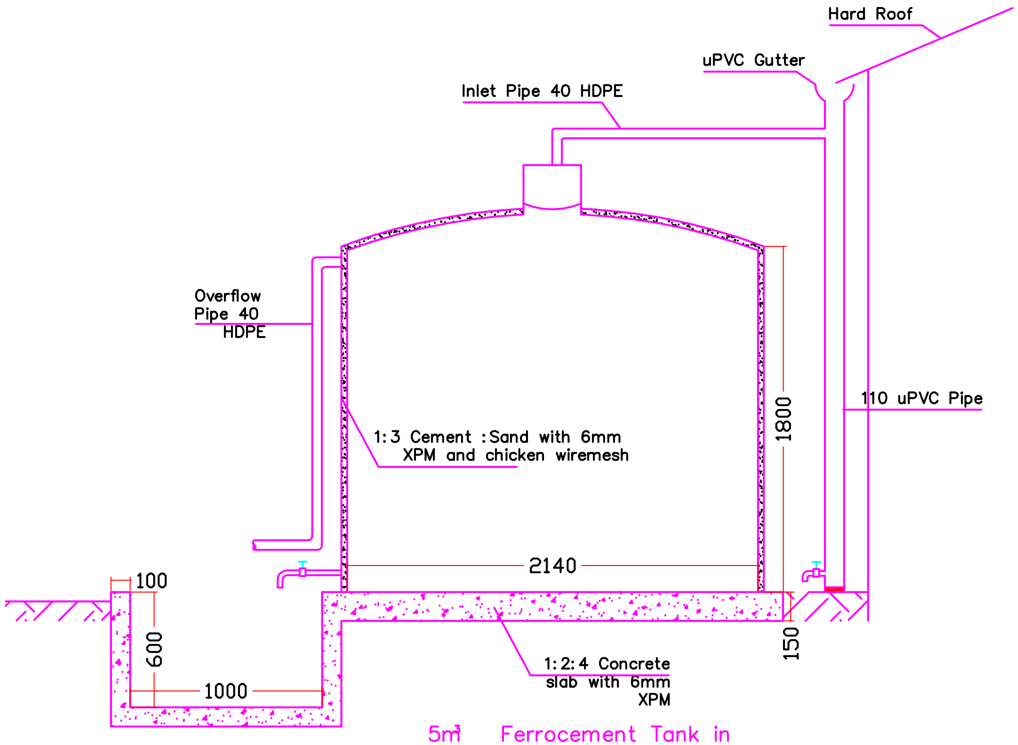
NRF National Research Foundation of Korea
KMTC
Rain for all
BEOM HAN Engineering & Architects

