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Investigation of the sources of pollution of harvested rainwater at household level: A case of Makoka sub ward, Makuburi Ward, Dar es Salaam

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Abstract

This study investigated sources of pollution of rainwater harvested and stored at household level in Makoka sub-ward, Makuburi Ward, Ubungo, Dar es Salaam. Results show roof deposition as most frequently cited source of contamination, followed by gutter deposition, leaking conduits and leaking or cracked storage tanks, the last of which was confirmed through physical inspection. Only 17% cleaned their storage tanks regularly. About 42% used unsafe methods, to draw water from storage tanks, 75% had trees overhanging their catchment area despite only 33% owning a leaf-control device. Although 75% considered first-flush diversion important, only 17% practised it consistently. Diversion was performed manually rather than through a dedicated device. Poor roof condition (42%) and deteriorated gutters and conduits (33%) further compounded the risk of contamination. The study concludes that rainwater pollution at household level in Makoka sub-ward originates mainly from inadequate catchment and storage maintenance rather than from the rainwater itself.

Keywords: Rainwater Harvesting, Water Pollution, Storage Tank, Roof Catchment, Household Water Quality, Dar es Salaam

1. Introduction

1.1 Background

Rainwater harvesting is a technique of collecting and storing of rainwater into natural reservoirs' or tanks or the infiltration of surface water into subsurface aquifers before it is lost as a subsurface run off. In rooftop rainwater harvesting, surfaces such as tiles, metal sheets and plastics are used to intercept the flow of rainwater which is then used for different household activities such as cooking, cleaning and drinking. (Gonzalez, 2012)

Rainwater harvested can also be used for other activities such as irrigation and livestock farming. Rainwater as a complementary water source is an option that can be easily installed and maintained

and renders water of good quality and if properly maintained it represents no hazard to human health (Christopher *et al.*, 2009).

Rainwater harvesting technique is being implemented in many different parts of the world. Some countries like Canada use this technique for storm water reduction and irrigation while others utilize this technique as a means to avoid ground water depletion as for the case of India. In Australia, many homes away from the city use rainwater harvesting as the primary source of water (Duke, 2014).

Many developing countries particularly in Africa face water shortages due to effects climate change. The overall quantity of rain falling across the Africa continent is equivalent to the needs of one and half times the global population (UN, 2006)

In many urban and rural areas of Tanzania, adequate water availability is a challenge. Rainwater harvesting technique therefore becomes an option to be highly considered. Some rural parts of Tanzania such as Rainwater harvesting is not new technology, however its implementation in many urban areas of Tanzania including Ubungo municipality is still low (Massawe, 2016).

Rainwater harvesting is advantageous in a sense that, it provides an independent water supply for households. In addition, rainwater harvesting can be used as a supplement source of water during scarcity and drought. Furthermore rainwater harvesting is also not saline and is free of pollutants that may be present in surface and ground water. Rainwater can also be a means to manage storm water and for agricultural activities (Zhu *et al.*, 2015).

The quality of rainwater has been reported to be at acceptable range for human consumptions, however some practices such as diversion of the first flush and frequent cleaning of the storage tanks are encouraged so as to maintain the quality of rainwater at acceptable. Furthermore it has been reported that storage materials have various different impacts on the quality of the harvested and stored rainwater (Achadu *et al.*, 2013).

1.2 Problem statement

Rainwater harvesting and storage for its use has been opted as either an alternative water source or as a complementary water source in many areas to combat water crisis issue. The quality of rainwater has been stated to be acceptable and good for human consumption but in some cases water quality has happened to be of unacceptable quality for human consumption. Many researches have been done concerning rain water quality in both small scale and large scale systems but the issue of the possible causes of deterioration of quality of rainwater harvested still requires more

information. Some complaints rising among indigenous people concerning stomach aches resulting from consuming rainwater that has been stored for a long period (months), bad odor as well as visible small organisms calls upon for efforts to investigate the causes of contamination. Therefore this research focus on investigating the main causes of pollution of rainwater harvested and stored for domestic use so as to get more information

1.3 Objective of the study

The main objective of this research is to determine the sources of pollution of rainwater harvested in selected households, Makoka Subward

1.4 Significance of the study

This study is very important since it lies in investigating the comparative quality of harvested rain water stored for various durations in different types of storage tank materials and whether the water fits for human consumption or not and hence call for monitoring to ensure consumers utilize water that is of acceptable quality. By meeting its objective, this research helps to provide means to prevent all sorts of pollution of the rainwater harvested and stored for its use. This research study is relevant to environmental science and technology since water availability and quality is directly and indirectly connected to the environmental and public health issues. This research, will add to the board of knowledge concerning the topic in question

1.5 Scope

The scope of the study focus on determining the possible causes of pollution of rainwater harvested and stored for its use as a complementary water source at household level in Makoka sub-ward in Ubungo municipality.

2. Literature review

2.0 Concept of rainwater harvesting

Rainwater harvesting henceforth RWH refers to a technique of collection from surfaces on which rain falls and storing it in surface or subsurface reservoir before it is lost as a surface run-off

(Sustainable Earth technologies, 1999)

2.1 Advantages of rainwater harvesting

- it can curtail the burden on the public water supply, which is the main source of city water;
- it can be used in case of an emergency (i.e., fire);
- it is solely cost effective as installation cost is low, and it can reduce expense that one has to pay for water bills;
- it extends soil moisture levels for development of vegetation;
- It is a solution to water shortage problem in winters because groundwater level is highly recharged during rainfall
- Reduces the runoff volume and the peak flow, hence mitigate floods.
- Reduces the cost per liter of water since a large amount of power that is consumed while pumping water from subsurface aquifers can be saved (Sarma *et al.*, 2006)
- It provides water that is of high quality and contains minerals in low concentrations.
- Rainwater also provides sufficiency to water supply in self-independence manner
- Improves the quality of ground water through dilution when recharged to groundwater
- Rooftop rain water harvesting is less expensive compared to other means of obtaining water
- Rainwater harvesting systems are simple and can easily be adopted by individuals
- Rooftop rain water harvesting systems have ensured ease to install, operate and maintain.
- Rainwater harvesting greatly reduces soil erosion especially in urban areas where cultivation is not done by controlling the floodwater (Eldho, 2002).

