World Journal of Advanced Research and Reviews
eISSN: 2581-9615 CODEN (USA): WJARAI
Cross Ref DOI: 10.30574/wjarr
Journal homepage: https://wjarr.com/

(Research Article)

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Assessment of variations in microbiological quality of water in the newly constructed rainwater-harvesting system storage tank

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World Journal of Advanced Research and Reviews, 2023, 18(01), 445–450

Publication history: Received on 25 February 2023; revised on 08 April 2023; accepted on 11 April 2023

Article DOI: https://doi.org/10.30574/wjarr.2023.18.1.0582

Abstract

Proper harvesting of rainwater requires a good knowledge of the storage conditions and the nature of physico-chemical and microbiological contaminant loads on the harvested water. This will help to determine the nature and level of treatment required. This study assessed the variations in the microbiological quality of water stored in a newly constructed galvanized steel tank over the course of one rainy season in Afikpo, Nigeria. A 2.0 mm thick galvanized steel tank of 1.728 m^3 capacity was constructed together with water collection system including coarse mesh, gutter, funnel, conduits, first-flushing device and filter. Rainwater was collected into the tank, sampled, discharged, and rinsed with chlorinated water at each sampling episode throughout the rainy season at Afikpo, from April to November 2021. The water samples were tested in the laboratory for total coliform and faecal coliform. The weekly concentrations of total coliform range between 90CFU/100 ml and 320CFU/100 ml; the mean is 177CFU/100 ml. The weekly concentrations of faecal coliform fall between 30CFU/100 ml and 261CFU/100 ml; the mean is 108CFU/100 ml. These results indicate that the concentrations of the two pathogens are far above the zero limit recommended by the World Health Organization (WHO) and Nigerian Standards for Drinking Water Quality (NSDWQ) . Hence, the rooftop-harvested rainwater is unsafe for human consumption without treatment. Boiling or chlorine treatment is needed. Public health authorities in Afikpo should sensitize the public on the dangers of consuming untreated rainwater as is the practice found among many in the area.

Keywords: Rainwater harvesting; Rooftop; Microbiological quality; Storage tank; Variation

1. Introduction

Water is a necessity of life, and access to portable water is a fundamental human right [1]. Lack of access to safe drinking water has become a global challenge especially in developing countries. According to Boschi-Pinto et al. [2], access to clean water is worst in the developing countries with at least one third of the population living without access to safe drinking water and about 1.87 million children die annually due to diarrhoea.

Majority of the households in developing countries do not enjoy structured and functional water supply system, hence they rely on individual arrangements for drinking water supplies. A good number of rural households in Nigeria lack access to piped water and so they rely on traditional water sources such as surface water, rainwater and water wells/boreholes. Unless properly managed these traditional sources of drinking water are vulnerable to contamination [3 – 5] and portend great health risk to water consumers.

In many countries of the world endowed with ample yearly rainfall, rainwater harvesting from rooftop can serve as an alternative source of potable and non-potable water supplies for many households [6]. Proper harvesting of rainwater in a manner that guarantees water safety can help mitigate stress on potable water supply and demand in the sub-

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Saharan African countries. Most of the countries in sub-Saharan Africa have rainfall for more than half of the year. Hence, proper harvesting and storage of rainwater can potentially meet more than 50% of the portable/non-portable water needs of families or households.

In Nigeria, rainwater harvesting from the rooftop is a practice by many, especially in the rural areas. Rainwater is collected into pots, buckets, vessels, surface tanks (of PVC or metals), and underground tanks or cisterns. However, the concern is about the design and management of the water storage devices/systems and on monitoring of the quality of water stored inside the devices. Many household in the developing countries seem to have erroneous belief that rooftop-harvested rainwater is safe and requires no treatment. In Nigeria, for instance, many use rainwater for direct consumption. However, this practice exposes the consumers of rooftop-harvested rainwater to health risks associated with gastro-intestinal waterborne pathogens of faecal origin.

