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Environmental Implications and Significance of Rainwater Harvested from Lagos, Southwest Nigeria

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Abstract

This study assessed heavy metals and some physicochemical properties in rainwater harvested from Lagos, Nigeria. Rainwater was collected from three different locations using varying collectors from the months of April to July, 2013. Physicochemical parameters like pH, temperature, electrical conductivity (EC) and few heavy metals were assessed. Eight Heavy metals were determined by Flame Atomic Absorption Spectrophotometer (AAS). pH (5.1 to 7.6), Temperature (23.0 to 27.2˚C), EC (648 to 894 µS/cm) is lower than the 1000 µS/cm limit by WHO. Mn and Cr were below the detection limits of the instrument. Ni, Pb and As were about 20 to 40 times higher in the rooftop samples and controls above the recommendation of standard organizations. Fe, Ca and Zn were detected but not believed to be of much environmental threats in all the study locations. The quadratic pattern was generated for the interaction between average monthly precipitation and heavy metal contents. Strong relationships were signaled by high R^2 value from the best fitting lines. The study suggests that rainwater consumption in all the study locations irrespective of the collector type or method may result in severe health hazards associated with overexposure to the three notorious heavy metals. It is concluded therefore that metal concentrations particularly of Ni, Pb and Asis an important issue which must be addressed in the task of considering rainwater as reliable water complement drive.

Keywords Rainwater; Physicochemical properties; Heavy metals; Roofing material; Health hazards

Introduction

One of the biggest challenges of the Twenty first century is to overcome the growing water shortage. In many parts of the world conventional piped water is either absent, unreliable or too expensive. Rainwater harvesting (RWH) for domestic use is becoming increasingly popular as the availability of good quality water is declining. Admitting that inadequate supply of portable and safe water is one of the most basic challenges of rural and urban dwellers in Nigeria for decades is obviously stating the truth. Sometimes, they have to trek few kilometers to rivers and streams to get water. The problem stems from the fact that government alone cannot provide all the portable water supply, and when the private provider does, it is always at an exorbitant price. In fact, according to Orebiyi et al. [1] staggering fifty two percent (52%) of Nigerians have no access to improved drinking water supply. This has in no small deal painted grim picture of the water challenges in the country; it is commendable however, that the present administration in Nigeria is striving relentlessly at arresting this ugly and disheartening trend.

Rainwater which is in adequate supply during the rainy season has then become succor for rural and urban dwellers in Nigeria. People collect and store rainwater in buckets, tanks, ponds and wells. They may device as many means as possible to store up water for their needs. The rainfall pattern over the year plays a key role in determining whether RWH can compete with other water supply systems. As a general rule, rainfall should be over 50 mm/month for at least half a year or 300 mm/year (unless other sources are extremely scarce) to make RWH environmentally feasible [2].

Rainwater is often collected and stored from different areas, such as the rooftops, the land surface and other catchments areas, all summed up as rainwater harvesting. Wirojanagud et al. [3] opined that rooftop catchment of rainwater can provide good quality water, clean enough for drinking, as long as the rooftop is clean, impervious, and made from non-toxic materials. The depletion of groundwater sources, the poor quality of some groundwater, high tap fees for isolated properties, the flexibility of rainwater harvesting systems, and modern methods of treatment provide excellent reasons to harvest rainwater for domestic use [4].

Rainwater contamination results often from air borne dust and mists, bird faeces, and other debris. Rainwater is slightly acidic and very low in dissolved minerals; as such, it is relatively aggressive. Metal contamination as a result of rainwater coming in contact with metallic roofs (e.g. galvanized iron for zinc) or fittings (lead and copper flashings) are other notable sources of harvested rainwater quality deterioration [5,6]. Rainwater can dissolve heavy metals and other impurities from materials of the catchment and storage tank. Heavy metals are metals which are majorly found in mineral earth and geological structures and they are said to have a specific gravity of greater than five. In most cases, their chemical concentrations in rainwater are within acceptable limits; however, elevated levels of zinc and lead have sometimes been reported. The chemistry of drinking water commonly has been cited as an important factor in many diseases. A strong relationship between contaminated drinking water

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with heavy metals from some of the Great Cairo Cities, Egypt and chronic diseases such as renal failure, liver cirrhosis, hair loss, and chronic anemia has been identified [7]. These diseases are apparently related to contaminant drinking water with heavy metals such as Pb, Cd, Cu, Mo, Ni, and Cr. This could result from leaching from metallic roofs and storage tanks or from atmospheric pollution [8]. Heavy Metals such as zinc, copper and lead, can be present at quite high levels in rainwater that has come into contact with metallic roofs (e.g. galvanized iron for zinc). Zinc has a low toxicity to humans, so that run-off water from the common galvanized steel roofs should not exceed WHO permitted zinc, harvesting process, storage and/or sale [10-12].

