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Urbanisation and Quality of Harvested Rainwater in Owerri, Imo State, Nigeria

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Abstract
Rainwater harvesting for portable and non-portable use has gained popularity in developing countries due to failure of conventional means of water supply for its increasing population, industrial and commercial activities. The objective of the study is to determine the quality of harvested rainwater with increasing urbanization. Rainwater samples were harvested from different locations in Owerri, Imo state, Nigeria and its physiochemical and microbiological quality analyzed using standard methods and procedures. The results were compared with WHO standards for drinking water and subjected to statistical analysis. The rainwater samples at the different locations showed statistically significant differences p (0.05) < *alpha* (0.708). The physicochemical quality was affected by increased amount of sulphate (484.81 ± 115.02)mg/l, color (56.23 ± 14.59)PCU, turbidity (23.92 ± 6.20)NTU, phosphate (25.03 ± 20.32)mg/l, phosphorus (8 ± 6.59)mg/l and heavy metals (0.92 ± 0.84)mg/l. Though there was no fecal coliform contamination, the microbial concentration (11.95 ± 5.04) in the present study exceeded standards. It is concluded that the harvested rainwater is not suitable for direct drinking without treatment but it could be used for other domestic purposes.

Keywords: Rainwater Harvesting, Quality analysis, urbanization.

Introduction

Water is essential for all dimensions of life. The common sources of water are Rainwater, surface water (e.g.: river, ocean, ponds, lakes) and underground water (e.g.: well, springs and borehole). Around the world rainwater has been used since time immemorial to augment the supply of water or even form the main store, depending on the situation (Pathak and Heijnen**,** 2006) [16]. Rainwater harvesting is an ancient practice of capturing rain runoff from roofs and other surfaces and storing it for a later use (Despins *et al*., 2009) [7]. Even in some areas where potable water is supplied by networks, harvested rainwater is still a significant supplemental resource for domestic use. Rainwater is nowadays used as a source for numerous domestic applications like drinking, bathing, laundry, toilet flushing, and water supply for gardening purposes.

Rainwater is relatively free from impurities except those picked up by rain from the atmosphere, but the quality of rainwater may deteriorate during harvesting, storage and household use (WHO, 2011) [18]. Urbanisation is a population shift from rural to urban areas. The quality of rainwater which has been properly collected and stored, is expected to be substantially free from minerals and most of the common pollutants that are present in the atmosphere, yet it is polluted mostly in the urban areas as a result of increased human activities and air pollution. Similarly, in the rural environment where industrial activities are low, production of gases such as carbon monoxide, hydrogen sulphide and hydrocarbons barely affect the quality of rainwater. Wind-blown dirt, leaves, fecal droppings from birds and other animals, insects and contaminated litter in the catchment areas due to the influence of urbanization can be a source of contamination of rainwater, leading to health risks from the consumption of contaminated water (Evans *et al.,* 2006) [10].

In addition, with increased industrialization, transportation, and other anthropogenic activities seen in urbanized areas, rainwater is likely to be contaminated by trace metals from dry and wet decomposition. Rainwater can also be contaminated by nutrients from decaying small animals; birds' droppings, and plant leaves (Abegunrin *et al*, 2014) [2]. Achadu *et al*. (2013) [3] showed that the physiochemical quality of water collected in a rainwater harvesting system in Wukari, North-eastern Nigeria can also be affected by many factors which include: the nature of the material of catchment system and the roof materials, environmental pollution from industries, automobiles and also generator fumes. The basic element of environment affecting the quality of harvested rainwater is atmosphere. Polluted atmosphere is an important factor that degrade the quality of material and affects rainwater (Abbasi, T. and Abbasi, S.A., 2011) [1].

There appears to be limited information on urbanisation and quality of harvested rainwater in Nigeria (Achadu *et al*., 2013; Ahmed *et al*., 2011) [3, 4]. The quality of harvested rainwater is therefore an issue of public health concern. As the potential public health risks associated with untreated rainwater have not been identified, no legislation regarding the use of rainwater in Nigeria has been stipulated. This is therefore of major concern as it has previously been noted that in order to use harvested rainwater as part of a solution to the water crisis, rainwater needs to be qualitatively and quantitatively assessed (Eruola *et al*., 2013) [9].