Appendix C: GIS based rainwater harvesting potential map for Dar es Salaam city

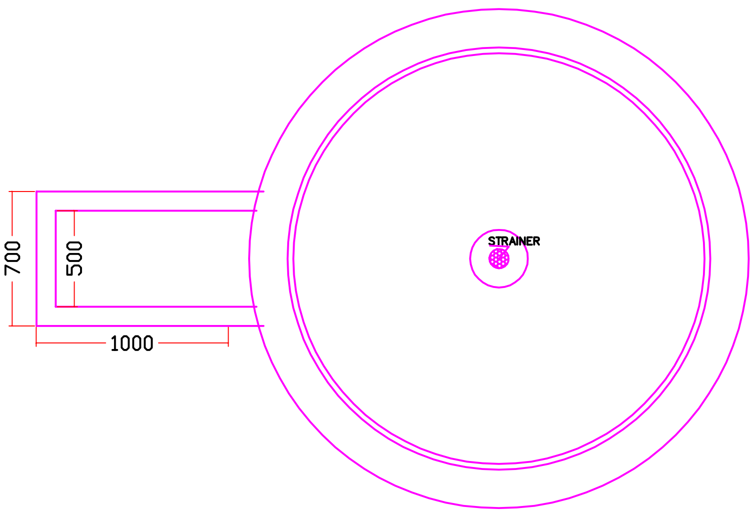


Dar es Salaam RWH Map

Appendix D: Rainwater harvesting system engineering design drawing

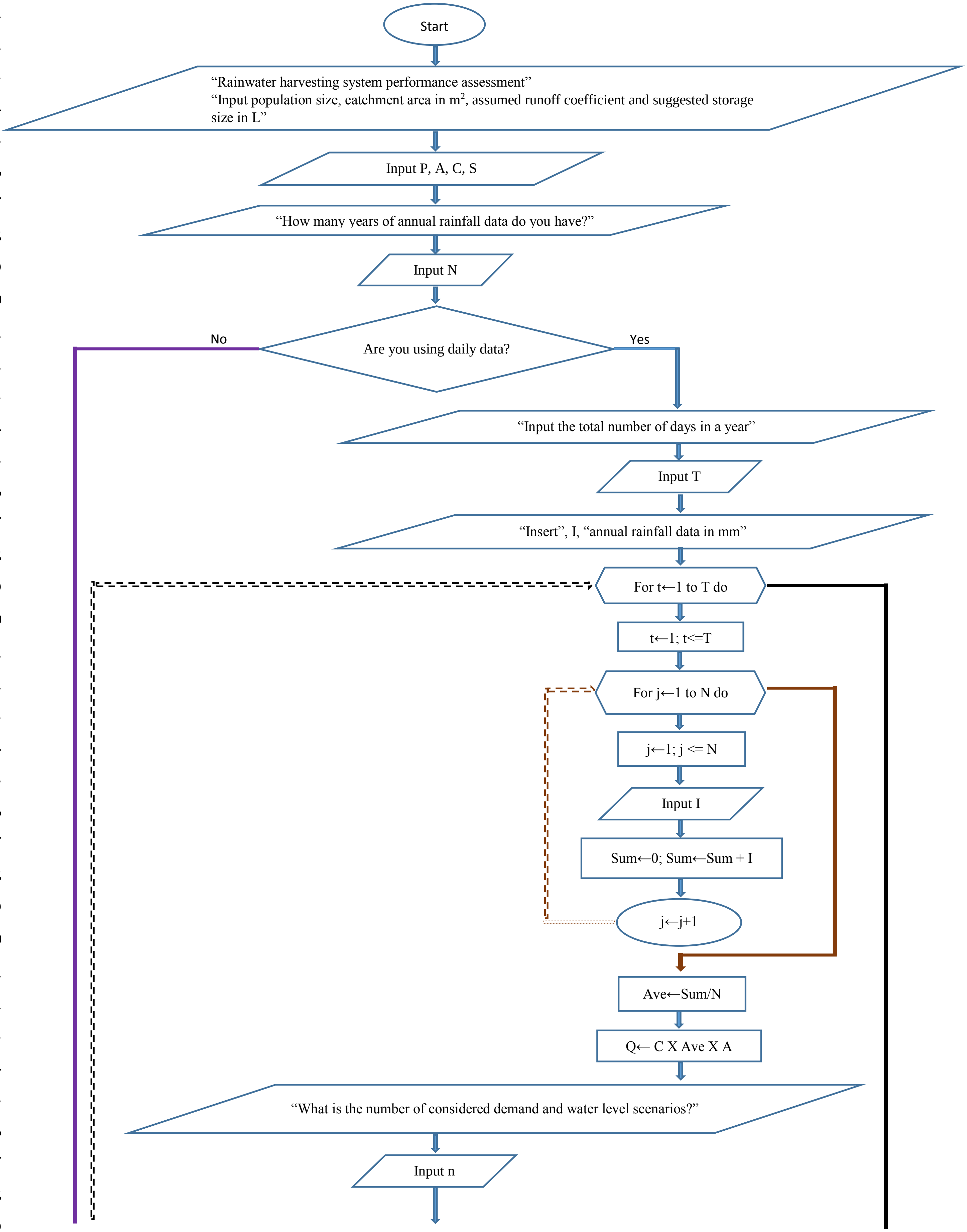


