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Rainwater harvesting for domestic use in suburb areas of Dar es salaam, Tanzania: a case study of Wazo Hill

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Keywords

Catchment System; Rainwater Harvesting; Rainwater Quality; Roofing Materials; Rainwater Storage.

Abstract

Despite the increasing reliance of rainwater harvesting in semi-urban areas, there is a lack of comprehensive localized data on the safety of harvested rainwater, particularly in areas such as Wazo Hill where communities predominantly depend on it. This study evaluates the quality of harvested rooftop rainwater intended for human consumption and assesses its compliance with the World health Organization (WHO) and Draft East Africa Standards (DEAS) for drinking water. Rainwater samples were collected from various catchment surfaces and storage systems located in Wazo Hill, Tanzania. A stratified random sampling technique was employed to select the households equipped with rainwater harvesting systems and sampling locations were georeferenced using a Portable GPS device (Garmin Oregon 700). A total of eighty-four (84) samples were analyzed for physicochemical parameters, including pH, turbidity, electrical conductivity, Total Dissolved Solids (TDS) and selected heavy metals (lead, chromium and iron). Microbial assessment focused on fecal coliforms and total coliforms. The results reveled that while physicochemical parameters generally conformed to WHO and DEAS guidelines for drinking water, microbial contamination was predominant. Fecal coliforms concentrations ranged from 40.1 to 48.0 CFU/100 mL and total coliforms ranged from 15.5 and 19.8 CFU/100 mL, both exceeded recommended thresholds. The likely sources of the microbial contamination were identified as fecal matter from birds, rodents and reptiles accessing the catchment areas as stated by other studies. These findings highlight the needs for appropriate treatment such as disinfecting prior to the consumption of harvested rainwater, regular monitoring and maintenance of harvesting and storage systems are recommended to ensure the microbial safety and overall quality of rainwater used for domestic purposes.

Introduction

Rainwater harvesting and storage systems are being implemented in various countries. Rainwater harvested can be an effective source of freshwater that can reduce the demand for tap water and be utilized during drought period (Kakoulas et al. 2022). Rainwater harvesting technologies are employed globally to support drinking water supplies, rainwater management, and prevent flood damage by reducing the amount of water that enters storm drainage systems (Freni and Liuzzo 2019). These technologies also contribute to efficient and environmentally sound functioning of buildings. In areas with scattered housing and high costs of building classic water supply systems, the RWHS (Rainwater Harvesting System) has been found to be an affordable

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and sustainable alternative for supplying drinking water (Khanal et al. 2020).

Most people in Dar es Salaam city experience a shortage of water regardless their connection to the water supply system named DAWASA (Dar es Salaam Water Supply Authority) (Mapunda et al. 2018). This has been a critical issue for them because they tend to rely on other available water sources such as wells, water tankers and rainwater (Dismas et al. 2018). According to studies, approximately 50% of potable water for domestic uses can be substituted by rainwater, and in public buildings, the proportion can reach nearly 65% (Marinoski et al. 2018). Rainwater harvesting is a solution to water shortage because it provides an independent water supply during regional water restrictions and in developed countries, it is often used to supplement the main supply (Rahmat et al. 2019).

The quality of most rainwater samples does not meet the drinking water quality standards as recommended by WHO and TBS (Kakoulas et al. 2022). The composition of rainwater actually reflects the composition of the atmosphere through which it falls. More than 90% of the total amount of pollutants present in the atmosphere is lixiviated by wet deposition, being the predominant cleansing mechanism to remove pollutants from the air (Khayan et al. 2019). Thus, rainwater can be a way to reduce the atmospheric load of pollutants, as well as a source of contamination for soil, water and terrestrial vegetation and therefore it carries a lot of pollutants which can affect the quality of harvested rainwater (Adegunwa et al. 2020). The WHO and DEAS drinking water quality standards may not be met by the harvested rainwater in Dar es Salaam because of contamination introduced during collection and storage.

