



Research Paper

Seasonal behavioural pattern of air pollutants and their dispersion rates implications in Port Harcourt and its environs, Niger Delta, Nigeria

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ABSTRACT

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The present study evaluated the computed coefficient of variation in pollutants concentrations and the exceedance factor (EF) for each criteria pollutant in the area. According to the results, Eleme area showed that PM_{2.5} and SO₂ have low dispersion rates in dry season; while TSP, PM₁₀ and PM_{2.5} have low dispersion rate in the wet season. In Etche area, PM_{2.5} and CO have low dispersion rates in the dry season, while TSP, PM₁₀ and PM_{2.5} have low dispersion rates in the wet season. In Ikwerre area, VOCs has low dispersion rate in the dry season, while TSP, PM₁₀ and PM_{2.5} have low dispersion rates in the wet season. Also, PM_{2.5} and SO₂ have low dispersion in the dry season in Obio/Akpor area, while TSP, PM₁₀ and PM_{2.5} have low dispersion in the wet season. Furthermore, H₂S has low dispersion in the dry season in Oyigbo area, while TSP and PM₁₀ have low dispersion in the wet season. Similarly, CH₄ has low dispersion in the dry season in Port Harcourt area, while TSP, PM₁₀ and PM_{2.5} have low dispersion in the wet season.

Key words: Dispersion rates implications, seasonal behavioural pattern, air pollutants.

INTRODUCTION

Statistical analysis of air pollutants measured in study area in the dry and wet seasons were computed. The minimum and maximum concentrations of each air pollutant were calculated. Also, the mean, standard deviation, and coefficient of variation were statistically computed. The Coefficient of Variation (CV) in pollutants concentrations in the area was computed as the ratio between the standard deviation and the mean and determines the relative measure of dispersion of pollutants in the study area.

The exceedance factor (EF) for each criteria pollutant in the area was calculated using the measured value of the *i*th parameter and the NAAQS regulatory permissible standard value. Exceedance factor less than 100 (EF < 100) is below prescribed limit, while exceedance factor greater than 100 (EF > 100) exceeds prescribed limit. Computed exceedance factors for all the criteria pollutants in the dry season were greater than 100 (>100) and are thus rated as very high (Table 4.1). This indicates that the mean values of all the criteria pollutants in the area exceeded stipulated NAAQS

limits in the dry season and constitute hazards to human health in the dry season period, while SO₂ and NO₂ pose greater risk to public health in the wet season and people with respiratory disease such as asthma might be at greater risk.

Aim and objectives of the present study

The aim of this present research is to determine or investigate coefficient of variation (CV) / dispersion rate in pollutants concentrations and the exceedance factor (EF) for each criteria pollutant in Port Harcourt and its environs.

METHODOLOGY

Method of data analysis and dispersion

Mean concentration of air pollutants was computed using

Equation (1):

$$\bar{X} = \frac{\sum_{i=1}^n X_{meas,i}}{N} \quad (1)$$

Standard deviation was computed using Equation (2):

$$s = \sqrt{\frac{\sum (X_{meas,i} - \bar{X})^2}{N-1}} \quad (2)$$

Standard error estimate was determined using Equation (3):

$$\sigma_{\bar{X}} = \frac{s}{\sqrt{N}} \quad (3)$$

Where, s is the standards deviation, $X_{meas,i}$ is the measured i^{th} data point, $\bar{X}$ is the mean and N is the total number of data set.

Coefficient of variation of air pollutants

The coefficient of variation of each parameter was computed using Equation (4):

$$\%CV = \frac{s}{\bar{X}} = \frac{\sqrt{\frac{\sum (X_{meas,i} - \bar{X})^2}{N-1}}}{\frac{\sum_{i=1}^N X_{meas,i}}{N}}$$

Computation of exceedance factor (EF)

A factor known as Exceedance Factor (CPCB, 2006) was used to determine pollutants compliance with national and international standards.

The Exceedance Factor (EF) was calculated using

Equation (5) as follows:

$$\text{Excedence Factor (EF)} = \left(100 \frac{C_i}{C_{std}} \right)$$

Where C_i is the measured concentration of the i^{th} parameter in the ambient air. C_{std} is the regulatory standard recommended for the i^{th} parameter.

For $EF < 100$, the parameter is said to be within permissible limit, and for $EF > 100$, the parameter is said to exceed permissible limit. The EF for each pollutant was computed based on the Federal Ministry of Environment (FMEnv) stipulated permissible limit as contained in FEPA (1991) and National Ambient Air Quality Standards.

RESULTS AND DISCUSSION

Statistical analysis of air quality in Eleme area

Statistical analysis of air pollutants measured in Eleme area (Figure 1) in the dry and wet seasons are presented in Tables 1 and 2. The minimum and maximum concentrations of each air pollutant were calculated as presented in the Tables. Also, the mean, standard deviation, and coefficient of variation were statistically computed as presented in Tables 1 and 2. The Coefficient of Variation (CV) in pollutants concentrations in the area was computed as the ratio between the standard deviation and the mean and determines the relative measure of dispersion of pollutants in the study area. Computed coefficients of variations (Table 1) in the dry season indicate that $PM_{2.5}$ and SO_2 have lower dispersion, followed by NO_2 and PM_{10} while methane hydrocarbon (CH_4) has high dispersion rate followed by NH_3 . Similarly, TSP, PM_{10} and $PM_{2.5}$ have low dispersion rate, while CH_4 , H_2S , NO_2 , CO, VOCs and NH_3 have high dispersion rates in the wet season as shown in Table 2.

The exceedance factor (EF) for each criteria pollutant in the area was calculated using the measured value of the i^{th} parameter and the NAAQS regulatory permissible standard value. Exceedance factor less than 100 ($EF < 100$) is below prescribed limit, while exceedance factor greater than 100 ($EF > 100$) exceeds prescribed limit. Computed exceedance factors for all the criteria pollutants in the dry season were greater than 100 (>100) and are thus rated as very high (Table 1). This indicates that the mean values of all the criteria pollutants in the area exceeded the stipulated NAAQS limits in the dry season and constitute hazards to human health in the dry season period.

Similarly, computed exceedance factors in the wet season (Table 2) indicated low mean concentrations of TSP and PM_{10} , and moderate mean concentrations of $PM_{2.5}$ and CO; while SO_2 and NO_2 have very high mean concentrations.

