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# Evaluating the Impact of Renewable Energy Integration on Air Quality: A Study of Pollutant Reduction in an Urban city of Calabar

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The characterization of air quality parameters was carried out in the coastal city of Calabar with the aim of reducing air pollutants in the atmosphere. Both mobile and stationary measurements were obtained. Mobile data were used for estimating air quality index and creating air quality map. The results show that the average concentration of ozone ($O_3$), carbon monoxide (CO), sulfur dioxide ($SO_2$) and nitrogen Oxides ($NO_x$) was 0.34, 4.52, 0.53 and 0.96 ppm, respectively. The air quality index determined for each station showed that 82% of the stations were classified as "marginally polluted," 14% were classified as "good," and the remaining 4% were classified as "unhealthy" according to the U.S. air quality standards. Correlation analysis showed that wind speed had the highest correlation with $SO_2$, R = -0.72, while temperature had a high correlation with ozone, R = -0.68. The 2016 polar plots show that CO sources are located in the south and southeast, $NO_x$ sources are located in the south and southwest, $SO_2$ sources are located in the southwest, and $O_3$ sources are located in the southeast. The 2017 polar plots show that CO sources are located in the northeast, $NO_x$ sources are located in the northwest, $SO_2$ sources are located in the northeast, and $O_3$ sources are located in the southwest.

*Keywords: Carbon monoxide; Ozone; Atmosphere; Air quality; Good*

## Introduction

One of the most important environmental problems facing the world today is air pollution. Due to its harmful effects, including decreased quality of life and altered characteristics of the biosphere, governments and international organizations are forced to invest financial and human resources to improve air quality in order to protect the biosphere [1]. The accelerated pace of urban construction and the resulting urbanization process have put tremendous pressure on the atmosphere. Air pollution is one of the results of this process, causing health concerns, especially fine particulate matter ($PM_{2.5}$) [2]. $PM_{2.5}$ is the specific material that has an aerodynamic diameter of smaller than 2.5 μm and is harmful to human health in addition to reducing air visibility. Fine particulate matter ($PM_{2.5}$) affects more people than any other pollutant, and it is repeatedly associated with mortality and morbidity from respiratory and cardiovascular diseases. Over the past decade, epidemiological data have linked $PM_{2.5}$ to a host of other health

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problems, including neurological diseases (such as stroke, dementia, Alzheimer's disease, autism, and Parkinson's disease), perinatal outcomes (such as premature birth and low birth weight), and cardio-metabolic diseases (such as diabetes, hypertension, and metabolic syndrome) [3].

One of the main challenges in addressing air pollution and its impact on air quality is the lack of adequate monitoring stations, especially in developing countries. Many developed countries have established comprehensive air quality monitoring networks that can accurately measure and report pollutant concentrations. However, this is not the case in many developing countries where monitoring infrastructure and resources are limited [4]. Air pollution levels depend largely on emission sources and meteorological conditions. If regional atmospheric emissions are relatively stable over a period of time, meteorological conditions may be the determining factor in the occurrence of air pollution [5]. The local and synoptic weather conditions that are in effect at the moment are crucial. Determining the relationships between air quality and meteorology is essential and can assist policymakers in creating environmental policies that will enhance people's quality of life [1]. Several authors have studied on the impact of meteorology on particulate matter [6]. Their research results conducted in South Korea showed that the generation, movement, and deposition of air pollutants were significantly influenced by meteorological factors. $PM_{10}$ levels peaked in April, while $PM_{2.5}$ levels peaked in January. Both were at their lowest in July. Among them, the $PM_{2.5}$ concentration was highest in winter, followed by spring, autumn and summer; the $PM_{10}$ concentration was highest in spring, followed by winter, autumn and summer. Particulate Matter (PM) concentration was negatively correlated with temperature, relative humidity and precipitation. Air quality was inversely correlated with wind speed, while PM was positively correlated with the zonal wind component and negatively correlated with the vertical wind component.

Rahaman *et al.* [7] carried out a research in Ankara, Turkey. The results showed that climate (temperature, humidity, air pressure, rainfall, etc.) and environmental factors (particulate matter, CO, NO and $NO_x$ in the air) had an impact on the number of patients admitted to hospital for pneumonia. The impacts of air pollution on human health include cancer and tuberculosis [8].

The aim of this research is to characterize the air quality parameters in Calabar, a city in the Niger Delta, Nigeria. This research addresses the composition of air pollution through extensive air quality monitoring in the Calabar region of Nigeria. This is intended to be achieved by monitoring gaseous pollutants over a period of twenty-four (24) months. The objectives of this study include:

1. to develop of an air quality map for Calabar.
2. to establish any relationship between pollutants and meteorological parameters.
3. to trace the source and sink of these pollutants.
4. to establish the best air quality forecasting model.
5. to determine air quality trend.
6. to determine air quality health impact and risk assessment.

## Methodology

### Materials and Methods

The gas components were measured using an Aeroqual series 500- ENV gas analyzer (Gas-Sensing, Inwood, IA, USA) with gas sensor heads of Aeroqual $SO_2$ (0-10 ppm, model 1905152-006), Aeroqual $O_3$ (0-10 ppm, model 1407150-003), Aeroqual CO (0-100 ppm, model 0807155-004), and Aeroqual $NO_2$ (0-1 ppm model, 2906150-003). Met One Instruments Aerocet 531S Mass Monitor/Particle Counter (Grants Pass, OR, USA) was used to measuring particulate matter (PM 2.5 and PM 10).

To operate the Aeroqual gas analyzer, each gas head is inserted on the top of the main gas analyzer and then takes three minutes to warm up. After a three-minute warm-up period, the values for the specific gas measured at the specific investigation location are displayed on the gas analyzer. The values are displayed in units of part per billion (ppb), part per million (ppm) or $\mu g/m^3$ depending on the settings. For this project, the values of the gases are presented in ppb or in ppm. These measurements were taken from site to site throughout the project. The coordinates and elevation of the different stations were obtained using Garmin Etrex 20 GPS. The map of the study location is shown in Figure 1.

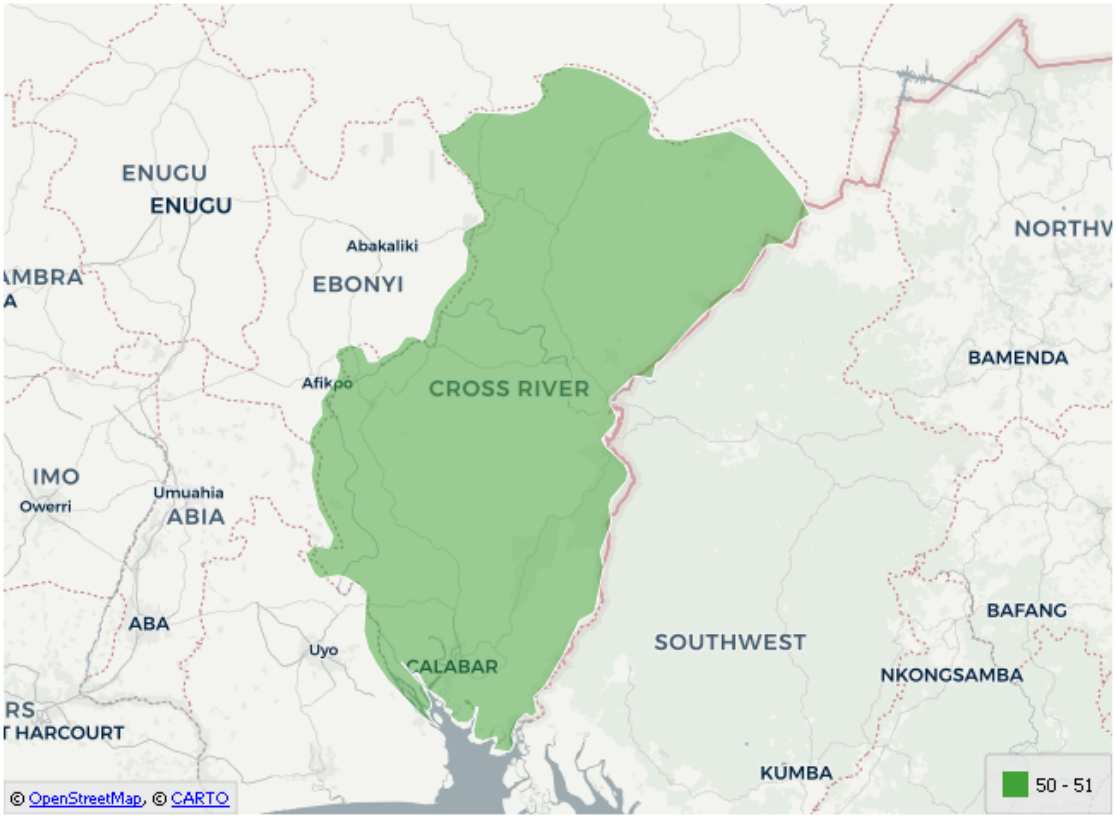


**Fig. 1.** Map of study location

Finally, a compass was used in determining the direction of the wind at all the locations of the project. This is a project sponsored by the Tertiary Education Trust Fund (TETFUND). Therefore, the equipment was procured using funds provided by the Fund. Study locations are shown on Table 1. The equipment shown in Figure 2 were used to obtain air quality data. Meteorological parameters at different locations of interest were

measured using an Extech 45170 4-in-1 Environmental Meter (Teledyne FLIR, Wilsonville, OR, USA). The device does not require preheating. It measures different parameters such as wind speed, relative humidity, air temperature and lux and shows the values on a display.

The data for this study are divided into two parts. The first part is from a mobile Aeroqual handheld device and the second part is from a stationary AQM65 device located at the Geoenvironmental Station of the University of Calabar. The data from the mobile devices were obtained at specific time intervals and on specific dates. The data were collected on 23/05/2015, 06/06/2016, 20/06/2016, 04/07/2016, 18/07/2016, 1/08/2016, 15/08/2016 and 29/08/2016. On the other hand, the AQM65 stationary device was programmed by the company to record data at minute intervals. The machine could also be re-programmed to record data at hourly intervals. For the purpose of this study, data were acquired at minute intervals. The data from both devices were presented as monthly means. The pollutant data obtained from the mobile devices in this research were: Nitrogen dioxide ($NO_2$), Ozone ($O_3$), Carbon monoxide (CO), Sulfur dioxide ($SO_2$), Carbon dioxide ($CO_2$), The pollutant data obtained from the stationary AQM65 machine were: Nitrogen oxides ($NO_x$) which is a combination of Nitrogen oxide (NO) and Nitrogen dioxide ($NO_2$), Ozone ($O_3$), Carbon monoxide (CO) and sulfur dioxide ($SO_2$). The meteorological parameters obtained for the research were: wind speed (WS), wind direction (WD), temperature (TEMP) and relative humidity (RH). Table 1 shows all the selected locations for this study. AQ1 to AQ50 are the selected locations. Each selected site was given a unique identifier to simplify the research process. The table consists of the sample point, latitude, longitude and elevation of the selected locations.

Visualizations were done using R programming language and tableau software. The correlation analysis was done using R programming language. Trend analysis is done using the Mann-Kendall trend test. The openair package in R has also been used.