Besides, human pathological manifestation resulting from heavy metal consumption from harvested rainwater, other notable detrimental implications associated with preponderance of heavy metals in harvested rainwater and runoffs are: soil contamination and eventual uptake by plants which in turn affect their physiological as levels [5,9]. Heavy metal contamination in the environment may result from irrigation of agricultural fields with contaminated rainwater, the addition of fertilizers and metal based pesticides, industrial emissions, transportation as well as metabolic processes. Besides, heavy metals, similar to other ecological stressors, also encourage amplified antioxidant enzyme processes in plants [13].

Previous study conducted between June and August 2006 from Ile-Ife, Nigeria had been reported. The samples were collected from different rain events from three different locations with different roof materials. The contribution of roof materials to heavy metals load of rainwater collected was implicated [14]. Similarly, investigation of some physico-chemical and microbiological parameters of rainwater collected from Industrial areas of Lagos State by Igwo-Ezikpe and Awodele [15] showed that anthropogenic activities contributed to the rain water contamination. Akintola and Sangodoyin, [16] has reported heavy presence of major microbiological contaminants such as: Escherichia coli and Pseudomonas fluorescence in domestic roof harvested rainwater (DRHRW) in Lagos, Ibadan and Port Harcourt, Nigeria, from four roof materials (corrugated iron sheet, long span aluminum, asbestos and step tiles), thereby rendering the harvested water unsuitable for homestead gardening irrigation, Other research also noted the atmospheric contamination of harvested rainwater by various contaminants in the air [17,18].

Despite these backgrounds, there exist a gap in the knowledge of research on the heavy metal contents and physiochemical parameters of harvested rainwater in relation to precipitation volume. More so, in Nigeria, rainwater harvesting techniques is still poorly understood and where such is practiced, lack of proper rain water collection or poor storage facilities render the system liable to high contamination threat. Furthermore, the collection of rain water from metallic roofs in locations where acidic rain is prevalent has not been cautioned, making more corrosion and leaching of metals from roofs to prevail under these conditions. Metal roofs that are visibly corroded needs to preferably be repaired or replaced. Even though, the iron in rain runoff from a rusting roof is unlikely to cause any health problems, it may affect the water color quality or aid the preferential dissolution of toxic ones.

As a result, the present study seeks to assess the environmental importance of location types; rural, urban and industrial on rainwater harvested during raining season using the relationship between precipitation volume, six heavy metal contents and physicochemical features of harvested rainwater from different collector types commonly used in Lagos, Nigeria. Since not many previous studies has taken cognizance of the impact of precipitation volume on contamination/pollution pattern, the results from the study are expected to provide an impetus to the significances of pollution type to location and source of contamination. The study used heavy metal source (inorganic) only, organic contaminants have not been included in this study. In addition, the microbiological impact of contaminants as it relate to rainwater harvesting is not under consideration.

Materials and Methods

Study areas

The study areas in Lagos statelies on 6˚27′N 3˚21′E as shown in Figure 1.

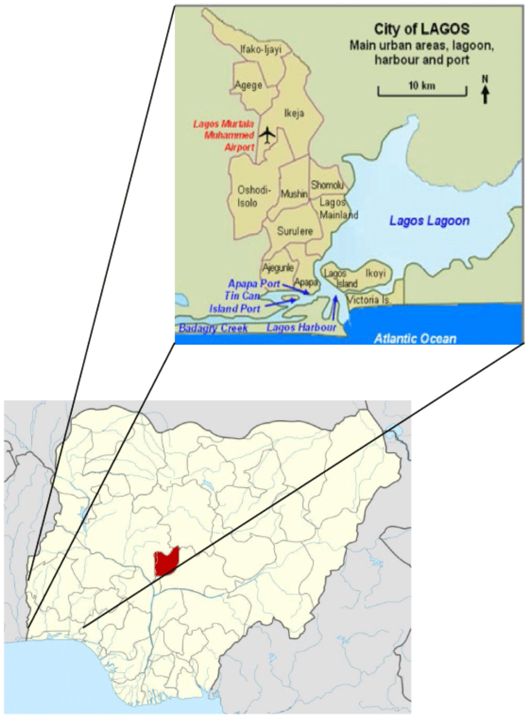

Figure 1: Map of Nigeria showing Lagos the study location.