2.1 General Conditions to consider in Planning for Rain Water Harvesting

2.1.1 Climate

When planning for Rainwater harvesting system, it is necessary to obtain the rainfall data of the area in question so as to estimate the volume of water that is expected to be harvested

and to properly size the components of the rainwater harvesting system. The following data are important:

- i. Rainfall amount, intensity, frequency, and return period.
- ii. Rainfall trends (daily, monthly, seasonal, annually) (Christopher *et al.*, 2009)

2.1.2 Catchment

Size and runoff coefficient of the rainfall catchment are important criteria in planning for RWH. Roof catchments are often used when collected water is for domestic purposes, and sometimes used as portable water. The relatively high runoff coefficient of the roofing materials enable higher collection efficiency compared to ground catchment techniques. For ground catchment techniques, the following catchment specific factors affect the amount and quality of harvested rainwater (Adeniy and Olabanji, 2005).

2.1.2.1 Soil type

The porosity of a soil determines the water storage capacity and affects the resistance of water to flow into deeper layers. The highest infiltration capacities are observed in loose, sandy soils while heavy clay or loamy soils have considerably smaller infiltration capacities. Soils with low infiltration rate has high yield compared to soils with high infiltration rate. The origin and composition of specific soil type affects the quality of water to be collected. To reduce the effect of soil type on the amount of harvested water, lining of the surface is usually done as already mentioned under types of rainwater harvesting techniques

2.1.2.2 Vegetation

A dense vegetation cover shields the soil from the raindrop impact and reduces the crusting effect. In addition, the root system as well as organic matter in the soil increases the soil porosity thus allowing more water to infiltrate. Vegetation also retards the surface flow particularly on gentle slopes, giving the water more time to infiltrate and to evaporate. This means that an area densely covered with vegetation, yields less runoff than bare ground (Spinks *et al.*, 2003)

2.1.2.3 Slope and catchment size

Usually, steep slope plots yield more runoff than those with gentle slopes. In addition, the quantity of runoff decreases with increasing slope length, mainly due to lower flow

velocities and subsequently a longer time of concentration (defined as the time needed for a drop of water to reach the outlet of a catchment from the most remote location in the catchment). This means that the water is exposed for a longer duration to infiltration and evaporation. (Adeniy and Olabanji, 2005).

Rainfall coefficients:

$$\text{Runoff [mm]} = K \times \text{Rainfall depth [mm]} \dots\dots\dots \text{eq 1}$$

The coefficient K, which describes the percentage of runoff resulting from a rainstorm, is however not a constant factor. Instead its value is highly variable and depends on the abovedescribed catchment-specific factors and on the rainstorm characteristics.

As explained above, the runoff coefficient from an individual rainstorm is defined as runoff divided by the corresponding rainfall both expressed as depth over catchment area (mm):

$$K = \frac{\text{Run off(mm)}}{\text{Rainfall(mm)}} \dots\dots\dots \text{eq 2}$$

An average value for a catchment can be found by carrying out actual measurements until a representative range is obtained.

2.1.2.4 Safety

Safety of a RWH system, in terms of risk of contamination or pollution is an important consideration during RWH planning. (Guideline for Rain Water Harvesting In Tanzania, 2016)

2.2 Methods of rainwater harvesting

There are mainly two widely known methods of rainwater harvesting that are explained below

2.2.1 Ground catchment techniques enable collection of water from a larger ground surface. They include:

2.2.1.1 Small dams: these area the dam having dam height of having the maximum capacity of 10,000 m³ and height of the wall not exceeding 5m. The dams are divided into three main categories namely: Charco dams, Hillside dams and Valley dams (MoWI, 2016)

2.2.1.2 Sand dams: these are structure constructed within a seasonal sandy river or stream to capture and store base flows. This technique is widely used in semi-arid rural areas (i.e. Shinyanga, Simiyu. Singida and Tabora Regions) (MoWI, 2016)

2.2.1.3 Rainwater collected from roads: this is one of the technique used water flowing through road ditches, paved area and culvert to be collected and stored for different uses. Pan, Ponds and Small dams are used to store the water collected from roads.

2.2.1.4 Lined water bodies/ponds: LDPE and PVC liners are normally used to line the pond footprint area in order to reduce loss of water through seepage. This is normally applicable is the porous geology areas.

2.2.1.5 Paved Catchment: the catchment area is paved by either clay (mud) or concrete liners and rainwater is normally collected into sub-surface storage facilities (MoWI,2016)

2.2.2 Rooftop rainwater harvesting

This refers to a rainwater harvesting method where the roof becomes a catchment and the rainwater is collected from the roof of the building. After collection, the rainwater is then directed to a storage tank or artificial recharge system (Christopher *et al.*, 2009).

2.3 Components of a rainwater harvesting system

2.3.1 Catchments

Catchment area refers to the surface which directly receives the rainfall and provides water to the system. It can be a paved area like a terrace or courtyard of a building, or an unpaved area like a lawn or open ground, a roof made of reinforced cement concrete (RCC), galvanized iron or corrugated sheets (Mishra, 2007)

2.3.2 Coarse mesh

This is a rainwater harvesting system component that functions to prevents the passage of debris coming from the roof in the roof.

2.3.3 Gutters

These are channels that surround the edge of the roof. These channels collect and convey rainwater from roof to the storage tank. Gutters can be semi – circular or rectangular and mostly made locally from plain galvanized iron sheet. Support is required on the gutter to

prevent sagging and falling off of the gutter due to heavy load of water. The way in which gutters are fixed mainly depends on the construction of the house (Mishra, 2007)

2.3.4 Conduits

Conduits are pipelines or drains that carry rainwater from the catchment or roof top area to the harvesting system. Polyvinyl chloride (PVC) or galvanized iron (GI) are the materials of which the commonly available conduits are made. However plastic pipes are highly recommended since they are more tolerant to acidic and soft rainwater. Painting is done to plastic pipes to prevent UV radiation from damaging the pipes (White *et al*, 2007)

2.3.5 First flushing

A first flush device is a valve which ensures flushing out of first spell of rain away from the storage tank that carries a relatively larger amount of pollutants from the air and catchment surface. Automatic devices that prevent the first 20–25 litres of runoff from being collected in storages are recommended to enable first flush diversion however if diverters are not available, a detachable down-pipe can be used manually to provide the same result (Virginia Rainwater Harvesting Manual, 2009).

2.3.6 Filters

The filter is used to remove suspended pollutants from rainwater collected from roof top water.

