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

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Abstract
Corrosion management and control skills are based on a clear understanding of specific material-environment corrosion rates. Atmospheric corrosion accounts for the greatest material losses on a tonnage basis with amounts that increase with its various location rates. Public information on practicable corrosion ratesof 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. The coupons were exposed in pairs for 36 months at 310 different atmospheric locations of the metropolis. Many residents, frequent traffic, industrial or commercial processes, open spaces, vegetation, and waste dumps, including possible effects of such variables on the study results. Thecoupons' location corrosion rates were systematically determined at the end of the duration through their respective average pair weight losses. Statistical analyses of variance at $F_{0.01}$ *level of significance and dispersion of the overall obtained rate data was conducted. The analyses indicated thatthe location variables had effects on corrosion rates of the steel. Still, allthe rates ranged from low to medium levels and varied randomlyfrom 0.007 to 0.092mm/yr with a range of 0.085mm/yr, overall mean of 0.0341mm/yr, the standard deviation of 0.015mm/yr, and coefficient of variation 44%. The paper aims to provide some applicable predictive supplementary information for corrosion management and control of steel components in assetsthat should be in appreciable service duration in the metropolitan atmosphere.*

Keywords: *Atmospheric conditions, relative humidity, pollutants, Corrosivity, variations,steel structures, durability, design and maintenance, Kaduna metropolitan area, practicable control data.*

I. 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 atmospheric corrosion. Atmospheric corrosion has been reported to account for more failures in cost and tonnage of the overall cost of corrosion, estimated to be in the range of 2-4% of the world's GNP's nations than any other type. About 80% of 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 atmosphere's complexity as a corrosion environment results from its composition and highly unpredictable factors such as pollutants, temperature, humidity, wind speed, direction, etc. These variables make meaningful results from laboratory experiments very difficult to obtain [4].

Corrosion of steel as a prime structural material accounts for about 90% of all corrosion problems worldwide. Steel is the most commonly employed metallic material in open-air structures. It is 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 manufactured steel is exposed to out-door 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 are well understood in typical atmospheric conditions. Still, 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 quantities 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 atmosphere's chemical composition (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 determining the degree and duration of corrosion's electrochemical processes. Changes from high to low atmospheric temperatures can condensate metal surfaces and corrosion [10, 11]. Air contaminants can influence corrosion in different ways. For example, it is known that the air concentration of SO_2 in um/m^3 promotes the formation of sulphuric acid, which is very corrosive to steel and other metals by combining with moisture in the atmosphere. Aerial Oxidation of hydrogen sulfide produces hydrogen peroxide, which promotes corrosion. Dust particles adhere to surface water on metals and prolong the time of wetness and corrosion. Chlorides increase corrosion and even turn to break down passive films on the surface of metals. Nitrogen oxide(NO_X) compounds lead to nitric acid formation, 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 the Sahara desert and on the southern end of the high plains of Northern Nigeria between Latitudes 100 40^{I}N and 100 60^{I}N and Longitudes 70 10^{I}E and 70 35^{I}E. It has historically been an administrative capital, industrial town, and a military garrison center. 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 center 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 is also a rail transportation and rehabilitation center. 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 a period of peak rainfall and the dry season from November to mid-April. The city metropolitan climate is a typical tropical type oscillating between cool hot, dry, and humid, wet weather with a mean annual rainfall of 87mm, the relative humidity of 53%, and temperature variation of 15 to 35^{o}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_x from a larger conglomeration of traffic and commercial cum domestic combustion processes. Other atmospheric pollutants such as hydrogen sulfide and chlorides from natural processes are also evidently possible [12]. Therefore, the city's metropolitan atmosphere can be reasonably thought of as being far from perfectly dry or unpolluted. Metallic corrosion progresses at an extremely low rate and for practical purposes can be ignored. Because of the there-eminence of atmospheric corrosion damage to materials and the preceding scenario on the Kaduna metropolitan area, some readily-available practicable data on atmospheric corrosivity level of the area is crucial 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 for about 90% of all corrosion problems worldwide [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 a lack of practicable, public information from research outputs on the Kaduna metropolitan atmosphere's precise corrosivity level to carbon steel as the main construction metal of critical assets in usage exposure. Macro and micro atmospheric conditions can cause to the 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, aircraft, train, railways, types of machinery, steelworks, 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 toa lack of precise information onsuch components' local environmental corrosion rates and sheer unawareness of corrosion problems in some quarters. This is particularly true in developing countries such as Nigeria. The populace's general level of corrosion-consciousness and counteractions is low with chronic antagonisms of economic and industrial development by the deleterious phenomenon.

D. Literature Review

Guma TN and Oguchi[10] conducted an afield study on the corrosivity level of river Kaduna asa freshwater environment of great importance to Kaduna's city to mild steel. They produced 11 consistently similar mild steel plate specimens to an overall average surface finish of 30 microns and 306.4kg. They 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 environmental river section was generally more or less moderate in Corrosivity to the steel by average corrosion penetration rate of 0.082mm/yr despite possible effects of the river pollution by human activities the city.

TN Guma *et al.* [15] stressed corrosion risks from huge underground engineering steel structures within Kaduna's metropolitan area. They examined cathodic protection (CP) as an effective, economical, and durable method of preventing such structures' corrosion. They recognized variables that could cause wide differences and difficulties in CP designs, such as material make, surface area, nature of the structure, and the environment's corrosivity level. They provided some information that accounted for such variables' complexity, which could optimize the 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/$CuSO_4$ 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 that the anodes' surface area could protect up to nearly 1200 units of the structure's area with the -0.85V protective potential depending on the anode type [5].

TNGuma *et al.* [16], on the other hand, conducted a field survey of soil corrosivity levels of the Kaduna metropolitan area at 310 different underground locations up to 4.5m-depth during the annual period of peak rainfall (August to October) using the electrical resistivity method. They found from analysis of their results that within the survey depths, the soil resistivity values as a 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 a depth of 0.5m to152.9 Ohm-m at a depth of 4.5m with an overall mean value of 72.13481 Ohm-m, the standard deviation of 33.78109 Ohm-m and coefficient of variation 46.83%. Translated into Corrosivity, they showed the metropolitan area had a randomly variable soil corrosivity spectrum that was mildly corrosive on average. Generally, they 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 the 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 weathering steel's corrosion rate was lower than 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 different stages. The chemical composition of steel and environmental conditions influenced the corrosion rate and the rust layer's morphology and composition. The layout that the effect of SO2 concentration played a major role in the initial stages. The time of wet and chloride concentration was 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/dm^2) were studied at Apapa in Lagos, Nigeria by Ambler and Bain with a report of their results as shown in Table 1.

Table 1: Atmospheric rates of rusting of ingot iron at some distances and salt contents of airfrom the tropical surf beach at Apapa, Lagos, Nigeria [18].

