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Atmospheric Corrosion of Corrugated Iron Roofing Sheet in Oil Producing Locations in Southeastern Nigeria

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Abstract

The study evaluated the atmospheric corrosion of corrugated iron roofing sheets in rural, urban, and marine environments using rain water harvested from roofs of various ages. Corrosion study was based on the weathering processes leading to high levels of sulphate, chloride and nitrate in rainwater in the three areas. Results showed that roofs below one year and 2 years in age were more susceptible to rusting than roofs above 15 years. The mean corrosion rates were higher in marine (Ibeno) ranging between 0.16×10^3 µm/yr and 2.94×10^3 µm/yr followed by rural (Okobo) 0.08×10^3 - 1.88×10^3 µm/yr, and the least was urban (Uyo) 0.031×10^3 µm/yr - 0.79×10^3 µm/yr. Sulphates, nitrates and chlorides were high in the marine environment, which also coincided with the area of gas flare by Mobil Oil exploration activities. Increase in temperature and acid rain formations in this area led to increased acid rainstorm. This could manifest in the erosion of beach and wetland, inundates low-lying areas (Ibeno, Ibaka (James town), Oron, Utan brama, Utan-Effiong and Mbe-Ndoro) flooding and loss of coastal land and mangrove forests. Above all, gas flaring affects atmospheric water quality in which soil, crops, fruits, streams, and rivers are affected.

Keywords: Atmospheric corrosion; Corrugated iron; Gas flaring; Oil production

Introduction

Corrosion is a natural process as nature attempts to return metals to their original, stable, oxidized state. The degree and severity of corrosion is a function of both the material and its operating environment [1]. Atmospheric corrosion refers to the corrosive action that occurs on the surface of a metal in an atmospheric environment. It occurs when the surface is wet by moisture formed due to rain, fog and condensation and it is defined to include corrosion by air at the temperatures between -18 to 70°C [2]. The corrosion process forms part of natural cycle in which the metal is striving through spontaneous chemical and electro-chemical processes to reach back to its most stable condition, i.e., as a mineral from which it was refined. Several investigations have studied the development and propagation of corrosion products on zinc at atmospheric conditions [3,4]. As roofing material undergoes processes of atmospheric corrosion during which wet and dry deposition occurs, a gradual degradation of the metal also occurs [5]. Corrosion have been extensively determined in different environments in varying conditions in Sweden [2], and have been determined on a short time scaling including days, weeks, and months [6]. The corrosion rate is generally high during the first year of exposure after which it decreases with prolonged exposure period. On a time scale it usually reaches and almost constant level [7]. High corrosion rates can be included by high concentrations of air pollutants such as SO_2, NO_2, and O_2 [8-10], low rain pH [11], low degrees of surface inclinations in the prevailing wind direction [12], and corrosion rate is always lower in rural areas than in urban and marine environment [6].

In oil-producing areas, gas flaring has led increased levels of such acid gases as SO_2 and NOx occasioning acidic atmospheric moisture and corrosion of roofs in the vicinities [13]. In Akwa Ibom state, Mobil Producing Unlimited flares an averages an average of 42.8MSCF of natural gas per day at Qua Iboe Terminal and several nearby onshore and offshore oil fields [14]. The state is also the operating base of such other oil exploration giants as shell and Total (ELF). The probability of roof failure can be determined by assessing metal's corrosion resistance; and exposure to acid rain, pollutants, particulate, and chlorides (coastal and deicing) and/or pollution. Inland sites that are exposed to deicing products and/or industrial pollution can be just as corrosive as coastal sites.

There is a growing trend in sustainable architecture toward capturing and using roof runoff water for human consumption and other non-potable purposes and the Leadership in Environmental and Engineering Design (LEED) system now offers additional points for this. While a number of metals are important trace nutrients for organisms, including humans, some can also cross the threshold of toxicity at relatively low levels. In this context, roof runoff rates and the bioavailability of the metal are important. Concentrations as low as 0.002 mg/ of copper/1 or 0.004-0.007 mg zinc/1 are hazardous for algae. As concentration increase, both metals become hazardous for crustaceans and fish. For crustaceans, only 0.005 mg of copper/1 or about 0.05 mg of zinc/1 is hazardous. The paper focuses on the impact of some atmospheric pollutants on corrugated iron roofing sheets in part Akwa Ibom State as influenced by gas flaring in oil exploration.