This implies that TSP and PM_{10} pose no immediate

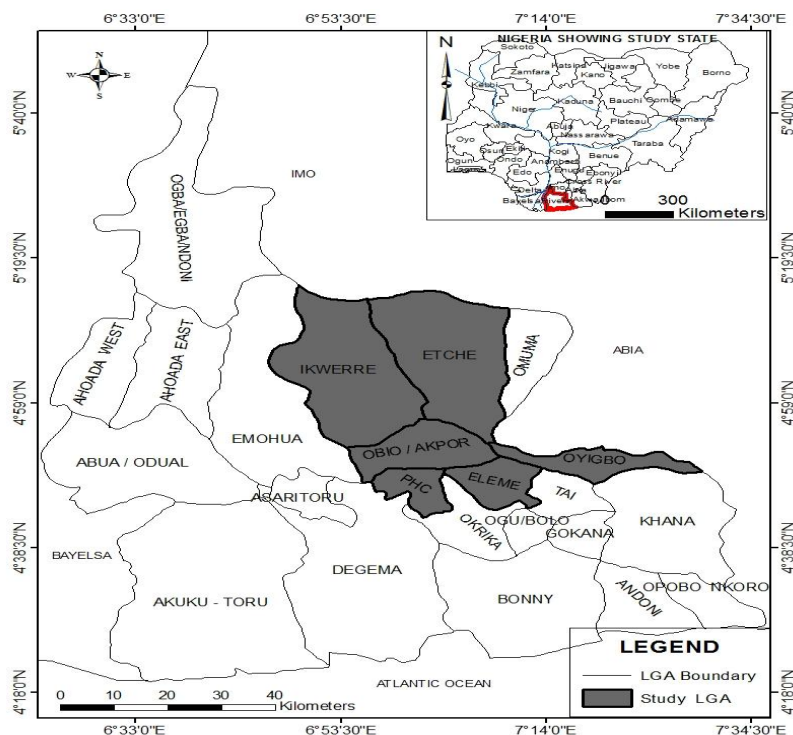


Figure 1: Port Harcourt and its environs showing study LGA.

Table 1: Dry season statistical analysis of air pollutants in Eleme area.

Parameter	Min	Max	Mean	Standard deviation	CV (%)	NAAQS limit	EF(%)	Rating
TSP ($\mu\text{g}/\text{m}^3$)	326.73	1102.1	583.19	279.19	47.87	200.00	291.60	Very high
PM ₁₀ ($\mu\text{g}/\text{m}^3$)	270.6	734.1	461.27	175.23	37.99	150.00	307.51	Very high
PM _{2.5} ($\mu\text{g}/\text{m}^3$)	22.7	101.6	92.48	13.13	14.20	35.00	264.23	Very high
SO ₂ (ppm)	1.0	1.77	1.18	0.29	24.58	0.14	842.86	Very high
NO ₂ (ppm)	0.333	1.0	0.89	0.3	33.71	0.10	890.00	Very high
H ₂ S (ppm)	0.67	3.67	1.87	1.01	54.01			
VOCs (ppm)	2.733	12.67	6.82	3.51	51.47			
CO (ppm)	9.0	35	21.06	10.48	49.76	9.00	234.00	Very high
NH ₃ (ppm)	2.067	10.87	5.98	3.53	59.03			
CH ₄ (ppm)	3.0	22.1	7.5	6.91	92.13			

Table 2: Wet season statistical analysis of air pollutants in Eleme area.

Parameter	Min	Max	Mean	Standard deviation	CV (%)	NAAQS limit	EF (%)	Rating
TSP ($\mu\text{g}/\text{m}^3$)	25.5	69.2	51.01	15.23	29.86	200.00	25.51	Low
PM ₁₀ ($\mu\text{g}/\text{m}^3$)	22.7	62.53	45.51	13.49	29.64	150.00	30.34	Low
PM _{2.5} ($\mu\text{g}/\text{m}^3$)	9.367	30.47	25.66	9.35	36.44	35.00	73.31	Moderate
SO ₂ (ppm)	0.29	1.0	0.69	0.42	60.87	0.14	492.86	Very high
NO ₂ (ppm)	0.0	1.0	0.57	0.53	92.98	0.10	570.00	Very high
H ₂ S (ppm)	0.0	1.0	0.37	0.48	129.73			
VOCs (ppm)	1.1	8.267	3.45	2.84	82.32			
CO (ppm)	1.7	15.6	7.74	7.05	91.09	9.00	86.00	Moderate
NH ₃ (ppm)	1.033	6.133	2.6	1.92	73.85			
CH ₄ (ppm)	0.0	4.97	1.27	1.82	143.31			

Table 3: Dry season statistical analysis of air pollutants in Etche Area.

Parameter	Min	Max	Mean	Standard deviation	CV (%)	NAAQS limit	EF (%)	Rating
TSP ($\mu\text{g}/\text{m}^3$)	264.8	1177.1	795.58	474.11	59.59	200.00	397.79	Very high
PM ₁₀ ($\mu\text{g}/\text{m}^3$)	210.8	793.3	554.13	304.9	55.02	150.00	369.42	Very high
PM _{2.5} ($\mu\text{g}/\text{m}^3$)	64.95	106.1	84.49	20.66	24.45	35.00	241.40	Very high
SO ₂ (ppm)	0.0	1.0	0.33	0.58	175.76	0.14	235.71	Very high
NO ₂ (ppm)	0.333	1.0	0.8	0.41	51.25	0.10	800.00	Very high
H ₂ S (ppm)	0.0	1.03	0.59	0.53	89.83			
VOCs (ppm)	1.433	7.8	4.93	3.23	65.52			
CO (ppm)	1.867	3.5	2.83	0.86	30.39	9.00	31.44	Low
NH ₃ (ppm)	0.0	0	0		0.00			
CH ₄ (ppm)	2.17	6.36	4.87	2.34	48.05			

Table 4: Wet season statistical analysis of air pollutants in Etche area.

Parameter	Min	Max	Mean	Standard deviation	CV (%)	NAAQS limit	EF(%)	Rating
TSP ($\mu\text{g}/\text{m}^3$)	53.3	64.1	59.17	5.46	9.23	200.00	29.59	Low
PM ₁₀ ($\mu\text{g}/\text{m}^3$)	43.6	49.5	46.67	2.96	6.34	150.00	31.11	Low
PM _{2.5} ($\mu\text{g}/\text{m}^3$)	25.27	27.67	25.87	1.59	6.15	35.00	73.91	Moderate
SO ₂ (ppm)	0.0	1.0	0.53	0.5	94.34	0.14	378.57	Very high
NO ₂ (ppm)	0.0	1.0	0.67	0.58	86.57	0.10	670.00	Very high
H ₂ S (ppm)	0.0	0.0	0.0	0.0	0.00			
VOCs (ppm)	1.4	3.433	2.12	1.14	53.77			
CO (ppm)	1.95	3.23	2.47	0.67	27.13	9.00	27.44	Low
NH ₃ (ppm)	0	0	0	0	0.00			
CH ₄ (ppm)	1.57	2.17	1.8	0.32	17.78			

hazard to human health; PM_{2.5} and CO may cause mild risk to human health; while SO₂ and NO₂ pose greater risk to public health in the wet season and people with respiratory disease such as asthma might be at greater risk.

Statistical analysis of air quality in Etche area

Analysis of air pollutants measured in Etche area in the dry and wet seasons are presented in Tables 3 and 4. The minimum and maximum concentrations of each air pollutant were computed as presented in the Tables. Also, the mean, standard deviation and coefficient of variation were statistically computed as presented in the Tables 3 and 4.

Computed coefficients of variations (Table 3) in the dry season indicate that PM_{2.5} and CO have lower dispersion followed by CH₄, while SO₂ and H₂S, have high dispersion rate followed by TSP, PM₁₀ and NO₂. Similarly, wet season computed CV (Table 4) indicated that TSP, PM₁₀ and PM_{2.5} have low dispersion followed by CH₄; while SO₂ and NO₂ have high dispersion rates followed by VOCs, meanwhile, CO showed moderate dispersion in the wet season in the area.