Approximate distance from the Surf	The salt content of air (mg NaCl/dm^2)	Rate of rusting (mm/yr)
50m	11.1	0.95
200m	3.1	0.38
400m	0.8	0.055
1300m	0.2	0.04
25 miles	-	0.048

E. Aim and Objectives

This paper aimed to conduct a field study onprecise corrosion rates of mild steel at several atmospheric locations withinthe Kaduna metropolis. The specific objectives were:

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

ii. A comparative analysis of the exposed mild steel rates establishes corrosivity ratings of the material in other various atmospheric environments to assess the metropolitan atmosphere's aggressiveness to the steelworks.

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 assetsin the metropolis.

II. MATERIALS AND METHODOLOGY

A. Materials

The following materials were used for the study:

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

ii. Mildsteel sheet of 4m by 3m and 2mm-thicknessprocured from a commercial dealer in Kaduna.

1. Ascertainment of the procured steel sheet

The Japanese-made Shimadzu model PDA 7000 optical emission spectrometer metal analyzer was used to analyze the procured steel sheet's chemical compositions to confirm it. Several pieces were cut at different positions on the sheet and separately analyzed to account for any chemical compositional variation of the material. The analysis confirmed that the sheet wasmild steel material with 99.53%Fe, 0.05%Ti, 0.17%Ba, 0.12%C, 0.07%Al, 0.03%Si, and 0.19%Niaverage elemental weight compositions.

B. Methodology

1. Preparation of Coupons

The ascertained mild steel sheet was cut into similar-sized pieces of 150 by 100 by 2mm-thickness and used to produce panel coupons for the study in principle to ISO 9226, 2013 [19]. A 2mm diameter hole was drilled 2mm from the edge at the mid-width of each coupon to facilitate hanging it in a 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 sandpaper until an average surface finish of 30±0.5 microns was achieved from measurements made with a profile meter. The thicknesses of all the coupons were-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 thence forth 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 be fore exposing them to the atmosphere, all following 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 was used to determine its surface areas (A) to the nearest 0.0001mm^2 according to the formula,

$$2(lw + tl + tw) + 2t\pi r - 2\pi r^2 = 31006.2857\text{mm}^2 \quad \ldots\ldots\ldots\ldots\ldots.. (1)$$

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

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

62 districts were mapped out for exposure of the coupons to the metropolitan atmosphere. Five locations were selected at each district: 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. Thecoupons were then exposed in pairs unsheltered out-door to the atmosphereat 1.5m above the ground in vertical positions with their larger surfaces facing the main direction of wind flow at each locationon 10 March 2014. In each area, a faithful resident 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 electrically neutral polyethylene cord through the 2mm-diameter hole drilled on the coupon and using the cord's endsto 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, put 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 Corrosivity of the metropolitan atmosphere to the steel according to [10, 21]:

$$\text{CPR} = \frac{87.6W}{DAT} \quad \ldots\ldots\ldots\ldots (2)$$

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 the Kaduna metropolis were collated and presented, as shown in Figs 1-16. The mean ($\bar{S_i}$), standard deviation (σ), range (R_i), and coefficient of variation (V_i) of the entire 310 data values were evaluated to measurethe 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 ($F_{0.10}$) and 309 by 4 degrees of freedom by testing the null hypothesis (H_o) that the effects the variables on the corrosion rates of the mild steel couponswere the sameagainst 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 $<F_{tr}$[24].

$$\bar{S_i} = \sum_{i=1}^{i=n} S_i/n$$
$$= 0.0341mmyr \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$\sigma = \sum_{i=1}^{i=n} \sqrt{([\bar{S_i} - S_i]^2/n)} \; = 0.015mm/yr \ldots (2)$$

$$R_i = S_{imax} - S_{imin} = 0.085\text{mm/yr}\ldots\ldots\ldots\ldots(3)$$

$$V_i = \sigma/\bar{S_i} \; = 0.44 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

$$\text{C}= \frac{T^2}{ab} = \frac{10.583^2}{310} = 0.3613 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

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.

$$SST = \sum_{i=1}^{i=a}\sum_{j=1}^{j=b} S_{ij} - C = 0.43422 - 0.3613 = 0.0729 \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

$$SS(Bl) = \sum_{i=1}^{i=a} T^2{}_i \Big/ b - C = \frac{22.49904}{62} - 0.3613 = 0.00159 \ldots.(7)$$

$$SS(Tr) = \sum_{j=1}^{j=b} T^2{}_j \Big/ a - C = \frac{1.871}{5} - 0.3613 = 0.0129 \ldots.(8)$$

Where, SS(Tr) = Treatment sum of squares

$$\text{SSE} = \text{SST} - \text{SS(Tr)} - \text{SS(Bl)} = 0.0681 \ldots\ldots (9)$$

Where, SSE = Error sum of squares

$$F_\alpha = \frac{MS(Tr)}{MSE} = \frac{SS(Tr)/a-1}{SSE/(a-1)(b-1)} = \frac{0.003225}{0.0002791}$$
$$= 11.64457$$

Using these sum of squares, we rejected the null hypothesis that the $\alpha_i\ are$ all equal to zero at the level of significance $\alpha = 0.1$