While rainwater is widely used as a supplementary domestic water source in suburban areas in Dar es Salaam, there is limited empirical data on its quality and safety. Numerous studies have examined the effectiveness and quality of rainwater harvesting system globally, but few have focused on Tanzania specifically in Dar es Salaam. In particular, the quality and safety of harvested rainwater in different neighbourhoods, including informal settlements, remain under-researched, despite widespread use. This gap hinders evidence-based guidance to policy makers on rainwater safety for households use. The study from Mayo and Mashauri (1991) conducted at the staff houses of University of Dar es Salaam indicates that 86% of water samples were free from faecal coliforms, suggesting a generally level of microbiological safety. However, faecal streptococci were detected in 53% of the samples and 45% tested positive for total coliforms, which highlights contamination concerns. While turbidity levels were below 5 NTU and colour values under 5 mg Pt/l. This is supported by the study of Dismas et al. (2018), who suggested that rooftop rainwater harvesting (RWH) systems equipped with appropriate components and maintenance properly can provide better quality water for domestic use. According to Hamilton et al. (2019) several epidemiological studies reported gastrointestinal illnesses linked to rainwater harvesting, primarily due to high levels of microbial contamination.

Previous studies have examined the reliability of rainwater harvesting systems in suburbs of Dar es Salaam (Ndomba and Wambura 2010), while Mdee et al. (2022) estimated the storage capacities of tanks based on different roof catchment sizes in urban areas. However, a lack of localized research limits the development of evidence-based policies and recommendations tailored to the city’s specific context. Although rainwater harvested in Wazo Hill is generally considered safe for domestic use, its quality may not meet nationl or WHO standards due to environmental issues and collection related factors. Also, the public may not be aware of the many other factors that can influence its quality. This paper aims to evaluate the quality of harvested rainwater and suggest ways for its safe and effective use.

Methods

The study area is located in Wazo Hill administrative ward, in Kinondoni district in

Dar es Salaam, Tanzania. It covers an area of 53.2 km^2 with geographic coordinates on the North (-6.6580139, 39.1653181), South (-6.6658421, 39.1683863), East (-6.6623457, 39.1648372) and West (-6.6611868, 39.1687714). According to the 2022 census, there are 153,013 people living in it. This study area was chosen as a representative of un-informal settlement for residents who heavily rely on rainwater due to lack of consistent portable and reliable public water supply systems. The community relies extensively on rainwater harvesting because it is free and accessible during rainy seasons and culturally believed to be safe for drinking and other domestic activities.

Data Collection Methods

Site visitation was conducted with observational checklist. Some of the elements considered on the checklist include, Method of rainwater collection, Type of roof/catchment area, Size of the storage facility/material and storage material type.

An interview was conducted with local authority (member of local government) regarding the water availability systems and other information about the research area. Questionnaires were administered to the household residents to understand their personal perception about rainwater harvesting systems as well as its quality with the aim of finding out about the main cause of deterioration of rainwater quality.

Random sampling method was used to select the surveyed houses. A total of 84 questionnaires were administered to collect opinions from dwellers harvesting rainwater around Wazo hill area. However, only 53% of the respondents utilize it for consumption purposes. Sampling rainwater during the rainy season is essential because it reflects real-time water quality, user exposure, and environmental conditions under which rainwater is harvested and used. It ensures valid, relevant, and timely data for assessing the quality and safety of the collected rainwater.

Sample size

The sample size for the household's respondents' survey was determined using the single proportion formula as shown in Equation 1 (Hasan and Kumar 2024).

$$n = z^2 pqN / \left(e^2 \left(N - 1\right) + Z^2 pq\right) \qquad (1)$$

where; n = Sample Size, N = total number of households, Z = Value of standard variation, e = Acceptable error, p = proportion of the target population estimated to have measured (50% or 0.5), q = 1-p, p = 0.5, q = 0.5 considering 95% level of confidence. Then the sample size (n) used was 84.

