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Article

Evaluating the Potential for Rainwater Harvesting for Non-Potable Use at the National University of Lesotho

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Abstract: An alarming rate of population growth and industrial and agricultural activities has put water resources at risk of over-abstraction. Despite adequate water in Lesotho, dry months and regular water cuts by the water utility affect institutions of higher learning like the National University of Lesotho, jeopardising the community's health through poor basic hygiene. Research on the potential of supplementary water supply, like rainwater harvesting, is scarce, and this study addressed this gap. This research aimed to examine the possibility of reducing Water and Sewerage Company (WASCO) water usage at the National University of Lesotho (NUL) campus through rainwater harvesting for toilet flushing, as the most compromised practice, using specific buildings. A quantitative data-collection method was used, including determining NUL water demand, collecting annual rainfall data in Roma, and annual harvesting capacity from rooftops across fourteen buildings on campus. The study was restricted to specific rooftop catchments and tank sizing, and the estimated theoretical annual harvesting potential did not account for storage limitations, temporal rainfall – demand mismatch, first-flush diversion, and RWH system reliability. Findings showed that with a total roof area of 26,234 m^2 and a runoff coefficient of 0.9, the estimated harvestable volume is 17,306.57 m^3. At least 17,306,569 L of water supply can be replaced through rainwater harvesting. NUL should practice rainwater harvesting to reduce reliance on WASCO water supply. Apart from economic benefits, environmental benefits include flood reduction on campus and nearby areas in Roma, low energy requirements for water treatment, and ecological benefits that are inclined towards availability and long-term management of water. It is worth noting that, in the midst of climatic variations, historical rainfall data and projected rainfall conditions have to be taken into consideration to estimate the performance of RWHs. To address this, a behavioral model has to be utilized in order to perform mass balance and reliability of precipitation and track changes in Roma inputs, outputs, and storage volume. This study focuses on a major higher-education institution in Lesotho where seasonal rainfall variability and recurrent interruptions of centralized water supply create a specific need for supplementary non-potable water sources. The goal is to assess a localized rooftop rainwater harvesting to provide a dependable backup supply for non-potable water needs. The university will also achieve SDGs 3 and 6.

Keywords: rainwater harvesting; rooftop catchment; non-potable water use; university campus; water savings; water security; Lesotho



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1. Introduction

Water demand is gradually increasing with urbanization, growing population, and industrialization, and previous studies have predicted that water demand will increase by about 55% by the year 2050 [1]. This will put more stress on the already scarce water resources [2]. It is further shown that global warming and climate change make it worse for water availability due to long hot summers, long-term droughts, and severe storms. Floods have a high velocity that renders water infiltration and storage nearly impossible. It is therefore important to practice rainwater harvesting (RWH) not only to relieve stress on available water but also for environmental sustainability for the betterment of coming generations [2]. RWH alleviates floods from stormwater [3] and sustains water availability during periods of water scarcity or drought [4,5].

Reduced water consumption and utilisation of alternative water sources like rainwater harvesting are the two major water management solutions [6]. RWH is defined as the diversion and collection of rainwater from catchment areas such as roofs and other urban structures and storing it to meet domestic, industrial, and agricultural demands when water sources are becoming scarce [7]. This is an easy and economical approach to deal with the crisis of water shortage, and human beings are becoming environmentally aware as rainwater harvesting is regaining popularity, leading to eco-conservation and constructive use of the natural resource. Studies conducted by Aladenola and Adeboye [8] and Ako et al. [9] in Nigeria and Cameroon, respectively, report that rainwater harvesting considerably contributes to supplementing the water supply.

Rainwater can be stored in surface storage tanks, which are common for roof collection. Materials used in this type of storage include metal, plastic, and brick-reinforced concrete. Subsurface storage tanks should use materials that are resistant to water pressure from outside, especially when the tank is empty. Paved areas are ideal for runoff water collection, whereas open areas would allow direct harvesting of water without contact with any surface. Universities have large buildings with high water demands, calling for a succinct catchment area and tank size design [6]. One other observation is that these institutes have specific demands and consumption patterns that depend on the teaching and/or lecturing season or calendar and activities (for example, laboratories or classrooms). RWH systems therefore need to have their performance and efficiency assessed. Performance indicators use numerical and simulation methods, and these include water-saving efficiency (WS efficiency), reliability (REL) and rainwater harvesting efficiency (RWH efficiency). All these translate to the system's economic, environmental and technical viability [10].

