A Field Study of Outdoor Atmospheric Corrosion Rates of Mild Steel around Kaduna Metropolis

T.N. Guma¹, James A. Abu²
¹,²Department of Mechanical Engineering, Nigerian Defence Academy, Kaduna, Nigeria

Abstract
Corrosion management and control skills are based on clear understanding of specific material-environment corrosion rates. Atmospheric corrosion is known to account for the greatest material losses on a tonnage basis with amounts that increase with its various location rates. Public information on practicable corrosion rates of carbon steel as the commonly employed metallic material in open air structures was found lacking for Kaduna metropolis—a top industrial, commercial, and populous center in Nigeria. Ascertained mild steel sheet was used to produce 620 similar panel coupons for the test in principle to ISO 9226 2013 procedure. The coupons were exposed in pairs for 36 months at 310 different atmospheric locations of the metropolis where there were many residents, frequent traffic, industrial or commercial processes, open spaces, vegetation, and waste dumps to include possible effects of such variables on the study results. The location corrosion rates of the coupons were systematically determined at the end of the duration through their respective average pair weight losses. Statistical analyses of variance at F0.01 level of significance and dispersion of the overall obtained rate data was conducted. The analyses indicated that the location variables had effects on corrosion rates of the steel but all the rates ranged from low to medium levels and varied randomly from 0.007 to 0.092mm/yr with range 0.085mm/yr, overall mean of 0.0341mm/yr, standard deviation of 0.015mm/yr, and coefficient of variation 44%. The aim of the paper is to provide some applicable predictive supplementary information for corrosion management and control of steel components in assets that should be in appreciable service duration in the metropolitan atmosphere.

Key words: Atmospheric conditions, relative humidity, pollutants, corrosivity, variations, steel structures, durability, design and maintenance, Kaduna metropolitan area, practicable control data.

1. INTRODUCTION

A. Background to the Study
Corrosion is an environmentally inevitable costly natural process of material degradation which greatly impedes technological and economic achievements to optimal levels and needs to be managerially technologically controlled cost-justifiably to the barest level to minimize its consequences. Corrosion rates determine the lifespan and maintenance requirements of metal-based structures. This reality dictates the choice of metals used for different purposes in different environments [1, 2]. One of the most frequently encountered corrosion type is the atmospheric corrosion. Atmospheric corrosion has been reported to account for more failures in terms of cost and tonnage of the overall cost of corrosion which has been estimated to be in the range of 2-4% of GNP of the world’s nations than any other type. About 80% from all degradations produced by corrosion in the metallic constructions are due to atmospheric corrosion [3]. The atmospheric conditions for corrosion are very complex and the corrosion rates vary with the geographic zones, micro-environments, seasons and daily times. The complexity of the atmosphere as corrosion environment, results from its composition and presence of highly unpredictable variable factors such as pollutants, temperature, humidity, wind speed and direction, etc. These variables make meaningful results from laboratory experiments very difficult to obtain [4].

Corrosion of steel as a prime structural material accounts to about 90% of all corrosion problems in the whole world. Steel is the most commonly employed metallic material in open-air structures, being used to make a wide range of equipment and metallic structures due to its low cost and good mechanical strength and fabrication properties. Much of the steel that is manufactured is exposed to outdoor conditions, often in highly polluted atmospheres where corrosion is much more severe than in clean rural environments. The general average corrosion rates of carbon steel is well understood in typical atmospheric conditions, but for the design engineer, the precise localized rates or micro-environment conditions must be well understood for him/her to have confidence in the ultimate durability of designed structures or systems [5, 6]. Mild steel is the carbon steel type used in very large quantity in amounts up to 85% of all steels for bridges, buildings, industrial systems, ships, road
vehicles, boilers, pipelines, power generating systems, etc. By design standard, optimal methodical corrosion control of any steel type can be based on information from the environmental corrosion rates of mild steel as the least corrosion-resistant type. Ipso facto, corrosion of mild steel is a fundamental academic and industrial concern that has received considerable research attention [7, 8, 9].