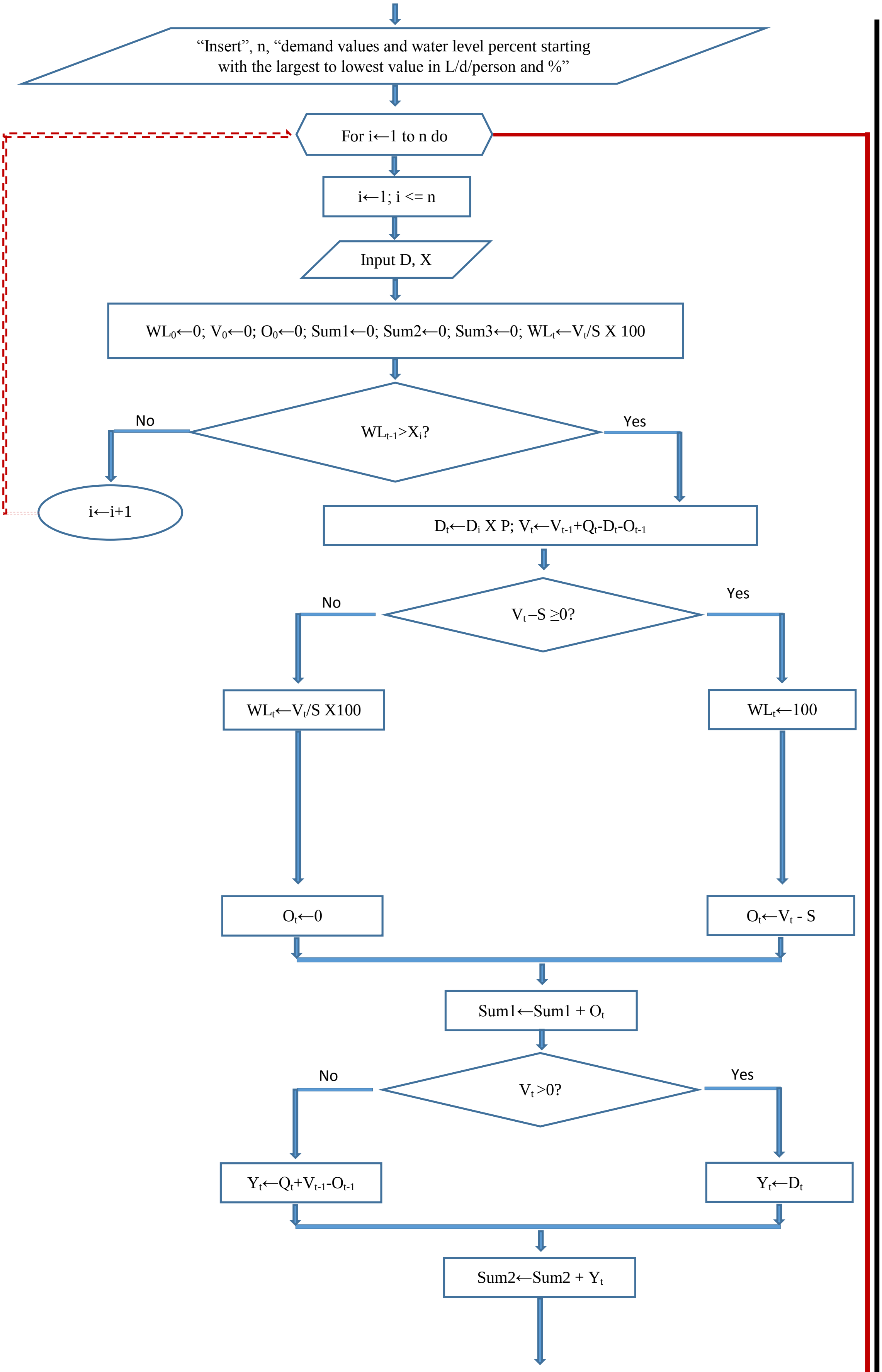
5m³ Ferrocement Tank in Elevation



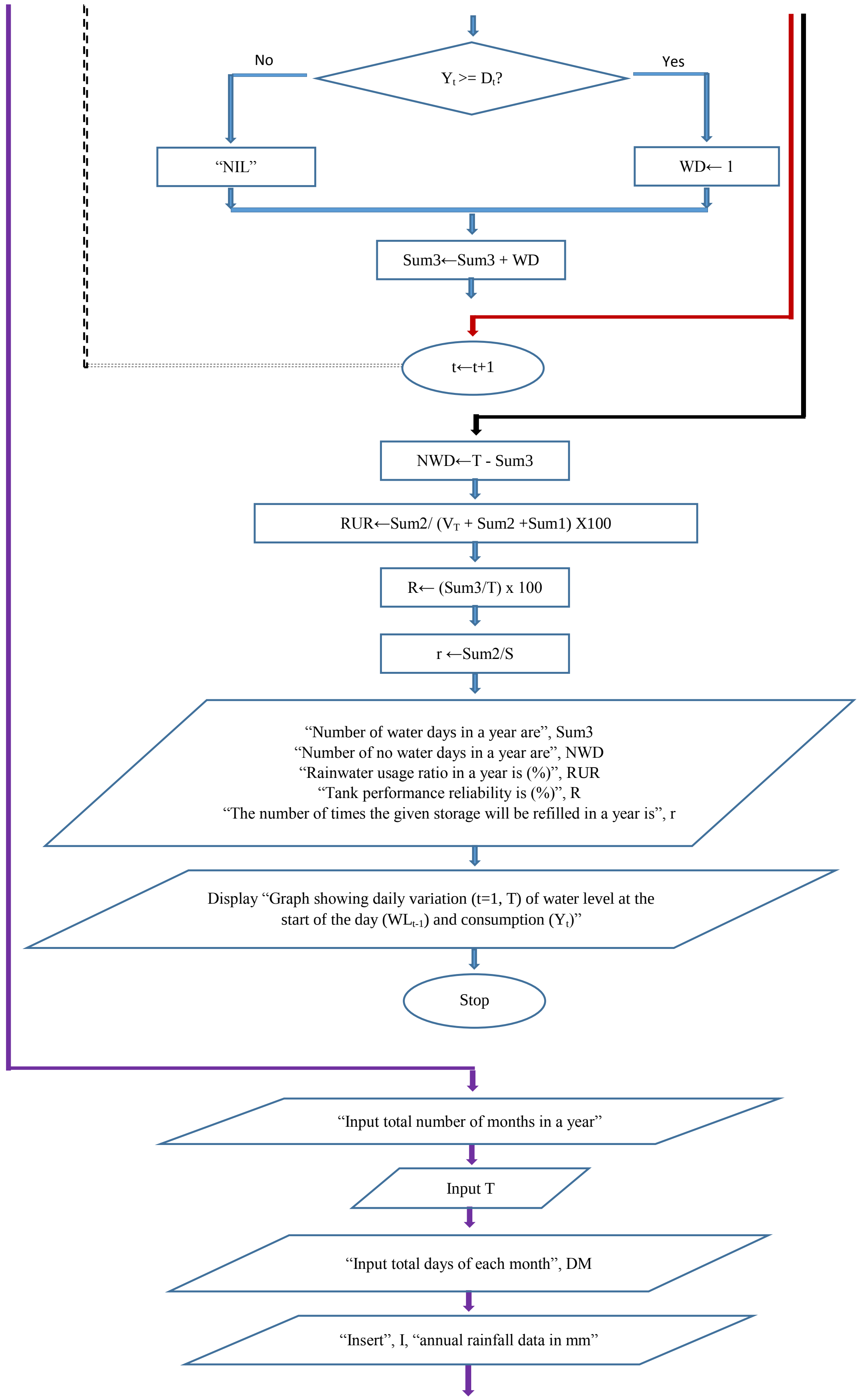
5m³ Ferrocement Tank in Plan

Appendix E: Flowchart for rainwater harvesting system performance assessment tool

