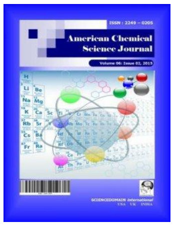

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Assessing the Quality of Rainwater from Different Roof Types in Kuntanase, Ghana

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Authors' contributions

This work was carried out in collaboration between all authors. Authors AAP and NB designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors SJC and ABD managed the analyses of the study and the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The present study assessed the quality of rainwater harvested from three different roofing types namely aluminium, thatch and galvanised in Kuntanase, Ashanti Region, Ghana.
Study Design: A total of twenty one samples were collected from three different roof types (aluminium, thatch and galvanised) from the study area.
Place and Duration of Study: Triplicate samples were collected from each sampling site in the study area from March to April, 2014.
Methodology: Samples were collected and kept in ice chest (4°C) and conveyed to Kwame Nkrumah University of Science Technology laboratory for analysis of total hardness and coliforms. pH and electrical conductivity of rainwater were determined immediately after sampling in the field.
Results: EC and total hardness values obtained were within World Health Organization stipulated limits for potable water except pH. The present study obtained total coliform count that ranged from

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4.0×10^5 to 4.4×10^7 cfu/100 ml with a general mean of $6.45 \times 10^6 \pm 9.58$ cfu/ 100 ml.

Conclusion: The study shows that microbial aerosols, debris and dirts and faecal waste are major pollutants of the rainwater harvested. The detection of total and faecal coliform from the harvested rainwater is evident that the rainwater is contaminated and has the potential of causing water-related disease burden if not treated before drinking.

Keywords: Coliforms; Ghana; microbial aerosols; rainwater harvested; roof types.

1. INTRODUCTION

Scarcity of water has become a crucial problem due to ever increasing urbanization, persistent frequent droughts and changing climate patterns. Rainwater harvesting systems are one of the ways to address the worldwide increase in demand for safe water. Rainwater is currently used as a source for many domestic purposes like drinking, bathing, laundry, toilet flushing and for gardening purposes. World-wide rainwater has gain recognition since time immemorial to augment the supply of water or even form the main store, depending on the situation. In hard water areas or where water contains a lot of iron, people may also be more inclined to use rainwater for drinking and cooking purposes. In many areas of the world today, it can either be the only source of water for the household, or more commonly a supplementary supply to ease the burden of water collection from other sources [1].

Rainwater harvesting (RWH) in urban areas is a strategy that brings many benefits and may serve to cope with current water shortages, urban stream degradation and flooding [2]. Most serious rainwater contaminants are normally limited to urban and industrial locations, pollutants can be transported over great distances before being washed out in the rain [3]. Water quality and the potential impacts of polluted water on human health is a fundamental concern in considering use of captured rooftop rainwater. The rooftop runoff may contain pollutants such as metals or hydrocarbons from roofing materials, nutrients from atmospheric deposition, bacteria from bird droppings that are generally found in significantly lower concentrations, and the runoff is generally free of the toxic contaminants that may be picked up after the runoff mobilizes off-site [4]. One of the primary areas of concern regarding the use of rainwater, for either non-potable or potable application, is quality. The quality of water collected in a rainwater system is affected by many factors including environmental conditions such as proximity to heavy industry or major roads, the presence of birds or rodents [5,6]. Contact with a catchment material and the dirt and debris that are deposited upon it between rainfall events [7,8]. Chang et al. [9] reported that roofs can be a serious source of non-point source pollution as well.