Computed exceedance factors in the dry season (Table 3)

indicated that mean values of TSP, PM₁₀, PM_{2.5}, SO₂, and NO₂ far exceeded limits and are thus rated as very high. These pollutants constitute health hazards in the area in the dry season. Similarly, computed exceedance factors in the wet season (Table 4) indicated low mean concentrations of TSP, PM₁₀ and CO, and moderate mean concentrations of PM_{2.5}; while SO₂ and NO₂ showed very high mean concentrations. This implies that TSP and PM₁₀ and CO pose no immediate hazard to human health; PM_{2.5} may cause minor risk to human health; while SO₂ and NO₂ pose greater risk to public health and people with respiratory disease such as chronic bronchitis might be at greater risk.

Statistical analysis of air quality in Ikwerre Local Government Area (LGA)

Analysis of air pollutants measured in Ikwerre LGA in the dry and wet seasons are presented in Tables 5 and 6 respectively; while the minimum and maximum concentrations of each air pollutant were computed as presented in the Tables. The mean, standard deviation, and coefficient of variation were statistically computed as presented in the Tables 5 and 6.

Computed coefficients of variations in the dry season

Table 5: Dry season statistical analysis of air pollutants in Ikwerre LGA.

Parameter	Min	Max	Mean	Standard deviation	CV (%)	NAAQS limit	EF (%)	Rating
TSP ($\mu\text{g}/\text{m}^3$)	77.53	814.9	281.56	356.39	126.6	200.00	140.78	High
PM ₁₀ ($\mu\text{g}/\text{m}^3$)	53	558.4	199.33	240.73	120.8	150.00	132.89	High
PM _{2.5} ($\mu\text{g}/\text{m}^3$)	17.27	43.13	25.64	11.96	46.6	35.00	73.26	Moderate
SO ₂ (ppm)	0.33	1	0.83	0.34	41.0	0.14	592.86	Very high
NO ₂ (ppm)	0	1.1	0.44	0.54	122.7	0.10	440.00	Very high
H ₂ S (ppm)	0	1.1	0.36	0.52	144.4		0.00	
VOCs (ppm)	1.37	1.97	1.58	0.29	18.4		0.00	
CO (ppm)	2.07	3.5	2.83	0.71	25.1	9.00	31.44	Low
NH ₃ (ppm)	0	0	0	0	0.0		0.00	
CH ₄ (ppm)	0.41	3.8	2.21	1.58	71.5		0.00	

Table 6: Wet season statistical analysis of air pollutants in Ikwerre LGA.

Parameter	Min	Max	Mean	Standard deviation	CV (%)	NAAQS limit	EF (%)	Rating
TSP ($\mu\text{g}/\text{m}^3$)	40.5	46	42.73	2.56	5.99	200.00	21.37	Low
PM ₁₀ ($\mu\text{g}/\text{m}^3$)	31.67	33.67	32.65	0.83	2.54	150.00	21.77	Low
PM _{2.5} ($\mu\text{g}/\text{m}^3$)	12.87	18.7	15.35	2.82	18.37	35.00	43.86	Low
SO ₂ (ppm)	0	0.4	0.15	0.19	126.67	0.14	107.14	High
NO ₂ (ppm)	0	1	0.25	0.5	200.00	0.10	250.00	Very high
H ₂ S (ppm)	0	0.31	0.08	0.16	200.00		0.00	
VOCs (ppm)	0.513	1.61	0.81	0.53	65.43		0.00	
CO (ppm)	0.6	2.9	1.54	0.98	63.64	9.00	17.11	Low
NH ₃ (ppm)	0	0	0	0	0.00		0.00	
CH ₄ (ppm)	0	1.97	0.77	0.95	123.38		0.00	

(Table 5) indicate that VOCs has low dispersion followed by CO, while SO₂ and PM_{2.5} have moderate dispersion rates followed by CH₄. Likewise, TSP, PM₁₀, NO₂, H₂S have high dispersion rates in the dry season. Similarly, wet season computed CV (Table 6) indicated that TSP, PM₁₀ and PM_{2.5} have low dispersion followed by VOCs and CO; while SO₂, NO₂, H₂S and CH₄ have high dispersion rates.

Computed exceedance factors in the dry season (Table 5) indicated that mean values of TSP, PM₁₀ exceeded NAAQS permissible limits and are thus rated as high, while PM_{2.5} is rated as moderate. These pollutants constitute serious health hazards in the dry season in the area. Similarly, SO₂ and NO₂ showed high exceedance factors and constitute very high pollution in the dry season in the area. These pollutants pose risk to public health in the area. Similarly, computed exceedance factors in the wet season (Table 6) indicated low mean concentrations of all particulate pollutants, SO₂ showed high pollution and NO₂ showed very high pollution. This implies that all the particulate pollutants pose no immediate hazard to human health in the wet season.

Statistical analysis of air quality in Obio/Akpor area

Statistical analysis of air pollutants measured in Obio/Akpor area in the dry and wet seasons are presented in Tables 7 and 8; while the minimum and maximum concentrations of each air pollutant were

computed as presented in the Tables. The mean, standard deviation and coefficient of variation were statistically computed as presented in the Tables 7 and 8.

Computed coefficients of variations (Table 7) in the dry season show that PM_{2.5} and SO₂ have low dispersion followed by CO, while NO₂, VOCs and CH₄ have moderate dispersion rates. TSP, PM₁₀, H₂S and NH₃ have high dispersion rates in the dry season. Similarly, wet season computed CV (Table 8) indicated that TSP, PM₁₀ and PM_{2.5} have low dispersion; SO₂, VOCs and CH₄ have moderate dispersion; while NO₂, H₂S, CO and NH₃ have high dispersion rates in the dry season in the area.

Computed exceedance factors in the dry season (Table 7) indicated that mean values of TSP, PM₁₀, PM_{2.5}, and CO have high pollution levels in the area, while SO₂ and NO₂ showed very high pollution level in the dry season in the area.

These pollutants may constitute severe health hazards in the dry season in the area thus posing risk to public health in the area. Similarly, computed exceedance factors in the wet season (Table 8) indicated that TSP and PM₁₀ have low pollution levels; PM_{2.5} and CO have moderate pollution levels; while SO₂ and NO₂ showed very high pollution levels in the area. This implies that SO₂ and NO₂ pose health hazards in the area in the wet season.

Statistical analysis of air quality in Oyigbo area

Analysis of air pollutants measured in Oyigbo area in the

Table 7: Dry season statistical analysis of air pollutants in Obio/Akpor area.

Parameter	Min	Max	Mean	Standard deviation	CV (%)	NAAQS limit	EF(%)	Rating
TSP ($\mu\text{g}/\text{m}^3$)	64.33	2745.2	342.84	493.0	139.59	200.00	174.31	High
PM ₁₀ ($\mu\text{g}/\text{m}^3$)	55.13	1927	254.19	342.16	130.89	150.00	171.73	High
PM _{2.5} ($\mu\text{g}/\text{m}^3$)	22.27	110.60	48.18	20.35	42.24	35.00	137.66	High
SO ₂ (ppm)	0.0	1.27	0.86	0.4	46.51	0.14	614.29	Very high
NO ₂ (ppm)	0.0	2.23	0.68	0.5	73.53	0.10	680.00	Very high
H ₂ S (ppm)	0.0	2.20	0.55	0.6	109.09			
VOCs (ppm)	0.0	21.74	5.67	4.3	75.84			
CO (ppm)	4.0	32.37	14.12	9.6	67.99	9.00	156.89	High
NH ₃ (ppm)	0.0	5.37	1.39	1.8	129.50			
CH ₄ (ppm)	1.47	20.30	4.16	3.4	81.73			

Table 8: Wet season statistical analysis of air pollutants in Obio/Akpor area.

