Rainwater quality from different roof catchments in the Port Harcourt district, Rivers State, Nigeria

Beatrice Nnene Uba and Onakufe Aghogho

ABSTRACT

Rainwater samples collected directly from the atmosphere and through various roof catchments (aluminium, zinc, asbestos and thatch) were analysed for their physico-chemical and microbiological qualities. Results showed that the physico-chemical qualities of the rainwater, except for colour, were within the limits approved by the World Health Organization. Asbestos and thatch materials caused an increase in colour of the rainwater. A near neutral pH (7.02–7.45) was obtained in all the samples. Higher levels of aluminium were obtained in the samples collected from the aluminium roof catchment while zinc was only detected in the rainwater collected from the zinc roof catchment. Manganese and iron were present in all the samples. Microbiological analysis showed varying degrees of contamination in the different samples. All the samples contained a high number (5.8×10^2–7.6×10^3 cfu/ml) of heterotrophic bacteria. The filamentous fungi population was in the range of 1.0×10–4.0×10^2 cfu/ml. *Pseudomonas* spp. were found in the samples in the range of 1.0×10–8.8×10^2 cfu/ml, except for the samples from the zinc roof where none (0 cfu/ml) were recorded. Rainwater samples from the roof catchments also contained high numbers of pathogenic bacteria, *Salmonella* spp. *Shigella* spp and *Vibrio* spp. This result therefore suggests that the purity of the rainwater should not be taken for granted. Microbiological analysis of all rainwater should be undertaken and appropriate treatment measures adopted before rainwater can be declared potable. Zinc appears to be a better material for rainwater collection than aluminium, asbestos and thatch. Direct collection, however, is the best option when low volumes of water are required.

Key words | aluminium, asbestos, direct catchment, rainwater quality, roof catchments, thatch, zinc

Dr Beatrice Nnene Uba (corresponding Author)
Onakufe Aghogho
Dept of Microbiology,
University of Port Harcourt,
P.M. B 5323,
Port Harcourt,
Rivers State,
Nigeria

INTRODUCTION

Studies on the qualitative aspects of rainwater have become necessary in reaction to heightened environmental awareness and to counter worries over its safety (Torsten & Götz 1999). To date, rainwater has been the only source of potable water in regions where water shortages occur. This situation is common in the rural areas of developing countries like Nigeria. Rainwater, being the only source of water in these regions, is used for almost all domestic purposes, such as washing, cooking, drinking, etc. It is generally believed in some areas that rainwater is pure and very cool to drink, especially if drunk immediately after collection and in rural areas where there is no electricity supply. Water shortages are also often experienced in urban centres with piped water supply, due to the poor maintenance of utilities and equipment failure. Inhabitants of such affected areas resort to rainwater collection for drinking and other domestic purposes.

The rainwater is usually collected either indirectly from the roof, by attaching a metal funnel at the edge of the roof to direct the water into a collection point or directly from the atmosphere into an open space using large mouthed bowls or basins. Some of these roofs are made with materials such as asphalt, aluminium, zinc, and thatch (raffia palm, leaves or grass). In advanced countries, wood, shingles, shakes, tiles, slates, concrete materials and copper are also used (Clois & John 1986).

Asphalt roofing is available in shingles, roll roofing, and saturated felts. It is commonly called asbestos because asbestos is one of the major components of asphalt roofing. This is one of the most common roofing materials in Nigeria and has an average life span of 20 years. The main reasons for its wide use in Nigeria is because it can provide thermal and electrical insulation and it is resistant to dissolution and biological removal. It is cheaper than aluminium. Asbestosis, lung cancer and mesothelioma are serious diseases associated with asbestos exposure and in particular with inhalation of very fine asbestos fibres (Cherubini *et al*. 1998). The International Agency for Research on Cancer (IARC) has classified asbestos among the carcinogenic agents for humans (IARC 1987).