However, it is rarely practised where water utilities provide safe and abundant water. Among all other methods that are used, the harvesting of rainwater still dominates over others, as it has been used for over 10 centuries; it boasts reliability, cost-effectiveness, and is mostly low-maintenance. As an outcome, rainwater harvesting still continues to be accepted as a sustainable, cheap, effortless process, and readily provides water with a lower carbon footprint [11], while also improving local drainage [12].

Existing data and scholarly inquiry regarding water stewardship methodologies are notably scarce, despite mismanagement of available water within institutions of higher learning [13], even though there is potential to conserve rainwater for sustainable water use. The University student population keeps soaring, and frequent water cuts have been experienced, sometimes compromising the students' education, health, and hygiene, especially toilet flushing. Evaluation of rainwater systems in university buildings should consider analysis of how different activities consume water, as the overall value of harvested water relies on the magnitude of non-potable requirements like toilet flushing [13]. The study intends to establish the potential for sustainable water conservation through rainwater harvesting, the possible location of storage tanks, and how much water can be saved from the potable water supplies to meet the increasing water demand, while also supporting the university in meeting the Sustainable Development Goals (SDGs): SDG 3 on health and well-being and SDG6 on provision of clean water and sanitation.

2. Materials and Methods

2.1. Research Design

This was a pilot study that used quantitative methods to address the aim of the study. Buildings with high student population size were identified and used for the pilot study, and the water demand of the university was requested from the campus service department.

2.2. Description of the Study Area

The study was carried out at NUL campus (Figure 1), the main and oldest university in Lesotho, which is situated 34 km southeast of Maseru, the capital of Lesotho, at S 29°26′13.92″ latitude and E 27°42′5.11″ longitude.

The campus area is about 0.8 km^2. The university was established in the year 1945 as a catholic University College. Its student population size has increased from 171 in the year 1959 to 10,000 [14].

Lesotho's climate is generally classified as temperate with hot summers and relatively very cold winters. Seasonal temperature fluctuations range from 10.9 °C to 27.6 °C, with minimum temperatures ranging between −6 °C (June to August) and 15 °C (November to March) [15].

Annual precipitation ranges from 500 mm to 760 mm, with a mean of 671.2 mm; the highest rainfall occurs between October and April, and is extremely low between May and September. January has the highest mean rainfall (118–130 mm), while June has the lowest (5.7–10 mm). The hydrological year starts in October, and the wet season lasts for about 7 months (October to April). This allows harvested rainwater to efficiently replace the use of potable water and reduce pressure on the water utility.

The Water and Sewerage Company (WASCO) is the main water provider to the university. There are no boreholes on campus for use during water cuts or water shortages in the dry season, with the oldest Administration buildings as the only ones that have water storage tanks. Water-consuming activities in the NUL campus include potable use, toilet flushing, bathing (for students and staff members who reside on campus), and irrigation. However, lack of data on these other uses has drawn attention to toilet flushing by the students during lecture days.

