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VARIABILITY OF RAINWATER QUALITY DUE TO ROOF CHARACTERISTICS

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ABSTRACT

Rainwater harvesting is receiving increased attention worldwide as an alternative source of drinking water. Although, some people typically consume collected rainwater without any type of disinfection, the microbial and other physic-chemical qualities of this water source can be poor. In this paper, the variability of rain water quality due to roof characteristics was investigated using some randomly collected data from both industrialized and rural areas in Gboko, Nigeria. Questionnaires were randomly administered in the rural areas to obtain data on the type of roofing materials and age of the roof. In addition, samples were also collected from both areas and examined for alkalinity, pH, NO_3^-, SO_4^{2-}, NH_4^+, Ca^{2+}, Mg^{2+}, dissolved heavy metals (Fe, Cu, Mn, Zn, Ni and Cr), and total coliform (not detected). The examined parameters gave average values of alkalinity, pH, NO_3^-, SO_4^{2-}, NH_4^+, Ca^{2+}, Mg^{2+}, Fe, Zn as 4.8mg/l, 7.77, 23.9mg/l, 1.2mg/l, 26.1mg/l, 120.3mg/l, 99.6mg/l, 0.12mg/l, 0.13mg/l respectively. It was discovered that, the period of rainfall, environmental factors, type and age of roofing materials have varying effects on the characteristics of rainwater. From the experimental result, the roof drainage water quality in Gboko can be used as grey water for domestic purposes but requires treatment to be used as drinking water.

KEYWORDS: Rainwater quality, Water availability, Rainwater harvesting, Variability, Roof drainage.

INTRODUCTION

Provision of adequate and regular water supply to increasing population is one of the serious problems facing water agencies at the State and Federal levels of most developing countries such as Nigeria. While the government agencies have made some efforts to increase the coverage of potable water, water supply still lags behind demand, and most of the water schemes are not functional (Agunwamba, 2000; Aho and Utsev, 2009). Inappropriate vision and inadequate feasibility studies; unnecessary haste in getting projects executed; lack of adequate involvement of the public, especially in the maintenance of the schemes; financial constraints and lack of professionalism (Odendall, 1999); have resulted in the preponderance of unsustainable water supply schemes (Williams, 2002).

Rainwater is usually the most clean available water source (Goncalves *et al.*, 2003), something that gives rainwater additional advantages for its use, in comparison to other water sources (Eriksson *et al.*, 2002). Furthermore, its collection and use reduces some of the catastrophical consequences of rain (e.g., flooding).

Rainwater and roof drainage pollution is caused by constituents existing in the atmosphere (Khare *et al.*, 2004; Hu *et al.*, 2003) and/or accumulated on the roof area. Acid pollutants in the atmosphere (e.g., H_2SO_4, HNO_3) mainly originate from combustion of fossil fuels in automobiles and buildings for heating, and the industry (Lee *et al.*, 2000; Hu *et al.*, 2003; Kulshrestha *et al.*, 2003). In water receivers with low buffer capability, acid precipitation leads to acidification of water and soil, and adverse effects on ecosystems and humans. Emissions of alkaline substances (e.g., dust particles and ammonia) significantly reduces rain acidity(Placet and Streets, 1987). Furthermore, several times the drainage system itself, (i.e., roofs and drains),

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contributes to runoff water pollution (F rster, 1999; Zobrist *et al.*, 2000; Polkowska *et al.*, 2002).

Since rain is an important physical pathway for air pollutant removal, the determination of rainwater and roof drainage chemical composition helps in identifying the sources contributing to change in rainwater chemistry. It reinforces the understanding of local and regional sources and dispersion of pollutants, and the possible effects of their deposition in ecosystems. Furthermore, knowing rainwater chemistry is important in planning use of this resource to meet potable water demands particularly when designing onsite collection and use systems. Unreliable provision of potable water by the responsible government agencies has resulted in the consumption of untreated rainwater harvested from roof-tops virtually in most homes in certain towns.