, that is $F_{(.1,\,309,\,4)} = 3.76073 < F_\alpha = 11.64457$

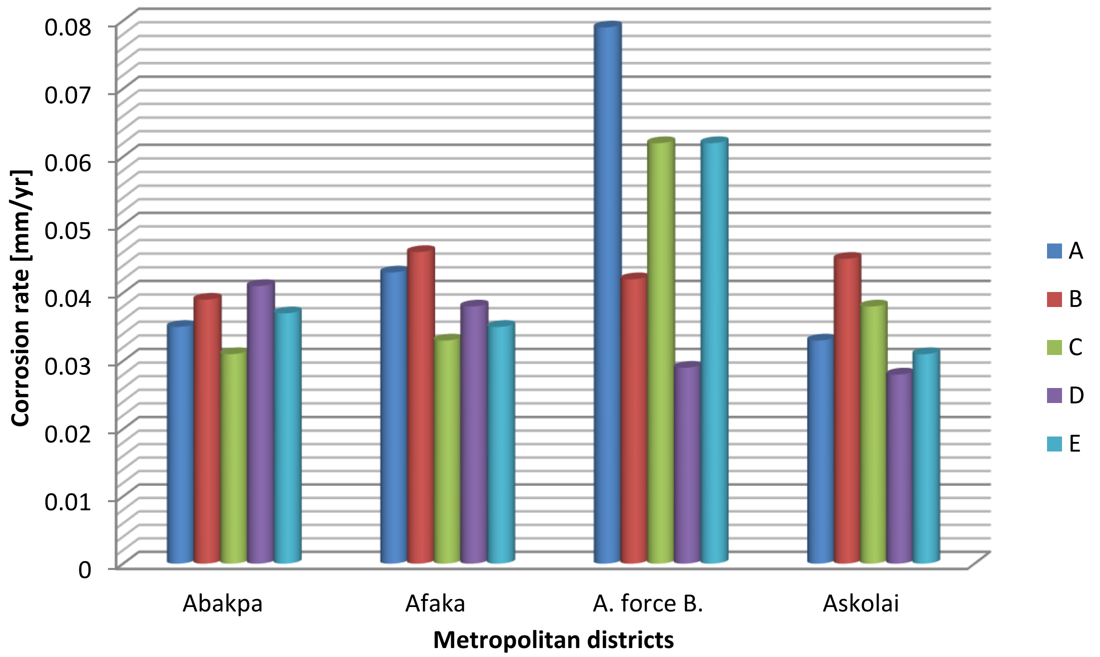

Fig 1: Corrosion rates for Abakpa, Afaka, Airforce base, and Askolai districts

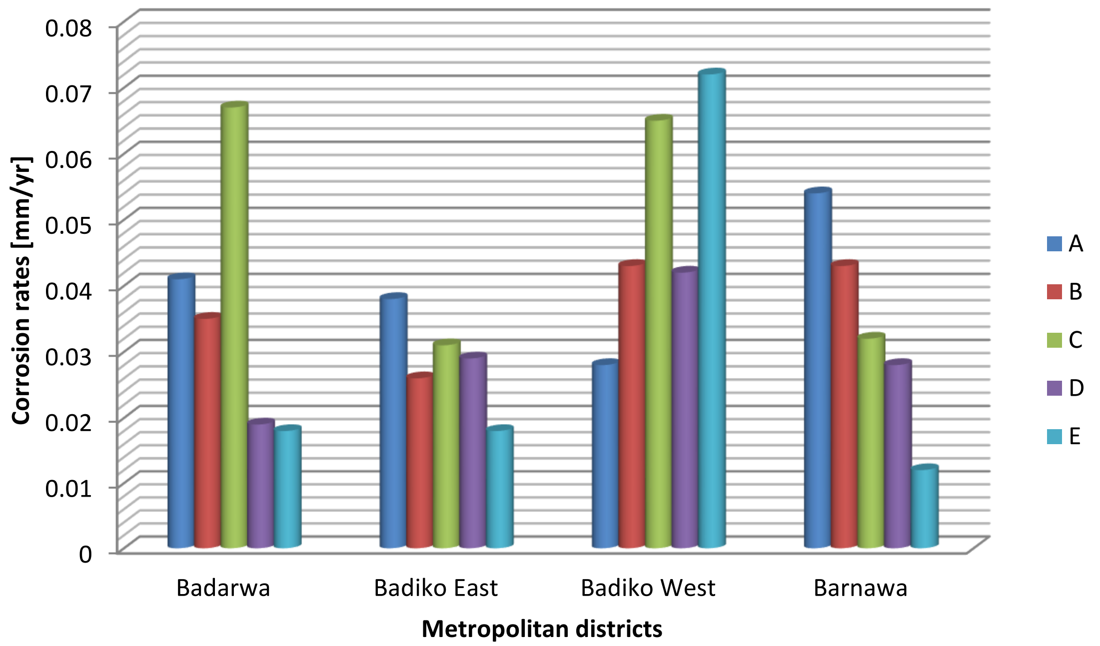

Fig 2: Corrosion rates for Badarwa, Badiko East, Badiko West, Barnawa districts

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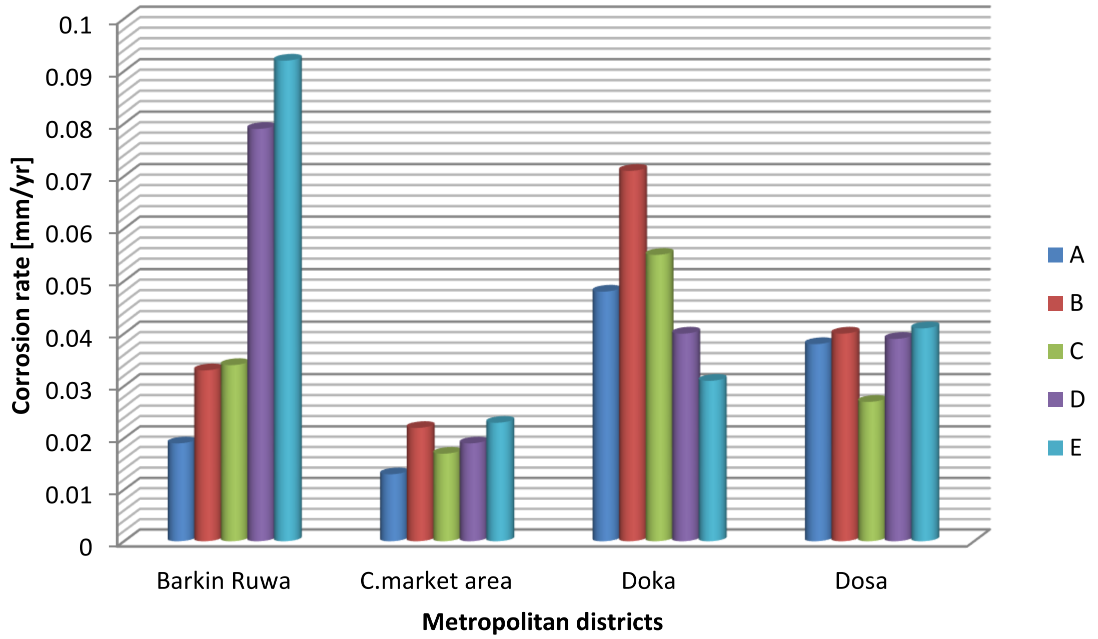

Fig 3: Corrosion rates for Barkin Ruwa, Central market area, Doka and Dosa districts