The Various types of filters generally used for commercial purpose are Charcoal water filter, Sand filters, Horizontal roughing filter and slow sand filter (Mishra.2007)

2.3.7 Storage facility

There are various options available for the construction of these tanks with respect to the shape, size, material of construction and the position of tank and they are: -Shape : Cylindrical, square and rectangular. Depending on land space availability these tanks could be constructed above ground, partly underground or fully underground. Some maintenance measures like disinfection and cleaning are required to ensure the quality of water stored in the container. If harvested water is decided to recharge the underground aquifer/reservoir, then some of the structures mentioned below are used (Massawe, 2016)

2.3.8 Recharge structures

Rainwater Harvested can also be used for charging the groundwater aquifers through suitable structures like dug wells, bore wells, recharge trenches and recharge pits. Various

recharge structures are possible – some which promote the percolation of water through soil strata at shallower depth (e.g., recharge trenches, permeable pavements) whereas others conduct water to greater depths from where it joins the groundwater (e.g. recharge wells)(MoWI, 2016) At many locations, existing structures like wells, pits and tanks can be modified as recharge structures, eliminating the need to construct any fresh structures. Some of the few commonly used recharging methods are recharging of dug wells and abandoned tube wells, Settlement tank, Recharging of service tube wells, Recharge pits, Soakaways /Percolation pit , Recharge troughs, Recharge trenches, Modified injection well.(Mishra 2007,)

2.4 Quality of harvested rainwater

The quality of harvested rainwater is an important issue, as it could be utilized for drinking purposes. Quality of captured water from roof top depends on both roof top quality and surrounding environmental conditions, that is, local climate, atmospheric pollution, and so forth (Farreny *et al.*, 2011)

Tests must be performed to check its viability and applicability before using as drinking water.

Quality of collected water usually doesn't always meet standard limits due to unprotected collection. Local treatment of harvested water could easily make water potable. Again rainwater could be also identified as non-potable sources for the purpose of washing, toilet flushing, gardening, and so forth, where quality is not a great concern. In this respect, treatment of collected water is of no such importance; rather it is used for household purposes. (Radaideh *et al.* 2009)

2.4.1 Factors determining water quality.

Atmospheric pollution can have a major effect on the composition of rainwater. Water that reaches the earth as rain, acquires other substances from processes such as leaching, weathering, and dissolution. Living organisms may enter the water. All these processes affect the composition of the water (Massawe, 2016)

2.4.1.1 (Micro) biological contamination:

The most common hazard in water sources obtained from roof or surface catchments is microbial (biological and microbiological) contamination, especially enteric pathogens. Enteric pathogens are micro-organisms (bacteria, viruses, and protozoa) that cause gastrointestinal illness. These organisms are introduced into drinking water supplies by contamination with faecal material (from human or animal origin) or dead animals and insects. The most important indicator is EColi (Namrata and Han, 2005)

2.4.1.2 Chemical contamination

Chemical contamination results from air pollution (industrial and traffic emissions), runoff and leaching of chemical substances (agricultural and human activities) and toxic material use. All these factors can pose a serious a health threat (Friedler, 2017)

2.4.1.3 Physical contamination.

Physical contamination includes inorganic and organic sediments like sand, silt, clay or plant material. Physical contamination affects the colour, odour or taste of the water, but it poses no direct health risk. Users can however object to water if its colour, odour and taste are found less attractive. The breeding of mosquitoes in or near RWH systems is another health hazard of rain water contamination (Spinks *et al.*, 2003)

2.4.2 Physical chemical parameters

Rainwater is slightly acidic and very low in dissolved minerals; as such, it is relatively aggressive. Rainwater can dissolve heavy metals and other impurities from materials of the catchment and storage tank. In most cases, chemical concentrations in rainwater are within acceptable limits; however, elevated levels of zinc and lead have sometimes been reported. This could be from leaching from metallic roofs and storage tanks or from atmospheric pollution (Friedler, 2017)

The physicochemical quality of roof runoff, as reported by many studies, is quite similar to potable water quality guidelines, with the notable exception of pH values (pH of rainwater is 4.5–6.5, increasing slightly once on the roof (Neibaur and Anderson, 2016).

However, wide variations in concentrations of ions, like lead, calcium, magnesium, sodium, potassium, chlorides, sulphates, and nitrates were observed (Chang *et al.*, 2014). These variations were reported to be a result of differences in roofing materials, orientation and

slope of roofs, air quality in the region, and precipitation characteristics (Neibaur *et al.*, 2016).

Rainwater lacks minerals, but some minerals, such as calcium, magnesium, iron and fluoride, in appropriate concentrations are considered very essential for health. Although most essential nutrients are derived from food, the lack of minerals, including calcium and magnesium, in rainwater may represent a concern for those on a mineral-deficient diet. In this circumstance, the implications of using rainwater as the primary source of drinking-water should be considered. The absence of minerals also means that rainwater has a particular taste or lack of taste that may not be acceptable to people used to drinking other mineral-rich natural waters (Namrata and Han, 2005)

Rainwater runoff from similar roofs in different seasons and at six locations were compared in Bayreuth, Germany. Large variations in ammonium concentrations that were measured during the same rain event in different locations (1.8–12.6 mg/L) observed. The highest concentration was measured on a roof adjacent to an agricultural field. At the same location, large variations were also observed between seasons. It was further indicated that similar patterns were also observed for chlorides (Forster, 1998).

Studies on rainwater runoff quality of four different roofing materials that was done in east Texas, found that pH, EC (electrical conductivity), and Zn were significantly affected by the types of roofing material. In addition, they reported that Al, Mn, Cu, Pb, Zn, and pH concentrations in roof runoff exceeded the national quality standards in at least 5% of the rainfall events. (Chang *et al.*, 2004)

2.4.3 Microbial quality

The microbial quality of roof-harvested rainwater often exceeds microbial quality standards, probably due to pollution originating from the excreta of animals (birds, rodents, etc.) that have access to roofs (Ahmed, 2011).

2.4.3.1 Determination of Coliform organisms (total coliforms)

Coliform organisms have long been recognized as a suitable microbial indicator of drinkingwater quality, largely because they are easy to detect and enumerate in water. The term “coliform organisms” refers to Gram-negative, rod-shaped bacteria capable of growth in the presence of bile salts or other surface-active agents with similar growth-inhibiting

properties and able to ferment lactose at 35–37°C with the production of acid, gas, and aldehyde within 24–48 hours. Although coliform organisms may not always be directly related to the presence of faecal contamination or pathogens in drinking-water, the coliform test is still useful for monitoring the microbial quality of water supplies (WHO, 1997)

Microbial contamination of collected rainwater indicated by *E. coli* (or, alternatively, thermotolerant coliforms) is quite common, particularly in samples collected shortly after rainfall. Pathogens such as *Cryptosporidium*, *Giardia*, *Campylobacter*, *Vibrio*, *Salmonella*, *Shigella* and *Pseudomonas* have also been detected in rainwater. However, the occurrence of pathogens is generally lower in rainwater than in unprotected surface waters, and the presence of non-bacterial pathogens, in particular, can be minimized. Higher microbial concentrations are generally found in the first flush of rainwater, and the level of contamination reduces as the rain continues (Sule *et al.*, 2011)

2.4.4 Relationship between rainwater quality and weather conditions

Various differences in weather conditions such as the rainfall distribution, rain intensity and depth as well as the dry periods between two consecutive rain events appear to have impact on the quality of roof harvested rainwater. A research was done focusing on the investigation of the quality of roof-harvested rainwater. The study further more based on rainwater collected from three types of roofs in an urban environment in northern Israel characterized by a Mediterranean climate. In this study analysis of the microbiological, chemical and physical characteristics was done, not leaving behind analysis of heavy metal concentrations. In this study, some estimations of the relationship between quality of harvested rainwater and weather conditions was established and determined to be significant. Furthermore, the association of selected pollutants and roof materials with rainwater quality was established and found to be significant (Farreny *et al.*, 2011).