Rainwater harvested can be contaminated through the media in which it is harvested thus roof type (such as roofing materials, slope and length). Due to the acidic nature of ambient rainwater, chemical compounds from roofing materials may leach into the harvested rainwater. Other studies showed that older roofs leach more metals, suggesting that the age of the roof can negatively impact the quality of harvested rainwater [9]. Although several additional studies in other countries have examined the effect of roofing material on harvested rainwater quality, domestic studies of the effect of roofing material on harvested rainwater quality might be more useful because roofing materials, coatings, and building practices vary globally [9]. Ambient rainwater also is susceptible to contamination by microbial aerosols; urban aerosols have recently been shown to contain up to 1,800 different types of bacteria, which is comparable to the diversity of bacteria found in soils [10]. Deposition of faecal microorganisms on rooftops from animals such as birds, lizards and squirrels is problematic as well [11,12]. Researchers have detected total coliform, faecal coliform, *Salmonella* spp., *Campylobacter*, *Escherichia coli, Cryptosporidium* and *Giardia* in rainwater storage tanks [7,11,13,14].

Harvested rainwater has received significant attention as a potential alternative source of potable and non-potable water in the community as result of scarcity of water. Rainwater harvesting systems have the potential to transmit microorganisms that can cause gastrointestinal illness in humans. Leaf litter, aerosols, animal and birds faecal waste, over age of roofing material or type and particulate air pollutants can significantly contribute to elevated coliform bacteria concentrations in roof runoff. Generally, rural indigenes feel that roof-harvested rainwater is safe to drink regardless of roofing material. Hence, the main objective of this study was to examine the quality of harvested rainwater from different roof types in the Kuntanase community.

2. MATERIALS AND METHODS

2.1 Study Area

The Bosomtwe district is one of the 30 created districts in the Ashanti Region. It lies within latitudes 6º 43' North and longitudes 1º46' West and it spreads over a land area of 718 sq.km. The district is bounded on the north by Atwima Nwabiagya and Kumasi Metropolis and on the east by Ejisu-Juaben district. The southern section is bounded by Amansie West and East districts. Kuntanase is the district capital. The district falls within the forest belt of the Ashanti Region and it is within the West semi-equatorial climate region with a rainfall regime typical of the moist semi-deciduous forest zone of the country. There are two well-defined rainfall seasons; the major season occurs from March to July with a peak fall in June. The minor season starts from September to November with a peak fall in October. August is generally cool and dry. The dry season begins in December and ends in February. Temperatures are generally uniformly-high throughout the year with an annual mean of 24ºC. The highest mean temperature (27.8ºC) occurs just before the major season in February as observed in Kumasi. The mean minimum occurs during the minor wet season. Relative humidity (RH) is generally high throughout the year. The relative humidity values ranges between 71.6% to 95% during the wet season with the lowest value of 42.5% in the dry season during January. The natural vegetation of the area falls within the semi-deciduous forest zone of Ghana, which is characterized by plant species of the Celtis Triplochetol Association. However due to extensive farming activities, the original vegetation has been degraded to mosaic of secondary forest, thicket and for re-growth and various abandoned farms with relics of food crops and vegetation.

2.2 Sample Collection and Analysis

Random sampling technique was employed in selecting the household. Three common roof types were used, namely: Galvanised metal roof type (Plate 2): samples were taken from three sources, designated as G1, G2 and G3; Thatch roof type (Plate 1); rainwater were collected from three sources designated as T1, T2 and T3; Aluminium roof type (Plate 3); rainwater were collected from three sources, designated as AL1, AL2 and AL3; and Control; samples were collected from three sources, designated as C1, C2 and C3. Three homes each with the above roof types were selected randomly and rainwater samples were collected from March to April, 2014. Samples were collected three times (in duplicates) from each sampling site in the study area making a total of twenty one samples in the study period. Care was taken to ensure that samples are representative of rainwater examined and that no accidental contaminations occurred during sampling. Sample containers were rinsed with sterile water and drained before they were used to collect the rainwater sample from the different roof types. The pH and electrical conductivity of the rainwater samples were measured immediately after collection using pH meter and conductivity meter respectively.