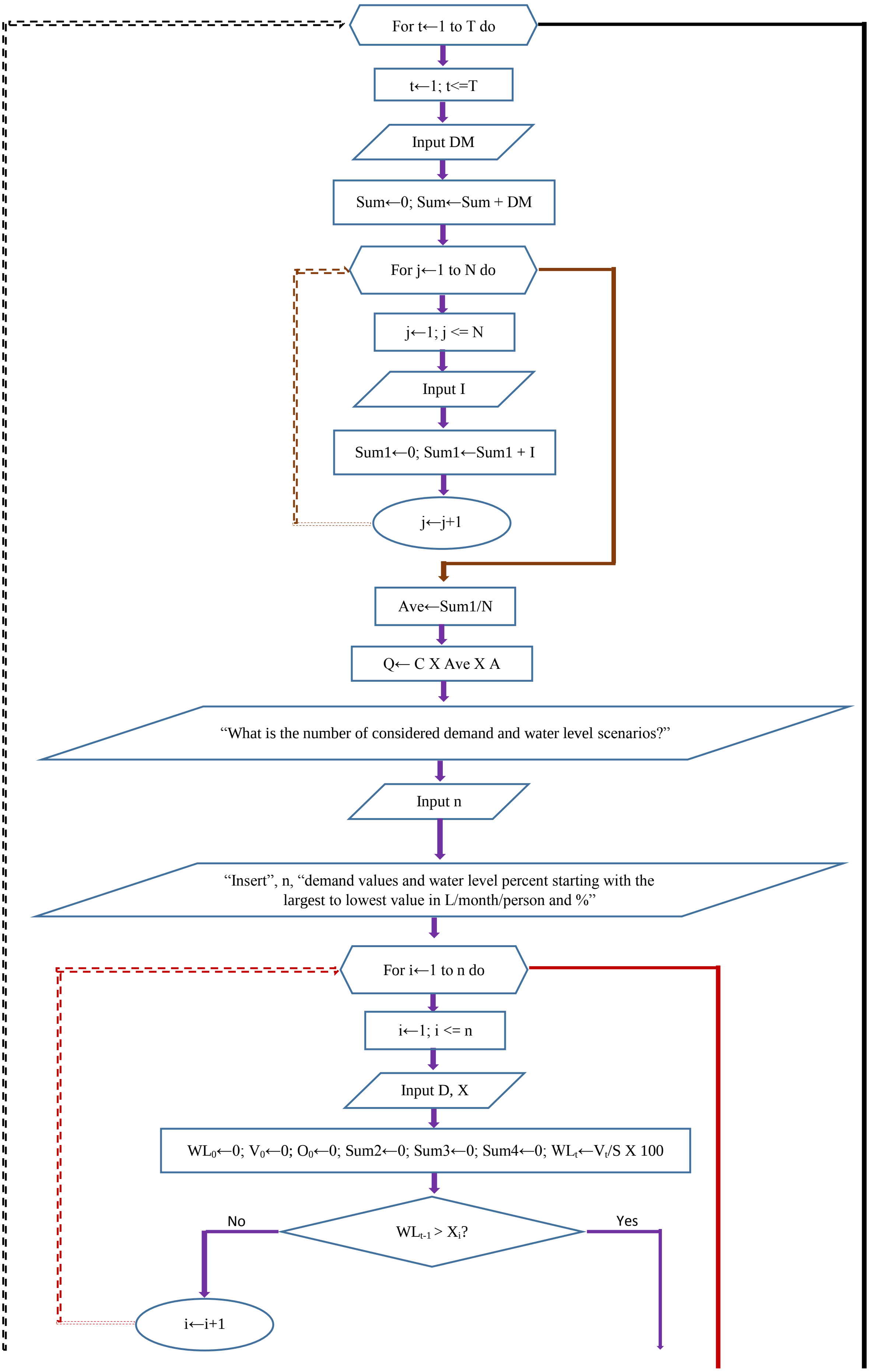


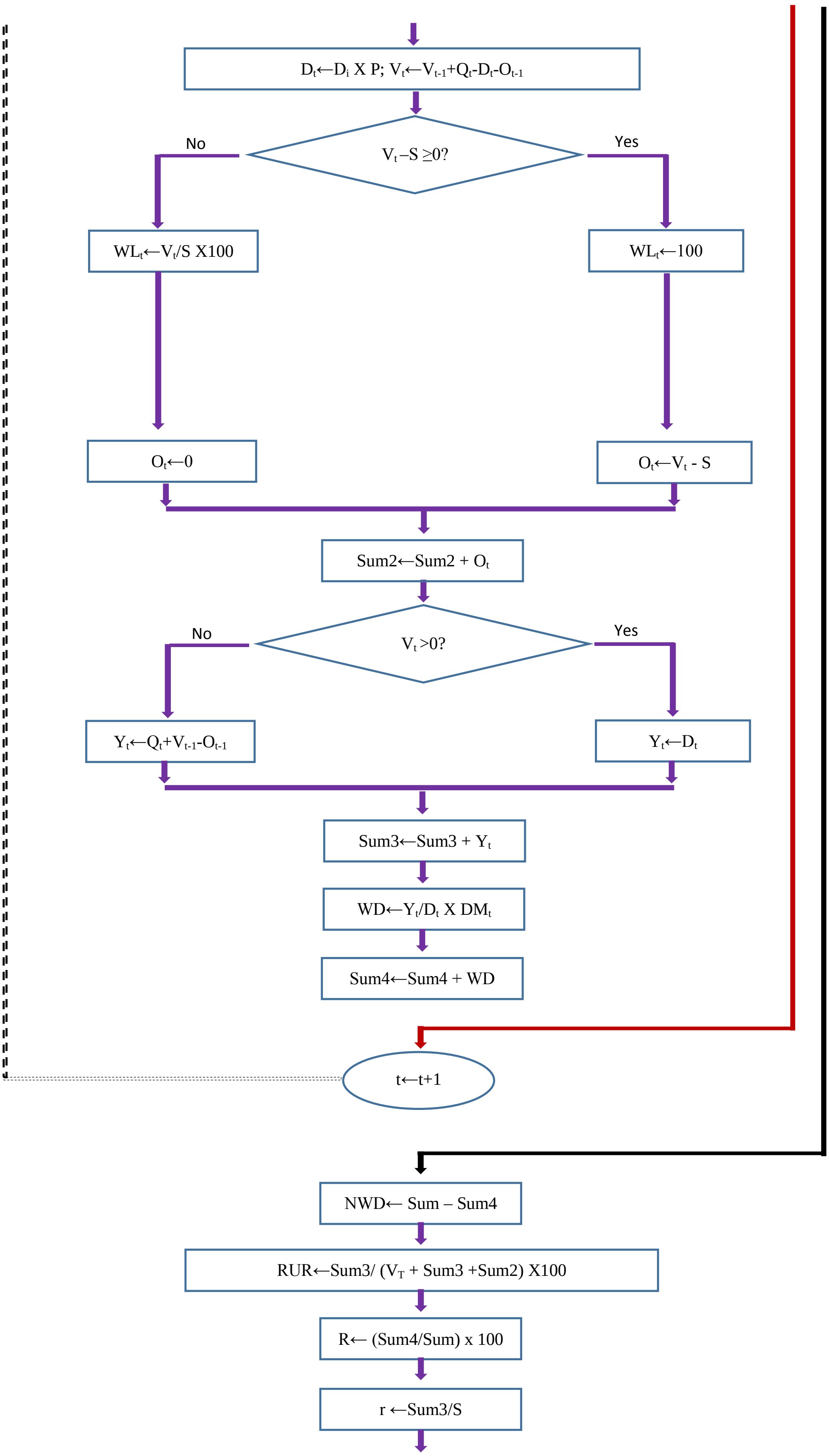


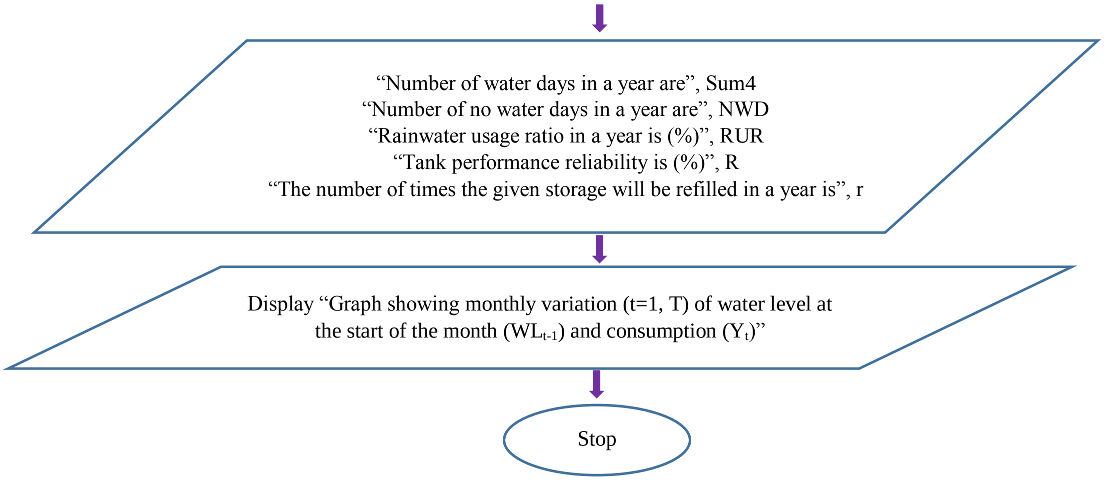
“Insert”, n, “demand values and water level percent starting with the largest to lowest value in L/d/person and %”
For i←1 to n do
i←1; i <= n
Input D, X
WL$_0$←0; V$_0$←0; O$_0$←0; Sum1←0; Sum2←0; Sum3←0; WL$_t$←V$_t$/S X 100
WL$_{t-1}$>X$_i$?
No
Yes
i←i+1
D$_t$←D$_i$ X P; V$_t$←V$_{t-1}$+Q$_t$-D$_t$-O$_{t-1}$
V$_t$−S ≥0?
No
Yes
WL$_t$←V$_t$/S X100
WL$_t$←100
O$_t$←0
O$_t$←V$_t$ - S
Sum1←Sum1 + O$_t$
V$_t$ >0?
No
Yes
Y$_t$←Q$_t$+V$_{t-1}$-O$_{t-1}$
Y$_t$←D$_t$
Sum2←Sum2 + Y$_t$



No
Yes
Yt >= Dt?
"NIL"
WD← 1
Sum3←Sum3 + WD
t←t+1
NWD←T - Sum3
RUR←Sum2/ (VT + Sum2 +Sum1) X100
R← (Sum3/T) x 100
r ←Sum2/S
"Number of water days in a year are", Sum3
"Number of no water days in a year are", NWD
"Rainwater usage ratio in a year is (%)", RUR
"Tank performance reliability is (%)", R
"The number of times the given storage will be refilled in a year is", r
