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Research Article

Assessment Of Onitsha Commercial City Air Pollution Variables, Their Effects, Control on Environment and Public Health.

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Abstract
Combustion of fossil fuels during transportation and industrial activities, dust particles and open dumps were identified as the main causes of air pollution in Onitsha, a West African foremost commercial bub and a port city in Nigeria. The city had the world's worst air in 2016 with PM_{10} annual concentration of 594 ug/m^3.Currently $PM_{2.5}$ concentration in Onitsha is 5.4 times the WHO annual air quality guideline value. Air quality parameters were sampled with portable air quality digital equipment and field data collection in forty stations of Onitsha metropolis during dry and wet seasons for one year. From the results of measurements of the pollutants, SO_2, NO_2, CO, PM_{10}, $PM_{2.5}$ exceeded the stipulated Standard NAAQS limits. Results of developed multiple linear forecasting models revealed sufficient explanation of relationship between meteorological variables and H_2S, NO_2 and VOCs levels in the dry season months and variation of SO_2 during wet season. Forecasting air pollution in this study serves as a cost-effective warning system for effective pollution control measures in Onitsha metropolis. Controlling sources of emissions pollution through compliance with relevant laws can have positive impacts on both health and environment.

Key Words: Air; Pollution; Onitsha; Forecast; Environment; Models.

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INTRODUCTION

Atmospheric pollution is one of the world's leading problems causing public health and environmental damage. In Nigeria, increased rate of construction, commercial, transportation, domestic use of fossil fuels, and industrial, activities are contributing immensely to air pollution (Lala et al.,2023). This is mainly governed by four factors: anthropogenic and/or biogenic emissions, transportation of primary pollutants and precursors of secondary pollutants, atmospheric chemistry, long-range transport and, of course, meteorology (Jacob and Winner, 2009). Urbanization and rapid industrialization have benefited mankind and made the life of humans easier and more comfortable. However, the adverse impact of contaminated air due to economic growth, urbanization and industrialization also pose harm to mankind, (Bikis,2023). Moving vehicles emit considerable amounts of carbon dioxide, carbon monoxide, hydrocarbons, oxides of nitrogen and Sulphur, particulate matters, lead, benzene, known as Traffic Related Air Pollutants (TRAP) among others (NIH,2024). The generation of pollutants is intrinsically linked to our lifestyles in cities (Pidgeon,2020). Research findings indicate that every year illnesses such as heart attack, lung cancer and other respiratory ailments kill many people who breath in dirty and contaminated air compared to those in cleaner environment (Kalpana S & Srivastava,2015). Forecasting gives an estimate of future concentration of air quality pollution parameters temporally and spatially within a given coordinate (Xing et al;2023). The imperativeness of this is that a mechanism for pollution control and an alarm system protecting environmental and human health is in place which provides early warning signal against adverse effects of atmospheric pollutants. Research by experts for the development of models for air pollution forecasting utilizes classical and non-classical methods (Wang et al;2018 &Wu et al;2024).

Onitsha is one of such cities with high commercial activities that contribute to air pollution, with $PM_{2.5}$ measured values 3.6 times the WHO standard limits in previous studies ((Onitsha AQLI, 2021). Recent research indicates the concentration of $PM_{2.5}$ in Onitsha is 5.4 times the WHO annual air quality guideline value (IQ Air, 2023). Anthropogenic activities such as heavy truck movement, commercial vehicular movement, heavy human congested/crowded areas, industrial activities, commercial market activities, mechanical workshop and open waste dump etc. constitute the main causes of air pollution in Onitsha metropolis Nigeria (Antai and Osuji, 2017). These air pollutants, including other greenhouse gases, have negative environmental impacts and health implications (EPA, 2022). In Onitsha like any other commercial and industrial cities in Nigeria, due to high cost of logistics for air quality data gathering and poor funding, accurate air quality data base or Air Quality Impact Assessment (AQIA) by any regulatory agencies responsible for such roles have not been effective. The imperativeness of this research therefore was to fill this gap of knowledge by assessing the spatial and temporal variation of major criteria pollutants and deploying statistical tools and modelling for air pollution forecasting to reduce the cost of air pollution control (Gupta et al.,2023; EPA,2023 Okpala and Yorkor, 2013; Antai *et al.,* 2018).

Criteria air pollutants and hazardous air pollutants constitute the two main branches of air polluting parameters. The high concentrations of the former on the atmospheric spheres adversely affect the socioeconomic environment and cause many diseases (EPA,2015). Hazardous air pollutants (HAPs), are known or suspected to cause cancer or other serious health effects (EPA,2022) for example benzene (USEPA, 2023). Methane with a high global warming potential and many atmospheric pollutants, for example black carbon are also discharged (UNEP, 2022). Sources of black carbon emissions in Onitsha include diesel engines, brick kilns and burning of biomass (including burning wood for heating). The quantity of air and toxic pollutants generated in Nigeria is increasing based on previous baseline research data (table 1).

Table 1: Nigeria Air and Toxic Pollutants in 2015

Carbon monoxide	9.95 MT
Non-Methane VOC	2.35 MT
PM2.5	1.632 MT
PM10	1.48 MT
NOx	422,590 T
Black Carbon	220,583 T
SO2 177	,143 T

Description of the Study Area.

The study area coverage is approximately16kilometer square comprising Onitsha commercial city and three adjoining LGAs of Anambra state of Nigeria, West Africa (Fig.1). Sampling was conducted in five Local Government Areas in all. Onitsha is an economic hub for commerce in West Africa with an area of 52 km². The current metro area population of Onitsha in 2023 is 1,623,000, a 4.51% increase from 2022. The metro area population of Onitsha in 2022 was 1,553,000, a 4.72% increase from 2021. The metro area population of Onitsha in 2021 was 1,483,000, a 4.81% increase from (Macrotends2020). In terms of meteorological parameters, the average temperature is 31°C, wind speed is 11 km/h and humidity, 66%.

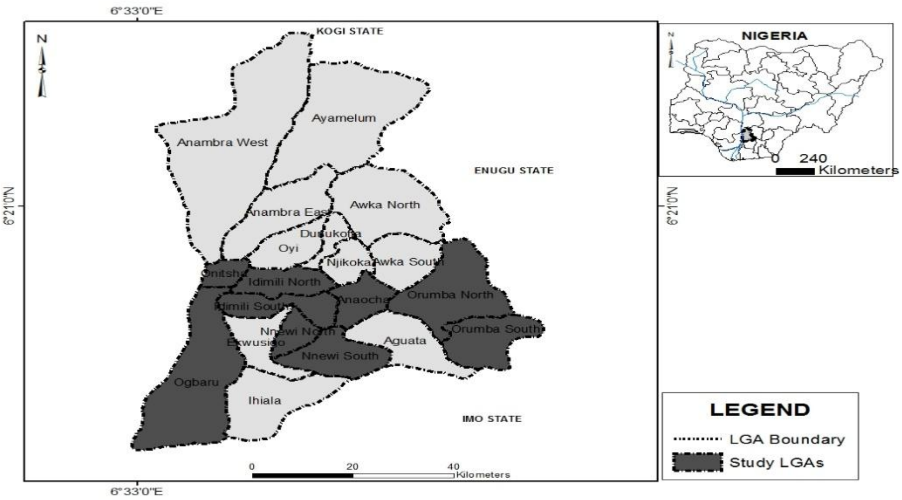

Figure 1: Map of Nigeria Showing Onitsha Metropolis.

The scope of research covers the Onitsha metropolis. Forty (40) sampling points and one control point (with their coordinates) were selected for the study (table 2). The following ambient air quality pollutants were measured for analysis, NO_2, SO_2, H_2S, NH_3, CO, VOCs, TSP, PM_{10} and $PM_{2.5.}$ Measurements were taken during wet and dry seasons for one year. The ambient limits for Nigerian air quality guidelines of the measured parameters are shown below (Table 2).

Table 2: Air Quality Guidelines, Nigeria Ambient limits

Pollutant	2021 Air Quality Guidelines	Nigeria Ambient Limits	Nigeria Limit for Stationary Sources (24h)
Carbon monoxide	4 mg/m3 (24 h)	11.4 mg/m3 (8h)	1.0 - 5.0 mg/m3 (24h)
Nitrogen oxides	10 ug/m3 (Annual) 25 ug/m3 (24 h)	75.0 - 114 mg/m3 (1h)	0.004 - 0.1mg/m3 (24h)
Ozone	60 Ug/m3 (peak season) 8 ug/m3 (8h)	0.06 ppm (1 hour) (120 mg/m3)	5133 ppm (24h)
Particulate Matters	PM 2.5: 5 ug/m3 (Annual) 15 ug/m3 (24h)	46.3 un/m3 250 ug/m3 (1h)	0. 15 mg/m3 (24h)
	PM10: 15ug/m3 (Annual) 45 ug/m3 (24h)		
Sulfur dioxide / sulfur Oxides	40 ug/m3 (24h)	26 ug/m3 - 260 u g/m3 (1h)	0.05 - 0.5 mg/m3 (24h

Air quality pollutants: ref https://www.iqair.com/blog/air-quality/2021a-WHO-air-quality-guidelines

Source: Environmental Pollution Control Handbook. Lagos, FEPA. 1991

Table 3: Description of Sampling Point and Coordinates

S/N	Sampling Point Key	Sampling Point Location	Coordinates
1	SP 1	Upper Iweka Flyover, Odoakpu	N 06º 07'. 892" E 006º 47'. 627"
2	SP 2	Ochanja Market Round-About Odoakpu	N 06º 08'. 446" E 006º 47'. 070"
3	SP 3	Modebe Avenue/Iweka Road Junction Odoakpu	N 06º 08'. 693" E 006º 46'.801"
4	SP 4	Zik Avenue/Belewa Junction, Govt Field Fegge	N 06º 08'.259" E 006º 46'.521"
5	SP 5	Uga Road Building Materials/PH Road, Fegge,	N 06º 07".976" E 006º 46'.437"
6	SP 6	Niger Head Bridge By Timber Market, Fegge	N 06º 07'. 898" E 006º 46'. 022"
7	SP 7	Main Market/Bida Road/Bright Street/ New Mkt Road Junction, Otu Onitsha	N 06º 09'. 014" E 006º 46'. 453"
8	SP 8	Oseokwa Odu Market/Main Market/ Old Mkt Road Junction, Otu Onitsha	N 06º 09' 305" E 006º 46' 452"
9	SP 9	Old Nkisi Road/Ridge Road (Holy Trinity) , European Qtrs	N 06º 09'.709" E 006º 46'.777"
10	SP 10	Akpaka GRA/Nigeria Prisons	N 06º 10'.232" E 006º 46'.735"
11	SP 11	Onitsha "33" Reserve Area	N 06º 09'.737" E 006º 47'.867"
12	SP 12	DMGS/All Saints Cath/Ziks Round About, Inland Town	N 06º 09'.164" E 006º 47'.311"
13	SP 13	Emmanuel Church St/Awka Rd/ St Mary Cath. Church Junction, Inland Town	N 06º 09' 101" E 006º 48'.081 "
14	SP 14	Savoy/Water Works Road/Awka Road Junction, Inland Town	N 06º 08'.792" E 006º 48'.673"
15	SP 15	Borromeo/Ziks Round About (Onosi Onira Retreat)	N 06º 08'.801" E 006º 48'. 831"
16	SP 16	Nkpor Junction	N 06º 08'.836" E 006º 50'.013"
17	SP 17	New Spare Parts Market/Enugu-Onitsha	N 06º 09'.099" E 006º 49'. 983"
18	SP 18	Oye – Nkpor/Awka Old Road Junction	N 06º 09' 173" E 006º 50'.740"
19	SP 19	St Peters/Tarzan/Nkpor Express Junction	N 06º 09'.502" E 006º 50'.613"

