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Trace metal and nutrient constitution of rain water and sediment/sludge harvested in various storage tanks from galvanized iron roof tops in Kampala City, Uganda

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ABSTRACT

Domestic rainwater harvesting (DRWH) provides an innovative solution to meeting water needs. However, problems of implementation, concerns about water quality and health remain unattended to especially in developing countries. In this study, rainwater and sediment/sludge samples were harvested from various storage tanks including concrete, metallic and plastic tanks whose house roofs are galvanized iron sheets. The samples were collected in four geographical locations in Kampala City, Uganda. Both rainwater and sediment/sludge samples collected were analysed for temperature, pH, EC, TDS, DO, hardness (Ca and Mg), nutrients (TN and TP) and some trace metals including Zn, Cu, Pb and Cd. Unlike sediment/sludge samples, the rainwater parameters such as temperature, pH, EC, TDS, DO were analysed on site using portable meters. Analysis of total dissolved trace metals was done using Atomic Absorption Spectrophotometer. The quality of rainwater varied slightly with different storage tanks. In terms of dissolved trace metals, Zn was the most predominant trace metal in rainwater samples with mean concentration values 0.389±0.186 mg/l, 0.920±0.629 mg/l and 1.119±1.039 mg/l for concrete, metallic and plastic tanks respectively. On the other hand, Cu was not detected in rainwater but had mean concentration values 0.498±0.193 mg/kg in the sediment/sludge samples. However, Pb exceeded WHO permissible limits for drinking water in all sampled tanks. The high levels of these trace metals, nutrients and other physico-chemical parameters obtained in this study may likely result in consumer complaints. This is because some of the parameters are not only liable to impacting bad taste in rainwater but are also carcinogenic.

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1. INTRODUCTION

Rainwater harvesting (RWH) is the ancient practice of capturing rain runoff from roofs and other surfaces and storing it for a later purpose (Despins et al., 2009). Rainwater is relatively free from impurities, except those picked up by the rain from the atmosphere. Wind-blown dust contributes large quantities of nutrients and trace metals to the atmosphere, particularly severe with certain industrial complexes (Hart and Lake, 1987). Also the wind-blown dirt, leaves and faecal droppings from birds and other animals, insects and contaminated litter on the catchment areas and in cisterns can be sources of contamination of rainwater, leading to health risks from the consumption of contaminated water from storage tanks. The quality of rainwater may deteriorate during harvesting, storage and household use. Poor hygiene in water storage and water abstraction from tanks or at the point of use can also represent a health concern (World Health Organisation, 2008).

Many factors, including: environmental conditions such as proximity to manufacturing industries or major roads, the presence of birds or rodents (Evans et al., 2006; Taylor et al., 2000); meteorological conditions such as temperature, antecedent dry periods, and rainfall patterns (Evans et al., 2006); contact with a catchment material, the dirt and debris that are deposited upon it between rainfall events (Simmons et al., 2001; Van Metre and Mahler, 2003); natural treatment processes taking place within the rainwater cistern (Coombes et al., 2005; Despins et al., 2009); and the roof material itself affects the quality of rainwater harvested. Metal roofs are often associated with the leaching of trace elements, detected in the dissolved form in the runoff itself and adhered to the particulate matter washed from the roof. For example zinc concentration may increase in runoff from galvanized iron roof sheets and, to a lesser degree from gutters. Therefore, roof tops and gutters can contribute both particulate matter and dissolved chemicals to runoff water. Though, the former is largely site specific; the impact of different roof materials is fairly consistent regardless of location (Despins et al., 2009).

Also street dust typically derived from anthropogenic sources via the interaction of solid, liquid or gaseous materials with pollutant sources such as water transported material from surrounding soils and slopes, dry and wet atmospheric deposition, biological inputs, road surface wear, road paint degradation, vehicle wear (tyres, body, brake lining etc) and vehicular fluid, particulate emissions and discharges from metal processing industries (Al-Khashman, 2004) are blown off by the wind onto the roofs. As a result, rain runoff from roofs is likely to be polluted.