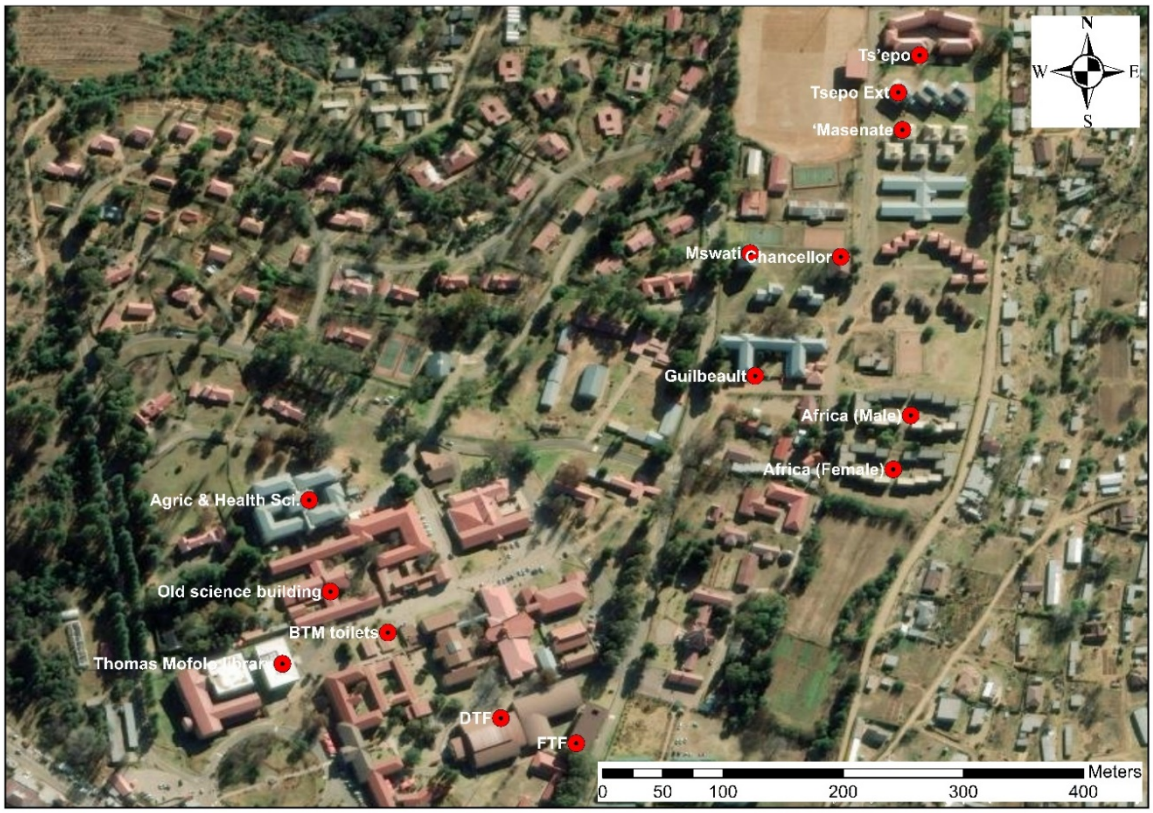


Figure 1. The study area and location of the selected fourteen buildings for rainwater harvesting. Source: Authors.

2.3. Data Sources

The NUL Works and Maintenance office provided water quantity supplied by WASCO and roof area data in order to calculate harvesting capacity, and this ranged from 125 m^2 to 4100 m^2 (Table 2). Rainfall data from the Lesotho Meteorological Service (LMS) was used to determine the harvestable rainfall. The student population accommodated by the halls of residence in the study is as follows: Africa Female (100), Africa Male (123), Chancellor (50), Guilbeault (123), Masenate (304), Mswati (50), Tsepo (50) and Tsepo Extension (150).

The infrastructure at NUL was carefully observed to determine the suitability of rooftop rainwater harvesting at NUL, and the choice of 14 buildings in this study was motivated by the high student population that uses them during the school days. Buildings like the Administrative Block and the Works and Maintenance have large rooftop areas; however, they were not chosen because they already have rainwater harvesting structures. Having a large rooftop area will ultimately result in more water being harvested. Kumar et al. [16] suggested that a small and effective technique named "rooftop rainwater harvesting" was implemented to increase potential benefits and draw maximum advantages. For example, for rooftop rainwater harvesting, factors such as roof design, roof area, storage

capacity, water demand and water savings [17] were considered. The most suitable buildings with high water demand were student residences (Africa Female, Africa Male, Chancellor, Guilbeault, Masenate, Mswati and Tsepo and Tsepo Extension), multipurpose buildings (Agric & Health Science, DTF, FTF, Old Science Building), the BTM restrooms, and the library. The areas of the buildings are important as they are used to calculate the amount of rainwater that can be harvested from the rooftops. They help to determine suitable locations for placement of rainwater harvesting structures. Table 1 and Figure 2 show the mean rainfall for the study area, with 733.65 mm as the total on an annual basis for the period 2015–2020.

Table 1. Mean monthly rainfall in the Maseru catchment for the period 2015 to 2020.

	Rainfall (mm)
Month	**2015–2020 Rainfall (mm)**
January	130
February	118.68
March	117.78
April	110.2
May	20.76
June	6.26
July	28.4
August	22.03
September	8.6
October	24.9
November	56.83
December	89.21
TOTAL	733.65 mm = 0.733 m