Parameter	Min	Max	Mean	Standard deviation	CV (%)	NAAQS limit	EF (%)	Rating
TSP ($\mu\text{g}/\text{m}^3$)	19.8	95.8	51.53	15.69	30.45	200.00	25.77	Low
PM ₁₀ ($\mu\text{g}/\text{m}^3$)	16.27	78.47	43.08	13.13	30.48	150.00	28.72	Low
PM _{2.5} ($\mu\text{g}/\text{m}^3$)	9.37	46.63	21.05	7.89	37.48	35.00	60.14	Moderate
SO ₂ (ppm)	0.0	1.49	0.43	0.35	81.40	0.14	307.14	Very high
NO ₂ (ppm)	0.0	1.0	0.38	0.49	128.95	0.10	380.00	Very high
H ₂ S (ppm)	0.0	1.0	0.21	0.33	157.14		0.00	
VOCs (ppm)	0.0	9.95	2.39	1.79	74.90		0.00	
CO (ppm)	0.74	21.8	6.2	6.46	104.19	9.00	68.89	Moderate
NH ₃ (ppm)	0.0	9.933	1.63	2.36	144.79		-	
CH ₄ (ppm)	0.0	4.53	1.77	1.17	66.10		-	

Table 9: Dry season statistical analysis of air pollutants in Oyigbo area.

Parameter	Min	Max	Mean	Standard deviation	CV (%)	NAAQS limit	EF (%)	Rating
TSP ($\mu\text{g}/\text{m}^3$)	129.00	1344.4	789.71	514.56	65.16	200.00	394.86	Very high
PM ₁₀ ($\mu\text{g}/\text{m}^3$)	92.1	894.50	551.2	343.17	62.26	150.00	367.47	Very high
PM _{2.5} ($\mu\text{g}/\text{m}^3$)	29.17	82.40	63.14	23.81	37.71	35.00	180.40	High
SO ₂ (ppm)	0	1.01	0.75	0.5	66.67	0.14	535.71	Very high
NO ₂ (ppm)	0.33	1.03	0.84	0.34	40.48	0.10	840.00	Very high
H ₂ S (ppm)	1.03	1.48	1.27	0.19	14.96	-	-	
VOCs (ppm)	1.5	6.57	3.6	2.33	64.72		-	
CO (ppm)	4.0	27.33	10.53	11.23	106.65	9.00	117.00	Very high
NH ₃ (ppm)	0.0	3.34	1.51	1.4	92.72		-	
CH ₄ (ppm)	1.0	2.35	1.8	0.66	36.67		-	

dry and wet seasons are presented in Tables 9 and 10; while the minimum and maximum concentrations of each air pollutant were computed as presented in the Tables.

The mean, standard deviation, coefficient of variation were statistically computed as presented in the Tables 9 and 10.

Computed coefficients of variations (Table 9) in the dry season show that H₂S has low dispersion followed by PM_{2.5}, CH₄; CO and NH₃ have high dispersion while TSP, PM₁₀, SO₂

and VOCs have moderate dispersion in the area. Similarly, wet season computed CV (shown in Table 10) indicated that TSP and PM₁₀ have low dispersion, followed by VOCs; PM_{2.5}, NO₂, and NH₃ have moderate dispersion; while SO₂, CO and CH₄ have high dispersion rates in the wet season in the area as shown in Table 10.

Computed exceedance factors in the dry season (9) indicated that TSP, PM₁₀, SO₂, NO₂, and CO have very high

Table 10: Wet season statistical analysis of air pollutants in Oyigbo area.

Parameter	Min	Max	Mean	Standard deviation	CV (%)	NAAQS limit	EF (%)	Rating
TSP ($\mu\text{g}/\text{m}^3$)	36.3	65.1	49.08	14.89	30.34	200.00	24.54	Low
PM ₁₀ ($\mu\text{g}/\text{m}^3$)	29.83	58.63	43.16	15	34.75	150.00	28.77	Low
PM _{2.5} ($\mu\text{g}/\text{m}^3$)	13.17	41.3	24.48	12.95	52.90	35.00	69.94	Moderate
SO ₂ (ppm)	0.0	1.07	0.31	0.51	164.52	0.14	221.43	Very high
NO ₂ (ppm)	0.0	1.0	0.75	0.5	66.67	0.10	750.00	Very high
H ₂ S (ppm)	0.0	0.0	0.0	0.0			-	
VOCs (ppm)	1.07	3.02	1.78	0.87	48.88		-	
CO (ppm)	1.4	9.77	3.83	4	104.44	9.00	42.56	Low
NH ₃ (ppm)	0.0	3.67	2	1.66	83.00		-	
CH ₄ (ppm)	0.0	0.67	0.27	0.33	122.22		-	

Table 11: Dry season statistical analysis of air pollutants in Port Harcourt area.

Parameter	Min	Max	Mean	Standard deviation	CV (%)	NAAQS limit	EF (%)	Rating
TSP ($\mu\text{g}/\text{m}^3$)	60.90	7661	596.64	1574.5	263.89	200.00	298.32	Very high
PM ₁₀ ($\mu\text{g}/\text{m}^3$)	45.3	7029	498.1	1441.92	289.48	150.00	332.07	Very high
PM _{2.5} ($\mu\text{g}/\text{m}^3$)	16	211.3	50.57	39.09	77.30	35.00	144.49	High
SO ₂ (ppm)	0	1.67	0.9	0.46	51.11	0.14	642.86	Very high
NO ₂ (ppm)	0	1.14	0.3	0.45	150.00	0.10	300.00	Very high
H ₂ S (ppm)	0	1.5	0.41	0.54	131.71		0.00	
VOCs (ppm)	0	10.6	4.72	3.32	70.34		0.00	
CO (ppm)	0	26	12.42	10.6	85.35	9.00	138.00	High
NH ₃ (ppm)	0	7.467	1.43	1.61	112.59		0.00	
CH ₄ (ppm)	1	7.4	4.19	1.65	39.38		0.00	

pollution levels in the area, while PM_{2.5} showed high pollution level in the dry season in the area. These pollutants may constitute severe health hazards in the dry season in the area thus posing risk to public health in the area. Similarly, computed exceedance factors in the wet season (Table 10) indicated that TSP, PM₁₀ and CO have low pollution levels; PM_{2.5} have moderate pollution level; while SO₂ and NO₂ showed very high pollution levels in the area. This implies that SO₂ and NO₂ pose health hazards in the area in the wet season.

Statistical analysis of air quality in Port Harcourt area

Statistical analysis of air pollutants measured in Port Harcourt area in the dry and wet seasons are presented in Tables 11 and 12; while the minimum and maximum concentrations of each air pollutant were computed as presented in the Tables. The mean, standard deviation, coefficient of variation were statistically computed as presented in the Tables 11 and 12.