Samples for coliform bacteria analysis were kept in ice chest at temperature of 4ºC prior to analysis. The samples were conveyed to Kwame Nkrumah University of Science Technology laboratory for analysis of total hardness and coliforms. The Most Probable Number (MPN) method was used to determine total and faecal coliforms in the samples. Serial dilutions of 10^{-1} to 10^{-4} were prepared by picking 1 ml of the sample into 9 ml sterile distilled water. One millilitre aliquots from each of the dilutions were inoculated into 5 ml of MacConkey Broth with inverted Durham tubes and incubated at 35ºC for total coliforms and 44ºC for faecal coliforms for 18-24 hours. Tubes that showed colour change from purple to yellow and gas collected in Durham tubes after 24 hours were identified as positive for both total and faecal coliforms. Counts per 100 ml were calculated from Most Probable Number (MPN) tables. For *E. coli* (Thermotolerant coliform) determination a drop was taken from each of the positive tubes identified and transferred into a 5 ml test tube of trypton water and incubated at 44ºC for 24 hours. A drop of Kovac' reagent was then added to the tube of trypton water. All tubes that showed a red ring colour development after gentle agitation denoted the presence of indole and recorded as presumptive for thermotolerant coliform (*E. coli*). Counts per 100 ml were calculated from Most Probable Number (MPN) table. The rainwater data was subjected to Pearson's correlation analysis to determine the common source or interaction that exists between the tested parameters.

Plate 1. Thatch used for roofing where samples were collected

Plate 2. Galvanised roof where samples were collected

3. RESULTS AND DISCUSSION

The presented study was conducted to determine the impact of different roof types on pH, electrical conductivity, total hardness and coliform bacteria of rainwater in the Kuntansi. Water with a low pH can be acidic, naturally soft and corrosive. Drinking water with a pH level above 8.5 indicates high level of alkalinity minerals is present. The elevated concentration of alkalinity does not pose a health risk, but can jeopardize aesthetic quality of the rainwater. pH values of rainwater from all the sampling sites ranged from 6.21 to 6.85 pH-unit with general mean of 6.59±0.22 pH-unit which fall within the WHO maximum allowable limit for potability of 8.5, but fall below the lower limit of 6.5 (Table 1). Fig. 1 below compares the various means of harvested rainwater samples. The study recorded pH values that are bit higher than 6.5 pH-unit.

However, pH values are generally within the supposed range of 4.5 to 6.5 pH-unit for ambient rainwater that could increase slightly after falling on the roof and during storage in tanks [15]. This implies that the harvested rainwater from the various catchments have not greatly affected the pH of the rainwater as the values obtained are not significantly different from the ambient rainwater pH values. Generally, samples from galvanized roof obtained the lowest pH values. This finding learn support from Hamdan [16] that reported that pH of rainwater can either increase or decrease when rainwater get in contact with the roof surface. This work is also in line with Mendez et al. [17] that reported that roofs comprised of metal (Iron-zinc, aluminum, galvanized iron, zinc) shows decreased in the pH of rainwater.