Material and Methods

Study area

Akwa Ibom State lies between Longitude 4°30'N and 5°30'N and between Latitude 7°30'E and 8°15'E. It has three major ethnic groups, Ibibio, Anang, and Oron with a total population of 2,395,756 (87.89% rural and urban 12.11%), spread across landmass of 8,412 km^2. The

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rainfall varies from more than 3000 mm along the coast to about 2000 mm inland, and the mean temperature varies between 25-25°C. The State holds some of the largest reserves of oil and gas, both on- and off-shore and these account for 28% of Nigeria's total crude oil export [15] (Figure 1).

Rainwater sampling methods and analysis

A random sampling technique was employed in selecting the sampled houses. The reconnaissance work was to identify houses with the choice roofing material (new and aged asbestos sheets and new and aged corrugated iron sheets) within the study area and then the houses from whose roofs the rainwater samples will be harvested was chosen randomly. Rainwater sample were collected, on the event basis, from roofs less than 1 year, 2 years and more than 15 years old in three locations namely Okobo (rural), Uyo (rural) and Ibeno (marine areas of Akwa Ibom State of Nigeria. The marine site is characterized by heavy rainfall with sunshine, urban site is characterized by waste incineration and heavy vehicular flow and other human activities, and rural site is a typical farming settlement.

All samples were exposed with an inclination of 45° to the horizon, facing direction of gas flaring, in accordance with the ISO standards 8565 and 9226 for atmospheric corrosion testing [16]. Stainless steel basins were positioned at least 1 m above ground level and transferred into 2 L plastic bottles. Temperature was measured in-situ using a mercury-in-glass thermometer, the HACK MODEL. 50150 conductivity meter was used for measuring electrical conductivity while the HACH MODEL 148600 digital pH meter was used for measurement of pH. Sulphate and chloride were determined turbidimetrically as barium sulphate silver chloride respectively, nitrate ion was determined by the phenol disulphonic acid technique, and zinc was determined by spectro-photometric method.

Field measurement

Wind speed direction was measured by a digital wind instrument, wind speed with portable anemometer in km per hour. The slope of rooftops of varying ages were determined using tape and houses roofed toward prevailing wind picked because of pre-deposition of dry deposits. The paper focuses on the impact of some atmospheric pollutants on corrugated iron roofing sheets in parts of Akwa Ibom State as influenced by gas flaring in oil exploration.

Corrosion rate

The corrosion rate is a measure of the total rate of oxidation, i.e., the total amount of the metal that has been oxidized into patina constituents. The corrosion rate is governed by electrochemical processes and is usually reduced with time as a more protective surface patina gradually develops. The runoff rate, on the other hand, depends on a combination of electrochemical, chemical and wear-processes, and is at atmospheric conditions largely dependent on the action of rainwater for the removal of released/dissolved metal species from the surface [17-19]. The corrosion rates were calculated in μm/yr using analytically-determined values according to Wenle's model [2]:

$$R_{corr}=104ML/(P.A.T) \quad (1)$$

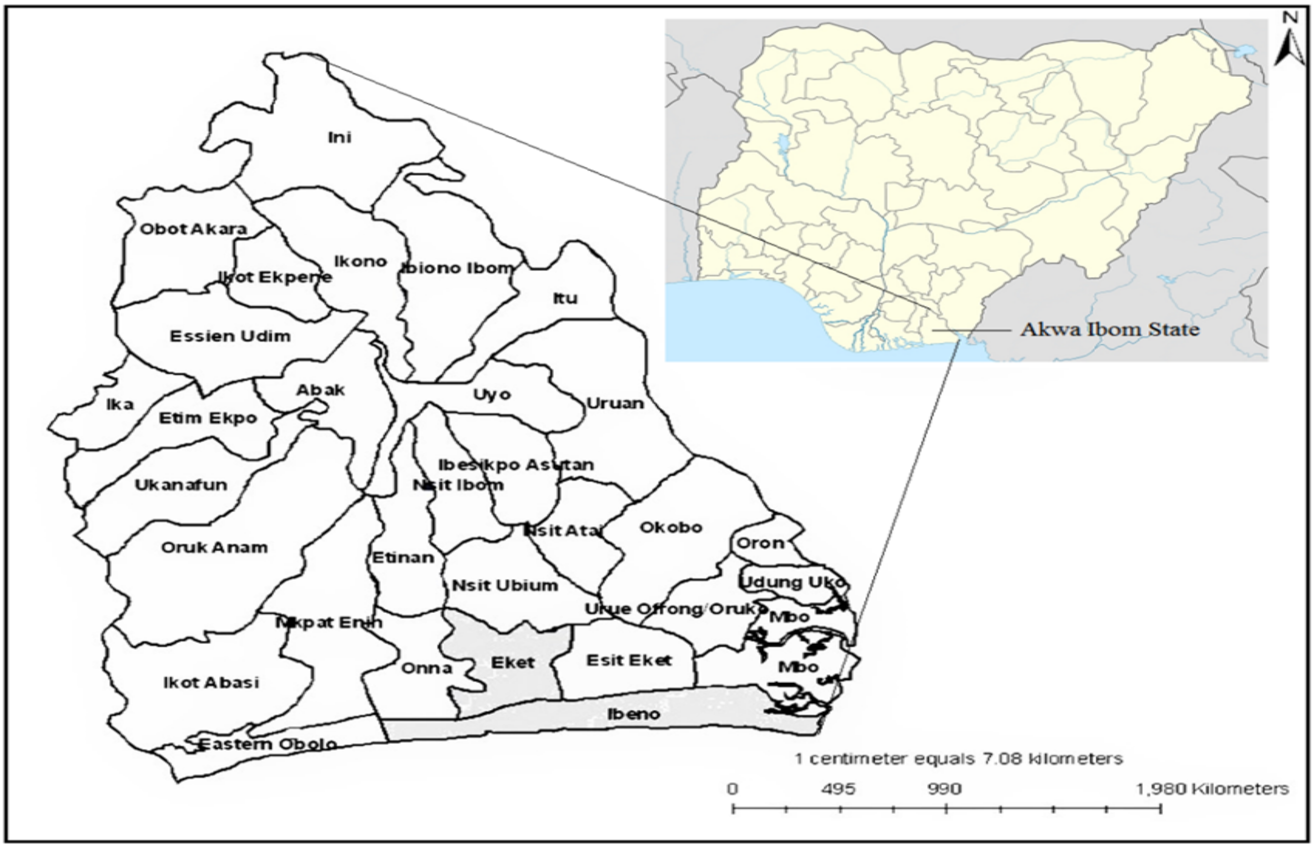

Figure 1: Map of Nigeria showing Akwa Ibom State as study area.

Where:

R_{corr}=the corrosion rate (μm/yr); ML=the metal mass loss (g) i.e., the weight change before and after exposure and removal of the corrosion products; P=the density of the mass (g/cm^3) i.e., panel; A=the exposed surface time (cm^2) and T=the exposure time (year) including dry and wet deposition.

Results and Discussion

Tables 1 and 2 show the character of rainwater directly from the atmosphere and from roofs of various ages in the three locations namely: rural, urban and marine environments respectively. The roofs have the same angle of inclination (45°) (Table 3). Tables 4-6 show the calculated corrosion rates with respect to individual water quality parameters for roofs of different ages.

Variation of rainwater quality from rural, urban, and marine environments

The rural area location-Okobo is characterized by absence of oil industry and gas flare. Here, it was observed that the average temperature was 24.3°C in the urban area (Uyo), which is characterized by vehicular activity and absence of oil exploration, the average temperature was 27.8°C. The marine area (Ibeno), characterized by oil exploration activities, had an average temperature of 38.9°C. The values indicate high temperatures around the oil exploration marine area of Ibeno in spite of the highest wind speed of 1.9 m/second (Table 5) recorded in the area. This situation is attributed mainly to gas flare activities accompanying the oil exploration in the area. The second higher temperature ranges were recorded for the urban area, which corresponded with the lowest wind speed of 0.4 m/second. This indicates a probable lower dispersion of heat mostly generated by high volume of vehicular activities in the urban area. The rural area (Okobo) had the least temperature range favored by the absence of industrial activities, presence of denser vegetation and absence of gas flare.