Computed coefficients of variations (Table 11) in the dry season show that CH₄ has low dispersion followed by SO₂, CH₄; while PM_{2.5}, VOCs and CO have moderate dispersion and TSP, PM₁₀, NO₂, H₂S and NH₃ have high dispersion in the area. Similarly, wet season computed CV (12) indicated that

TSP, PM₁₀ and PM_{2.5} have low dispersion; SO₂, VOCs, CO and CH₄ have moderate dispersion; while, NO₂, H₂S and NH₃ have high dispersion rates in the dry season in the area.

Computed exceedance factors using mean values in the dry season indicated that TSP, PM₁₀, SO₂, and NO₂ have very high pollution levels in the area, while PM_{2.5} and CO showed high pollution level in the dry season in the area. These pollutants may constitute severe health hazards in the dry season in the area thus posing risk to public health in the area. Similarly, computed exceedance factors in the wet season (Table 12) indicated that TSP, PM₁₀, PM_{2.5} and CO have low pollution levels; while SO₂ and NO₂ showed very high pollution levels in the area. This implies that SO₂ and NO₂ pose health hazards in the area in the wet season.

DISCUSSION

Evaluation of pollutants dispersion pattern in the study area in the dry season

The pollutants dispersion patterns in the study area in the dry season were evaluated with the aid of pollution roses and bivariate polar plots of each pollutant with respect to wind speed and wind direction. The dry season results are

Table 12: Wet season statistical analysis of air pollutants in Port Harcourt area.

Parameter	Min	Max	Mean	Standard deviation	CV (%)	NAAQS limit	EF (%)	Rating
TSP ($\mu\text{g}/\text{m}^3$)	20.1	66.2	36.38	12.72	34.96	200.00	18.19	Low
PM ₁₀ ($\mu\text{g}/\text{m}^3$)	18.8	59.07	30.61	10.57	34.53	150.00	20.41	Low
PM _{2.5} ($\mu\text{g}/\text{m}^3$)	9.0	26.6	15.51	5.2	33.53	35.00	44.31	Low
SO ₂ (ppm)	0.0	0.77	0.45	0.27	60.00	0.14	321.43	Very high
NO ₂ (ppm)	0.0	1.0	0.2	0.39	195.00	0.10	200.00	Very high
H ₂ S (ppm)	0.0	0.87	0.17	0.28	164.71			
VOCs (ppm)	0.0	6.767	1.77	1.46	82.49			
CO (ppm)	0.0	11	4.33	3.81	87.99	9.00	48.11	Low
NH ₃ (ppm)	0.0	7.5	1.2	1.78	148.33			
CH ₄ (ppm)	0.0	2.4	1.2	0.81	67.50			

presented in Figures 2 (a-j) to 3 (a-j). The pollution roses and polar plots were developed using the mean concentration of each pollutant in different wind speed and percentage frequency count of wind direction categories (Munir, 2016). They were simulated with the aid of Generalized Additive Model (GAM) smoothing techniques by Carslaw (2015) that depict pollutant concentrations as a continuous surface.

Pollution roses (Figure 2 (a-j)) showed that pollutant concentrations increase with increased wind speed. Low concentrations of pollutants were obtained at low wind speed and vice-versa. This implies that wind speed has positive influence on the concentration levels of pollutants in the study area.

The wet season pollutant polar plots (Figure 3 (a-j)) showed that concentrations of air pollutants in the area are associated with wind speed up to 2.5 m/s. It is also observed from Figure 3 (a-j) that pollutants concentrations increase with increased wind speed.

Surface polar plots of pollutants concentrations in the study area revealed that high concentrations of SO₂ is associated with the south-east, south-west and north-east directions and are dispersed toward the north-west direction. This may imply that sources of this pollutant are in the south-eastern, south western and north-eastern part of the study area. NO₂, VOCs, H₂S, CO, and NH₃ are associated with both south-east and south-west directions and are dispersed towards north-east and north-west directions. This may imply that sources of these pollutants are in the south-eastern and south-western part of the study area. The Figure also indicated that concentrations of Methane and Particulate matter (CH₄, TSP, PM₁₀ and PM_{2.5}) in the wet season are associated with all the wind directions but while CH₄ is more on the south-eastern and south-western directions; Particulate matters are more in the eastern direction. The pollutants dispersion patterns in the wet season showed pollutants are from diffuse sources probably caused by industrial activities, unprofessional destruction of illegal refineries and bunkering plants and facilities/petroleum products in the coastal area, asphalt vehicular exhaust emissions in both the coastal and up-

land areas and influenced by the dynamic nature of wind pattern in the wet season. Kumar et al. (2011), Nwokocha et al. (2015), Ubonget al. (2015a), Antai (2016) and Yorkoret al. (2017a and b) also showed in their studies the same air pollution pattern, hence the finding is in line with the concentrations of air pollutant and their dispersion pattern in the study area.

Modeling the relationship between air pollutants and meteorological parameters in the dry season

Variation of total suspended particulate matter (tsp) with meteorological parameters in the dry season

The results (shown in Figure 4 (a-e)) indicated that TSP correlated positively with wind direction, relatively humidity. The linear models (shown in Table 13) derived from the stepwise regression of TSP with each meteorological parameter indicate that the linear correlation between TSP and wind speed and temperature are not significant at 0.05 confidence level. However, the relationship between concentrations of total suspended particulate matter and wind direction is highly significant at 0.01 confidence level for a 2-tail test with a coefficient of determination (R^2) of 0.026). This implies that though TSP varies significantly with wind direction, only a fraction of 2.6% of the variation can be explained. In addition, the results (Table 13) also indicated that wind speed accounted for 0.63%, relative humidity accounted for 2.5%, while temperature and air pressure each accounted for 0.56% of the total variation of TSP concentrations in the dry season. A multiple linear regression model for the prediction of TSP was developed using all the meteorological parameters that affect TSP concentrations as predictor variables. A model for the prediction of TSP concentrations in the dry season was thus derived as shown in Equation (6). The derived Equation (6) was used to predict the concentrations of TSP in the study area in the dry season:

$$\text{TSP} = -88595.74 - 165.908 \cdot \text{Wsp} + 1.94 \cdot \text{Wd} - 23.129 \cdot \text{Rh} - 0.158 \cdot \text{Temp} + 89.949 \cdot \text{Pres}$$