Wazo Hill was selected as the study area based on its known reliance on rainwater harvesting and limited access to City water supply. Sampling locations were selected by identifying the residents who harvest rainwater and presence of rainwater harvesting systems (e.g. roof catchment, gutters, and storage tanks), ensuring that samples represented active users of rainwater. Sites were chosen based on criteria such as unformal settlement, reliance on rainwater harvesting systems, and accessibility. The selection aimed to ensure a representative sample across different wards in Dar es Salaam. The variation in roofing materials, storage tanks types and household socioeconomic status were also ensured to capture a range of conditions likely to influence the harvested water quality. Site surveys were also conducted to identify and confirm eligible households for the study. Stratified random sampling technique was used in selecting the households with rainwater harvesting systems. Portable GPS (Garmin Oregon 700) was used to locate the sampling points as depicted in Figure 1.

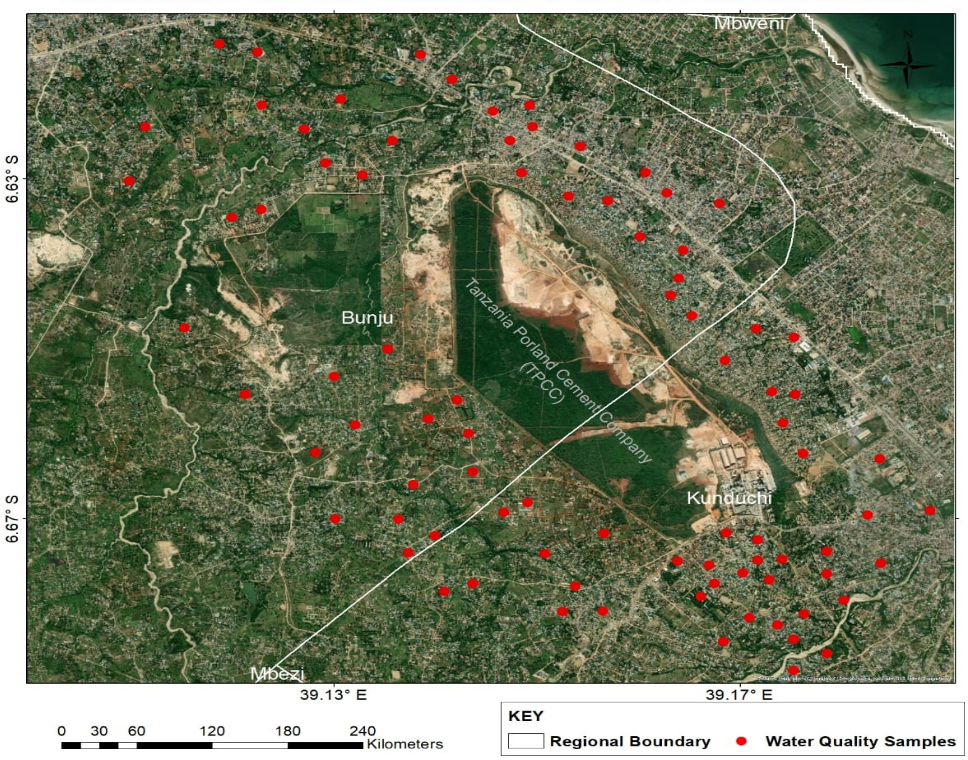

Figure 1: Distribution of Sampling Points

Sample handling and transportation

After sample collection, the water samples were kept in well labelled containers (bottles). The samples were collected in polypropylene of 250 ml bottles specifically to avoid contamination of the water samples and were put in cooler box. This is done so as to maintain the sample conditions and prevent the variation due to environmental factors such as temperature which can affect the analysis of major anions and cations before being taken to the laboratory for analysis. The purpose of the cooler box is to preserve water samples and avoid reactions from the collection site before reaching to the Laboratory.