Display "Graph showing daily variation (t=1, T) of water level at the start of the day (WLt-1) and consumption (Yt)"
Stop
"Input total number of months in a year"
Input T
"Input total days of each month", DM
"Insert", I, "annual rainfall data in mm"


For t←1 to T do
t←1; t<=T
Input DM
Sum←0; Sum←Sum + DM
For j←1 to N do
j←1; j <= N
Input I
Sum1←0; Sum1←Sum1 + I
j←j+1
Ave←Sum1/N
Q← C X Ave X A
“What is the number of considered demand and water level scenarios?”
Input n
“Insert”, n, “demand values and water level percent starting with the largest to lowest value in L/month/person and %”
For i←1 to n do
i←1; i <= n
Input D, X
WL_0←0; V_0←0; O_0←0; Sum2←0; Sum3←0; Sum4←0; WL_t←V_t/S X 100
No
$WL_{t-1} > X_i$?
Yes
i←i+1


$D_t \leftarrow D_i$ X P; $V_t \leftarrow V_{t-1}+Q_t-D_t-O_{t-1}$
No
$V_t - S \geq 0$?
Yes
$WL_t \leftarrow V_t/S$ X100
$WL_t \leftarrow 100$
$O_t \leftarrow 0$
$O_t \leftarrow V_t$ - S
Sum2←Sum2 + O_t
No