OrileIganmu town which was taken as rural area lies on 6˚27′N 3˚23′E in ApapaLocal Government Area of Lagos State. It is fully residential with low density population (NPC, 2006).TafawaBalewa Square which was used as an urban area is located on 6˚27′N 3˚24′E on Lagos Island, Lagos. It is a highly populated area with lots of commercial activities. Eric Moore town in Surulere Local Government Area was used as an industrialized area with about seventy factories situated around it. The collector types commonly used in the rural and urban areas are the Zn galvanized iron roofing sheets. The urban area sometimes have some asbestos and painted aluminum roofing materials, while the industrial area is majorly characterized by asbestos, painted or plain Aluminum roofing sheets. The precipitation volumes used for the study were extracted from the data set of the Climatic Research Unit (http://www.ipcc-data.org).

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Sampling and samples preservation

Samples of rainwater were harvested from different roof materials from April to July 2013 in the different locations in Lagos city Lagos state, Nigeria. The exact rooftop used were randomly selected for each location type, simultaneously, some rainwater samples were also collected directly from the sky to serve as control. All samples were collected in 1000 ml polypropylene plastics previously cleaned with dilute acid solution and rinsed severally with distilled water. The samples were fixed/acidified with 5 ml Nitric acid (HNO_3) and stored in the refrigerator at 4°C prior to the determination of heavy metal concentration. Treating the sample with acid at the time of collection places the metals in solution and prevents adsorption or deposition on the container walls. About 250 ml and 100 ml of the samples were filtered through a 20 mm/0.45 µm cellulose acetate membrane filter for physico-chemical and heavy metal analysis respectively. Care was taken to ensure that no accidental contamination of samples occur during sampling

Chemical analyses

The water chemical analysis was done using standard analytical methods for water analysis, The United Nation Environment Programme [19]. Labile parameters such as temperature, pH and electrical conductivity (EC) were determined at the time of sampling on the field. The pH of the sample was measured with a pH meter (Phep 98201) that has been previously calibrated with buffer solutions. The electrical conductivity was measured with a conductivity meter (Medfab 190) calibrated with potassium chloride solution and the temperature was determined using a digital thermometer (CE 0434).

A variety of inorganic techniques have been proposed to measure trace elements in water including flame atomic absorption spectrometry (FAAS), which most importantly offer great selectivity and sensitivity to the analytes of interest, graphite furnace (or electro thermal) atomic absorption spectrometry (GFAASor ETAAS), inductively coupled plasma optical emission spectrometry (ICP-OES) and inductively coupled plasma mass spectrometry (ICP-MS). Factors that guide the choice of any of these methods are: number of elements to be determined, expected concentration range of analytes and the number of samples to be run, however the most suitable technique in relation to availability can be chosen.

The concentrations (ppm) of eight metals Ni, Pb, Ca, As, Zn, Fe, Cr and Mn were determined in the samples and the blank (distilled water) using a computerized Thermo Scientific V11.02 Flame Atomic Absorption Spectrophotometer.

Data treatment

Samples were collected from three rooftop of same materials in a location type and the results averaged for that location. Microsoft Excel package from Microsoft Inc. USA and SPSS 13.0 were used for all data treatments and Figure drawings.

Results and Discussion

Physicochemical

The physiochemical parameters of the roof harvested rainwater are shown in Figure 2.

Data obtained in this study were also compared with the Nigerian Standard for Drinking Water quality, World Health Organization (WHO) and United State Environmental Pollution Agency (USEPA) Standards.

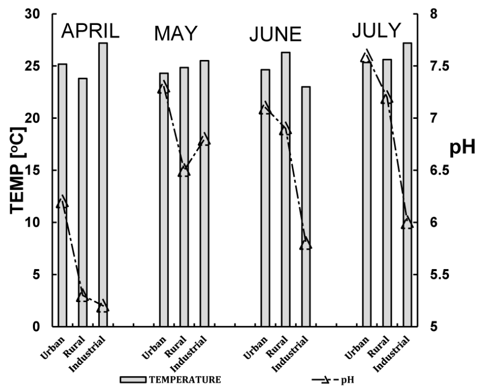

Figure 2: Interplay of Temperature with pH for rainwater harvested from Lagos city (Values are mean of at least three measurements per month)

Temperature recorded for the three locations from April to July are clearly close when compared within the locations and for the different months. Temperature and Electrical Conductivity are fairly comparable to the WHO standard [9]. Electrical conductivity is the ease to which a substance allows free flow of electricity through the ions in electrolytes, example of water sample [20]. Prolonged consumption of water with extremely high EC can pose health risk of defective endocrine functions and also total brain damage [21]. This may not be a treat to be careful of in this particular study as the maximum measured EC from the present study is much lowered than the 1000 limit µS/cm [22]. Interestingly, the EC and the measured Temperature shared positive linear correlations (Figure 3).