With the recent developments in investigation technology and knowledge base, it has been noted that there can be health risks associated with the use of untreated rainwater for human consumption. The high possibility of biological and chemical pollutants in a roof could eventually end up in rainwater tanks (Evans et al., 2006). Some of the components are the trace metals and nutrients such as nitrates and phosphates. Many of these components are considered toxic to living organisms. The trace metals considered essential to life can be toxic when present at excessive levels that impair important biochemical processes and pose a threat to human health, plant growth and animal life (Tanushree et al., 2011). These trace metals including zinc, lead, copper, cadmium among others may cause diseases such as rheumatoid arthritis, cancer, acute gastrointestinal infections, kidney and heart failure, and nervous system damages and in extreme cases, exposure to trace metals may lead to death (Akpor and Muchie, 2010). Also nutrients pose a health threat to people who consume rainwater without treatment. Diseases like diarrhea, vomiting, goose bumps, weakness, liver hemorrhaging, gastroenteritis, and kidney failure result from intake of phosphates (Weirich and Miller, 2014), and “blue baby” syndrome is as result of drinking water containing nitrates (Mendez et al., 2011).

With increased industrialization, urbanization, transportation, and other anthropogenic activities, rainwater is likely to be contaminated by these trace metals from dry and wet decomposition, nutrients from decaying small animals, birds’ droppings, and plant leaves. Also galvanized iron roof tops contributing to trace metal loads in storage tanks. These parameters altogether with a likelihood to cause diseases and bad taste to rainwater, there was a need to carry out a study in Kampala City, Uganda with intentions; to determine the levels of physico-chemical components, concentration of nutrients and trace metals of rainwater and sediment/sludge harvested in various storage tanks from galvanized iron roof tops and open space for control. The data shall be of benefit to the public and Government as whole in pursuance of fresh water supply before 2015 as one of the millennium development goals. The research findings shall provide and enhance among others, increased understanding of the possible health risks associated with water from rainwater tanks. Hence, the results of this research study would enrich the existing database on the extent to which physico-chemical parameters, nutrients and trace metals contribute to rainwater pollution.

2. MATERIALS AND METHODS

Study area

The research study was conducted in Kampala City, the capital city of Uganda covering a total area of 189 km^2 (73 sq mi). Kampala lies within coordinates of 00° 18’49’’N, 32° 34’52’’E, and a population was at 1.79 million people in mid 2013 (UBOS, 2013). Four different locations were considered after field survey. These areas included Makerere Mukubiila zone, Mengo, Nansana and Kawempe. Sampling was done in the month of May and June, 2014. Kampala has a tropical wet and dry climate with an altitude of 1,190 m (3,900 ft), and features two annual wet seasons; August to December and February to June, with April typically having the heaviest amount of precipitation at an average of around 175 mm of rain ("http://en.wikipedia.org/wiki/Kampala#Population accessed on 9/10/2013,").

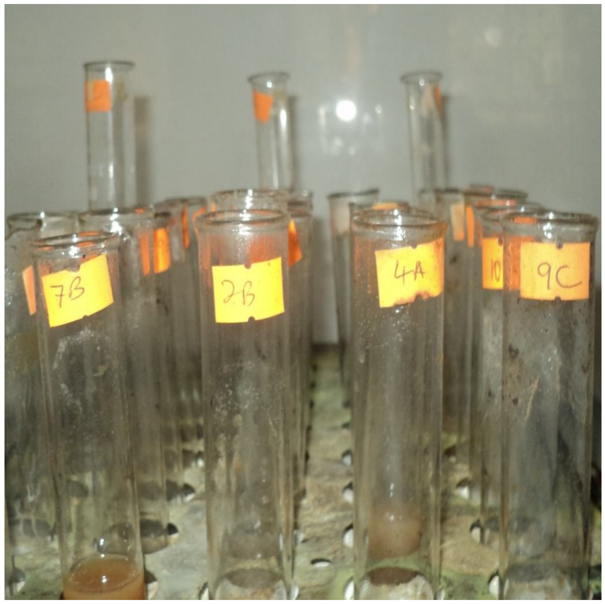
Sampling of rainwater and sediment/sludge

Sampling bottles were washed with dilute nitric acid, and rinsed with distilled water in the laboratory. The sampling bottles were washed three times with the rainwater before they were filled with samples. Rainwater samples were drawn at the tap of each storage tank using a linear polyethylene (500 ml empty water bottles). At least three concrete, metallic and plastic tanks each was sampled for sediment/sludge and rainwater in each of the location in Kampala City. The rainwater samples were transported in an ice box to the laboratory and stored in a refrigerator. To check the effect of galvanization and roof joints, a sample from open space at a height of 1.5 m above the ground was obtained. Also the sediment/sludge samples were drawn from the storage tanks using a sampling device (Fresenius et al., 1987 as cited in Sazakli et al., 2007). .