$V_t > 0$?
Yes
$Y_t \leftarrow Q_t+V_{t-1}-O_{t-1}$
$Y_t \leftarrow D_t$
Sum3←Sum3 + Y_t
WD← Y_t/D_t X DM_t
Sum4←Sum4 + WD
t←t+1
NWD← Sum – Sum4
RUR←Sum3/ (V_T + Sum3 +Sum2) X100
R← (Sum4/Sum) x 100
r ←Sum3/S


"Number of water days in a year are", Sum4
"Number of no water days in a year are", NWD
"Rainwater usage ratio in a year is (%)", RUR
"Tank performance reliability is (%)", R
"The number of times the given storage will be refilled in a year is", r
Display "Graph showing monthly variation (t=1, T) of water level at the start of the month (WL_{t-1}) and consumption (Y_t)"
Stop

SHERIA YA SERIKALI ZA MITAA (MAMLAKA ZA WILAYA)

(SURA YA 287)

SHERIA NDOGO

Zimetungwa chini ya Kifungu cha 153

SHERIA NDOGO ZA (UVUNAJI WA MAJI YA MVUA), HALMASHAURI YA WILAYA YA KWIMBA 2011

1. Sheria ndogo hizi zitaitwa Sheria Ndogo (uvunaji wa maji ya mvua) za halmashauri ya wilaya ya Kwimba, 2011 na zitatumika katika eneo lote la Halmashauri ya Wilaya ya Kwimba.

