Water Supply

Water Supply Vol 22 No 1, 1141 doi: 10.2166/ws.2021.207

Rainwater harvesting (RWH): a supplement to domestic water supply in Mvog-Betsi, Yaoundé-Cameroon

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ABSTRACT

This research is aimed at assessing the possibility of using a rainwater harvesting (RWH) system to supplement domestic water supply in the Mvog-Betsi neighbourhood of Yaoundé. The research made use of a 63-year long data series on the amount of rainfall available in the study area, an analysis of rainwater quality and an estimate of the population's monthly water demand in relation to the monthly harvestable rainwater supply. Rainwater supply for the months of September, October and November is 53.05 m^3 which is considerably greater than the households' water demand of 25.56 m^3 during the long dry season. This led to the design of a 27 m^3 ferrocement tank as minimum storage requirement. Furthermore, a rainwater quality analysis showed that all tested parameters conform to water quality standards except for microbiological quality. The rainwater needs to be disinfected before consumption as potable water. Finally, cost estimates for installing RWH systems for low ($419), medium ($549) and high standard ($668) habitations were calculated. RWH can effectively serve as a water supply supplement in the Mvog-Betsi neighbourhood.

Key words: Cameroon, domestic water supply, Mvog-Betsi-Yaoundé, rainwater harvesting

HIGHLIGHTS

- Rainwater harvesting is a supplement to urban water supply.
- Access to domestic water in Yaounde is problematic.
- There is abundant rainwater in Yaounde.
- Rainwater quality in Yaounde is chemically fit for drinking but not bacteriogically fit.
- Rainwater in Yaounde can be used for other domestic uses.

1. INTRODUCTION

Rainwater harvesting (RWH), is defined as the collection of water from surfaces on which rain falls, and subsequent storage of this water for later use (Sustainable Earth Technologies 1999). Researchers employ a wide variety of terms and definitions to describe the various methods aimed at using, collecting and storing rain runoff in order to increase the availability of water mainly for domestic and agricultural uses in arid and semi-arid areas (Haut *et al.* 2015). Yannopoulos *et al.* (2016) defined rainwater harvesting as an umbrella term for a range of methods of concentrating and storing rainwater runoff, including from roofs (rooftop harvesting), the ground (runoff harvesting) and from channelflow (flood water harvesting), from various sources (rain or dew) and for various purposes (agricultural, livestock, domestic water supply, environmental management). According to Antoniou *et al.* (2014), rainwater harvesting is the collection of atmospheric precipitation, usually collected and stored in artificial reservoirs known as cisterns in order to be used for household purposes such as bathing and washing, as well as irrigation and other urban uses and after appropriate treatment to be used in dwellings, offices, housing estates, industry, horticulture, and parks. Rainwater harvesting for supplying drinking water in urban areas has a long history especially in semi-arid areas. Decentralized multi-purpose rainwater harvesting systems should be useful infrastructure to mitigate water-related disasters such as flooding, sudden water break and fire events, especially in highly developed urban areas in the future. A cost-effective and environmentally friendly solution to flood risks due to urbanisation is the harvesting and reuse of stormwater runoff, in general, and particularly from roofs (Pazwash 2016).

While there are some disadvantages to harvesting rainwater (dependency on climatic patterns, storage capacity limitations, require regular maintenance, incur high cost initially, and contamination from poor collection and storage methods) these disadvantages can be avoided with proper planning and management. The flexibility and the many benefits associated with rainwater harvesting (avoids many surface-water pollutants; cost effective: reduces water bills and running costs are low; is a simple yet flexible technology: local people can be trained to build, operate and maintain a RHW system; water can be delivered nearer or directly to the household, relieving women and children from the burden of carrying it, saving time and energy; does not depend on terrain, geology, or infrastructure management schemes) make it a welcomed, widely accepted, and increasingly-promoted alternative for the water demands of today (United Nations Environmental Program 1997; International Rainwater Catchment Systems Association 2021).

Although 95% of those living in urban areas worldwide are served by improved water supply (WHO/UNICEF/ JMP 2015), there are still a great number of people who live in informal, overcrowded peri-urban settlements where access to water is low. As a result, there are many cases where rainwater collection provides an important supplementary source of domestic water (CAWST 2011).

According to WHO/UNICEF (2012), Sub-Saharan Africa has the lowest water supply coverage, with only 61% of its population having access to improved water supplies. It is estimated that 50% of Africa's population will be affected by water stress by 2025 (Malley *et al.* 2009). The root causes are ineffective governance, underinvestment, and mismanagement, which result in the absence of infrastructure to provide water access (Steven *et al.* 2014). In Cameroon for instance, though being a country blessed with vast bodies of water, many peri-urban communities and suburbs are water stressed, confronted with the issue of lack of access and continuous availability of water supply for their daily domestic and drinking water needs. This is the case of the Mvog-Betsi neighbourhood in Yaoundé, capital of Cameroon.

The availability of potable water in the Mvog-Betsi neighbourhood is really a cause of concern as a majority of the population tend to rely on groundwater resources to meet their daily domestic water needs. This is as a result of the fact that the water distribution network has been established in only few Blocs (Blocs I, V, VI and VII), out of a total of nine Blocs which make up the neighbourhood. These groundwater resources including springs and wells tend to reduce in flow rate or dry up during the dry periods of the year. Boreholes, for their part, though more resilient to climate or seasonal changes are expensive to construct, and the pumps are more difficult to maintain and hence frequently breakdown (GWP & MINEE 2009). It is of great necessity therefore, to strive to remedy or attenuate the prevailing situation in this neighbourhood of the capital city of Cameroon. In this regard, Rainwater Harvesting (RWH) presents an alternative solution in the short to medium term in view of providing a better-quality supplement for domestic and potable uses to the Mvog-Betsi population.

This paper, therefore, is aimed at demonstrating how RWH through roof catchment systems could act as a domestic water supply supplement to the inhabitants of this neighbourhood of Cameroon's capital city.

2. MATERIALS AND METHODS

2.1. Study area

The Mvog-Betsi neighbourhood, also known as Eba'a, is located in Yaoundé, capital of Cameroon, in the Yaoundé VII Sub Division (Figure 1). It extends from 3°51″19 and 3°52″00 N to 11°28′09″ and 11°29′20″ E and has an approximate surface area of 1.54 square kilometres. The Mvog-Betsi neighbourhood is bounded to the North by Melen, to the South by Etoug Ebé, to the West by Cité Verte and to the East by Biyem-Assi and Obili neighbourhoods (GMUS 2008; Ndongo *et al.* 2012). The neighbourhood comprises of nine Blocs, however, only five of these are of interest in this study (i.e. Blocs II, III, IV, VIII and IX), where the urban water supply network is either completely absent or no longer functional.