Analysis of Physical Parameters

The physicochemical parameters of the collected samples were analyzed in this study. These include pH, electric conductivity, total dissolved solids, turbidity, colour, and selected heavy metals lead and iron. Laboratory analysis was done at Ardhi University, SEES Laboratory. Quality control measures were employed during laboratory analysis including using of standard operating procedures as per TBS and WHO guidelines, calibration of equipment before each batch of tests and use of the standard calibration curves to validate the results. The selected parameters were analyzed to determine the quality of harvested water for consumption by comparing the quality with WHO and TBS Standards. This was done to identify potential risks and take appropriate measures to ensure safety and suitability for consumption purposes. Benchmarking rain water quality against recognized standards allows responsible institutions to issue guidelines on safe rainwater harvesting practices and develop public health advisories or legal regulations for rainwater harvesting system in urban areas.

Heavy Metal Analysis

The concentrations of heavy metals were determined with the aid of standard calibration curves. The curves were obtained by plotting the absorbance of a standard samples in one axis and the respective concentration in the other axis as shown in Figure 2. From the observed absorbance, the standard calibration curve prepared from known concentrations of a particular metal was used to obtain concentration in the sample. The concentration obtained from water samples after analysis was then compared against the allowable value of concentration.

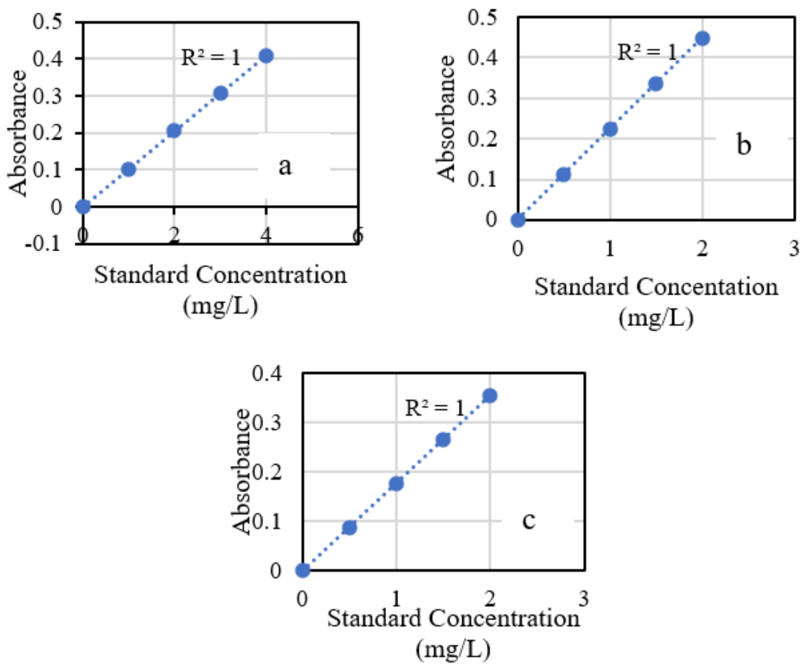

Figure 2: Standard Calibration Curves for a) iron, b) lead and c) chromium

Heavy metals were analyzed by using an atomic absorption spectrophotometer (AAS - Perkin Elmer instrument AA analyst 100) by measuring the absorbance of the water sample. Heavy metals analyzed were lead and iron. The selected heavy metals were analyzed because they are the key indicators of pollution from the choice of roofing materials.

Biological Analysis

Control Test

The control test was conducted to ensure reliability and accuracy of microbial contamination testing in distilled water by using negative and positive control samples.

In a negative control, the sterile distilled water was spread on MacConkey agar plates and incubated under same conditions. No bacterial growth was observed; this means no contamination in media.

In positive control, the sterile distilled water inoculated with a known *E. coli* culture (10^3 CFU/mL) was spread on MacConkey agar plates. The growth of *E. coli* colonies confirms that the medium and incubation setting are effective for fecal coliform detection.