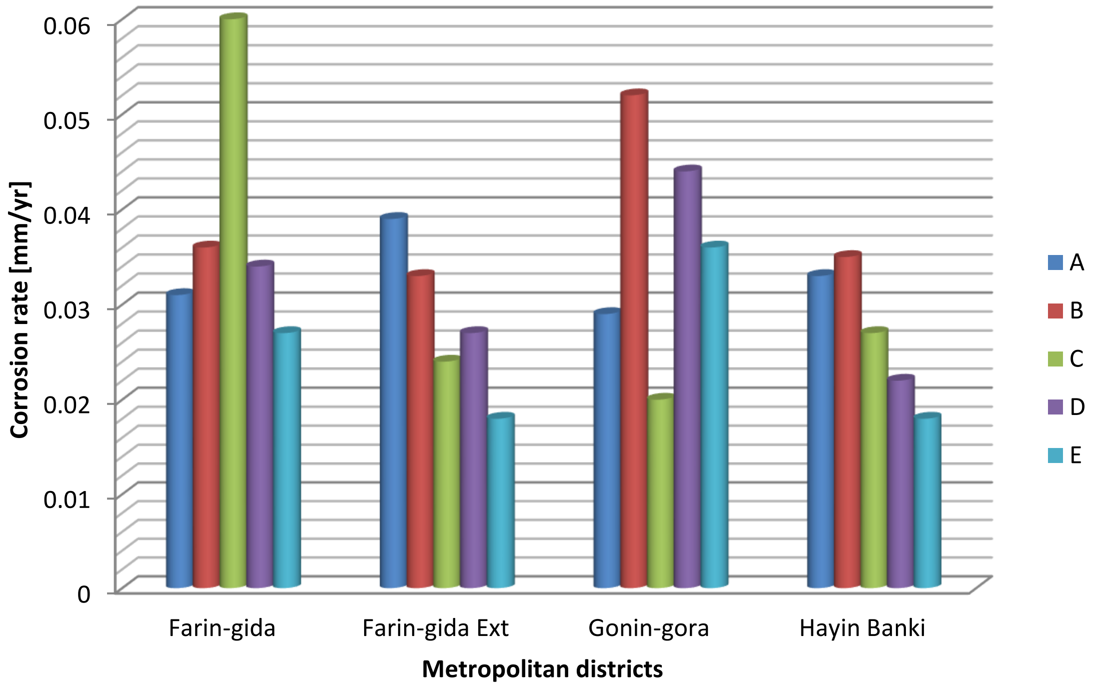

Fig 4: Corrosion rates Farin-gida, Farin-gida Extension, Gonin -gora, and Hayin Banki districts

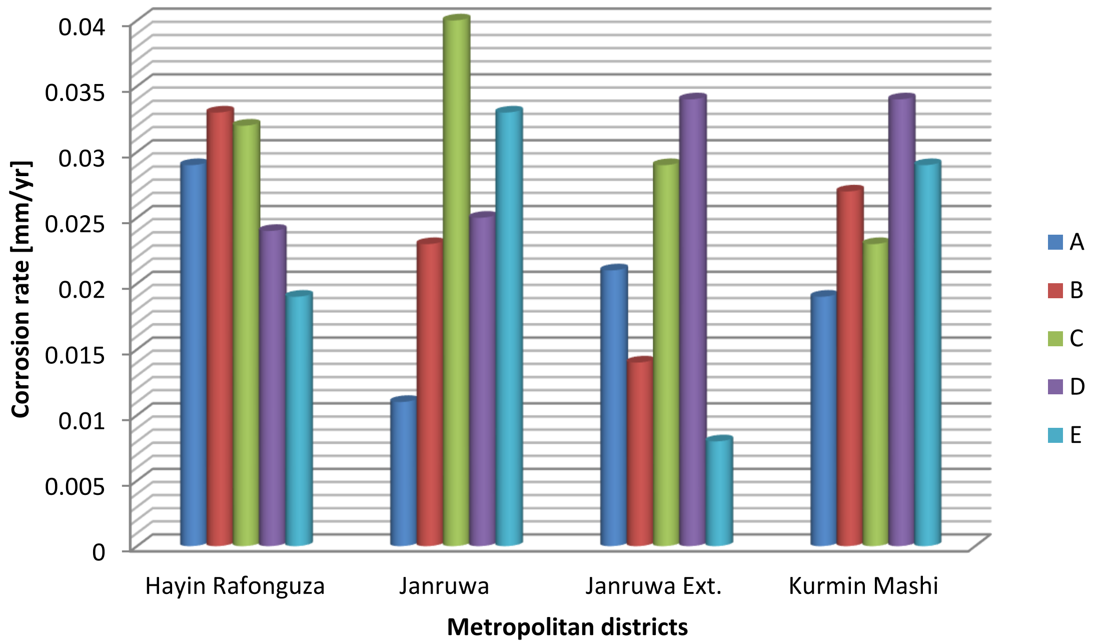

Fig 5: Corrosion rates for Hayin Rafonguza, Janruwa, Janruwa Extension, and Kurmin Mashi districts

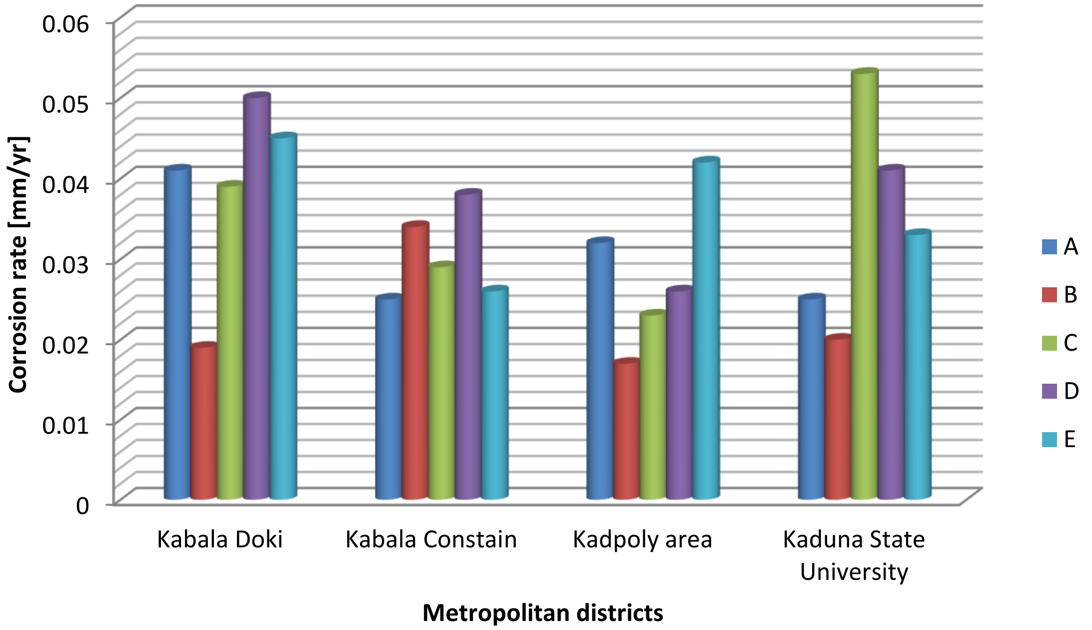

Fig 6: Corrosion rates for Kabala Doki, Kabala Constain, Kadpoly area, and Kaduna State University districts