Plate 3. Aluminium roof where samples were collected

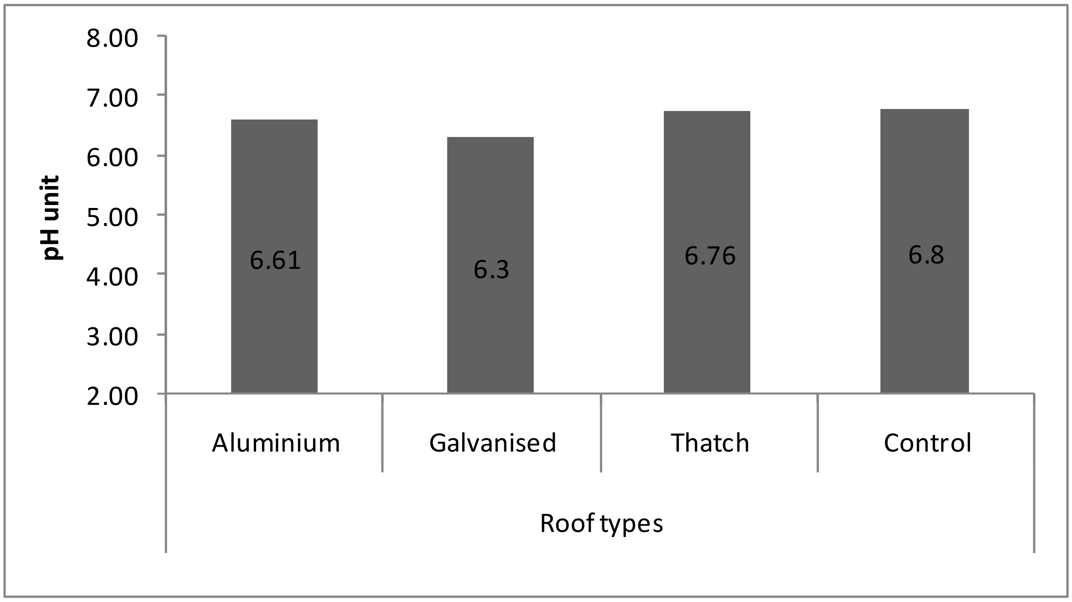

Fig. 1. Mean pH values of the rainwater harvested

Table 1. Results of harvested rainwater samples at Kuntanase

Parameter	pH	Conductivity	Hardness	Total coliform	Faecal coliform	*E. coli*
Units	pH-unit	µS⁄cm	mg⁄l	cfu/ 100 ml	cfu/ 100 ml	cfu/ 100 ml
AL1	6.54	119.6	24.01	4.3 x 10^5	Nil	Nil
GA1	6.21	142.2	23.08	4.3 x 10^5	Nil	Nil
TH1	6.71	129.8	21.11	2.4 x 10^5	4.3 x 10^5	Nil
C1	6.82	186.3	22.04	9.3 x 10^5	Nil	Nil
AL2	6.44	139.6	25.1	9.3 x 10^5	Nil	Nil
GA2	6.31	152.2	24.28	1.5 x 10^5	Nil	Nil
TH2	6.81	148.6	23.11	4.3 x 10^5	Nil	Nil
C2	6.72	176.3	24.32	2. 4 x 10^7	Nil	Nil
AL3	6.51	141.2	25.48	4.4 x 10^7	Nil	Nil
GA3	6.38	146.8	24.61	4.6 x 10^6	Nil	Nil
TH3	6.78	146.3	22.54	8.3 x 10^5	4.3 x 10^6	Nil
C3	6.86	178.7	23.24	4.5 x 10^5	Nil	Nil
Mean	6.59	150.63	23.58	6.45 x 10^6	2.37 x 10^6	-
Min	6.21	119.6	21.11	4.0 x 10^5	4.0 x 10^5	-
Max	6.86	186.3	25.48	4.4 x 10^7	4.3 x 10^6	-
SD	0.22	21.09	1.37	9.58	8.09	-
WHO Limits	6.5-8.5	-	500	0	0	0

Electrical conductivity values ranged from 119.6 to 186.3 µS/cm with general mean of 150.63±21.09 µS/cm (Table 1). The minimum electrical conductivity value was obtained from the alumimium roof type and the maximum electrical conductivity value was from the control samples. The mean electrical conductivity values for rainwater samples are presented in Fig. 2 below. Similar study conducted by Efe [18] in rural areas in Delta State, Nigeria also reported similar electrical conductivity values of rainwater. Based on the electrical conductivity values, it can be concluded that environmental quality of Kuntansi has not negatively influenced the harvested rainwater.