**Table 1. Study locations**

| S/N | SAMPLE POINT | LOCATIONS | LATITUDE | LONGITUDE | ELEVATION (m) |
|---|---|---|---|---|---|
| 1 | AQ1 | CRUTECH GATE ROUND ABOUT | 4°55’53.1’’ | 8°19’42.0’’ | 26 |
| 2 | AQ2 | NEW AIRPORT BY ESSIEN ST. | 4°55’37.1’’ | 8°19’25.5’’ | 18 |
| 3 | AQ3 | ABITU BY POULTRY FARM | 4°55’26.4’’ | 8°19’19.7’’ | 15 |
| 4 | AQ4 | ANATIGHA BY THE APOSTOLIC CHURCH | 4°55’04.2’’ | 8°19’16.0’’ | 14 |
| 5 | AQ5 | IBESIKPO BY IMAN PRISON | 4°55’47.8’’ | 8°18’43.1’’ | 16 |
| 6 | AQ6 | AMBO MARKET ROUND ABOUT | 4°56’15.2’’ | 8°19’0.2’’ | 43 |
| 7 | AQ7 | EYO ITA BY EDIBE EDIBE | 4°56’39.0’’ | 8°18’46.4’’ | 40 |
| 8 | AQ8 | HENSHAW TOWN BY CHAMBLY CALABAR RD. | 4°57’02.3’’ | 8°18’59.9’’ | 43 |
| 9 | AQ9 | WHITE HOUSE BY CHAMBLY | 4°57’07.4’’ | 8°19’13.5’’ | 39 |
| 10 | AQ10 | MAYNE AVENUE BY WHITE HOUSE | 4°56’30.9’’ | 8°19’18.3’’ | 33 |
| 11 | AQ11 | INYANG BY AFOKANG | 4°56’14.0’’ | 8°19’15.9’’ | 34 |

| | | | | | |
|---|---|---|---|---|---|
| 12 | AQ12 | YELLOW DUKE BY EKPOABASI | 4°56'10.2'' | 8°19'32.0'' | 30 |
| 13 | AQ13 | YELLOW DUKE BY MBUSAHA | 4°56'08.5'' | 8°19'44.5'' | 28 |
| 14 | AQ14 | ATAMUNU BY MOUNT ZION | 4°56'23.5'' | 8°19'44.5'' | 22 |
| 15 | AQ15 | MOUNT ZION BY OROK OROK | 4°56'38.8'' | 8°20'19.6'' | 44 |
| 16 | AQ16 | UWANSE END OF STREET | 4°56'17.3'' | 8°20'26.8'' | 26 |
| 17 | AQ17 | MAYNE AVENUE BY GOLDIE | 4°57'02.8'' | 8°19'58.6'' | 48 |
| 18 | AQ18 | MAYNE AVENUE BY ADAM DUKE | 4°56'49.2'' | 8°19'45.9'' | 33 |
| 19 | AQ19 | TARGET BY PALM STREET | 4°47'10.4'' | 8°19'21.6'' | 52 |
| 20 | AQ20 | GOLDIE BY TARGET | 4°57'17.8'' | 8°19'40.8'' | 31 |
| 21 | AQ21 | UNICAL MAIN STATION POINT | 4°57'07.78'' | 8° 20' 51'' | 62 |
| 22 | AQ22 | MARY SLESSOR ROUND ABOUT | 4°58'35.46'' | 8°19'57.15'' | 65.45 |
| 23 | AQ23 | IKA IKA OKUWA MARKET | 4°58'35.46'' | 8°20'26.28'' | 83 |
| 24 | AQ24 | EFIO ETTE ROUND ABOUT | 4°59'36.89'' | 8°20'42.28'' | 74.2 |
| 25 | AQ25 | IKOT EFA BY NDIDEN ISO PARLIAMENTARY | 5°00'12.88'' | 8°20'44.90'' | 84 |
| 26 | AQ26 | GOOD LUCK JOHNATHAN BY PASS OVERHEAD BRIDGE | 5° 01'13.77'' | 8°15'57.87'' | 56 |
| 27 | AQ27 | DESTINATION CROSS RIVER ROUND ABOUT BY BASIN AUTHORITY | 5°02'43.35'' | 8°21'26.58'' | 93 |
| 28 | AQ28 | ARMY JUNCTION BY WELCOME TO CALABAR | 5° 02'04.36'' | 8°28'01.06'' | 102 |
| 29 | AQ29 | SPC JUNCTION BY EPZ JUNCTION | 5°01'13.55'' | 8°20'00.43'' | 95 |
| 30 | AQ30 | EPZ TANK FARM | 5°01'08.1'' | 8°19'20'' | 53 |
| 31 | AQ31 | NNPC TANK FARM | 5°01'01.12' | 8°19'29.3'' | 61 |
| 32 | AQ32 | ISHIE TOWN BY JOHNSON/ISHIE MARKET | 4°59'51.4'' | 8°20'20.2'' | 71 |
| 33 | AQ33 | ESSIEN TOWN JUNCTON BY HIGHWAY | 4°59'22.08'' | 8°19'59.57'' | 69 |
| 34 | AQ34 | MARINA RESORT | 4°57'55.4'' | 8°19'05.5'' | 20 |
| 35 | AQ35 | NEW SECRETERIATE CALABAR | 4°58'51.23'' | 8°19'53.96'' | 65 |
| 36 | AQ36 | IBB BY STADIUM TRAFFIC LIGHT | 5°49'70.9'' | 8°20'54.76'' | 69 |
| 37 | AQ37 | ATAKPA POLICE STATION BY TRAFFIC LIGHT | 4°57'34.0'' | 8°19'17.7'' | 54 |
| 38 | AQ38 | IBB ROUND ABOUT BY RABANA | 4°57'46.93'' | 8°20'10.41'' | 71 |
| 39 | AQ39 | AIR PORT BY POLICE STATION | 4°57'56.9'' | 8°20'59.6'' | 52 |

| | | | | | |
|---|---|---|---|---|---|
| 40 | AQ40 | IBB BY ATIMBO ROUND ABOUT, CALABAR | 4°58'22.4'' | 8°20'10.41'' | 71 |
| 41 | AQ41 | AKPABUYO BY BIG QUA RIVER | 4°56'53.0'' | 8°23'46.2'' | 18 |
| 42 | AQ42 | AKPABUYO LOCAL GOVERNMENT HQ. | 4°52'58.8'' | 8°28'50.4'' | 53 |
| 43 | AQ43 | MCC BY GOOD LUCK BY PASS | 4°00'35.76'' | 8°22'00.53'' | 31 |
| 44 | AQ44 | UNICEM FACTORY SITE | 5°04'05.9'' | 8°30'44.9'' | 28 |
| 45 | AQ45 | LEMNA DUMP SITE | 5°01'59.7'' | 8°21'54.8'' | 27 |
| 46 | AQ46 | 8 MILES BY AGRO FEED | 4°03'22.4'' | 8°21'16.6'' | 70 |
| 47 | AQ47 | TINAPA JUNCTION | 5°04'09.6'' | 8°20'59.9'' | 65 |
| 48 | AQ48 | TINAPA BUSSINESS RESORT | 5°02'54.3'' | 8°18'58.8'' | 31 |
| 49 | AQ49 | RUBER ESTATE HIGHWAY | 5°05'59.3'' | 8°20'36.3'' | 57 |
| 50 | AQ50 | ODUKPANI JUNCTION | 5°09'19.00'' | 8°20'45.7'' | 31 |


**Fig. 2.** AQM65 equipment and Aeroqual had held equipment

The Mann-Kendall Z-statistic

$$Z_{mk} = \frac{S-1}{\sqrt{VAR(S)}} \; if \; S > 0 \qquad \text{Eq. 1}$$

$$Z_{mk} = 0 \text{ if } S = 0 \qquad \text{Eq. 2}$$

$$Z_{mk} = \frac{S+1}{\sqrt{VAR(S)}} \; if \; S < 0 \qquad \text{Eq. 3}$$

where $VAR(S) = \frac{1}{18}[n(n-1)(2n+5) - \sum_{p-1}^{g} t_p(t_p - 1)(2t_p + 5)$ Eq. 4

The Mann-Kendall test has been used to analyze trends across different fields. For example, it was used to analyze the variations of ambient temperature [9], long-term

trend and seasonality detection of the observed flow in Yangtze River [10], and air quality trends [11].

## Sen's Slope Estimator

If a time series has a linear trend, a simple nonparametric approach devised by Sen can be used to estimate the true slope (change per unit time). As a result, the linear model f (t) can be written as:

$$f(t) = Qt + B \quad \text{Eq. 5}$$

where Q denotes the slope and B denotes the constant.

The slopes of all data pairs are calculated to produce an estimate of the slope Q:

$$Q_i = \frac{X_j - X_k}{j-k}, i = 1, 2 \ldots N, j > k \quad \text{Eq. 6}$$

The Sen's estimator is used to rank the N values of $Q_i$ from the smallest to the largest:

$$Q = \begin{cases} Q_{\frac{n+1}{2}} \; if \; N \; is \; odd \\ \frac{1}{2}\left(Q_{\frac{N}{2}} + Q_{\frac{N+2}{2}}\right) if \; N \; is \; even \end{cases} \quad \text{Eq. 7}$$

The sign of Q indicates whether the data is trending upward or downward, and the number indicates how steep the trend is [12].

## Calculating Air Quality Index (AQI)

Let's say there are n air quality parameters $P_i$ (i= 1, 2, 3...n) that must be considered when computing the AQI. Let $V_i$ be the observed values of the $i^{th}$ parameter in ambient air, and $V_{si}$ denotes the suggested standard value for this parameter. Then

$$Q_i = 100 * \frac{V_i}{V_{si}} \quad \text{Eq. 8}$$

gives the quality rating $Q_i$ for this attribute. If $Q_i$ is greater than 100, the given parameter is inside the prescribed range. On the other hand, if $Q_i > 100$, it means that the $i^{th}$ parameter exceeds the prescribed standard and that the ambient air is unsafe for humans to breathe. Because all of the indicators are believed to be of equal importance, only the unweighted air quality indices are calculated.

$$\text{GM} = (Q_i) * \frac{1}{n} \quad \text{Eq. 9}$$

$$\text{AQI} = \text{Antilog } \left(\frac{\sum log Q_i}{n}\right) \quad \text{Eq. 10}$$

The Ambient AQI can be calculated using Eqs. 9 and 10.

## AQI based on the Individual Pollutants and Categorization of AQI

Equation 11 was used to determine the AQI for the four contaminants. This equation is used to calculate the AQI for a location based on the measured concentrations of specific pollutants. The AQI calculated based on pollutants is $I_p$, while $C_p$ is the pollutant concentration rounded to the nearest decimal place. BPHi is a breakpoint that is larger than or equal to the pollutants' rounded concentration. BPLo is the breakpoint that is less than or equal to the pollutant $C_p$'s rounded concentration. The AQI value that corresponds to BPHi is IHi. The AQI value that correlates to BPLo is ILo. The calculated value was based on the measured concentrations of the four contaminants. AQI is categorized based on Table 2. The Air Quality Index (AQI) was developed using breakpoints given by the United States Environmental Protection Agency (USEPA) in

2006. To illustrate the AQI for each position, the average of the AQI for each point was determined as:

$$Ip = \frac{IHi - ILo}{BPHi - BPLo}(Cp - BPLo) + Lo \quad 11$$

where IP is the pollutant P index, and $C_p$ denotes the pollutant P's rounded concentration.

**TABLE 2.** AQI Categorization Table

| Category | AQI | Description of Ambient Air |
|---|---|---|
| I | 0-50 | Good |
| II | 51-100 | Marginally polluted |
| III | 101- 200 | Unhealthy |
| IV | 201-300 | Very unhealthy |
| V | >300 | Hazardous |

## Results and Discussion

### Concentration of Pollutants

The average concentration of pollutants is presented in Table 3. A quick inspection of the Table shows that the highest concentration of ozone ($O_3$) was obtained in December with a concentration of 0.031 ppm, which is lower than the World Health Organization standard annual average value of 0.1 ppm. The lowest concentration value was obtained in March with a concentration value of 0.01 ppm. The high ozone concentration in December may be because ozone concentration increases with increasing solar radiation, and December is the peak of the dry season in Calabar, accompanied by strong solar radiation.