Analytical procedures

The chemicals used in this research study were obtained from Bitish Drug House (BDH), Wagtech and were of analytical grade (AnalaR).

Sample preparation: Acid digestion pretreatment procedures for sediment/sludge samples. The sludge samples were first spread out on aluminium foil and dried in an oven at 103°C for 24 h to a constant mass. After cooling, the sludge samples were carefully ground in a ceramic mortar and passed through a 2.5 mm nylon sieve. The finely ground sample (0.50 g) were weighed into a clean dry 100 ml Pyrex test tube.



2.1 Figure 1: Modified sampler used for collecting rainwater samples

Concentrated nitric acid, concentrated hydrochloric acid and 70% perchloric acid in the ratio of 15:5:3 were mixed together to make 23 ml of the digestion mixture. To the weighed sample (0.5 g) of the sediment/sludge samples, the digestion mixture (10 ml) was added. The resultant mixture was shaken with care and then heated in a fume cupboard on a block digester set at medium heat until digestion was complete. On cooling, concentrated nitric acid (3 ml) was added to the Pyrex test tube, followed by 30% hydrogen peroxide (2 ml). The digested samples were diluted to make 50 ml. The resultant mixture was left to stand for 1 hour and then decanted to obtain a clear solution. The subsequent solution was made to 50 ml again with distilled water. Triplicate determinations were made on the sediment/sludge samples (Clesceri et al., 1998).

Determination of physico-chemical parameters of rainwater samples. The physico-chemical characteristics such as electric conductivity, pH, temperature, dissolved oxygen, total dissolved solids were determined on site using portable meters (Kruis, 1994). Samples were picked from storage tanks into a well cleaned cup. A portable meter was inserted into after cleansing it with the rainwater sampled. The results were read from the display and recorded.

Determination of physico-chemical parameters of sediment/sludge samples. The sediment/sludge sample temperature, pH and (EC) measurements were measured as follows: the sediment/sludge sample (20.0 ± 0.1 g) was measured into a 250 ml conical flask and distilled water (50 ml) was added. The mixture was thoroughly shaken for 10 min and allowed to stand for 30 min. The pH of the sediment/sludge suspensions were subsequently measured using a pH meter. The EC of the supernatant liquid were taken using an EC bridge after the suspension had settled for an hour (Kruis, 1994).

Determination of total nitrogen in rainwater samples. The rainwater samples (0.2 ml) were pipetted into 50 ml volumetric flasks. To the samples in each volumetric flask and blanks, 5 ml of each of the two mixed reagents used in the colour development (Akalebo et al., 1993) were added. The mixture was allowed to stand for 2 hours to allow colour development. All the standards were treated the same way as the rainwater samples to cater for the difference in concentrations. Using Jenway PFP7 spectrophotometer model at 650 nm wave length, a calibration plot was plotted and the absorbance of the samples was determined from the plot (Akalebo et al., 1993).

Determination of total nitrogen in sediment/sludge samples. The sediment/sludge samples were first digested using the following digestion mixture. The mixture was prepared by mixing selenium powder (0.042 g), lithium sulphate (1.400 g) and 30% hydrogen peroxide (35 ml) thoroughly well. Concentrated sulphuric acid (42 ml) was slowly and carefully added to the above mixture while cooling in a running tap water. To the sediment/sludge samples (0.500 g) in 100 ml heating tube, a digestion mixture (5 ml) was added and the blanks were prepared in a similar way. The resultant mixtures were digested at 360^oC for at least 2 hours till digestion was complete. On cooling, distilled water was added to make up 50 ml (Okalebo et al., 1993). The resultant supernatants (0.2 ml) were micropipetted into 50 ml volumetric flasks. The same procedures for determining the concentration of rainwater was repeated for the sediment/sludge samples.