Other roof materials, such as grass, reduce the amount of collectable water and the earth imparts colour to the water. There is also contamination in the form of organic materials and heavy metals that flow from the roof every time it rains, mostly from weather-beaten roofs.

Another problem associated with rainwater is the phenomenon of acid rain. The study of acid rain has become a major component of air pollution research. Heavily industrialised areas of the world and land masses downward of these regions have acid rain. The deposition of acid in natural water has an effect on microbial processes. The acidification of lakes and streams in Europe and North America has been related to atmospheric deposition of strong acids. Acid rain contains ions of sodium, potassium, magnesium, calcium, ammonium, and hydrogen.

Even in a pristine environment, precipitation is not pure, it contains a variety of ions and other pollutants. The concentration of pollutants in rain and drinking water has been evaluated (Mottier 1995; Truffer 1997). It appears that the heavy metals content is much greater in rain than in drinking water for some pollutants (Pb, Cu) and only slightly higher for other heavy metals (Zn, Cd) (Crettaz *et al*. 1998). Sometimes rain contains significant amounts of bacteria, pollen particles, soot, dust and sand. Significant amounts of salt and other minerals from the sea are found in rain near coastlines. Extremely polluted rain has been observed downward of erupting volcanoes, such rains are occasionally black and extremely acidic because of suspended particles and sulphur dioxides (MacGraw Hill 1992).

This project was undertaken to study the physico–chemical and microbiological quality of rainwater in the Port Harcourt district of Rivers State, Nigeria, and to access the impact of roof catchment materials on the rainwater quality. This study will determine if the quality of rainwater meets the guidelines for drinking water quality as stipulated by the World Health Organization (WHO 1984) and so ascertain the potability of the water.

MATERIALS AND METHODS

Sampling locations

The rainwater samples were collected from different areas in Port Harcourt and its environs during the mid rainy season in 1997. Port Harcourt is an urban centre which serves as the capital of Rivers State, Nigeria. Rivers State is located in the Niger Delta region of Nigeria. A number of oil companies are located in Port Harcourt, and these led to increased industrial activities in the town. Rainwater samples were collected directly from zinc, aluminium, asbestos, and thatch roofs in Port Harcourt.

Rainwater was also collected directly in an industrialised area of Port Harcourt (Trans Amadi), and in Aluu village, a non-industralised area about 20 km from Port Harcourt.

Sample collection

Clean surface–sterilised plastic bowls of 5-litre capacity were employed for the collection of the rainwater samples. The bowls were raised from the ground surface on stands that were high enough to prevent splashes or contamination from the soil. They were placed at the edge of the roofs so that rainwater dropped directly from the roof into the bowl. Rainwater samples from the industrial and non-industrial areas were collected directly into the bowl placed in an open field. The collections were made 10–20 min after the rain started, to minimise contamination from dust and debris.

After collection, the samples were poured into a sterile polyethylene container of 4-litre capacity and labelled.

The temperature and dissolved oxygen of the samples were measured *in situ* before being transferred to the laboratory. The samples were stored at 4°C and analysed within 24–48 h.

Analysis of samples

Physico-chemical analysis

The pH of the samples was measured with a conventional portable meter. Turbidities were measured with a Hach Turbidimeter (model 18900-70). Taste and odour were determined by the threshold test as described in APHA (1992). True colour, phosphate, ammoniacal nitrogen, nitrite, nitrate, sulphate, and dissolved iron were analysed following standard methods. Hardness, calcium, magnesium and chloride were determined by titration. Biochemical oxygen demand (BOD_5) was determined as described in APHA (1992). Sodium and potassium were determined by a flame photometer. The Perkin–Elmer direct flame photometer (model 51 ca serial no N2260) was used. Zinc, aluminium, lead, calcium, mercury vanadium, manganese and arsenic were determined using a Perkin-Elmer atomic absorption spectrophotometer (AAS) (model 3100). The samples were acidified to $pH<2$ with ultra pure nitric acid (Merck) and filtered. All sample manipulations were performed following the techniques designed for trace metal analysis.