Different patterns of weather including wind directions, wind speed and environmental conditions were appeared to significantly influence the loads and the profile of microbes in the roof runoff. Lye (2009) claimed that the potential microbial risks are greatly associated with the systems of rainwater harvesting can be simply predicted by weather pattern analysis.

Furthermore, the microbial quality of roof-harvested rainwater is strongly influenced by length of dry period, season, animal activities, roof material, characteristics of rainwater storage tanks, as well as geographical location.

3. Materials and Methods

3.1 Description of the case study area

Makoka sub ward is among the sub wards of Makuburi ward located in Ubungu municipality in Dar es Salaam region. Makoka sub ward has same climatic conditions as those of Dar es Salaam that is; an average temperature range between 21°C and 30°C. Hot season is from October to March while the cool season is between May and August. There are two rain seasons that are; short light rains of October through December while on the other hand, the long heavy rains start from March through May. The annual rainfall ranges between 1000mm and 1300mm (Tanzania Meteorological Agency)

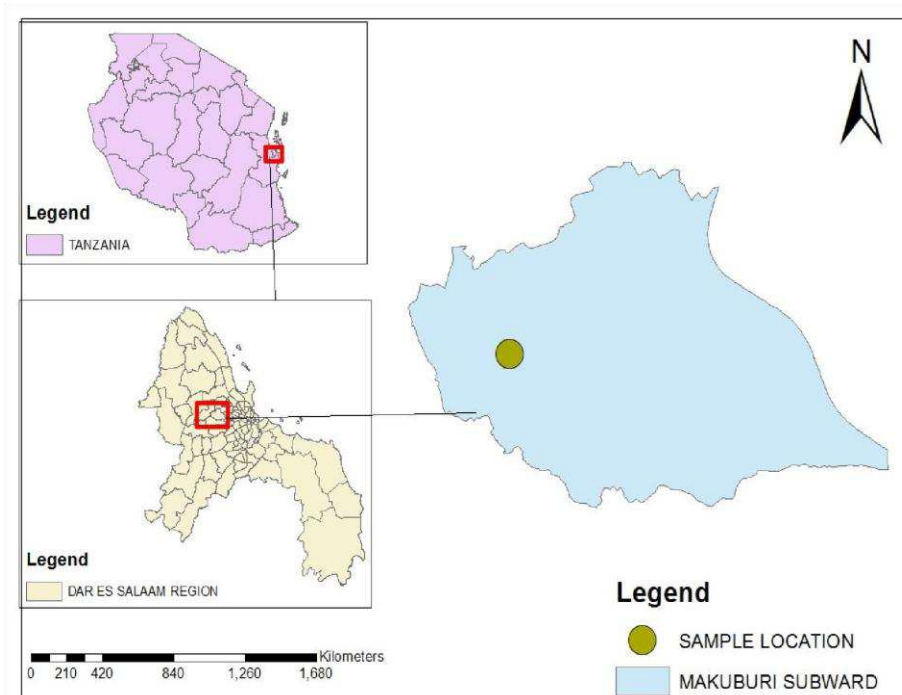


Figure.1: Map showing sample location area (Makoka sub ward)

3.2 Case study area selection

Figure 1 presents the location of the study area. This case study area was selected since water crisis in Makoka sub ward is a persisting problem as in many other areas of Ubungu due to the increasing population growth. In some urban areas such as Makoka sub-ward water supply service is not continuous since there is serious water rationing in areas with pipes for days or sometimes weeks

for the users connected to the municipal water supply. Furthermore there are cost expenses incurred by using the billed water hence use of water becomes limited to some individuals for the purpose of saving costs, also there are limited boreholes hence citizens opt to harvest rainwater to supplement the municipal water supply. Also due to limited time and funds, collection of information from the whole Ubungo municipality or Makuburi ward became limited therefore only some locations of the Makoka sub ward were used as sample points.

3.3 Sampling design

Sampling technique used was stratified random sampling, the case study was divided into various strata basing on Presence of rainwater harvesting systems that were identified through physical observation and directives from local inhabitants.

3.4 Data collection methods

3.4.1 Physical observation and questionnaires

Both physical observation and questionnaires were used to obtain information required concerning the existing situation of the rainwater harvesting systems in selected sample points. A number of twelve households was selected through stratified sampling to obtain the required details. Survey was conducted through questionnaires which were close ended and open ended. The questionnaires were conducted to the households that were purposively selected in stratified manner basing on presence of the rainwater harvesting system as some presented in figure 2.

Information that was obtained through the methods of observation and questionnaires include;

- Sources of pollution of the harvested and stored rainwater
- Frequency and practices of cleaning of the water storage tanks
- Complaints and deficiencies in the rainwater harvesting system



Figure 2 Rainwater Harvesting system at the visited site.

3.4.2 Checklists

Checklists were mainly used to attain specific objectives including regarding the features that are the possible sources of pollution or contamination of the harvested rainwater including

- Determining means of accessing the harvested rainwater
- Determining the location of the tank
- Determining the tank materials used
- Determining visible sources of pollution.

Through checklists, various deficiencies and strengths of the existing rainwater harvesting systems were noted.

3.4.3 Consultation

Professionals, experts and authorities familiar with the subject matter of household rainwater harvesting were consulted for the purpose of obtaining relevant and reliable information concerning rainwater harvesting including my research supervisors, experienced personnel and authorities.

3.4.4 Literature review

Books, research papers, journals, manuals, scholarly articles and other sources relevant to rainwater harvesting were surveyed so as to obtain relevant information and theoretical

backgrounds and guidance through this research. Literature review also help in identifying areas of prior scholarship to prevent duplication of effort as well as to reveal any gaps that's exist in literature.

3.5 Data analysis tools

During the study, data obtained from checklists, questionnaires and laboratory analysis were analyzed using Microsoft excel 2013. This statistical analysis tool was used to determine average values as well as to plot graphical illustrations of the data obtained.