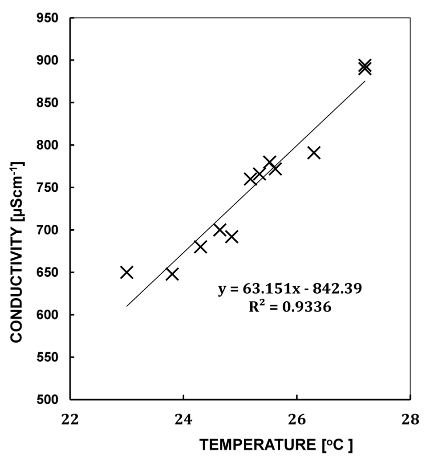

Figure 3: Relationship between Temperature and the Electrical conductivity of the rainwater harvested in Lagos City for four Months.

The pH ranged between 5.1 and 7.6. This range is slightly lowered than the 6.8-8.5 range recommended for the pH of drinking water [23, 24].

However, it is not uncommon for most rainwater to fall out of the recommended range. There is a similar pattern of pH for all the months even though the result for April was markedly lower than other months. The Industrial locations pHs are the lowest for all months. The pHs in the rural and urban locations are comparable to the pH values (5.5-6.0) obtained by Chukwuma et al. [25] while assessing the physicochemical parameters of harvested rainwater in Oko, Anambra State. The lower pH value of rainwater from industrial locations is usually associated with sulfur and nitrogen compounds (NOx and SO_2) released by vehicular emissions and from industrial processes into the atmosphere. Acidic pH may be involved in heavy metal dissolution in rainwater. This may go hand in hand with roof materials deterioration and acidic water consumption both of high negative economic and health implications [7].

Heavy metals

Chromium and Manganese were either present at very low concentrations than can be detected by the instrument used or not present all, as such; the present study did not report the duo. The different months had different distribution patterns of heavy metal concentrations. The difference could be due to varying meteorological conditions (wind speed and direction) during the periods, increased humidity and precipitation etc. [26].

Generally, the metals have their concentrations higher in the roof harvested samples than their controls, thus indicating contributions of roof materials to heavy metal load of rainwater. The possibility of traces of heavy metals from bird's droplets, fallen leaves, particulate matters and other assorted materials present on the roof cannot be ignored. Nevertheless, contributions from leached metal from roof materials may be highly likely.

With the exception of Ca whose total concentrations in all the samples and controls are much lowered than the 75 ppm recommended by WHO [27,28], all other heavy metals were significantly higher and above the recommended limit for health based guideline. Calcium (Ca) has the highest concentration among all the metals analyzed. Ca concentration decreased steadily from April to July (Figure 4a).

The reason for this may be as a result of contamination and accumulation of roof-tops with fly ash during the dry season. Generally, Calcium at lower concentration below 2,500 mg per day is desirable for bone formation; cholesterol lowering and blood pressure lowering. As a matter of fact, (IOM) [29] had established a tolerable upper level (UL) of 2,500 mg per day for all age groups.

Very high doses can cause nausea, vomiting, loss of appetite, increased urination, kidney damage, confusion, and irregular heart rhythm, with majority of these adverse effects resulting from excessive use of calcium supplements [30].

Nickel is obviously a problem in the rainwater collected for all locations throughout the sampling period. Highest concentration of Ni was recorded in the Industrial location (sample and control) in the month of April with regular decrease down to the month of July. Rural and Urban location however, alternated between increment/ decrement across the different months. This observation was reported by Adedeji and Olayinka [31] that metal concentration trend in roofing materials used for harvested rainwater are in the order: Asbestos > rusted galvanized iron sheet >aluminum long span sheet>recent galvanized iron sheet>ambient water, and that metal deposition in the respective order is Cu>Cr>Ni>Pb>Cd. Ni is regarded as an essential trace metal but toxic in large amount to human health. Figure 4b depicts a concentration range of about 30 to 40 times higher than the safe limit in drinking water [22].