Determination of total phosphorus in the rainwater samples. The rainwater sample solutions (0.5 ml) were placed in 10 ml volumetric flasks. To each flask, ammonium molybdate/ammonium vanadate and ascorbic acid mixed reducing reagent (1 ml) was added. The mixture was diluted to mark with distilled water. After colour development, the sample concentration was determined at 880 nm wave length using Jenway PFP7 spectrophotometer model. The standards were treated in the same way as the samples. A calibration plot was plotted and the concentration of the samples was determined from the plot (Akalebo et al., 1993).

Determination of total phosphorus in sediment/sludge samples. The concentration of total phosphorus in sediment/sludge samples was determined from acid digests (See sample preparation for sediment/sludge samples). From the resultant solutions, (0.5 ml) were micropipetted into 10 ml volumetric flasks. To each flask, ascorbic acid reducing agent (1 ml) was added. The mixture was diluted to mark with distilled water. After colour development, the absorbance was determined at 880 nm wave length using Jenway PFP7 spectrophotometer model. The standards were treated in the same way as the samples. A calibration plot was plotted and the concentration of the samples was determined from the plot (Akalebo et al., 1993).

Determination of magnesium in rainwater samples. To rainwater samples (49 ml), concentrated nitric acid (1 ml) was added to make 50 ml of solution. The resultant solutions were direct aspirated into a flame atomic absorption spectrophotometer (AAS) after calibration with suitable elemental standards at close intervals using direct air-acetylene flame method (Clesceri et al., 1998).

Determination of magnesium in sediment/sludge samples. The concentration of magnesium was determined in sediment/sludge samples after acid digestion. The procedures are exactly the same as those for trace metal analysis.

Determination of calcium in rainwater samples. Rainwater sample (1 ml) was pipetted into a 10 ml flask and 0.15% lanthanum chloride solution (1 ml) added and the mixture made up to 5 ml with distilled water. The mixture was mixed well with shaking. The concentration of samples was read directly from Jenway PFP7 flame photometer output screen after calibration.

Determination of calcium in sediment/sludge samples. The concentration of calcium in sediment/sludge samples was determined after acid digestion**.** The resultant solution (1 ml) from acid digested samples was placed in a 10 ml flask. 0.15% lanthanum chloride solution (1 ml) was added and the mixture made up to 5 ml with distilled water. The mixture was mixed well with shaking. The concentration of samples was read directly from Jenway PFP7 flame photometer output screen after calibration.

Determination of trace metals in the rainwater samples. To rainwater samples (49 ml), concentrated nitric acid (1 ml) was added to make 50 ml of solution. The resultant solutions were direct aspirated into a flame atomic absorption spectrophotometer (AAS) after calibration with suitable elemental standards at close intervals using direct air-acetylene flame method (Clesceri et al., 1998).

Determination of trace metals in the sediment/sludge samples. The sediment/sludge samples were acid digested as described (See sample preparation for sediment/sludge samples). The resultant solutions were direct aspirated into a flame atomic absorption spectrophotometer (AAS) after calibration with suitable elemental standards at close intervals using direct air-acetylene flame method. The concentrations (mg/l) of five metals Mg, Zn, Cu, Pb, and Cd were determined in the samples and the blanks without further dilution (Clesceri et al., 1998).

Statistical Analysis

The raw data obtained was analysed using Microsoft Excel and StatView statistical softwares designed by SAS, 1998, with a confidence interval of 95%. The Analysis of Variance mean concentrations, Fisher's PLSD and correlation for all samples were done using SatView software.

3. RESULTS AND DISCUSSION

The mean values of physico-chemical parameters of the rainwater and sediment/sludge samples are presented in Table 1. The mean concentration of hardness and nutrients parameters of the rainwater and sediment/sludge samples are presented in Tables 2 and 3 respectively. The mean concentration of trace metals in rainwater and sediment/sludge samples collected from three different storage tanks in Kampala City, Uganda is presented in Table 4.