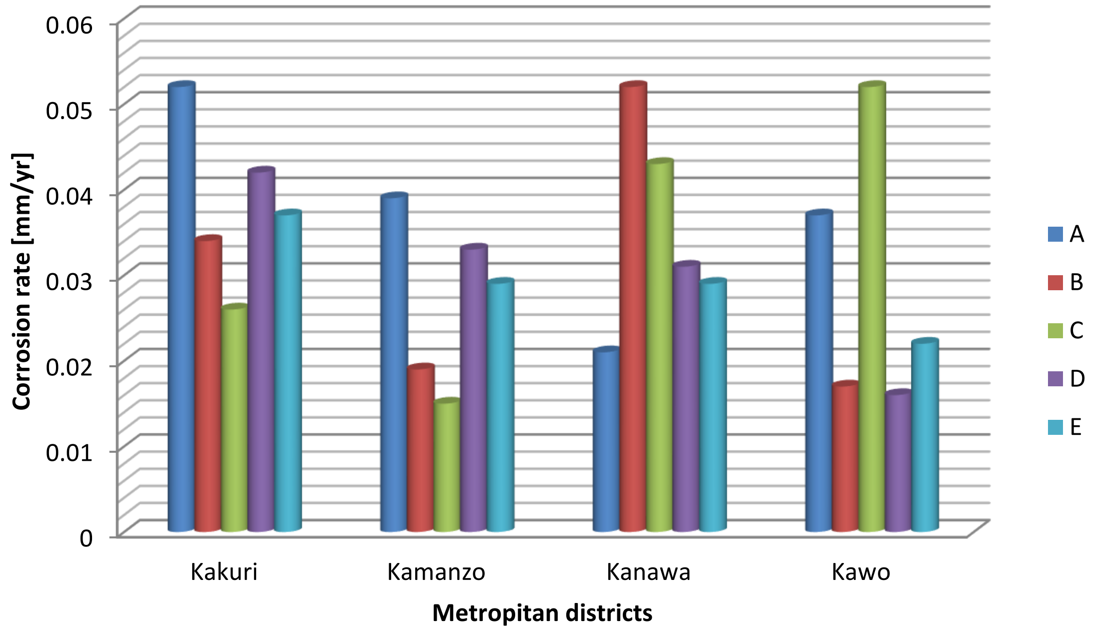

Fig 7: Corrosion rates for Kanuri, Kamanzo, Kanawa, and Kawo districts

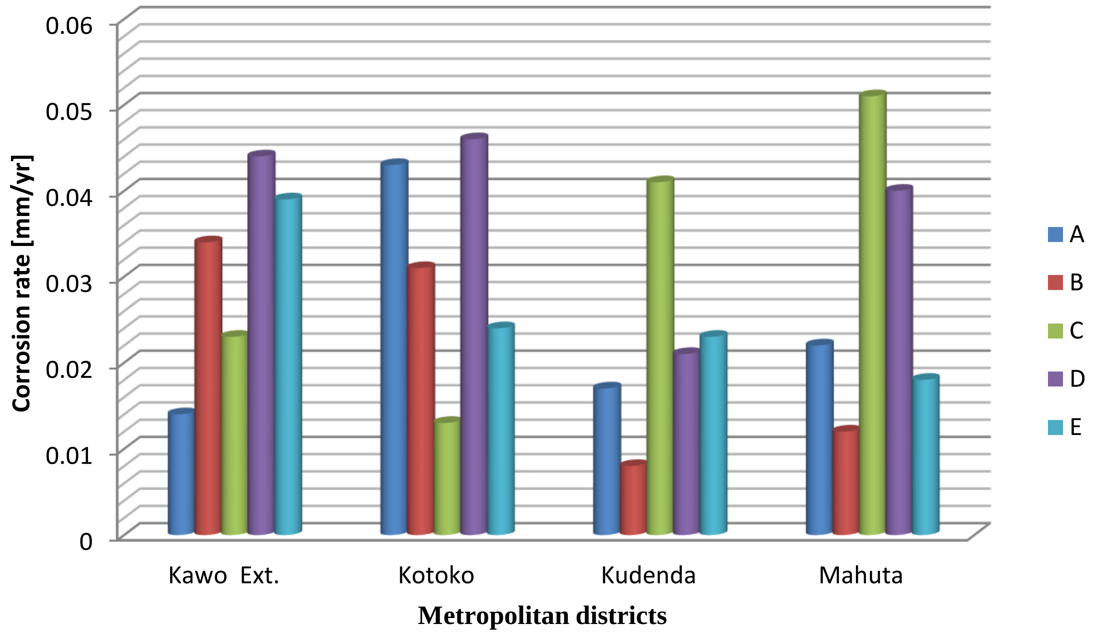

Fig 8: Corrosion rates for Kawo Extension, Kotoko, Kudenda, and Mahuta districts

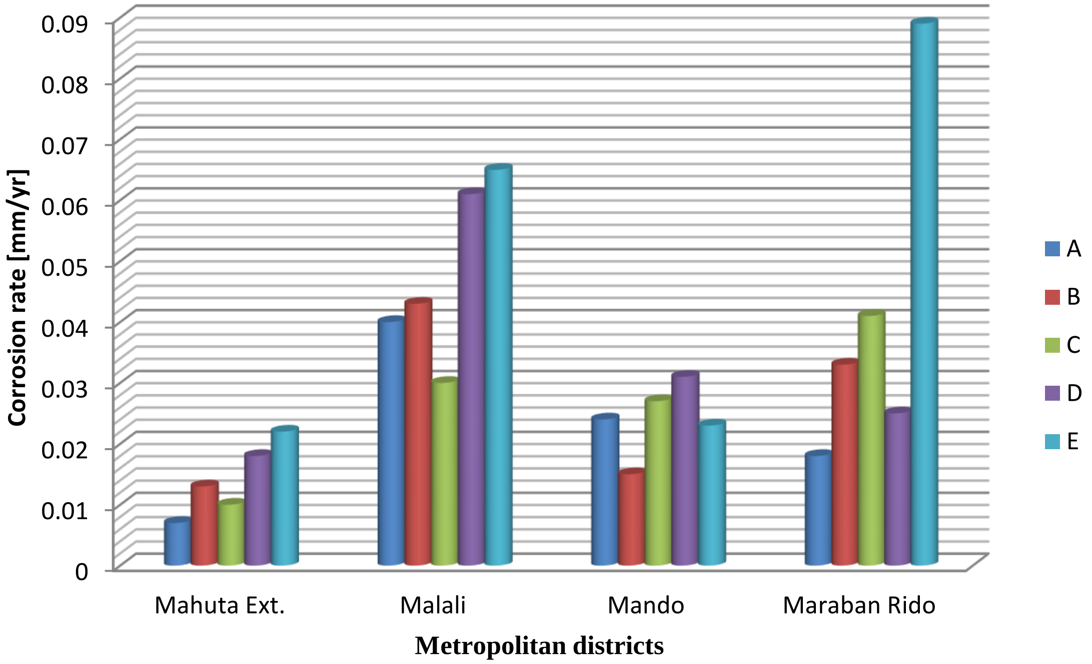

Fig 9: Corrosion rates for Mahuta Extension, Malali, Mando, and Maraban Rido districts