The highest concentration of carbon monoxide (CO) was obtained in August with a concentration of 9.876 ppm which is higher than the Nigerian national standard annual average value of 4.05 ppm. The lowest concentration value was obtained in March with a concentration value of 1.141 ppm. August is the peak of the rainy season in Nigeria. During this period, many people tend to stay indoors. This prompts the use of gasoline generators to keep them occupied. More private cars also ply the roads during this period. This could explain the slightly higher CO concentrations during this period.

The highest concentration of sulfur dioxide ($SO_2$) was obtained in August with a concentration of 0.017 ppm which is lower than the Nigerian national standard annual average value of 0.08 ppm. The lowest concentration value was obtained in February and march with a concentration value of 0.01 ppm. It could also be observed that there is no marked difference in the average concentration of $SO_2$ from January to December. The highest concentration of Nitrogen Oxides ($NO_x$) was obtained in October with a concentration of 0.005 ppm which is lower than the Nigerian national standard annual average value of 0.08 ppm. $NO_x$ concentrations were lower from March to August, ranging from 0.02 to 0.013 ppm.

Figure 3 shows a correlogram of pollutants with the meteorological parameters used for this study. It can be seen from the figure that the correlation coefficient between CO and temperature is the highest, R = -0.81, and the correlation coefficient with ozone is the lowest, R = 0.11. This shows that temperature had an effect on CO of about 81% compared to other variables, albeit in a negative manner. $SO_2$ had the lowest correlation coefficient R of 0.36 with ozone. $O_3$ had the highest correlation coefficient R = -0.43 with temperature, while it had the lowest correlation coefficient R = 0.11 with CO. $NO_x$ had

the highest correlation coefficient R = -0.67 with CO, while it had the lowest correlation coefficient R = 0.17 with wind speed. This shows that $NO_x$ had about 67% impact on CO compared with the other variables though negatively. The correlation coefficients presented in the correlogram of Figure 3 do not vividly reflect the monthly relationship between this pollutant and meteorological conditions.

**Table 3.** Monthly average concentration of pollutants

| Month | $O_3$ (ppm) | CO (ppm) | $SO_2$ (ppm) | $NO_x$ (ppm) | WS (m/s) | TEMP (°C) | RH |
|---|---|---|---|---|---|---|---|
| Jan. | 0.013 | 1.218 | 0.008 | 0.004 | 0.695 | 30.237 | 66.445 |
| Feb. | 0.014 | 3.01 | 0.01 | 0.004 | 0.746 | 30.609 | 68.539 |
| Mar. | 0.01 | 1.141 | 0.01 | 0.003 | 0.762 | 30.071 | 73.073 |
| Apr. | 0.015 | 5.141 | 0.014 | 0.002 | 0.696 | 29.376 | 77.403 |
| May. | 0.02 | 5.643 | 0.016 | 0.003 | 0.637 | 29.02 | 77.712 |
| Jun. | 0.027 | 5.78 | 0.014 | 0.002 | 0.628 | 28.197 | 80.959 |
| Jul. | 0.014 | 5.831 | 0.02 | 0.002 | 0.583 | 27.666 | 83.312 |
| Aug. | 0.015 | 9.876 | 0.017 | 0.002 | 0.6 | 27.781 | 82.754 |
| Sep. | 0.022 | 7 | 0.015 | 0.003 | 0.612 | 28.512 | 80.173 |
| Oct. | 0.022 | 2.776 | 0.015 | 0.005 | 0.641 | 29.159 | 76.303 |
| Nov. | 0.027 | 2.993 | 0.015 | 0.004 | 0.593 | 29.117 | 79.162 |
| Dec. | 0.031 | 3.812 | 0.016 | 0.004 | 0.61 | 29.656 | 73.894 |

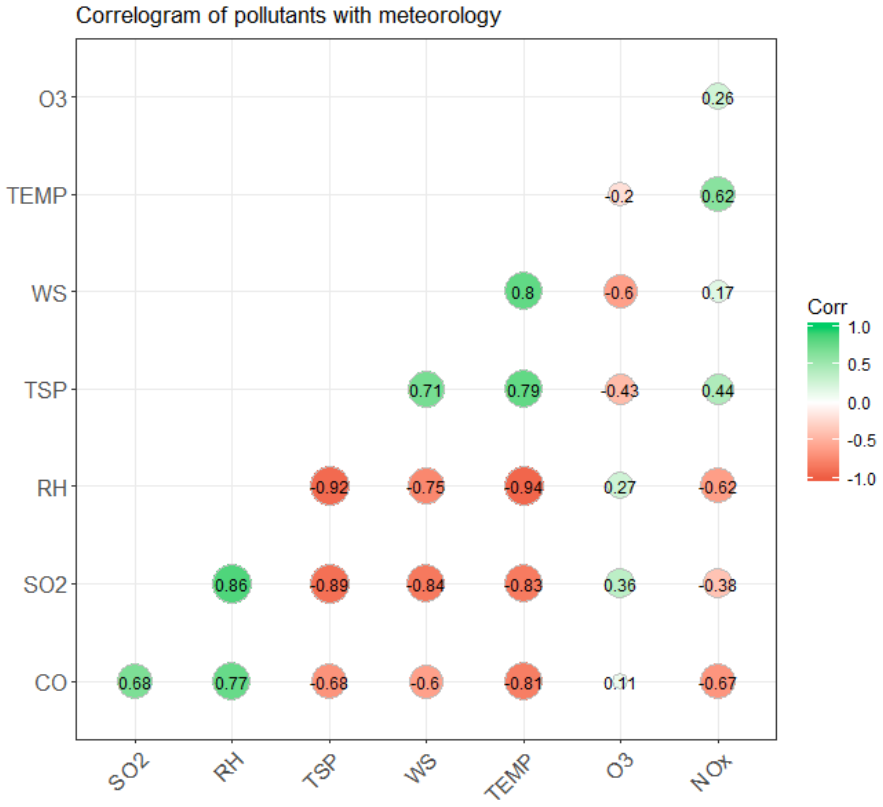


**Fig. 3.** Correlogram of pollutants with meteorology

## Air Quality Index

The AQI values for the city of Calabar were obtained using data recorded by the mobile Aeroqual gas modules. Table 4 shows AQI breakpoints, while Tables 5 and 6 show AQI standards. In these tables, the following pollutants are represented: particulate matter with diameter less or equal to 2.5 micrometer per meter square (PM2.5), particulate matter with diameter less or equal to 10 micrometer per meter square (PM10), sulfur dioxide ($SO_2$), nitrogen dioxide ($NO_2$), carbon monoxide (CO), ammonia ($NH_3$) and total suspended particulate matter (TSP). NIL in Table 4 means that no standard was available for that contaminant at the time of publication. Table 7 shows the AQI for the fifty (50) locations selected for this research. A close examination of Table 7 reveals that 82% of the stations were categorized as "marginally polluted", which belong to the group (51-100). It can also be seen that 14% of the stations were categorized as "Good", while the remaining 4% of the stations were categorized as "unhealthy". An air quality map has been developed based on this Table and is presented in Figure 4. This air quality map was developed based on the AQI values. Based on this map, the stations with the green dots represent the stations categorized as "good", those with light green colored dot are categorized as "marginally polluted", the stations with the red colored dots represent the "unhealthy category", and the dark green dotted stations are categorized as "critical". According to the results of this research, it can be concluded that the city of Calabar is marginally polluted with average AQI values between 51 – 100. AQI values were also obtained based on the data obtained from the stationary AQM65 machine stationed at the University of Calabar main station. The AQI valued obtained are presented in Table 8. It's found that these AQI values were all categorized as "marginally polluted" throughout the period of study. The difference between the values obtained from the mobile equipment and that obtained from the stationary equipment could be due to the fact that the mobile equipment were held close to the ground during data taking, while the stationary AQM65 stationary equipment is mounted at an elevation of 10 m. Figure 5 shows a plot of AQI as it varies throughout the period of study. The highest AQI was recorded in December 2015 and the lowest in March 2017.

**Table 4.** Breakpoint for different pollutants

| $O_3$ (ppm) 8-hour | $O_3$ (ppm) 1-hour | $PM_{2.5}$ ($\mu g/m^3$) | $PM_{10}$ ($\mu g/m^3$) | CO (ppm) | $SO_2$ (ppm) | $NO_2$ (ppm) | AQI | Category |
|---|---|---|---|---|---|---|---|---|
| 0.000–0.064 | - | 0.0 – 15.4 | 0 – 54 | 0.0 – 4.4 | 0.00 – 0.034 | ([2]) | 0 -50 | Good |

*NOTE: $N0_2$ has no short-term NAAQS and can generate an AQI only above a value of 200.*

**Table 5.** National air quality standards

| POLLUTANTS | TIME WEIGHTED AVERAGE | CONCENTRATION IN ANBIENT AIR ($G/M^3$) | CONCENTRATION IN ANBIENT AIR (ppm) |
|---|---|---|---|
| PM2.5 | ANNUAL | 300 $\mu g/m^3$ | 0.128 |
| | 24HRS | 500 $\mu g/m^3$ | 0.213 |
| PM10 | ANNUAL | 120 $\mu g/m^3$ | 0.05 |
| | 24HRS | 150 $\mu g/m^3$ | 0.06 |
| $SO_2$ | ANNUAL | 80 $\mu g/m^3$ | 0.03 |
| | 24HRS | 120 $\mu g/m^3$ | 0.05 |
| $NO_2$ | ANNUAL | 80 $\mu g/m^3$ | 0.03 |
| | 24HRS | 120 $\mu g/m^3$ | 0.05 |
| CO | ANNUAL | 5.0 $mg/m^3$ | 4.5 |

| | | | |
|---|---|---|---|
| | 24HRS | 10.0 *mg /m*$^3$ | 9.0 |
| $NH_3$ | ANNUAL | 0.2 *mg /m*$^3$ | 0.18 |
| | 24HRS | 0.6 *mg /m*$^3$ | 0.54 |
| TSP | | 250 $\mu g/m^3$ | 0.11 |

**Table 6.** World Health Organization (WHO) standards

| POLLUTANTS | TIME WEIGHTED AVERAGE | CONCENTRATION IN ANBIENT AIR ($G/M^3$) | CONCENTRATION IN ANBIENT AIR (ppm) |
|---|---|---|---|
| PM2.5 | ANNUAL | 10$\mu g/m^3$ | 0.004ppm |
| | 24HRS | 25 $\mu g/m^3$ | 0.011ppm |
| PM10 | ANNUAL | 20 $\mu g/m^3$ | 0.009ppm |
| | 24HRS | 50 $\mu g/m^3$ | 0.021ppm |
| $SO_2$ | 10 MINUTE | 500 $\mu g/m^3$ | 0.213ppm |
| | 24HRS | 20 $\mu g/m^3$ | 0.009ppm |
| $NO_2$ | ANNUAL | 40 $\mu g/m^3$ | 0.017ppm |
| | 1HOUR | 200 $\mu g/m^3$ | 0.085ppm |
| $O_3$ | ANNUAL | NIL | NIL |
| | 8HRS | 100 $\mu g/m^3$ | 0.042 |
| $NH_3$ | ANNUAL | NIL | NIL |
| | 24HRS | NIL | NIL |
| CO | NIL | NIL | NIL |