Table 3contd): Description of Sampling Point and Coordinates *Cont’d.*

S/N	Sampling Point Key	Sampling Point Location	Coordinates
20	SP 20	Ogbunike Building Materials (Km 8 Onitsha-Enugu Express Road	N 06° 09’.918” E 006° 51’.448”
21	SP 21	UgwuNwasike Round- About/OldAwka Road	N 06° 09’.126” E 006° 51’.837”
22	SP 22	Abatete/Alor/Ogidi/Ideani Junction	N 06° 07’.658’’ E 006° 55’.740”
23	SP23	Eke Nkpor (Umuoji/Npor/Obosi) Junction	N 06° 07’. 550” E 006° 51’.740’’
24	SP 24	Iyasele Obosi Road, Ukwu-Udara Junction	N 06° 07’.441” E 006° 50’.088’’
25	SP 25	Akaora/Minaj Junction, Obosi	N 06° 06’.513’’ E 006° 49’. 148’’
26	SP 26	Idemili/Obosi Flyover	N 06° 05’ 759’’ E 006° 48’. 571’’
27	SP 17	Open Waste Dump Opposite Metallurgical Training Institute.	N 06° 06’.134’’ E 006° 47’.980’’
28	SP 28	Ngbuka-Obosi (Old Spare Parts Market)	N 06° 06’.400’’ E 006° 47’ 947’’
29	SP 29	Amanato/ Lord Chosen Church/ Transformer Junction	N 06° 06’ 825’’ E 006° 47’.738”
30	SP 30	Eze Iweka/Ezenwa Junction	N 06° 07’. 771’’ E 006° 47’. 814’’
31	SP 31	14 Field Engr Regiment (Sign Post), Millitary Catonement, Onitsha.	N 06° 08’.300’’ E 006° 48’ 689’’
32	SP 32	Open Field Omoba, Phase 2	N 06° 09’.165’’ E 006° 49’.355’’
33	SP 33	CKC/QRC /Ugwunakpankpa Junction, Woliwo	N 06° 08’. 506’’ E 006° 47’.499’’
34	SP 34	Atani Road By Sir Tony Ezenwa Road Junction, Harbour Industrial Layout 1, Ogbaru LGA.	N 06° 07’.576’’ E 006° 46’314”
35	SP 35	New Era Goat Market/Batho-Way, Habour Industrial Layout 2, Ogbaru LGA	N 06° 07’. 337’’ E 006° 45’.966’’
36	SP 36	Second Niger Bridge Head, Ogbaru LGA	N 06° 06’.928’’ E 006° 45’.949’’
37	SP 37	GMO Company Road, Okpoko, Ogbaru LGA	N 06° 07’.073’’ E 006° 46’.468’’

Table 3(contd): Description of Sampling Point and Coordinates *Cont’d.*

S/N	Sampling Point Key	Sampling Point Location	Coordinates
38	SP 38	Ogboefere Industrial Market, Okpoko	N 06° 07’. 428’’ E 006° 47’.671’’
39	SP 39	New Heaven Layout, Okpoko (St Rita Cath Church/ Christ Holy Church)	N 06° 07’.419’’ E 006° 47’.054’’
40	SP 40	New Heaven Layout 2 (Diocese Of Ogbaru, El Shalom Convent, Okpoko.	N 06° 07’. 223’’ E 006° 47’ 237’’
41	Control Point	Ideani/Nnobi Junction, Ideani, Idemili LGA	N 06° 05’.282’’ E 006° 55’.891’’

MATERIALS AND METHODS

Sampling Procedures and Experimental design

The research was conducted at forty sampling points and one control point (Fig.2) in Onitsha metropolis and standard procedures were adopted in the sampling and field data collection (WHO, 2005).

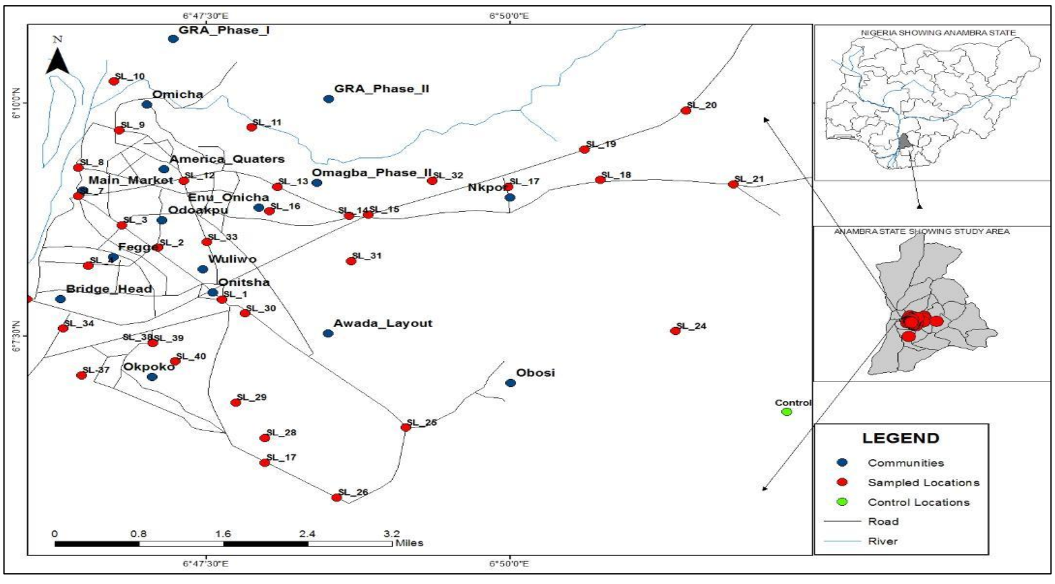

Figure 2: Map of Description of the Study Area.

The portable air quality digital equipment was deployed to collect air quality data *in situ*. Aarocet 531S was used for particulate matter while all gases were measured using Aaroqual 500 series. Also, GPS map model 76Cx mapped out sampling points coordinates and elevation.

The portable meters were held in the prevailing wind direction at about two (2) meters height with three (3) minutes exposure for air pollutant logging/reading .
The data collection was done by using portable air quality meters. This was done on an hourly basis for 3 times daily (3 hours a day) morning, afternoon, and evening for the two seasons in one year.
Essential sampling characteristics & Descriptive statistics.

Active PM sampling involved the use of an air sampling pump to actively pull air through a filter (a collection device); Passive sampling, however uses a different procedure. Remote Sensors for sampling Particulate Matter involved active sensors and passive sensors (Whalley & Zandi, 2016).
All the instruments deployed for field work sample collections and analysis were certified and calibrated in line with manufacturer's guideline before the field work measurement/data collection.

Plate 1: Aarocet 531S

Method of Data Analysis
This was done using XLSTAT software, premium version (Lumivero, 2020). in line with Standard Operating Procedures.

Model Evaluation
Statistical indices such as mean square error (MSE) , root mean sqaure error (RMSE) and mean absolute percentage error (MAPE) were used to evaluate the performances of the developed models(EPA,2007). Equations 1 to 4 were applied for the computation.
The mean square error (MSE) was computed as the mean difference between predicted and measured values using Equation (1), while the root mean square error was computed using Equation (2).

$$MSE = \frac{1}{N}\sum_{i=1}^{n}\left(Y_{pred,i} - X_{meas,i}\right) \quad (1)$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{n}\left(Y_{pred,i} - X_{meas,i}\right)^{2}\right]^{\frac{1}{2}} \quad (2)$$

where N is the number of measured data or observations.
The Mean Absolute Percentage Error (MAPE) is computed using Equation (3).

$$\text{MAPE} = \frac{1}{\text{N}}\sum_{i=1}^{\text{N}}\left|\frac{\text{X}_\text{i} - \text{Y}_\text{i}}{\text{X}_\text{i}}\right| \text{x}\,100\% \quad (3)$$

$$\text{R}^2 = \frac{\text{Explained variation}}{\text{Total variation}} = \frac{SS_M}{SS_T} = \frac{\sum_i\left(Y_{pred,i} - \overline{X}\right)^2}{\sum_i\left(X_{meas,i} - \overline{X}\right)^2} \quad (4)$$

RESULTS
Data and Analysis
The mean, standard deviation (inserted in brackets respectively) and coefficient of variation were statistically computed, and the calculated concentrations and analysis of some measured variables shown in Figures 3 to 7. The standard deviations indicate measure of dispersion of pollutants for the analyzed data. During the months in dry season, sulphur dioxide ranged in value from 0.5ppm to 2.8ppm (1.86ppm; 0.58ppm);

while in wet season the range was from 0.0ppm to 1.33ppm with mean and standard deviation of 0.73ppm and 0.41ppm (Fig.3). The mean values far exceeded the FMEnv and NAAQS permissible limits. No concentration of SO_2 was detected in both seasons at the control station (CP1), which is Ideani/Nnobi Junction, Ideani, Idemili LGA. Measured concentrations of NO_2 ranged from 0.33ppm to 3.0ppm(1.71ppm; 0.67ppm) and 0.00ppm to 1.33ppm (0.30ppm; 0.29ppm) in the seasons respectively, (Fig.4). The control station (CP1) had a value of 0.33ppm. Dry season concentrations of H_2S measured in study area vary between 0.67ppm and 2.33ppm (1.54ppm; 0.5ppm); while the rainy season value vary between 0.0ppm to 1.0ppm (0.42ppm; 0.32ppm). A measured value of 1.67ppm was recorded at the control station. The seasonal variations of the VOC measured between 0.0ppm and 2.33ppm(0.91ppm and 0.54ppm) in dry period; while the wet season concentrations vary between 0.0ppm and 0.33ppm (0.01ppm and of 0.05ppm). CO varied from 2.0ppm to 33.0ppm (12.31ppm and 6.66ppm) during the dry season; the other values vary from 0.0ppm to 20.7ppm(5.27ppm and 5.45ppm. The control station had a value of 0.33ppm. Ammonia (NH_3), varied between 0.07ppm and 3.33ppm in the dry months (1.31ppm and 0.87ppm); while the wet season value varied between 0.0ppm to 2.33ppm(0.16ppm and 0.43ppm and the control recorded 0.33ppm. Total Suspended Particulate, TSP ranged from 18.3μg/m^3 to 1506.5μg/m^3(376.7μg/m^3 and 269.6μg/m^3) and 86.4μg/m^3 to 1835.3μg/m^3 (464.9μg/m^{3}and 378.4μg/m$^{3)}$ respectively for the two seasons, while the control station in the dry and wet seasons was 78.3μg/m^3 and 67.7μg/m^3 respectively. The concentrations of PM_{10} ranged between 76.3μg/m^3 and 1070.9μg/m^3(mean value of 263.3μg/m^3; standard deviation of 171.0μg/m^3). The values obtained during rainy season ranged between 40.9μg/m^3 and 1110.3μg/m^3 with a mean value of 313.1μg/m^3 and a standard deviation of 236.8μg/m^3, while the control station shows 57.3μg/m^3 and 51.3μg/m^3 for both seasons. The values of $PM_{2.5}$ obtained after analysis for dry and wet seasons respectively ranged between 25.1μg/m^3 and 133.1μg/m^3 (68.7μg/m^3 and 18.5μg/m^3); and 31.9μg/m^3 and 184.0μg/m^3 values measured in the wet season (62.2μg/m^3 and 26.2μg/m^3). The control station shows 18.4μg/m^3 and 21.8μg/m^3 in the dry and wet seasons respectively. The mean values of all the criteria pollutants in the studied locations exceeded stipulated NAAQS limits in the dry season which pose serious challenge to public health of the inhabitants during the months that fall into this period.