Table 1: The physico-chemical parameters in sediment/sludge and rainwater samples

Parameters	Tank Types	Sediment/sludge samples		Rainwater samples		WHO (2011)	Control sample
		Count, N	Mean±sd	Count,N	Mean±sd		
Temperature (^{0}C)	Concrete	4	23.03±1.18	4	23.05±1.03	25	22
	Metallic	3	22.40±0.10	6	24.10±2.52		
	Plastic	3	22.43±0.15	4	24.10±3.48		
pH	Concrete	4	7.04±0.36	4	7.84±0.45	6.5-8.5	7.04
	Metallic	3	7.08±0.15	6	7.07±0.48		
	Plastic	3	7.39±0.72	4	6.89±0.46		
EC (µS/cm)	Concrete	3	22.67±12.22	4	36.50±3.11		5
	Metallic	3	25.67±15.57	6	13.67±8.19		
	Plastic	3	40.33±20.26	4	12.75±4.19		
TDS (ppm)	Concrete		Na	4	21.00±7.44	600	9
	Metallic		Na	6	5.67±4.23		
	Plastic		Na	4	6.00±2.94		
DO (ppm)	Concrete		Na	4	0.78±0.23		1.39
	Metallic		Na	6	0.92±0.11		
	Plastic		Na	4	0.92±0.19		

Na = not applicable, sd = standard deviation

Temperature in rainwater samples. The mean temperature values of rainwater samples for various storage tanks are shown in Table 1. Concrete tanks had slightly the highest mean value compared to metallic and plastic tanks. The mean temperature values for the storage tanks were below the recommended temperature value by WHO, 2011. Since higher water temperatures enhance the growth of microorganisms, then the low mean temperature values obtained for these storage tanks may result into a decrease in problems related to taste, odour and colour.

Temperature in sediment/sludge samples. The mean temperature values of sediment/sludge samples for various storage tanks are shown in Table 1. The statistical analysis of data showed that there were no significant differences between the mean temperature results obtained for the sediment/sludge samples.

Table 2: The hardness parameters of sediment/sludge and rainwater samples

Parameters	Tank Types	Sediment/sludge samples		Rainwater samples		Control sample (mg/l)
		Count,N	Mean±sd (mg/kg)	Count,N	Mean±sd (mg/l)	
Ca	Concrete	4	29.83±2.78		ND	ND
	Metallic	3	19.56±0.84		ND	
	Plastic	3	21.56±3.15		ND	
Mg	Concrete	4	7.15±0.21	3	0.19±0.20	0.49
	Metallic	3	6.92±0.14	4	0.14±0.06	
	Plastic	3	7.13±0.22	3	0.11±0.03	

ND = not detected, sd = Standard deviation

pH in rainwater samples. The mean pH values of rainwater samples for various storage tanks are shown in Table 1. The highest mean pH value for rainwater samples was observed in concrete tanks, where as the plastic tanks had the lowest mean value. The mean pH values of rainwater samples were within the WHO, 2011 drinking water guidelines. The high mean pH value observed in the concrete tanks is due to leaching of calcium carbonate from the tank walls. Similar results were recorded by Scott and Waller, 1987 and Zhu et al., 2004 who attributed the increased pH in concrete tanks due to leaching of calcium carbonate from the tank walls. The statistical analysis of data showed a statistically significant difference between concrete and metallic tanks, concrete and plastic tanks. Simmons et al., 2001 reported a statistically significant difference between concrete and non-concrete cisterns (plastic, wood, fibre glass or galvanized iron) in a study carried out in New Zealand.

pH in sediment/sludge samples. The mean pH values of sediment/sludge samples for various storage tanks are shown in Table 1 above. The mean pH value for sediment/sludge samples was highest in plastic tanks compared to other storage tanks. The least mean pH value was observed in concrete tanks.

Table 3: The nutrients levels in sediment/sludge and rainwater samples

Parameters	Tank Types	Sediment/sludge samples		Rainwater samples		Control sample (mg/l)
		Count,N	Mean±sd (g/kg)	Count,N	Mean±sd (mg/l)	
TN	Concrete	4	3.19±0.39	4	23.41±8.43	16.82
	Metallic	3	3.23±0.94	6	26.01 ±7.29	
	Plastic	3	4.11±1.88	4	22.49 ±4.53	
TP	Concrete	4	2.18±1.16	4	0.87±1.29	0.20
	Metallic	3	1.37±0.21	6	0.13±0.04	
	Plastic	3	2.15±1.26	4	0.16±0.08	

sd = standard deviation

Dissolved oxygen in rainwater samples.The mean DO values of sediment/sludge samples for various storage tanks are shown Table 1. Metallic and plastic tanks recorded the highest mean DO values. Metallic and plastic tanks had the same mean DO values as shown in the figure above. Both tanks had the highest DO values compared to concrete tanks. The minimum acceptable DO value in drinking water is 5.0 mg/l. Since the DO values were below 5.0 mg/l as recommended by WHO, 2008, may suggest aquatic contamination of rainwater within the storage tanks (Sekabira et al., 2010). This means that water in the tanks was poorly aerated as indicated by very low DO values.