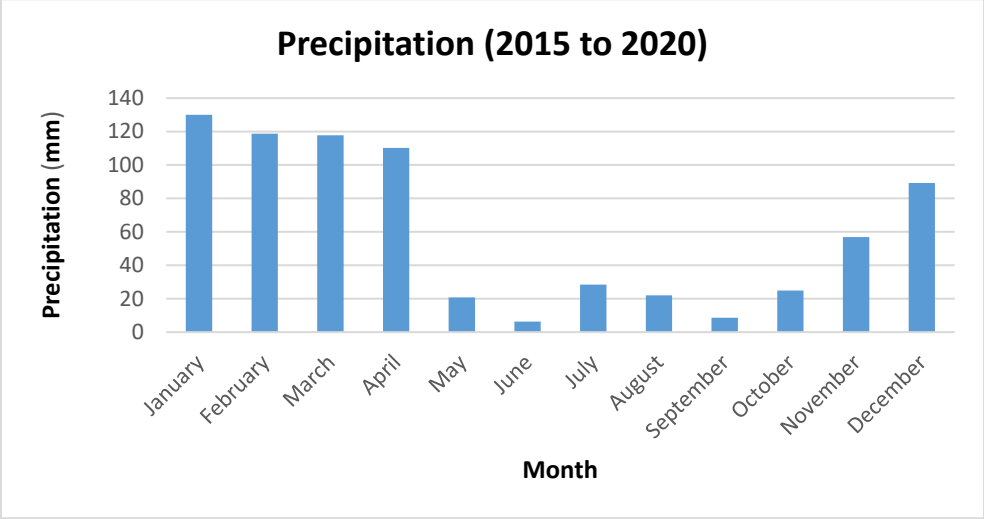


Figure 2. Mean monthly rainfall from 2015 to 2020.

The water mass balance approach was used for the calculation of storage tank capacity. Equation 1 was used to calculate the inflow tank volume [18].

$$Vt = \frac{Pt.C.A}{1000} \quad (1)$$

where:

Vt = inflow volume to tank (m^3) at time step t (day);
Pt = rainfall depth on day *t* (mm) already converted to *m* in this calculation;
C = rooftop runoff coefficient;
A = rooftop superficial (m^2).

3. Results and Discussions

3.1. Harvestable Rainfall

Annual rainfall (m) for the area was determined to be 0.735 m (Table 1). Representative buildings with their rooftop area and their GPS coordinates are shown in Table 2. NUL has a population of approximately 10,000

students [14], who will benefit from the harvested water. Data on water quantity supplied by WASCO was obtained from the NUL Works and Maintenance Office. It was assumed that 1 mm of rain on 1 m^2 is equivalent to 1 L of water, before any losses can be incurred. A runoff coefficient of 0.9 represents smooth impermeable materials such as metals and plastic [19]. As a result, a runoff coefficient of 0.9 will be used because all the roofs are made of metal, and the harvestable rainfall was determined as 0.735 m. Rainfall data were obtained from the Lesotho Meteorological Service, and harvestable rainwater was calculated using Kumar et al. [16] Equation (2):

$$\text{Rainwater harvesting}(m^3) = \text{Roof coefficient (K)} \times \text{Precipitation}\left(\frac{m}{yr}\right)\text{(I)} \times \text{Roof Area}\ (m^2) \quad (2)$$

$$\text{Rainwater harvesting}(m^3) = 0.9 \times \text{Precipitation}\left(\frac{m}{yr}\right) \times \text{Roof Area}\ (m^2)$$

which is also:

$$V\ (m^3) = K \times I \times A$$

where: V = volume of water that can be harvested annually (m^3);

K = runoff/roof coefficient;

I = annual rainfall (m);

A = roof area (m^2).

For buildings in the study:

$$\text{Rainwater harvesting } (m^3/\text{year}) = 0.9 \times 0.733\ m \times 26{,}234\ m^2 = 17{,}306.57\ m^3/\text{year}$$

OR:

$$0.9 \times 733\ L/m^2 \times 26{,}234\ m^2 = 17{,}306{,}569\ L$$

Table 2. Location of selected buildings, their rooftop areas and harvesting capacity.