Studies have confirmed presence of contaminants in rain-harvested water under storage conditions [7]. The contaminants were such that contaminate the physico-chemical and microbiological quality of drinking water. Various categories of pathogenic organisms could be present in the faeces of birds, insects, mammals, and reptiles that have access to the rooftop of dwellings. The animal faeces have been identified as one of the possible sources of microbiological contaminants in rooftop-harvested rainwater [8]. Some microbial pathogens excreted by birds unto the rooftop cause gastro-intestinal infections when ingested from contaminated water. Examples are *E-coli, Salmonella spp, Campylobacter, Giardia spp*, etc.

The condition of the storage devices can influence the propagation or growth of pathogens inside the water containers. Containers with dirty, rough or rusty internal surfaces may provide nurseries for growth of microorganisms. Deterioration of tank material may facilitate cleavage of microorganisms and induce their reproduction. Leaks may encourage intrusion of pathogens into the water storage device from the outside. In addition, ambient or physical conditions such as temperature and pH may influence the growth of microorganism in water storage containers.

A properly constructed water storage tank must be in a condition that discourages the growth of microorganisms. The longer the pathogens remain in the stored water, the more likely the microbial loads will increase. For safety of water users, there should be an objective basis for knowing when the rainwater storage tanks are to be cleaned or disallowed from receiving water. There may be periods during the rainy season when microbial loads on the rooftop would be high. In such cases water should be allowed into the tank only when the rooftop has been adequately washed by the rain. The aim of this study is to assess the variations in the microbial quality of water stored in a newly constructed galvanized steel tank over the course of one rainy season in Afikpo, Nigeria.

2. Material and methods

2.1. The study area

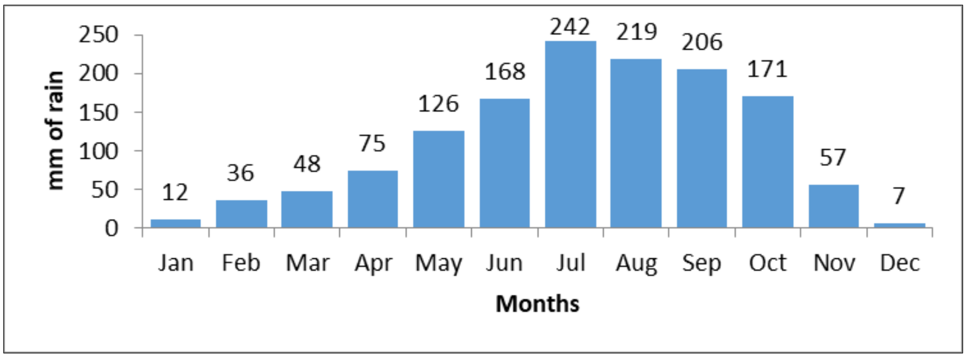

Figure 1 Average monthly rainfall for Afikpo, Nigeria [9]

The study area is Afikpo, the administrative headquarters of Afikpo North Local Government Area of Ebonyi State, Nigeria. Afikpo is situated in the southern part of Ebonyi State, Nigeria. It is located on 5.8911° N, latitude and 7.9307° E longitude. It occupies an area of about 64 square miles (164 km^2). Afikpo is a hilly area despite occupying a region low in altitude, which rises 350 feet (110 m) above sea level. It is a transitional area between open grassland and tropical forest. Afikpo has an average annual rainfall of 77 inches (198 cm). The study area has tropical climate with two seasons: the rainy and the dry season. In Afikpo, rainfall varies very significantly throughout the year. The rainy season lasts for about 7.5 months, while the dry season takes about 4.5 months. Fig. 1 depicts the rainfall pattern and intensity (mm of rainfall) of the study area.

The study area is an emerging urban area still having a large population with rural characteristics. Many household rely majorly on rooftop- harvested rainwater for their drinking water supplies during the rainy season.