In Nigeria, literature on water quality deterioration and its effects on health are scarce. Basher and Adebayo (2003) examined the variation of water quality and outbreak of water borne diseases in Yola area. Relationship was found between water quality deterioration and the number of reported cases of some water borne diseases such as diarrhoea and typhoid (Aho and Utsev, 2009). The study evaluates the chemical characteristics of rainwater in the city of Gboko, after its route on roofs and roof drainage pipes, and the comparison of these characteristics to drinking water standards.

MATERIALS AND METHODS

Study Area

The study area is Gboko, Benue State, located in north-central Nigeria (7^{o}19M48nN, 9^{o}00M00nE, Altitude å350m). It has an estimated population of about 500,000 people (National Population Commission, 2006). Gboko is a fast growing city and attracts people from the surrounding villages. The major areas surrounding the city are mostly forest and agricultural land. The industries in the city include cement production, Orange and Mango juice factories, and marble quarries.

Gboko is located near the Mkar Mountain. Geologically, Gboko area is known for metamorphic rocks (gneiss, amphibolites, and marbles), granite and volcanics. The total mean annual rainfall is 761 mm (range 1095.6 to 368.2 mm). The months with the highest rainfall are August and September. The dryer months are January, February and March.

Data Collection and Analysis

Six sampling sites were selected in the city, which represent as much as possible various distinct categories of residential density, traffic volume and industrial activity. Water samples were collected based on the period of rainfall, environmental factors, type and age of roofing materials as shown in Table 1.Roof drainage water from the six mentioned sampling sites in the city were collected (60 samples) from August, 2009 to October, 2010. The meteorological data of the months of sampling were obtained from weather station at Nigerian Air force Base, Makurdi. The samples were collected during rainfall events. The collection of the samples from all the sampling sites was done as the rain starts dropping on the roof. For roof drainage water sample collection, plastic containers washed with 10% HCl and then rinsed with ultra-pure water were placed at the final point of the roof drain pipes.

Measurements of pH, temperature, electrical conductivity (EC) and dissolved oxygen (DO) of the collected rainwater samples were made *in situ* using HI 9828 Multiparameter Water Quality Meter. Water samples were transported to the laboratory and analysed within six hours using standard methods described in APHA, 1998); for total coliforms (Method 9000), alkalinity (Method 2320-B), nitrate (Method 4500-Nitrate-E), ammonium (Method 4500-Ammonia-F), sulphate (Method 4500-Sulphate-C), calcium, magnesium, potassium (HPLC) and dissolved heavy metals (Method 3110).

Additional information was generated through personal interviews from house owners, or their caretakers to obtain data on the source of roofing materials and age of the roof. Identified construction men of some of the sampled roofs and the consumers were also interviewed. About 400 persons including rainwater consumers and land lords in Gboko completed questionnaires. Interviews augmented the questionnaires in cases where the respondents were illiterates.

RESULTS AND DISCUSSION

Tables 1 and 2 are the main characteristics of the sampling areas and mean monthly meteorological data during the sampling period respectively. Table 3 presents Mean, Standard

Deviation (SD), minimum and maximum concentration values of measured anions and cations in roof drainage water samples, for all sites. The dominant cations were Ca^{2+} and Mg^{2+}, which are mainly products of erosion of mountain rocks and roof construction materials. The anions, $NO_3^{ï}$ and $SO_4^{2ï}$ were present in high concentrations of 43.8mg/l and 4.3mg/l, that could be duct combustion of fossil fuels. pH values for all samples ranged between 3.6ï 11.4.

Table 1: Main characteristics of the sampling areas.

Sampling Site # Sampling Site Name	Roof Construction Material	Drainage Pipe Material*	Traffic Volume (Veh.No./hr)	Land Use
1. BCC cement factory, Tsekucha.	concrete	metal/plastic	812	industrial
2. Katsina ala Street.	mosaic	metal/plastic	548	commercial
3. Adekaa market.	mosaic	metal/plastic	721	commercial
4. Agashua Street.	clay tiles	metal	182	Residential
5. Mku Achika Street.	Iron-sheet	metal/plastic	365	Residential
6. College of Agric, Yandev.	Asbestos-tiles	metal	196	campus

***Metal:** stands for Iron and zinc alloy.

Table 2: Mean monthly meteorological data during the sampling period.

