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QUALITY CHARACTERISTICS OF HARVESTED RAINWATER FROM GALVANIZED ROOFING SHEET IN ESAN WEST, EDO STATE

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ABSTRACT

Direct rainwater harvesting (DRWH) from rooftop is an important alternative source of water supply for both rural and semi-urban populace in developing countries to meet the increasing demand for domestic purposes. Nevertheless, the quality of this water supply source is of utmost importance as the health condition of water is a determinant of community health status. The aim of this research is to investigate the quality of harvested rainwater as an alternative source of drinking water in rural areas of Esan West Local government areas, Edo State. The Local Government Area was delineated into its already existing ten (10) political wards. Households were randomly selected and rainwater samples were collected during rainfall events for two sampling periods; onset and peak of rainfall via rooftop runoff with the aid of pre-sterilized plastic containers connected to the selected rooftops. Two (2) control (ambient rainwater) samples were also collected directly from rain drop without contact with any roof material. Water samples were analyzed for physical, chemical and bacteriological characteristics using standard method for the examination of water. The examination of physical parameters showed no evidence of water pollution as samples collected had values below the WHO permissible limits. Notwithstanding there was indication that harvested rainwater were slightly acidic. The examination of chemical parameters showed that Calcium ion (Ca^{2+}) exceeded WHO permissible limits, while heavy metals (Fe, Pb, Cr) showed no pollution in all samples collected as they were within WHO permissible limits. Bacteriological qualities of samples showed evidence of contamination which is likely to be either from dust or bird, lizard, and squirrel droppings. Escherichia coli (E. coli) was isolated from almost all the samples considered. The two rainfall periods (onset and peak of rain) showed marked difference in the quality of water harvested. Water samples collected at the peak of rain had better water quality than these collected at the onset of the rain. However, the rainwater harvested at the peak of rain did contain some contaminants at levels above WHO drinking water standards such as TCC and E. Coli. This implies the need for treatment of harvested rainwater before domestic use.

Key words: Water quality, galvanized rooftop sheet, rainwater runoff, rainwater harvesting

INTRODUCTION

Access to potable water supply and sanitation remain a global issue, particularly in developing countries where access to water and water related facilities are very low when compared to developed countries. In the rural Africa, this poses a serious concern largely due to irregular and unsatisfactory distribution, quality issues and various constraints which affect availability. Africa for example has been reported to have the lowest total water supply coverage in the world (ADF, 2005). The problem is compounded by industrialization, rapid urbanization and population expansion with resultant effects which range from poor solid waste management to pollution of surface and ground water resources. In 2008, the WHO/UNICEF joint Monitoring Programme (JMP) on global access to potable water supply and sanitation coverage showed that whilst access to potable water supply rose from 77% to 89% in developed countries, access to safe water supply is still very low in developing countries (WHO/UNICEF, 2010). Studies have further reported that Nigeria and many other Sub-Sahara African countries are lagging behind in achieving the millennium development goals and targets set for water and sanitation, as drinking water coverage decreased from 49 per cent in 1990 to 48 per cent in 2004, as against the expected 65 percent coverage (WHO/UNICEF, 2006) and that sub-Sahara Africa would only reach the MDG-Goal 7 targets for water services by 2040 and those of sanitation by 2076 (World Bank, 2001). According to Krebs (2010), of the over 150 million people in Nigeria, less than 30 percent have access to adequate drinking water. Overall effective urban water supply coverage is as low as 30% of the total population due to poor maintenance and unreliability of supplies (Muta'aHellandendu 2012), while rural areas are worst hit due to poor electricity supply and almost absence of basic water related facilities.

Lack of access to safe water supply and sanitation are believed to be the root causes of the emergence of water borne diseases which kill over 1.8 million people annually in the world, mostly children under the ages of five (WHO, 2004, UNICEF, 2009). In Nigeria, these diseases kill over 194,000 people annually with children below 5 years being the most affected (WHO/UNICEF, 2008).

According to Amin and Han (2009), the problems of inadequate supplies and insufficient treatment is prompting the search for alternative approaches which are also decentralized systems, keeping in mind the technical and financial limitations of the poor living in underdeveloped areas. Direct rainwater harvesting (DRWH) from rooftop is assuming a very important alternative source of water supply for both rural and semi-urban populace in developing countries to meet the increasing demand for domestic uses (Jackson Carpenter, Dahn, Mckinght, Naiman, Postel and Running, 2001; FAO, 2007; Grandet Binning, Mikkelsen and Blanchaet., 2010; Miguntanna, Egodawatta and Goonetilleke, 2010; Olaoye, and Olaniyan, 2012). Nevertheless, the quality of harvested rainwater is also of concern as local environmental and material types influence the quality of harvested water. The objective of this research is therefore to investigate the quality of harvested rainwater as an alternative source of drinking water in the rural areas of Esan West by analyzing the

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physico-chemical and bacteriological quality of harvested rainwater.

Study area

The study area is Esan West Local Government Area, Edo State. It is geographically situated between Latitudes 6^o43^1& 6^045^1 North of the equator and Longitudes 6^o60^1& 6^o80^1East of the Greenwich Meridian (Fig. 1). The local relief of the area is 150meters above sea level; however, some areas are as low as 50meters above sea level. Esan West has been identified as the source or head water of many streams and rivers some of which flow into the Benin Lowlands while others flow northwards into the river Niger.