3.6 Ethical consideration

Ethical considerations were practised in the planning and carrying out of this study. The well-being and rights of participants throughout all stages of the research process were highly prioritised by carrying ethical measures including: informed Consent, confidentiality, voluntary participation and transparency in research practices including publication.

Informed consent was obtained from all participants. There was clear communication about the purpose of the study and the voluntary nature of participation. Participants were assured that their involvement would not affect their relationship with the relevant institutions.

Confidentiality of all data collected was strictly maintained. Data was securely stored and accessible only to the researcher. To ensure the privacy and confidentiality of the study participants, the practice of using participant identifiers rather than real names or positions was adopted. This was done so as to safeguard the anonymity of participants, maintain the trust and confidence of participants while presenting the findings accurately and ethically.

Participation in the study was voluntary whereas participants were free to withdraw without facing any ramifications. This was emphasised during the informed consent process, ensuring that no one felt obligated to participate. The purpose, methods, and intended use of the collected data were openly discussed with participants. This transparency helped build trust and ensured that participants understood the study's objectives.

4. Results and Discussion

4.1 Sources of rainwater pollution in the harvesting system

Based on the questioners conducted the possible sources of pollution of harvested rainwater that were mentioned by respondents are roof depositions, gutter deposition, leaking conduits conveying water towards and leaking storage tanks with maximum response of roof depositions and minimum response being leaking conduits conveying water towards storage tanks as presented in figure 3.

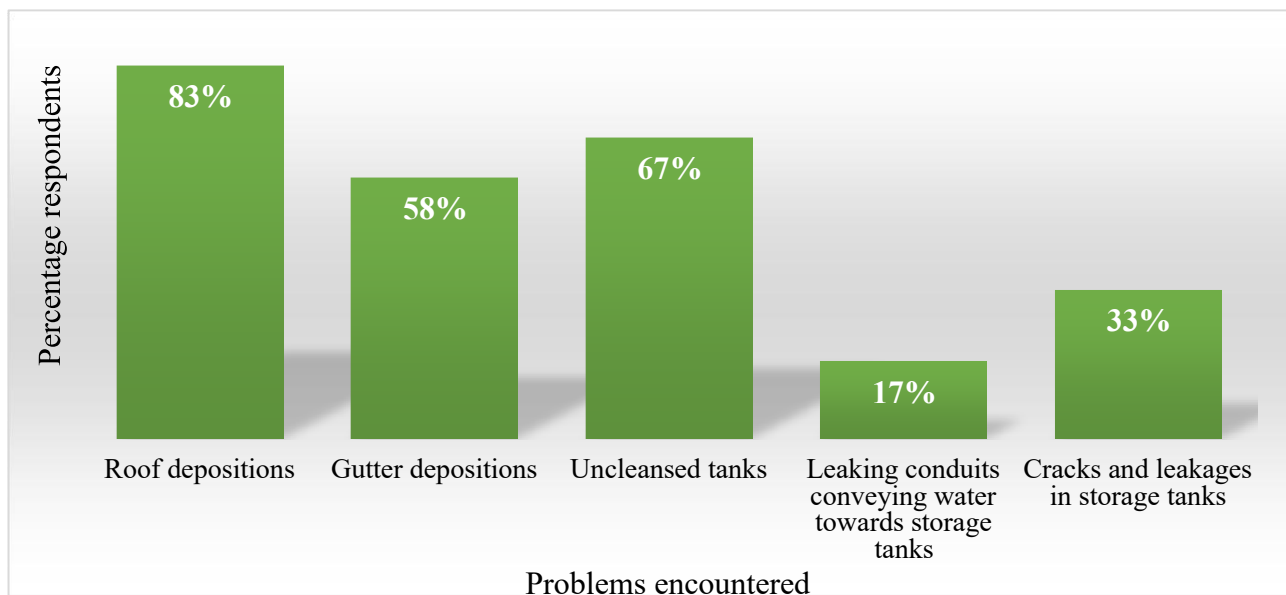


Figure 3 Potential sources of harvested rainwater contamination(Source: Researcher)

To back up the questionnaire analysis, through physical observation accompanied by checklists, cracks and leaks were identified in some storage tanks as seen in figure 4. This shows that similar cracks and leakages can appear in underground tanks and cause pollution of the stored water. This in one way or another contributes to the contamination of stored water.



Figure 4 Cracks and leakages in storage tanks (Source: Researcher field visit)

4.2 Storage tank cleansing frequency

According to the data obtained from questionnaires, rain water is also contaminated due to long time uncleansed tanks. The analysis shows that 33% of the respondents have never cleaned their storage tanks, only 17% of the respondents have often cleaned their storage tanks and 50% of the respondents rarely clean their storage tanks as shown in figure 5 and 6 below.