**Table 7.** Air quality Index for different locations

| SITE NO | DATE OF SAMPLES | SAMPLING STATIONS | AQI | AIR QUAITY CATEGORY |
|---|---|---|---|---|
| AQ1 | 23/05/2016 - 19/12/2016 | CRUTECH GATE ROUND ABOUT | 74.13 | MARGINALLY POLLUTED |
| AQ2 | 23/05/2016 - 19/12/2016 | NEW AIRPORT BY ESSIEN ST. | 62.70 | MARGINALLY POLLUTED |
| AQ3 | 23/05/2016 - 19/12/2016 | ABITU BY POULTRY FARM | 52.80 | MARGINALLY POLLUTED |
| AQ4 | 23/05/2016 - 19/12/2016 | ANATIGHA BY THE APOSTOLIC CHURCH | 79.13 | MARGINALLY POLLUTED |
| AQ5 | 23/05/2016 - 19/12/2016 | IBESIKPO BY IMAN PRISON | 51.9 | MARGINALLY POLLUTED |
| AQ6 | 23/05/2016 - 19/12/2016 | AMBO MARKET ROUND ABOUT | 59.60 | MARGINALLY POLLUTED |
| AQ7 | 23/05/2016 - 19/12/2016 | EYO ITA BY EDIBE EDIBE | 64.57 | MARGINALLY POLLUTED |
| AQ8 | 23/05/2016 - 19/12/2016 | HENSHAW TOWN BY CHAMBLY CALABAR RD. | 47.20 | GOOD |
| AQ9 | 23/05/2016 - 19/12/2016 | WHITE HOUSE BY CHAMBLY | 48.80 | GOOD |
| AQ10 | 23/05/2016 - 19/12/2016 | MAYNE AVENUE BY WHITE HOUSE | 58.88 | MARGINALLY POLLUTED |

| | | | | |
|---|---|---|---|---|
| AQ11 | 23/05/2016 - 19/12/2016 | INYANG BY AFOKANG | 114.8 | UNHEALTHY |
| AQ12 | 23/05/2016 - 19/12/2016 | YELLOW DUKE BY EKPOABASI | 54.95 | MARGINALLY POLLUTED |
| AQ13 | 23/05/2016 - 19/12/2016 | YELLOW DUKE BY MBUSAHA | 49.89 | GOOD |
| AQ14 | 24/05/2016 - 19/12/2016 | ATAMUNU BY MOUNT ZION | 59.43 | MARGINALLY POLLUTED |
| AQ15 | 24/05/2016 - 19/12/2016 | MOUNT ZION BY OROK OROK | 74.13 | MARGINALLY POLLUTED |
| AQ16 | 24/05/2016 - 19/12/2016 | UWANSE END OF STREET | 74.50 | MARGINALLY POLLUTED |
| AQ17 | 24/05/2016 - 19/12/2016 | MAYNE AVENUE BY GOLDIE | 70.79 | MARGINALLY POLLUTED |
| AQ18 | 24/05/2016 - 19/12/2016 | MAYNE AVENUE BY ADAM DUKE | 58.88 | MARGINALLY POLLUTED |
| AQ19 | 24/05/2016 - 19/12/2016 | TARGET BY PALM STREET | 72.44 | MARGINALLY POLLUTED |
| AQ20 | 24/05/2016 - 19/12/2016 | GOLDIE BY TARGET | 45.92 | GOOD |
| AQ21 | 24/05/2016 - 19/12/2016 | UNICAL MAIN STATION POINT | 51.05 | MARGINALLY POLLUTED |
| AQ22 | 24/05/2016 - 19/12/2016 | MARY SLESSOR ROUND ABOUT | 66.07 | MARGINALLY POLLUTED |
| AQ23 | 24/05/2016 - 19/12/2016 | IKA IKA OKUWA MARKET | 67.61 | MARGINALLY POLLUTED |
| AQ24 | 24/05/2016 - 19/12/2016 | EFIO ETTE ROUND ABOUT | 66.07 | MARGINALLY POLLUTED |
| AQ25 | 24/05/2016 - 19/12/2016 | IKOT EFA BY NDIDEN ISO PARLIAMENTARY | 57.54 | MARGINALLY POLLUTED |
| AQ26 | 24/05/2016 - 20/12/2016 | GOODLUCK JOHNATHAN BY PASS OVERHEAD BRIDGE | 57.54 | MARGINALLY POLLUTED |
| AQ27 | 24/05/2016 - 20/12/2016 | DESTINATION CROSS RIVER ROUND ABOUT BY BASIN AUTHORITY | 66.07 | MARGINALLY POLLUTED |
| AQ28 | 24/05/2016 - 20/12/2016 | ARMY JUNCTION BY WELCOME TO CALABAR | 53.70 | MARGINALLY POLLUTED |
| AQ29 | 25/05/2016 - 20/12/2016 | SPC JUNCTION BY EPZ JUNCTION | 63.10 | MARGINALLY POLLUTED |

| | | | | |
|---|---|---|---|---|
| AQ30 | 25/05/2016 - 21/12/2016 | EPZ TANK FARM | 51.29 | MARGINALLY POLLUTED |
| AQ31 | 25/05/2016 - 21/12/2016 | NNPC TANK FARM | 67.61 | MARGINALLY POLLUTED |
| AQ32 | 25/05/2016 - 21/12/2016 | ISHIE TOWN BY JOHNSON/ISHIE MARKET | 61.66 | MARGINALLY POLLUTED |
| AQ33 | 25/05/2016 - 21/12/2016 | ESSIEN TOWN JUNCTON BY HIGHWAY | 58.88 | MARGINALLY POLLUTED |
| AQ34 | 25/05/2016 - 21/12/2016 | MARINA RESORT | 44.66 | GOOD |
| AQ35 | 25/05/2016 - 21/12/2016 | NEW SECRETERIATE CALABAR | 51.29 | MARGINALLY POLLUTED |
| AQ36 | 25/05/2016 - 21/12/2016 | IBB BY STADIUM TRAFFIC LIGHT | 89.13 | MARGINALLY POLLUTED |
| AQ37 | 25/05/2016 - 21/12/2016 | ATAKPA POLICE STATION BY TRAFFIC LIGHT | 75.86 | MARGINALLY POLLUTED |
| AQ38 | 25/05/2016 - 21/12/2016 | IBB ROUND ABOUT BY RABANA | 83.18 | MARGINALLY POLLUTED |
| AQ39 | 26/05/2016 - 21/12/2016 | AIR PORT BY POLICE STATION | 66.10 | MARGINALLY POLLUTED |
| AQ40 | 26/05/2016 - 21/12/2016 | IBB BY ATIMBO ROUND ABOUT, CALABAR | 79.43 | MARGINALLY |
| AQ41 | 26/05/2016 - 21/12/2016 | IBB BY ATIMBO ROUND ABOUT, CALABAR | 72.44 | MARGINALLY POLLUTED |
| AQ42 | 26/05/2016 - 21/12/2016 | AKPABUYO LOCAL GOVERNMENT HQ. | 51.29 | MARGINALLY POLLUTED |
| AQ43 | 26/05/2016 - 21/12/2016 | MCC BY GOOD LUCK BY PASS | 67.60 | MARGINALLY POLLUTED |
| AQ44 | 26/05/2016 - 21/12/2016 | UNICEM FACTORY SITE | 81.28 | MARGINALLY POLLUTED |
| AQ45 | 26/05/2016 - 21/12/2016 | LEMNA DUMP SITE | 50.20 | GOOD |
| AQ46 | 27/05/2016 - 21/12/2016 | 8 MILES BY AGRO FEED | 72.44 | MARGINALLY POLLUTED |
| AQ47 | 27/05/2016 - 21/12/2016 | TINAPA JUNCTION | 70.79 | MARGINALLY POLLUTED |
| AQ48 | 27/05/2016 - 21/12/2016 | TINAPA BUSSINESS RESORT | 48.75 | GOOD |

| | | | | |
|---|---|---|---|---|
| AQ49 | 27/05/2016 - 21/12/2016 | RUBER ESTATE HIGHWAY | 60.07 | MARGINALLY POLLUTED |
| AQ50 | 27/05/2016 - 21/12/2016 | ODUKPANI JUNCTION | 105.68 | UNHEALTHY |

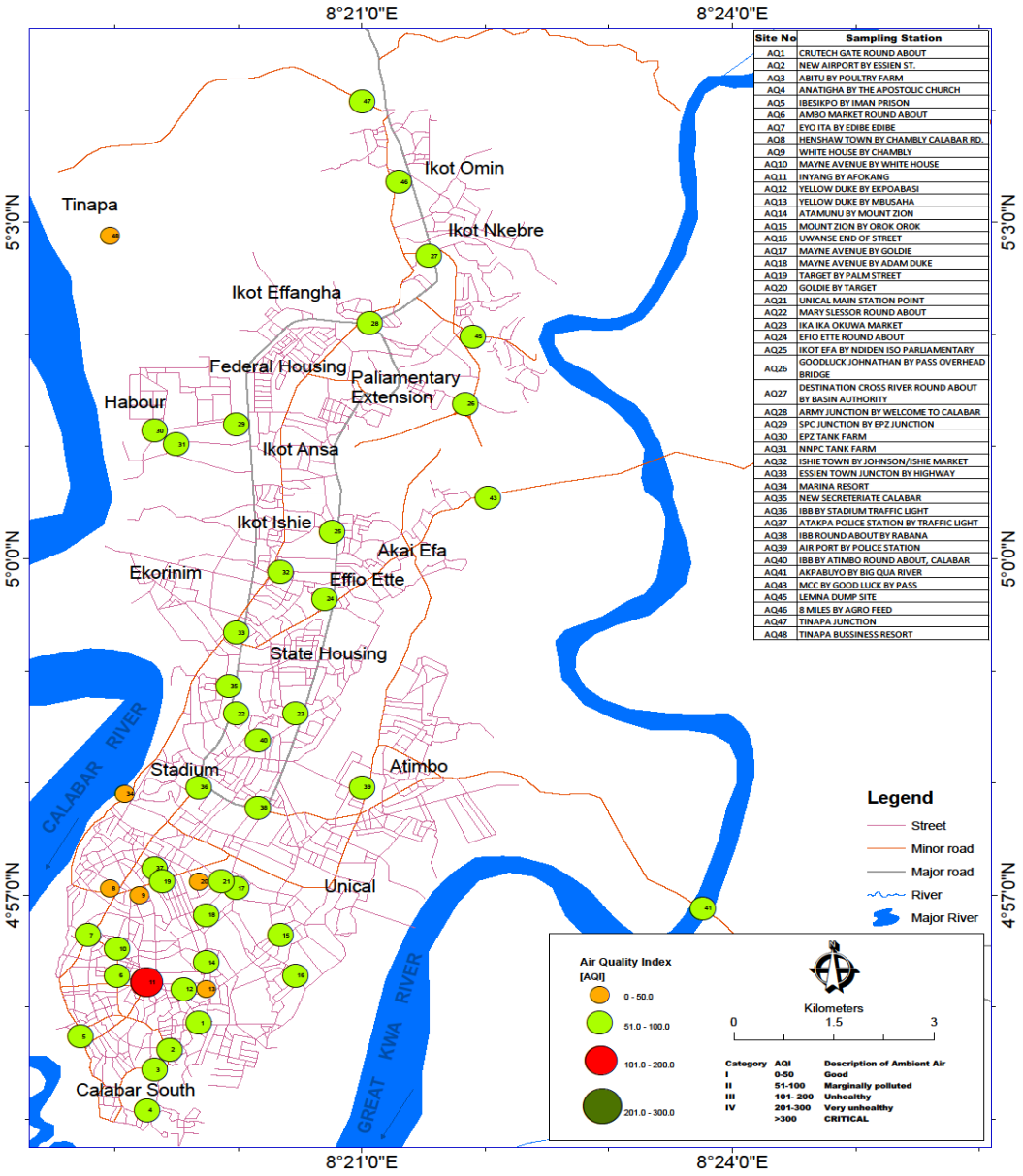


**Fig. 4.** Air quality map for Calabar

## Correlation Analysis

Table 8 shows the correlation between AQI values and pollutants. It can be seen that AQI has the highest correlation of R = 0.93 with $NO_x$. This shows that $NO_x$ has the greatest impact on AQI, while CO has the lowest impact with R = -0.12. Table 9 shows the coefficient of determination $R^2$ between the AQI and pollutants. The coefficient of determination between TSP and AQI is presented as the highest $R^2$ = 0.873. This shows

that 87.3% variation of AQI in the location can be explained by the concentration of TSP in ambient air. The lowest value of $R^2 = 0.014$ was between AQI and CO. This also tells us that only 1.4% variation of AQI can be attributed to the concentration of CO.