Possible sources of Nickel in the rainwater may include among others the use of Ni containing compounds in anthropogenic significant quantities. Nickel is used as alloys product, nickel-plating for anticorrosion and in the manufacture of batteries. The high persistence rate as a result of its longer settling time in the atmosphere may explain the very high concentrations in both samples and controls recorded in the present study [32]. Nickel may be released into the air by power plants, generator sets and trash incinerators; it will settle to the ground or fall down after reactions with raindrops. Excessive consumption of water rich in Ni may be marked with some health hazards, common of which are: higher chances of development of lung cancer, nose cancer, larynx cancer and prostate cancer. Kaaber et al. [33,34] reported worsening of eczema for human exposed to high level for Nickel. Hair loss patients are related to contaminant drinking water and nickel can be related to derma toxicity in hypersensitive humans.

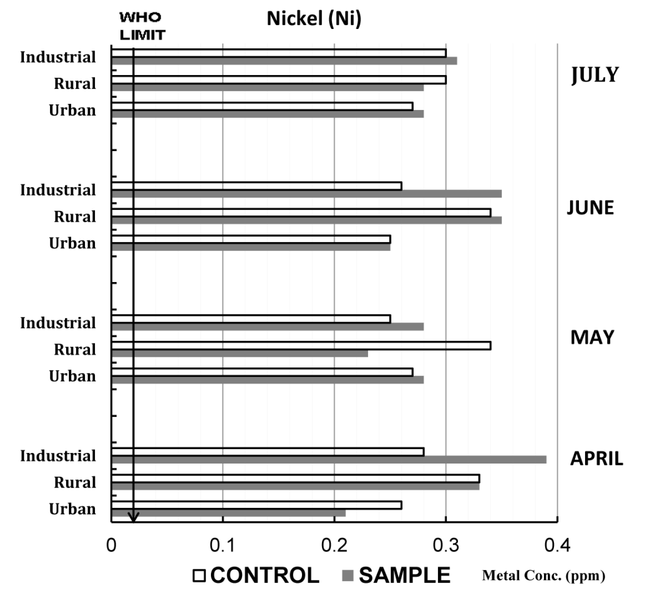

Figure 4a: Concentration of Calcium (Ca) in Rainwater for four months.

Lead was a bit lower than Nickel concentration but yet far above the safe limit as shown in Figure 4c.

As expected, the Industrial location contributed more to Pb in the collected rainwater both for samples and control, the relative general increase in Industrial location from April to July may be due to higher automobile throughputs and industrial activities in the area that usually facilitates transportation of particulate matter containing Pb.

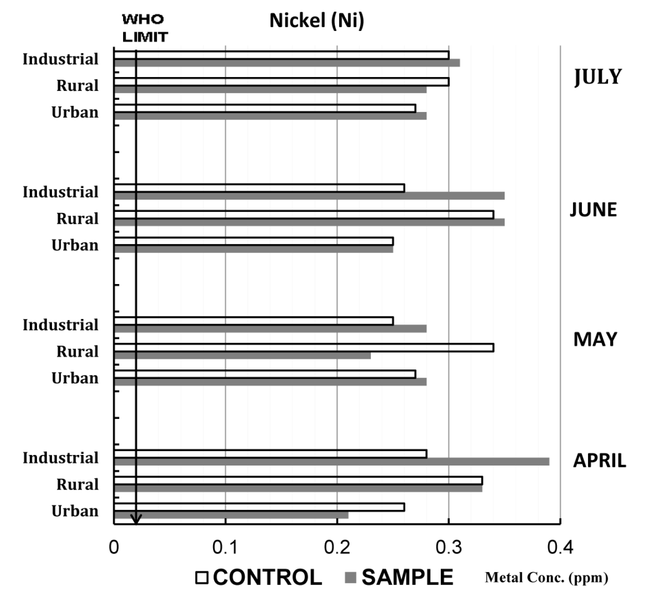

Figure 4b: Concentration of Nickel (Ni) in Rainwater for four months.

The roof material type may however affect variations in the concentration between sample and control. For example, Aluminum surfaces are smoother and it has high thermal conductivity than asbestos. This seemly good property may affect contaminant retention on it as against asbestos with higher propensity to retain particulates, causing increment in metal deposition. There were no clear trend observed for the rural and urban location, however, there was a noticeable high lead concentration in urban sample location in the month of July.