Analysis of Total Coliforms

The spread plate method adopted from Mendez et al. (2011) was used to analyze the total coliforms from water samples collected. The coliform counts were cultured using M001 Nutrient agar (HIMEDIA®). The incubation was done using an incubator (Fisher scientific: 630D model) for 24 hours, at 37 ºC. The Nutrient agar media for total coliform was prepared before injecting sterilized media into the sterilized petri dishes (BOSOLIC model) and allowing it to solidify for 5 minutes. A 1 mL of rainwater sample was measured by micro pipette (Thermo-scientific model) and spread on the petri dish. The plates were placed upside down in the incubator and were left for 24 hours at 37 ºC for incubation purposes. The results of colony count were taken after 24 hours of incubation then the coliforms were enumerated and recorded.

Analysis of Fecal Coliforms

The spread plate method was used for the analysis of fecal coliforms especially *E. coli* from the rainwater samples as the method adopted by Zdeb et al. (2021). The M061 MacConkey agar w/Bromo Thymol Blue (HIMEDIA®) was used to culture these coliforms. The incubation time and temperature were 24 hours and 37 ºC respectively. A 1 ml of the sterile media was injected into the sterilized petri dishes and allowed to solidify for 5 minutes, then 1 ml of rainwater sample measured by a micro-pipette was spread on the petri dish using a glass spreader. The plates were placed inverted in the incubator and left there for 24 hours at 37 ºC for incubation purposes. The results of the colony count were taken after 24 hours of incubation and the coliforms were enumerated and recorded.

Results

The results in Figure 3 displays the sources of water available in Wazo Hill area. According to observations, rainwater is the main source of water for more than 50% of the residents in the Wazo Hill area, with tap water and wells being used infrequently. Due to the high cost of water from Dar es Salaam Water Supply and Sanitation Authority (DAWASA) and the geographical location of Wazo Hill, rainwater is the main choice over other water sources for most people. DAWASA distribute water using bulldozers, and one unit (1,000 L) is priced at TZS 10,000, which is more expensive compared to people's income. To meet basic needs and minimize health concerns, the World Health Organization (WHO) recommends 50 to 100 L of water per day for each person (WHO 2021). Thus, a family of five people will only consume one unit of water for two days. The geographical location of the Wazo Hill area is another reason for the shortage of water. Wazo hill area is situated on hills and the water from DAWASA moves due to gravitational force from the upholding tanks, consequently, the water pressure decreases. From the survey results shown in Figure 3, at least 24% use tap water, 53% use rainwater, 6% use wells, while the rest 17% use other water sources.

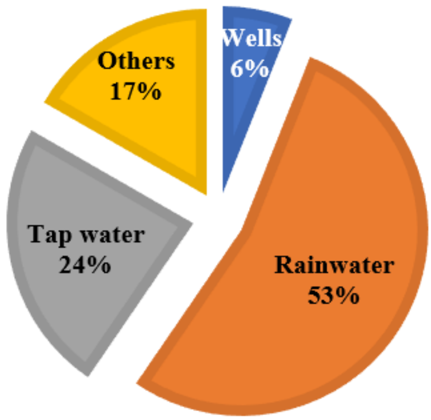

Figure 3: Survey results on Sources of water

Despite the absence of any costs for rainwater, some residents believe that they utilize it due to lack of water supply from DAWASA. However, few residents believe that rainwater is natural and it doesn't require treatment. Figure 4 demonstrates how the residents of Wazo Hill area view the use of rainwater whereby 6% use it due to unreliable supply of water, 71% use it due to less costs, 11% use it because they believe it is pure and clean while 12% use its due to absence of alternative water sources.