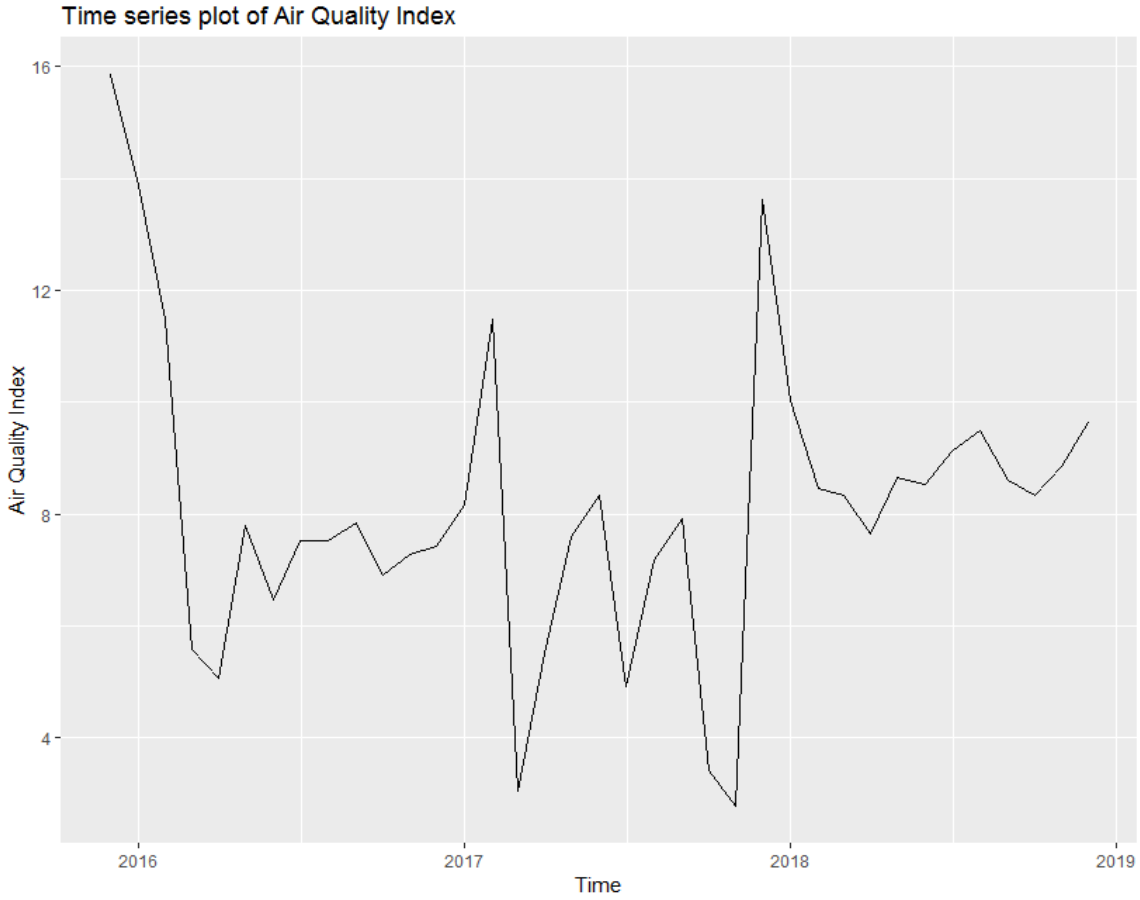


Fig. 5. Seasonal variation of AQI for Calabar

**Table 8.** Correlation coefficient for pollutants

| | $O_3$ | $SO_2$ | CO | $NO_x$ | AQI | WS | TEMP | RH |
|---|---|---|---|---|---|---|---|---|
| $O_3$ | 1 | | | | | | | |
| $SO_2$ | 0.01 | 1 | | | | | | |
| CO | 0.45 | 0.50 | 1 | | | | | |
| NOx | 0.38 | -0.45 | -0.36 | 1 | | | | |
| AQI | 0.46 | -0.33 | -0.12 | 0.93 | 1 | | | |
| WS | -0.28 | -0.72 | -0.42 | 0.50 | 0.48 | 1 | | |
| TEMP | -0.68 | -0.06 | -0.31 | 0.06 | 0.14 | 0.47 | 1 | |
| RH | -0.08 | 0.34 | 0.35 | -0.86 | -0.87 | -0.64 | -0.52 | 1 |

**Table 9.** Correlation coefficient between AQI and pollutants

| Correlation | $R^2$ |
|---|---|
| AQI with $O_3$ | 0.211 |
| AQI with CO | 0.014 |
| AQI with $SO_2$ | 0.108 |
| AQI with $NO_x$ | 0.858 |
| AQI with TSP | 0.873 |
| AQI with wind speed | 0.235 |
| AQI with Temperature | 0.018 |
| AQI with Relative humidity | 0.766 |

$R^2 = 0.094$ is the coefficient of determination between AQI and $H_2S$. This means that the effect of $H_2S$ is responsible for 9.4% of the variation in the Air Quality index over the study period. $R^2 = 0.211$ is the coefficient of determination between AQI and $O_3$. This means that the effect of $O_3$ is responsible for 21% of the variation in the Air Quality index across the research period. $R^2 = 0.014$ is the coefficient of determination between AQI and CO. This means that CO is responsible for 1.4% of the change in the Air Quality index across the study period. $R^2 = 0.108$ is the coefficient of determination between AQI and $SO_2$. This means that the effect of $SO_2$ accounts for 10.8% of the variation in the Air Quality index across the research period. $R^2 = 0.858$ is the coefficient of determination between AQI and $NO_x$. This means that the effect of $NO_x$ is responsible for 85.8% of the variation in the Air Quality index over the study period. $R^2 = 0.873$ is the coefficient of determination between AQI and TSP. This means that the effect of TSP is responsible for 87.3% of the change in the Air Quality index across the study period. $R^2 = 0.235$ is the coefficient of determination between AQI and wind speed. This means that the effect of wind speed is responsible for 23.5% of the variation in the Air Quality index over the study period. $R^2 = 0.018$ is the coefficient of determination between AQI and Temperature. This means that the effect of temperature accounts for 1.8% of the change in the Air Quality index across the research period. $R^2 = 0.766$ is the coefficient of determination between AQI and relative humidity. This means that the effect of relative humidity is responsible for 76.6% of the variation in the Air Quality index over the study period.

## Bipolar Plots

Figure 6 shows wind rose plot for 2016 that characterize the speed and direction of winds at a location. When multiple monitoring stations are available, the wind speed dependence of a source can reveal important details about the source type and characteristics. In 2016, when easterly and southeasterly wind speeds increased, there were signs that $CO_2$ concentrations increased, as shown in Figure 7. For various wind speeds, there was also evidence of origin from the SSE. In 2016, there was evidence of an increase in $NO_x$ concentrations with increasing wind speeds from the south and southwest, as seen in Figure 8. In 2016, when the easterly and southwesterly wind speeds increased, $SO_2$ concentration showed signs of increasing, as seen in Figure 9. For various wind speeds, there is additional evidence that the wind source is located in the southwest. In 2016, there is evidence that $O_3$ concentrations increase when wind speed increases from the southeast, as seen in Figure 10. For a variety of wind speeds, there is additional evidence of a source to the southeast.

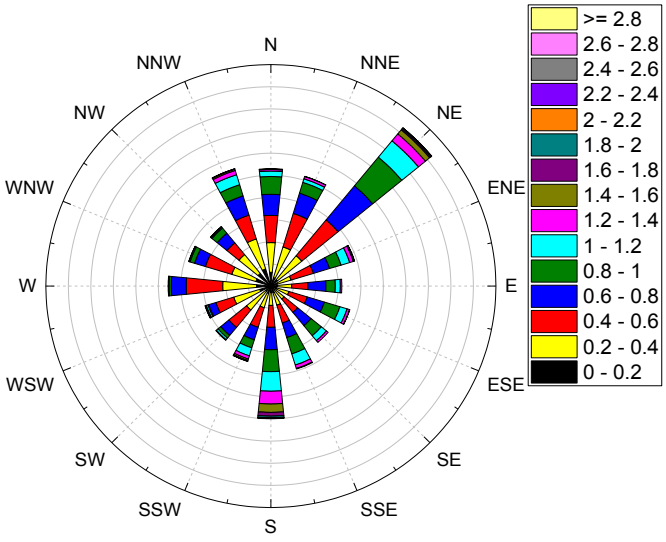


**Fig. 6.** Wind rose diagram for mean wind direction for year 2016

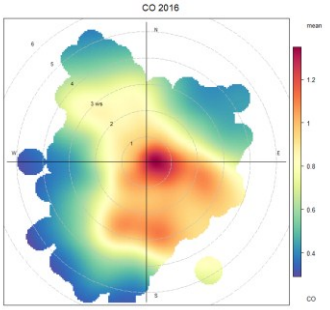

**Fig. 7.** Polar graph for CO in 2016

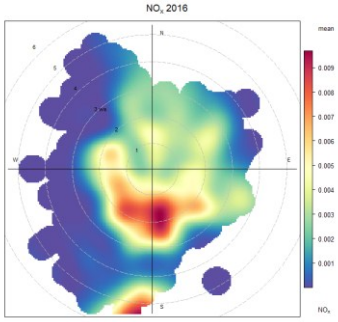

**Fig. 8.** Polar graph for $NO_x$ 2016

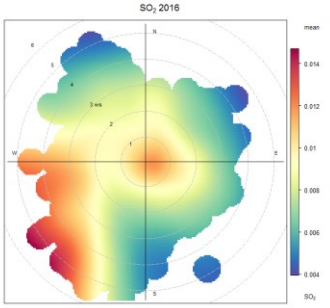

**Fig. 9.** Polar graph for $SO_2$ 2016

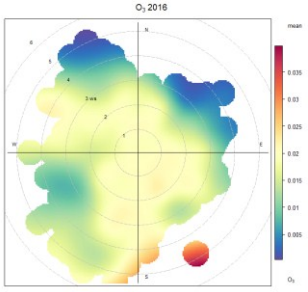

**Fig. 10.** Polar plot ozone 2016

Figure 11 shows wind rose plot for 2017. When multiple monitoring stations are available, the wind speed dependence of a source can reveal important details about the source type and characteristics. In 2017, there was indications of increasing CO concentrations when wind speed increased from the east and south-east, as seen in Figure 12. For a variety of wind speeds, there was also evidence that the source is located in the SSE. In 2017, there was evidence of increasing $NO_x$ concentrations as wind speed increased from the south and south-west, as seen in Figure 13. In 2017, there were indications of increasing $SO_2$ concentrations when wind speed increased from the east and south-west, as seen in Figure 14. For a variety of wind speeds, there is additional

evidence of a source to the southwest. In 2017, there was evidence of increasing $O_3$ concentrations when the wind speed increased from the south-east, as seen in Figure 15. For a variety of wind speeds, there is additional evidence of a source to the southeast.