B. Basics of Atmospheric Corrosion Variables and Kaduna Metropolis as the Study Centre

The amount of water precipitation-rain, snow or mist, humidity condensation (dew) due to temperature changes allied to solar radiation and the chemical composition of the atmosphere (air contamination by gases, acid vapors) are the main factors that determine the atmospheric corrosive ability at any global location. The relative humidity and mean annual rainfall are critical variables that determine the degree and duration of the electrochemical processes of corrosion. Changes from high to low atmospheric temperatures can result in effects such as condensation on metal surfaces and corrosion [10, 11]. Air contaminants can influence corrosion in different ways. For example, it is known that air concentration of SO$_2$ in um/m$^3$ promotes formation of sulphuric acid which is very corrosive to steel and other metals by combining with moisture in the atmosphere. Aerial oxidation of hydrogen sulphide produces hydrogen peroxide which promotes corrosion, dust particles adhere to surface water on metals and prolong the time of wetness and corrosion, and chlorides increase corrosion and even turn to break down passive films on the surface of metals, and nitrogen oxide (NO$\alpha$) compounds lead to the formation of nitric acid which like any other acid is corrosive to metals [12].

Kaduna metropolis is an inland location situated at an average aerial distance of about 500Km from the Atlantic Ocean and 200Km from the southern fringe of Sahara desert and on the southern end of the high plains of Northern Nigeria between Latitudes 10° 40’N and 100 60’N and Longitudes 70 10’E and 70 35’E. It has historically been an administrative capital, industrial town and a military garrison centre. It has been a top city in the ranking of growing population, industrial and commercial activities in Nigeria. The city had a projected population of about 1,371,805 according to the 2006 Nigerian population census [13, 14]. It is also a noted centre for refining crude oil, automobile manufacturing, producing weapons, bottling and brewing, electric power distributing, textile manufacturing, sand-casting, metal forging, civil engineering construction works, agricultural processing, metalworking, warehousing, machinery manufacturing, steel working, treating water, etc. It also is a rail transportation and rehabilitation centre. One of the international airports and three refineries in Nigeria are located in its metropolitan area. The refinery has a production capacity of about 110,000 barrels per stream day [10, 15]. Kaduna metropolis experiences a tropical continental climate characterized by distinct wet and dry seasons with August to October as period of peak rain fall and dry season from November to mid-April. The city metropolitan climate is a typical tropical type that oscillates between cool hot dry and humid wet weather with a mean annual rainfall of 87mm, relative humidity of 53%, and temperature variation of 15 to 35°C. The city’s dry season is frequently attended with dusty winds and storms of high intensities. The possible sources of air pollutants that can increase atmospheric corrosion attack in the metropolis are from dust and industrial activities such as textile manufacturing, agricultural processing, crude oil refining, and automobile assembling and exhaust emissions such as SO$_2$ and NO$_\alpha$ from a larger conglomeration of traffic and commercial cum domestic combustion processes. Other atmospheric pollutants such as hydrogen sulphide, and chlorides from natural processes are also evidently possible [12]. The city metropolitan atmosphere can therefore be reasonably thought of being far from perfectly dry or unpolluted whereby, metallic corrosion progresses at an extremely low rate and for practical purposes can be ignored. In view of the pre-eminence of atmospheric corrosion damage to materials and the foregoing scenario on Kaduna metropolitan area, some readily-available practicable data on atmospheric corrosivity level of the area is crucial for optimal corrosion control of carbon steel as the basic material of construction therein.