Selected Sample Building	Classification	GPS Coordinates	Roof Type	Area (m^2)	Harvestable Rain (m^3)
Africa (Female)	Residence	29°26′55.104″ S 27°43′34.116″ E	Pitched	2125	1403.8
Africa (Male)	Residence	29°26′53.648″ S 27° 43′34.585″ E	Pitched	2125	1403.8
Agric & Health Sci.	Mixed use	29°26′55.928″ S 27°43′18.374″ E	Pitched	4100	2708.5
Chancellor	Residence	29°26′49.38″ S 27°43′32.70″ E	Pitched	896	591.9
DTF	Mixed use	29°27′1.806″ S 27°43′23.541″ E	Pitched	1715	1132.9
FTF	Mixed use	29°27′2.484″ S 27°43′25.572″ E	Pitched	990	653.9
Guilbeault	Residence	29°26′52.584″ S 27°43′30.396″ E	Pitched	1544	1019.9
‘Masenate	Residence	29°26′45.96″ S 27°43′34.36″ E	Pitched	2415	1595.3
Mswati	Residence	29°26′49.282″ S 27°43′30.26″ E	Pitched	896	591.9
Old science building	Mixed use	29°26′58.392″ S 27°43′18.949″ E	Pitched	3990	2635.8
Thomas Mofolo	Library	29°27′0.342″ S 27°43′17.654″ E	Pitched	3112	2055.8
Ts’epo	Residence	29°26′43.944″ S 27°43′34.824″ E	Pitched	1176	776.9
Ts’epo Ext	Residence	29°26′44.952″ S 27°43′34.248″ E	Pitched	1025	677.1
BTM toilets	Rest rooms	29°26′59.498″ S 27°43′20.496″ E	Pitched	125	82.58
TOTAL				**26,234 m^2**	**17,330.18**

Total harvesting capacity for the fourteen buildings is 17,306.57 m^3 (17,306,569 L) per year. The total amount of water supplied to NUL by WASCO monthly is roughly 24,206.6 m^3 (24,206 600 L) (806.87 m^3/day), as given by the Works and Maintenance office. This means that the utility supplies roughly 294 507 m^3 (294,507,000 L) annually. It should be noted, however, that estimates for the first precipitation water that the first flush and runs to waste have not been considered.

The potable water that can be saved (water savings) annually through rainwater harvesting is expressed as the ratio of the total amount of water harvested to the total water demand, and is represented in Equation (3) below:

$$\text{Water savings (\%)} = \frac{\text{Total amount of harvested water}}{\text{Total water demand}} \times 100 \quad (3)$$

$$\text{Water savings (\%)} = \frac{17\ 330.2}{290\ 479} \times 100 = 5.97$$

For the entire university, other non-potable uses such as irrigation and laundry, and other buildings would have to be included in the study, and this is a gap to be addressed by other studies. The university closes for winter break from mid-May to July, and during this period, harvested water is used only by staff members. This suggests that more water could be saved until the classes resume. The theoretical yield of 17,306.57 m^3/year is moderately meaningful since it covers 5.97% of the actual water demand of 290,479.2 m^3. It could be more significant (11.93 %) when scaled to include half of the excluded buildings. The absence of infrastructure investments at some universities like NUL limits the RWH systems from satisfying reasonable daily non-potable demands, and this observation is supported by Chowdhury and Akter [20]. Economically, a full-scale implementation would save nearly 34,660 m^3 of treated water in operational water utility bills.

Figure 3 below shows the proposed harvesting system for pitched buildings.

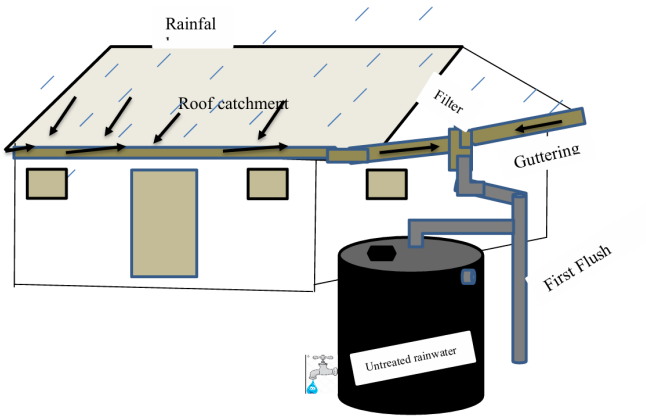


Figure 3. Proposed harvesting system from the rooftops.