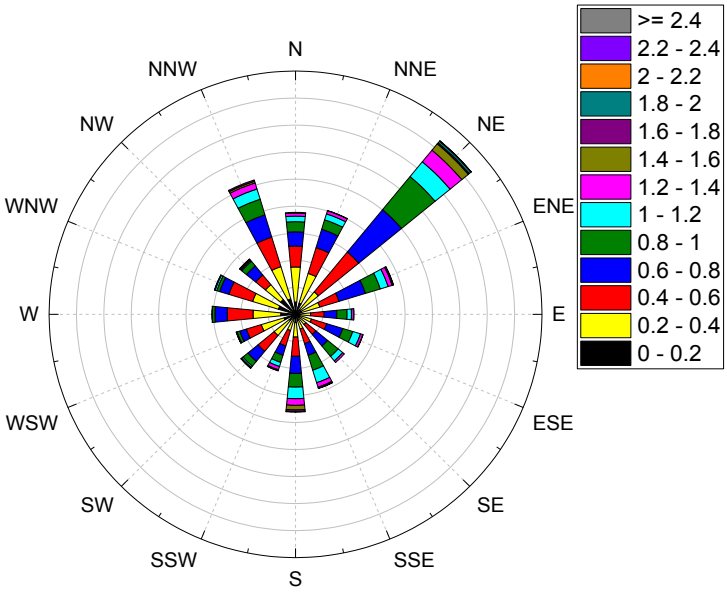


**Fig. 11.** Wind rose diagram for mean wind direction for year 2017

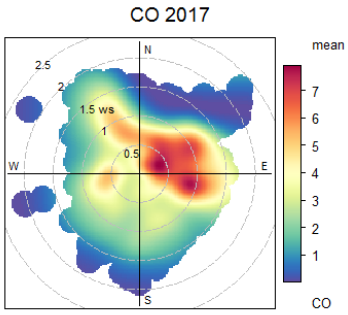


**Fig. 12.** Polar plot of CO for 2017

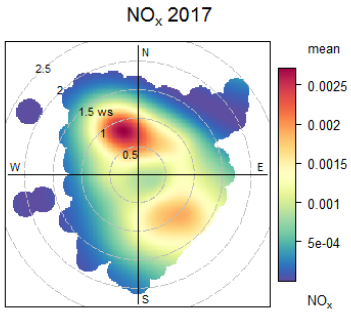


**Fig. 13.** Polar plot of $NO_x$ for 2017

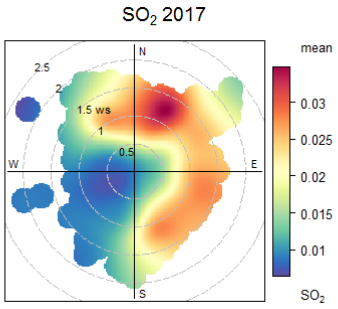


**Fig. 14.** Polar plot of $SO_2$ for 2017

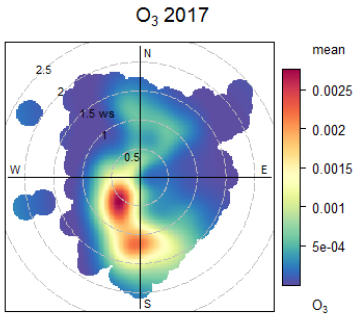


**Fig. 15.** Polar plot of $O_3$ for 2017

## Time Variation of Pollutants

Figure 16 shows a time variation plot of CO for the year of 2016. The graph shows that over a 24-hour day in 2016, CO concentrations were higher during the first 12 hours of the day but steadily decreased over the remaining 12 hours of the day. Starting in June, CO concentrations have been rising steadily. From the weekly analysis, CO concentrations increased sharply on Fridays and dropped sharply on weekends.

Figure 17 shows a time variation plot of $NO_x$ for the year of 2016. The graph shows that over the 24-hour period in 2016, $NO_x$ concentrations increased steadily throughout the 24 hours. $NO_x$ concentration increases steadily from August onwards. In the analysis of weekdays, a sharp increase in NOx concentration was observed on Wednesdays, a sharp drop in concentration in the middle of the week and a slight increase during weekends.

Figure 18 shows a time variation plot of $SO_2$ for the year of 2016. The graph shows that in the 24-hour day of 2016, there was a steady increase in $SO_2$ concentration throughout the 24-hour day. However, during the last 6 hours of the day, the concentrations decreased. The concentration of $SO_2$ increased steadily since August. For the weekday analysis, there was a sharp increase in $SO_2$ concentration on Wednesdays and Fridays, a sharp drop in concentration on Thursdays and a sharp decrease during the weekends.

Figure 19 shows a time variation plot of $O_3$ for the year of 2016. The plot shows that in the 24-hour day of the year of 2016, there was a steady increase of $O_3$ concentration throughout the 24 hours of the day. However, during the last 6 hours of the day, the concentrations decreased. The concentration of $O_3$ increased steadily since May. For the weekday analysis, there was a sharp increase in $O_3$ concentration on Thursdays and Saturdays, a sharp drop in concentration on Fridays and a sharp decrease during the weekends.

Figure 20 shows a time variation plot of CO for the year of 2017. The plot shows that in the 24-hour day within the year of 2017, there was a steady increase of CO concentration throughout the 24 hours of the day. However, there was a drop-in concentration during the last 6 hours of the day. The concentration of CO increased steadily since August. For the weekday analysis, there was a sharp increase in CO concentration on Thursdays and Saturdays, a sharp drop in concentration on Fridays and a sharp decrease during the weekends.

Figure 21 shows a time variation plot of $NO_x$ for the year of 2017. The graph shows that in 2017, $NO_x$ concentrations rose sharply during 12 hours of the day over a 24-hour period. The concentration of $NO_x$ increased sharply in the month of July. For the weekday analysis, there was a sharp increase in $NO_x$ concentration on Wednesdays and a sharp drop in concentration towards the weekends.

Figure 22 shows a time variation plot of $SO_2$ for the year of 2017. The plot shows that in the 24-hour day of 2017, there was a steady increase of $SO_2$ concentration throughout the next 12 hours of the day. However, there was a drop-in concentration during the last 6 hours of the day. There was a sharp increase in concentration of $SO_2$ in the month of May. For the weekday analysis, there was a sharp increase in $SO_2$ concentration on Tuesdays and a sharp drop in concentration towards the weekends.

Figure 23 shows a time variation plot of $O_3$ for the year of 2017. The plot shows that in the 24-hour day of 2017, there was a steady increase of $O_3$ concentration during the first 12 hours of the day. However, there was a slight increase in the concentration during the last 6 hours of the day. The concentration of $O_3$ increased steadily since March.