C. Statement of the Problem

Corrosion of carbon steel as a prime construction material accounts to about 90% of all corrosion problems world over [1, 8, 13, 15]. Corrosion of carbon steel and even alloy steels in micro-environments can be very complex [6]. Our preliminary survey part of this research work showed lack of practicable public information from research outputs on the precise corrosivity level of Kaduna metropolitan atmosphere to carbon steel as the main construction metal of critical assets in usage exposure to it. Macro and micro atmospheric conditions can cause to various extent different forms of corrosion of a large quantity of steel which find applications in the metropolis as structural components or parts in automobiles, aircrafts, train, railways, machineries, steel works, water tanks, industrial and domestic buildings, fluid transmission systems, bridges, etc. with costly consequences. Although corrosion protection is usually built into such components or structures, corrosion problems with them are inevitable due to the way they are sometimes used without corrosion
consideration and shear improper or non-compliances to their designed maintenance strategies. These can be due to lack of precise information on local environmental corrosion rates of such components as well as sheer unawareness of corrosion problems in some quarters. This is particularly true in developing countries such as Nigeria, where the general level of corrosion-consciousness and counteractions by the populace is low with chronic antagonisms of economic and industrial development by the deleterious phenomenon.

**D. Literature Review**

Guma T.N. and Oguchi [10] conducted a field study on the corrosivity level of river Kaduna as a fresh water environment of great importance to the city of Kaduna to mild steel. They produced 11 consistently similar mild steel plate specimens to an overall average surface finish of 30 microns and mass 306.4kg and exposed them to a section of the river that adjoined the city at different mapped out locations for various durations of 31 up to 789 days after which each was removed and systematically cleaned off of corrosion products, moisture and all other adherents on their surfaces and used the measured weight losses of each specimen to determine their respective corrosion penetration rates. Their overall analysis of their results indicated that the river environmental section was generally more or less moderate in corrosivity to the steel by average corrosion penetration rate of 0.082mm/yr in spite of possible effects of the river pollution by human activities in the city.

T.N. Guma et al [15] stressed corrosion risks from huge underground engineering steel structures within the metropolitan area of Kaduna. They examined cathodic protection (CP) as an effective, economical and durable method of preventing corrosion of such structures. They recognized variables that could cause wide differences and difficulties in CP designs such as material make, surface area, nature of structure, and corrosivity level of environment. They provided some information that accounted for complexity of such variables which could be used to optimize CP design of the structures through experimental studies. Their results with zinc, pure magnesium and magnesium alloy as common and cheap galvanic anodes for CP indicated that; corrosion of the structures could be optimally reduced to negligible rates by polarizing them to -0.85V versus Cu/CuSO₄ electrode with the anodes. They found pure magnesium comparatively the best of the anodes for CP of the structures in terms of economy and effectiveness followed by magnesium alloy. They concluded from the results that a unit surface area of the anodes could protect up to nearly 1200 units of the structure’s area with the -0.85V protective potential depending on the anode type [5].

T.N. Guma et al [16] on the other hand conducted a field survey of soil corrosivity levels of Kaduna metropolitan area at 310 different underground locations up to 4.5m-depth during annual period of peak rainfall (August to October) using electrical resistivity method. They found from analysis of their results that within the survey depths, the soil resistivity values as measure of the corrosivity levels were generally different at each location and increased downwards and varied within the extremes of 31.9 Ohm-m at the depth of 0.5m to 152.9 Ohm-m at the depth of 4.5m with overall mean value of 72.13481 Ohm-m, standard deviation of 33.78109 Ohm-m and coefficient of variation 46.83%. Translated into corrosivity, they showed the metropolitan area had randomly variable soil corrosivity spectrum that was mildly corrosive on average and generally decreased downwards underground from aggressive at depths of less than about 0.5m to slightly corrosive around the depth of 4.5m.

The effect of chemical composition of steel and environmental conditions on the atmospheric corrosion behavior of weathering steel and carbon steel exposed in different environments was investigated by Zhifen Wang et al [17]. Their results showed that the corrosion rate of weathering steel was lower compared with carbon steel due to the alloying additions of Cr, Cu, P, and Ni. They found that the different environmental factors affected the corrosion behavior of steel in the different stages, and the chemical composition of steel and environmental conditions influenced the corrosion rate as well as the morphology and composition of the rust layer. They lay it out that the effect of SO₂ concentration played a major role in the initial stages, the time of wet and chloride concentration were important mainly in the later stages, and the different alloying elements played a major role in different environments.

Atmospheric corrosivity levels of the tropical surf beach environment to ingot iron at various approximate distances and salt contents of air (mg NaCl/dm²) was studied at Apapa in Lagos Nigeria by Ambler and Bain with report of their results as shown in Table 1.