2.2. The rooftop rainwater harvesting system (RRHS)

A 2.0 mm thick galvanized steel tank of 1.728 m^3 capacity was constructed at an engineering workshop at Afikpo. An opening of 0.004 x 0.004 m^2 was created on top of the tank to receive rainwater. The tank was elevated with a reinforced concrete support close to a building used for catchment of rainwater. The rooftop material for the building is aluminum-roofing sheet. Other components of a rainwater harvesting system - coarse mesh, gutter, funnel, conduits, first-flushing device and filter - were connected to the steel tank.

2.3. Sample collection

The steel tank including every other component of the RRHS was thoroughly washed with detergent water solution. The tank was soaked with chlorinated water for 2 hours to get rid of microorganisms. The system was then flushed with portable water from a water borehole before rainwater was allowed in. The early rains before April were prevented from entering the tank with the help of first – flush device connected to the system to stop excess dust and debris from getting into the tank. After which the harvesting of rainwater commenced. Harvested rainwater was stored in the constructed galvanized steel tank.

Samples of harvested rainwater were collected from the tank weekly for a period of eight months, from April 2021 to November 2021. A total of 32 samples of rooftop-harvested rainwater were collected for analysis within the sampling period. The samples were collected using sterilized sampling bottles with stopper. The sampling bottle was rinsed thrice with the rainwater sample before sample collection. Necessary precautions were taken to ensure that no accidental contaminations occurred during water sampling. The temperature of the rainwater samples were measured immediately after collection using a liquid in glass thermometer.

The samples were placed inside an ice chest to protect them from sun light and to maintain a constant temperature of 4°C.The samples were then transferred to the laboratory for microbiological analyses within 24 hours of collection. Rainwater was collected into the tank, sampled, discharged, and rinsed with chlorinated water at each sampling episode throughout the study.

2.4. Laboratory analysis

The water samples were tested in laboratory within 24 hours of arrival for concentrations of total coliform and faecal coliform. Temperature and pH of the water samples were also measured. The total coliform and faecal coliform bacteria tests were used to assess the microbiological quality of the rooftop-harvested rainwater. Since total coliform and faecal coliform are usually associated with faecal contamination of water and their presence and concentration in water samples reveal the degree of pathogenic risks, their tests are used to index hygienic quality of water. The most commonly used indicator to determine the possible presence of pathogenic organisms in water is the faecal coliform.

2.4.1. Temperature determination

The temperature (°C) of the rooftop-harvested rainwater samples was measured using liquid-in-glass thermometer.

2.4.2. pH determination

The pH of the rainwater samples was determined using the HANNA pH meter (model HI 8424). The pH meter was calibrated using 4.7 and 10 buffer solutions before use.

2.4.3. Total coliform and faecal coliform determination

Total coliform and faecal coliform bacteria tests were carried out at the laboratories in accordance with the APHA Standard Methods for the Examination of Water and Wastewater [10].

3. Results and discussion

3.1. Variations in microbiological quality of rooftop- harvested rainwater inside storage tank

Figs, 2a and 2b show the variations of microbiological quality (indicated by total coliform and faecal coliform) of the harvested water inside galvanized steel storage tank. The result in fig. 2a shows that the weekly concentrations of total coliform range between 90CFU/100 ml and 320CFU/100 ml; the mean is 177CFU/100 ml. The weekly concentrations of faecal coliform fall between 30CFU/100 ml and 261CFU/100 ml; the mean is 108CFU/100ml. These results indicate that the concentrations of the two pathogens are far above the zero limit recommended by the WHO [11] and NSDWQ] 1]. Hence, the rooftop-harvested rainwater is unsafe for human consumption without treatment.

The high concentrations of total and faecal coliform in the water samples indicate that rooftop-harvested rainwater is heavily polluted by faecal materials. The source of water pollution is unlikely to come from the tank and rainwater collecting system since they were newly constructed and sanitized at the beginning of the investigation. Hence, pollution of the water might have come from either the rooftop or the rain itself. Studies suggest that faecal materials that are laden in the air could microbiologically contaminate rainwater. However, the bulk of pollution will most likely come from the rooftop serving as the catchment.