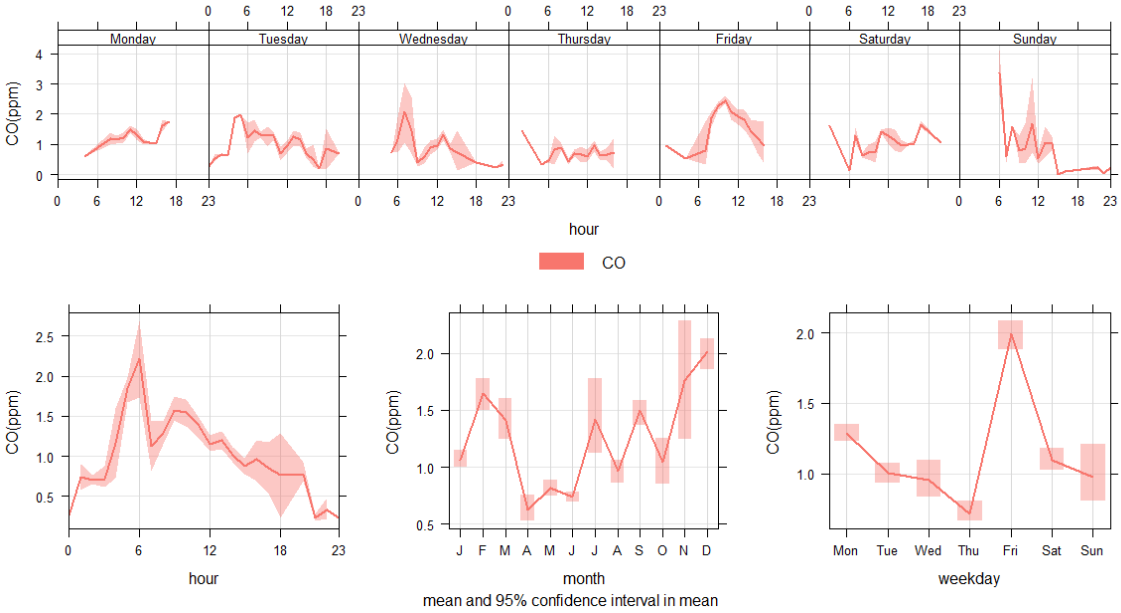


**Fig. 16.** Time variation of CO for 2016

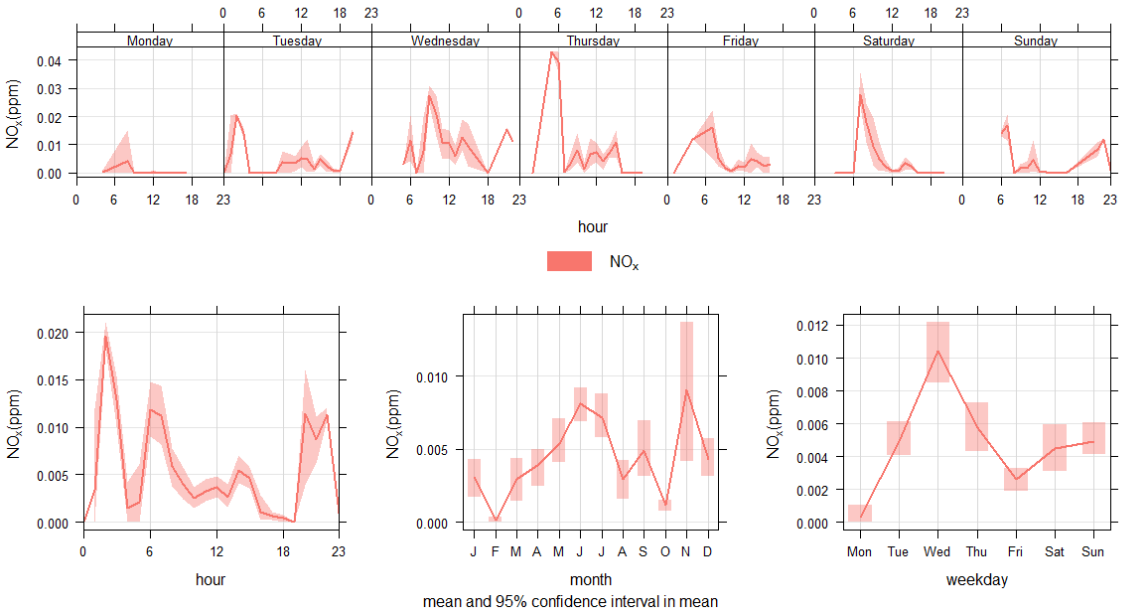


**Fig. 17.** Time variation of $NO_x$ for 2016

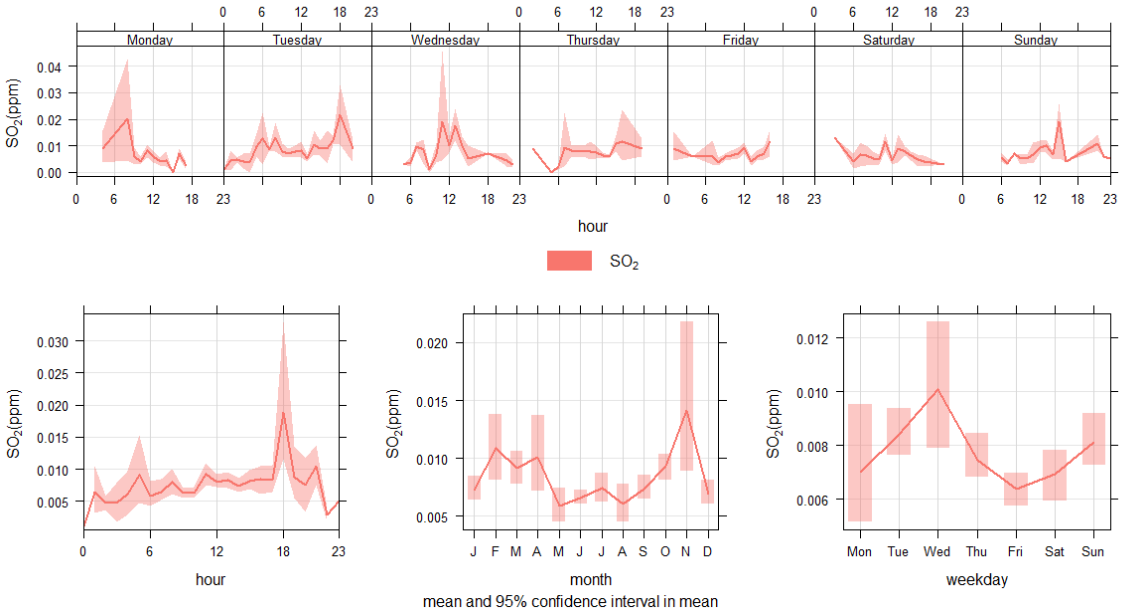


**Fig. 18.** Time variation of $SO_2$ for 2016

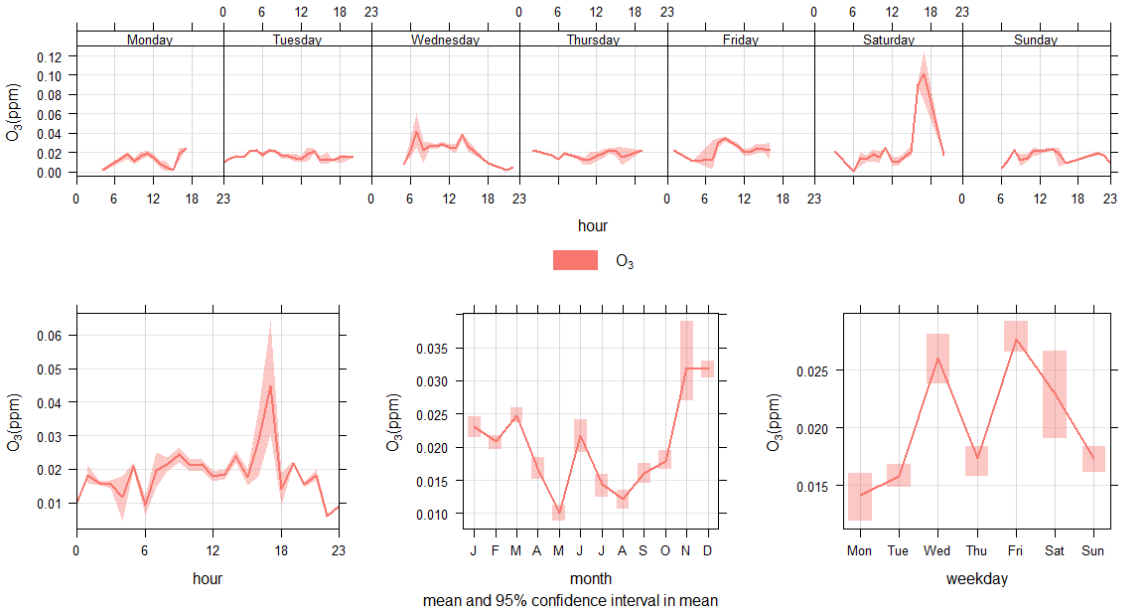


**Fig. 19.** Time variation of $O_3$ for 2016

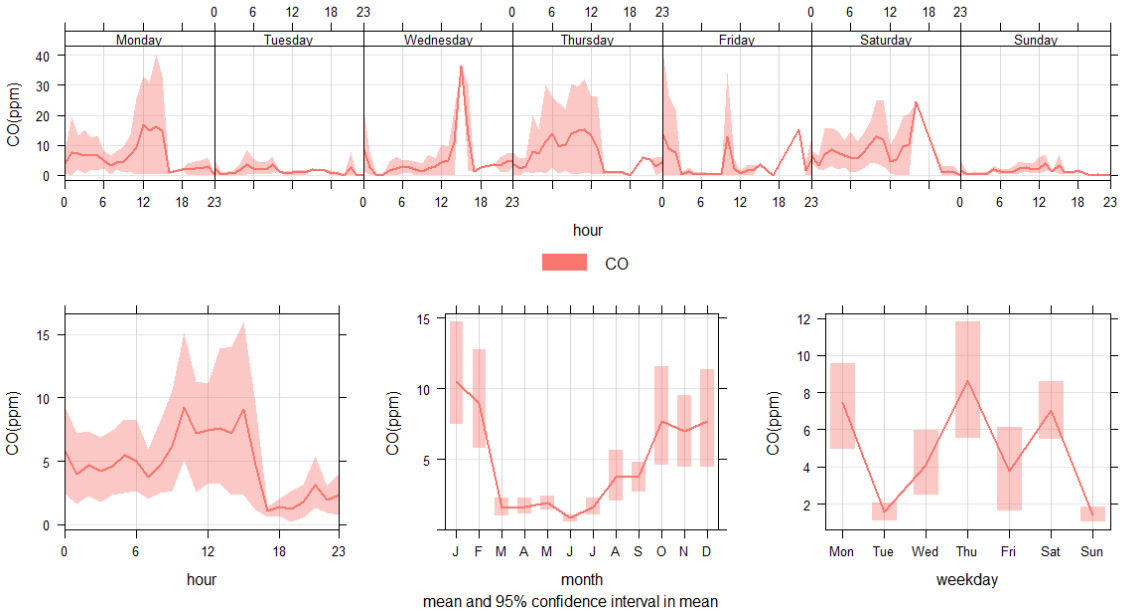


**Fig. 20.** Time variation of CO for 2017

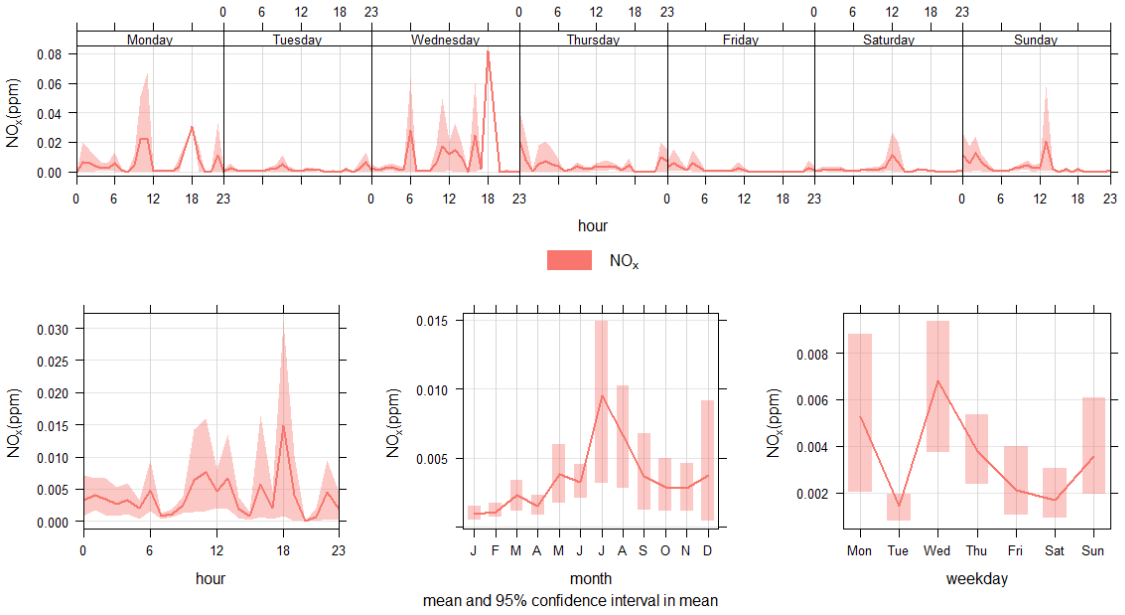


**Fig. 21.** Time variation of $NO_x$ for 2017

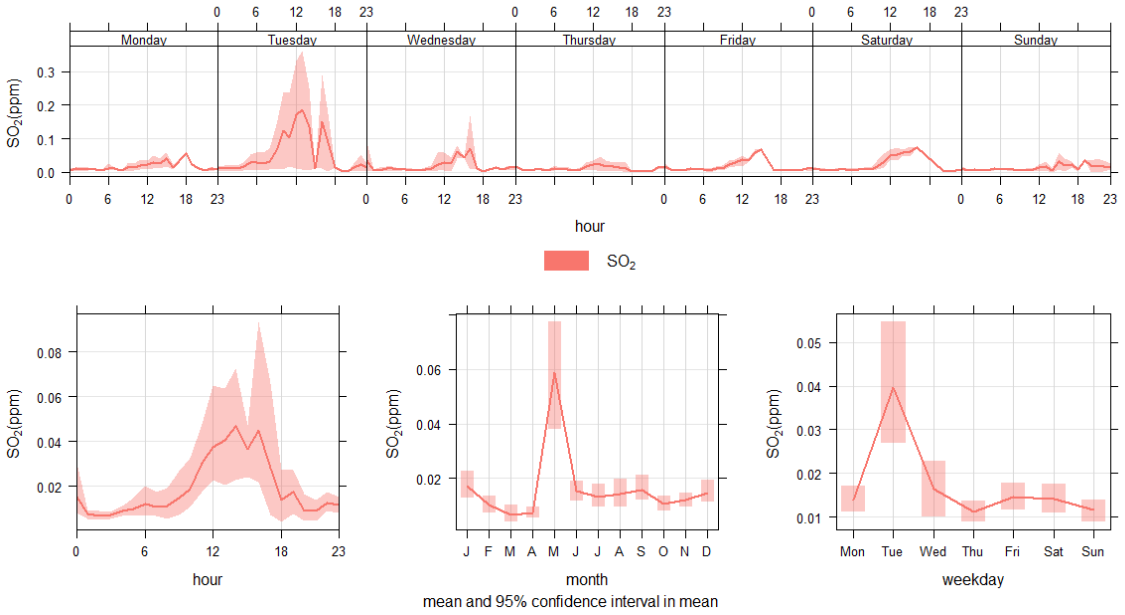


**Fig. 22.** Time variation of $SO_2$ for 2017

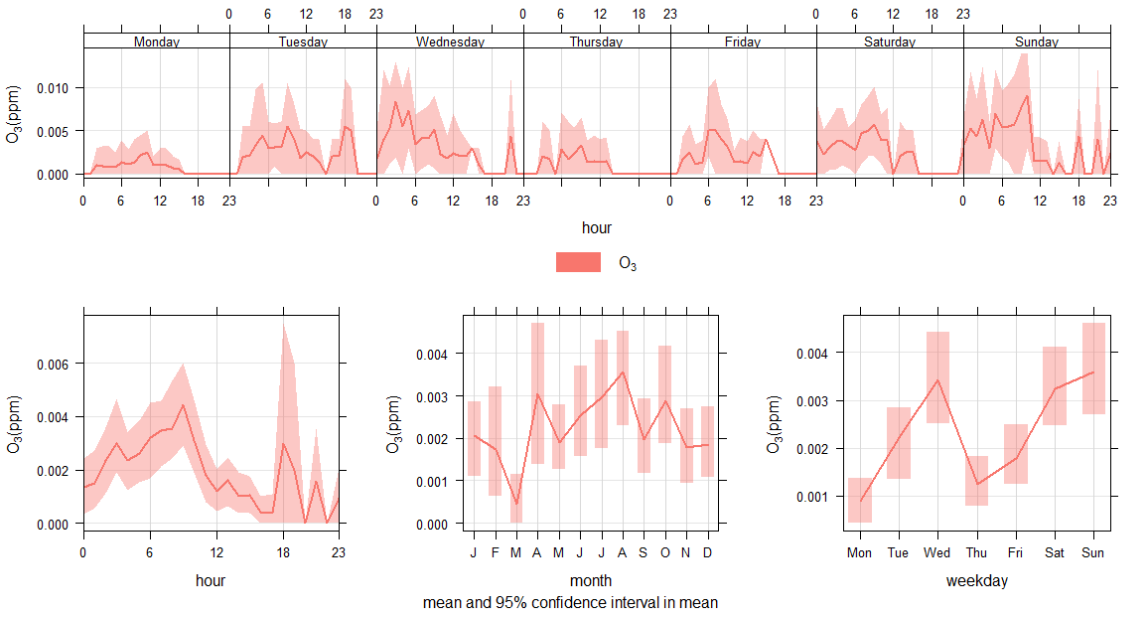


**Fig. 23.** Time variation of O3 for 2017

## Trend Analysis

Table 10 shows the Mann-Kendall trend analysis parameters representing the air quality index analysis, including: Z-value, Mann-Kendall statistic (S), probability value (p-value), and tau (τ) for 2016. It can be seen that there were "no trend" recorded for $O_3$ and $NO_x$. This is because the p-value is greater than the set alpha value of 0.05, so we concluded that there was no trend. Since there is no trend, the positive z-scores become insignificant, as well as the positive tau values. For $SO_2$, and CO, the p-value is less than

the set alpha value of 0.05, hence we concluded that there was a trend. Positive z-scores, along with positive tau values, indicated an upward trend.

Table 11 shows the Mann-Kendall trend analysis parameters including the Z-value, the Mann-Kendall statistic (S), the probability value (p-value), and the tau (τ) for the year of 2017. It can be seen that there were "no trend" recorded for CO, $SO_2$, $NO_x$ and $O_3$.

Table 12 shows the Mann-Kendall trend analysis parameters which include the Z-value, the Mann-Kendall statistic (S), the probability value (p-value), and the tau (τ) for the combined period of study. From this Table, it can be seen that there were "no trend" recorded for $O_3$, $NO_x$ and CO. For $SO_2$, the p-value is less than the set alpha value of 0.05, hence we concluded that there was a trend. The positive z-value as well as the positive tau value for CO and $NO_x$ show that the trend was an increasing trend. The smaller value of Sen's slope indicates a smaller increase.

**Table 10.** Mann-Kendall trend test parameters for 2016

| Pollutant | Z-value | Sen's slope | p-value | tau(τ) | Trend |
|---|---|---|---|---|---|
| $O_3$ | 0.702 | 0.177 | 0.483 | 0.167 | No Trend |
| $NO_x$ | 0.071 | 0.000 | 0.944 | 0.030 | No Trend |
| CO | 2.126 | 1.161 | 0.034 | 0.485 | Increasing Trend |
| $SO_2$ | 2.072 | 0.863 | 0.038 | 0.470 | Increasing Trend |

**Table 11.** Mann-Kendall trend test parameters for 2017

| Pollutant | Z-value | Sen's slope | p-value | tau(τ) | Trend |
|---|---|---|---|---|---|
| $O_3$ | 1.519 | 2.042 | 0.129 | 0.348 | No Trend |
| $NO_x$ | 0.139 | 0.000 | 0.890 | 0.045 | No Trend |
| CO | 0.962 | 12.940 | 0.336 | 0.227 | No Trend |
| $SO_2$ | 0.630 | 0.694 | 0.529 | 0.151 | No Trend |

**Table 12.** Mann-Kendall trend test parameters for 2016-2017

| Pollutant | Z-value | Sen's slope | p-value | tau(τ) | Trend |
|---|---|---|---|---|---|
| $O_3$ | -0.342 | 0.000 | 0.733 | 0.041 | No Trend |
| $NO_x$ | 0.253 | 0.000 | 0.800 | 0.003 | No Trend |
| CO | 3.584 | 1.317 | 3.385 | 0.413 | No Trend |
| $SO_2$ | 2.838 | 0.410 | 0.004 | 0.326 | Increasing Trend |

## SUMMARY AND CONCLUSIONS

### Summary

The characterization of air quality parameters has been carried out for the coastal city of Calabar. The data for this work were obtained in two parts. The first part which was used for the development of an air quality map based on AQI calculation was obtained via mobile hand held aeroqual gas sensors. The second part was obtained via the stationary AQM65 machine stationed at the University of Calabar. The data obtained covered a period of twenty-four (24) months. The results show that the average concentration of ozone ($O_3$) was 0.34ppm which is higher than the World Health Organization standard annual average value of 0.04ppm. The least concentration value was obtained in March with concentration value of 0.01ppm. The average concentration

of carbon monoxide (CO) was 4.52ppm which is higher than the Nigerian national standard annual average value of 4.05ppm. The average concentration of Sulfur dioxide ($SO_2$) was 0.53ppm which is greater than the World health Organization (WHO) standard of 0.008ppm 24hr mean and 0.213ppm 10 minutes mean. It is also greater than the Nigerian national standard annual average value of 0.08ppm. It was also observed that there is no marked difference in the average concentration of SO2 from January to December. The average concentration of Nitrogen Oxides ($NO_x$) was 0.06ppm which again is greater than the WHO standard of 0.02ppm but less than 0.09ppm 1hr mean. It is also less than the Nigerian national standard annual average value of 0.08ppm. The concentration of $NO_x$ was low in months of March to August with concentration ranging from 0.02 to 0.013ppm.