<table>
<thead>
<tr>
<th>Approximate distance from the Surf</th>
<th>Salt content of air (mg NaCl/dm²)</th>
<th>Rate of rusting (mm/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50m</td>
<td>11.1</td>
<td>0.95</td>
</tr>
</tbody>
</table>
E. Aim and Objectives

The aim behind this paper was to conduct a field study on precise corrosion rates of mild steel at several atmospheric locations within Kaduna metropolis. The specific objectives were:

i. To analyze the obtained information to understand the peak rate, average rate, minimum rate, overall range and general pattern of variation for the metropolis,

ii. To assess the level of aggressiveness of the metropolitan atmosphere to steel works by comparative analysis of the exposed mild steel rates with established corrosivity ratings of the material in other various atmospheric environments.

iii. To contribute to any previous research efforts for providing comprehensive supplementary information of practical and research interests for corrosion management and control of steel structures or components of assets in the metropolis.

II. MATERIALS AND METHODOLOGY

A. Materials

The following materials were used for the study:

i. 1.5mm-diameter polyethylene cords of length 1m (620 No.).

ii. Mild steel sheet of 4m by 3m and 2mm-thickness procured from a commercial dealer in Kaduna.

I. Ascertainment of the procured steel sheet

The Japanese-made Shimadzu model PDA 7000 optical emission spectrometer metal analyser was used to analyse the chemical compositions of the procured steel sheet to confirm it. Several pieces were cut at different positions on the sheet and separately analysed so as to account for any chemical compositional variation of the material. The analysis confirmed that the sheet was indeed mild steel material with 99.53%Fe, 0.05%Ti, 0.17%Ba, 0.12%C, 0.07%Al, 0.03%Si, and 0.19%Ni average elemental weight compositions.

B. Methodology

1. Preparation of Coupons

The ascertained mild steel sheet was cut into similar-sized pieces of dimensions 150 by 100 by 2mm-thickness and used to produce panel coupons for the study in principle to ISO 9226, 2013 [19]. A hole of 2mm diameter was drilled 2mm from the edge at the mid-width of each coupon to facilitate hanging it in vertical position using a PVC cord of diameter 1.5mm. Each coupon was polished manually using first the 300 and finishing with the 400 grade sand paper until average surface finish of 30±0.5 microns was achieved from measurements made with a profilometer. The thicknesses of all the coupons were re-measured at several locations with a very accurate micrometer and averaged and found to be negligibly different from their 2mm-thickness values. The finish-polished coupons were thenceforth cleaned with acetone, rinsed in distilled water, dried with a dry clean woolen towel, handled with clean hand-worn gloves and stored in moisture-free desiccators prior to exposing them to the atmosphere all in accordance with the ASTM G1-03 standard practice for preparing, cleaning, and evaluating corrosion test specimens [20].

The length (l), width (w), and thickness (t) of each coupon were used to determine its surface areas (A) to the nearest 0.0001mm² according to the formula,

\[2lw + tw + 2\pi r - 2\pi r^2 = 31006.2857mm^2\] ................ (1)

Where: \(l = 150mm, w = 100mm, t = 2\) mm, \(r = 1mm\) = radius of the drilled holes on the coupons.