This research study would explore the impact of urbanization on the physic - chemical and microbiological parameters of rainwater harvested in Owerri, Imo state, Nigeria. The research findings shall provide among others reference information for future intervention, research and increased understanding of the possible health risks associated with contamination of harvested rainwater from environmental influences as a result of urbanization.

Methodology

Study Area

Owerri became the capital of Imo state in 1976 following the creation of the old Imo state, which was carved out from East central state. Upon assumption of the status of a state capital, most private, state and Federal institutions started establishing their offices in Owerri. It lies within the 5°29′06″N 7°02′06″E and 5.485°N 7.035°E Coordinates. Owerri consists of three Local Government Areas including Owerri Municipal, Owerri North and Owerri West. It has approximately 100 square kilometers (40 sq mi) in area and estimated population of about 400,000 as of 2006 National population census of Nigeria. Owerri is bordered by the Otamiri River to the east and the Nworie River to the south. Its mean annual temperature ranges from 25-30 °C and mean annual rainfall range of 2500-3500mm.

Data Collection

Sample Collection and Transportation

Water samples were taken aseptically from different locations in Owerri, Imo State, Nigeria including Eziobodo (Owerri West), Douglas (Owerri Municipal), Imo Housing Estate (New Owerri) and Orji (Owerri North LGA) using ethanol to sterilize water cans and 0.1M of hydrochloric acid for pretreatment of water basins before harvest.

The membrane filter technique method was employed for all microbiological analysis. The concentrations of metals were determined using flame Atomic Absorption Spectrophotometer according to FSAI, 2015 [11]. Anions detected using High-Performance Ion Chromatography (HPIC). The Chemical Oxygen Demand (COD), dissolved oxygen and Biological Oxygen Demand (BOD) were determined for each rainwater sample using DO_2 meter. pH and conductivity was determined using hand held PH meter model HI98107 (HANNA) and conductivity meter model HI98302 (HANNA) respectively. Turbidity was determined by photometric method using HACH DR/2010 spectrometer at a wavelength of 860nm.

Phosphate, Calcium, Magnesium hardness and Total chlorine was determined using HI83200 multipara meter bench photometer at a wavelength of 525mm. Calcium carbonate was determined by Oxalate method using HI93200 multipara meter bench photometer wavelength of 466nm. The colour of water was determined by colorimetric platinum cobalt method for the adaptation of standard method for the examination of water and waste water at 420nm with HI83200 multipara meter bench photometer.

Data Analysis

All results were analyzed statistically using SPSS version 16.0 for one way ANOVA.

Results

Table 1: Physical parameters of harvested rainwater compared with WHO standards

Parameter, Unit	WHO Standard	Douglas Road	Imo Housing Estate	Orji	Eziobodo
Temperature, °C	20-30	26.4	24.8	25.8	24.8
Conductivity, µs/cm	100	13	5	27	103
Colour, PCU	5	37	53	69	66
Turbidity, NTU	5	20.93	18.23	32.52	23.98
Total suspended Solids, mg/l	250	194	80	88	142
Total Dissolved Solids mg/l	250	9.55	1.72	18.65	68.05

Table 2: Chemical parameters of harvested rainwater compared with WHO standards

Parameter, Unit	WHO Standard	Douglas Road	Imo Housing Estate	Orji	Eziobodo
Ph	6.5-8.5	6.6	7.6	6.2	6.3
Dissolved Oxygen, mg/l	5	0.9	2.6	0.6	4.8
BOD	5	0.3	0.8	0.1	2.4
Calcium, mg/l	100-300	0.39	0	0.22	0.3
Total Hardness ($CaCO_3$), mg/l	150	0.27	0	0.84	0.05
Magnesium, mg/l	250	0	0	0	0.23
Alkalinity	100	102	84	16	58
Nitrate, mg/l	50	81.1	43	18	27.1
Phosphate, mg/l	5	45.4	38	1.3	15.4
Phosphorus, mg/l	0.3	14.6	12.2	0.3	4.9
Sulphate, mg/l	250	506.6	571.22	544.5	316.9