Total hardness of the harvested rainwater samples ranged from 21.11 to 25.48 mg/l with a general mean of 23.58±1.37 mg/l (Table 1). The minimum total hardness value was obtained from samples from thatch roof type while maximum total hardness value was obtained from aluminium roof type samples. The total hardness values of harvested rainwater from all the samples were within WHO stipulated limit of 500 mg/l for potability. Fig. 3 below compares the various mean of total hardness concentration of the harvested rainwater samples. Hardness does not pose a health risk but calcium and magnesium in the drinking water augment the dietary minerals requirement for human well-being. Similar study conducted by Efe [18] in rural areas in Delta State, Nigeria also reported that total hardness of rainwater samples were generally below WHO recommended standard of drinking water. Based on water hardness classification by WHO [19] thus; soft (0 to 50 mg $CaCO_3$/l), moderate soft (50 to 100 mg $CaCO_3$/l, slightly hard (100 to 150 mg $CaCO_3$/l), moderate hard (150 to 200 mg $CaCO_3$/l), hard (200 to 300 mg $CaCO_3$/l) and very hard (over 300 mg $CaCO_3$/l). It is evident that the harvested rainwater is soft which implies potable for normal growth, health and indicate palatability of the water. This implies that the low concentration of this mineral in harvested rainwater have the tendency of causing disease burden. Donato et al. [20] reported that soft water is associated with increased morbidity and mortality from cardiovascular diseases (CVDs) compared to hard water as well as water high in magnesium.

The present study obtained total coliform count that ranged from 4.0 ×10^5 to 4.4×10^7 cfu/100 ml with a general mean of 6.45 x 10^6±9.58 cfu/ 100 ml (Table 1). The minimum total coliform value recorded was for roof type galvanized metal and the maximum total coliform value recorded was from the aluminium roof type. The study observed elevated count of total coliform that exceeded WHO stipulated limit for potability. Hence, the harvested rainwater is unwholesome for drinking without treatment and could lead to water-related disease burden that currently is claiming live in every 20 seconds. Similar work conducted by Ahmed et al. [11] also detected total coliform contamination in rainwater harvested from roofing materials. The study show no significant difference in terms of total coliform count from the various roof types though samples from thatch roof are bit higher than the others. The total coliform counts from the control samples indicate that microbial aerosols have contaminated the harvested rainwater. As Brodie et al. [10] reported that ambient rainwater is susceptible to contamination by microbial aerosols; urban aerosols have recently been shown to contain up to 1,800 different types of bacteria, which is comparable to the diversity of bacteria found in soils. Samples from thatch roof type were bit higher perhaps due to debris from thatch used for the roofing or deposit by other means. Since, it has been reported that in rain events dirt and debris that are deposited catchment material comes in contact with the rainwater [7,8].

The present study obtained faecal coliform count that ranged from 4.0 ×10^5 to 4.3×10^6 cfu/ 100 ml with a general mean of 2.37 x 10^6±8.09 cfu/ 100 ml (Table 1). The rainwater samples from aluminium, galvanized metal roof type and control sample recorded zero faecal count that fall within WHO stipulated limit for potability except some sample from thatch roof. This gives indication that rainwater from thatch roof has been contaminated with faecal waste. This implies there is a greater risk of pathogens in the rainwater and when consumed without treatment could be very deleterious to human health. The study obtained zero faecal coliform count from aluminium, galvanized metal roof type and the control which contrast Lye et al. [14] who reported that rainwater from roofing materials are contaminated with faecal coliform except thatch roof. Samples from all the roofs catchments recorded zero for *E. coli* count that is within WHO stipulated limit of potability. This indicates the absence of wind-blown dirt, leaves, faecal droppings from birds and animals, insects and contaminated litter on the catchment areas.