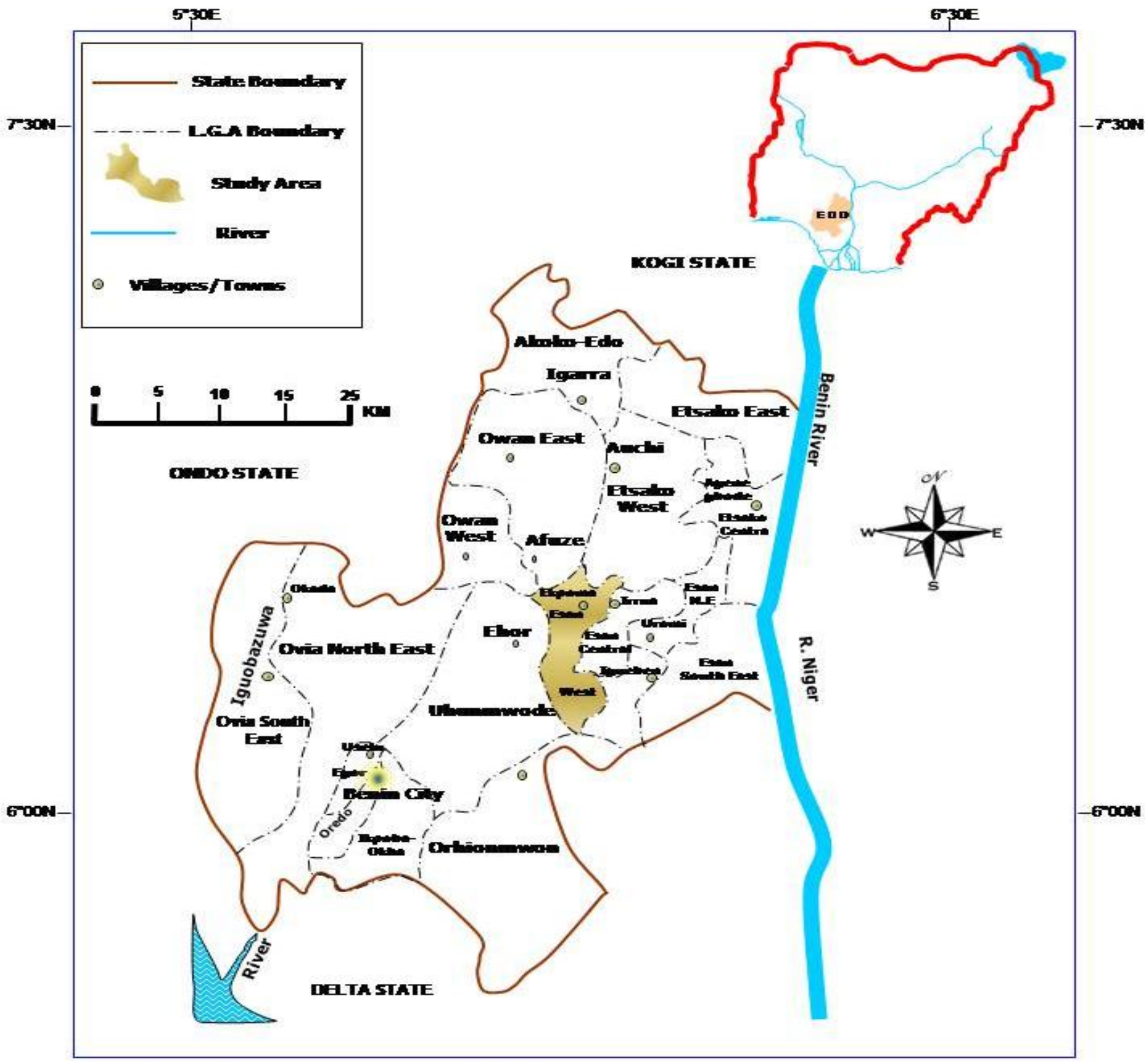

FIG. 1 MAP OF EDO STATE SHOWING THE STUDY AREA
Source: Ministry of Lands and Survey, Benin City.

The study area has the tropical climate characterized by two seasons; these are wet and dry season. The wet season occurs between April and October with a break in August while the dry season lasts from November to April with a cold harmattan spell between December and January. The temperature averages about 25^0C (77^0F) in the rainy season, and about 28^0C (82^0F) in the dry season. The highest mean monthly temperature of 29.1^oC is recorded in March and the lowest of 24.4^oC in June (Aziegbe, 2006).

MATERIALS AND METHODS

Data Collection and Presentation

The study employed quantitative a quantitative laboratory experimentation method while sampling was based on purposive approach. In other words, samples were not randomly selected from the entire household that made up a ward, instead only rainwater from galvanized roofing sheet. The reason for this, as opposed to a purely random sampling program, was based on the overall study objectives of the study. The Local Government Area was delineated into its already existing ten (10) political wards (Table 1) and rainwater samples collected from each ward. In each ward, samples were collected in two (2) replicates. This implies that on houses with galvanized roofing sheets were considered in the study. Rainwater samples were collected during rainfall events (for two sampling periods) via rooftop runoff each for the ten (10) political wards) with the aid of pre-sterilized plastic containers connected to the selected rooftops. Two (2) control (ambient rainwater) samples were also collected directly from rain drop without contact with any roof material. Control 1 was collected at the city centre (commercial area) while Control 2 was collected from a rural settlement (Agrarian area) with the aid of sterilized plastic containers with funnel mounted 1.5 meters above the ground to avoid rain splash.

Table 1: The 10 Political Wards in Esan West Local Council

S/NO	Town/Village	Wards
1	Ogwa	1
2	Ujiogba/Ebute	2
3	Egoro/Idoa	3
4	Eguare / Emaudo	4
5	Ihimhudumu /Ugiemen, Ido-ebo/Uke	5
6	Iruekpen	6
7	Ukpenu /Emuhi	7
8	Urhohi	8
9	Uhiele	9
10	Ile	10

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Samples were taken in February being onset of rainfall in the study area and July being the peak of rainfall. A total of 80 samples were collected for analysis (i.e. 40 samples for each sampling period). Water samples were analyzed for physical, chemical, bacteriological and selected heavy metal content using standard method for the examination of water as follows;

Determination of pH

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

Determination of Turbidity

Turbidity was read using a visible spectrophotometer VS721G. The cuvettes were washed and rinsed with distilled water. One of the cuvettes was filled to mark with the sample and the other was filled to mark with distilled water which was used to standardize the spectrophotometer. The sample was read at a wavelength of 420nm.

Determination of Total Dissolved Solids (TDS)

The total dissolved solid (TDS) was analyzed using the HACH 44600-00 Conductivity/TDS meter. The probe was dipped into the container of the samples until a stable reading in mg/l was obtained and recorded.

Determination of Total Suspended Solids(TSS)

This is obtained by a simple subtraction method. The total solid was first determined and the total dissolved solid obtained was subtracted from it.

TSS = TS - TDS.

The total solid was obtained by gravimetric method: 10ml of the samples was measured into a pre-weighed evaporating dish which was oven dried at a temperature of 103^{o}C to 105^{o}C for two and half hour. The dish was cooled in a desiccator at room temperature and was weighed. The total solid was represented by the increase in the weight of the evaporating dish.

$$\text{Total solids (mg/L)} = \frac{(W2-W1)\text{ mg} \times 1000}{\text{mL of sample used}}$$

Where W1 = initial weight of evaporating dish

W2 = Final weight of the dish (evaporating dish + residue)

Determination of alkalinity (HCO_3^-)

50ml of the sample was pipette into a clean 250ml conical flask. Two drops of methyl red indicator were added and the solution titrated against a standard 0.01M NaOH solution to a pink end-point. (ASTM, 1982).

$$\text{Total alkalinity (mg/L)} = \frac{V \times M \times 100{,}000}{\text{mL of sample used}}$$

Where V = volume of acid used

M = Molarity of acid used

The amounts of iron, zinc, copper, lead, chromium, Nitrite were determined using Atomic Absorption Spetrometer (AAS) with acetylene flame.