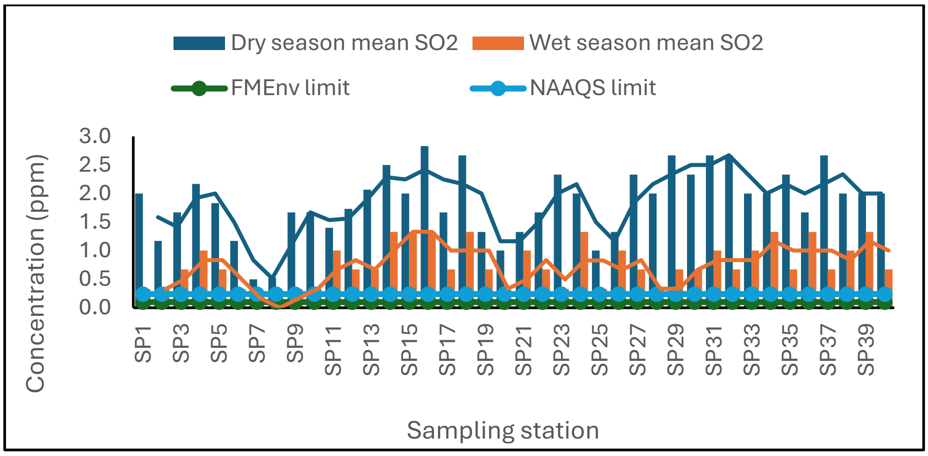

Figure 3: SO_2 Concentrations for both sampled seasons

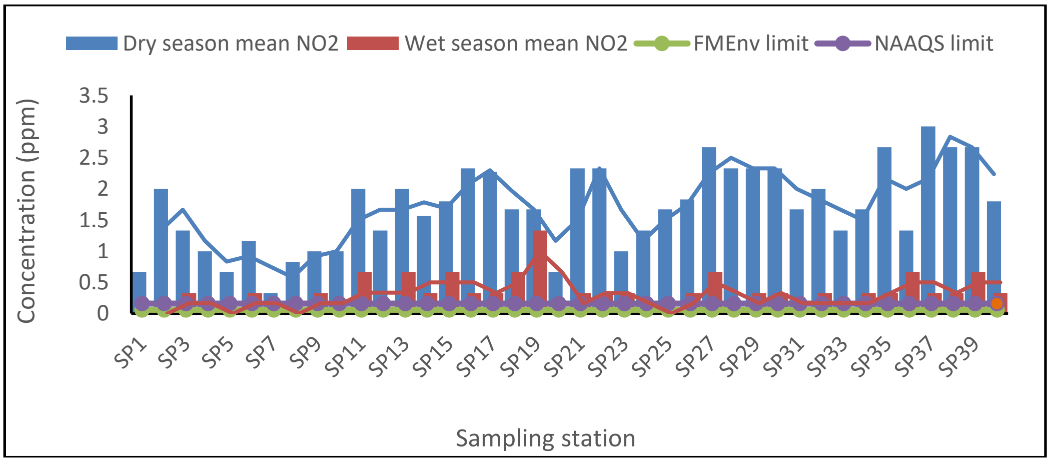

Figure 4: NO_2 Concentrations in the Study Area for both the Dry and Wet Seasons

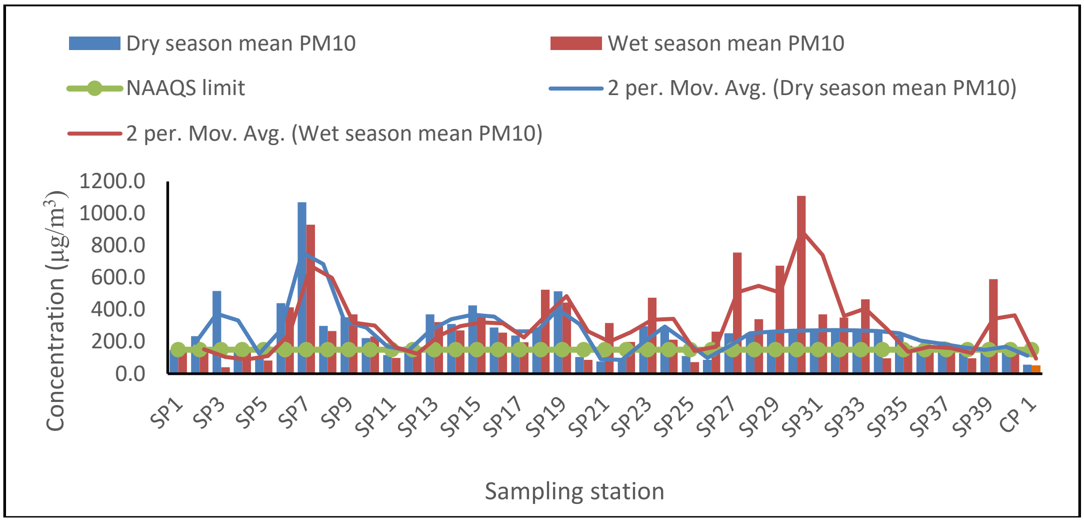

Figure 5: PM_{10} **Concentrations Measured in the Study Area in the Dry and Wet Seasons.**

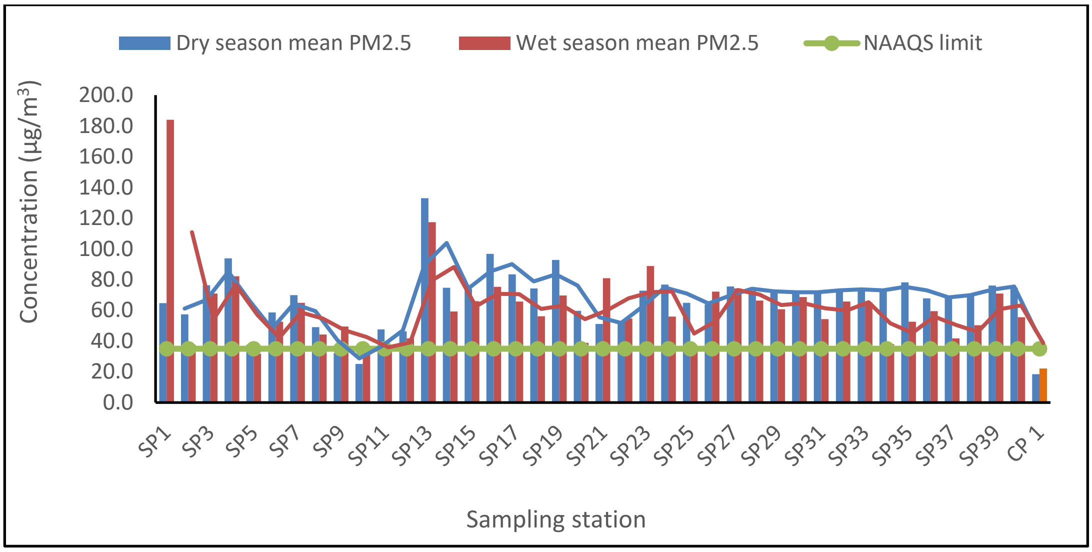

Figure 6: $PM_{2.5}$ **Concentrations Measured in the Study Area in the Dry and Wet Seasons**

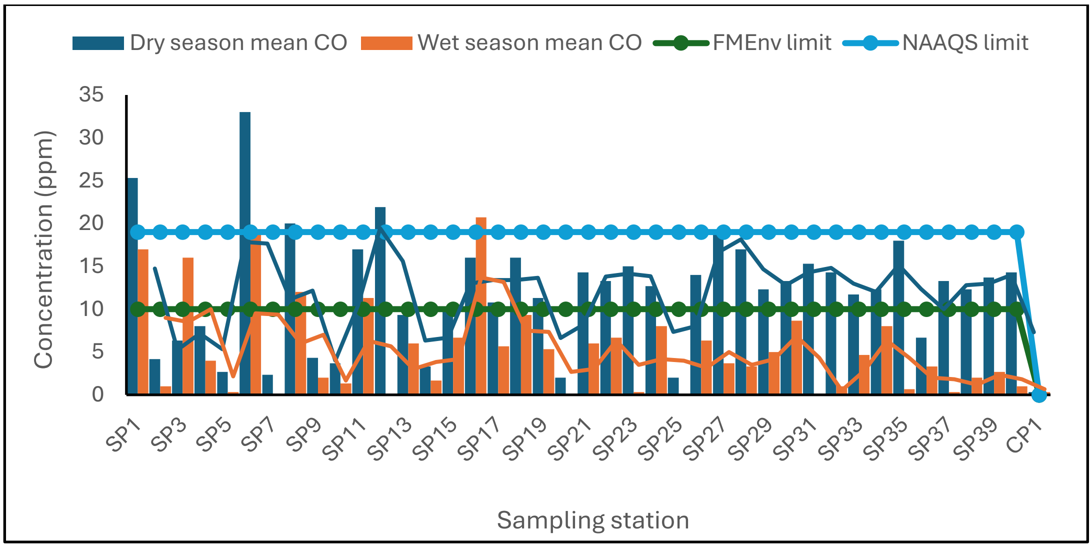

Figure 7: CO Concentrations Measured in the Study Area in the Dry and Wet Seasons

FORECASTING AIR POLLUTANT CONCENTRATIONS

Forecasting Air Pollutant Concentrations in the Dry and Wet seasons

The results of the developed air pollutant forecasting models using multiple linear regressions method for parameters that were sufficiently explained in this research are indicated in Figures 8 to 11. The models determine the influence of meteorological parameters used as input variables on air pollutant concentrations in both seasons. The model output shows a coefficient of determination (R^2), which indicates that the meteorological variables explain the derived percentage of the variability of the sampled parameters concentrations in the dry season and further implies their strength (weak or strong) and relationships with respect to the meteorological parameters in the area. The concentrations of parameters model include two errors namely, RMSE and MAPE while ANOVA indicate the significance of each developed forecasting model for the dry season are also indicated. The comparisons between the predicted and measured parameters concentrations in dry season are shown in the Figures.

Prediction of H_2S Concentrations in the Dry Season

The model output shows a coefficient of determination (R^2) of 0.240, which implies that the linear relationship between H_2S concentrations and meteorological parameters in the area is relatively weak.

$$H_2S \text{ derived model} = 1.603 + 0.224*WS - 0.0006*WD + 0.014*RH - 0.051*Temp$$

These are clearly shown in the analysis of variance below:

Analysis of variance for dry season H_2S model

RMSE (ppm)	MSE (ppm)	F-statistic	MAPE (%)	P-value	R^2
0.461	0.212	2.770	27.90	0.042	0.240

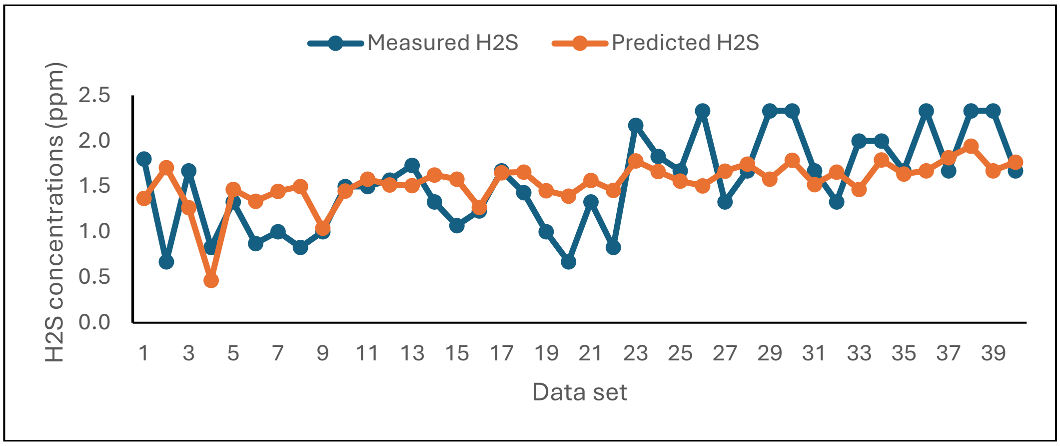

Figure 8: Comparison between Predicted and Measured H_2S Concentrations in the Dry Season

Prediction of NO_2 Concentrations in the Dry Season

The model output shows a coefficient of determination (R^2) of 0.309, which implies that the linear relationship between NO_2 concentrations and meteorological parameters in the area is relatively weak.The analysis of variance indicates that below.

$$NO_2 \text{ derived model} = 2.931 + 0.530*WS - 0.0007*WD - 0.0024*RH - 0.066*Temp$$

Analysis of variance for dry season NO_2 model

RMSE (ppm)	MSE (ppm)	F-statistic	MAPE (%)	P-value	R^2
0.585	0.342	0.535	39.68	0.010	0.309

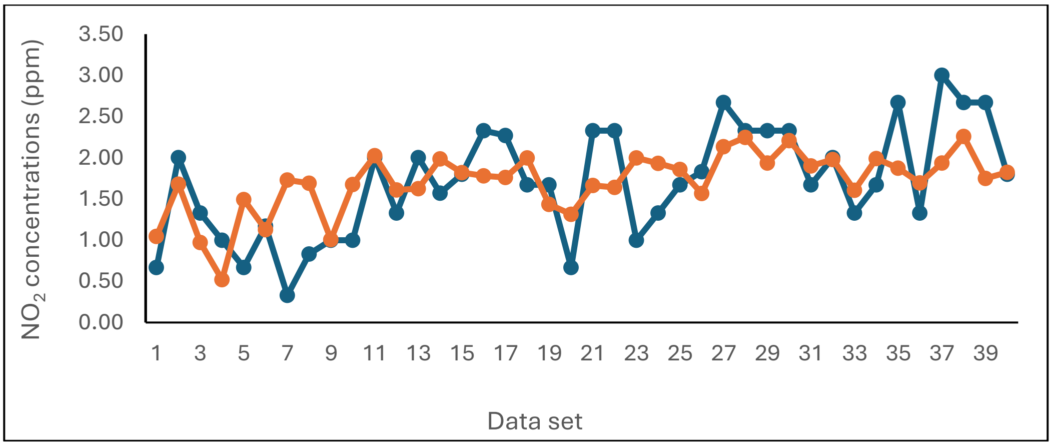

Figure 9: Comparison between Predicted and Measured NO_2 Concentrations in the

Dry Season

Prediction of VOCs Concentrations in the Dry Season

The model output shows a coefficient of determination (R^2) of 0.347, which indicates that the meteorological variables explain only about 34.7% of the variability of VOCs concentrations in the dry season which is relatively weak.