The analyses of the physico-chemical parameters were replicated for quality assurance of the data, and mean results were obtained.

Microbiological analysis of samples

Total heterotrophic plate count (THPC) was determined by the pour plate method on plate count agar (PCA) at 35°C for 48 h in accordance with techniques described by the American Public Health Association (APHA 1992). Total coliforms (TC), faecal coliforms (FC) and faecal streptococci (FS) were quantified by a membrane filtration technique using appropriate media as stated in APHA (1992) while *Vibrio* spp. were enumerated on thiosulphate citrate bile salt (TCBS) agar (Oxoid) after enrichment with alkaline peptone water. Pathogenic bacteria, *Salmonella* and *Shigella* spp., were quantified after enrichment. Selective enrichment for *Salmonella* isolation was carried out in selenite cysteine broth and brilliant green tetrathionate broth (Collins & Lyne 1984) which was incubated at 41.5°C for 48 h. Bismuth sulphate agar (BSA) was used for the enumeration of black colonies with a 'halo effect' which are characteristics of *Salmonella* spp. Gram negative (GN) broth was used for the selective enrichment of the sample for *Shigella* spp. and incubation was at 37°C for 24 h. The incubated samples were plated out on xylose lysine desoxycholate (XLD) agar and incubated at 37°C for 24 h (APHA 1992). The number of *Shigella* pink colonies which developed were counted for each sample.

Pseudomonas spp were quantified by membrane filtration as indicated in APHA (1992). Filamentous fungi populations were enumerated by a pour plate method on potato dextrose agar (PDA) into which was incorporated 50–100 mg/l chloramphenicol. Yeasts were quantified on dichloran rose bengal chloramphenicol (DRBC) agar using the spread plate technique. Incubation was at 30 ± 2°C for 4 days. Replicate analyses was carried out for each microbial group and the mean results recorded.

RESULTS

Table 1 shows the physico–chemical characteristics of the rainwater samples from various catchment sources. The temperature of the samples ranged from 26–28.5°C, which was within the range of average temperature values recorded in the mid rainy season. pH was in the range of 7.02–7.45 while dissolved oxygen ranged from 8.27 to 8.71 mg/l. Turbidity was low in all the samples ranging from 0.25–0.43 NTU. Taste and odour were not detected in any of the samples. A colour range of 5–20 Pt–Co was recorded in all the samples and the highest value was obtained with the samples from the thatch roof followed by the asbestos roof. Rainwater samples from the asbestos roof were dark while those from the thatch roof were deep amber in colour. Phosphate concentration was in the range of 0.056–0.082 mg/l (mean = 0.069 mg/l). The highest value was recorded from the zinc roof samples. Ammonia and nitrite were in the ranges of 0.01–0.02 mg/l

Table 1 | Physico-chemical characteristics of rainwater from the various catchment sources