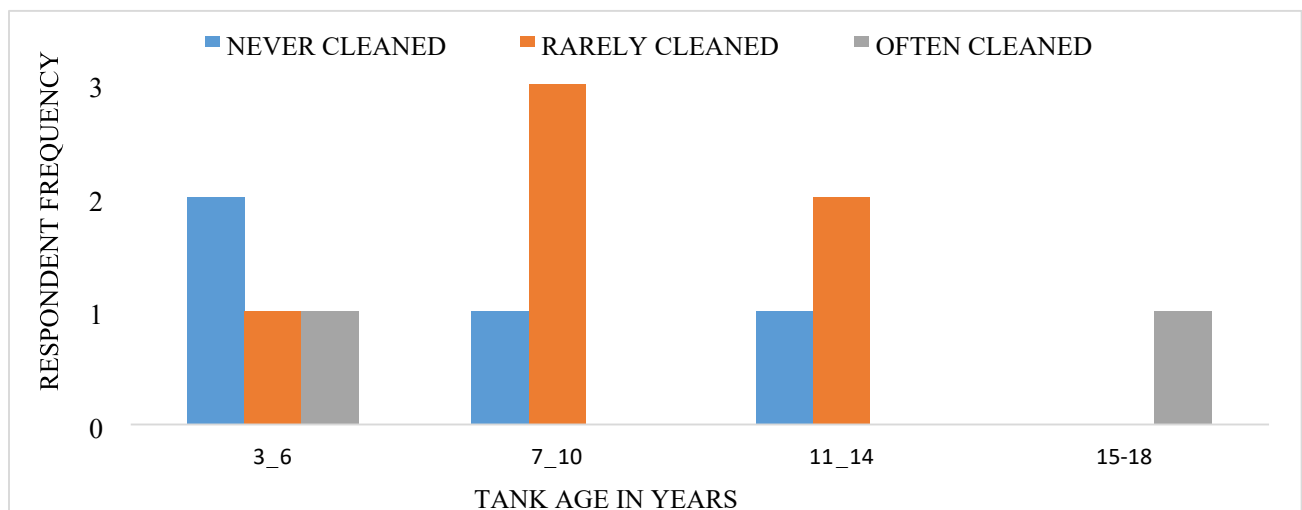


Figure 5 : Tank age and cleansing frequency

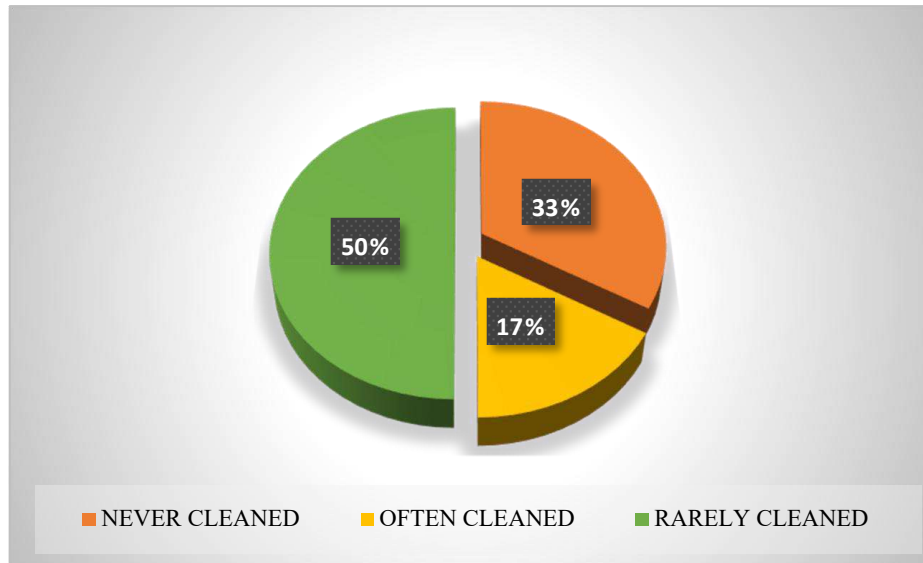


Figure 6 : Tank age and cleansing frequency

Sule *et al.* (2011) reports that quality of stored water depends on the handling of the storage tanks, frequent cleansing being among the practices which help to maintain an acceptable bacteriological and physico-chemical water quality.

4.3 Means of accessing the harvested rainwater

Figure 7 presents on presence of safe access to stored water. Through physical observation, questionnaires as well as checklists, it was identified that 41.67% of the respondents use poor means such as the use of buckets to access the stored water from tanks and as seen in figure 8. This method is poor and contributes to contamination of stored water. However, the remaining 58% of the respondents use clean means to obtain water from storage tanks that are tap and pump.

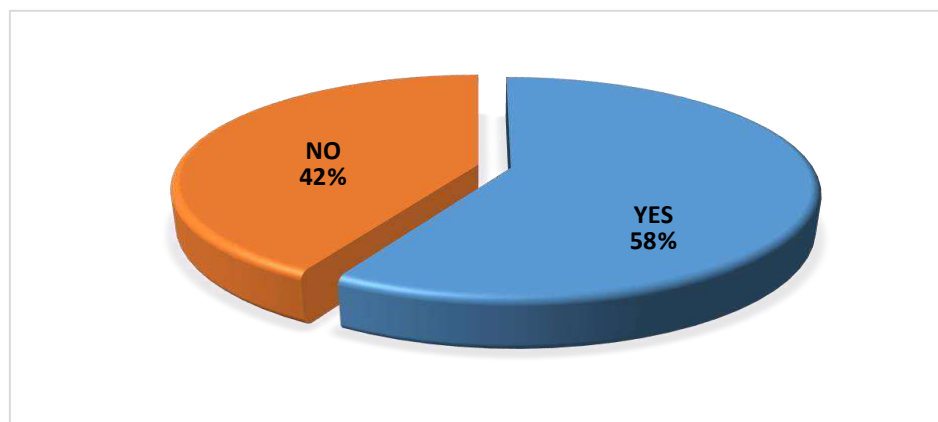


Figure 7: Presence of safe access to stored water



Figure 8: Safe means (on the left) and unsafe means (on the right) used to obtain rainwater stored in tanks.

4.4 Presence of leaf control in the harvesting system

Leaf control device is usually a device placed either at the gutter or at the inlet of the rainwater storage tank for the purpose of screening the leaves that are present in the roof or gutter. From the questionnaires conducted it was identified that only 33% of the respondents had leaf control device. However, through checklists and physical observation, trees whose leaves fall in to the system were identified in the households of the 75% of the respondents as illustrated next on figure 9.

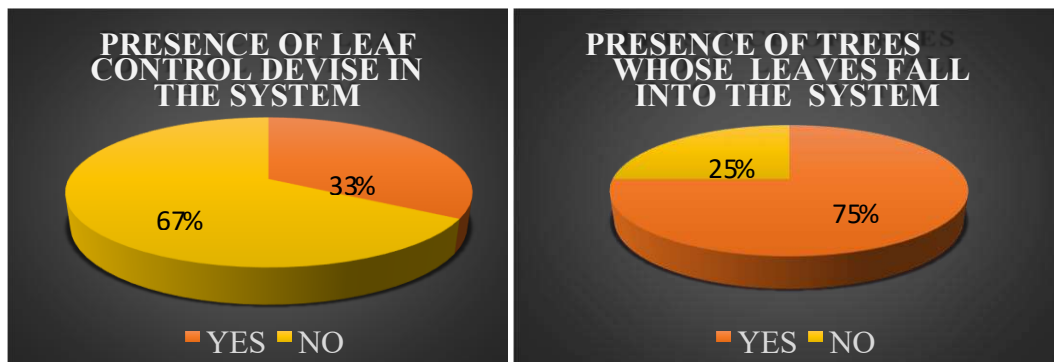


Figure 9: Leaf control and presence of falling leaves

4.5 First flush diversion practice

First flush refers to the initial rainfall that runoffs from a roof. This initial rainfall tends to rinse the roof and gutter paving way to cleaner water the more it rains (Virginia Rainwater Harvesting Manual, 2009). It is thus necessary to prevent this first flush from entering the storage tank. Figure 10 illustrates on First flush diversion practice. Seventy five percent (75%) of the respondents consider first flush diversion as an important choice while the remaining 25% do not consider it as an important practice. Furthermore it was identified that the first flush diversion is not done automatically rather it is done manually by disconnecting the conduits that conveys water from gutter to storage tank. Basing on the response from questionnaires conducted only 17% of the respondents practice first flush diversion very often and 41% of the respondents never divert the first flush.