VOCs derived model = 2.707 + 0.392*WS – 0.0012*WD – 0.004*RH – 0.065*Temp

Analysis of variance for dry season NH_3 model

RMSE (ppm)	MSE (ppm)	F-statistic	MAPE (%)	P-value	R^2
0.460	0.211	4.640	54.995	0.004	0.347

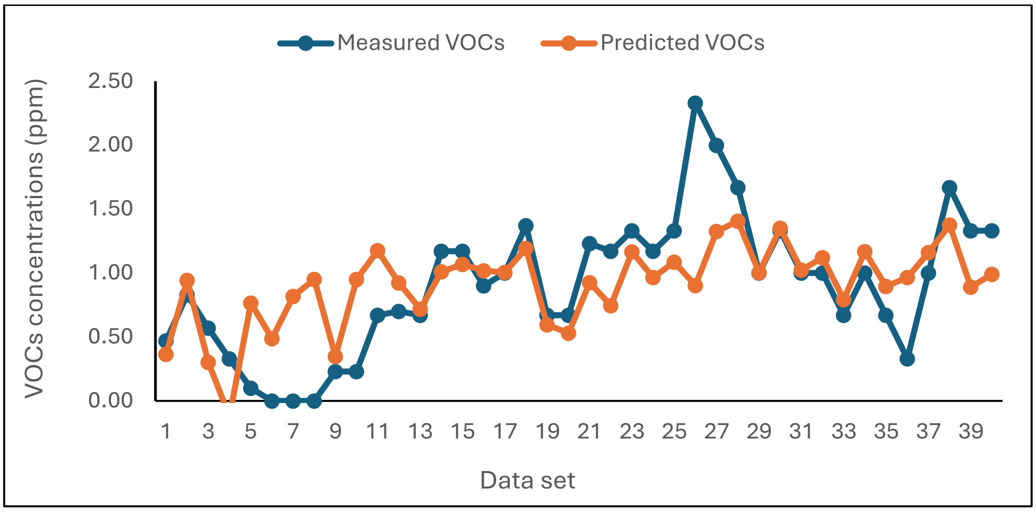

Figure 10: Comparison between Predicted and Measured VOCs Concentrations in the Dry Season

Prediction of SO_2 Concentrations in the Wet Season

The model output shows a coefficient of determination (R^2) of 0.272, indicating that there is a weak linear relationship between the concentrations of SO_2 and meteorological parameters in the area.

SO_2 developed model = 4.559 + 0.333*WS + 0.0011*WD – 0.0011*RH - 0.144*Temp

Analysis of variance for wet season SO_2 model

RMSE (ppm)	MSE (ppm)	F-statistic	MAPE (%)	p-value	R^2
0.373	0.139	3.267	37.686	0.022	0.272

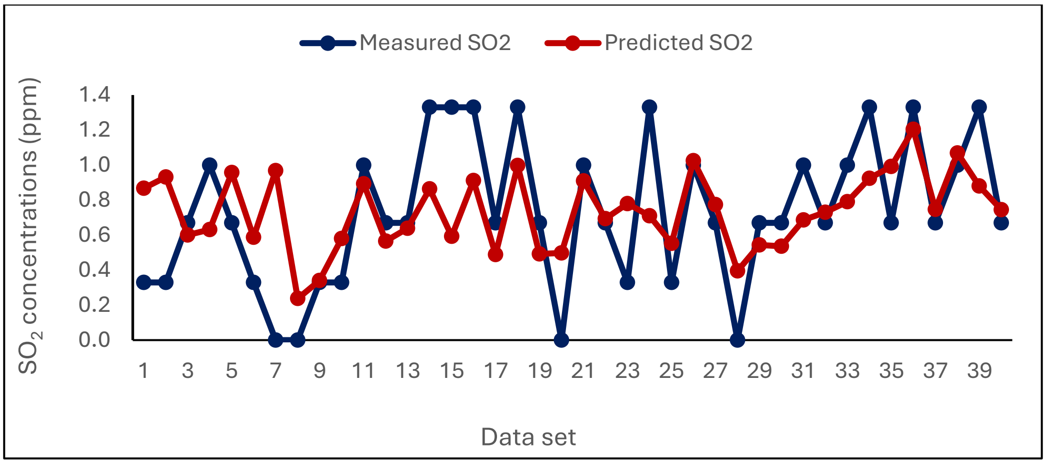

Figure 11: Comparison between Predicted and Measured SO_2 Concentrations in the Wet Season

DISCUSSION

The mean values of SO_2, NO_2 exceeded FMEnv and NAAQS permissible limits in both the dry and wet seasons; hotspot is observed around *Nkpo* area dispersing from the central region of the study area to the Northern, Eastern and Western parts (Fig.3,4). The higher values for SO_2, NO_2 during dry season in Onitsha may be due to increased emissions by the burning of fossil fuels during transportation, combustion processes by industries and traffic (Bralic et al.,2012). This indicates that the mean values of all the criteria pollutants in the area exceeded stipulated NAAQS limits in the dry season and pose serious hazards to human health in the dry season period. SO_2(in dry deposition or dissolved forms) and its associated compounds contribute to the formation of acid rain and radiative forcing of climates. The computed mean level of CO exceeded stipulated limit in the dry season, but within limit in the wet season and poses low immediate hazard to human health (Fig.7). PM_{10} hotspot was observed around the *Main Market* in the dry season, while the hotspot was observed close to Onitsha in the wet season (Fig.5). The high concentration of PM10 during the dry season could be as a result high occurrence and transport of dust storms in the North -East direction (LingYang,2003). Other factors may be the impact of regional meteorology over local events and sources and relatively large coarse particles (Gehrig & Buchmann,2003, Sowaboma et al.,2022). PM 2.5 value of 68.7µg/m3 in the dry season which is higher than the value in wet season is consistent with other findings in some Nigerian cities (Shuaibu & Nwagbara,2017). $PM_{2.5}$ hotspot was observed around *Bridge* head and *Awada* Layout dispersing along the Northeast-Southwest region (Fig.6). Transportation activities, combustion by industrial activities, electric generators, dust particles from untarred roads and local combustion activities were identified as the major contributors of air pollution in the study area. Wind direction is predominantly North-east in the dry season and South-west in the wet season.

This shows that SO_2, NO_2, PM_{10} and $PM_{2.5}$ also pose great risk to human health in the wet season and asthmatic people might be at greater risk, while CO poses low immediate hazard to human health.

PM_{10} and $PM_{2.5}$ exceeded the Nigeria ambient limits. These are fugitive emissions that are associated from points where exhausts are not captured and passed through a stack (Arif & Abdullahi,2022). Particulate matter especially PM2. 5, affects ecosystems, climate and visibility in the atmosphere (Sultan & Pillai,2023). Some constituents of the ambient PM mixture promote climate warming (e.g., black carbon), while others have a cooling influence (e.g., nitrate and sulfate). PM can adversely affect ecosystems, including plants, soil, and water through deposition of PM which may affect the ability of stomata on plant leaves during photosynthesis and may pose some challenge on food security in the area. Particulate matter (PM) is one of the most important constituents of air pollution which adversely effects air quality (Seinfeld and Pandis, 2016) , human health (Pope and Dockery, 2006; Kampa and Castanas, 2008; Anderson et al., 2012;) and ecosystems (Grantz et al., 2003). Studies have shown that the life expectancy of the population can change drastically in areas densely polluted by atmospheric aerosols (SoGA,2023 &Pope et al., 2009) putting Onitsha residents to greater public health dangers. Acute Lower Respiration Infection (ALRI) among residents of Onitsha residents has a direct relationship with contamination of the earth's atmosphere by particulate matters especially PM 2.5 (Horne et al,2018).

The intricacy of studying PM as is the case during this study increases when coupling its effects with climate change, as air quality and climate change have intertwined interactions (Kinney, 2008; Wild, 2009; Seinfeld & Pandis, 2016). Changes in Onitsha meteorological conditions have varied effects on air quality and climate change and are affected by the radiative forcing of air pollutants measured during the period of this investigation. These effects can, in some cases, be similar in direction, or they may cause inverse outcomes when compared with results from other Nigerian cities. Therefore, it is necessary to explore the effects of each driver separately and relate them to national guidelines values. Other atmospheric air pollutants such as NOx, SO2 and CO are mainly associated with combustion processes from exhaust and open burning which is not considered good practice and should be avoided in Onitsha, as the generation of polluting emissions from this type of source cannot be controlled effectively. Results of developed multiple linear forecasting models show that meteorological parameters do not significantly explain how CO, NH_3 SO_2, TSP, PM_{10} and $PM_{2.5}$ vary in the studied locations of Onitsha in the dry season months. However, the study found that meteorological parameters significantly explain the variations of H_2S, NO_2 and VOCs concentrations during this period of study. Similarly, it was found that meteorological parameters do not significantly explain the variations of CO, H_2S, NH_3, NO_2, VOCs, TSP, PM_{10} and $PM_{2.5}$ concentrations in the wet season, but significantly explain the variation of SO_2 concentrations in the wet season. The degree of variations of the air pollutants with meteorological parameters may be attributed to local sources, which is due mainly to transportation activities in the study area. The study also found a weak linear relationship between the air pollutant concentrations and meteorological parameters. This finding corroborated with studies by Yorkor *et al.,* (2017), Petrovski,2015; and Antai *et al.,* 2020d), who in their studies reported a poor linear relationship between the air pollutant concentrations and meteorological variables in Port Harcourt, Nigeria. In another study, Munir (2015) reported that a nonlinear relationship exists between air pollutants and meteorological parameters. This was further corroborated by Carslaw (2019).

SUMMARY AND CONCLUSION

The outcome of this research showed that the mean concentration levels of SO_2, NO_2, PM_{10} and $PM_{2.5}$ were high in both the dry and wet seasons, exceeding stipulated NAAQS limits; the mean concentrations of CO exceeded the limit in the dry season but within the limit in the wet season The mean concentrations of H_2S, VOCs and NH_3 were high in the dry season and low in the wet season. The study showed that the mean values of all the criteria pollutants in the area exceeded stipulated limits set by National Ambient Air Quality

Standards (NAAQS) and Federal Ministry of Environment (FMEnv) of Nigeria. The levels of these climate forcers promote climate change related adverse effects on human health of Onitsha residents and the environment.SO_2, NO_2, TSP, PM_{10} and $PM_{2.5}$ pollutants were found to pose greater risk to public health. Chronic exposure to these parameters contributes to the risk of developing cardiovascular and respiratory diseases as well as lung cancer. $PM_{2.5}$ penetrates deeply into the lungs and could lead to Chronic Obstructive Pulmonary Diseases (COPD) and possibly cancer. Combustion of fossil fuels during transportation and industrial activities are the main causes of atmospheric contamination in Onitsha. Onitsha, a port city in southern Nigeria, had the world's worst air (PM_{10} pollutants) in 2016 with PM_{10} annual concentration of 594 ug/m3 – WHO (2015). The data from the current research shows that PM_{10} values were 263.3 ug/m3 in dry season and 313 ug/m3 in wet season. These concentrations exceeded the Nigerian ambient limit of 250 ug/m3 and 15 ug/m3(annual),45 ug/m3 of WHO 2021 air quality. Also, for $PM_{2.5}$ the value for the present study indicates that dry season had 68.7 ug/m3 and 62.2 ug/m3 for wet season. These concentrations exceeded the Nigerian ambient limit of 46.3 ug/m3 and 5 ug/m3(annual).

In other Nigerian cities, the situation reports of air pollution the impact on the environment and public health did not differ much from the findings of the present study. This summary finding in some Nigerian geographical space shows that on average, people living around the Niger Delta Region of Nigeria are likely to lose nearly 6 years of life expectancy if the air pollution situation around the area is not controlled, (AQLI, 2021) report has revealed. Air pollution is second only to HIV/AIDS in terms of impact on life expectancy in Nigeria according to Chicago's report (AQLI,2021). More than 114,000 people died from air pollution in Nigeria in 2017, the top in Africa as per health effects with Kano state, Nigeria had Africa's worse air pollution in 2018 – (IQAir,2018). Nigeria's air quality monitoring agency does not issue air quality alerts even when air quality levels are expected to adversely impact health. Nigeria has a mortality rate for air pollution of 307.4 for every 100,000 people (WHO.2021).

RECOMMENDATIONS

Control strategies that can both reduce emissions from burning fossil fuels and the adverse impacts on environment and public health. For example, controls for organic compounds will reduce emissions of pollutants that form ground-level ozone and emissions of methane, a pollutant that has a global warming potential of 28 times CO2. Also, measures that lessen the demand for energy (e.g., using more energy efficient products) reduce associated air pollution and carbon emissions from power plants. Sources of black carbon emissions include diesel engines, brick kilns and burning of biomass (including burning wood for heating). Because fine particle pollution has harmful health effects, controlling emissions of black carbon from these and other sources can have positive impacts on both health and climate. The government at Federal and State levels should aim at meeting up with the sustainable Development Goals (SDGs) as it relates to air pollution and climate change. There is a connection between air quality and Sustainable Development Goals in terms of goals, target and indicator (Arif & Abdullahi,2022).