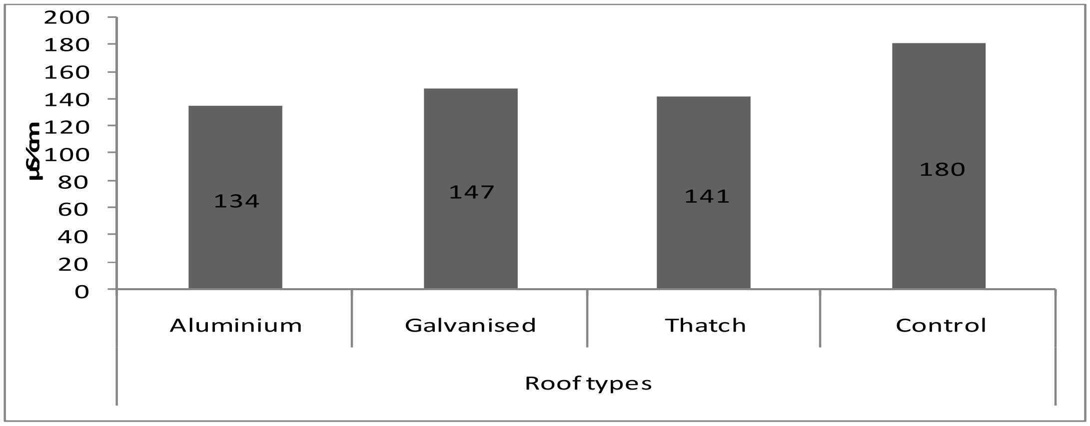

Fig. 2. Mean E. conductivity of the rainwater harvested

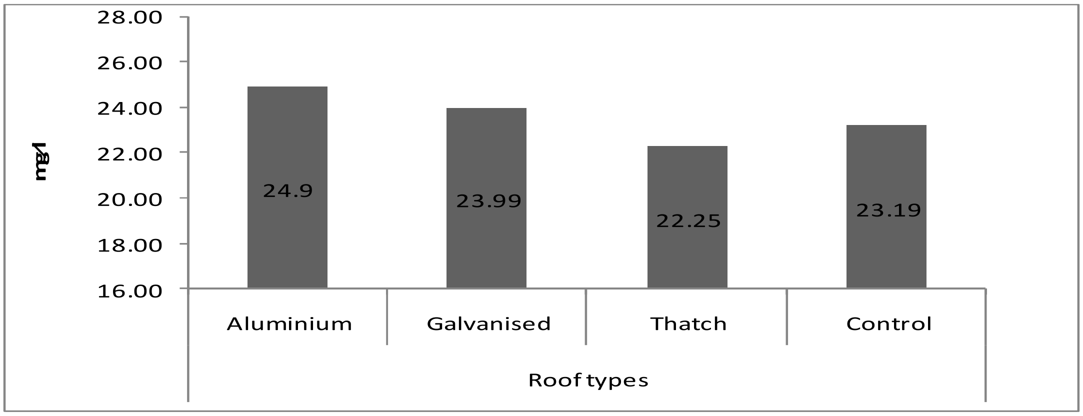

Fig. 3. Mean total hardness concentration of the rainwater harvested

Table 2. Correlation matrix of the parameters considered in the study

Parameter	pH	EC	Hardness	TC	FC
pH	1				
EC	0.47	1			
Hardness	-0.50	-0.12	1		
TC	-0.04	0.06	0.54	1	
FC	1.0**	1.0**	1.0**	1.0**	1

***. Correlation is significant at the 0.01 level (2-tailed)*

The bivariate correlation results show strong positive correlation among faecal coliform with pH, EC, total hardness and total coliform at 0.01 significant level indicating their source of pollution is faecal waste or are effectively interacting in the rainwater harvested (Table 2). The count of total and faecal coliform from the harvested rainwater is evident that the rainwater is contaminated and has the potential of causing water-related disease burden if not treated before drinking.

4. CONCLUSION

The presented study revealed that parameters such as electrical conductivity and total hardness of harvested rainwater samples were generally within the WHO stipulated limits for potability in Kuntanase with the exception of pH. The count of total and faecal coliform from the harvested rainwater is evident that the rainwater is contaminated and has the potential of causing water-related disease burden if not treated before drinking. Samples from all the roofs catchments recorded zero for *E. coli* count that is within WHO stipulated limit of potability. The study shows that microbial aerosols, debris and dirts and faecal waste are major pollutants of the rainwater harvested. The bivariate correlation results shows strong positive correlation of faecal coliform with pH, EC, total hardness and total coliform indicating their source of pollution is faecal waste or are effectively interacting in the rainwater harvested. It is recommended that harvested rainwater should be treated against biological contamination before drinking purpose.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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