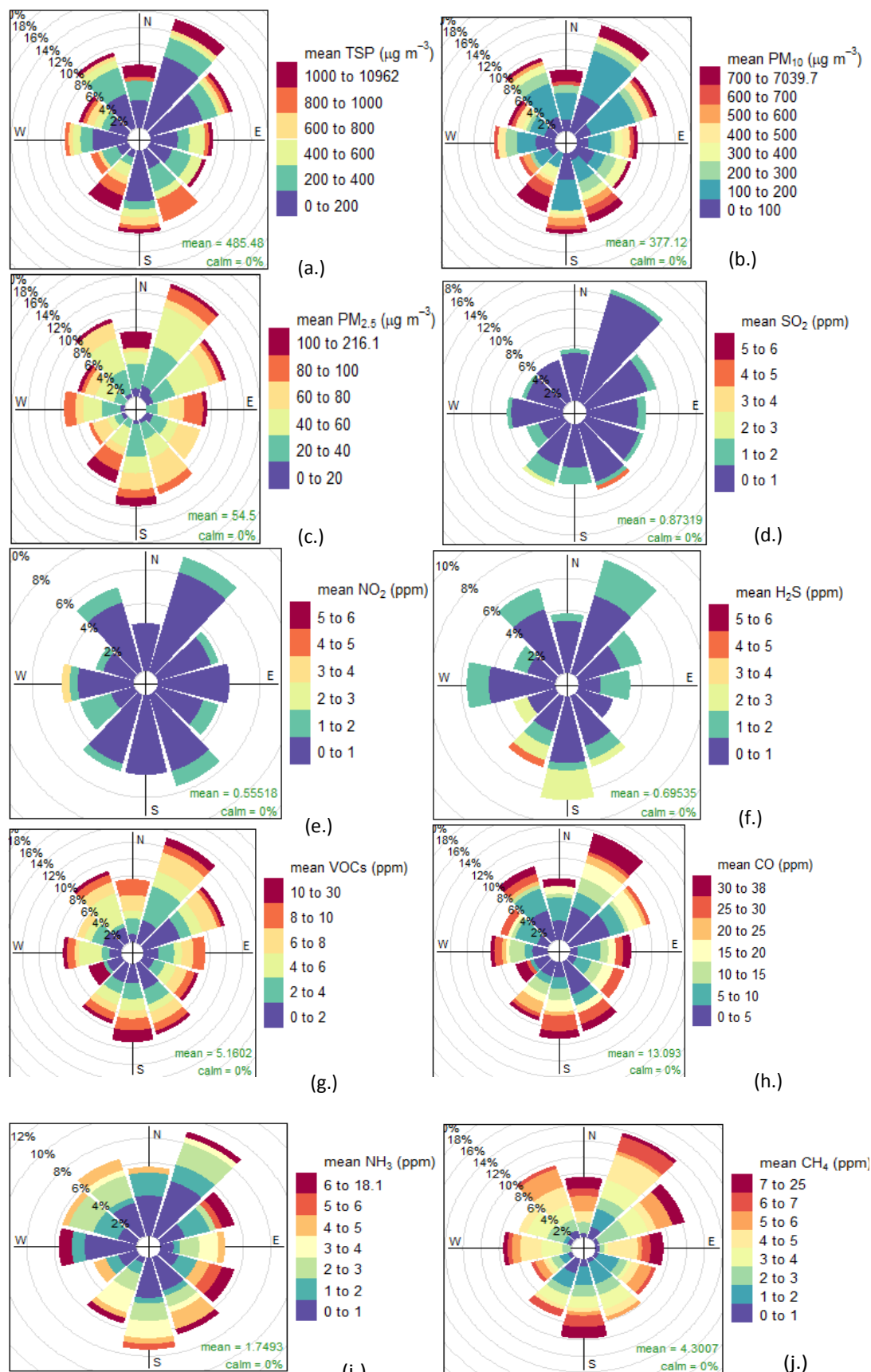
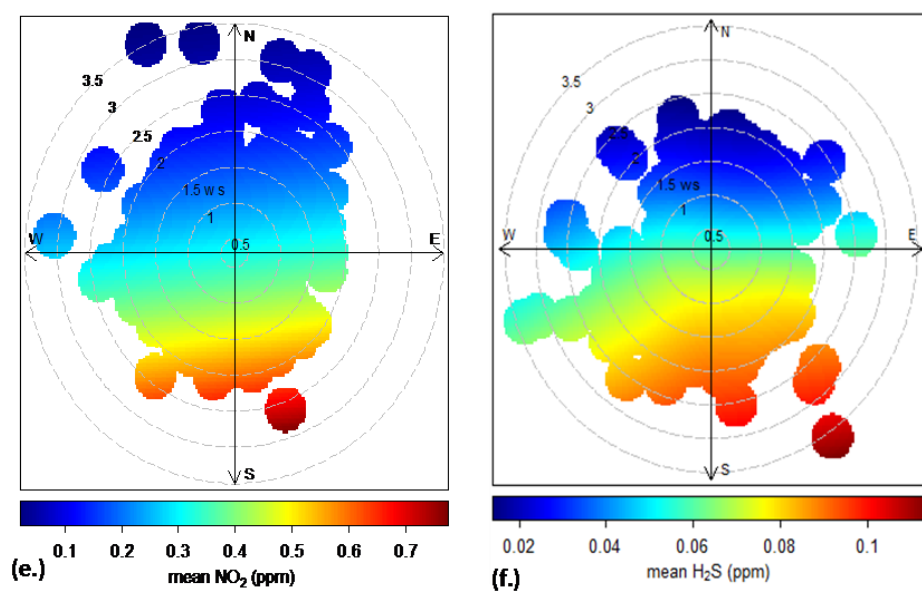
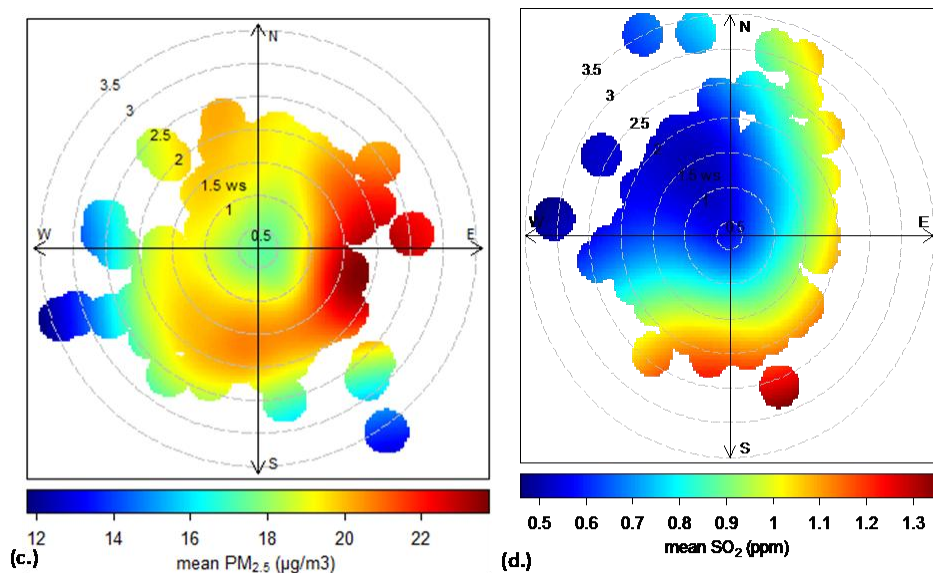
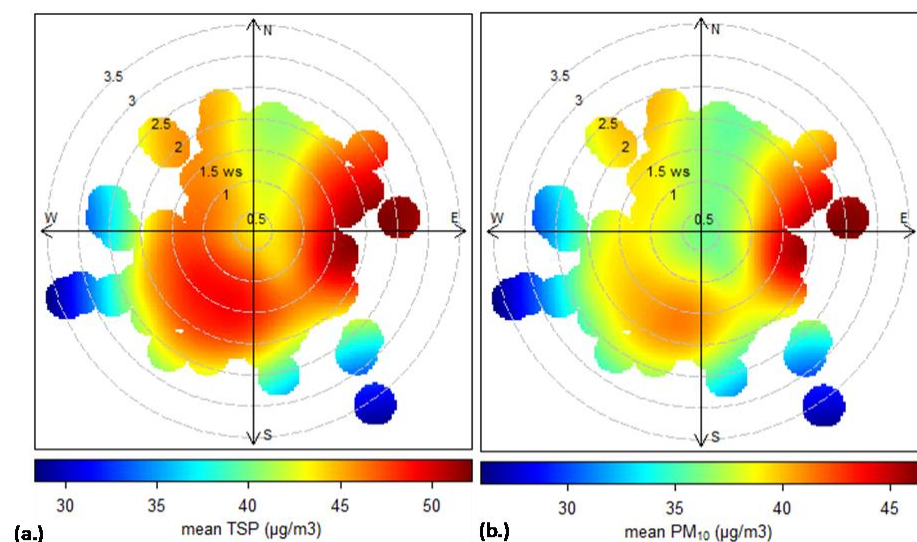


Figure 2 (a-j): Pollution roses of pollutants in the study area in the dry season.