2. Exposure of the Coupons the atmosphere and determination of their corrosion rates

62 districts were mapped out for exposure of the coupons to the metropolitan atmosphere. Five locations where selected at each district where there were; many residents-A, commercial or industrial activities-B, open spaces-C, vegetation-D, and waste dumps-E. The strategy was to include any possible effects of such location variables on atmospheric corrosivity. Each coupon was removed from the desiccators where it was kept, weight-determined to the nearest 0.01g using a Mettler Toledo, Japan AB 135-S/FACT, single pan analytical balance, and recorded. The coupons were then exposed in pairs unsheltered outdoor to the atmosphere at 1.5m above the ground in vertical positions with their larger surfaces facing the main direction of wind flow at each location on 10 March 2014. A faithful resident in each area was engaged as
an assistant at each district with remuneration for safe-
keeping the coupons. The coupons were exposed and
kept in place by passing the 1.5mm-diameter elec-
trically neutral polyethylene cord through the 2mm-
diameter hole drilled on the coupon and using the ends
of the cord to tie-suspend the coupon to erected or
suitable nearby structures or frames such as poles,
fences, gates, etc. In that way the coupons were allowed
to undergo possible levels of natural atmospheric
corrosion for 36 months. Just at the exposure duration,
the coupons were removed from the exposure points on
the same day 10 March 2017 through the assistants,
pit in clean leather bags and taken to the laboratory where
they were cleaned with water and bristle brush to
remove rust and dust and other undesirability on their
surfaces and sun-dried for one hour in line with ASTM
G-1 procedures and reweighed. The corrosion
penetration rates (CPR) of the coupons were
determined through their weight losses as a measure of
corrosvity of the metropolitan atmosphere to the steel
according to [10, 21]:

\[ \text{CPR} = \frac{87.6W}{DAT} \]  

(2)

Where: \( W \) =weight loss of coupon in milligram, \( D \) =density of the mild steel coupons (7.87 g/cm\(^3\)), \( A \)
=total exposed surface area of the coupon in square centimeters (310.062857cm\(^2\)), and \( T \) = the36-month exposure time of the coupons in hours (26298 hours). The corrosion rates were reported as averages of the
respective specimen pairs exposed at each location.

III. RESULTS AND DISCUSSIONS

A. Results

The study results of out-door atmospheric corrosion rates (\( S_i \)) of mild steel at 310 different mapped out districts around Kaduna metropolis were
collated and presented as shown in Figs 1-16. The mean
(\( \bar{S}_i \)), standard deviation (\( \sigma \)), range (\( R_i \)), and coefficient of variation (\( V_i \)) of the entire 310 data values were
evaluated as measure of dispersion of the data using
Microsoft Excel statistical tools according to equations
1-4 [22, 23]. To know whether the location variables
such as where there were many residents (A), frequent
traffic (B), industrial or commercial processes (C),open
spaces (D), vegetation and waste dumps (E) had effects
on the corrosion rates, analysis of variance of the 310
data points was also conducted at 99.9 % level of
confidence using the F statistical distribution (\( F_{0.00} \)) and
309 by 4 degrees of freedom by testing the null
hypothesis (\( H_0 \)) that the effects the variables on the
corrosion rates of the mild steel coupons were the same
against the alternative hypothesis (\( H_1 \)) that not all the
variables had the same effects on the rates by equations
5-8. Reject the null hypothesis if \( F_{0.1} \) is < \( F_{α} \) [24].

\[ S_i = \sum_{i=1}^{n} S_i/n \]

\[ = 0.0341 \text{mmyr} \]  

(1)

\[ \sigma = \sqrt{\sum_{i=1}^{n} \left( \frac{|S_i-S|^2}{n} \right)} = 0.0155 \text{mmyr} \]

(2)

\[ R_i = S_{\text{max}} - S_{\text{min}} = 0.085 \text{mmyr} \]

(3)

\[ V_i = \frac{\sigma}{\bar{S}_i} = 0.44 \]  

(4)

\[ C=\frac{T^2}{ab} = \frac{10.5842^2}{310} = 0.3613 \]  

(5)

\( C \) = the correction term, \( T \) = the grand total of all the
corrosion rates at the locations, \( a = 62 \) = number of
districts, \( b = 5 \) = number of district variables.

\[ SS(T) = \sum \sum_{i=1}^{a} \sum_{j=1}^{b} S_{ij} = 0.43422 - 0.3613 = 0.0729 \]

(6)

\[ SS(Bl) = \sum_{i=1}^{a} T^2_i/b - C = \frac{22.49904}{62} - 0.3613 = 0.00159 \]

(7)

\[ SS(Tr) = \sum_{i=1}^{a} T^2_j/a - C = \frac{1.871}{5} - 0.3613 = 0.0129 \]

(8)