The climate in Mvog-Betsi is the Equatorial climate of the Guinean type as in all of Yaoundé city marked by four seasons (a long rainy season from mid-September to mid-November, a long dry season from mid-November to mid-March, a short rainy season from mid-March to mid-June and a short dry season from mid-June to mid-September) (Suchel 1998). The average monthly precipitation data of Yaoundé for a period of 63 years (1951–2013) is presented in Figure 2.

One of the first steps in deciding if rainwater harvesting is an appropriate technology is to estimate the potential rainfall supply to make sure that it meets household needs. For rooftop harvesting, an annual rainfall of at least 100–200 mm is required in order to meet the water demand of 50–150 litres per day for residents in developing countries as proposed by UNESCO in 2000 (CAWST 2011).

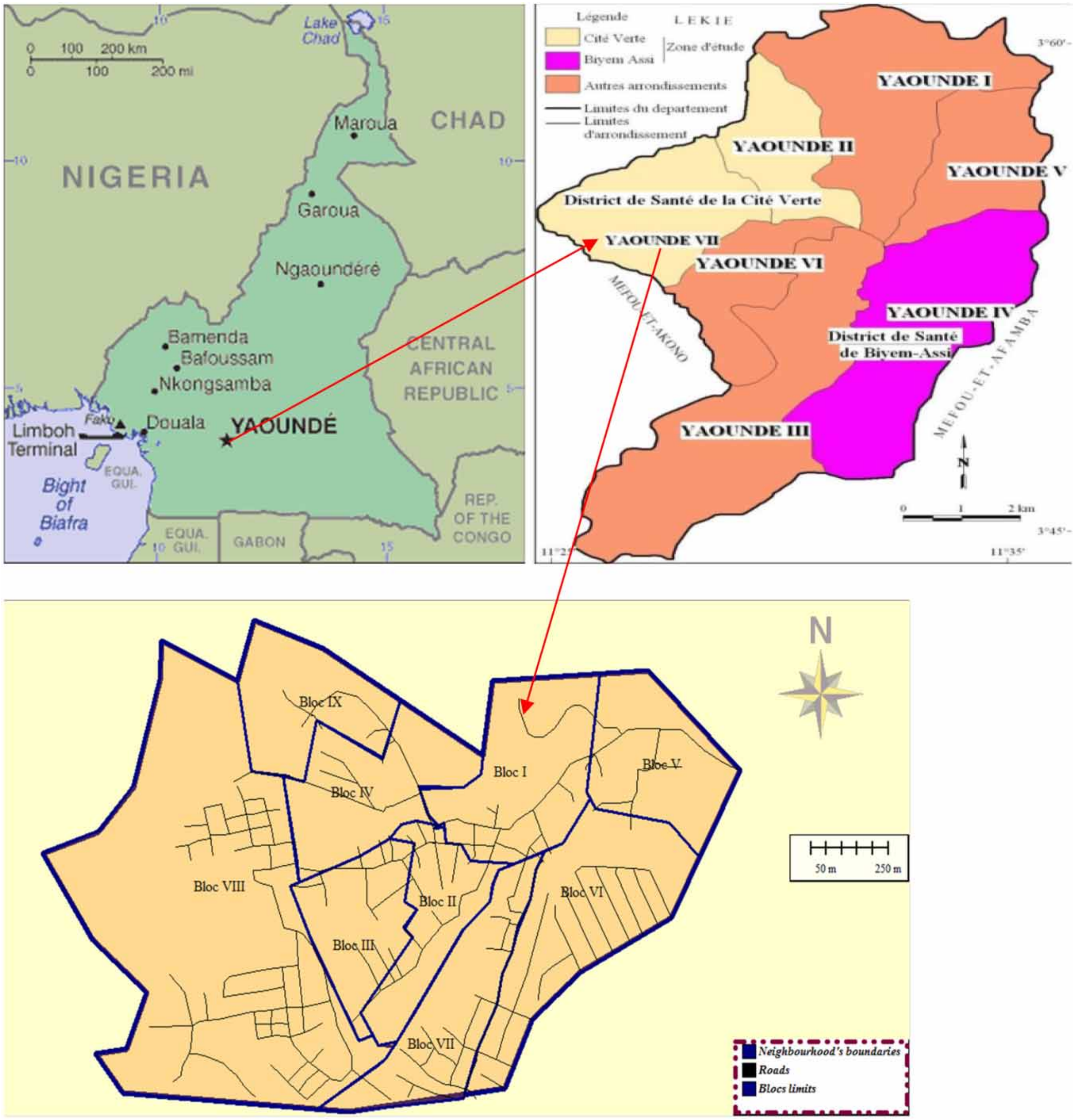

Figure 1 | Location of the study area.

In Yaoundé, the Mvog-Betsi neighbourhood included, rainfall is recurrent in the months of March, April, May and June for the short rainy season and in the months of September, October and part of November for the long rainy season. The rainiest months are October and September with 620 and 512 mm respectively and the mean monthly rainfall depth is about 300 mm. Thus, RWH through roof catchment systems could act as a domestic water supply supplement to the inhabitants of Mvog-Betsi neighbourhood.

2.2. Data collection

2.2.1. Household survey

The feasibility of rainwater harvesting in a particular locality is highly dependent upon the amount and intensity of rainfall. Other variables, such as catchment area and type of catchment surface, can usually be adjusted according to household needs. As rainfall is usually unevenly distributed throughout the year, rainwater collection methods can serve as only