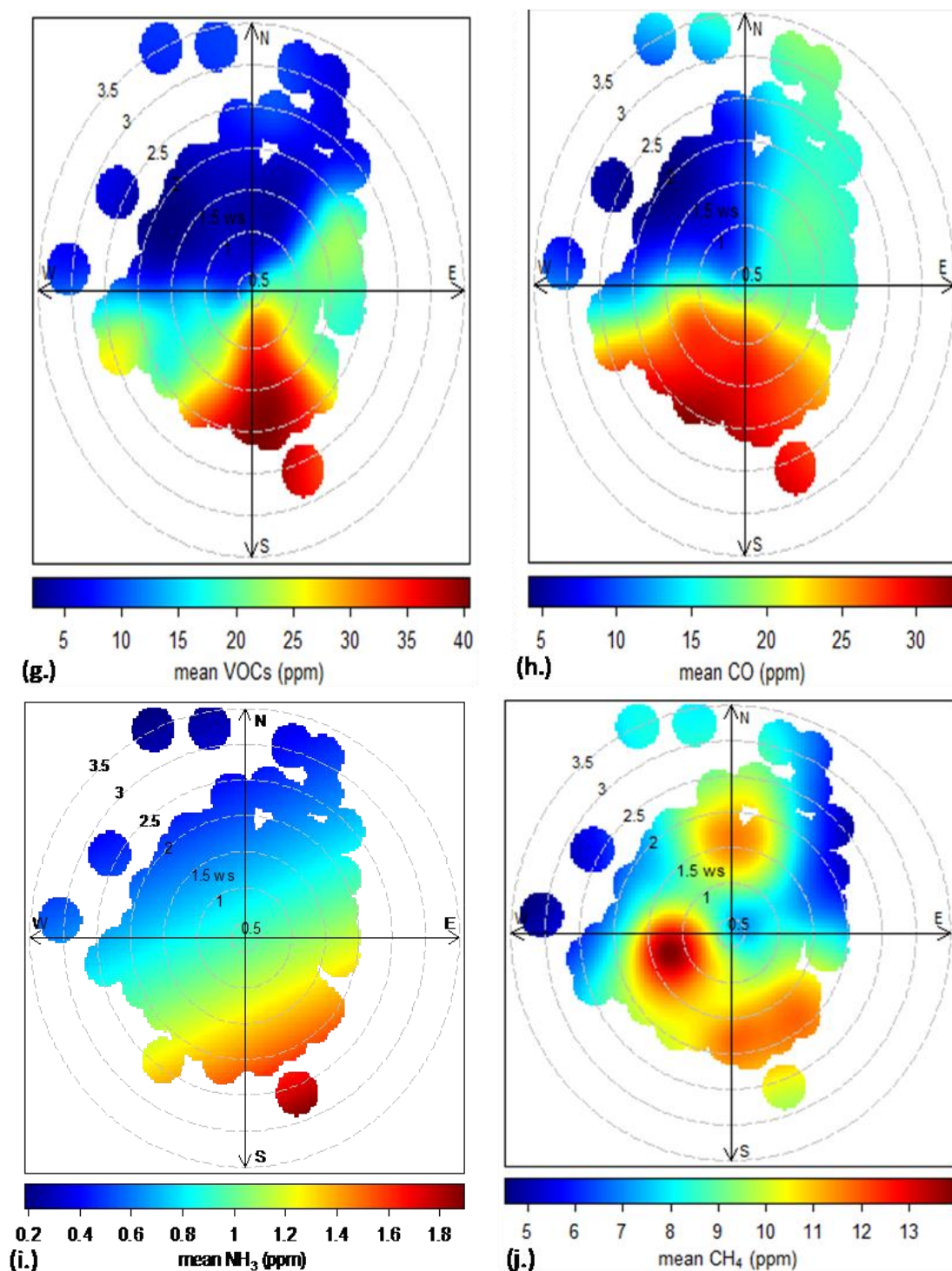


Figure 3 (a-j): Polar plots of pollutants in the study area in the wet season.

The mean square error (MSE) and the root mean square error of the model were computed to be 4159139.156 and 2039.3968 $\mu\text{g}/\text{m}^3$ respectively. The model sum of squares error (SS_M), residual sum of squares error (SS_R) and total sum of squares error (SS_T) were computed to be 20795695.781, 241046683.048 and 261842378.829 $\mu\text{g}/\text{m}^3$, respectively as shown in Table 14. The result

(Table14) showed that meteorological parameters significantly influence the concentrations of TSP in the area ($P\text{-value} < 0.05$). However, the goodness of fit (Figure 5) between predicted and measured values indicated poor linear relationship between TSP and meteorological parameters with a coefficient of determination (R^2) of 0.079. This implies that only 7.9% of the variation of TSP