Quality Parameters	Rural	Urban	Marine
Temperatures (°C)	24.3	27.8	38.9
Electrical Conductivity (μS/cm)	6.3	44.3	51.4
pH	5.6	6.7	5.3
Sulphate (mg/l)	60.4	87.4	155.2
Chloride (mg/l)	75.1	0.03	163.4
Nitrate (mg/l)	7.57	10	0.02
Zinc (mg/l)	0.05	0.05	0.02

Table 1: Rainwater quality from Rural, Urban and Marine Environments at Control Points (Average values).

Quality Parameters	Rural	Urban	Marine
Temperatures (°C)	24.0-24.1	24.1-27.5	38.6-38.8
Electrical Conductivity	47-50	42.8-45.6	49.5-58.4
pH	5.2-5.5	6.4-6.6	4.5-4.7
Sulphate	35.5-38.3	40.8-49.4	79.2-95.3
Nitrate	3.4-6.7	3.0-5.3	59.9-68.3
Chloride	41.3-60.4	0.001-0.02	35.3-98.1

Table 2: Variation of Rainwater Quality from Roofs in Various Environments.

Quality Parameters (/m/s)	Wind Direction	Wind Speed
Rural	SWTW (South West Trade Wind)	0.6
Urban	SWTW (South West Trade Wind)	0.4
Marine	SWTW (South West Trade Wind)	1.9

Table 3: Wind Direction and Speed in the Study Areas.

Parameters	<1 years	<2 years	>15 years
Sulphate (× 10^3 μm/yr)	1.61	1.14	0.10
Chloride (× 10^3 μm/yr)	2.56	1.22	0.1
Nitrate (× 10^3 μm/yr)	2.84	1.04	0.09
Zinc (× 10^3 μm/yr)	0.5	0.2	0.02

Table 4: Corrosion Rates of Roofs in Rural Environment.

Parameters	<1 years	<2 years	>15 years
Sulphate (× 10^3 μm/yr)	2.09	0.095	0.11
Chloride (× 10^3 μm/yr)	0.08	1.02	0.002
Nitrate (× 10^3 μm/yr)	0.23	1.08	0.008
Zinc (× 10^3 μm/yr)	0.56	0.02	0.002

Table 5: Corrosion rates of Roofs in Urban Environment.

Parameters	<1 years	<2 years	>15 years
Sulphate	4.04	1.84	0.22
Chloride	4.16	1.91	0.24
Nitrate	2.90	1.34	0.16
Zinc	0.64	0.21	0.02

Table 6: Corrosion Rates of Roofs in Marine Environment.

The marine area also showed the highest values for sulphate (155.2 mg/l), nitrate (163.4 mg/l), electrical conductivity (51.4 μs/cm) and chloride (163.4 mg/l) (Table 4). The pH was, however, lowest (5.3). All values show the effect of oil exploration activities on the air quality indicated by acid rain, rich in combustion products (SO_2 and NO_2) and marine (chloride) effects in the area, which culminated in the high electrical conductivity observed in rainwater from the marine area.

Unexpectedly, the next higher level of nitrate, electrical conductivity and chloride were observed for the rural area (Okobo). The pH of the rainwater was also slightly acidic. This is attributed to the influence of the south-West Trade winds blowing from the marine environment across the rural area with the speed of 0.6 km/hr. The urban area had elevated levels of sulphate and nitrate but higher pH values and little or no chloride. This indicates low levels of effects from the exploration activities. The urban area is far from the zone of gas flare, with south west trade and wind speed of 0.4 km/hr., and ionic concentrations such as sulphate, and nitrate originate from vehicular emission and auto-exhaust and chloride ion originates from human activities in urban area: it may be result from refuge incineration such as PVC, which produces HCL in gas phase [20] (Tables 1-3).

Figures 2-4 show the variation from rainwater quality from roofs of different ages in a rural, urban, and marine environment respectively, while Figures 5-7 show the comparison of rainwater quality from roofs of different ages in each environment. Sulphate and nitrate were highest in <1 year roofs, followed by <2 years and least in >15 years roofs in the marine environment. Chloride was highest in the marine, followed by rural and least in the urban area. This confirms the effect of the sea in enriching the atmosphere with chlorides which is carried by the SW wind towards the rural area. Sulphates and nitrates were generally high in the marine environment.

Variation of rainwater quality from roofs of same ages in different environments

The trend was the same in the three roof ages studied. Rainwater from roofs in the marine environment was the highest in electrical conductivity, sulphate, chloride and nitrate. Rural area had the next higher chloride values while the urban area had more sulphate than the rural area. The observations are explained by the reasons already given (Figures 5 and 6).