Artificial Neural Network that mimics animal behaviour characteristics is an advanced mathematical model of distributed parallel information processing that has capabilities of self-learning and self-adaptation. This can be used for further studies to explain the concentration of pollutants and meteorological parameters. Other models that can be suggested for further studies include Support Vector Machine, Fuzzy Time Series Analysis, Three Dimensional models such as Emission methods, the atmospheric dispersion modelling system, the California Puff model and CALMET Model.

Based on the outcomes and findings of the study, the researchers recommend the following measures:

1) Regular medical check-ups on the inhabitants of Onitsha metropolis should be conducted periodically.
2) Regulatory agencies should monitor Air quality regularly in their stations around the Onitsha metropolis.
3) The State Government should enforce environmental compliance laws and regulate the activities of industries in the areas.
4) All untarred roads should be tarred to reduce particulate pollution.
5) Flyover bridges should be constructed at major junctions to reduce traffic congestion in Onitsha metropolis.
6) Further studies should be carried out to assess the impact of air pollution on the health of the people of Onitsha metropolis.
7) Advanced modelling methods should be carried out to evaluate and explain fully the nonlinear relationship between air pollutants and meteorological parameters.

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STATEMENTS AND DECLARATIONS

Ethical Approval

The authors did not indulge in any act of misconduct such as misrepresenting research results and intend to maintain the integrity of the research by following rules of good scientific practice as outlined in the code of practice of this journal.

Individual Participants consent

All individual participants in this research gave their unconditional consents for the various activities at the locations .

Consent to Publish

The participants consented to the publishing of some case studies mentioned in the study area to the journal. However, the research did not involve animals and as such no consent on welfare of animals was sought.

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Competing Interests

The authors have no competing interests to declare that are relevant to the content of this article

Authors Contributions

All authors contributed to one form or the other to this draft manuscript. The field data gathering, literature preparation and data analysis were performed by Asso. Prof Johnbosco Umunnakwe, Surv Dr Richard Njoku and Dr (Mrs) Bernadine Umunnakwe. The first draft of the manuscript was written by Asso. Prof Johnbosco Umunnakwe and all authors read and approved of the final manuscript.

DATA AVAILABILITY

This research falls under Environmental Sciences and my data should be deposited in Generalist Repositories. The data generated and research findings in this study are available from the corresponding author on reasonable request.

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APPENDICES

The appendices contain the results of the measured concentrations of other parameters for dry and wet seasons and comparisons between predicted and measured concentrations of the parameters which were not placed in the main paper for publication (Figs.i-xv).

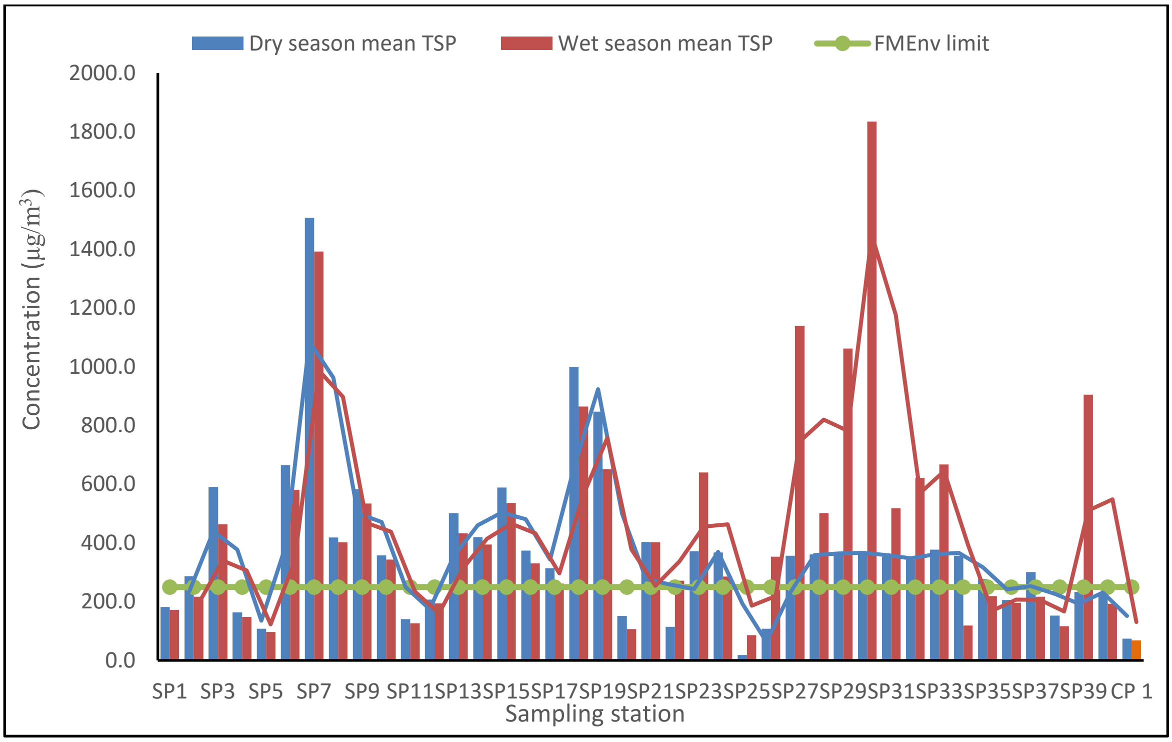


Figure i: TSP Concentrations Measured in the Study Area in the Dry and Wet Seasons

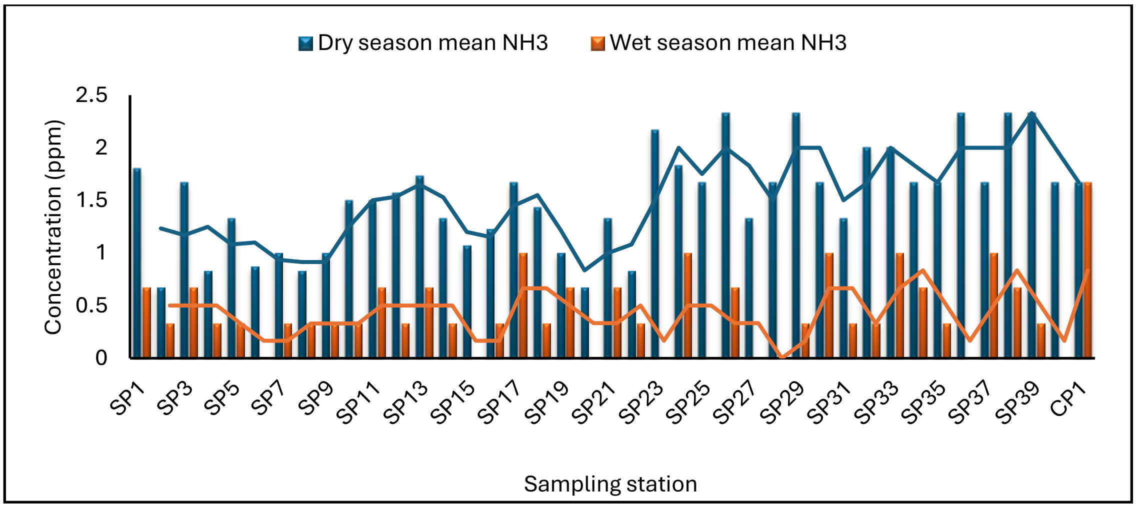


Figure ii: NH_3 Concentrations Measured in the Study Area in the Dry and Wet Seasons

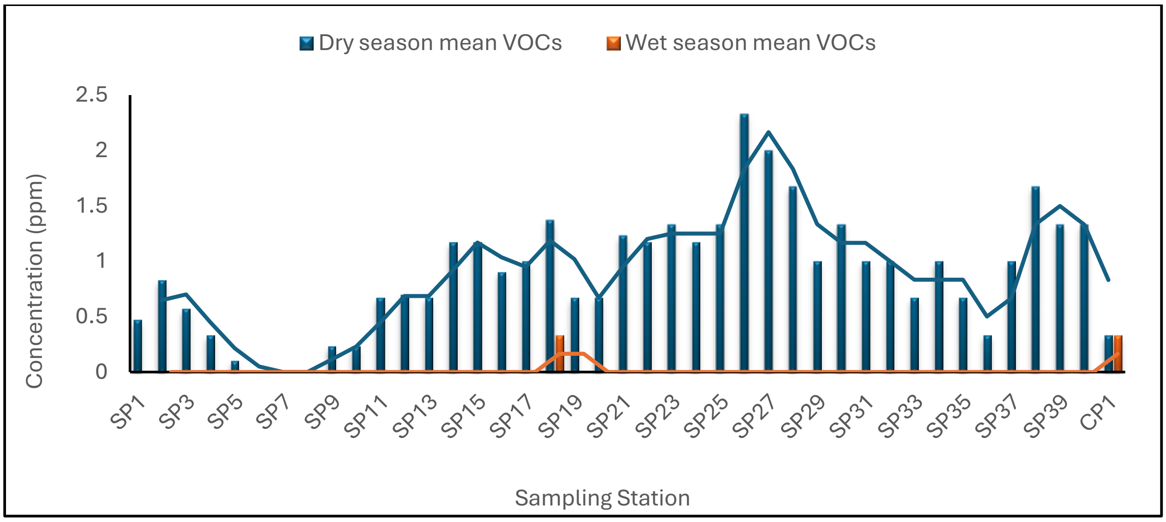


Figure iii: VOC Concentrations Measured in the Study Area in the Dry and Wet Seasons

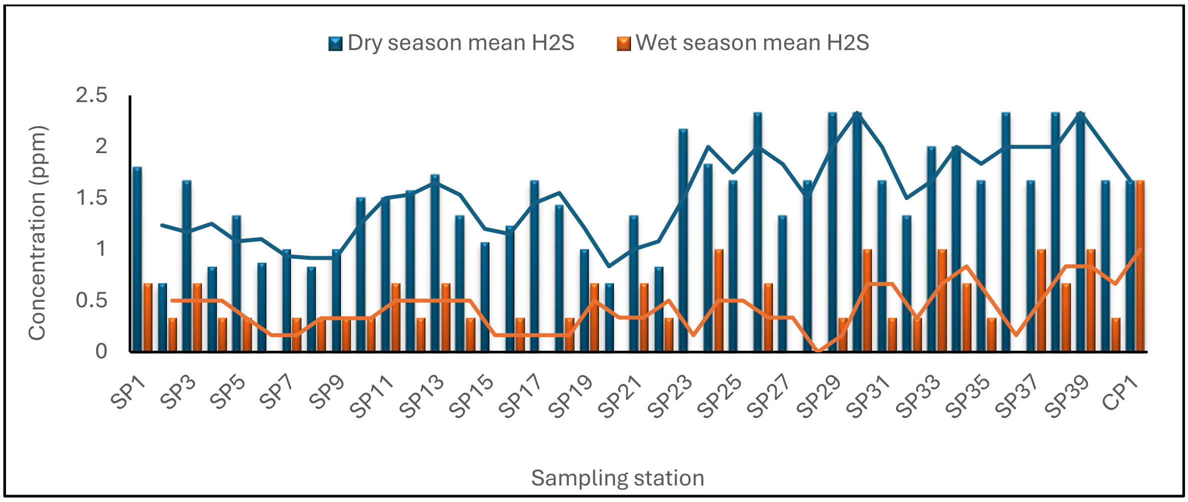


Figure iv: H_2S Concentrations Measured in the Study Area in the Dry and Wet Seasons

Prediction of CO Concentrations in the Dry Season

The model output shows a coefficient of determination (R^2) of 0.058, which implies that there is a weak linear relationship between CO concentrations and meteorological parameters in the area.