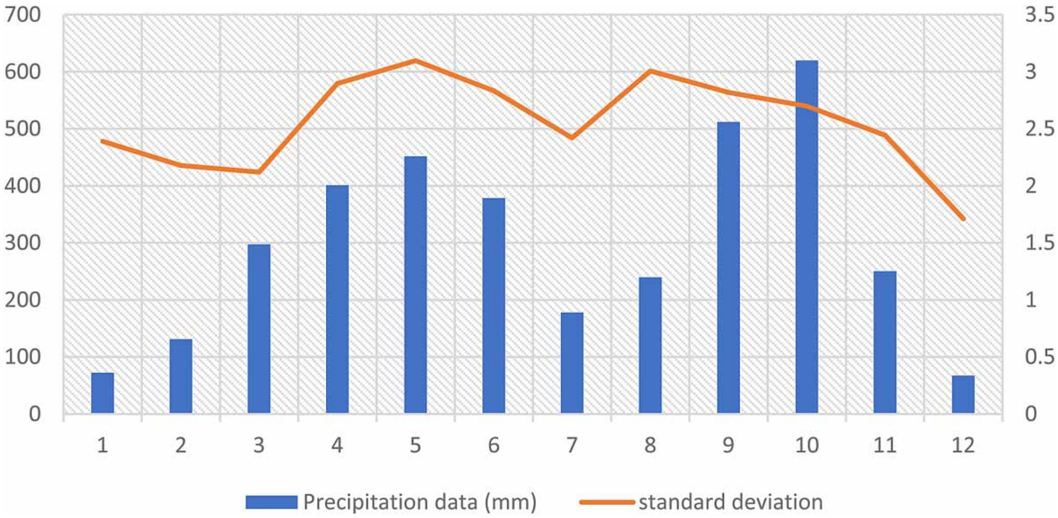

Figure 2 | Average monthly precipitation (1951–2013) of Yaoundé. *Source*: National Meteorology Service Yaoundé.

supplementary sources of household water. The viability of rainwater harvesting systems is also a function of: the quantity and quality of water available from other sources; household size and per capita water requirements; and budget available. The decision maker has to balance the total cost of the project against the available budget, including the economic benefit of conserving water supplied from other sources. Likewise, the cost of physical and environmental degradation associated with the development of available alternative sources should also be calculated and added to the economic analysis.

A survey should be the starting point to estimate the household water demand. There are several variables that affect domestic water consumption, such as the: number of adults and children (i.e. adults use more water than children); family members staying at home (i.e. absentee members working or studying away from home for part of the year); time of year (i.e. more water is used during the hottest and driest seasons). When water supplies become more consistent and there is a great volume of water available to users, the amount that is used tends to increase.

To obtain information on water demand, other sources of potable water, rainwater harvesting practices, habitat types and roofing materials in the neighbourhood, a household survey was carried out. This survey was carried out using a questionnaire administered to 250 households in the neighbourhood. The study focused on the following Blocs in the neighbourhood; Blocs II, III, IV, VIII and IX. The sampling technique which was used was cluster sampling. Households of the neighbourhood's Blocs were grouped into clusters, then a random sampling of the houses to be surveyed per cluster was made. This sampling technique generally best suits personal interviews as it can render the sampling procedure easier and increase efficiency of field work. It also allows for an extrapolation of results across a given cluster.

2.2.2. Rainwater sampling and laboratory analysis

Microbial and chemical contaminants have been detected in domestic rainwater harvesting (DRWH) tanks, and if this water is used for potable purposes, it could produce adverse health effects. Microbial and chemical contaminants in DRWH tanks can originate from: (i) raindrops that traverse through polluted air, (ii) catchment areas, and (iii) storage tanks (Abbasi & Abbasi 2011; de Kwaadsteniet *et al.* 2013).

Rainwater collection systems are commonly believed to provide safe drinking water without treatment, because the collection surfaces (roofs) are isolated from many of the usual sources of contamination (Mosley 2005). Thomas & Martinson (2007) further explain that when considering the water quality of an RWH system, it is useful to observe the complex path a contaminant must follow in order to enter a human being. The usual paths are shown in Figure 3.

The primary means of tank contamination is through water washed in from the roof. Material washed in from the roof can come from several sources: material that has accumulated on the roof or is blown onto the roof during a storm, decayed roof materials (e.g. low-quality roof materials such as thatch or tar sheets) which can contribute to the dirt load, and from the passage of water along unclean gutters which may add further debris.

To ascertain the quality of rainwater in the Mvog-Betsi neighbourhood, 10 rainwater samples were collected in the months of September, October and November 2018 in 1.5 litres plastic bottles placed on a stand directly under corrugated iron sheet