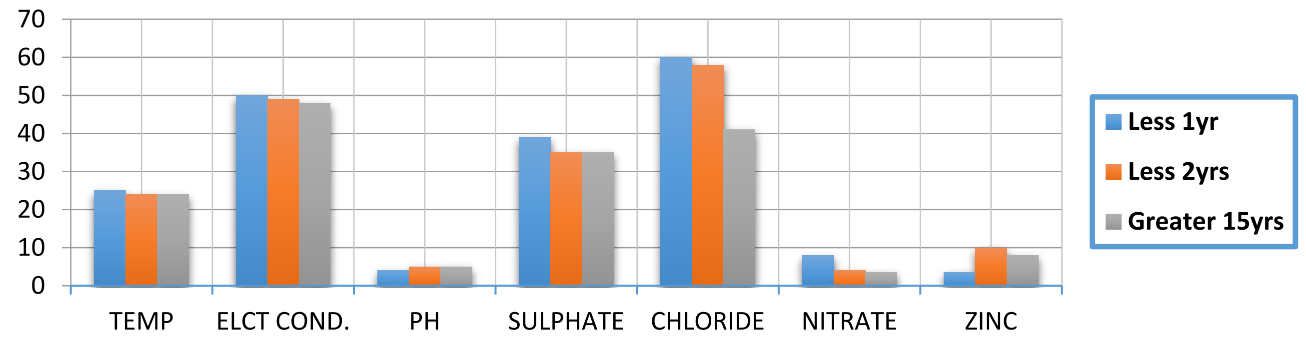

Figure 2: Variation of rainwater quality from roofs of different ages in a rural environment.

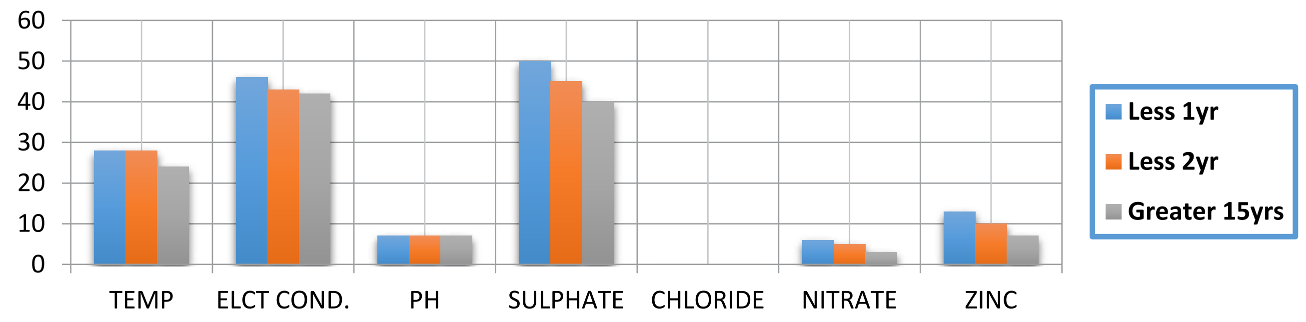

Figure 3: Variation of rainwater quality from roofs of different ages in an urban environment.

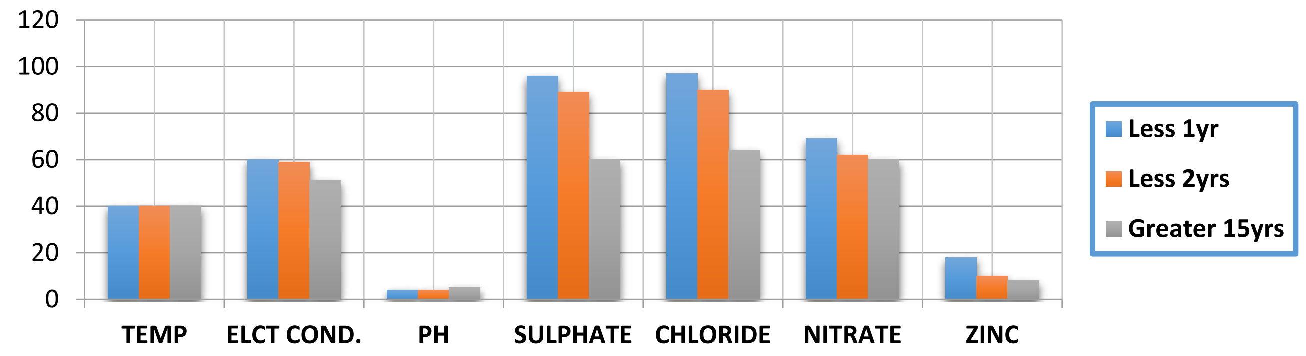

Figure 4: Variation of rainwater quality from roofs of different ages in marine environment.