Total Bacteria Count

1ml of each sample was plated out using a serial dilution of 1:1000 (10^{-3}). Molten nutrient agar was added to the petri dish and shaken for even distribution. Solidified nutrient agar plate was then incubated at a temperature of 37^{0}C for 24hours. After incubation, emergence colonies were counted and colonies forming unit per ml calculated and recorded. Identification was done based on the cultural, morphological and biochemical tests of the isolates.

Identification of Bacteria

Table 2: Cultural Characteristics

Isolate	Size	Shape	Colour	Margin	Elevation	Surface Colony
A	1 mm	Round	Pink	Smooth	Raised	Moist
B	1 mm	Round	Yellow	Smooth	Raised	Dry
C	1 mm	Round	Golden yellow	Smooth	Raised	Dry
D	1 mm	Round	Green	Smooth	flat	Moist
E	1 mm	Round	Cream	Rough	flat	Moist

Source: Author's Laboratory Analysis (2014).

Table 3: Morphological Characteristics

Isolate	Gram Reaction	Cells Type	Cells Arrangement
A	Negative	Rods	Singly
B	Positive	Cocci	Cluster
C	Positive	Cocci	Cluster
D	Negative	Rods	Singly
E	Negative	Rods	Singly

Source: Author's Laboratory Analysis (2014).

Table 4: Biochemical Characteristics

Isolates	Coag.	Cat.	Ind.	Cit.	Oxid.	Lact.	Mot.
A	Negative	Negative	Negative	Positive	Negative	Positive	Positive
B	Negative	Positive	Positive	Positive	Negative	Negative	Negative
C	Positive	Positive	Negative	Negative	Positive	Positive	Negative
D	Negative	Negative	Negative	Negative	Positive	Positive	Positive
E	Negative	Negative	Negative	Negative	Negative	Positive	Positive

Source: Author's Laboratory Analysis (2014).

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Suspected Bacteria

a = Enterobacter; b = Micrococusspp;
c = Staph Epidy; d = Pseudomonas;
e = Klebsiella.

Key:

Coag. = Coagulase test; Cat. = Catalase test;
Ind. = Indole test; Cit. = Citrate test;
Oxid. = Oxidase test; Lact. = Lactose test;
Mot. = Motility test.

Positive = Present **Negative = Absent.**

Total coliform count (Using MacConkey broth)

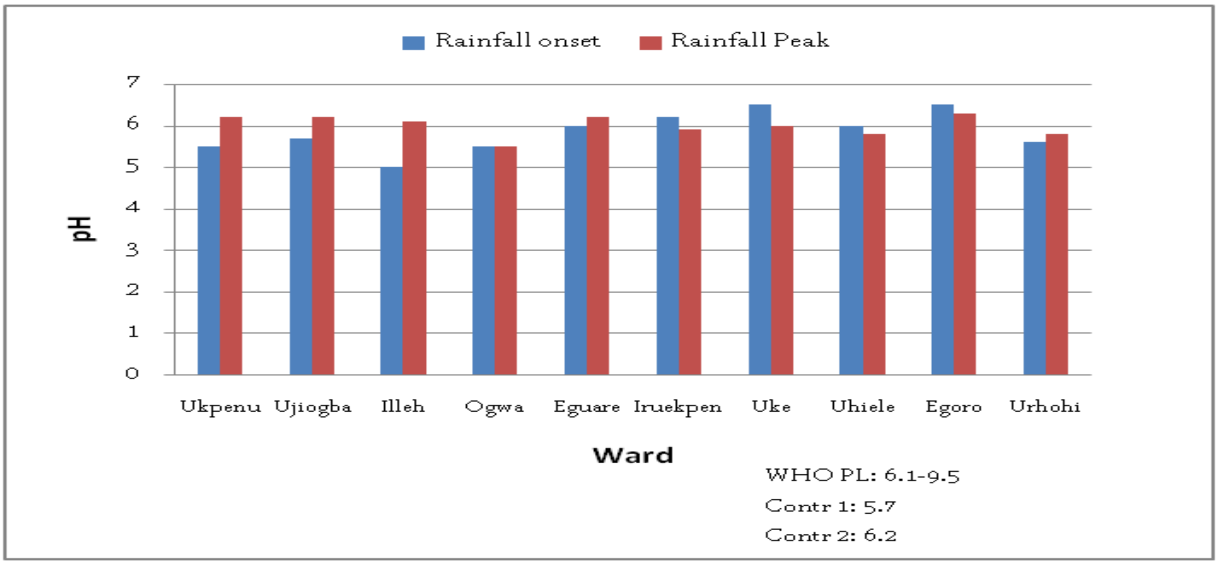
The multiple tube technique (MTT) was employed and the 3 tube method was used. All tubes were incubated at a temperature of 37^0C for 24hrs after which tubes showing colour changes (acid production) were regarded as positive tubes while those without a change in colour were discarded. The Magady Statistical Table was then used to get the value for the Most Probable Number (MPN) per 100ml and recorded.

E-coli Count

The same method used in total coliform count was also employed here in determining the total *E-Coli* count except that all tubes were incubated at a temperature of 44^0C for 24 – 48 hours.

RESULTS AND DISCUSSION

The results of the laboratory analysis for physical, chemical, heavy metals and bacteriological characteristics of rainwater samples collected at the onset of the raining season (February) and peak of rain (July) are presented in Figs. 2 – 13.