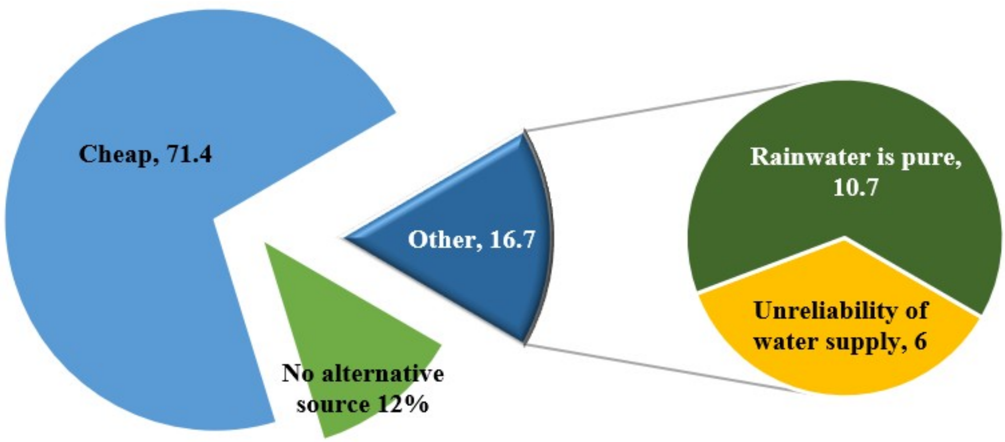

Figure 4: Reasons for using rainwater as the main water source

The collected rainwater is mainly used for cooking and drinking, cleaning and gardening. The results revealed that about 53% of the respondents use rainwater for cleaning (i.e., moping houses, flushing toilets and laundry), 24% use it for gardening, 18% use it for cooking and drinking and 5% of the respondents use it for non-domestic uses e.g., car wash as shown on Figure 5.

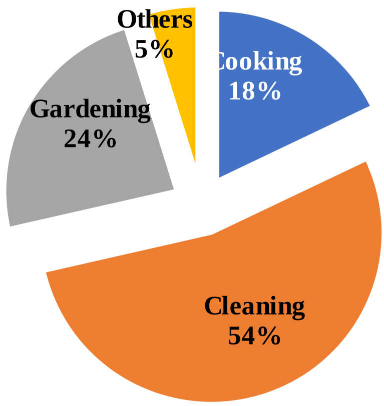

Figure 5: Different households Uses of harvested rainwater in Wazo Hill

Rainwater was not used by 47% of the surveyed residents because of the hygiene, taste and personal preference. From the survey, 62% of the respondents believed that rainwater is not clean. It is difficult to clean collection systems such as storage tanks, pipes and roofs unless the household installs automatized filtration system from roofs to storage units. Most people clean their water storage during summer because of the intermittent rain in Dar es Salaam. This method does not guarantee that the water collected will be clean. In addition to that, the remaining 38% respondents do not prefer using rainwater as shown in Figure 6.

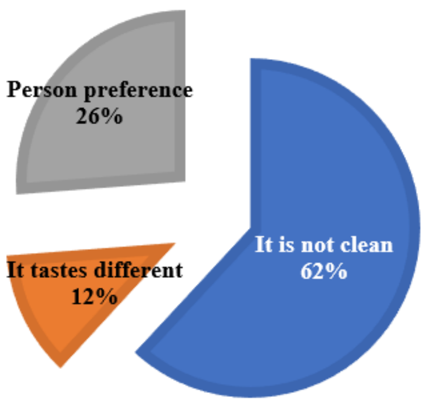

Figure 6: Reasons for not using rainwater for consumption.

Rainwater treatment at the household level

About 85% of the respondents who harvest rainwater were surveyed do not treat their collected rainwater. However, 6% respondents boil the water before using it, while 7% respondents claim to use on hand chemical treatment options such as Water Guard. Only 2% of respondents perform filtration when there is an installed filter in the gutter connected to the storage material. It was observed that most of the respondents around Wazo Hill do not have enough knowledge about the importance of water treatment.

Sources of Rainwater pollution

Various sources can cause pollution to various water. Rainwater can become polluted through various sources as it travels from the atmosphere to collection systems. However most common source of contamination is catchment surfaces and storage materials.