Electrical conductivity in rainwater samples. The mean EC values of sediment/sludge samples for various storage tanks are shown in Table 1. EC is the measure of water's ability to conduct an electric current. The conductivity increases with increase in the dissolved salts in water. The highest mean EC value was observed in concrete tanks followed by metallic tanks. The least mean EC value was recorded by plastic tanks. The high mean EC value in concrete tanks could be as a result of leaching. Although, no drinking water limit for EC is defined by WHO, its values should not exceed that of TDS.

Table 4: Trace metal concentration values in sediment/sludge and rainwater samples

Parameters	Tank Types	Sediment/sludge samples		Rainwater samples		WHO (2011)	Control sample (mg/l)
		Count,N	Mean±sd (mg/kg)	Count,N	Mean±sd (mg/l)		
Zn	Concrete	4	14.57±1.26	4	0.39±0.19	3	0.06
	Metallic	3	11.22±5.00	6	0.92±0.63		
	Plastic	3	13.20±0.57	4	1.12±1.04		
Cu	Concrete	4	0.45±0.03		ND	2	ND
	Metallic	3	0.52±0.34		ND		
	Plastic	3	0.54±0.21		ND		
Pb	Concrete	4	2.60±2.08	3	0.04±0.02	0.01	ND
	Metallic	3	0.77±0.22	2	0.06±0.01		
	Plastic	3	0.81±0.09	1	0.100		

ND = not detected, sd = standard deviation

Total dissolved solids in rainwater samples. The mean TDS values of sediment/sludge samples for various storage tanks are shown Table 1. The highest mean TDS value was observed in concrete tanks followed by metallic tanks. The least mean TDS value was recorded by plastic tanks. This is probably due to materials used in the construction of concrete tanks that are likely to contribute to TDS when leaching takes place. The mean values of TDS recorded for the rainwater samples from different storage tanks were in the acceptable WHO drinking water guidelines.

Electrical conductivity in sediment/sludge samples. The mean TDS values of sediment/sludge samples for various storage tanks are shown in Table 1. The mean EC values of sediment/sludge samples observed from metallic tanks was the highest. Concrete tanks recorded the lowest mean EC value though it was expected to have a higher mean value.

Calcium in sediment/sludge samples.The mean calcium values of sediment/sludge samples for various storage tanks are in Table 2. The highest calcium mean value was observed in concrete tanks followed by plastic tanks. The high mean concentration of calcium in concrete tanks is due to leaching. This implies that concrete materials contribute calcium to sediment/sludge in the storage tanks.

Magnesium in rainwater samples. The mean magnesium values of rainwater samples for various storage tanks are in Table 2. The highest magnesium mean value was observed in concrete tanks followed by plastic tanks. The high mean concentration of magnesium in concrete tanks is due to leaching. This implies that concrete materials contribute magnesium to rainwater in the storage tanks. Our findings were in agreement with that of Zhu et al., 2004. Zhu and others reported results ranging from 11.2 to 31.15 mg/l and 0.930 to 1.143 mg/l for calcium and magnesium respectively. Whereas the calcium was not detected in control sample, magnesium was detected and 0.4911 mg/l was the mean concentration.

Magnesium in sediment/sludge samples. The mean magnesium values of sediment/sludge samples for various storage tanks are in Table 2. The highest magnesium mean value was observed in concrete tanks followed by metallic tanks. The high mean concentration of magnesium in concrete tanks is due to leaching of minerals. This implies that concrete materials contribute magnesium to rainwater in the storage tanks.