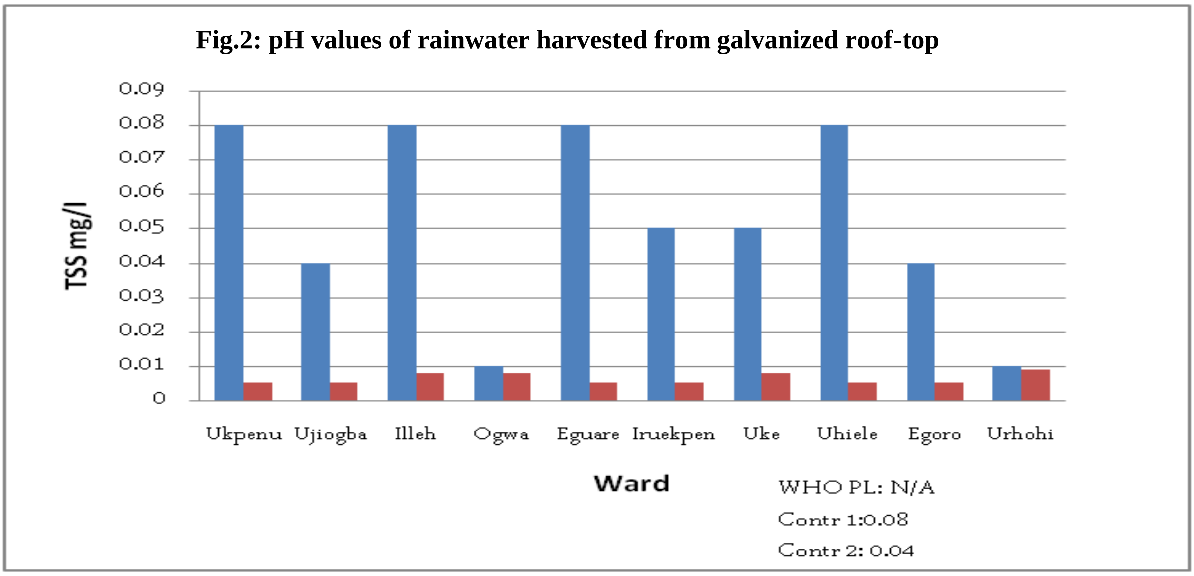


Fig. 3: TSS values of rainwater harvested from galvanized roof-top

The pH levels for onset of rain ranged from 5.0 in Illeh to 6.5 in Uke and Egoro with a mean value of 5.9. The control samples (ambient rainwater) recorded pH values of 5.7 and 6.2 for control 1 (City Centre) and control 2 (Suburb) respectively. Similarly, at the peak of the rain, pH levels range from 5.5 – 6.3 with a mean 6.0. For the onset of the rainy season, the mean pH values of water sample is lower than that of ambient rainwater collected from the suburb (control 2 which has a pH value of 6.2), but has similar values with ambient rainwater collected from the city centre (control 1, which has a pH value of 5.7). For the peak of the raining season, mean pH values of water is lower than that of ambient rain water collected from the suburb (control 2, which has a pH value of 6.2), but recorded values above ambient rain water from collected from the city centre (control 1, which has a pH level of 5.7). The pH values of water samples indicate that they are below the World Health Organization (WHO) minimum permissible level for potable water (6.15 – 9.50). Figure 2 shows that generally, the mean values of harvested rainwater from galvanized rooftop are acidic especially at the onset of the raining season. The values of Total Suspended Solids (TSS) (Fig.3) for the onset of the rain ranged from 0.01mg/l to 0.08mg/l with a mean of 0.052mg/l. The ambient rainwater (control) values were 0.08mg/l and 0.04mg/l for control 1(city centre) and control 2 (suburb) respectively. Peak of rain TSS values ranges from < 0.005 – 0.009mg/l with a mean of 0.0057mg/l. Samples collected at the onset of the rain recorded higher amount of suspended solids than those collected at the peak of the rain. This may be attributed to the accumulation of particulates from the air and droppings from birds, lizards during the long dry spell (October - January).

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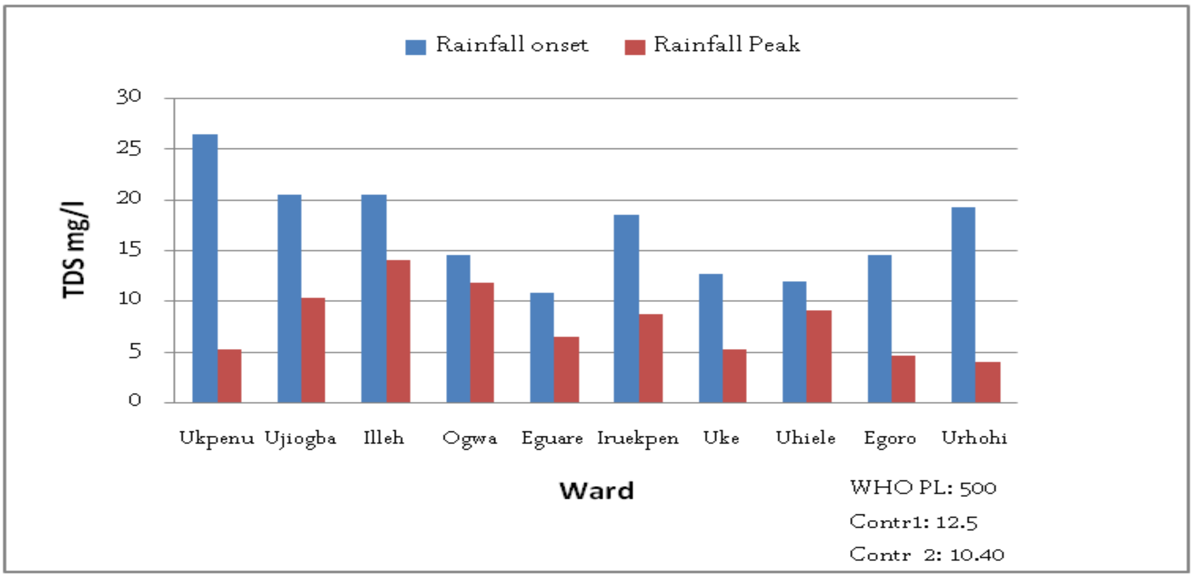