Table 3: Heavy metals of harvested rainwater compared with WHO standards

Paramete, Unit	WHO Standard	Douglas Road	Imo Housing Estate	Orji	Eziobodo
Iron, mg/l	0.3	1.18	1.27	1.236	4.8
Mangane, mg/l	0.2	0	0.3	0.4	0.2
Aluminiu, mg/l	0.1-0.2	1.022	1.516	4.272	0
Copper, mg/l	1	0.23	0.237	0.22	0.22
Zinc, mg/l	3.0 – 5.0	0.184	0.045	2.015	0.994
Lead, mg/l	0.01	0.913	0.495	0.047	0.322

Table 4: Microbiological parameters of harvested rainwater in Owerri, Imo state compared with WHO standards

Parameter, Unit	WHO Standard	Douglas Road	Imo Housing Estate	Orji	Eziobodo
Total Heterotrophic Plate Count	0-30	45	30	13	65
Total Coliform Count	0-10	2	2	0	0
E.coli Count	0	0	0	0	0
Total Fungal Count	0	19	21	23	19

1. Table 1 shows a comparison of the physical parameters analysed on rainwater harvested from different locations in Owerri with WHO standards. The values of Colour, and turbidity exceeded the limits. Other parameters temperature, conductivity, TSS and TDS were within limits.
2. Table 2 shows a comparison of the chemical parameters analysed on harvested rainwater from different locations in Owerri with WHO Standards. The values of phosphorus, sulphate and phosphate exceeded limits.
3. Table 3 shows a comparison of the heavy metals of harvested rainwater from different locations in Owerri with WHO standards. Zinc and copper were within limits while iron, manganese, aluminium and lead exceeded.
4. Table 5 shows a comparison of the microbiological indicators analysed in harvested rainwater from different locations in Owerri with WHO standards. *Escherichia coli* was not detected but other indicators such as THPC, TFC and TCC exceeded WHO limits.

Discussion

Physical parameters

The Hydrogen Ion Concentration (pH)

The pH of the harvested rainwater in different locations was in the range of 6.2-7.6. The pH values in Douglas road, Owerri Municipal and Imo Housing Estate, New Owerri were higher but within the WHO standards while the samples from Orji in Owerri - North and Eziobodo in Owerri - West LGA were lower than the WHO standards. The rainwater harvested from Owerri, Imo state, Nigeria might not be classified as an acid rainwater when compared with other works such as Origho (2015) [15] who recorded pH values of 5.45 in urban areas in Ughelli North, Delta state, Nigeria. The low pH value was attributed to the high rate of industrial atmospheric pollution from rubber processing industries and fumes of automobile.

Turbidity, TSS and TDS

The turbidity of a sample is the reduction of transparency due to the presence of particulate matter such as sand, clay or slit, finely divided organic matter, plankton or other microscopic organisms. These particulates cause light to be scattered and absorbed rather than transmitted in straight lines through the sample (FSAI, 2015) [11]. The values obtained from the present study ranged from 18.23-35.52 NTU and were above the WHO standards of 5NTU. This is similar to the results obtained by Origho (2015) [15] of 9.11 NTU from the urban areas and 1.01 NTU from rural areas.

The values of Total Suspended Solids (TSS) and Total Dissolved Solids (TDS) of the harvested rainwater samples though within the WHO limits of 250mg/l for all the locations was higher in samples from Douglas road, Owerri municipal and Imo housing Estate, New Owerri which corroborates the impact of urbanisation on the environment and quality of harvested rainwater. Turbidity, TSS and TDS contaminants might have been from atmospheric deposition (dust, fumes from automobiles, plants and animal waste on the roof top, particulate matter containing heavy metals, etc.) [Sanchez *et al*., 2015]. This is expected as the factors contributing to these variables are of universal occurrence.