Total nitrogen in rainwater samples. The mean TN values of rainwater samples for various storage tanks are shown in Table 3. The highest TN mean value was observed in plastic tanks followed by metallic tanks. It should be noted that the earth's atmosphere contributes to total nitrogen (78%), an explanation for the concentration in the control sample. Zhu et al., 2004 reported that the average concentrations analysed in the roof-yard were 1.118±0.734 mg/l, N = 4, for TN. Total nitrogen analysis included all nitrogen compounds. These nitrogen compounds include nitrite, nitrate and ammonia. Excessive concentrations of nitrate and/or nitrite can be harmful to humans and wildlife. Nitrate is of most concern to humans. Nitrate is broken down in our intestines to become nitrite. Nitrite reacts with hemoglobin in human blood to produce methemoglobin, which limits the ability of red blood cells to carry oxygen. This condition is called methemoglobinemia or "blue baby" syndrome (because the nose and tips of ears can appear blue due to lack of oxygen) (Mendez et al., 2011). It is especially serious to infants, because they lack the enzyme necessary to correct this condition. Also the presence of nitrogen may promote algal growth in rainwater tanks, if not controlled.

Total nitrogen in sediment/sludge samples. Plastic tanks recorded the highest mean TN value, followed by metallic tanks and the concrete tank had the lowest mean TN values as shown in Table 3. It was found that the concentrations of TN for all the investigated storage tanks had a range between 0.535 and 9.117 mg/l, less than the WHO guidelines of 10 mg/l for drinking water (WHO, 2011). However, the mean concentrations of TN in all the investigated storage tanks were higher than the maximum admissible limit 2 mg/l set by the European Environment Council (EEC) standard.

Total phosphorus in rainwater samples. The mean TP values of rainwater samples for various storage tanks are shown in Table 3.The highest TP mean value was observed in plastic tanks followed by concrete tanks. The high mean concentration of TP in concrete tanks is due to leaching of tank wall materials used in construction. It was noted that, one of the concrete tanks had an outlier value and was not considered in the statistical analysis. Phosphorus is one of the nutrients that aid the growth of algal blooms in a water system. Some of the algal blooms are haramful to humans because they produce elevated toxins and bacterial growth that can make people become sick especially the children. These illness include; diarrhoea, vomiting, goose bumps, weakness, liver hemorrhaging, gastroenteritis, kidney failure, and liver failure (Weirich and Miller, 2014).

Total phosphorus in sediment/sludge samples. The mean TP values of sediment/sludge samples for various storage tanks are shown in Table 3 above. The highest TP mean value was observed in concrete tanks followed by plastic tanks. The high mean concentration of TP in concrete tanks is due to leaching of materials used in the construction of inside walls of the tanks. This implies that concrete materials contribute TP to rainwater in the storage tanks. The mean TP of rainwater from metallic tanks was greater than that of sediment/sludge samples from concrete tanks which in turn was greater than the mean TP from plastic tanks.

Zinc in rainwater samples. The mean zinc values of rainwater samples for various storage tanks are shown in Table 4. The highest zinc mean value was observed in concrete tanks followed by plastic tanks. The lowest mean zinc value was observed in metallic tanks. The mean concentrations of Zn for all the storage tanks were below the WHO drinking water concentration limits 3 mg/l (WHO, 2011). All the mean values of Zn in rainwater samples were higher than that of the control (0.063 mg/l) (Table 4), thus indicating contributions of roof materials to trace metals load of rainwater. According to Hart and White, 2006, leaching of zinc from metal tanks was found to be significant, but concrete or plastic tanks did not have any notable impact on the concentration of zinc, lead or copper.

Zinc in sediment/sludge samples. The mean zinc values of rainwater samples for various storage tanks are shown in Table 4. The highest mean concentration values of Zn were observed in concrete tanks, followed by plastic tanks. The lowest men concentration value was observed in metallic tanks (Table 4). The mean zinc values ranged from 5.451 to 15.707 mg/kg for all sediment/sludge samples. The mean concentrations of Zn for all the storage tanks exceeded the WHO drinking water concentration limits 3 mg/l (WHO, 2011). In general, the high concentrations of zinc in all samples as result of urbanization, transportation and other anthropogenic activities.

Copper in sediment/sludge samples. Plastic tanks registered the highest mean value 0.544±0.213 mg/kg, followed by 0.515±0.338 mg/kg for concrete tanks (Table 4). The least mean value was recorded with metallic tanks. This is probably possible because copper is one of the materials used in the manufacture of PVCs (Jiang and Kamdem, 2004). Copper was not detected in rainwater samples. This could be true with flocculation and co-precipitation of the Cu and Pb hydroxides, where water pH and TDS could be the major mechanisms explaining the rapid removal of trace metals from water to sediment/sludge as reported by Sekabira et al., 2010. It was noted with concern that most metallic tanks had been made without an option of cleaning them. This aids the accumulation of the sediment/sludge samples in the tanks. Therefore there was a big variation in the results obtained from the field.