Corrosion effects of rainwater qualities on various roofs

Corrosion study was based on the weathering processes leading to high levels of sulphate, chloride and nitrate concentration in rainwater in the three areas (Tables 4-6). The marine and urban areas have elevated levels of oxides of sulphur and nitrogen. In addition, the marine environment also has high chloride content which promote the main formation of phases including zinc oxide (ZnO) from rooftop. Chlorides are known atmospheric corrosion stimulators towards metals including zinc and zinc-based materials [21,22]. The result from rainfall there produces relatively strong acids (H_2SO_4, HNO_3 and HCL) which are corrosive and accelerate the rusting of the corrugated iron roofing sheet in these areas. Higher corrosion was observed for younger roofs than for older ones. The result is consistent with the finding of Stockholm [4] who observed that as the patina is gradually built up, the corrosion rate usually decreases with time. There was also more corrosion of roofs in the marine environment than in the urban and rural areas (Tables 4-6) [23-25].

The urban is far from the zone of gas flare, with south west trade and wind speed of 0.4 km/h, and ionic concentrations such as sulphate, and nitrate originate from vehicular emission and auto-exhaust and chloride ion originates from human activities in urban area: it may be result from refuge incineration such as PVC, which produces HCL in gas phase [20,23,26,27]. During 1 year of roof exposure, sulphate was found to be more prominent with 2.09 mg/l in urban site and 4.04 mg/l. These results are in consonant with the observation of Tice who observed that $SO_{2(gas)}$ content of the air is probably the most significant

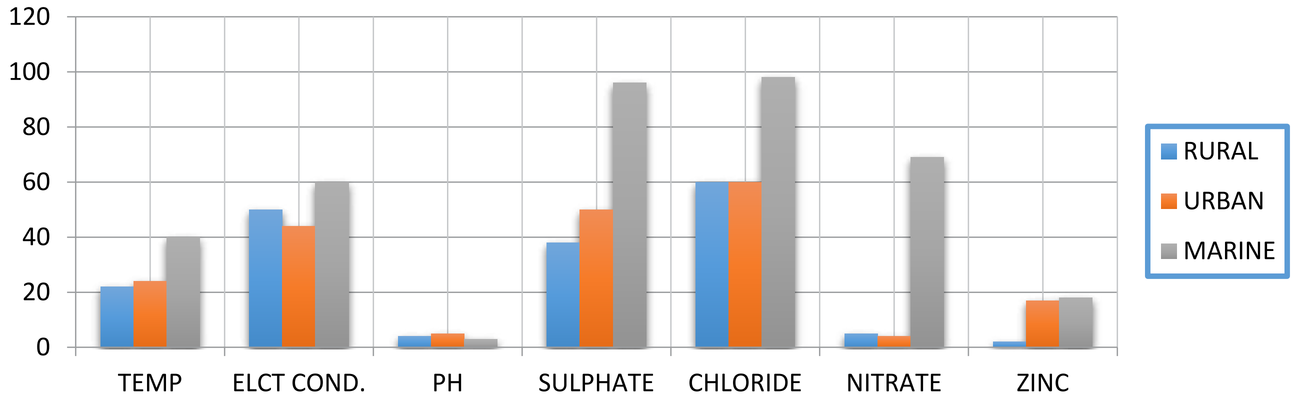

Figure 5: Variation of rainwater quality roofs of below one year in different environments.