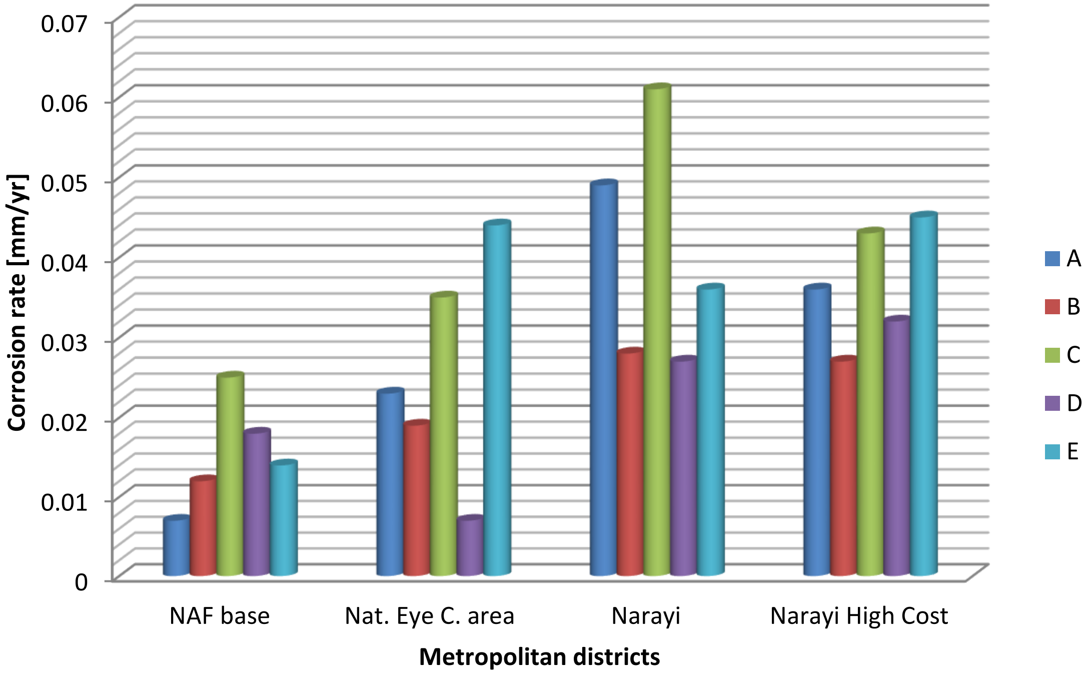

Fig 10: Corrosion rates for NAF base, National Eye Centre, Narayi, and Narayi High Cost districts

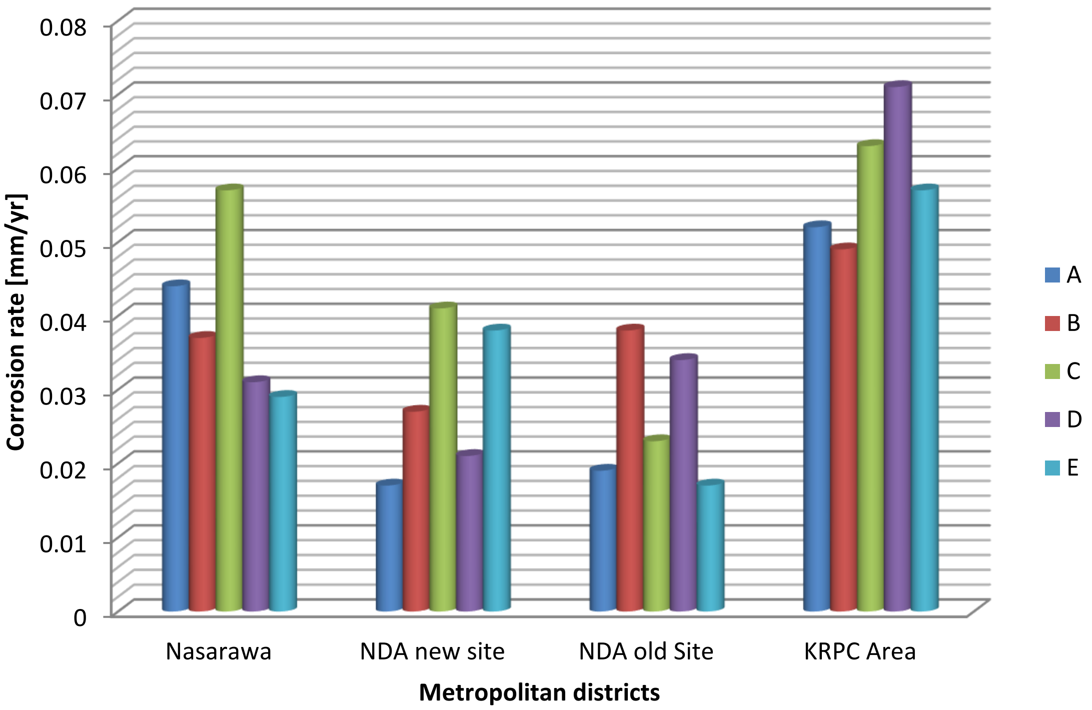

Fig 11: Corrosion rates for Nasarawa, NDA new and old sites, and KRPC area districts