Fig. 4: TDS values of rainwater harvested from galvanized roof-top

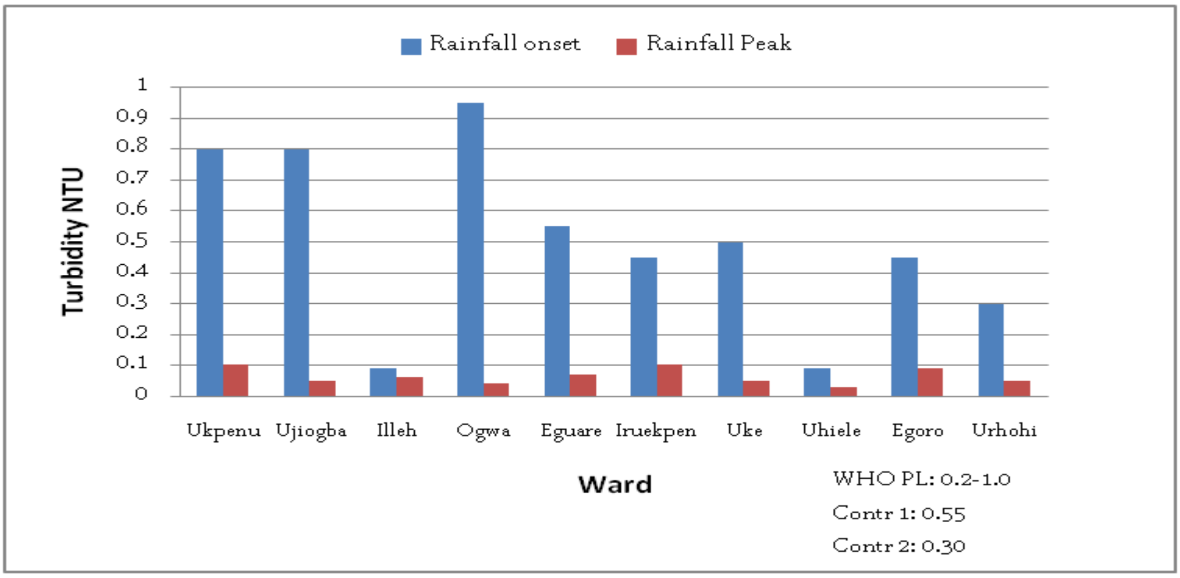

Fig. 5: Turbidity values of rainwater harvested from galvanized roof-top

Although the threshold is not emphasized by the World Health Organization (WHO), TSS is known to reduce water transparency. In addition, pathogens are often clumped or adherent to suspended solids in water (WHO, 2004). This implies that water samples collected from this source does pose some health concerns, especially in households where harvested water is consumed directly without any form of purification.

The mean values for Total Dissolved Solids (TDS) of rainwater samples were recorded as 16.9mg/l and 7.9mg/l for onset and peak of rain respectively, while the values ranged from 11.90 – 26.45mg/l for onset of rain and 4.0 – 14.1mg/l for peak of rain. Dissolved solids decreased from the onset of the rain to the peak (Fig. 4). All samples collected (both for onset and peak of rain) had total dissolved solid concentrations below WHO limit (500mg/l). Although no health based guideline value for Total Dissolve Solid (TDS) has been proposed, the presence of high levels of TDS (above 500mg/l) may become objectionable to consumers owing to excessive scaling in heaters, boilers and other household appliances (WHO, 2004 and 2011). Turbidity values of rainwater samples ranged from 0.09 – 0.95NTU with a mean of 0.58NTU for onset of rain and 0.03 – 0.10NTU with a mean of 0.06NTU for peak of rainfall. Ambient rainwater recorded a turbidity values of 0.55NTU for control 1(city centre) and 0.30NTU for control 2 (suburb) (Fig. 5).

Turbidity values of all rainwater samples including the control samples are within the WHO limits of 0.2 – 1.0 NTU. Mean turbidity values at the onset of the rain was above the WHO lower limit of 0.2 NTU while samples collected rainfall peak were below the WHO lower limit of 0.2 NTU. Figure 6 shows that rainwater samples recorded mean acidity level of 4.83mg/l with a range of 4.00 – 5.70mg/l for onset of rain and a mean of 4.47mg/l with a range of 3.60 – 5.60mg/l for peak of rain. Ambient rainwater had acidity mean values of 5.50mg/l for control 1 and 4.60mg/l for control 2 respectively (Fig. 6).