This trend was reported by Ayenimo et al. [14]. Lead can cause several unwanted effects, such as: disruption of the biosynthesis of hemoglobin and anemia, a rise in blood pressure, kidney damage, miscarriages and subtle abortions. Disruption of nervous systems, brain damage, and declined fertility of men through sperm damage diminished learning abilities of children, behavioral disruptions of children, such as aggression, impulsive behavior and hyperactivity. Lead can enter a fetus through the placenta of the mother. Because of this it can cause serious damage to the nervous system and the brains of unborn children [32].

Higher concentrations of Zn could be as a result of the chemical constituent of the galvanized roofing sheets used in sampling of the rural and industrial areas. Overdose of Zn can depress the immune system, elevated risk of prostate cancer, brain lethargy, problems associated with the gastrointestinal tract, anemia, copper deficiency, and decrease high density lipoprotein cholesterol (HDLC) in blood [33-36]. The recommended dietary allowance (RDA) for zinc is 11 mg/day for men and 8 mg/day for women [37]. Though, lower zinc intake is recommended for infants (2-3 mg/day) and children (5-9 mg/day) because of their lower average body weights [37].

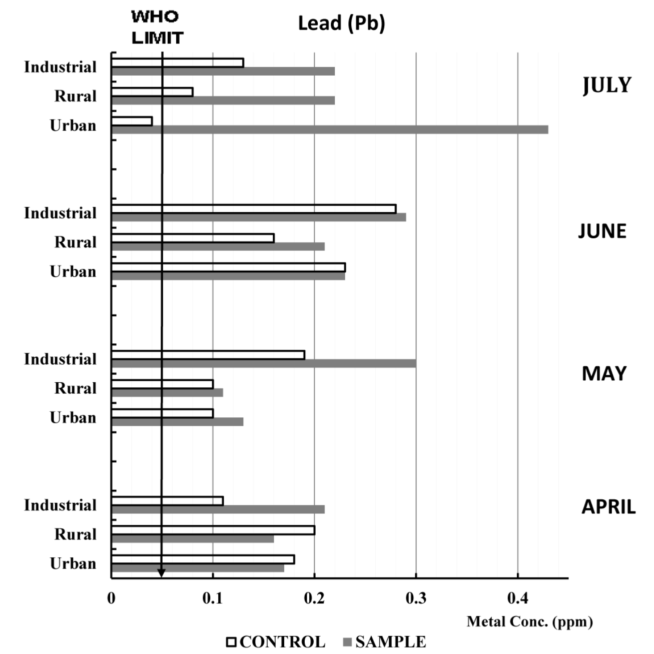

Figure 4c: Concentration of Lead (Pb) in Rainwater for four months.

Also, Zinc imparts an undesirable astringent taste to water at a taste threshold concentration of about 4 mg/l (as zinc sulfate) zinc is not of health concern at levels found in the harvested rainwater (Figure 4d).

Arsenic (As) was noticeably very high in the Industrial and rural controls (Figure 4e), with highest concentration recorded in rural sample in the month of April and a consistent decrease down to the month of July. This might be due to the combined effects of industrial emissions and vehicle exhaust from traffic areas, while decrease in concentration down from the Month of April through July may have resulted from dilution in the harvested rainwater as rainfall intensity increases.

Arsenic was detected in the entire samples and controls, with concentration higher than WHO recommendation for drinking water. Since its concentration remain fairly stable in the atmosphere even as the rainfall increases. The composition of the area under investigation may account for the presence of Arsenic as particulate matter in the atmosphere. Arsenic is one of the most toxic elements found in nature. Despite their toxic effect, inorganic arsenic may bond to earth naturally in small amounts. Humans may also be exposed to arsenic through food, water and air. Exposure may also occur through skin contact with soil or water that contains arsenic [38].

Iron (Fe) concentration was constant in industrial area in April and May but was not pronounced in June and July, which may be due to the asbestos and aluminum roofing sheets chiefly used in industrial area. All other samples have traces of Fe in them, far below the WHO minimum standard. Iron is an essential part of hemoglobin; the red coloring agent of the blood that transports oxygen through the human body. Lack of Iron, may cause conjunctivitis, choroiditis, and retinitis if it contracts and remains in the tissues. Chronic inhalation of excessive concentrations of iron oxide fumes or dusts may result in development of a benign pneumoconiosis, called siderosis. A more

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common problem of human iron deficiency is anemia. A man needs an average daily intake of 8 mg of iron and a woman 18 mg; luckily, a normal balanced diet will generally provide all Fe that is needed [39]. Despite not being of health concern in the present (Figure 4f), high concentrations of iron may affect the quality of water, leading to bad taste and coloration of cooking utensils and food [40]. There is no noticeable taste at iron concentration below 0.3 ppm, even though turbidity and color may develop [41].