2. Sheria Ndogo hizi zitaanza kutumika baada ya kutangazwa katika Gazeti la Serikali.

3. Labda iwe imetamkwa vinginevyo, maneno yafuatayo yatakua na maana ifuatayo;

"Halmashauri" ina maana ni Halmashauri ya Wilaya ya Kwimba.
"Mchoro" maana yake ni ramani ya jengo/ nyumba ya biashara au makazi inayoonesha namna jengo au nyumba hiyo itakavyojengwa.
"miundo mbinu"
""

4. Ili kuwezesha na kufanikisha uvunaji wa maji ya kutosha kwa ustawi wa jamii yetu, kila mwenye ardhi anayetaka kujenga nyumba ya biashara au ya makazi atatakiwa kuweka miundo mbinu ya uvunaji wa maji ya mvua.

5. Kwa utekelezaji na ufanisi wa sheria ndogo hizi ni muhimu kwa kila nyumba itakayojengwa

6. Katika utekelezaji wa kifungu cha 4 cha Sheria Ndogo hizi, kila mwenye ardhi anayetaka kujenga nyumba ama ya biashara au ya makazi ni lazima katika michoro yake abainishe na kuonesha miundombinu ya kuvuna maji ya

7. Mchoro ambao hautaonesha na kubainisha miundo mbinu ya uvunaji wa maji ya mvua utakua ni batili na hautopitishwa na Halmashauri kwa ajili ya ujenzi hadi hapo utakapoonesha na kubainisha miundombinu ya uvunaji wa maji ya mvua.

8. Wakati wowote Halmashauri kupitia Idara ya Ujenzi itafanya ukaguzi kuhakikisha kuwa nyumba zote zilizojengwa chini ya sheria ndogo hizi zinajengwa na miundo mbinu ya uvunaji wa maji ya mvua na miundo mbinu hiyo inatumika baada ya ukamilikaji wake.

9. Mtu yeyote atakayemzuia kwa namna yoyote ile mtumishi wa halmashauri katika utekelezaji wa sheria ndogo hizi atakua ametenda kosa la jinai na atafikishwa mahakamani.

10. Iwapo mtu yeyote anayejenga nyumba bila ya kufuata masharti ya Sheria Ndogo hizi atakua ametenda kosa chini ya sharia ndogo hizi hivyo;

i. Mchoro au ramani ya nyumba yake haitokubaliwa na kupitishwa na Halmashauri,
ii. Ikiwa ameshaanza kujenga, atalipa faini isiyopungua kiasi cha shilingi 300,000/= na ujenzi kusimamishwa hadi hapo kasoro zitakaporekebishwa.

Appendix G: Action plan and Work plan for sustainable water supply with rainwater harvesting in Tanzania

ACTION PLAN

Objective: Introducing rainwater harvesting (RWH) as a water source for sustainable water supply in Tanzania

Goal: RWH adoption as a prime water source for selected urban and rural village by 2020

Strategies	Tactics	Skills required	Resource required	Lead measure
Establishing governing regulations for rainwater harvesting technology application	Study existing RWH regulations Compile and assess LGAs' by laws Establish regulations Register, legalize and promote	Water resources engineers, lawyers	Existing regulation documents, LGAs' by laws, policy documents and acts, time	Draft of regulation
Establishing water related institutions	Involve an existing reputable university/college Demonstrate the demand for rainwater research and training center Develop proposal for the establishment of a research and training center Apply for funds and sponsorship	Water resources engineers, lecturers, researchers	Institutional profiles, working programs	Rainwater/Water research center in action
Enhancing financial stability/support	Study the role of key parties in financing ongoing water projects	Water resources engineer, Finance	Water sector development	

	Make plans to enhance the role of sponsors and beneficiaries	experts, Community development officer (CDO), Cooperative officer (CO)	documents, policy documents, finance documents	Finance strategy for communities and individuals
	Introduce 1C-1C campaign for private sector involvement			
	Introduce self-supply initiatives for beneficiaries: e.g. cofinancing, microfinancing, cash/in-kind/labor contributions			
	Suggest motivational strategies to beneficiaries by government			
Community-based demonstration project planning and execution	Raise awareness on rainwater quantity modeling	Water resources engineers, Journalists, Media experts, DWE, DED, CDO	Historical rainfall data; site details including population and catchments; media	RWH awareness; increased technology adoption
	Raise awareness on water quality maintenance			
	Construction, operation and maintenance empowerment			
	RWH technology awareness promotion, and adoption extension			