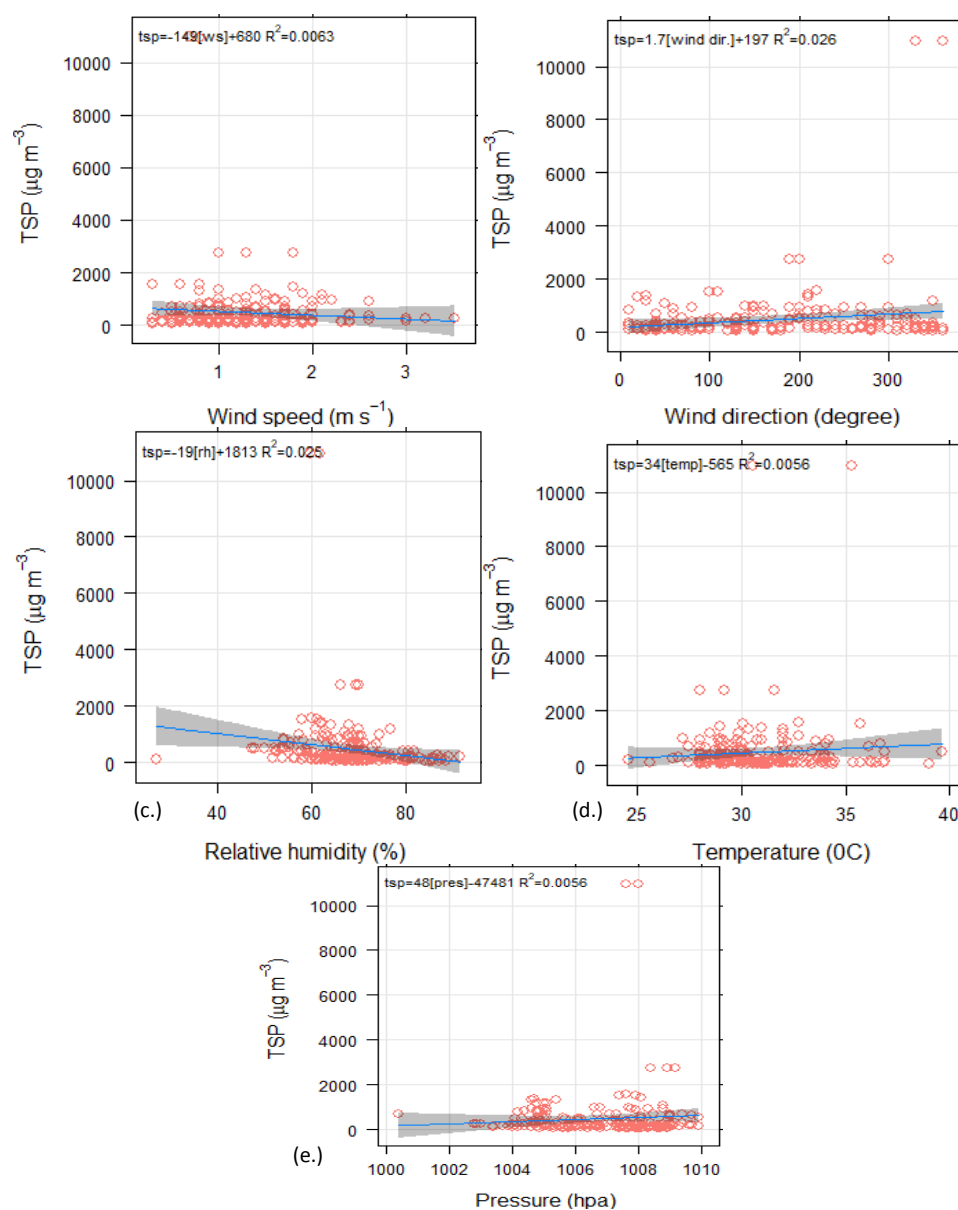


Figure 4 (a-e): Relationship between predicted TSP and meteorological parameters in the dry season.

Table 13: Stepwise linear models for dry season TSP.

Pollutant	Model	R ²	t-statistic	Sig.(2-tailed)
TSP	= 680 - 149*Wsp,	0.0063	- 1.281	0.202
	= 197 + 1.7*Wd	0.026	2.775	0.006**
	= 1813 - 19*Rh,	0.025	- 2.388	0.018*
	= -565 + 34*Temp	0.0056	- 0.005	0.996
	= -47481 + 48*Pres	0.0056	2.022	0.044*

* Correlation is significant at the 0.05 level (2-tailed).

**Correlation is significant at the 0.01 level (2-tailed).

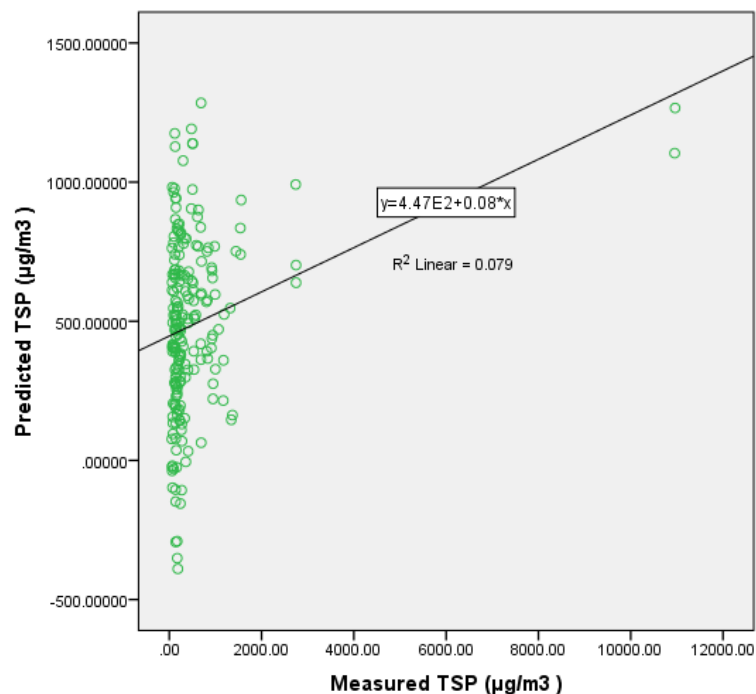
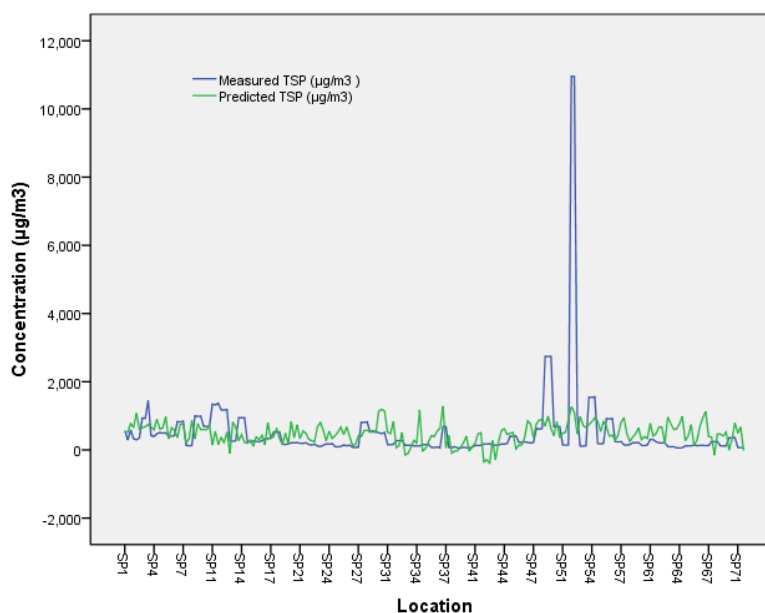
concentrations in the dry season can be explained by the meteorological parameters. The goodness of fit between

predicted and measured concentrations of TSP is shown in Figure 5, while the predicted values are plotted against

Table 14: Analysis of Variance (ANOVA) for Dry Season TSP Prediction model.

Model	SSE ($\mu\text{g}/\text{m}^3$)	Df	MSE ($\mu\text{g}/\text{m}^3$)	RMSE ($\mu\text{g}/\text{m}^3$)	F	Sig.
Regression (SS_M)	20795695.781	5	4159139.156	2039.3968	3.572	0.004*
Residual (SS_R)	241046683.048	207	1164476.730			
Total (SS_T)	261842378.829	212				

*Significant at the 0.01 level (2-tailed).

**Figure 5:** Relationship between predicted TSP and measured TSP in the dry season.**Figure 6:** Predicted TSP versus measured TSP in the dry season.

measured values as shown in Figure 6.

CONCLUSION

The study showed that some air quality parameters indicated high dispersion rates while others indicated moderate and low dispersion rates. However, this implies that the air pollutants with high dispersion rates pose greater risk to the public health, while the air pollutants with moderate dispersion rates pose mild risk to public health and the air pollutants with low dispersion rates pose no risks to public health in the dry and wet seasons.

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