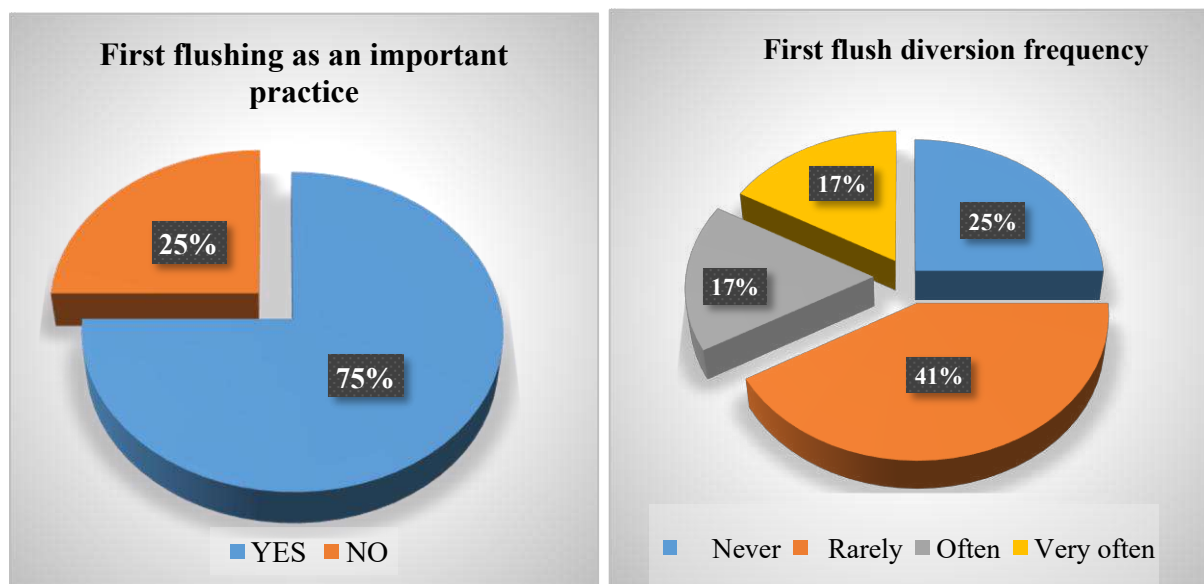


Figure 10: First flush diversion practice

4.6 Condition of the catchment area, gutter and conduits

Through checklists and physical observation it was noticed that the roofs in the households of 42% of the respondents were in bad condition. In addition to that gutter and conduits in the households of 33% of the respondents were also in bad condition as further illustrated on figure 11. The worn out roofs and gutter contributes to contamination of the harvested rainwater since the contents tends to dissolve in the running water.

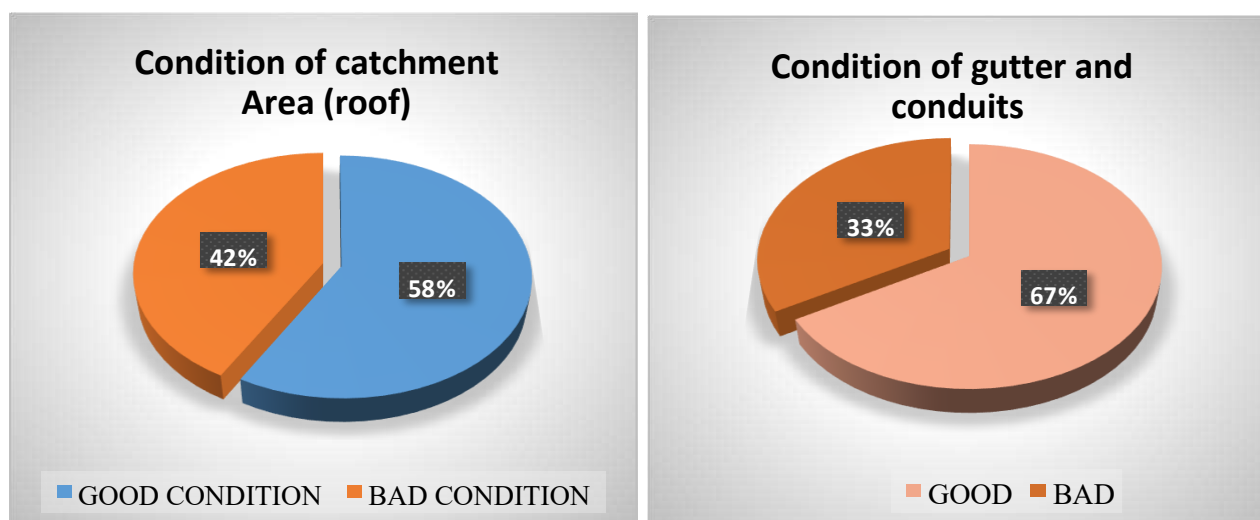


Figure 11: Condition of the catchment area, gutter and conduits

4.7 Engineering solutions on safe storage of harvested rainwater based on the findings

4.7.1 Design of an automatic fixed volume first flush interceptor that needs no man intervention to perform.

A first flush interceptor helps to keep the rainwater harvested and stored in storage tanks clean by not allowing the initial runoff to enter the storage tank. A first flush refers to the initial rainfall that runoff from roof surface and it rinses the roof leading to cleaner water as rainfall continues. The first flush usually contains offensive materials which accumulates during the dry period. These offensive materials include leaves, animal and bird droppings, dust which generally lower water quality. The first flush therefore should not be allowed to enter the storage tank so as to maintain a good quality of the water harvested and stored in the storage tanks for later use.

4.7.1.1 Components of the first flush interceptor

A first flush interceptor has various components namely interceptor funnel, floating ball, interceptor cylinder, gate valve, and drain pipe. The functions of the first flush interceptor components are described in table 1 below.

Table 1 Functions of first flush interceptor components

Component	Function
Interceptor funnel/pipe	To direct first flush towards the interceptor cylinder
Floating ball valve	To prevent the diverted water from washing back out of the interceptor and go into the storage tank
Cylinder	To collect and store the first flush
Gate valve	To allow and disallow drainage of the first flush collected in the interceptor cylinder through the drain pipe
Drain pipe	To drain the first flush collected in the interceptor cylinder hence

4.7.1.2 Detailed design of the fixed volume first flush interceptor

The design works in a way that, the initial runoff is stored in a container and prevented from mixing with the clean water in storage tank. After (a fixed volume of) water fills up the

cylinder, a ball at the bottom will float up and seal the funnel bottom hence first flush water will be prevented from washing back and no more water enters the cylinder and hence goes to the storage tank. The capacity of the first flush interceptor cylinder should be equivalent to the volume of water considered as the dirty first flush. Unlike a fixed rate diverter/interceptors, the fixed volume interceptors do not work in the mechanism of rainfall rate where

I. Factors to be considered.

Below are the guiding factors that need to be considered in the design of the first flush interceptor.