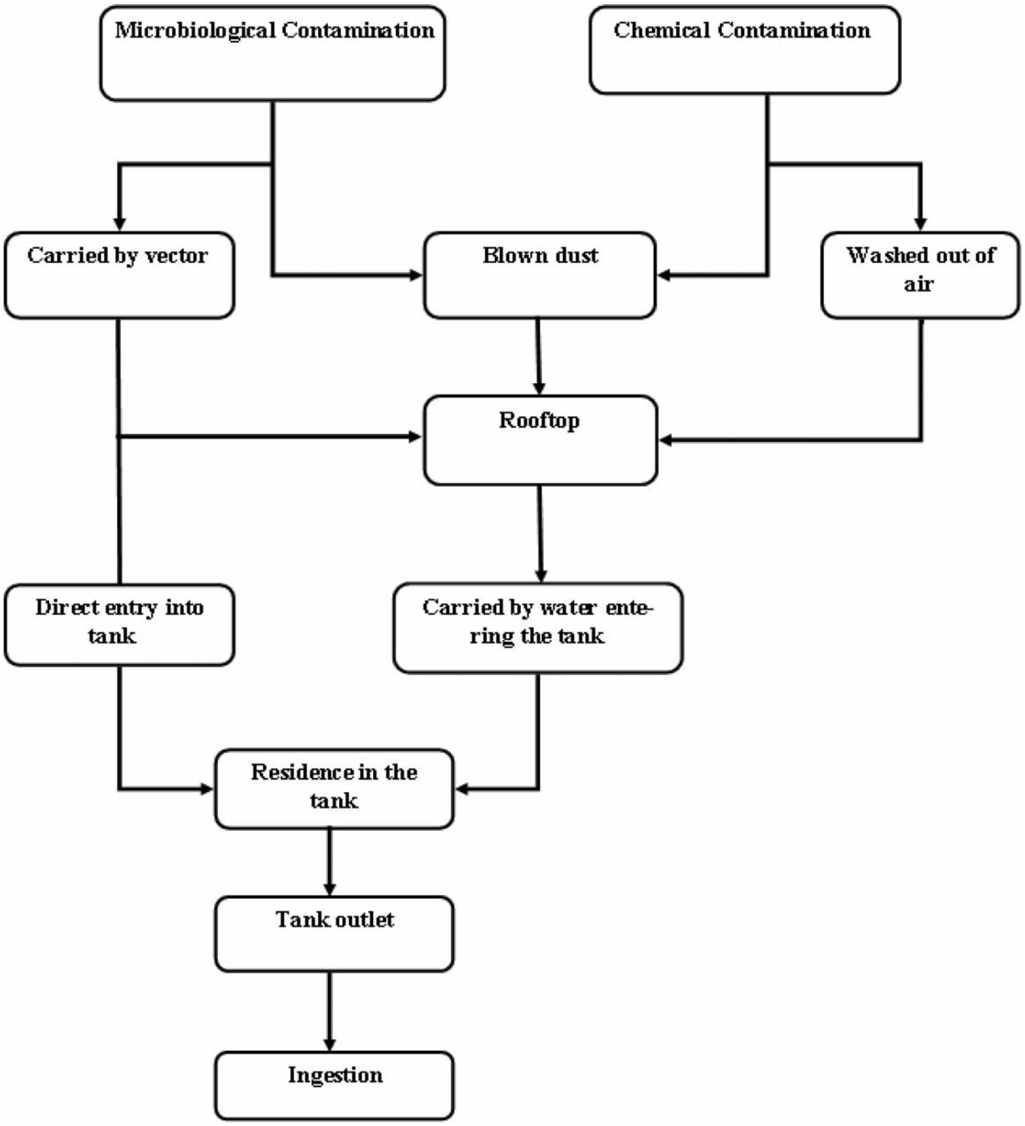

Figure 3 | Contamination paths for roof water harvesting *Source*: Thomas & Martinson 2007.

roof-endings of the houses surveyed. The bottles were first thoroughly rinsed several times with distilled water to ensure they were free from contamination and then filled with the rainwater sample to be collected. Samples were then preserved airtight (in order to minimize oxygen contamination and the escape of dissolve gases) and kept in a refrigerator prior to analysis for a period of 1 day after collection. Samples were transported and deposited at the Geochemical Water Analysis laboratory (LAGE) of the Institute for Mining and Geological Research (IRGM), Yaoundé, for chemical analysis and bacteriological analysis (Total Coliform and Feacal Coliform Counts) at the Animal Biology Laboratory of the University Yaoundé I.

2.2.3. Methods for designing a rainwater catchment system

Usually, the main calculation when designing a rainwater catchment system is to size the water tank correctly to give adequate storage capacity. Often the only variable that a designer can influence is the tank size since existing roofs are used as catchments and the amount of rainfall cannot be changed (CAWST 2011). When sizing the system, it is important to consider whether it is going to be used in conjunction with other water sources as a supplementary, partial or backup supply.

According to CAWAST (2011), there are a number of different sizing methods which vary in complexity and sophistication, such as the dry season demand method, the graphing method and the computer models methods. The dry season demand method estimates the largest storage capacity needed to meet the household water demand throughout the dry season (i.e. the period during which there is no significant rainfall). It has as disadvantages that it: only provides a rough estimate of tank size; is only suitable in areas where a distinct dry season exists; does not consider rainfall availability and variations between different years; does not consider capacity of the catchment area. Graphing the catchment runoff and daily water demand is another simple method that will give a more reasonable estimation of storage requirements. This is important in areas with low or uneven rainfall, where more care has to be taken to size the storage tank properly. During some months of the year, there may be an excess of water, while at other times there may be a deficit. If there is enough total rainfall throughout the year to meet the demand, then sufficient storage will be required to bridge the periods of water scarcity. The basic steps that have to be followed under this method are: 1. plot a bar graph of the average monthly water supply (i.e. runoff) and add a line showing the average monthly water demand; 2. use a table to calculate the cumulative water supply and demand; 3. plot a bar graph of the cumulative water supply and add a line showing the cumulative water demand – the difference between these values indicates the minimum storage requirement. Computer models can be used to simulate rainwater supplies and design storage requirements. The output can compare the performance of specific designs under various water demand scenarios. The results of any simulation exercise should always be treated with some caution since they are only as good as the historic rainfall data entered into the model.

3. RESULTS AND DISCUSSION

3.1. Rainwater quality

The results of the chemical and bacteriogical analysis of rainwater in the Mvog-Betsi neighbourhood are shown on Table 1.

It can be observed in Table 1 that rainfall in Mvog Betsi, though an urban area, has an average pH of 6.25, within the WHO (2004) and Cameroon (ANOR 2003) potable water standards.

The major cation in the rainwater samples is potassium with 26.56 mg/l whereas the major anion is bicarbonate (HCO_3^-) with a value of 54.78 mg/l (Table 1). However, it is clear that all tested parameters conform to water quality standards set by both the WHO and Cameroon. These results also confirm the fact that rainwater is not very rich in mineral content, thus can be described as being soft, since the ions responsible for water hardness (Ca^{2+}, Mg^{2+} and HCO_{3-} in this case) are in very little amounts compared to the standards. A little exception is seen in the level of the Potassium (K^+) ion in which concentration is greater than that of the Cameroon potable water standard. The adverse effect of high (K^+) ion values is a health condition called hyperkalaemia (WHO 2009). However, WHO prescribes a greater value which can conveniently be used. Particularly

Table 1 | Results of chemical and bacteriological analyses of rainwater in compliance with WHO (2004) and Cameroon (ANOR 2003) potable water standards

Parameter	Unit	Rainwater results $n = 10$	Standard deviation	WHO Limits (2004) (≤)	Cameroon potable water standard (ANOR 2003) (≤)
pH	–	6.25	0.45	Between 6.5 and 8.5	Between 6.5 and 9
Electrical Conductivity	µS/cm	57.75	34,13	NA	1000
Suspended Solids	mg/l	0		NA	NA
Ca^{2+}	mg/l	11.16	9,28	75	NA
Mg^{2+}	mg/l	0.39	0,22	30	50
Na^+	mg/l	0.19	0,04	200	150
K^+	mg/l	26.56	36,17	50	12
Cl^-	mg/l	15.34	16,65	250	NA
F^-	mg/l	0.05	0,04	1.5	0.7/l
HCO_3^-	mg/l	54.78	13,29	200	250
PO_4^{3-}	mg/l	0.01	0,01	NA	5
Total Coliform Count	CFU	100	25	0	0
Feacal Coliform Count	CFU	50	31	0	0

Note: NA: not applicable.

in urban areas, pollutants such as heavy metals and sulphates can enter the water and these materials have been found in several studies in urban roof runoff (de Kwaadsteniet *et al.* 2013).

The World Health Organization (WHO 2004) guidelines state that faecal bacteria should not be detectable per 100 mL of sample. However, Fujioka (1994) stated that a more realistic standard may be 10 faecal coliforms/100 mL. Total coliform tests are not considered a reliable indicator of risk to human health in the tropics as they are naturally present and can reproduce in the soil and water (Fujioka 1994; WHO 2004), meanwhile faecal coliforms and enterococci are considered much better indicators of faecal contamination, since these are commonly found in high numbers in human and animal faeces. Their presence in drinking water, therefore, indicates a strong likelihood that faecal contamination has occurred and that the water is therefore not suitable for drinking. Table 1 reveals that rainwater in Mvog Betsi contains on average 100 Total Coliform bacteria and 50 Feacal Coliform bacteria. This rainwater is feacally contaminated and therefore not fit for drinking but fit for other domestic uses. The rainwater needs to be disinfected before use as potable water.