Fig.2b shows the variations in the total and faecal coliform alongside rainfall measure on a monthly time scale. Investigation began in early rainfall in April (2021) and continued towards the late rainfall in November (2021). Analysis of fig. 2b indicates that loads of pathogens of the rooftop-harvested water in the storage tank reduce with increase in rainfall. This is possible because the rooftop that serves at the catchment would usually be dirty at the onset of rain. The more the rain intensity, the cleaner is the rooftop catchment. Same reasoning goes for pollutants in the atmosphere. Nevertheless, the result of this study suggests that the intensity of rain is most unlikely to eliminate pollution of harvested rainwater. Intensity of rains may not be enough to prevent animals, especially birds from defecating on rooftops.

3.2. Variations in temperature and pH (physical conditions) of rooftop- harvested rainwater inside storage tank

Figs 3a and 3b show the weekly and monthly physical conditions, respectively, of the rooftop-harvested rainwater inside the galvanized steel tank. Temperature in the tank during the investigation ranged between 14 ℃ and 22 ℃; mean is 190 ℃. The pH varied between 5.5 and 7.4; the mean is 6.8. The results indicate that variations in physical conditions did not present any significant effect on water quality. The temperature throughout the period was below ambient due to poor conductivity of water inside the tank. The variation in temperature was affected by the ambient temperature. The pH of the stored water was below 6 for the April and May possibly due to high levels of dirt on the rooftop. It was however, within the acceptable limit for most of the months.

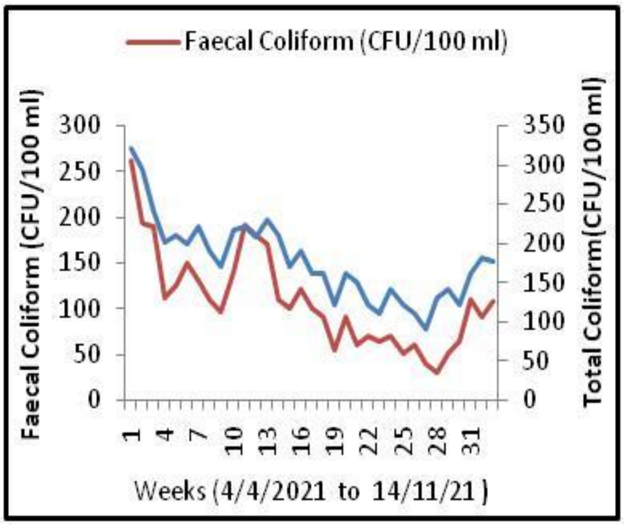

Figure 2a Weekly Variations in microbiological parameters

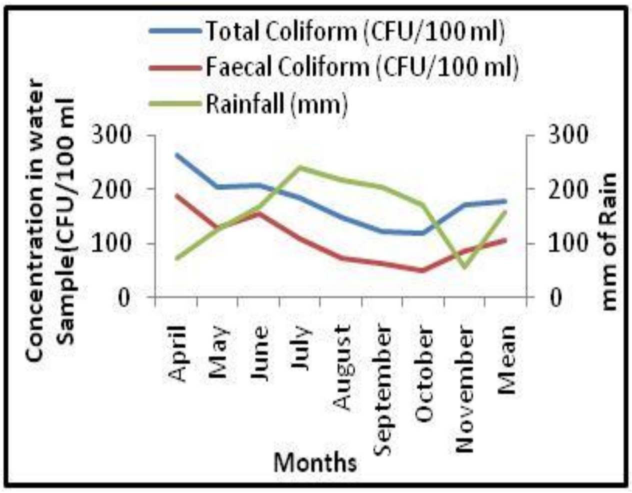

Figure 2b Monthly variations in microbiological parameters together with rainfall