- a) Roof area
- b) Pollution factor for the roof

Various literatures have given the pollution factor that is the amount of water to be diverted per roof area as

- The first 1-2 gallons per 100 square feet (Malcolm 2007)
 - 25 gallons per 1000 square feet(Virginia rainwater harvesting manual)
 - 10 gallons per 1000 square feet (Texas Water Development Board, 2005)
 - 0.5L- 2L Per square meters depending on the environment if open fields, absence of trees, no bird droppings and clean environment or areas with leaves and debris, bird droppings and animal matter.
 - 10 gallons (37.85litres) per 1000 square feet (93 square meters) (Guideline For Rain Water Harvesting In Tanzania, 2016)
- c) Diversion volume
- Diversion volume for first flush diverter depends on roof size and pollution factor and it is given by

$$V = Pf \times Ar \dots \dots \dots \text{eq 3}$$

Where;

V is amount of rainwater to be diverted

Pf is Pollution factor for the roof

Ar is roof area

II. A real example can be deducted from household where water sample S1 was obtained

- a) The total roof area was 144 square meters equivalent to 1000 square feet.

b) Taking a pollution factor of 10 gallons ``6tgV` (37.85litre) per 1000 square feet (93 square meters) according to Guideline For Rain Water Harvesting In Tanzania (2016)

c) Diversion volume for first flush diverter is given by

$$V = Pf \times Ar$$

$$V = 37.85 \text{ litres} / 93 \times 144$$

Volume to be diverted = 58.6 Liters

Take volume to be diverted as 60 liters that is equivalent to 16 gallons and 0.06 cubic meters.

Hence opt for a 60 liters cylinder or 7m of 100mm PVC pipe whereas 1m of 100 mm PVC pipe holds approximately 8.8L of water

d) Sizing the local fixed volume first flush interceptor cylinder

Volume of a cylinder is given by

$$V = \pi r^2 L \dots \dots \dots \text{eq. 4}$$

Where as

V is interceptor cylinder capacity

r is radius of interceptor

cylinder L is depth of the

interceptor cylinder

$$0.06 = \pi D^2 L / 4$$

Selecting a length of 1m therefore

Putting in numbers D is 0.28meters equal to 280mm

Provide;

- A cylinder with diameter of 300 mm, (0.3m),
- An inlet PVC pipe of 100mm and
- A floating ball valve of size 150mm (5.91 inches)

Strengths of first flush interceptors

- Improvement of water quality

- Prevents entrance of mosquitoes, spiders, debris and animal droppings into the storage tank
- Can be designed to suit various roof sizes
- The system consists of a firm and sound assembly
- Has minimum cost of installation about 5% of the cost of the whole rainwater harvesting system
- Low maintenance requirements

Weaknesses of the first flush interceptors

- A flush interceptor can be disrupted by large debris in the runoff
- It is not self-cleaning, therefore it requires occasional manual cleaning

4.7.2 Use of screens and pre-tank filters

Screens and filters have a function to prevent leaves, particulate matter and other objects from entering the storage tank. These should be generally employed as initial step to obtain an improved quality of the harvested rainwater. The screens and filters can be installed anywhere before the tank and the first flush interceptor for the purpose of protecting the quality of rainwater stored in the tank by preventing the introduction of debris. Filters collect rainwater through a straining action which occurs through some form of screens or mesh

Things to consider include; the fabric or mesh used should be self-drying to prevent growth of algae and biofilm and the filter should be made of stable materials which do not change shape and can withstand temperature changes.

4.7.3 Provide a ladder to access the tank for cleansing

Difficult cleaning and low cleansing frequency were among the findings during this research. This is highly contributed by poor means to access the tank for cleaning. Therefore a ladder should be provided to enhance easier access the tanks to enable cleaning. A ladder can be fixed to the tank or a loose ladder that can be placed and removed after tank cleaning.

4.7.4 Boiling

Boiling is among the methods of disinfecting water. It is very simple option, less expensive and effective. A great number of pathogenic organisms like bacteria, virus and parasites that cause waterborne diseases get killed when water is boiled to a high temperature of about 100°C (degrees centigrade). Boiling should be done for at least 20 minutes to ensure effectiveness of this method in killing bacteria. Vigorous boil as recommended by WHO is believed to be capable of killing and inactivating most organisms that may cause diarrhoea. Furthermore it has been brought forth that turbidity does not affect disinfection of pathogens by boiling. However it has been recommended that filtering should be done before boiling if needed. For household use, water is usually boiled in a pot that is placed on a stove. After boiling is completed, the boiled water should immediately be poured on storage container so as to enable the heat of the boiled water to kill any bacteria that are present in the storage container. This method of disinfection by boiling is limited by factors such as fuel costs and time used to boil and cool the water before consumption (Gilman & Skillicorn, 1985)

5. Conclusions

The potential sources of contamination of stored rainwater identified are roof depositions as given by a response of 83% of the respondents, gutter deposition, leaking conduits and leaking storage tanks

Unsafe means of obtaining water from storage tank also contributes to contamination as identified from 42% of the respondents while only 52% used safe means such as use of taps and pump. The means of first flush diversion done is manual means involving disconnection of the conduit that conveys water from gutter to storage tank.

6. Recommendations

Appropriate rainwater harvesting system design including proper construction of storage tanks as well as maintenance and regular cleaning of the system should be adhered. Also frequent tank cleansing should be taken into practice so as to remove the settled dirt at the bottom as well as dirt in tank walls so as to prevent contamination of newly filled water. Rainwater that was obtained direct from atmosphere without roof or tank contact and used as a baseline in this study should be collected using a sterilized glass container so as to make more difference from the sample obtained

from the storage tanks I the coming studies. In addition, repair and replacement of old and worn out gutter, conduits and tanks should be done whenever required so as to prevent contamination that results from easy dissolving of contents of tank, gutter and conduits in stored or conveyed water. Education provision concerning recommended water quality should be provided to the society. This will provide a sound mind to the society when consuming water

7. Conflicts of Interest

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10. Declarations of AI assisted tools

During preparation of this manuscript, ChatGPT (OpenAI) was used to assist with language editing, improving clarity, readability and refining the presentations of some sections. The author reviewed and verified all AI assisted content and take full responsibility for the accuracy, originality and interpretation and final content of the manuscript. No AI tool was used to generate, fabricate or manipulate research data, results or references.

11. Data availability

The datasets generated and analysed during current study are available from the author upon reasonable request.

12. Author contribution declaration

The author conceived and designed the work. The author performed data collection, analysis and interpretation of findings. The manuscript was drafted and critically revised by the author. The author approves the final version of the manuscript and accepts responsibility for the work.

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