3.2. Rainwater use in the studied community

3.2.1. Water demand

The estimated water demand for household daily activities and personal needs is around 30–40 litres per capita per day (lpcd). This amount is seen to increase during the dry seasons where more water is needed for bathing and consumption (WHO/UNICEF/JMP 2015). WHO/UNICEF/JMP (2015) goes further to define basic access as the availability of a water source that is at most 1,000 metres or 20 minutes away that affords the possibility of reliably obtaining at least 20 litres per day per family member allowing for consumption, hand washing and basic hygiene, but it does not guarantee laundry or bathing and therefore impact on health can be notable; intermediate access refers to the situation where people have access to 50 litres per day at a distance less than 100 metres or 5 minutes, covering laundry and bathing as well as basic access uses, having low impact on health; meanwhile optimal access allows for the consumption of 100 litres per person per day on average, supplied continuously through multiple taps and which meets all consumption and hygiene needs.

Results of the household survey indicate that the water demand per capita per day in the households of the neighbourhood is as follows: 15–25 L (30%), 25–40 L (35%), 40–60 L (22%), 60–75 L (9%) and 80 L+ (4%). Hence, most inhabitants (35%) use between 25 and 40 lpcd for their entire domestic and potable water needs. However, this amount increases during the dry season by about 15 litres as more water is needed during hot periods.

Based on the WHO/UNICEF/JMP (2015) criteria, water demand in the Mvog-Betsi neighbourhood can be ranked under intermediate access even though the distance covered to the water source is greater than 100 meters and the topography of the zone does not permit easy access to water points.

3.2.2. Potable water and non-potable supply coverage in the neighbourhood

According to the household survey results, 32% of the households fetch their potable water from private dug wells (Figure 4). This is followed by rainwater and springs with 24 and 11% respectively, while community standpipes and house taps are used by 7 and 5% of the households as a potable water source.

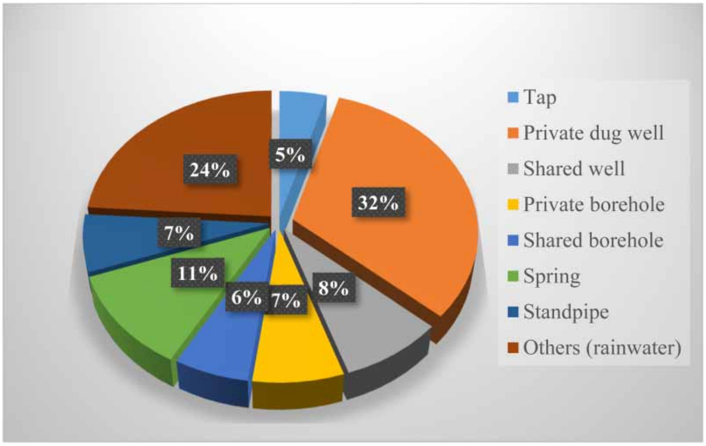

Figure 4 | Potable water and non-potable supply coverage in the neighbourhood.

Private dug wells are the most used source of potable water supply in the study area. This is because dug wells are less onerous in their construction and maintenance than other structures like boreholes. In addition, less financially well-off people cannot drill water boreholes for their domestic purposes as the cost of drilling the boreholes is prohibitive (Okpoko *et al.* 2013).

The Mvog-Betsi Eba'a neighbourhood, in spite of its more than five decades of existence, is practically excluded from the conventional urban water supply service due to its high-altitude position above all of the Yaoundé city water reservoirs. Thus, the neighbourhood has a very low pipe-borne water access estimated to be about 13.1% (ERA 2013). As a result, access to potable water is a key issue in certain parts of the neighbourhood including Blocs II, III, IV, VIII and IX. Only 5% of the surveyed population do receive pipe-borne water to their homes. Others are connected to the water supply network but do not receive water because these houses are located at a geographically more elevated point which does not favour gravitational flow of water from the reservoirs to their homes.

Though rainwater is one of the main sources of water for non-potable uses in the neighbourhood, it cannot solely meet the water demands of the population as the rudimentary techniques used in its harvesting do not permit its effective collection. Results of the survey show that about 58% of the population do practise RWH. However, 78% carry out RWH in a rudimentary way owing to the fact that they do not have sufficient funds to buy a suitable reservoir and fit appropriate gutters to their roofs. 22% of households have well-elaborated systems and this is in great part true for households with household heads having a high level of education and/or a certain financial strength. The fact that the greater proportion of the population practise RWH in a primitive way can be explained by the fact that constructing or buying a storage tank is onerous. Thomas & Martinson (2007) asserted that the storage tank usually represents the largest capital cost of a domestic rainwater harvesting system, and also that the tank or jar used to store water in a roofwater harvesting system is usually its most expensive component. The population mainly use the harvested rainwater for non-potable needs including bathing and household chores (that is, dish washing, laundry, mopping the floor, washing of vehicles, watering of plants and flushing of toilets), while the potable rainwater uses include cooking and drinking.

3.2.3. Rainwater harvesting practices in the neighbourhood

RWH is very currently practiced in the Mvog-Betsi neighbourhood, particularly in areas where access to and availability of alternative water sources is problematic. Out of the 250 households subjected to the survey, 166 practice RWH. However, most of these households practice it in a very rudimentary or archaic way, owing to financial constraints. That is, some use old metal sheets folded into a semi-circular structure, then hastily attached or fixed to their roofs as means of gutters and one or more barrels placed at the gutter end on the ground to collect rainwater. Meanwhile other houses do not even have gutters to convey water; runoff from roof falls directly into receiving container (usually a bucket). On the other hand, households which are financially well-off have well-elaborated DRWH systems including gutters, downpipes and a reservoir (though not properly designed) (Figure 5(a)–5(c)).

Furthermore, most inhabitants (164 households) do not perceive rainwater as potable and thus use it mainly for non-potable domestic purposes including laundry, mopping the floor, washing of vehicles and washing of plates. However, 44 households consider rainwater as potable and use it for bathing, cooking and drinking. These households mainly treat their roof-harvested rainwater with either chlorine or bleach before drinking.