It has been discovered that the highest concentration of ozone (O3) was obtained in December with concentration of 0.031ppm which is lower than the World Health Organization standard annual average value of 0.1ppm. The least concentration value was obtained in March with concentration value of 0.01ppm. This high concentration in December could be due to the fact that ozone concentration increases with increase solar radiation, hence December is the peak of dry season in Nigeria which comes with intense solar radiation. The highest concentration of carbon monoxide (CO) was obtained in August with concentration of 9.876ppm which is higher than the Nigerian national standard annual average value of 4.05ppm. the least concentration value was obtained in march with concentration value of 1.141ppm. August is the peak of rainy season in Nigeria. During this period, many people tend to stay indoors. This prompts the use of gasoline generators to keep them occupied. More personal cars also ply the roads during this period. This can explain the slightly high concentration of CO during this period. The highest concentration of sulfur dioxide ($SO_2$) was obtained in August with concentration of 0.017ppm which is lower than the Nigerian national standard annual average value of 0.08ppm. The least concentration value was obtained in February and march with concentration value of 0.01ppm.

It could also be observed that there is no marked difference in the average concentration if $SO_2$ from January to December. The highest concentration of Nitrogen Oxides ($NO_x$) was obtained in October with concentration of 0.005ppm which is lower than the Nigerian national standard annual average value of 0.08ppm. The concentration of $NO_x$ was low in months of March to August with concentration ranging from 0.02 to 0.013ppm. Considering the effect of meteorology on the pollutants, CO had the highest correlation coefficient R = -0.81 with temperature while it had the least correlation coefficient R = 0.11 with ozone. This shows that temperature had about 81% impact on CO compared with the other variables though negatively. SO2 had the highest correlation coefficient R = -0.89 with TSP while it had the least correlation coefficient R = 0.36 with ozone. This shows that $SO_2$ had about 89% impact on TSP compared with the other variables though negatively. As the concentration of TSP increased in the atmosphere, the concentration of $SO_2$ decreased. $O_3$ had the highest correlation coefficient R = -0.43 with temperature while it had the least correlation coefficient R = 0.11 with CO. This shows that $O_3$ had about 43% impact on TSP compared with the other variables though negatively. NOx had the highest correlation coefficient R = -0.67 with CO while it had the least correlation coefficient R = 0.17 with wind speed. This shows that $NO_x$ had about 67% impact on CO compared with the other variables though negatively. TSP had the highest correlation coefficient R = -0.92 with relative humidity while it had the least correlation coefficient R = -0.43 with ozone. This shows that relative humidity had about

92% impact on TSP compared with the other variables though negatively. The air quality map developed reveals that 82% of the stations were categorized as “marginally polluted”, which falls with the group (51-100). Also 14% of the stations were categorized as “Good”, while the remaining 4% of the stations were categorized as “unhealthy”. From the stationary data, AQI has the highest correlation of R = 0.93 with NOx. This shows that NOx has the greatest impact on AQI while CO has the least impact with R = -0.12. Ratio analysis shows mobile sources are contributing to CO and $SO_2$ concentration in the city of Calabar compared to point sources. This work will also provide scientist with a tested model which is the DWT-ARIMA model which has outperformed the ARIMA model in the forecasting of air quality in the city of Calabar. For the year 2016, there were Increasing trends for $SO_2$, CO. There were no trends recorded for NOx and $O_3$. This is because the p-value is greater than the set al. pha value of 0.05 hence we conclude that there is no trend. The positive z-value as well as the positive tau value becomes insignificant since there is no trend. For the year 2017, there are no trends recorded for CO, $SO_2$, $NO_x$ and $O_3$.

## Conclusions

The following conclusions have been drawn from this research work:

1. A comprehensive air quality study has been carried out for Calabar, Nigeria. There has not been such a study in Calabar prior to this study.
2. An air quality map has been developed for Calabar. This map will give policy makers the insight on the air quality situation in Calabar and its environs. It will als help them come up with method to improve air quality in the affected areas.
3 That due to the importance of this research, monitoring of Air Quality should be done comprehensively throughout the country by placing monitoring equipment at strategic positions.
4 Further research should be done on transboundary air pollution to ascertain all the possible sources of transboundary pollution.
5 Catalytic converters should be inserted at the exhaust pipe of motor vehicles to reduce pollution.
6 Biofuels should be adopted in Nigeria as an alternative to fossil fuels.
7 Bicycles should be adopted as means of transportation in Nigeria.

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## CONFLICTS OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this paper.

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