CO derived model = 38.794 - 0.782*ws – 0.0096*wd – 0.0497*rh - 0.5611*temp

Table 4: Analysis of variance for dry season CO model

RMSE (ppm)	MSE (ppm)	F-statistic	MAPE (%)	P-value	R^2
6.83	24.92	0.535	85.08	0.711	0.058

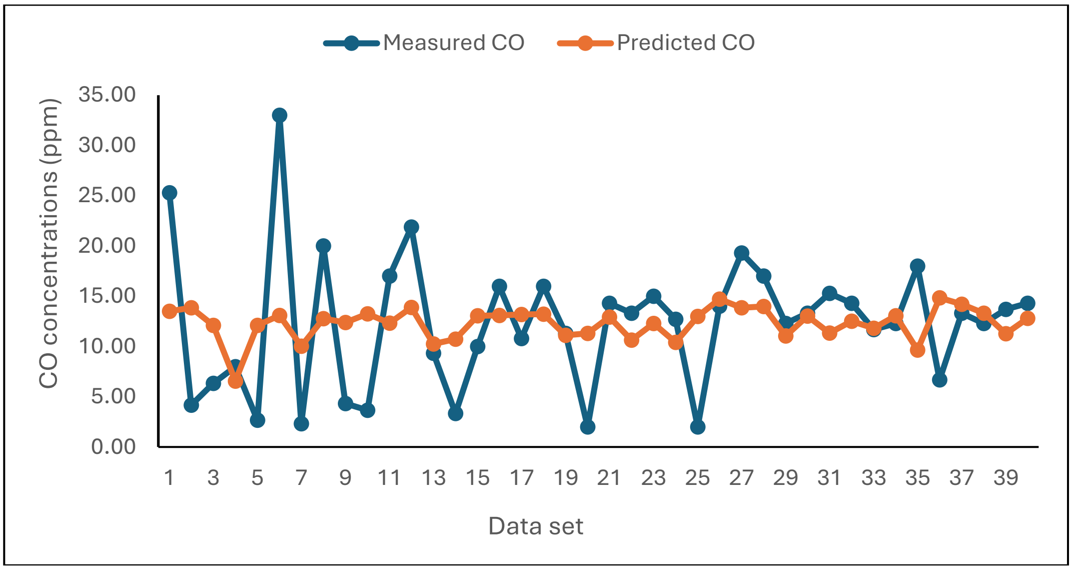


Figure v: Comparison between Predicted and Measured CO Concentrations in the Dry Season

This linear relationship between NH_3 concentrations and meteorological parameters in the area is relatively weak.

NH_3 derived model= 3.653 – 0.098*WS – 0.0005*WD + 0.0101*RH – 0.087*Temp

Table 6: Analysis of variance for dry season NH_3 model

RMSE (ppm)	MSE (ppm)	F-statistic	MAPE (%)	P-value	R^2
0.872	0.760	0.861	116.4	0.497	0.090

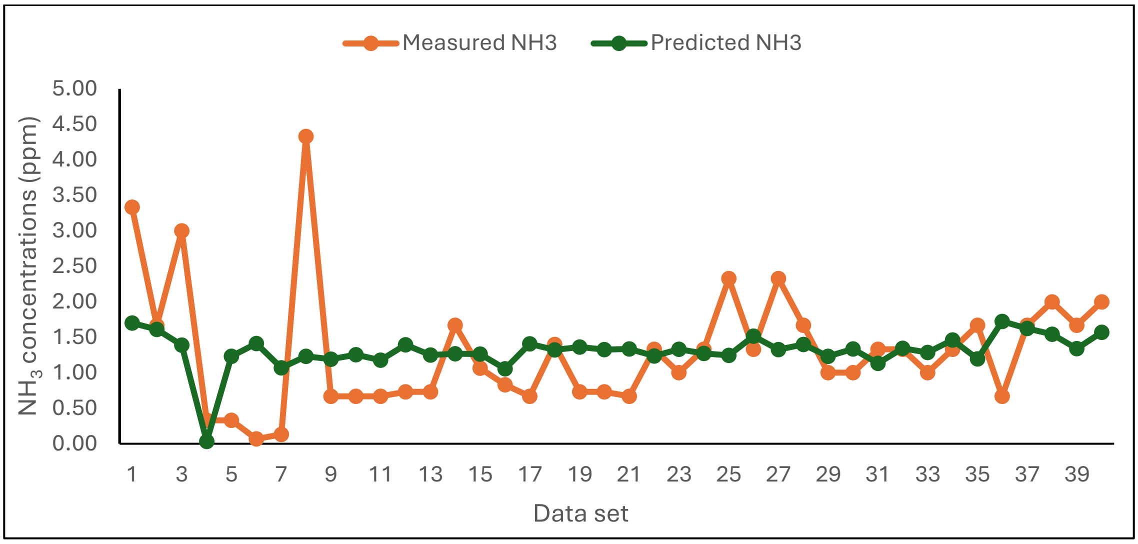


Figure vi: Comparison between Predicted and Measured NH_3 Concentrations in the Dry Season

Prediction of SO_2 Concentrations in the Dry Season
The R^2 value implies that the linear relationship between SO_2 concentrations and meteorological parameters in the area is relatively weak.

$$SO_2 = 3.192 + 0.367*WS + 0.0004*WD - 0.018*RH - 0.022*Temp$$

Table 8: Analysis of variance for dry season NH_3 model

RMSE (ppm)	MSE (ppm)	F-statistic	MAPE (%)	P-value	R^2
0.558	0.312	1.815	32.670	0.148	0.172

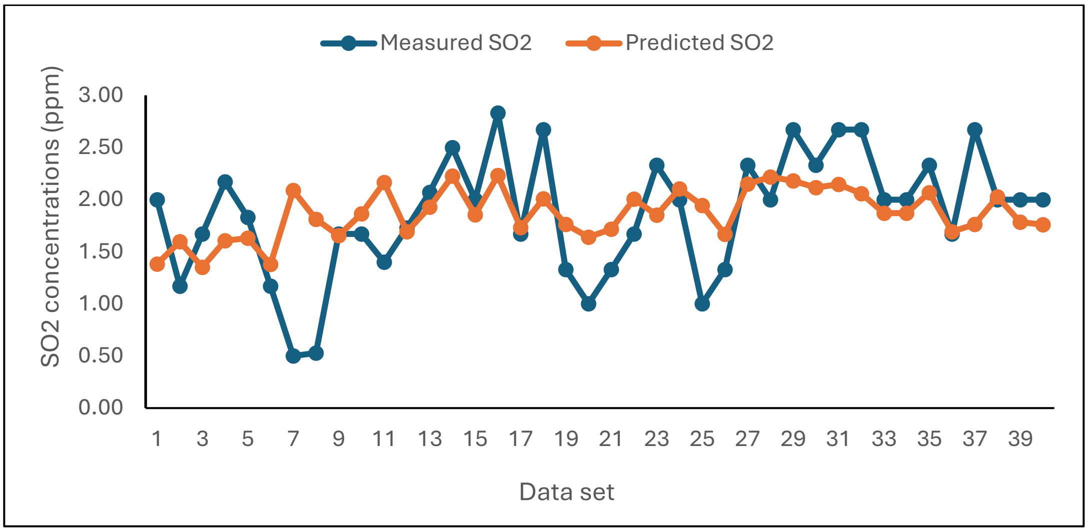


Figure vii: Comparison between Predicted and Measured SO_2 Concentrations in the Dry Season

Prediction of TSP Concentrations in the Dry Season
The model output shows a coefficient of determination (R^2) of 0.052, which implies that the linear relationship between TSP concentrations and meteorological parameters in the area is relatively weak.

$$TSP = 476.197 + 17.616*WS + 0.538*WD - 3.164*RH + 1.424*Temp$$

Table 10: Analysis of variance for dry season NH_3 model

RMSE (μg/m^3)	MSE (μg/m^3)	F-statistic	MAPE (%)	p-value	R^2
277.118	76794.530	0.481	101.353	0.749	0.052

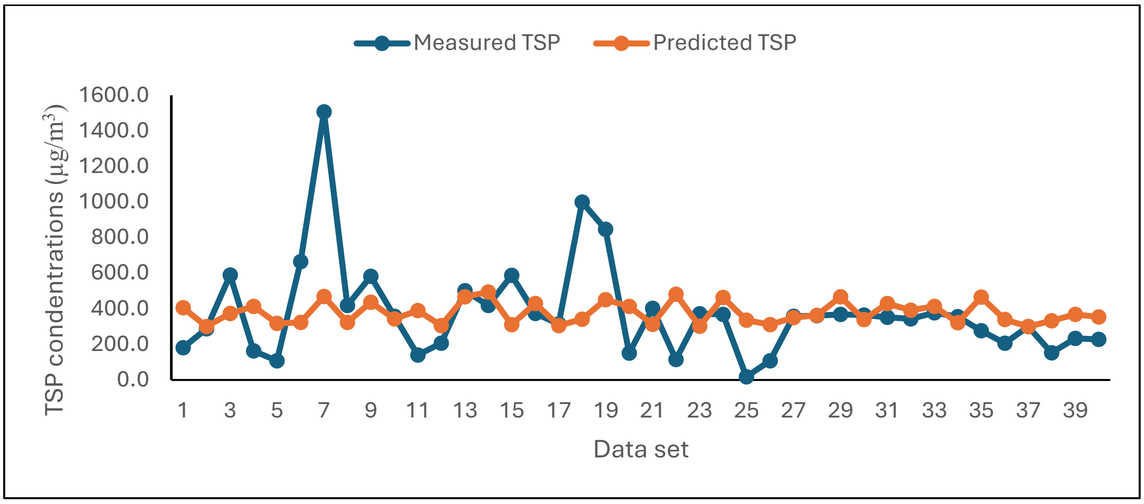


Figure viii: Comparison between Predicted and Measured TSP Concentrations in the Dry Season

Prediction of PM_{10} Concentrations in the Dry Season

Given the p-value and the F-statistic (Table 4.11), the meteorological parameters do not significantly explain the variation of PM_{10} concentrations in the area (p-value = 0.449). However, the goodness of fit (Figure 4.49) between predicted and measured values indicated a poor linear relationship between PM_{10} and meteorological parameters with a coefficient of determination (R^2) of 0.098.

$$\mathbf{PM_{10} = 124.758 + 11.907*WS + 0.478*WD - 1.1824*RH + 4.092*Temp}$$

Analysis of variance for dry season PM_{10} model

RMSE (µg/m³)	MSE (µg/m³)	F-statistic	MAPE (%)	p-value	R^2
171.457	29397.335	0.946	52.628	0.449	0.098

Figure vix: Goodness of Fit between Predicted and Measured PM_{10} Concentrations in the Dry Season

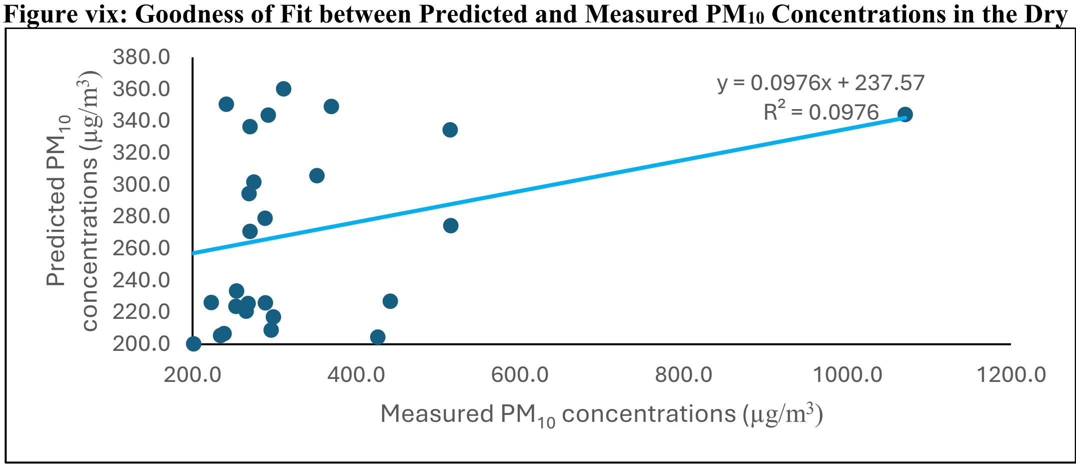
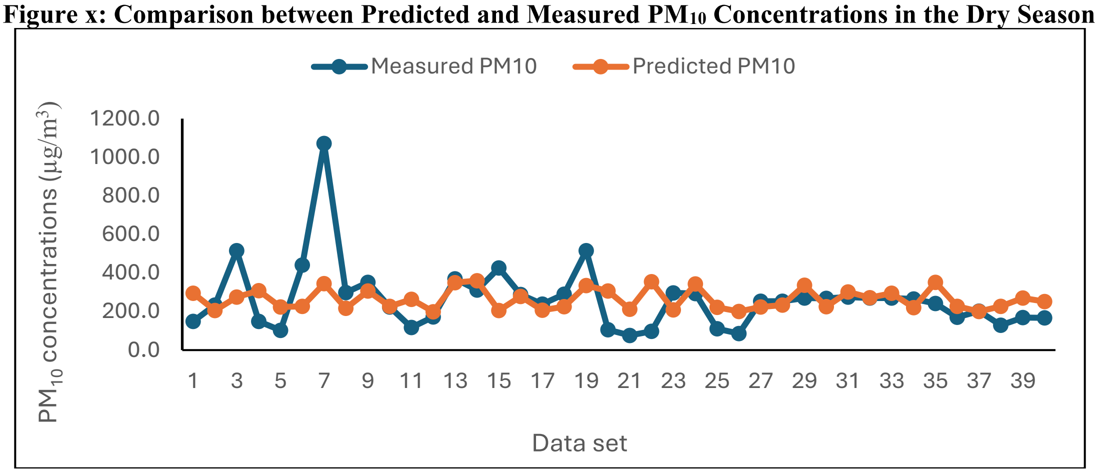