Month	Total Rainfall Depth(mm)	Mean Temperature(^oC)	Mean Wind Speed(m/s)	Wind Direction Frequency (%) North	South
August 2009	75.0	25.3	0.7	98.1	2.9
Sept 2009	90.2	6.2	3.2	44.2	29.8
Oct 2009	83.1	4.4	3.6	42.5	54.2
April 2010	25.0	10.3	3.0	97.0	3.5
May 2010	23.2	17.7	0.8	95.1	9.7
June 2010	17.4	22.8	0.9	95.9	12.6
July 2010	11.0	9.8	0.5	95.2	1.3
August 2010	74.5	25.3	0.7	98.1	2.9
Sept 2010	89.8	6.2	3.2	44.2	29.8
Oct 2010	74.8	4.4	3.6	42.5	54.2

Table 3: Concentration statistics of various measured constituent in rain drainage water.

Constituent	Drinking water Standard (mg/l)	Roof Drainage water Concentrations (mg/l) Mean	SD*	Range
NH_4^+	30	26.1	19.2	6.9 - 73.3
K^+	310	147.2	144.6	11.8 - 445.0
Mg^{2+}	412	99.6	85.2	15.3 - 244.4
Ca^{2+}	5000	1203	453.7	549.5 - 1630
$N0_3^-$	45	23.9	11.5	6.2 - 43.8
$S0_4^{2-}$	100	1.2	2.7	0.2 - 4.3

*SD = Standard deviation

Table 4: Comparison of Roof Drainage Water pH and Concentration (mg/l) of Inorganic ions in the Present Study with those in other Cities in Nigeria.

Constituent	Present Study	Yola (Nigeria)[X]	Bauchi (Nigeria)[Y]	Enugu (Nigeria)[Z]
pH	7.40	5.70	4.90	5.30
NO_3^-	7.40	27.30	29.10	25.00
SO_4^{2-}	2.95	97.80	102.00	56.20
NH_4^+	21.80	20.20	26.30	18.70
Ca^{2+}	980.00	140.10	101.10	121.30
Mg^{2+}	136.00	30.80	27.00	32.20

[X] Basher and Adebayo (2003)
[Y] Williams (2002)
[Z] Agunwamba (2000)

Fig. 1 presents mean values of pH, alkalinity, nitrate and sulphate concentrations of roof drainage water for the six sample areas. The pH of rainwater from roofs in the six sampling sites ranged from 7.4ï 8.3 with a mean value of 7.77. The relatively high pH can be explained by the existence of calcium and magnesium in the rainwater. pH was within drinking water standards (6.5ï 9.5) (WHO, 1993). The pH mean values also indicate a slight presence of acid substances in the atmosphere. Samples with pH below 6.0, which indicates human activities (Ba¸sak and Alagha, 2004; Mouli *et al.*, 2005), numbered only 3% of all samples (Fig. 3b). The majority of samples (more than 90%) had pH values between 7.4 and 8.4 (Fig. 1a), which also indicates that the concentrations of acid gases in the atmosphere are low.