WORK PLAN

Strategies & Tactics	2016												2017												2018												2019												2020												Service Provided
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
RWH adoption as a prime water source for selected urban and rural village by 2020																																																													
1. Establishing governing regulations for rainwater harvesting technology application																																																													
Study existing RWH regulations																																																													Existing RWH related regulations survey
Form a team	■																																																												
Collect existing regulations of selected countries	■																																																												
Review/survey the collected regulations	■																																																												
Compile a report	■																																																												
Compile and assess LGAs' RWH bylaws																																																													LGA's bylaws compilation
Collect RWH by laws from all LGAs	■	■																																																											
Review the collected by laws		■																																																											
Compile a report		■																																																											
Establish regulations																																																													RWH regulation draft
Review report 11 & 15			■																																																										
Brainstorm and outline scope of the regulation			■	■																																																									
Identify responsible Government body and relevant stipulations			■	■																																																									
Prepare and present the regulation to the Ministry of Water and Irrigation			■	■																																																									
Finalize the regulation					■																																																								
Register, legalize and promulgate																																																													RWH regulation approved
Proceed with registration and legalization process					■																																																								
Disseminate and raise awareness of the regulation to stakeholders					■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					
2. Establishing water related institutions																																																													
Involve an existing reputable university/college																																																													College affiliation allocated
Identify a potential institute for affiliating with					■																																																								
Form a team/committee					■																																																								
Demonstrate the demand for rainwater research and training center services																																																													Rainwater research center demand awareness
Research the status or existence of the anticipated research center						■																																																							
Conduct a brainstorming survey of relevant stakeholders						■	■																																																						

Assess and compile survey feedback	
Specify scope of the research facility functions	
Develop proposal for the establishment of a research and training center	Proposal for research center establishment
Draft the proposal	
Present the proposal at the college level	
Review the proposal	
Apply for funds and sponsorship	Funding raised and implementation of a research center
Identify relevant funding organizations	
Submit proposal for funding application	
Implement the proposal, establish and run the center	
3. Enhancing financial stability/support	
Study the role of key parties in financing ongoing water projects	Awareness on water projects financing
Form a team	
Select representative LGAs as case studies	
Assess roles of external funders and beneficiaries in water projects financing	
Make a report	
Make plans to enhance the role of sponsors and beneficiaries	Plan for sponsors and donors role enhancement
Conduct a survey to address challenges in water projects financing	
Prepare and present a plan to enhance sponsors and beneficiaries' roles	
Introduce 1C-1C campaign for private sector involvement	Business sector role enhancement
Identify potential business sectors	
Conduct seminars to introduce the 1C-1C approach	
Involve media for promotion of the 1C-1C approach	
Disseminate knowledge through brochures, pamphlets	
Introduce self-supply initiatives for beneficiaries: e.g. manpower, cofinancing, microfinancing	Self-supply initiatives awareness
Brainstorm and consult finance experts	
Organize seminars and trainings for villagers' empowerment	

Involve media for promotion of knowledge and techniques		
Allocate and assign responsible body within LGAs for facilitation and supervision		
Suggest motivational strategies to beneficiaries by government		Government role enhancement
Learn from governments with succesful case studies on RWH adoption		
Review government involvement strategies in other sectoral growth e.g. agirculture, TASAF		
Brainstorm and propose potential incentives and subsidies alternatives for interested RWH mediators and end users		
4. Community-based demonstration project planning and execution		
Raise awareness on rainwater quantity modeling		Rainwater tool application; Quantity control awareness
Establish simple and user friendly RWH system design and modeling tool		
Train LGAs' engineers and technicians on rainwater software application		
Plan for localization of rainfall monitoring facilities such as raingauges in schools		
Train community members on monitoring and controlling water level, usage strategies, and simple consumption tracking facilities such as meters, gages		
Raise awareness on rainwater quality maintenance		RWH guidelines and rainwater quality management awareness
Establish guidelines for pre and post rainwater treatment techniques		
Conduct seminars on RWH system management for water quality maintenance		
Construction, operation and maintenance empowerment		Demonstration project in place; RWH manual and national RWH standard established
Form a working team from among benefiting community members		
Allocate, inspect proposed sites, and design project		
Survey, facilitate and allocate market for rainwater system components		
Supervise construction in selected sites		
Faciltate establishment of water committees		
Train on operation and maintenance , prepare and provide manual		

Train on various potential RWH system financing techniques	
Draft and propose a national standard for domestic RWH construction practices	
RWH technology awareness promotion, and adoption extension	Improved RWH awareness, and adoption
Plan for extending RWH adoption through knowledge dissemination	
Mass education on RWH technology through media	
Suggest and plan on including RWH technology in primary and secondary schools' curriculum	
Propose a plan for establishing children's play areas and parks with RWH associated themes	
Assessment of workplan achievement and techniques advancement	Yearly progress report