Where, \( SS(Tr) \) = Treatment sum of squares

\[ SSE = SST - SS(Tr) - SS(Bl) = 0.0681 \]  

(9)

Where, \( SSE \) = Error sum of squares

\[ F_{\alpha} = \frac{MS(Tr)}{MSE} = \frac{SS(Tr)/a - 1}{SSE/(a - 1)(b - 1)} = 0.003225 \]

\[ = 11.64457 \]

Using these sum of squares we rejected the null
hypothesis that the \( \alpha \) are all equal to zero at the level
of significance \( \alpha = 0.1 \)
n, that is \( F_{0.1, 309, 4} = 3.76073 < F_{\alpha} = 11.64457 \)
**Fig 1: Corrosion rates for Abakpa, Afaka, Airforce base, and Askolai districts**

**Fig 2: Corrosion rates for Badarwa, Badiko East, Badiko West, Barnawa districts**
Fig 3: Corrosion rates for Barkin Ruwa, Central market area, Doka and Dosa districts

Fig 4: Corrosion rates Farin-gida, Farin-gida Extension, Gonin-gora, and Hayin Banki districts
Fig 5: Corrosion rates for Hayin Rafonguza, Janruwa, Janruwa Extension, and Kurmin Mashi districts

Fig 6: Corrosion rates for Kabala Doki, Kabala Constain, Kadpoly area, and Kaduna State University districts
Fig 7: Corrosion rates for Kanuri, Kamanzo, Kanawa, and Kawo districts

Fig 8: Corrosion rates for Kawo Extension, Kotoko, Kudenda, and Mahuta districts
Fig 9: Corrosion rates for Mahuta Extension, Malali, Mando, and Maraban Rido districts

Fig 10: Corrosion rates for NAF base, National Eye Centre, Narayi, and Narayi High Cost districts
Fig 11: Corrosion rates for Nasarawa, NDA new and old sites, and KRPC area districts

Fig 12: Corrosion rates for Panteka, Rigachikun, Rigachikun Extension, and Rigasa districts
Fig 13: Corrosion rates for Sabon Tasha, Trade fair area, Trikania, and Tudun Nupawa districts

Fig 14: Corrosion rates for Tudun Wada, Ungwan Borou, Ungwan Gwari, and Ungwan Muazu districts
B. Discussion

From the results presented in Fig.1-16, it can be observed that corrosion rates of the study mild steel coupons at the various atmospheric district locations of Kaduna metropolis vary randomly from location to location. Conducted dispersion analysis of the information using Microsoft Excel statistical facility indicated that the rates ranged from 0.007 at Mahuta Ext district to 0.092mm/yr at Barkin Ruwa district with a range of 0.085mm/yr, overall mean of 0.0341mm/yr, standard deviation of 0.015mm/yr and coefficient of variation 44%. Relative corrosion resistances of a material in an environment can be judged as outstanding if its corrosion rate is less than 0.02mm/yr, excellent if the rate is from 0.02 to 0.1mm/yr, good if the rate is from 0.1 to 0.5mm/yr, fair if the rate is from 0.5 to 1mm/yr, poor if the rate is from 1 to 5mm/yr, and unacceptable if the rate is over 5mm/yr [1, 25]. ISO
9223 1992 categorized atmospheric corrosivity from the point of view of corrosiveness to some base materials. For carbon steel, the five attack categories and corrosion rate ranges (Vcorr) are shown in Table 3.

Table 3: ISO 9223 atmospheric corrosivity categorization of carbon steel [26]

<table>
<thead>
<tr>
<th>Category</th>
<th>Corrosivity</th>
<th>Corrosion rate [µm/yr]</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>Very low</td>
<td>Vcorr ≤ 1.3</td>
</tr>
<tr>
<td>C2</td>
<td>Low</td>
<td>1.3 &lt; Vcorr ≤ 25</td>
</tr>
<tr>
<td>C3</td>
<td>Medium</td>
<td>25 &lt; Vcorr ≤ 50</td>
</tr>
<tr>
<td>C4</td>
<td>High</td>
<td>50 &lt; Vcorr ≤ 80</td>
</tr>
<tr>
<td>C5</td>
<td>Very high</td>
<td>80 &lt; Vcorr ≤ 200</td>
</tr>
</tbody>
</table>