Catchment Surfaces

The main identified type of roofing materials used in Wazo are acrylic roofs and corrugated metal roofs. Despite being durable acrylic roofs, can leach volatile organic compounds (VOCs), particularly over time, especially when exposed to UV radiation (Ojo 2019, Zdeb et al. 2020). Corrugated metal roofs can leach harmful metals such as zinc and lead, particularly when protective coatings degrade (Anabtawi et al. 2022). Therefore, the choice of roofing material and regular maintenance are crucial for ensuring the quality of harvested rainwater. From the questionnaire analysis, 40% respondents use acrylic roofs, 4% have clay tile roofs, 47% have corrugated metal roofs and 9% have stone coated roofing material.

Storage Materials

The storage materials from the surveyed study are plastic tanks, concrete tanks and metal tanks which were either mounted or stored underground. The main source of contamination in storage materials is sediment accumulation where dirt and debris can settle and accumulate at the bottom (Ranaee et al. 2021). Also, stagnant water promotes the growth of bacteria, algae and other micro-organisms (Hamilton et al. 2019). From the analysis, 70% respondents store water in plastic tanks, 22% store their collected rainwater in the concrete tanks and about 5% store their collected rainwater in metal tanks.

Physio-chemical Water Quality Characteristics

Physical analysis of the collected samples

The acceptable pH range for drinking water is 6.5-8.5 (WHO 2021). However, the pH values for all samples collected ranged between 5.2 and 6.6. Most of the samples with pH values below WHO standard were recorded from households using a metal tank, as shown in Table 1. Metal tanks are made of materials such as iron or steel, which tend to corrode over time. When rainwater comes into contact with these metals during storage, it can pick up metal ions such as iron, which can lower the pH of the water (Nicholas et al. 2024).

Table 1: Physical characteristics of rain collected from different roofing materials

Roofing materials	Storage materials	pH	EC (µs/cm)	TDS (mg/L)	Turbidity (NTU)	Color (TCU)
Acrylic coated roofs	Concrete tank	6.5±0.04	271.2±10.53	139.7±2.64	31.5±2.08	22.2±2.09
	Metal tank	5.2±0.09	275.8±2.60	147.7±3.01	40.2±3.18	27.3±1.96
	Plastic	6.5±0.03	280.0±1.86	145.9±2.68	37.7±2.62	22.6±1.37
Corrugated metal sheets	Concrete tank	6.6±0.02	244.3±4.51	139.8±3.34	26.3±0.24	21.7±2.40
	Metal tank	5.8±0.00	275±3.33	138.3±3.68	32.3±2.96	19.3±2.89
	Plastic	6.3±0.02	274.8±1.26	142.0±4.19	34.1±3.90	20.0±1.45
DEAS 12: 2022 (For natural portable water)		5.5 – 9.5	<2500	<1500	<25	<50
WHO (2021)		6.5 – 8.5	170 - 2700	<600	0.3 - 25	0.5 - 50

The allowable turbidity limit for drinking water is below 25 NTU (WHO 2021, DEAS 2022). However, the turbidity values for all samples collected were above the allowable limit. Higher turbidity is attributed to the accumulation of particulate matter (dust, pollen and debris) from the rooftops. Other parameters Electric conductivity, color and Total dissolved solids are within the recommended limits as shown in Table 1.

Chemical analysis of the collected samples

The metals analyzed in water quality for this study were iron, lead, and chromium. The roofing sheets can be a source of iron. When rainwater flows on rusted roof surfaces, it can dissolve iron oxide particles leading to an increased iron concentration (Nicholas et al. 2024). The concentration of Pb is due to the of roofing materials as most of roofing materials are coated with lead-based primers and paints. Also, particulate matter, sulfur dioxide, nitrogen oxide and industrial emissions can settle on rooftops which is most common in urban and peri-urban areas. This study yielded the same results as the one conducted by Ojo (2019). The parameters analyzed in this research are within the required limits as shown in Table 2.