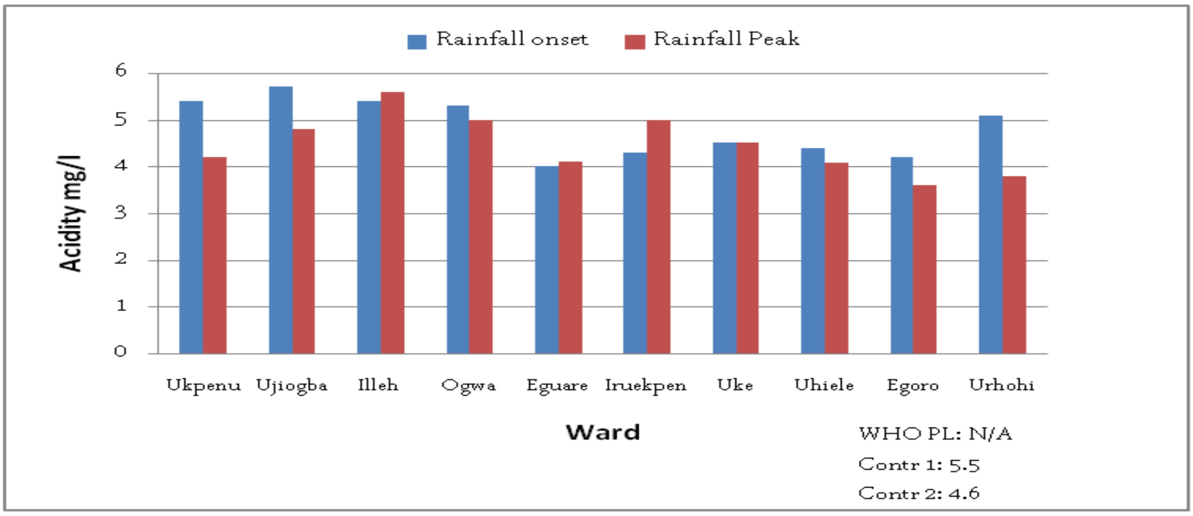

Fig. 6: Acidity values of rainwater harvested from galvanized roof-top

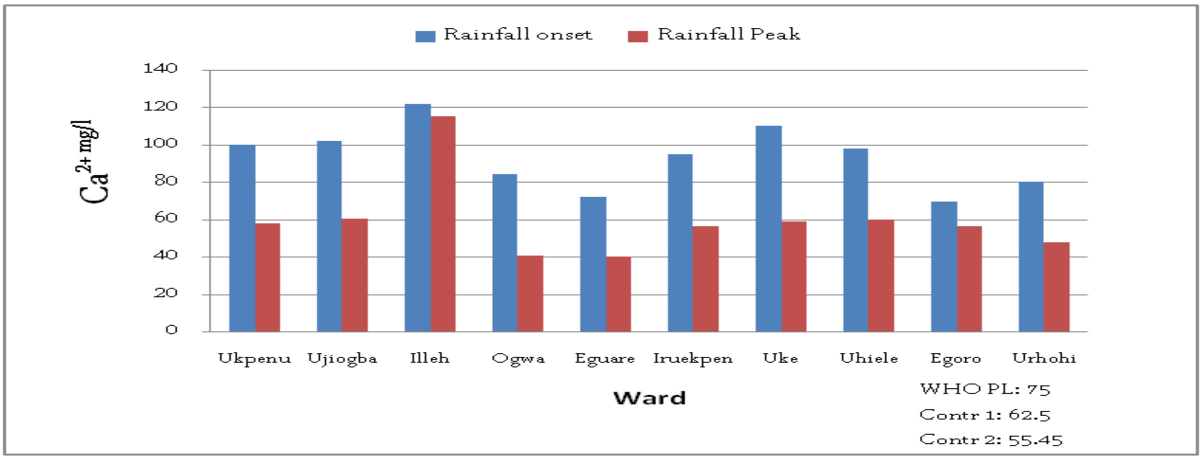

Fig. 7: Ca^{2+} values of rainwater harvested from galvanized roof-top

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Figure 7 shows the mean concentration of Calcium ion (Ca^{2+}) in rainwater samples. The concentration of Ca^{2+} in ranged from 69.5 – 122.3mg/l with a mean of 93.6mg/l for onset of rain and 40.1 – 115.7mg/l with a mean of 59.5mg/l for peak of rain. The rainwater samples at the onset of rain recorded higher Ca^{2+} concentration than those collected at the peak of rain. This concentration also were higher than WHO limit of 75mg/l for Ca^{2+} in potable water while the concentration were lower than the limit at the peak of rain.

The rainwater samples collected at the onset of the rain recorded Iron values ranging from 0.114 – 0.199mg/l with a mean of 0.15mg/l. At the peak of the rain Fe values ranged from 0.045-0.088mg/l with a mean of 0.06mg/l. This shows that Fe concentrations at the onset of rain were above the WHO (2011) limit of 0.1mg/l while those collected at the peak of rain had lesser values (Fig. 8).

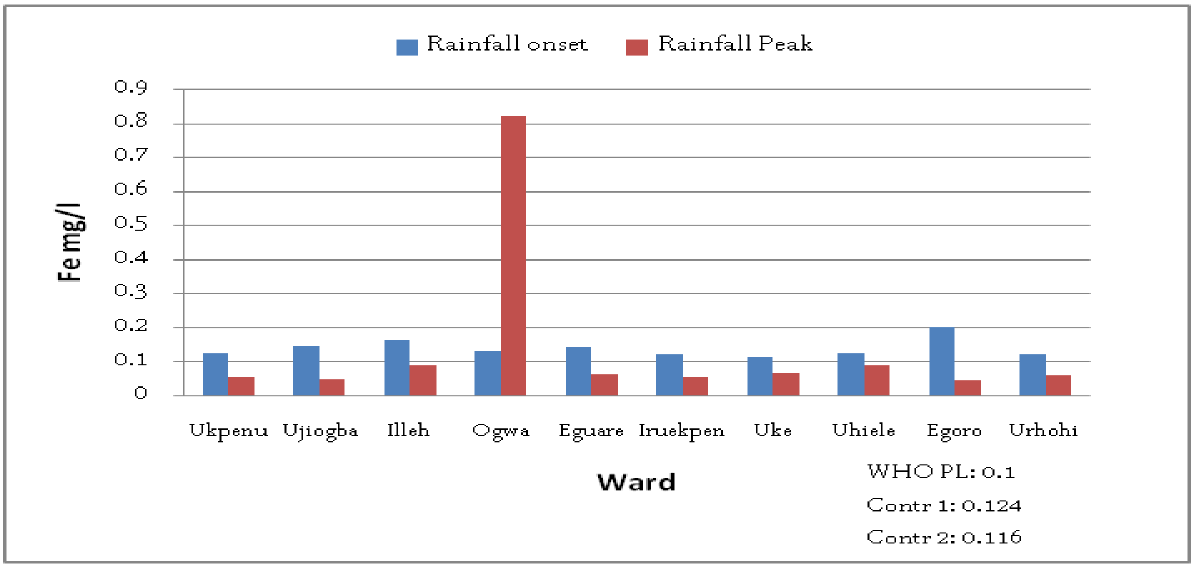

Fig. 8: Fe values of rainwater harvested from galvanized roof-top

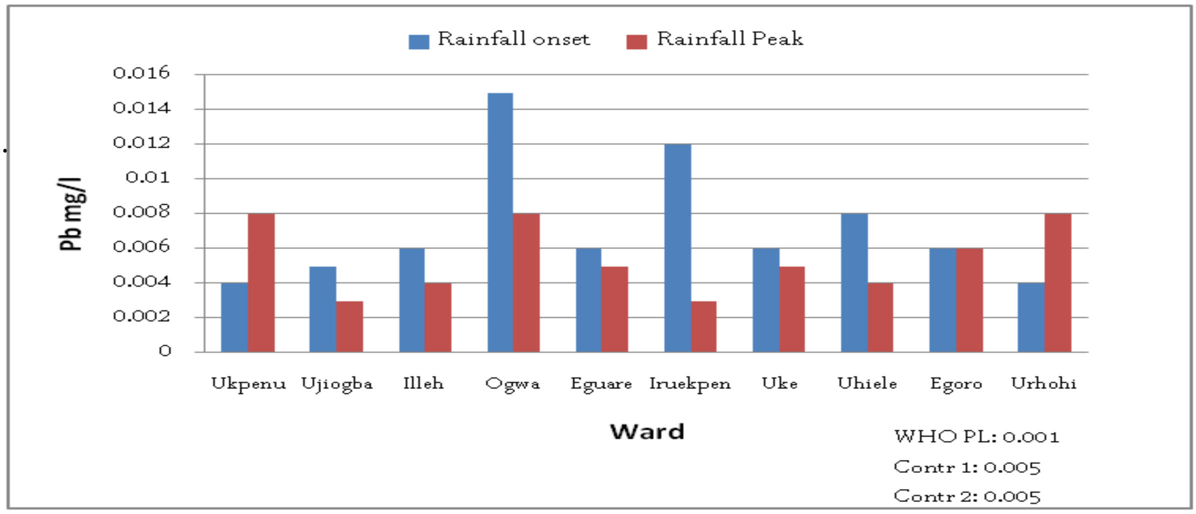

Fig. 9: Pb values of rainwater harvested from galvanized roof-top

The rainwater samples collected at the onset of rain had Lead concentration levels ranging from 0.004 – 0.015mg/l with a mean of 0.007mg/l. At the peak of rain had Lead concentration in harvested rainwater ranged from 0.003 – 0.008mg/l with a mean value of 0.005mg/l. Ambient rainwater had Lead concentration of 0.005mg/l for both control 1 and control 2. All rainwater samples collected irrespective of sampling season and the control samples had lead levels within the WHO limit of 0.01mg/l for potable water. (Fig.9). Figure 10 shows the mean values of chromium concentration of rainwater samples collected at different seasons. Chromium levels of rainwater samples at the onset of the rain ranged from 0.011 – 0.026mg/l with a mean of 0.019mg/l. At the peak of rain, Chromium levels ranged from 0.008 – 0.024mg/l with a mean of 0.018mg/l. Ambient rainwater had Chromium values of 0.016mg/l for control 1 and 0.017mg/l for control 2. All rainwater samples collected had Chromium levels within the WHO limit of 0.05mg/l.