	Catchment source					
Parameter	**Non-industrial area**	**Industrial area**	**Aluminium roof**	**Zinc roof**	**Asbestos roof**	**Thatch roof**
Temperature (°C)	26	28.5	27.4	28	27	26
pH	7.2	7.45	7.08	7.3	7.02	7.12
DO (mg/1)	8.27	8.65	8.42	8.36	8.56	8.71
Turbidity (NTU)	0.3	0.35	0.28	0.43	0.4	0.25
Taste	Unobjectionable	Unobjectionable	Unobjectionable	Unobjectionable	Unobjectionable	Unobjectionable
Odour	Unobjectionable	Unobjectionable	Unobjectionable	Unobjectionable	Unobjectionable	Unobjectionable
Colour (Pt-Co)	5.0	5.0	5.0	5.0	10	20
Phosphate (mg/l)	0.069	0.068	0.067	0.082	0.056	0.072
Ammonia (mg/l)	0.02	0.01	0.01	0.02	0.01	0.02
Nitrite (mg/l)	0.05	0.04	0.02	0.05	0.03	0.03
Nitrate (mg/l)	0.1	5.95	6.2	5.61	5.88	6.98
Sulphate (mg/l)	0.042	0.073	0.071	0.075	0.073	0.039
Hardness (mg/l $CaCO_3$)	0.85	0.53	0.58	0.68	1.78	1.78
Calcium (mg/l)	0.23	0.27	0.71	0.22	1.94	0.72
Magnesium (mg/l)	0.172	0.012	0.01	0.043	0.03	0.106
Chloride (mg/l)	0.329	0.247	0.06	0.067	0.057	0.073
BOD (mg/l)	0.23	0.4	0.4	0.50	0.2	0.3
Sodium (mg/l)	0.047	0.077	0.05	0.043	0.019	0.024
Potassium (mg/l)	0.017	0.09	0.074	0.038	0.017	0.053
Iron (mg/l)	0.02	0.04	0.16	0.04	0.03	0.04
Zinc (mg/l)	0	0	0.0	0.88	0.0	0
Aluminium (mg/l)	0.083	0.106	0.95	0.14	0.08	0.092
Cadmium (mg/l)	0	0	0	0	0	0
Mercury (mg/l)	0	0	0	0	0	0
Vanadium (mg/l)	0.007	0	0.01	0	0.006	0.008
Manganese (mg/l)	0.074	0.06	0.17	0.38	0.07	0.15
Arsenic (mg/l)	0	0	0	0	0	0
Lead (mg/l)	0	0	0	0	0	0

Table 2 | Microbiological characteristics of rainwater from the various catchment sources

	Catchment source					
Microbiological parameter	**Non-industrial area**	**Industrial area**	**Aluminium roof**	**Zinc roof**	**Asbestos roof**	**Thatch roof**
Total heterophic plate count (cfu/ml)	8.30×10^2	5.8×10^2	1.26×10^3	5.9×10^3	1.75×10^3	7.60×10^3
Total coliforms (cfu/100 ml)	21	<3	39	<3	4	40
Faecal coliforms (cfu/100 ml)	0	0	0	0	0	0
Faecal *Streptococcus* (cfu/ml)	0	0	0	0	0	0
Vibrio spp. (cfu/100 ml)	0	0	9.5×10^2	4.5×10	2.0×10	1.0×10
Salmonella spp. (cfu/100 ml)	0	0	7.3×10^2	3.5×10	8.0×10	1.2×10
Shigella spp. (cfu/ml)	0	0	1×10^2	1.0×10	1.9×10^2	1.2×10
Pseudomonas spp. (cfu/100 ml)	3.2×10	1.0×10	8.8×10^2	0	5.8×10^2	2.1×10
Filamentous fungi (cfu/100 ml)	3.0×10	7.0×10	1.0×10^2	1.0×10	1.0×10	4.0×10^2
Yeasts (cfu/100 ml)	1.5×10^2	7.0×10	5.1×10^2	0	0	1.28×10^3

(mean = 0.015 mg/l) and 0.02–0.05 mg/l (mean = 0.036 mg/l) respectively. Nitrate was in the range of 0.1–6.98 mg/l (mean = 5.12 mg/l). The highest value was recorded from the thatch roof while rainwater samples from the non-industrialised area had the lowest nitrate value. Sulphate concentration was low in all the samples, being in the range of 0.039–0.0.075 mg/l. Rainwater samples from the asbestos roof had the highest values for hardness (1.98 mg/l $CaCO_3$) and calcium (1.94 mg/l). Hardness was also high in the rainwater samples collected from the thatch roof (1.78 mg/l).