Judging the presented information in Fig.1-16 with the foregoing literature information on environmental corrosivity ratings of metals particularly atmospheric corrosivity categorization of carbon steel shown in Table 3, it is evident that corrosion of the mild steel coupons in the metropolitan atmosphere ranged from low to medium levels. One reason attributable to this is that Kaduna is an inland city that is closer to the Sahara desert than the sea and the duration of wetness and level of relative humidity of its metropolitan atmosphere is generally low throughout the year due to fast drying rates of the moisture by dry winds so making any possible corrosion effects of atmospheric impurities in the metropolis per se negligible on the coupons. Average corrosion rates have also been reported in many locations around the globe. For example, the rates in the United Kingdom reportedly vary between 0.048mm/yr at rural sites, 0.079mm/yr at marine sites and up to 0.17mm/yr in some industrial atmospheres. In the driest atmospheres, for example at Khartoum Sudan, the rate can be as low as 0.003 mm/yr [18, 27]. Corrosion rates (mm/year) for mild steel obtained by British Iron and Steel Research Institute [26] for some inland industrial environments were; Motherwell (0.095), Woolwich (0.102), Sheffied (0.135), Frodingham (0.160), Derby (0.170) in Britain; and Pittsburgh, Pa (0.108) in the United State of America. The average global corrosion rates of steel for the rural, urban, industrial, and marine industrial environments reported by the American Galvanizers Association [6] are in the ranges of 4 to 60, 30 to 70, 40 to 60 and 60 to 170 µm/yr respectively. From these it can also be inferred that the average atmospheric corrosion rate of the study mild steel coupons in Kaduna metropolis fall within rates for the less corrosive rural and rural urban atmospheres.

IV. CONCLUDING REMARKS

Information on specific environmental corrosivity is important for the selection of materials and protective systems for various products and objects. The general average rates of corrosion of carbon steel is well understood in typical atmospheric conditions, but for the design engineer, the precise localized rates or micro-environment conditions must be well understood for him/her to have confidence in the ultimate durability of designed structures or systems. Corrosion of carbon steel and even alloy steels in micro-environments can be very complex. Kaduna metropolis was recognized as an important industrial, administrative, military garrison, and populous area in Nigeria with some environmental peculiarities that were thought could make the atmosphere around it not perfectly dry and unpolluted for metallic corrosion to progress therein at an extremely low rate and for practical purposes be ignored. Atmospheric micro conditions were seen to be capable of affecting corrosion of a large quantity of steel which find applications in Kaduna metropolis as structural components or parts in automobiles, aircrafts, train structures, railways, machineries, steel works, water tanks, industrial and domestic buildings, fluid transmission systems, bridges, etc. with attendant consequences. Preliminary survey part of this study however showed lack of practicable public information from research outputs on the precise corrosivity level of the city metropolitan atmosphere to carbon steel as the main construction metal of critical assets within the city metropolis. So, corrosion rates of mild steel coupons exposed unsheltered at 310 different outdoor atmospheric locations of the metropolis for 36 months was systematically investigated to provide supplementary information of practical and research interests for corrosion management and control of steel structures or assets that should be in appreciable service.
duration in the metropolitan atmosphere to ensure their adequate service lives with reliability. Results indicated that corrosion rates of the steel in the metropolitan atmosphere vary randomly from 0.007 to 0.092mm/yr with overall mean of 0.0341mm/yr, standard deviation of 0.015mm/yr, and coefficient of variation 44% and is influenced by location variables that determine the level of pollution around. Analysis of the results vis-à-vis generally known average corrosion rates of some metallic materials, particularly carbon steel in various types of environments around the globe indicated that corrosion rates mild steel in the metropolitan atmosphere range from low to medium levels.

REFERENCES


[2] Terence Bell. How to Calculate the Rate of Metal Corrosion, 13, November, 2017