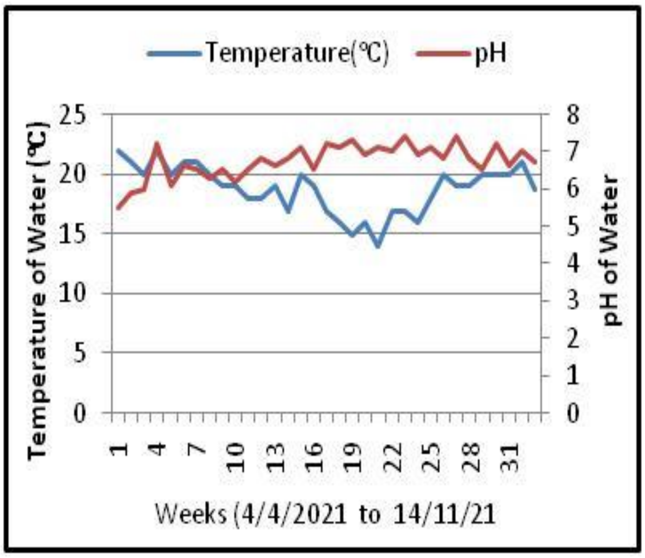

Figure 3a Weekly variations in temperature and pH of water sample

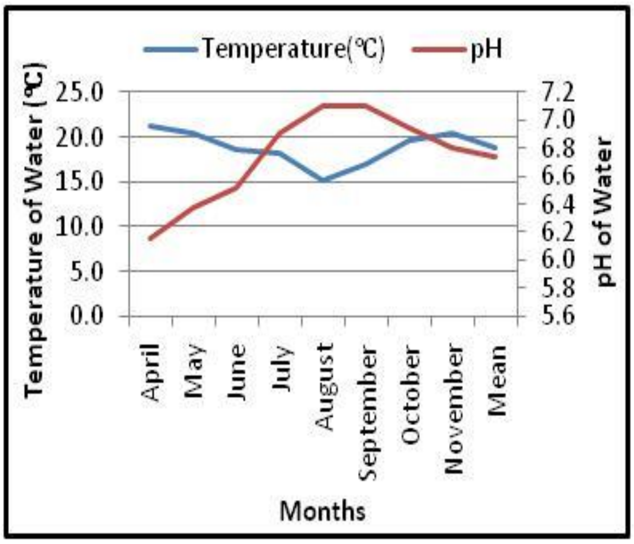

Figure 3b Weekly variations in temperature and pH of water sample

4. Conclusion

This paper investigated the variations in microbiological quality of rooftop-harvested rainwater stored in a newly constructed galvanized steel tank for 8 months from the beginning of rains in April 2021 toward the subsiding of rains in November 2021 at Afikpo, Nigeria. The study found high loads of total and faecal coliform in all months, indicating faecal contamination. The pathogen loads were highest at the beginning and end of rains; they reduced with increasing intensity of the rains but reductions were not enough to eliminate compromise of drinking water quality. The storage tank and the water collection systems were new and in sanitary conditions at the beginning of the investigation. Their surfaces most unlikely did not significantly compromise the microbiological quality of water. The study concludes that rooftop harvested water in the study area is faecally contaminated and is therefore unsafe for direct human consumption.

Recommendation

The following are the recommendations:

- Rooftop rainwater meant for drinking, cooking and personal hygiene should not be harvested at the first two months of early rain.
- Tanks and containers for storing rooftop-harvested water should be periodically cleaned and emptied, suggestively every two months.
- Rooftop- harvested rainwater must not be consumed directly without treatment. Boiling or chlorine treatment is needed,
- Public health authorities in Afikpo should sensitize the public on the dangers of consuming untreated rainwater as is the practice found among many in the area.

Compliance with ethical standards

Acknowledgments

The authors thank the students of the Department of Civil Engineering Technology, Akanu Ibiam Federal Polytechnic Unwana, Nigeria, who assisted us in this work in various ways.

Disclosure of conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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