Chloride was in the range of 0.057–0.329 mg/l (mean = 0.138 mg/l). Samples from non-industrial and industrial areas had higher chloride concentrations than those from the roof catchments. Biochemical oxygen demand was low in all the samples. Sodium and potassium values ranged from 0.019–0.077 mg/l and 0.017–0.09 mg/l respectively. The highest values were recorded with the samples collected from the industrial area. Iron concentration was in the range of 0.02–0.16 mg/l. Samples from the aluminium roof had the highest value. Zinc was only detected in samples from the zinc roof where a mean concentration of 0.88 mg/l was recorded. Aluminium concentration was in the range of 0.083–0.95 mg/l and the highest was obtained with the samples collected from the aluminium roof catchment. The heavy metals, cadmium, mercury, arsenic and lead were not detected in any of the samples. Vanadium occurred in low concentrations in a range of 0–0.01 mg/l and the highest value was obtained with samples from the aluminium roof. Manganese concentration ranged from 0.06–0.38 mg/l and the highest value was obtained with rainwater from the zinc roof.

The results of the microbiological analysis of all the water samples appear in Table 2. All the samples contained heterotrophic bacteria and filamentous fungi and the highest values (7.6×10^3 cfu/ml and 4.0×10^2 cfu/ml respectively) were recorded with the thatch roof rainwater samples. Total coliform (TC) organisms were low in samples from the industrial area and the zinc roof

(<3 cfu/100 ml), while high values (40 cfu/100 ml and 39 cfu/100 ml) were recorded with the thatch roof and aluminium roof rainwater samples respectively. Faecal coliforms (FS) and faecal *Streptococcus* (FS) were not detected in any of the samples; the pathogenic bacteria *Vibrio* spp., *Salmonella* spp. and *Shigella* spp. were all non-detectable in the rainwater samples from the non-industrial and the industrial areas, but occurred in varying numbers in rainwater samples from the roof catchments. *Pseudomonas* spp. occurred in all the samples except samples from the zinc roof catchment. Yeast was not detected in samples from the zinc and asbestos roofs.

DISCUSSION

The highest desirable level for pH, as stipulated by the WHO (1984), is within the range 7.0–8.5. The pH of all the rainwater samples fell within that range. The presence of industrial activities did not seem to alter the pH of the rainwater. Dry deposition (particulates and aerosols) account for greater inputs of H + . Usually the areas of lowest pH correspond to areas within and around heavy industrialisation and urbanisation where emissions of sulphur and nitrogen oxides are high. It is with these emissions that the most acidic precipitation is thought to originate. The results obtained in this study may be attributed to dilution of the atmospheric particulates and aerosols by rain, since the samples were collected during the mid rainy season. Probably a varied result would have been obtained had the samples been collected during the early rainy season.

The dissolved oxygen concentrations of the samples show that rainwater is oxygen–rich and this is also reflected in the low biochemical oxygen demand. The 'true colour' of the rainwater collected from the asbestos roof and thatch roof varied from that obtained from the other catchment areas. The asbestos and thatch materials seem to affect the colour of the water. Thatch roofs reduce the amount of collectable water and colour the water brown (Torsten & Götz 1999). The WHO approved limit for colour is 5 Pt–Co. The values obtained for the rainwater from the asbestos and thatch roofs far exceeded this limit. Generally, the values of the other physico-chemical parameters in the rainwater collected from the different sources were within the WHO limits, however slight differences occurred with some parameters based on the catchment source. For instance, whereas zinc was not detected in the samples from the other sources a level of 0.88 mg/l was obtained with samples from the zinc roof catchment. The level of aluminium in the samples collected from the aluminium roof was about ten times higher than levels detected in the other samples. This result can be attributed to metal ion leaching of these roof materials. The high level of manganese detected in the rainwater sample can also be attributed to this factor, although manganese was found in all the samples.

The microbiological analysis indicated a low level of contamination in the rainwater collected directly when compared with that collected through a roof catchment. None of the rainwater can be said to be pure based on the bacteriological standards as set by the World Health Organisation. These results contradict the argument put up by those who propose the use of rainwater, that rainwater requires no purification (Torsten & Götz 1999). The WHO limit for heterotrophic bacteria is 500 cfu/ml. The lowest level obtained in this study was 580 cfu/ml, which exceeded the WHO limits. The total coliform population in the rainwater samples from the non-industrial area, aluminium and thatch roofs also exceeded the WHO limit of <10 coliforms/100 ml.