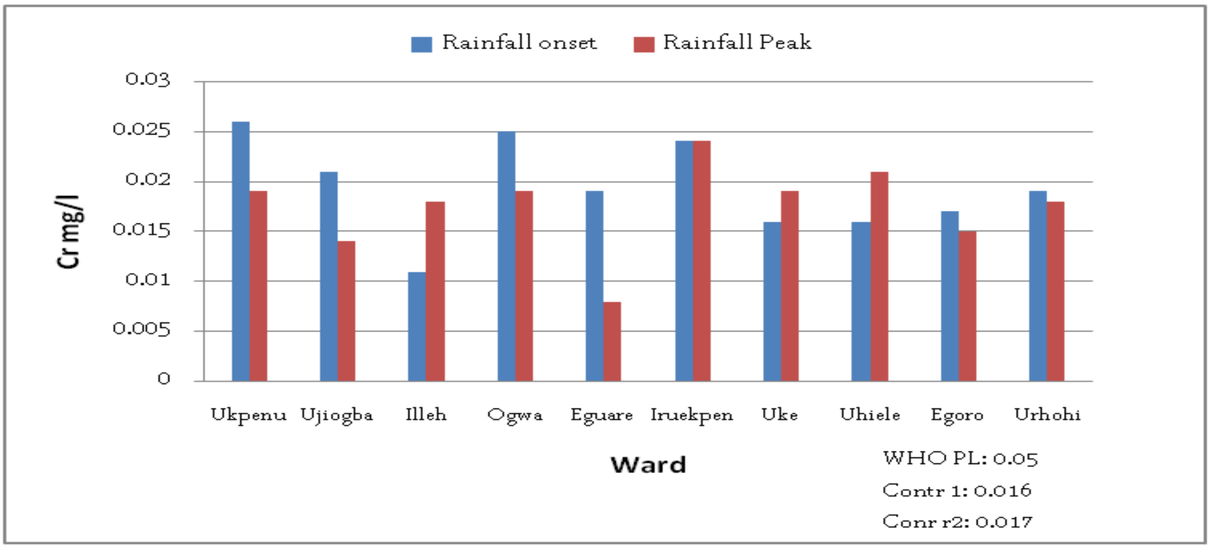

Fig. 10: Cr values of rainwater harvested from galvanized roof-top

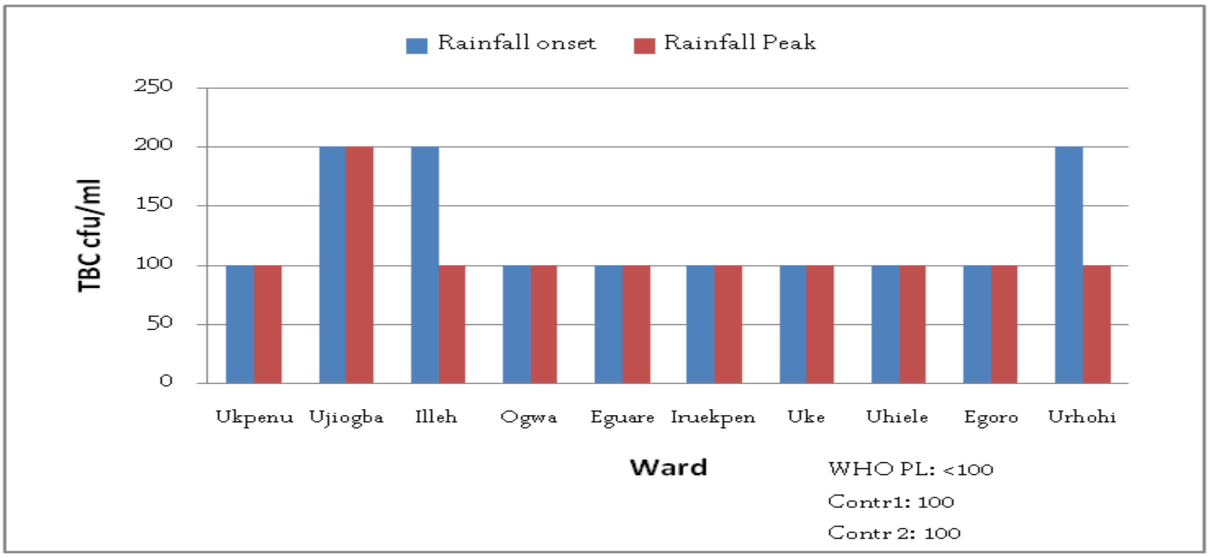

Fig. 11: TBC values of rainwater harvested from galvanized roof-top

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Figure 11 shows the mean bacteria count in rainwater samples collected at different seasons. The Total Bacteria Count (TBC) in rainwater samples at the onset of the rain ranged from 1000 – 2000cfu/ml with a mean of 1300cfu/ml. Samples collected at the peak of the rain had TBC ranging from 1000 – 2000cfu/ml with a mean of 1100cfu/ml. Ambient rainwater samples had a total bacteria count of 1000cfu/ml for control 1 and control 2. As shown in Figure 11, samples collected for both seasons exceeded WHO limit of <100cfu/ml. The presence of the high bacterial load in harvested rain water poses serious health concerns because it is indication that there is a high possibility of the presence of harmful bacteria like *E-coli*, *Clostridium botulinum*, *Campylobacter jejuni*, *Vibrio cholera etc*., all of which are agents of waterborne diseases that affects human health. The total coliform count of samples collected at the onset of the rain ranged from 0.4 – 1.0 Most Probable Number per 100ml (MPN/100ml) with a mean of 0.74MPN/100ml. At the peak of rain Total Coliform Count (TCC) ranged from 0.1 – 0.5MPN/100ml with a mean of 0.3, 0.33 and 0.45MPN/100ml.

All samples collected had detectable Coliform count per 100ml as against WHO standard which states that total coliform bacteria must not be detectable in any 100ml sample of water (0 MPN/100ml.