Lead in rainwater samples. The mean concentration values of Pb were in the order; concrete ‹ metallic ‹‹ plastic as shown in Table 4. Comparing these results with those presented in the literature, the findings by Sekabira et al., 2010 for rainwater collected from experimental site (Nakivubo) had an average Pb of 13±9 µg/l and 33±19 µg/l rainwater collected from control site (Namalere research centre-Watindo).

Lead in sediment/sludge samples. The mean concentration values of Pb for sediment/sludge from concrete tanks was greater than that of sediment/sludge from plastic tanks which in turn was less than the mean Pb from metallic tanks as shown in Table 4. It was generally found that the mean values in all sediment/sludge samples had the highest mean values compared to rainwater samples. This was in agreement with Desphins et al., 2009. In their findings, the sedimentation played a primary role in reducing the contamination load of stored rainwater. Our findings too are in agreement as most parameters showed higher mean concentration of lead for the sediment/sludge samples.

Cadmium in rainwater and sediment/sludge samples. Both rainwater and sediment/sludge samples were analysed for Cd. However, cadmium was not detected in any of the samples collected from all the sampled storage tanks. According to Ayenimo et al., 2006, Cd was detected in rainwater samples harvested using metal sheets as roof materials. The mean value of Cd was reported at 0.34±0.24 mg/l. The findings reveal that such water is not healthy for human consumption. This is because the mean values of Cd exceeded the WHO, 2011 drinking water limit.

4. CONCLUSION AND RECOMMENDATIONS

Domestic rainwater harvesting (DRWH) appears to be one of the most promising alternatives for supplying fresh water in the face of increasing water scarcity and escalating demands. The research findings show that the levels of most of the physico-chemical parameters determined in both rainwater and sediment/sludge samples were not exceeding the WHO, 2011 drinking water limits. Rainwater is soft water according to obtained results. Calcium and magnesium salts being one responsible for water hardness, their mean values were very low. The micronutrient levels were taken into account, these included TN and TP. TN was most predominant in both rainwater and sediment/sludge samples. The levels did not exceed those from WHO, 2011 drinking water guidelines. Based on the mean concentrations of zinc and lead in all sampled storage tanks, it was found out that their mean concentrations were in the decreasing order: concrete›plastic›metallic for sediment/sludge samples and plastic›metallic›concrete for rainwater samples. Concrete tanks had the highest mean concentrations of both zinc and lead followed by plastic tanks. It was further noted that plastic tanks had the highest mean concentrations of copper for sediment/sludge samples, zinc and lead for rainwater samples. The mean zinc concentration values in rainwater samples fell within acceptable range of World Health Organization (WHO, 2011) guidelines for water quality. However, the mean lead concentrations exceeded the acceptable range of World Health Organization (WHO, 2011) guidelines for water quality. Though mean differences are not very significant therefore rainwater may not necessarily be toxic since most of the rainwater analysed parameters concentration values fell within acceptable range of World Health Organization except lead. The results of the analysis of the blank solution indicated no contamination from the reagents used as all the metals were below their detection limits. Similarly control samples showed no contamination of all the analysed water parameters. The results further indicate that the age factor for the roofs and tanks did not put it clear whether the older the tank or roof, the higher the concentration of a number of water parameters. Therefore the general cleanliness exhibited by the house hold owners is very important concerning the quality of rainwater harvested.

Like in most developed countries, where scientists have recommended 1st and 2nd flushes before actual harvesting, an integrated system approach where quantity and quality of the rainwater harvesting should be incorporated with in MWE. Seasonally cleaning of the storage tanks is highly recommended. This reduces the accumulation of sediment/sludge in the storage tanks. This is so because the sediment/sludge samples exhibited higher mean concentration of most water parameters that were analysed than in rainwater samples. It should therefore be noted that the sustainability of the DRWH requires close cooperation between the government, the private sector (NGOs and Scientists) and the household owners.

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