Other faecal pollution indicator bacteria were, however, absent in all the samples. The World Health Organization recommended that *Pseudomonas aeruginosa* should not be present in water intended for drinking. This requirement was included because of the vulnerability of children and the elderly to this organism (Organisation Mondiale de la Santë 1985). The presence of vibrios and the other pathogenic bacteria, *Salmonella* and *Shigella,* in the samples collected from the roof catchments suggests that these catchment roofs are major sources of contamination of rainwater, and also indicates that the contaminants are due to anthropogenic rather than natural causes. In fact our observation during this study showed that reptilian faecal droppings, mostly from lizards, were deposited on the roofs. These reptiles and their faecal pellets harbour coliforms and pathogenic organisms (Holme 1999) which may have been washed into the rainwater.

The presence of *Vibrio*, *Salmonella* and *Shigella* spp., in the absence of faecal coliforms, could be due to the selective enrichment techniques used for the enumeration of these pathogens. This procedure will enable the isolation of these enteric pathogens, even when they fail to grow in a general purpose media, e.g. MacConkey agar (for lactose fermenters), mostly when they occur in low numbers in water or wastewater. First, selective media and or selective isolation methods are said to affect the direct culture of bacterial species (Toze 1999). Secondly, viable bacterial strains in the environment can enter a dormancy state where they are non-culturable (viable but non-culturable) (VBNC) (Xu *et al*. 1982; Porter *et al*. 1995), which can cause an underestimation of pathogen numbers or a failure to isolate a pathogen from water and wastewater. The microbiological analysis of the rainwater samples provided more useful information on the purity of the rainwater based on the catchment source. It is not possible to sterilize the roof catchment before collection of rainwater. As a result it is advisable to carry out microbiological analysis of any rainwater before it can be considered fit for consumption even if the water was collected directly. Otherwise rainwater should be treated before consumption. We should realise that all water, even distilled water, can contain contaminants (Holme 1999).

Rainwater is said to have good properties and around 50% of drinking water can be replaced by clean rainwater. It is an ideal medium for enabling plants to absorb minerals and it offers better washing efficiency as 50% of detergent can be saved. There is no calcification of the washing machine and there is no urinal calculus in the WC (Torsten & Götz 1999).

The method of collection and handling are known to affect the bacteriological quality of rainwater (Pinfold *et al*. 1993). To achieve the desired result therefore, care has to be taken in the method of collection and handling of the rainwater.

CONCLUSIONS

Rainwater quality varies depending on the source of its catchment and period of collection. An appreciable concentration of ions is present in rainwater irrespective of its source of collection. The levels of most of these ions are within the acceptable limits stipulated by WHO. Asbestos and thatch roofs affect the colour of rainwater to an unacceptable level.

Other metallic roofing materials such as zinc and aluminium have an impact on the concentrations of the specific metal in the rainwater, though not excessively. The purity of rainwater, as revealed by microbiological analysis is not guaranteed. Pathogenic organisms such as *Pseudomonas* spp. may be found in rainwater collected directly, and the heterotrophic bacteria population is higher than the stipulated number. Rainwater collected through roof catchments may contain other pathogenic organisms such as *Salmonella* spp., *Shigella* spp. and *Vibrio* spp. as well as even a higher number of heterotrophic bacteria, filamentous fungi and yeasts. It is therefore wrong to assume that it is safe to drink untreated rainwater. Rainwater intended for drinking purposes should not be collected through asbestos or thatch roofs. Zinc roofs have less impact on the physico-chemical and microbiological qualities of rainwater than aluminium, asbestos and thatch roofs. Potable water can best be obtained through direct collection from the atmosphere. This may be applicable in high rainfall areas and when low volumes of water are required. Special devices may be used to increase the volume of rainwater thus collected if need be. Irrespective of the method of collection, microbiological analysis of the samples should be carried out to ascertain its level of purity, and appropriate treatment applied, to achieve the best results in the interest of public health.

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