Figure x: Comparison between Predicted and Measured PM_{10} Concentrations in the Dry Season



Prediction of $PM_{2.5}$ Concentrations in the Dry Season
The derived model shown in Equation (4.9) was used to forecast $PM_{2.5}$ concentrations in the study area in the dry season.

$$PM_{2.5} \text{ derived model} = -42.232 + 9.006*WS + 0.053*WD + 0.300*RH + 1.631*Temp$$

Analysis of variance for dry season $PM_{2.5}$ model

RMSE (μg/m³)	MSE (μg/m³)	F-statistic	MAPE (%)	p-value	R^2
17.664	312.033	1.974	21.339	0.120	0.184

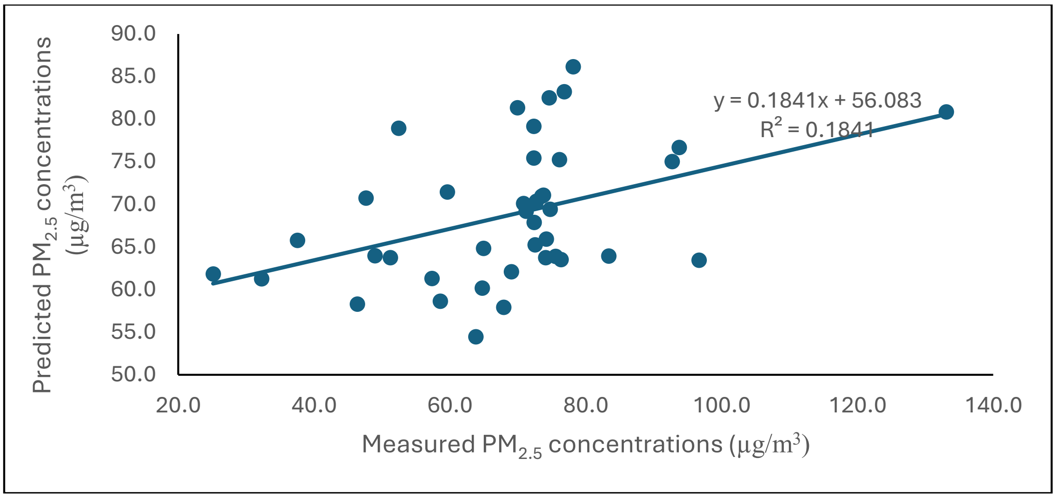


Figure xi: Goodness of Fit between Predicted and Measured $PM_{2.5}$ Concentrations in the Dry Season

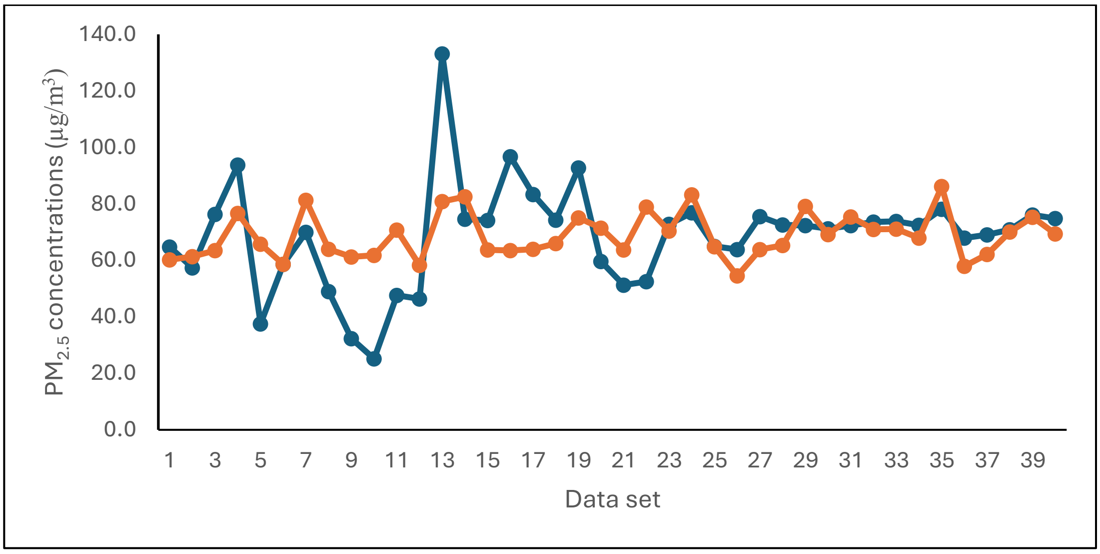


Figure xii: Comparison between Predicted and Measured PM_{10} Concentrations in the Dry Season

Forecasting Air Pollutant Concentrations in the Wet Season
The results of the developed models in wet season and Analyses of Variance (ANOVA) are shown in Figures 4.53 to 4.70 and tables 4.13 to 4.21.

Prediction of CO Concentrations in the Wet Season
The model output shows a coefficient of determination (R^2) of 0.010, which indicates weak linear relationship between CO concentrations and meteorological parameters in the area.

$$CO = -6.269 + 0.108*WS - 0.006*WD + 0.015*RH + 0.373*Temp$$

Analysis of Variance for Wet Season CO Model

RMSE (ppm)	MSE (ppm)	F-statistic	MAPE (%)	p-value	R^2
5.725	32.780	0.087	230.402	0.986	0.010

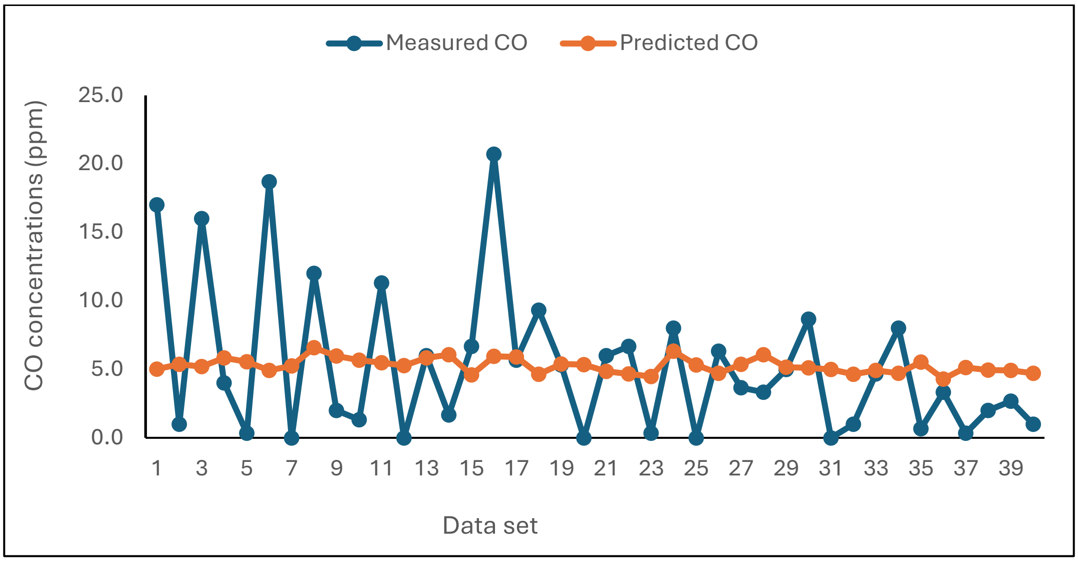


Figure xiii: Comparison between Predicted and Measured CO Concentrations in the Wet Season

Prediction of H_2S Concentrations in the Wet Season

The model output shows a coefficient of determination (R^2) of 0.141, indicating that the meteorological variables explains only about 14.10% of the variability of H_2S concentrations in the wet season, which is weak.

$$H_2S = 0.784 + 0.032*WS - 0.0009*WD + 0.005*RH - 0.022*Temp$$

Table 14: Analysis of Variance for Wet Season H_2S Model

RMSE (ppm)	MSE (ppm)	F-statistic	MAPE (%)	p-value	R^2
0.312	0.097	1.440	37.374	0.241	0.141

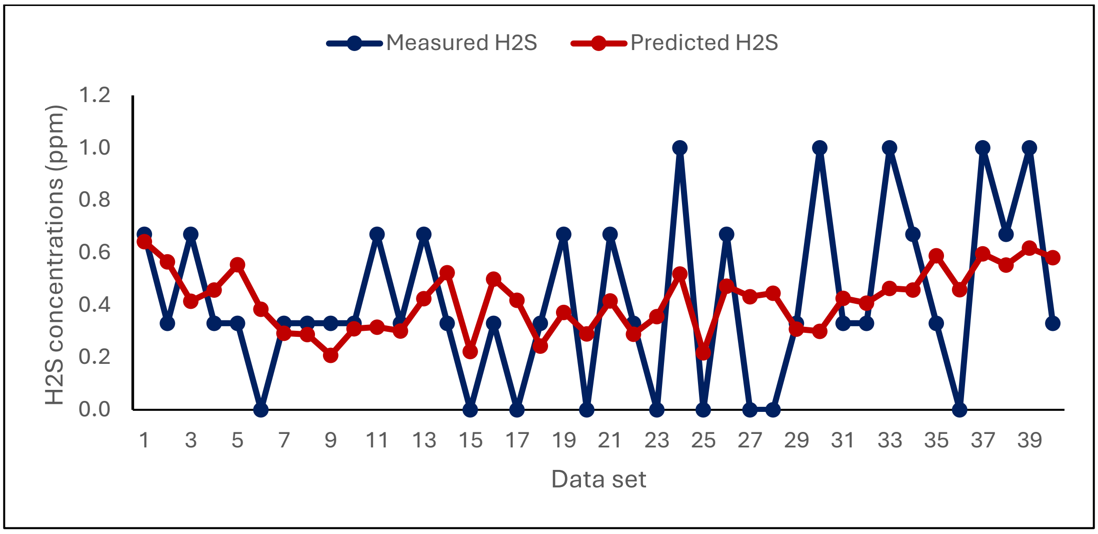


Figure xiv: Comparison between Predicted and Measured H_2S Concentrations in the Wet Season

Prediction of NH_3 Concentrations in the Wet Season

The model output shows a coefficient of determination (R^2) of 0.155, indicating that there is a weak linear relationship between NH_3 concentrations and meteorological parameters in the area.

$$NH_3 = - 6.795 - 0.042*WS - 0.002*WD + 0.022*RH + 0.184*Temp$$

Analysis of variance for wet season NH_3 model

RMSE (ppm)	MSE (ppm)	F-statistic	MAPE (%)	p-value	R^2
0.420	0.177	1.602	66.582	0.196	0.155

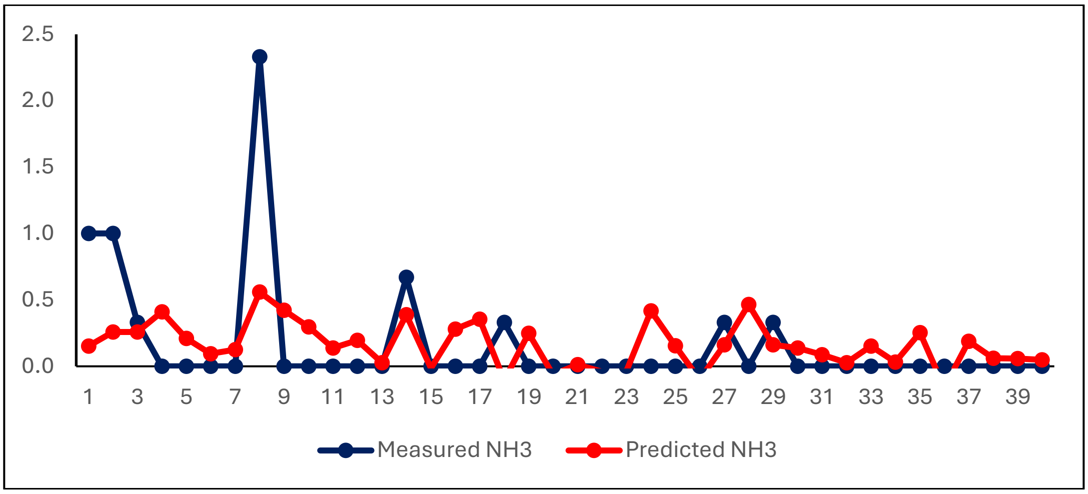


Figure xv: Comparison between Predicted and Measured NH_3 Concentrations in the Wet Season