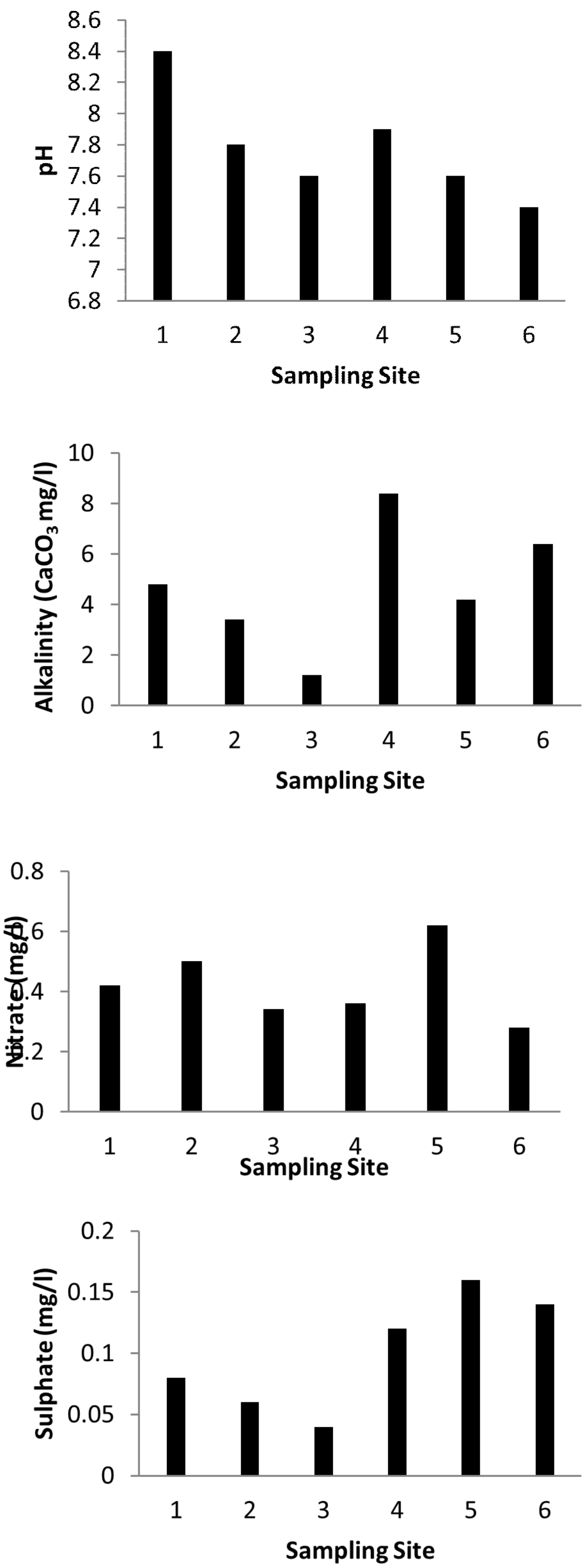

Fig. 1: Mean Values of pH, Alkalinity, Nitrate and Sulphate Concentrations for the Six Sample Areas.