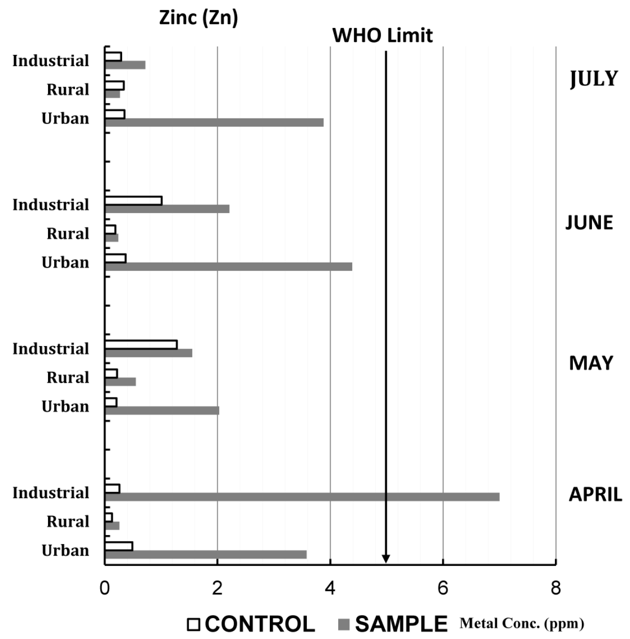

Figure 4d: Concentration of Zinc (Zn) in Rainwater for four months.

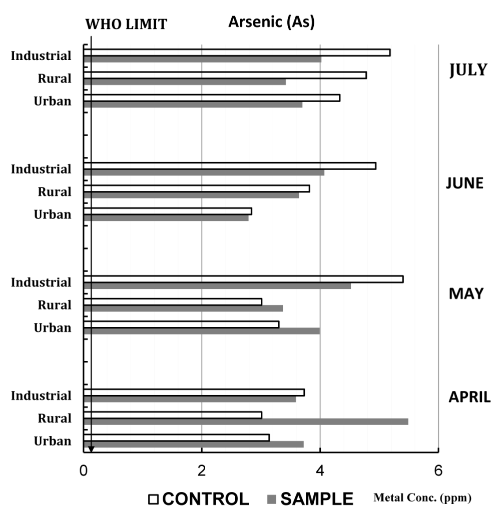

Figure 4e: Concentration of Arsenic (As) in Rainwater for four months.

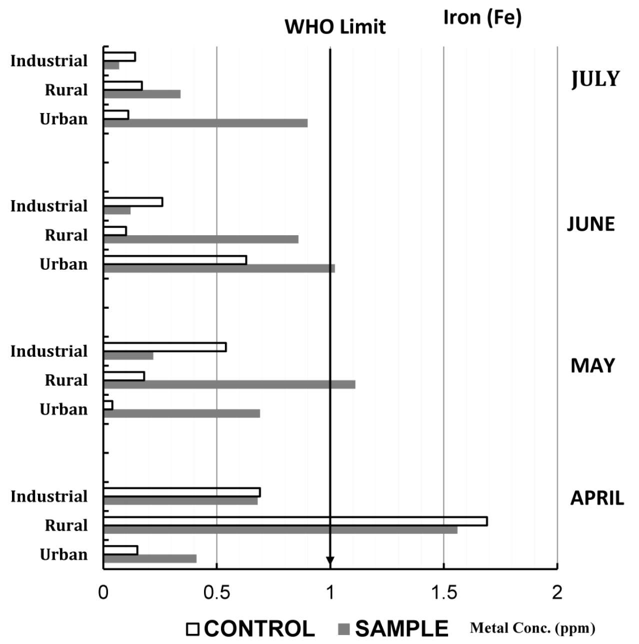

Figure 4f: Concentration of Iron (Fe) in Rainwater for four months.

The relationship between total monthly precipitation and heavy metal content

It must be stated here that monthly precipitation refers to the average amount (mm) of the rainfall measured for each month indicated. Figure 5a,5b are generated through the best fitting lines representing the quadratic relationships that exists between the precipitation volume and the heavy metals recorded from April through July, 2013. The relationships were generated mainly for samples of rainwater collected via the rooftops.