Inflow volume to the tanks was determined using Equation (1) above, as:

$$Vt = \frac{Pt\ C.A}{1000}$$

$$Vt = \frac{733.65 \times 0.9 \times 26{,}234}{1000}$$

$$Vt = 17{,}345{,}291.18/1000$$

$$Vt = 17{,}321.91\ m^3$$

3.2. Discussions

After surveying the infrastructure found at NUL, it was established that a rooftop rainwater harvesting system can be used to harvest rainwater at NUL. This is because a large number of large buildings with large rooftop areas have put NUL at an advantage. Harvested water is higher from the Agric & Health Science (2708.5 m^3), Old Science (2635.8 m^3), and Thomas Mofolo Library (2055.8 m^3), and this is supported by findings from Campos Cardoso et al. [21] that there is an increase in harvested water with an increase in catchment area. Other studies in university residences have indicated that integrating rainwater harvesting with demand-side water efficiency strategies can substantially lower reliance on the main water supply [13]. Furthermore, large-scale public buildings

and infrastructure like university campuses and municipal complexes can scale up water self-reliance, significantly offset non-potable municipal demand, and ease urban stormwater strain. Concerning semi-arid and semi-humid areas that experience long periods of high evaporation and erratic rainfall, the 11.93% water savings from NUL can be achieved by a combination of technological retrofits, infrastructure optimisation and behaviour modification

Toilet flushing is the only use that is focused on in this study, since there is no direct data on the exact consumption rate for the other uses. The study established that 109,500 m^3 would be required to sustain student toilet flushing during lecture days annually. However, a sub-daily scale approach could provide a clearer water demand for toilet flushing to enable establishing the performance of the RWH system [22]. Harvested volumes can directly supply high-demand public operations like commercial toilet flushing and landscape irrigation [23].

Rainwater harvesting systems' costs are usually high during initial installation, and this may depend on the system size and technology level. Also, according to information from an interview at the Works and Maintenance office, one interviewee noted that installing a rainwater harvesting system may be expensive but beneficial in the long run.

WASCO supplies NUL with about 24,206.6 m^3, which is about 24,206,600 L per month, with a bill of roughly M468,212 per month (Motsamai, personal communication, 1 June 2022) and M5,618,544 per year. With the 1,730,180 L saved from RWH per year, the university could save M330,171 per year for the fourteen buildings in the study. This implies that, since the fourteen buildings are being used as a demonstration, if half of the remaining buildings are included, there could be more than twice (M670,612.06) as much in savings per year. The maximum tank size available on the market is 40,000 L, so NUL would need 433 tanks of this capacity to harvest 17,306,569 L of rainwater.

Even though there are different views about rainwater harvesting, this approach remains the best and can be used in sustainable development by nations to ease strain on local supplies and to manage water resources. Adding to this, it is a low-cost supply for non-potable use that extends to flood mitigation, which usually overwhelms drainage systems in the urban regions. Lesotho aims to manage its water resources in an integrated and long-term manner to guarantee that sufficient quantity and quality are available for current and future generations [24]. This is done through the promotion of water conservation methods such as rainwater harvesting.

4. Conclusions, Recommendations and Future Research

4.1. Conclusions

The study concludes that, with an estimated rainfall of 734.64 mm between the years 2015 and 2020, at least 17,330,180 litres of rain can be harvested. There can be 5.97% water savings that amount to M330,171.16 annually. A high potential for RWH system development at NUL will have both environmental and financial benefits. There will also be reduced water supply costs for toilet flushing across the halls of residence and lecture rooms. The expenditure could be on potable water only, while planning to treat the rainwater further for consumption. The university would need 433 tanks of 40,000 L capacity to harvest the 17,306,569 L of rainwater.

4.2. Recommendations

It is recommended that rainwater harvesting should be practised at NUL to reduce the mounting pressure on WASCO and also for sustainable water provision. It could also be beneficial to implement new rules at the local level to impose a rainwater harvesting system and facilitate its adoption through public funding.

4.3 Future Research

Data on all non-consumption uses of water and their quantities are significant for determining the amount of water that needs to be collected during the rainwater harvesting season to meet water demand. The entire staff population and water consumption rate should also be determined to holistically estimate storage tanks' capacity.

Water quality for rainwater within a few storage tanks on the campus was not assessed, and this leaves a gap in terms of biological contaminants like E. coli, chemical parameters like pH, and physical ones like turbidity and TSS. These tests would be significant in situations where the water would be utilised for consumptive purposes during water shortages, and to avoid or be proactive regarding corrosion of distribution pipes by acidic water.

Author Contributions

M.A.G., L.M. and T.M.: conceptualization, methodology, software; M.A.G., L.M. and T.M.: data curation, writing—original draft preparation; M.A.G.: supervision, validation, writing—reviewing and editing. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement

The raw data supporting the conclusions of this article will be made available by the authors upon request.

Conflicts of Interest

The authors declare no conflict of interest.

Use of AI and AI-Assisted Technologies

No AI tools were utilized for this paper.

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