3.2.4. Habitat types and house roofing materials in the neighbourhood

In the Mvog-Betsi neighbourhood a variety of habitat types are found, though the most widespread are the low standard houses which make up 52% of houses, followed by medium standard houses (38%), and 10% are high standard houses (Figure 6(a)–6(c)).

The prevailing roof material in the Mvog-Betsi neighbourhood is corrugated aluminium sheets which are found in 78% of the surveyed houses, while galvanised sheets make up 9%. Corrugated aluminium sheets are very affordable, easy to obtain and maintain, and thus are very much preferred by the local population. Metal sheet roofs are very smooth and are less likely to retain contaminants such as dust, leaves and bird droppings than rougher material types such as concrete tile roofs. Corrugated aluminium sheets also get hot in the Tropics, which helps in the disinfection of the rainwater (Mosley 2005).

Forty six percent of the surveyed houses have gutters on their roofs; out of this 46%, 40% of the gutters are used for RWH purposes while 60% are used for drainage. Of the 40% used for RWH, 30% of the households have strived to provide good gutter configurations for their houses while the 70% remaining have resorted to rudimentary ways of installing gutters on their roofs.

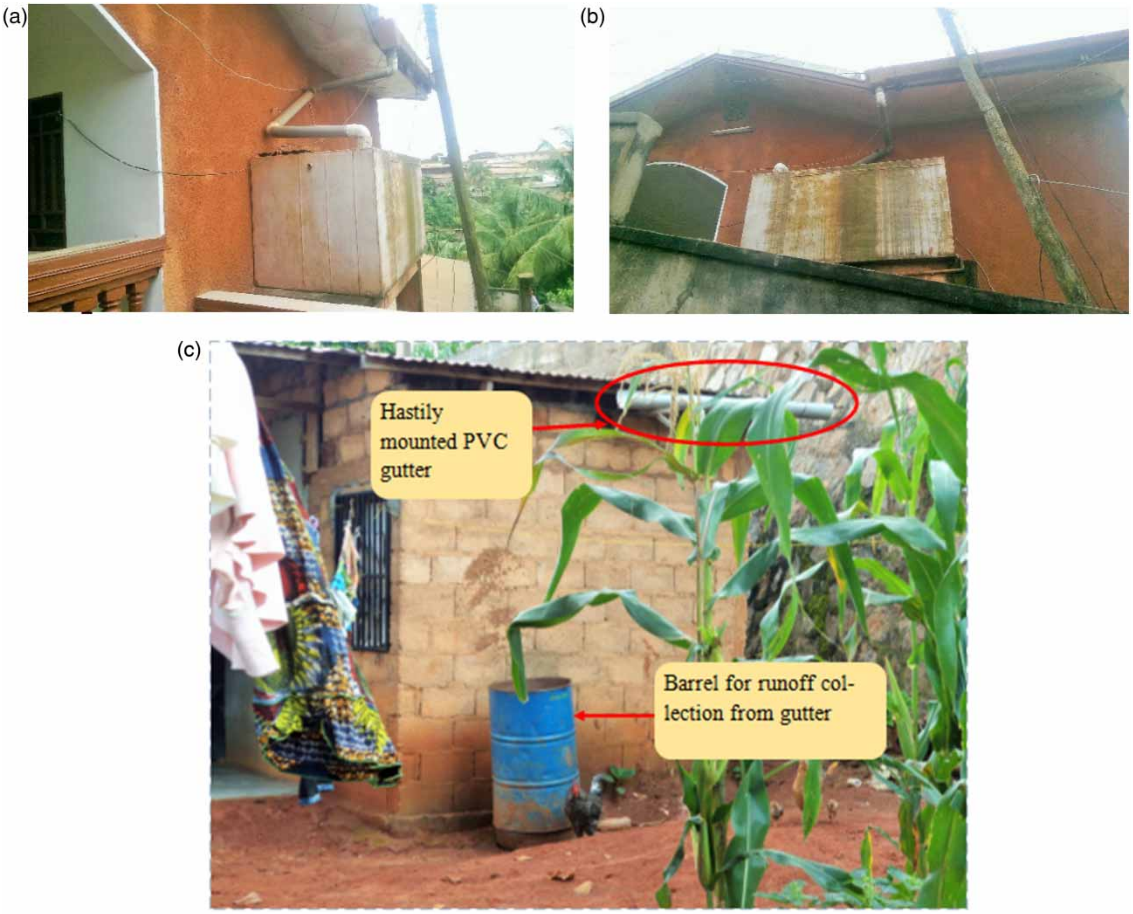

Figure 5 | Well-elaborated and rudimentary roof-harvested rainwater systems in the Mvog-Betsi neighbourhood.

The low proportion of houses having good gutter systems can be explained by the fact that the provision of gutters for rainwater collection was not taken into consideration from the onset. Due to the increasing water stress situation in the neighbourhood, many inhabitants have resorted to adapt gutters to their roofs or to effectively integrate them during the construction of their houses.

The Mvog-Betsi neighbourhood fulfils all the criteria for the design of a RWH system in order to supplement the available water sources. These include: availability of sufficient quantity of rainwater during the water-rich seasons of the year, suitable roof collection surfaces and available space for storage reservoirs.

3.3. Design of roof-harvested rainwater system for the Mvog-Betsi neighbourhood

A typical rainwater harvesting system comprises the following components: roof catchment, gutters, downpipe, first flush chamber and storage tank. A schematic of the system is presented in Figure 7.

Among the above components, the storage tank is the most expensive and critical component. The capacity of the storage tank determines the cost of the system (Joleha *et al.* 2019).

In this study, we adopted the graphing method and the different steps of the procedure are presented below.

Step 1: Producing a histogram of the average monthly water supply with a line showing average monthly water demand.

(i) Calculating household water demand, D.

The household water demand, D = Average daily water use (lpcd) × Number of people living in the house × 365 days/year
Average water demand/capita/day = 40 liters
Average number of persons/household = 7
Monthly water demand = 8.52 m^3/month

Figure 6 | Habitat types in the neighbourhood (a) Low standard house (b) Medium standard house (c) High standard house.

$$D = 40\,\text{litres/person/day} \times 7\ \text{persons} \times 365\ \text{days/year} = 102,200\text{L/year} = 102.2\text{m}^3\text{/year}$$

When divided by 12 (number of months in a year), a value of 8.52 m^3/month is obtained.
Note: lpcd: liter per capita per day.