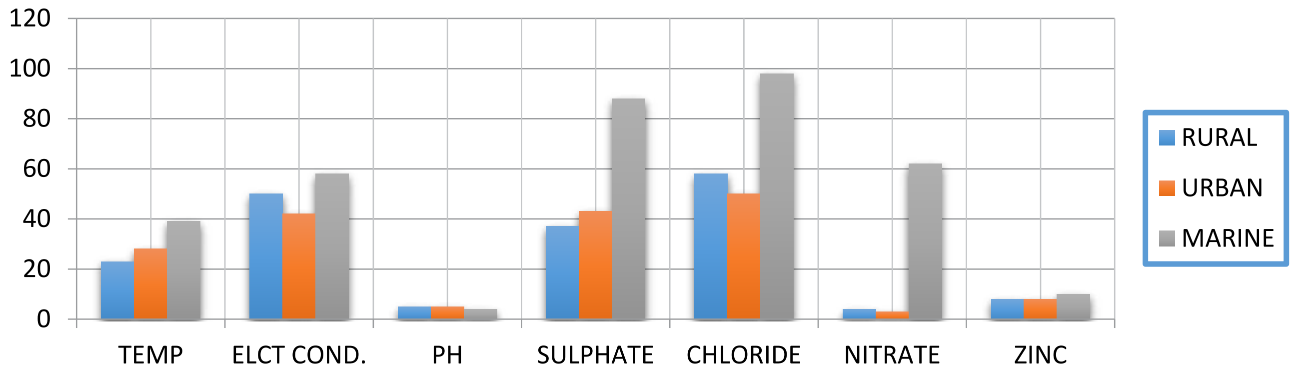

Figure 6: Variation of rainwater quality roofs of below two year in different in environments.

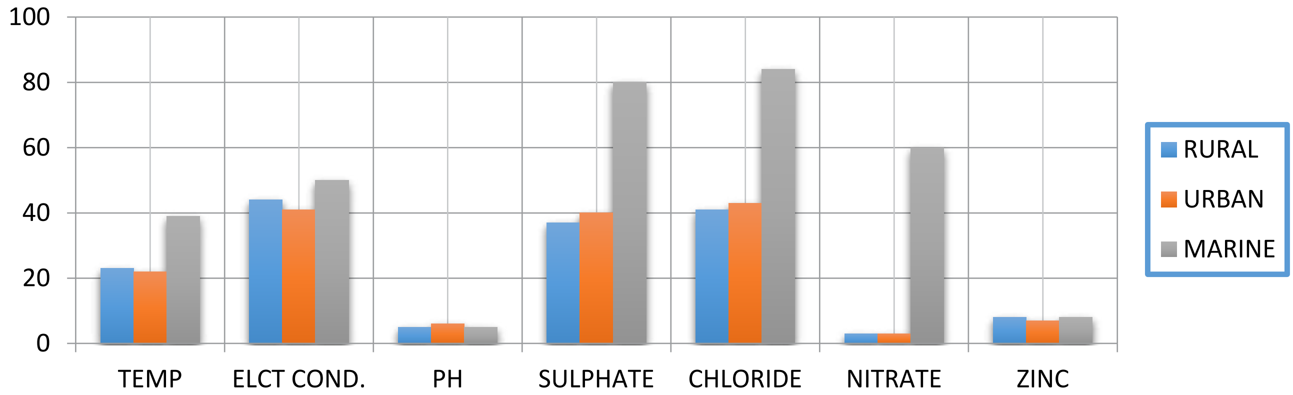

Figure 7: Variation of rainwater quality roofs of below two year in different environments.

constituent responsible for this increased corrosivity, that affect roofing corrugated iron roofing sheet [24,28].

Conclusion

The study has shown that fresh roofing sheets of less than 1 year and 2 years were susceptible to corrosion than roofing sheets more than 15 years of age. The corrosion rate was higher in marine and rural areas due to incessant gas flaring and less in urban where influence of gas flaring is not felt. Gas flaring has raised the ambient temperature and acidic content of rainwater in Okobo and Ibeno, Okposo, Ibaka (James town), Utan brama, Oron, Utan-Effiong and Mbe-Ndoro along the coastline. This confirms that industrial atmospheres may be manyfold more corrosive than rural ones. Gas flaring affects atmospheric water quality and soils, hence the growth and survival of crops and biological species.

Recommendation

Based on the result, Government should enforce the law for the stoppage or reinjection of gas flared by the Mobile Oil for environmental sustainability. In the absence of this, common ways to reduce corrosion of the corrugated iron roofing sheet to apply different kinds of surface treatments such as chromate-based surface treatments, thin organic coatings, primers, topcoats, or duplex coatings on the surfaces of zinc and galvanized steel.

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