Table 2: Chemical characteristics of rain collected from acrylic coated roofs

Roofing materials	Storage materials	Iron (mg/L)	Lead (mg/L)	Chrom (mg/L)
Acrylic coated roofs	Concrete tank	0.2±0.07	0.02±0.00	0.03±0.01
	Metal tank	0.27±0.02	0.02±0.00	0.03±0.01
	Plastic	0.24±0.05	0.02±0.00	0.03±0.01
Corrugated metal sheets	Concrete tank	0.23±0.03	0.01±0.00	0.02±0.01
	Metal tank	0.26±0.01	0.02±0.00	0.01±0.00
	Plastic	0.20±0.07	0.01±0.00	0.02±0.00
DEAS 12: 2022 (For natural portable water)		<0.3	<0.01	<0.05
WHO (2021)		0.2 – 2.0	0.005 – 0.1	0.04 – 0.5

Bacteriological Characteristics

Both the total coliforms and fecal coliforms are exceeding the necessary limits, as shown in Table 3. The presence of total coliform and fecal coliform was also presented by Ojo (2019). This is attributed to rodents, reptiles, and birds' faeces, as well as the close proximity of the septic system to the underground rainwater storage tank.

Table 3: Biological characteristics of rain collected from acrylic coated roofs

Parameters	Storage materials	TOTAL COL (CFU/100 mL)	FECAL COL (CFU/100 mL)
Acrylic coated roofs	Concrete tank	43.2±7.22	19.7±4.62
	Metal tank	47.2±7.08	15.5±1.26
	Plastic	40.1±10.51	18.8±2.24
Corrugated metal sheets	Concrete tank	41.8±9.33	18.5±3.39
	Metal tank	48.0±8.28	19.8±5.49
	Plastic	41.3±9.18	18.6±2.68
DEAS 12: 2022 (For natural portable water)		0.0	0.0
WHO (2021)		0.0	0.0

Conclusions

The study found that a significant proportion of households in Wazo Hill rely on harvested rainwater for drinking and domestic use due to its reliability and low cost. Laboratory analysis revealed that while most of the parameters (colour, TDS, Electric conductivity) and chemical parameters were within the acceptable range, other parameters such as pH, Turbidity and biological parameters exceeded the stipulated standards indicating potential contamination from environmental exposure or inadequate storage practices. The main source of pollution in harvested rainwater was mainly due to animal and bird droppings. The results demonstrate that while rainwater is widely used and valued in suburban Dar es Salaam, its quality is inconsistent and often falls short of the safety standards for direct consumption. Therefore, untreated harvested rainwater is unsuitable for consumption purposes unless appropriately treated. It should also be noted that, these findings are context specific and may offer insights into similar peri-urban areas, any broader application of the results should be made cautiously and with consideration of local variations in infrastructure, water access, and community practices.

It is recommended that harvested rainwater should be treated before consumption using accessible methods to remove contaminants as shown in Figure 6. Most common methods that can be used include chlorination, UV disinfection, boiling, flocculation, etc. The low-cost treatment intervention such as first flush diverters and water filters should be incorporated into the designed rainwater harvesting system to reduce the number of impurities in harvested rainwater. Policy recommendations include developing guidelines for safe design, installation and maintenance of rainwater harvesting systems at the household level; integration of rainwater harvesting standards into building codes and urban planning policies and promoting community awareness campaign on safe rainwater collection, storage and treatment practices. Regular monitoring and testing of household water sources by local health authorities is also recommended to ensure that water is safe for consumption purposes.

Study limitations include the use of a relatively small and localized sample size limited to Wazo Hill, which may affect generalizability; sample collection during one rainy season, which may not capture temporal variability in rainwater quality and the absence of control tests on tap water for direct bacterial contamination comparison. Future research studies should focus on multiple seasons to assess temporal changes in rainwater quality; expanding sampling to multiple urban and peri-urban areas across Dar es Salaam for broader representativeness; evaluating the effectiveness of household level treatment practices for harvested rainwater and assessing the socio-economic factors that may influence the adoption and maintenance of rainwater harvesting systems.

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Conflict Of Interest

The authors declare that there is no conflict of interest.

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