(ii) Determining household rainwater supply, Q

Rainwater supply Q (m^3/month) = precipitation P (m/month) × catchment area A (m^2) × runoff coefficient C

$$Q_{\text{September}} = 0.5117\text{m} \times 48\text{m}^2 \times 0.8 = 19.65\text{m}^3$$

$$Q_{\text{October}} = 0.61952\text{m} \times 48\text{m}^2 \times 0.8 = 23.79\text{m}^3$$

$$Q_{\text{November}} = 0.2503\text{m} \times 48\text{m}^2 \times 0.8 = 9.61\text{m}^3$$

$$Q_{\text{September}-\text{November}} = 53.05\text{m}^3$$

Note: The average surface area of the roofs of the houses in the neighbourhood is 48 m^2

Figure 8 shows the histogram of the average monthly water supply with a line showing average monthly water demand.

Step 2: Producing the calculations of cumulative water supply and demand in a table.
Table 2 presents water supply by rainfall for the months of September, October and November and water demand of the sampled population.
It can be observed that the minimum storage requirement (27.49 m^3) is greater than the total water demand (25.56 m^3) for that period of time (i.e, $Q' \geq D$) (Figure 8). This fulfils the basic assumption that the storage capacity should be at least equal to

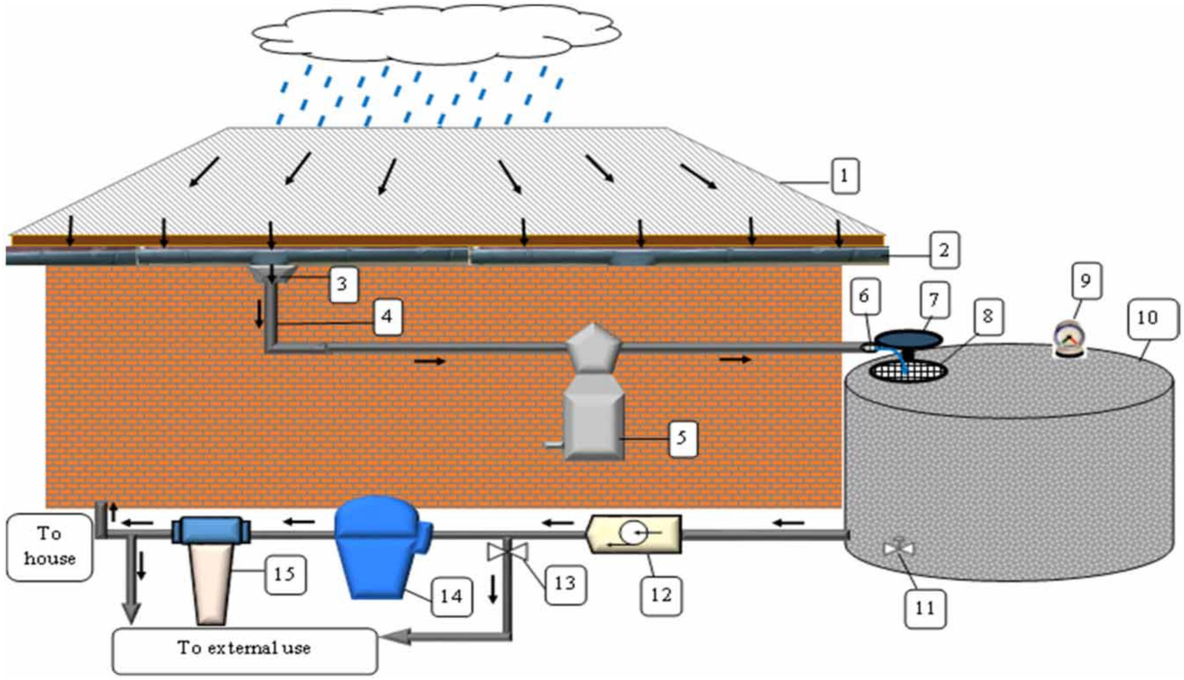

Figure 7 | Roof-harvested rainwater system for the Mvog-Betsi neighbourhood. 1 = roof surface; 2 = semi-circular PVC gutter; 3 = gutter outlet to direct RW to downpipe; 4 = PVC down pipe directing RW to first flush system; 5 = first flush device to divert unwanted materials from roof; 6 = pipe screen to further reduce entry of debris into the tank; 7 = tank clasp to close the tank entrance when needed; 8 = tank screen to prevent entry of pests and mosquitoes; 9 = water level indicator to help monitor water usage; 10 = rainwater tank for rainwater storage; 11 = globe tap for water use directly from the tank; 12 = pump (if required) to distribute water into and out of the house; 13 = gate valve to regulate flow of water out; 14 = filter to remove unwanted particles and microorganisms; 15 = disinfection unit where filtered water is disinfected using UV light.

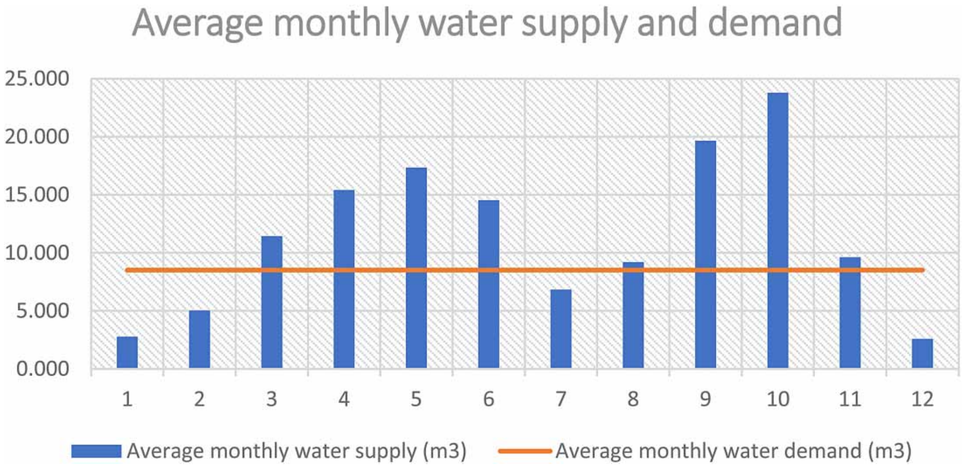

Figure 8 | Average monthly rainwater supply and demand (m^3).

the total water demand during the dry months ($Q' \geq D$) in order that demand is met by supply (CAWAST 2011). Therefore, a minimum storage of 27 m^3 is required for storing water during the long dry season. A cylindrical shaped tank with the following dimensions; Volume, $V = 27\ m^3$; Height, $H = 2$ m (chosen); Diameter, $d = 4.15$ m; thickness of wall = 15 cm (where volume of cylinder, $V = \pi\ r^2\ h$) meets the design specifications.