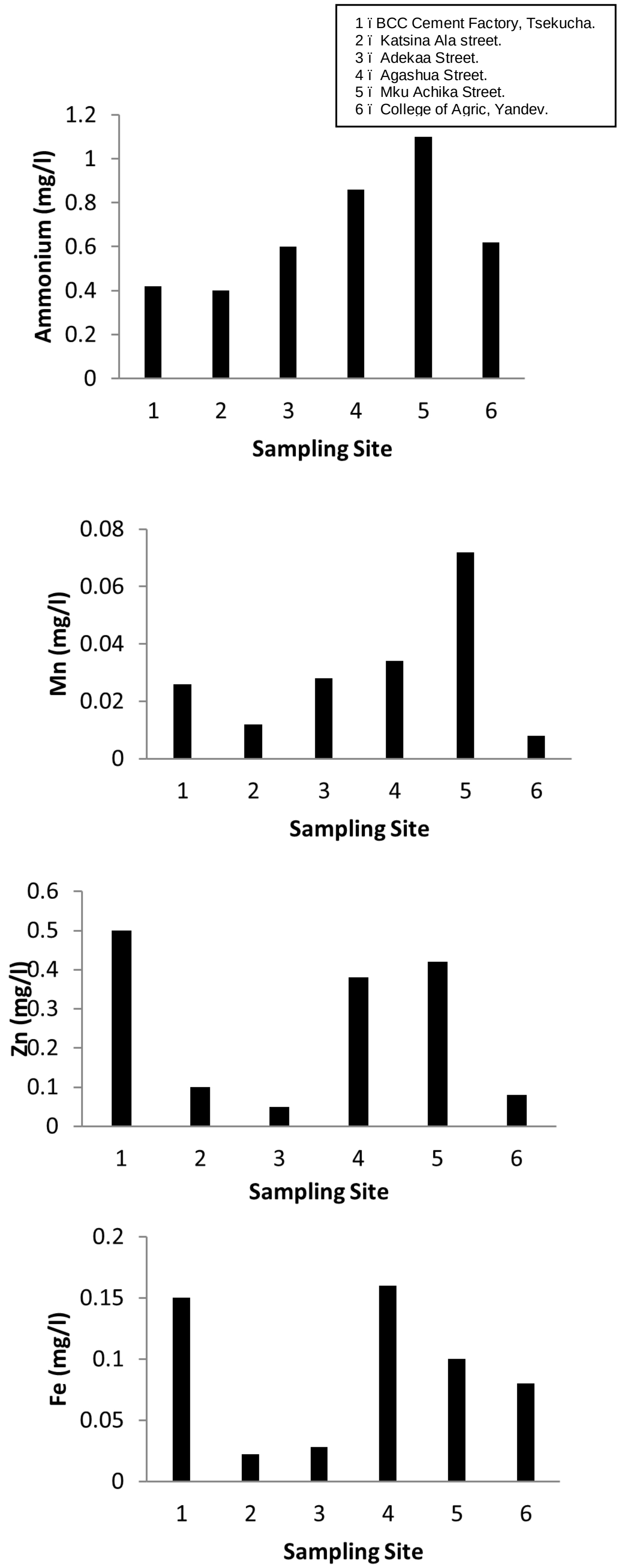

Fig. 2: Mean Values of Ammonium and main dissolved heavy metal Concentrations for the Six Sample Areas.

Alkalinity (4.8<pH<8.5) results from dilution of calcium carbonate ($CaCO_3$) in roof drainage water. The alkalinity values for all samples ranged between 0ï 21.5 mg/l as $CaCO_3$. Mean alkalinity in the six sampling sites roof drainage ranged from 1.2 to 8.4 mg/las $CaCO_3$ with a mean value of 4.8 mg/l as $CaCO_3$ (Fig.1b). In many cases, $CaCO_3$ results from the erosion of roof construction materials such as concrete and asbestos-tiles, as a result of raindrop impact.

Nitrates ($NO_3^{ï}$) and sulphate ($SO_4^{2ï}$) are products of fossil fuel combustion (Mouli *et al.*, 2005; Polkowska *et al.*, 2005). Nitrate concentrations for all samples ranged between 0ï 2.5 mg/l. Mean nitrate concentrations in the six sampling sites in roof drainage water were below drinking water standards (45mg/l). Nitrates ranged approximately between 0.28ï 0.62 mg/l(Fig. 1c). Higher concentrations were observed, as expected, in areas with high traffic volumes and densely populated residential areas, (e.g., sampling sites 2, 3, 5 and 6) (Table 1). However, these overall low concentrations do not affect the H_3O^+(acidic) concentrations, which with the presence of alkaline constituents (NH_4^+ and Ca^{2+}) increases the pH values to the alkaline range.

Sulphate concentrations for all samples ranged between 0ï 0.5 mg/l. Mean values of sulphate ($SO_4^{2ï}$) (Fig. 1d) for the six sampling sites ranged approximately between 0.04ï 0.16 mg/l in roof drainage water. All values were lower than drinking water standards (100 mg/l). Generally, the higher sulphate concentrations were detected in areas with high traffic volumes and dense residences, due to the use of fossil fuels in cars and houses.