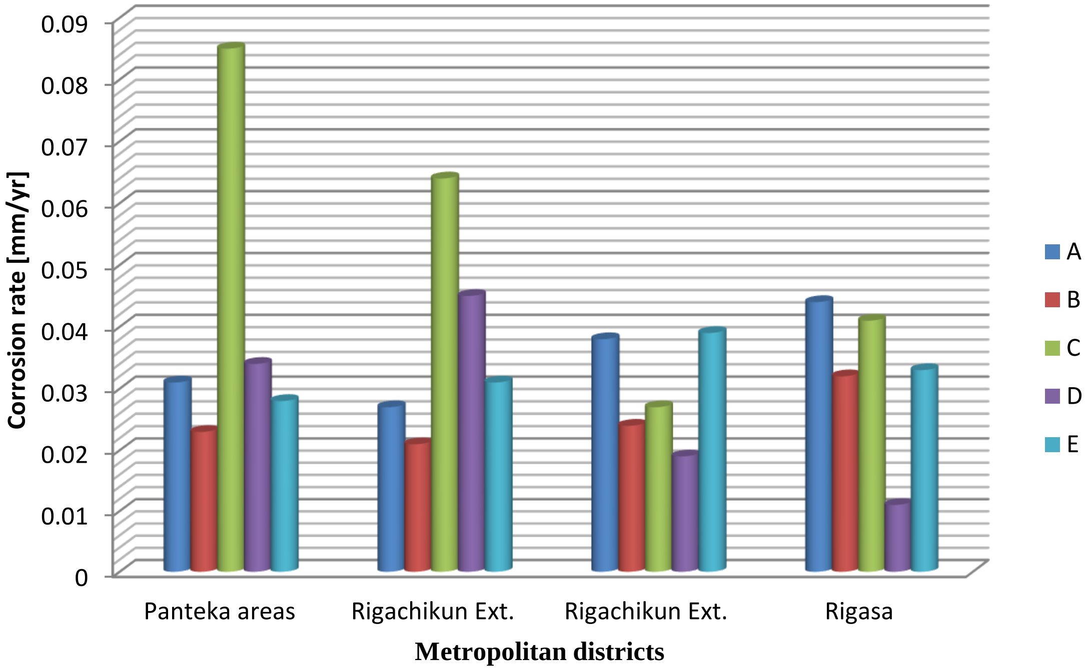

Fig 12: Corrosion rates for Panteka, Rigachikun, Rigachikun Extension, and Rigasa districts

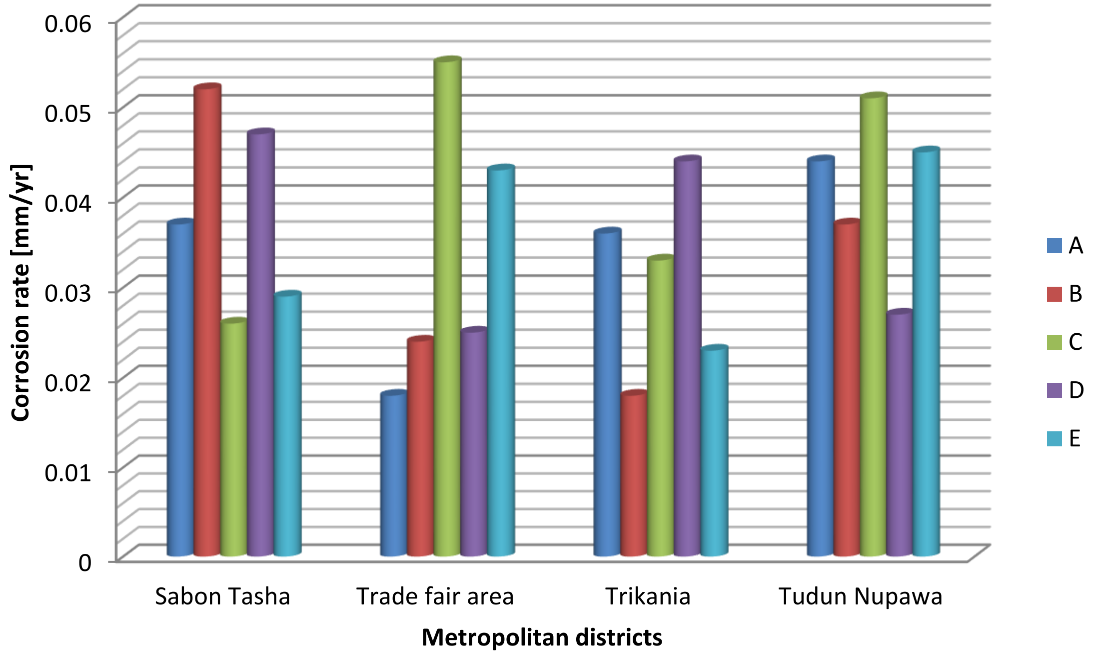

Fig 13: Corrosion rates for Sabon Tasha, Trade fair area, Trikania, and Tudun Nupawa districts

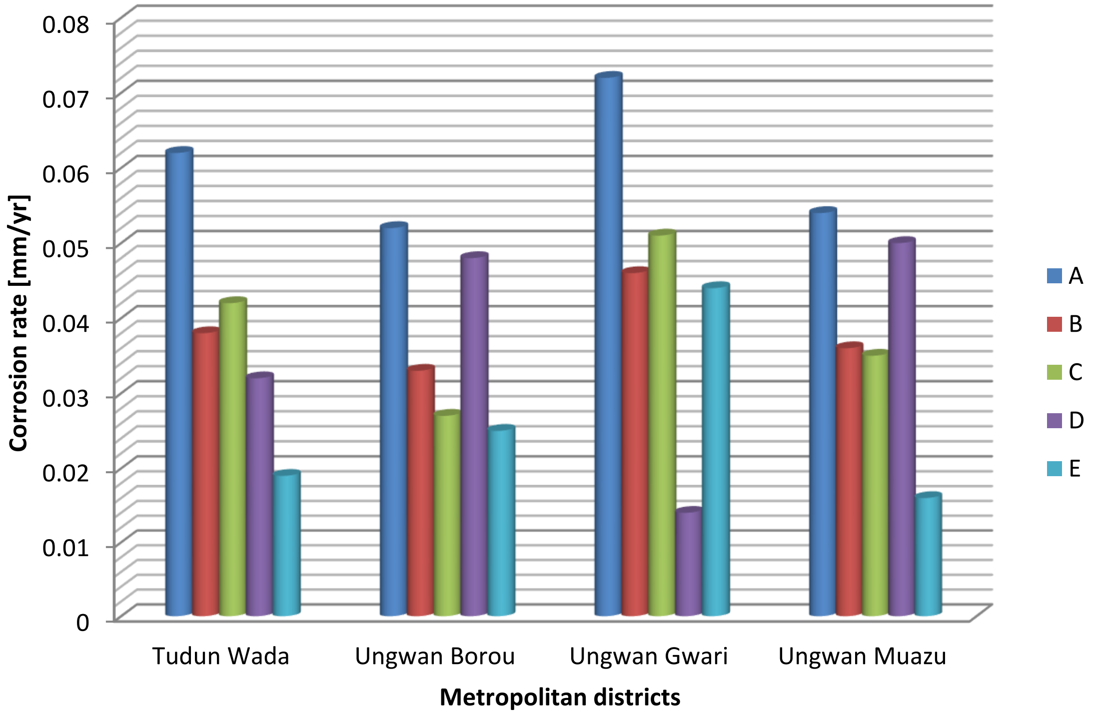

Fig 14: Corrosion rates for Tudun Wada, Ungwan Borou, Ungwan Gwari, and Ungwan Muazu districts