Table 2 | Cumulative supply for the months of September, October and November, and demand during the dry season

Month	P (mm)	Supply, Q (m^3)	Cum. Supply (m^3)	Water dd. (m^3)	Cum. Water dd. (m^3)	Storage requirement, Q' (m^3)
September	511.75	19.65	19.65	8.52	8.52	11.13
October	619.52	23.79	43.44	8.52	17.04	26.40
November	250.30	9.61	53.05	8.52	25.56	27.49
Total	1,381.57	53.05		25.56		

Note: P, precipitation; cum., cumulative; dd., demand.

3.4. Other system components' design

The other components of the developed RWH system (first flush system, filters and gutters) were designed as follows. The first flush systems proposed constitutes a floating ball device for the high and medium standard habitations, and a self-cleaning screen at the tank inlet, inclined at an angle of 60° to the tank inlet hole, for the low standard habitations. According to Cunliffe (1998), for average roof catchments, 20–25 liters of rainwater could be diverted or discarded as first flush to maintain water quality. If a volume of 0.5 liters is diverted per square metre as first flush, for a catchment area of 48 m^2 a first flush of 24 liters will therefore be diverted. The filter selected for the high and medium standard houses was the hydrocyclone rainy FL 200 filter, while a sand charcoal gravel filter has been proposed to be employed for the low standard houses. The gutters' dimensions and configuration were chosen based on the specifications proposed by Thomas & Martinson (2007). The gutters will be semi-circular shaped and made of plastic PVC (polyvinyl chloride), as they are cheap to purchase, easiest to clean and locally available already manufactured. The gutters' dimensions (size) and configurations can be chosen based on the parameters presented in Table 3.

The average roof area for our study area is 48 m^2, and this can be approximated to 46 m^2 and thus the recommendations for gutter sizes in Table 3 can be conveniently adopted. From Table 3, for a roof area of 46 m^2, a semi-circular gutter of width 90 mm and a downpipe of 40 mm as external diameter is recommended.

3.5. Cost estimations for installation of the RWH system

Table 4 below presents the cost estimation for installation of an RWH system for the different types of habitations in the study area.

It can be seen from Table 4 that the cost estimate for the installation of RWH systems in the neighbourhood is least lowest for the low standard habitations. Low standard houses make up 52% of the neighbourhood and 72% of the population are ready to adopt RWH as a supplement to their water needs. Of this 72%, 81% are willing to financially participate to up to 40% of the budget for their individual households (with the remaining 60% provided by government as a subvention). RWH can effectively serve as a water supply supplement in the Mvog-Betsi neighbourhood but its promotion is subject to government support. In developing countries, many urban and rural households are below the poverty line and cannot afford the installation of a rainwater harvesting system (Mwenge *et al.* 2007; de Kwaadsteniet *et al.* 2013). Other challenges in the widespread acceptance of these systems include socioeconomic pressure, lack of clear rainwater usage legislation in many countries, and need for national management organizations that coordinates the expansion of roof RWH (Mwenge & Taigbenu 2011; de Kwaadsteniet *et al.* 2013). The sustainability of the rainwater system can also only be achieved when all the physical attributes (location and rainfall) and the socioeconomic attributes are taken into account during the design of such a system (Mwenge *et al.* 2007).

Table 3 | Recommended gutter sizes

Area of roof served by one gutter (m^2)	10	13	17	21	29	34	40	46	66
Semi-circular or trapezoidal gutter (recommended width in mm)	50	55	60	65	75	80	85	90	100
Recommended down-pipe size (outside diameter in mm)	15	20	25	25	32	32	40	40	40

Source: Thomas & Martinson (2007).

Table 4 | Cost estimation for the high, medium and low standard habitations

S No.	Part	Units required for HSH, MSH and LSH	Cost per unit (XAF) for HSH	Cost per unit (XAF) for MSH	Cost per unit (XAF) for LSH
1	PVC circular pipe for gutter (Ø 3.5″)	1 each	2500	2500	2500
2	PVC pipe (Ø 1.6″)	2 each	950	950	950
3	90° Bends (Ø 1.6″)	6 each	800	800	800
4	First flush diverter	1 each	15000	15000	Can be locally made
5	Tank screen on opening of manhole and insect proof screen at all pipe end to tank	3 each	2075	1500	1000
6	Cement bags	10, 8, 8	4450	4450	4450
7	Rebar-iron rods for reinforcement (Ø 8 mm)	8 rods each	2500	2500	2500
8	Sand (wheel.barrows)	12 wheelbarrows each	1500	1500	1500
9	Gravel	16 wheelbarrows each	1800	1800	1800
10	Fastening metal wire	5 rolls each	1000	1000	1000
11	Sikalite waterproofing additives	8, 6, 6 sachets	1550	1550	1550
12	HDPE inner tank lining	1 (43 m^2) each	500/m^2	500/m^2	500/m^2
13a	Hydrocyclone filter	1 each for the HSH and MSH	30055	30055	–
13b	Sand-charcoal-gravel filter	1 each for the LSH and/or MSH	–	Can be locally made	Can be locally made
14	Water level indicator	1 each for HSH and MSH	20350	10000	–
15	Disinfection unit	1 each	22080	15400	15400
16	Pump (if needed)	1 each	14300	14300	–
17	Labour cost (XAF)	–	30% of project cost (267410) = 80223	30% of project cost (236655) = 70996.5	30% of project cost (165800) = 49740
18	Transport cost (XAF)	–	20000	20000	15000
	Total cost (XAF)	–	**367633 ($668)**	**327651.5 ($596)**	**230540 ($419)**

Where: HSH, High Standard Habitations; MSH, Medium Standard Habitations; LSH, Low Standard Habitations; HDPE, High Density Polyethylene; XAF, Central African CFA franc; 1″ = 2.54 cm.

4. CONCLUSIONS

Roof-harvested rainwater can serve as a supplement to water supply to the Mvog-Betsi population. There is enough available harvestable rainfall in the region, the rainwater chemistry is good and the monthly harvestable rainwater supply surpasses the population's monthly water demand. There is a potential public health risk associated with using untreated rainwater as potable water due to microbiological contamination. The rainwater needs to be disinfected before consumption as potable water. To promote the adoption of this technology, new water legislation around the adoption of RWH for drinking purposes needs to be put in place by the Ministry in charge of the management of water resources in Cameroon.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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First received 6 May 2021; accepted in revised form 18 June 2021. Available online 2 July 2021