As shown on the Figures, the metals exhibit convex or concave pattern for specific location type. For example, Ni which generated a very high R2 value significantly demonstrated convex relationship with the precipitation volume for both rural and industrial settings. However, on a different note, concave relationship for urban location. A high R2 value generated for some relationship patterns connotes a high degree of agreements in the volume of rainfall and heavy metal contents measured during the assessment period vis-à-vis a low R2 value. It is not yet clear from the interpretation of these relationship patterns from this study how these values will signify low or high source characterization of heavy metals in the monthly downpour values. However, it is assumed that the knowledge of these relationships will be of importance when considering a future simulation studies that may require more meteorological and environmental data interplay.

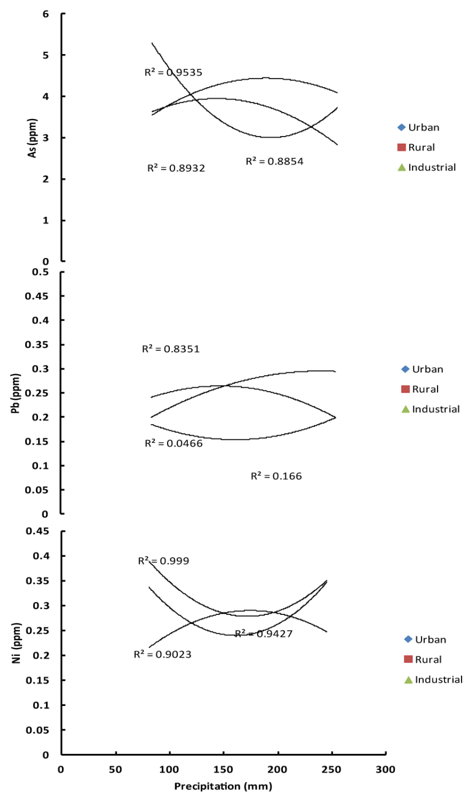

Figure 5a: Quadratic Relationships between Heavy metals (Ni, Pb, As) and Precipitation volume (mm) from April to July, 2013.

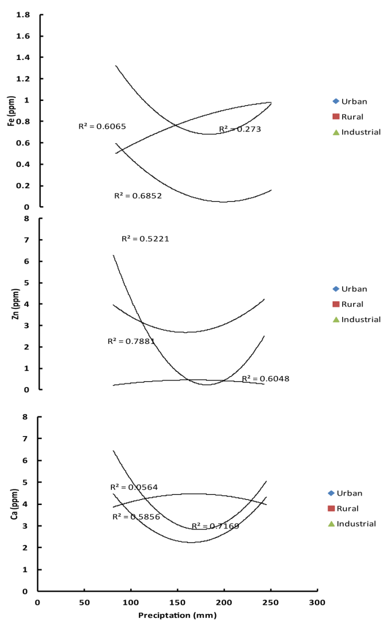

Figure 5b: Quadratic Relationships between Heavy metals (Ca, Zn, Fe) and Precipitation volume (mm) from April to July, 2013.

Conclusion

The rainwater harvested in this research work is slightly acidic and contained few dissolved heavy metals and other impurities from materials used in harvesting. The presence of heavy metals in the rain water resulting from industrial activities in Lagos, may even affect residential areas at remote distances from industrial sectors [42-45], posing a serious environmental challenge that may be of adverse health implications on human within the area Natural emissions (crustal minerals, forest fires and oceans), traffic and anthropogenic/ industrial emissions (combustion of fossil/gasoline fuel and industrial exhaust) may be the principal sources of heavy metals in rainwater. Since most of the world acclaimed notorious heavy metal pollutants (Ni, Pb and As) are significantly higher than those recommended by standard organizations, this study has establish a major environmental concern that if not addressed in good time, could trigger some health malady on the populace living within and around the study locations. Aside, there is also the possibility of severe contamination of other environmental matrices like soil from rainwater runoffs in view of the significant heavy metal load in the harvested rainwater. Moreover, consequent upon the limited heavy metals and physicochemical parameters reported in the present study, detailed study encompassing other highly significant metals and other vital water quality parameters is suggested. This will in no small deal capture more reliable detail information which would be used by concerned authorities in the formulation of informed decisions. The publics are thereby enjoined to participate fully in the enforcement of the strict environmental management practice already promulgated by the state. Stable electrification projects by the concerned private and/or government agencies will reduce the use of gasoline and diesel generating sets.

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