The ammonium concentrations for all samples ranged between 0ï 2.6 mg/l. The concentrations of ammonium (NH_4^+) are normally of natural origin in areas with low industrial activity. Measured concentrations in the study area were very low (Fig. 2a). Ammonium has an active role in neutralization reactions and leads to the configuration of the final pH value in roof drainage. Mean values for the six sampling sites ranged approximately between 0.4ï 1.1 mg/l.

In most sites, ammonium concentrations were below drinking water standards (0.5 mg/l). Comparing the measured values in rainwater in this study area to other studies in two cities in Nigeria (Table 4), one can see that in the region of Gboko, rain pH is in the alkaline area, which could be as a result of the neutralization which takes place because of limestone dust and combustion of fossil fuels.

Various studies on rainwater pollution ascertain that main source of dissolved heavy metals is the erosion of any metallic materials on roofs and drains (Kanellopoulou, 2001; Azimi *et al.*, 2003; Al-Momani, 2004; Azimi *et al.*, 2005). Fig. 2 presents the mean values of measured main dissolved heavy metal concentrations (Fe, Mn and Zn). Copper concentrations in roof drainage were nearly undetectable and are considered negligible compared to drinking water standards (2 mg/l). Chromium and nickel were also undetectable, and therefore, are not presented.

Iron concentrations in most cases were low; in certain sites, however, values near the upper limit for drinking water of 0.2 mg/l were detected (e.g., sampling site 3). Similar observations were made for manganese; however, there were measured values exceeding the upper limit of 0.05 mg/l. Exactly the same observations were made for zinc. The high concentrations of zinc are mainly as a result of drainage pipe erosion. Fig. 3 presents time series graphs of pH, alkalinity, nitrate, sulphate, ammonium, manganese, zinc and iron for sampling sites 3 and 4. The two selected sites are typical of an area with high traffic volume in the commercial zone (Site 3), and a low traffic residential area (Site 4).

As presented in Fig. 3, pH did not show any significant variations in the two sites, Adekaa market and Agashua Street during the sampling period. All pH values were in the alkaline area for both sampling sites. On the contrary, nitrates appear to have significant variations in both sites during the sampling period. Specifically, for both sites the maximum values of nitrates were observed from April to May, which probably is due to the intense use of fossil fuels for building heating. Furthermore, the comparable values of nitrates in the two sampling sites during the same period are probably caused by the intense winds in those months (Table 2).

For iron and zinc, although significant variation during the sampling period does not exist, there are obvious differences between the two sampling sites. Sampling site 4, agashua street has higher concentration of iron and zinc than sampling site 3, Adekaa market. This fact may be related to the age of the two buildings. The building in sampling site 3 is relatively new compared to that of sampling site 4 where the building is older. As a result, the drainage pipes of the building in sampling site 4 seem to contribute higher concentrations of iron and zinc in roof drainage water.

A good correlation (r = 0.926 to 0.984) of the selected anions and cations between the main anions ($NO_3^- + SO_4^{2-}$) and the main cations ($Ca^{2+} + Mg^{2+} + K + NH_4^+$) would confirm the neutralization of acidity of rainwater (Mouli *et al.*, 2005; Tang *et al.*, 2005). From this study, roof drainage correlation of r = 0.858 between the main anions and cations is not good enough. This in combination with the higher concentrations of the cations of Ca^{2+} and Mg^{2+}, explains the high values of pH suggesting lack of acidic substances in rainwater.

CONCLUSION

In conclusion, roof drainage pH in Gboko is alkaline. This is due to the intense northern and north-central winds eroding away alkaline dust and solids from the adjacent mountains (rock erosion) that settles on roofs. The airborne solids of erosion raise the concentrations of the alkaline ions in the atmosphere.

Pollutant concentrations were generally higher in roof drainage samples than drinking water standards. It was discovered that, the period of rainfall, environmental factors, type and age of roofing materials have varying effects on the characteristics of Gboko rainwater. From the experimental result, the roof drainage water quality in Gboko can be use as grey water for domestic purposes but requires treatment to be used as drinking water. Attention should be paid on using environmentally friendly materials in roof covers and in roof drain pipes.

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