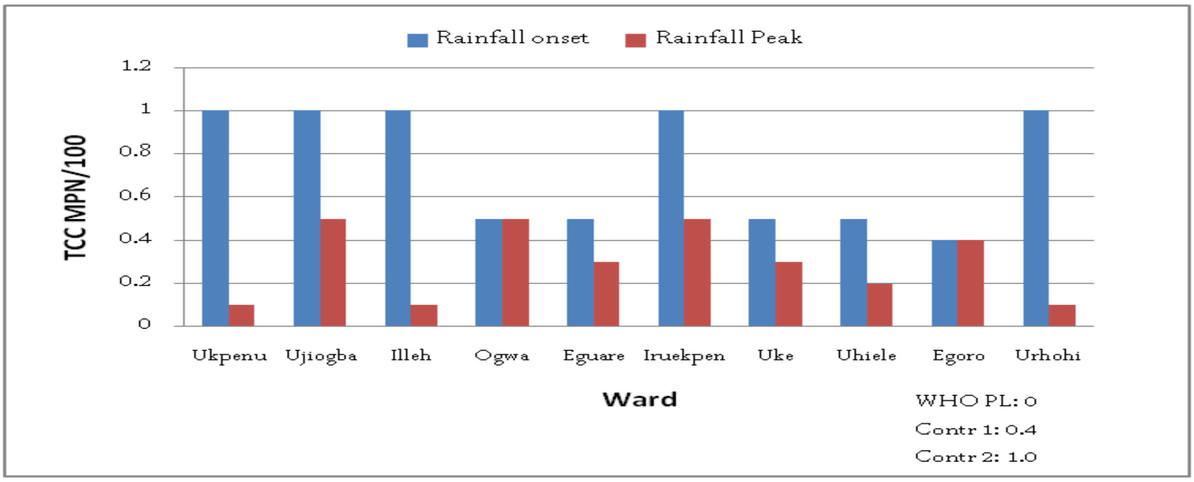

Fig. 12: TCC values of rainwater harvested from galvanized roof-top

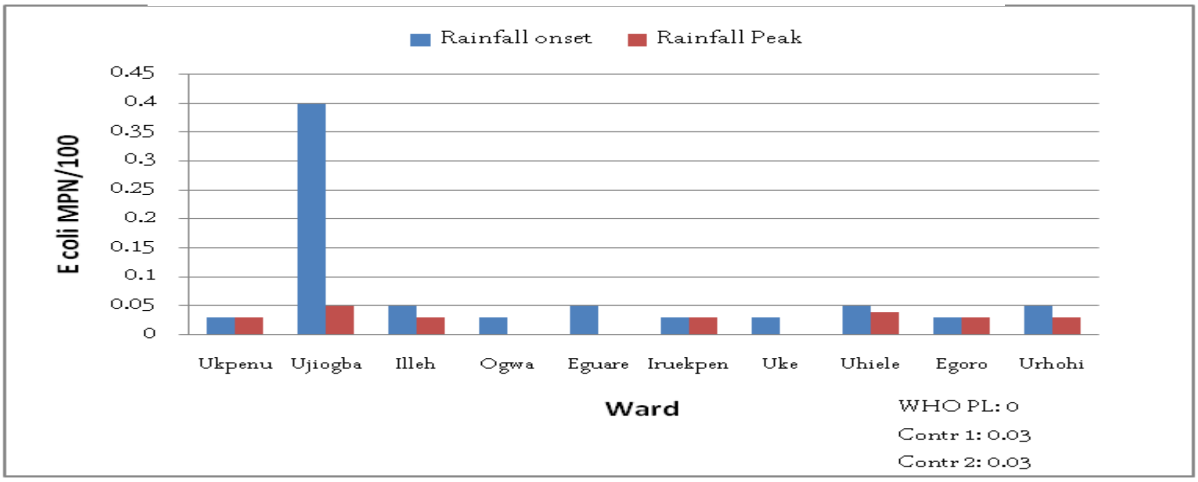

Fig. 13*:* *E-coli* values of rainwater harvested from galvanized roof-top

Figure 13 shows the mean of the Most Probable Number of E-coli count on rainwater samples collected at different seasons. The *E-coli* count in all samples ranged from non-detectable (0) – 0.7MPN/100ml for onset and peak of rain. Generally, water samples collected at the onset of the rain had more *E-coli* count than those collected at the peak of the rain. Atmospheric contamination of harvested rainwater by various contaminants that harbour in the air has been noted by various researchers (TCEQ, 2007; Thomas and Green, 1993; WHO, 2011). Contamination of rainwater by urine of the rodent species *Mastomys natalensis'* has been implicated in the spread of a disease, Lassa fever, an acute viral haemorraghic disease endemic in parts of West Africa, including Nigeria (Acha and Szyfres, 2003; Heymann, 2008; Public Health Agency of Canada, 2010).
Mean values showed detectable *E-coli* count per 100ml on water samples collected in all the wards as against WHO standard which states that it must not be detectable in any 100ml sample of water (0 MPN/100ml). *E-coli* can cause serious hemorrhagic diarrhea and can have long term, if not fatal, complications.

The examination of physical and chemical parameters of harvested rainwater from galvanized rooftop sheet showed no obvious evidence of water pollution as samples collected had values below the WHO permissible limits. However, analysis of pH trend goes to show that the samples are slightly acidic. Examination of heavy metals also showed no pollution in all samples collected as they were within WHO permissible limits. Bacteriological qualities of samples showed evidence of contamination which is likely to be either from dust or bird, lizard, and squirrel droppings. *Escherichia coli (E. coli)* were isolated from almost all the samples considered.. Generally, samples collected at the onset of the rain showed more presence of indicator organisms. The presence of these organisms in water has been linked to water-borne diseases such as diarrhea, cholera, typhoid fever, shigellosis, giardiasis, schistosomiasis, hepatitis, cryptosporidiosis, onchocerciasis and dracuncuculiasis. However, it will only be of major concern if the water is consumed directly without any form of treatment. The two rainfall periods (onset and peak of rain) showed marked difference in the quality of harvested rainwater. Water samples collected at the peak of rain (July rainfall event), had better water quality than collected at the onset of the rain (February event). This may be attributed to roof flushing as the rain event progressed, indicating the importance of an effective first-flush system to allow for proper washing of roof before water is harvested from the roof for use. However, the rainwater harvested at the peak of rain did contain some contaminants at levels above WHO drinking water standards (for TCC and *E. Coli*). This suggests that harvested rainwater must be treated by (chlorination, boiling etc.) before potable use.

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