Colour

Drinking water should ideally have no visible colour. Colour in drinking water is usually due to the presence of coloured organic matter, iron and other metals either as natural impurities or as corrosion products. The concentration of colour in the present study ranged from 37- 69TCU. No health-based guideline value is proposed for colour in drinking water (WHO, 2011) [18]. The result also collaborates with study by Chukwuma *et al.*, 2012) [5].

Chemical parameters

Total Hardness

The total hardness values (0-0.84) mg/l of water samples analysed were within the maximum limits of WHO standards of 150mg/L. This is also seen from the mean of 30.2 total hardness recorded in urban area and mean of 19 total hardness recorded in the rural area of Ughelli North, Delta state, Nigeria recorded by Origho (2015) [15].

Nitrate

Nitrate is the most highly oxidized form of nitrogen compounds commonly present in natural waters (FSAI, 2015) [11]. Significant sources of nitrate are chemical fertilizers, decayed vegetable and animal matter and industrial discharge. Unpolluted natural water contains minute amounts of nitrate (FSAI, 2015) [11]. The nitrate levels of the rainwater samples collected in the present study ranged from 18.0-81.1mg/l. The nitrate concentration of rainwater harvested from Douglas road, Owerri municipal exceeded the WHO limits of 50mg/l. The concentration of nitrate in the other locations in the study were within the WHO standard. Excessive concentration of nitrate in drinking water is considered hazardous especially to infants as it causes 'blue baby syndrome' (Abegunrin *et al.*, 2012; FSAI, 2015) [11].

Magnesium and calcium

The concentration of calcium and magnesium salts in water is a significant contributory factor in water hardness and often used as a measure of potable water quality (FSAI, 2015) [11]. Magnesium is used in alloys, drying agents, fertilizers, pharmaceuticals, and foods. It is also an essential element in chlorophyll. Concentrations greater than 125 mg/L also can cause the body to get rid of excess water. In the present study, Eziobodo in Owerri - west LGA with magnesium content of 0.23mg/l is the highest magnesium concentration while Douglas road in Owerri Municipal had the highest calcium concentration of 0.39mg/l. Magnesium and calcium concentration in the samples were within WHO standards.

Sulphate

Sulphate ions usually occur in natural waters. Most of them originate from the oxidation of sulphate ores in the atmosphere, the presence of sedimentary rocks, particularly those rich in organic compounds, and atmospheric sulphur dioxide formed by the combustion of fossil fuels and emitted by the metallurgical roasting process from automobiles and generators in these locations. In the present study, Imo Housing Estate in New Owerri has the highest sulphate concentration of 517.22mg/l above the 100mg/l WHO limits.

Phosphorus

Sources of phosphorus from natural sources such as bird faeces and lichens that contaminate the roof runoff can also be added to the rainwater. In addition to the organic phosphorous that would be later added to the runoff, the concentration of inorganic phosphorous present in the rainwater (in the form of phosphate, PO_4^{3-}) can by itself exceed the concentration threshold for algal blooms of 0.03 mg P/L (Weibel *et al.,* 1966) [17]. Duncan (1995) [8] proposed an average concentration for suspended solids of 20 mg/L and a range of 0.01-0.1 mg/L for phosphorous, in rainfall at urban sites. The concentration of phosphorus and phosphate in the samples collected from the different locations in the present study ranged between 0.3-14.6mg/l and 1.3-45.4mg/l respectively. This exceeded the WHO standards.