Prediction of NO_2 Concentrations in the Wet Season

The model output shows a coefficient of determination (R^2) of 0.117, indicating a weak linear relationship

. **NO_2 = 4.655 + 0.0216*WS + 0.0012*WD – 0.016*RH - 0.110*Temp.**

Table 16: Analysis of Variance for Wet Season NO_2 Model

RMSE (ppm)	MSE (ppm)	F-statistic	MAPE (%)	p-value	R^2
0.288	0.083	1.159	29.630	0.346	0.117

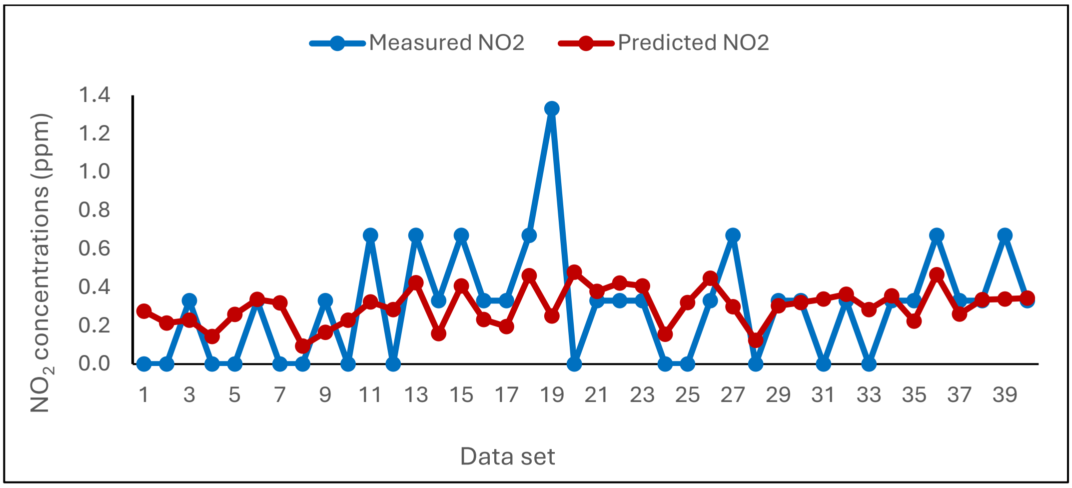


Figure xvi: Comparison between Predicted and Measured NO_2 Concentrations in the Wet Season

Prediction of VOCs Concentrations in the Wet Season

The model output shows a coefficient of determination (R^2) of 0.191, indicating that there is a weak linear relationship between VOCs concentrations and meteorological parameters in the area.

VOCs = 0.350 +0.0298*WS + 0.0003*WD – 0.0012*RH – 0.011*Temp

Analysis of variance for wet season VOCs model

RMSE (ppm)	MSE (ppm)	F-statistic	MAPE (%)	p-value	R^2
0.050	0.002	2.064	78.890	0.107	0.191

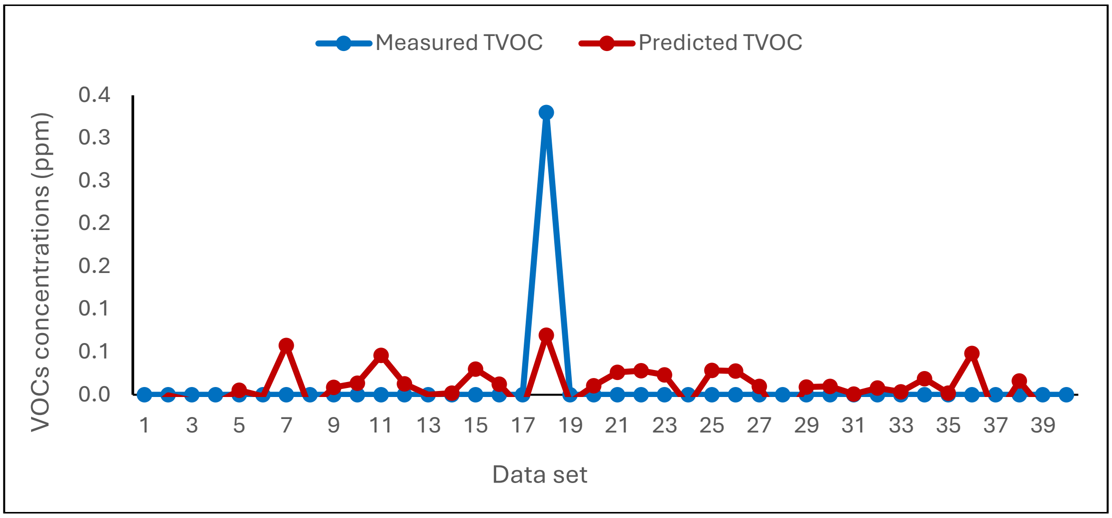


Figure xvii: Comparison between Predicted and Measured VOCs Concentrations in the Wet Season

Prediction of TSP Concentrations in the Wet Season
Analysis of variance for wet season TSP model

RMSE (μg/m³)	MSE (μg/m³)	F-statistic	MAPE (%)	p-value	R^2
374.426	140194.813	1.207	93.204	0.325	0.121

The model output shows a coefficient of determination (R^2) of 0.121, indicating that there is a weak linear relationship between the concentrations of TSP and meteorological parameters in the area.

TSP developed model = - 1065.225 - 78.530*WS + 1.266*WD + 4.083*RH + 35.902*Temp **(15)**

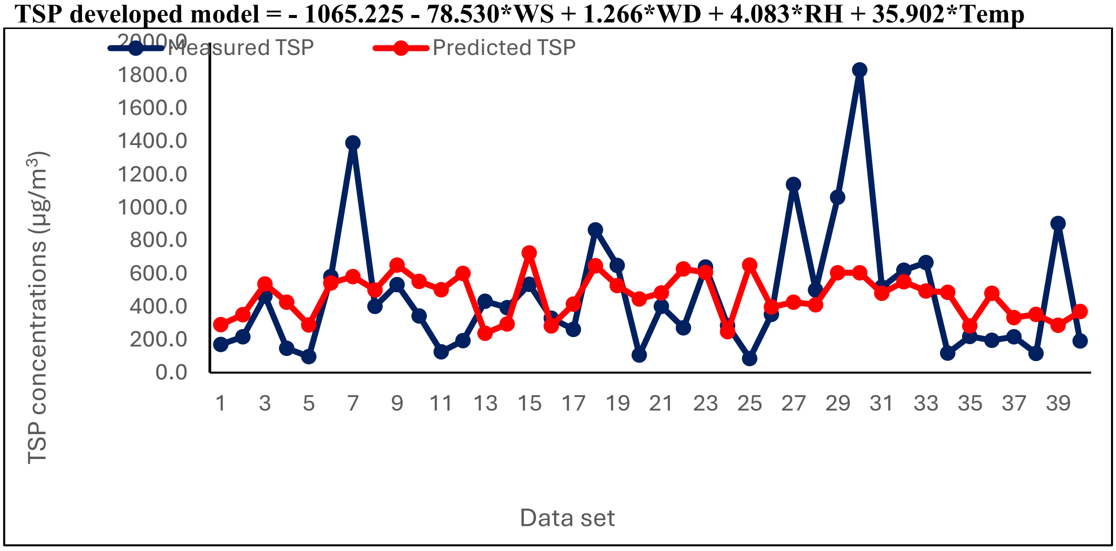


Figure xviii: Comparison between Predicted and Measured TSP Concentrations in the Wet Season

Prediction of PM_{10} Concentrations in the Wet Season
The model output shows a coefficient of determination (R^2) of 0.101, indicating that there is a weak linear relationship between the concentrations of PM_{10} and meteorological parameters in the area.

PM_{10} = - 107.967 - 26.298*WS + 0.797*WD + 0.229*RH + 9.954*Temp **(16)**

Table 20: Analysis of variance for wet season PM_{10} model

RMSE (μg/m³)	MSE (μg/m³)	F-statistic	MAPE (%)	p-value	R^2
237.073	56203.576	0.978	92.121	0.432	0.101

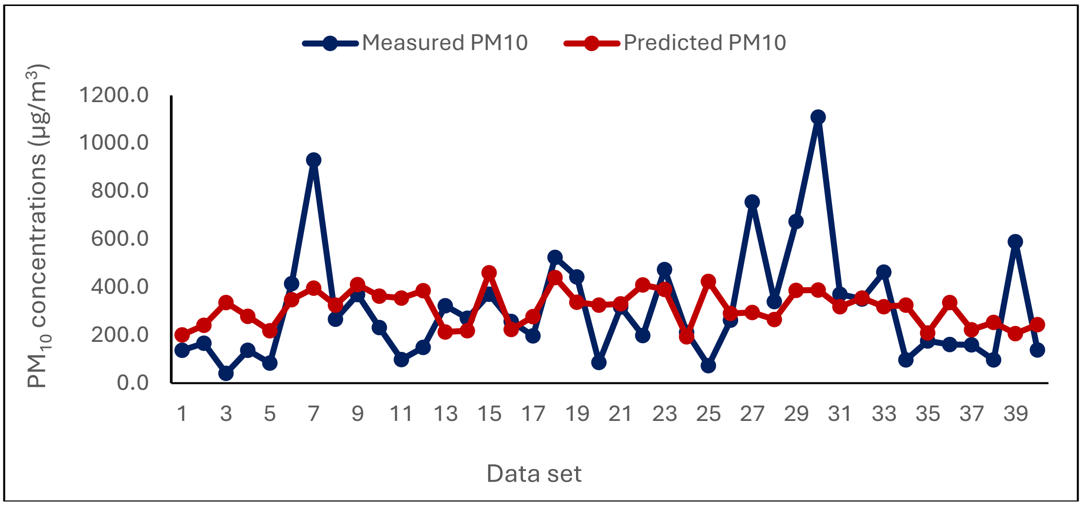


Figure xv: Comparison between Predicted and Measured PM_{10} Concentrations in the Wet Season

Prediction of $PM_{2.5}$ Concentrations in the Wet Season

The model output shows a coefficient of determination (R^2) of 0.137, indicating that there is a weak linear relationship between the concentrations of $PM_{2.5}$ and meteorological parameters in the area.

$$PM_{2.5} = 320.936 - 6.050*WS - 0.044*WD - 0.733*RH - 6.127*Temp$$

Analysis of variance for wet season $PM_{2.5}$ model

RMSE (μg/m^3)	MSE (μg/m^3)	F-statistic	MAPE (%)	p-value	R^2
25.695	660.227	1.393	28.453	0.257	0.137

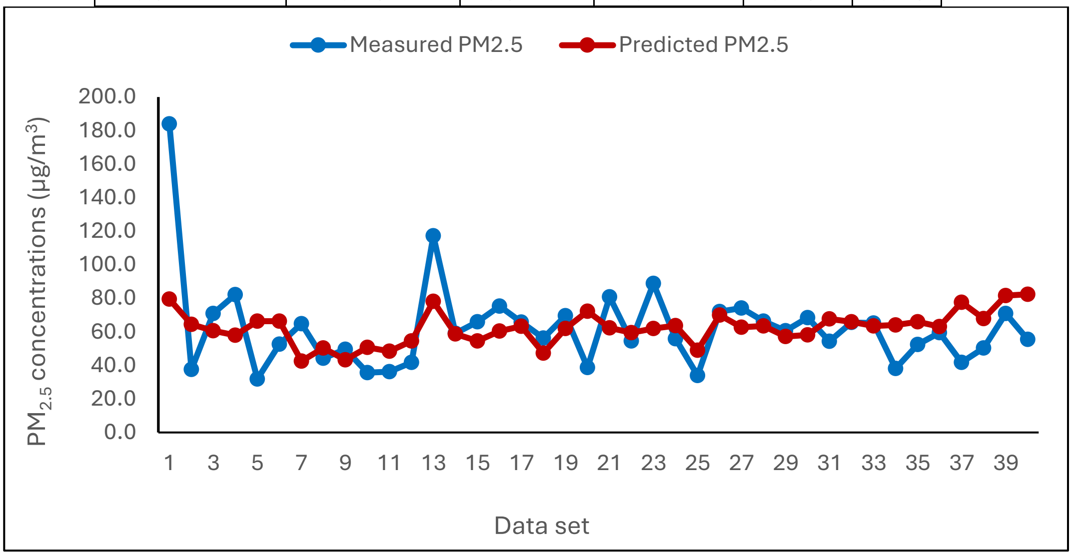


Figure xv: Comparison between Predicted and Measured $PM_{2.5}$ Concentrations in the Wet Season