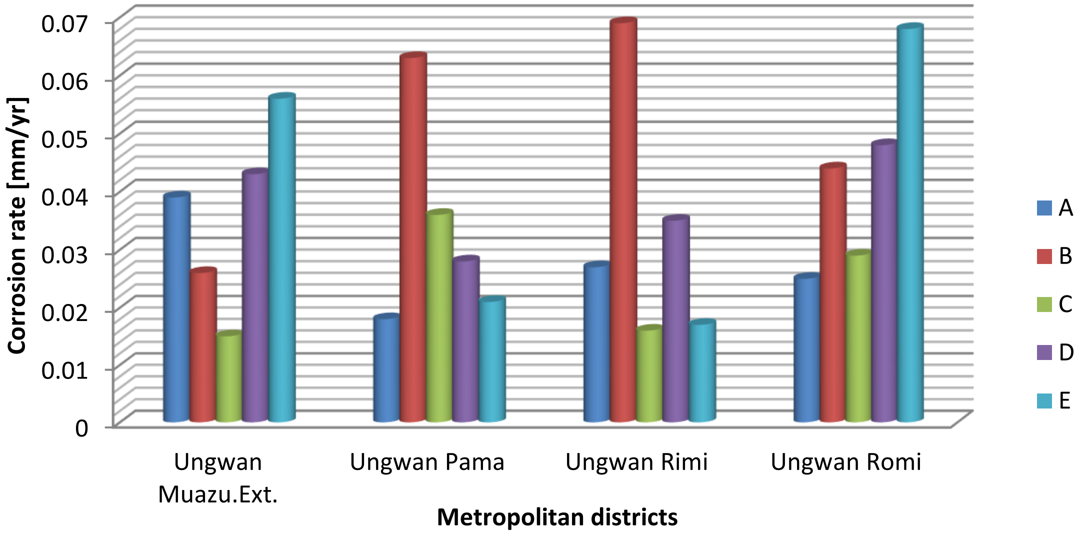

Fig 15: Corrosion rates for Unwan Muazu Extension, Ungwan Pama, Ungwan Rimi, and Ungwan Romi districts

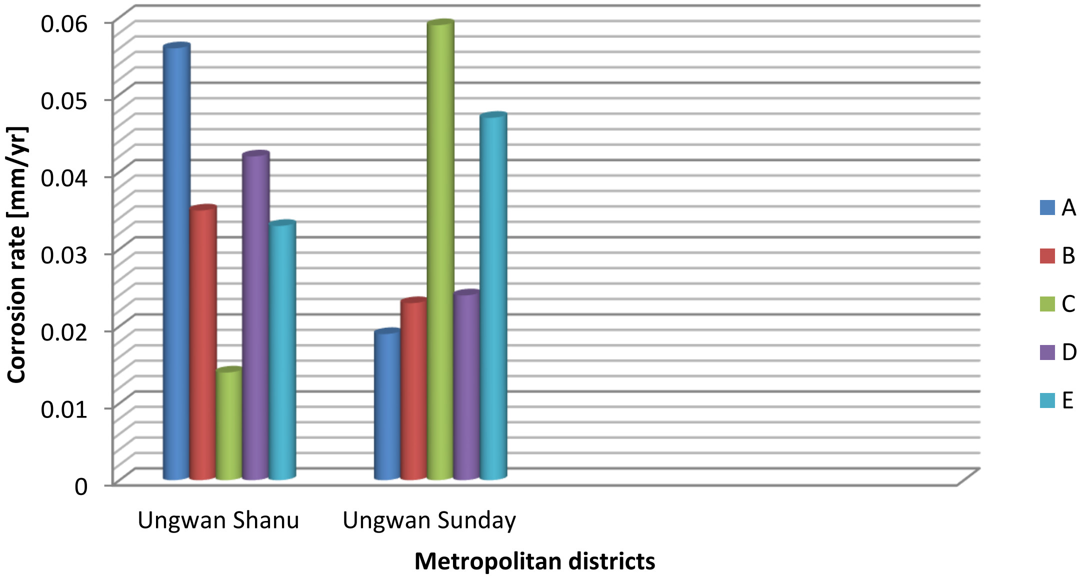

Fig 16: Corrosion rates for Ungwan Shanu and Ungwan Sunday districts

B. Discussion

From theresults 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 rangedfrom 0.007 at Mahuta Ext district to 0.092mm/yrat BarkinRuwa district witha range of 0.085mm/yr, overall mean of 0.0341mm/yr, the standard deviation of 0.015mm/yr and coefficient of variation 44%. The relative corrosion resistance 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 atmosphericcorrosivity categorization of carbon steel[26]

Category	Corrosivity	Corrosion rate [μm/yr]
C1	Very low	Vcorr ≤ 1.3
C2	Low	1.3 <Vcorr ≤ 25
C3	Medium	25 <Vcorr ≤ 50
C4	High	50 <Vcorr ≤ 80
C5	Very high	80 <Vcorr ≤ 200

Judging the presented information in Fig.1-16 with the preceding literature information onmetals' environmental corrosivity ratings, particularly atmospheric corrosivity categorization ofcarbon 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 the 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 ofatmospheric 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 United Kingdom rates 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. For example, in Khartoum Sudan's driest atmospheres, the rate can be as low as 0.003 mm/yr [18, 27]. Corrosion rates (mm/year) for mild steel obtained bythe British Iron and Steel Research Institute [26] for some inland industrial environments were;Motherwell (0.095), Woolwich (0.102),Sheffield (0.135),Frodingham (0.160), Derby (0.170) in Britain; and Pittsburgh, Pa (0.108) in the United States 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] arefrom 4 to 60, 30 to 70, 40 to 60, and 60 to 170 μm/yr, respectively. From there, the average atmospheric corrosion rate of the study's mild steel couponsin Kaduna metropolis falls within rates for the less corrosive rural land 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 are well understood in typical atmospheric conditions. Still, 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. Some environmentalpeculiarities that werethought could make the atmosphere around it not perfectly dry and unpolluted for metallic corrosion to progress therein at an extremely low rate and be ignored for practical purposes. Atmospheric micro conditions were seen to be capable of affecting corrosion of a large quantity of steel, which finds applications in Kaduna metropolis as structural components or parts in automobiles, aircraft, train structures, railways, types of machinery, steelworks, water tanks, industrial and domestic buildings, fluid transmission systems, bridges, etc. with attendant consequences.This study's preliminary surveyshowed a lack of practicable, public information from research outputs on the city metropolitan atmosphere's precise corrosivity level 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 out-door atmospheric locations of themetropolis 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 thatcorrosion rates of the steel in the metropolitan atmospherevary randomly from 0.007 to 0.092mm/yr with an overall mean of 0.0341mm/yr, the standard deviation of 0.015mm/yr, and coefficient of variation 44% and is influenced by location variablesthat determine the level of pollution around.Analysis of the results vis-à-vis isgenerally knownaverage 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.

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