Heavy Metals

Heavy metals contamination can be seen with iron (1.236-4.8mg/l) and lead (0.047-0.913mg/l) having the highest percentage distribution in all the locations. This is followed by aluminium (0.00-4.272mg/l) and manganese (0.0-0.4mg/l). Zinc (0.045-2.015mg/l) and copper (0.220-0.237mg/l) has the least percentage distribution. However Imo Housing Estate in New Owerri has the highest concentration (of heavy metals followed by Douglas Road in Owerri Municipal. Eziobodo in Owerri - West is the least. Heavy metals concentrations in the present study were above WHO standards but Lead and iron were particularly significant. Contamination could be from atmospheric depositions, the roofing materials, etc. Origho (2015) [15] observed that zinc concentration in the urban and rural areas of Ughelli North was generally within the maximum limits of 0.05mg/L standard of WHO. This is evident from the mean of 0.04 and 0.02 zinc concentration in harvested rainwater quality. However, the concentrations of copper were below the acceptable WHO standards. Succinctly, the increase in the heavy metals properties in the different locations in the present study may be attributed to increased air pollution from industries, fossil and non - fossil fuel combustion and automobiles.

Bacterial Indicators

Airborne microorganisms and aerosolized bacteria can be transferred to harvested rainwater through atmospheric deposition and decomposing organic matter. In the present study, bacterial contamination (13- 65cfu/ml) exceeded WHO standards in Eziobodo in Owerri - West (65cfu/ml) and Douglas road in Owerri municipal (45cfu/ml). Pathogens known to cause disease such as pneumonia and typhoid fever were isolated amongst others. In the present study obtained levels of *Escherichia coli* (0cfu/ml) in rainwater were within the WHO standards of 0 cfu/mL for a highly urbanized site. Total faecal count (0cfu/ml) was also within the standards. Total coliform count was within WHO standards in Eziobodo and Orji. Total coliform count of 2cfu/ml was obtained in Douglas and Imo Housing Estate in New Owerri.

Fungal Indicators

The presence of fungal flora in rainwater was studied by Nishihara *et al*. (1989) who detected 29 fungal genera, while Czeczuga and Orłowska (1997) identified 33 fungus species in the rainwater falling from six different roof types. Fungal contamination in the present study showed high prevalence of *Aspergillus niger*. Eziobodo in Owerri – West had the highest percentage of fungal contamination. This could be because of the algal plants and waste present on the roof. Over all fungal contamination (19-23cfu/ml) exceeded WHO standards.

From the Analysis of Variance (ANOVA) $P = 0.78 > p = 0.05$ meaning there is significant difference in the variation in quality of harvested rainwater in Owerri, Imo state. Hence, we accept the alternative hypothesis that urbanisation has an impact on harvested rainwater quality in Owerri, Imo state.

Conclusions

The present study provided reference information on the effect of urbanisation and quality of harvested rainwater at different locations in Owerri, Imo state, Nigeria. The results obtained re-established the link between urbanisation and the Physical, Chemical and microbial quality of harvested rainwater.

The microbial load from the rainwater samples from Douglas road in Owerri municipal and Imo Housing Estate in New Owerri did not meet the WHO standard for potable water. This may be due to relatively higher human activities and urbanisation in these locations than in Eziobodo in Owerri - West and Orji in Owerri - North and pathogens such as *Salmonella, Klebsiella, Enterobacter* spp were isolated in all the locations.

The pH, temperature, dissolved oxygen, BOD, calcium, magnesium, total hardness, copper and zinc in harvested rainwater in the present study were within WHO standards. Physiochemical parameters like colour, turbidity, phosphate, sulphate, phosphorus, and heavy metals exceeded WHO standards for potable water in the different locations sampled in Owerri, Imo State, Nigeria.

Rainwater could be used for both potable and non-potable purposes and in order to have better quality of harvested rainwater. The following are recommended:

Storage tanks must be properly washed before the start of rainy season.

Stored water should be treated by adding some disinfecting agents such as chlorine and pre - boiling of water which might help in reducing the risk of microbial contaminations.

Rainwater samples from Douglas road in Owerri municipal and Imo Housing Estate in New Owerri from this study due to their high microbiological load is not advisable to use as drinking water or washing plates but can be used for other domestic activities like flushing toilet, washing of clothes, cleaning the floors, etc.

Further research in this area should be on the quality characterization using water quality index rating of the harvested rainwater in Owerri, Imo state, Nigeria.

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