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Influence of Meteorological Parameters on Particle Pollution ($PM_{2.5}$ and PM_{10}) in the Tropical Climate of Port Harcourt, Nigeria

Christopher U. Onuorah[1*], Tambari G. Leton[1] and Yusuf O. L. Momoh[2]

[1]Centre for Occupational Health, Safety and Environment, University of Port Harcourt, Nigeria.
[2]Department of Civil and Environmental Engineering, University of Port Harcourt, Nigeria.

Authors' contributions

This work was carried out in collaboration among all authors. Author CUO designed the study, wrote the protocol and wrote the first draft of the manuscript, which was approved by his supervisors. Authors CUO, TGL and YOLM equally collected field samples and carried out laboratory analyses. Author TGL guided literature searches and field sampling while author YOLM guided the statistical analysis. All authors read and approved the final manuscript.

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ABSTRACT

Aims: This study explores the influence of meteorological parameters such as wind direction, wind speed, rainfall, air temperature and relative humidity on $PM_{2.5}$ and PM_{10} concentration.

Place and Duration of Study: The study was conducted in Woji, an urban area of Port Harcourt city in Nigeria, between May and December 2019 covering wet and dry season.

Methodology: The PM_{10} and $PM_{2.5}$ concentrations were monitored for 236 days using photometric laser based particulate monitor while meteorological parameters were collected using Misol weather station mounted 10m above ground at Woji monitoring location.

Results: PM concentration for all the months under study were below USEPA 24-hr standard except the month of December with $PM_{2.5}$ = 58.8 µg/m³ and PM_{10} = 164.5 µg/m³.

The result showed a significant but positively strong correlation between $PM_{2.5}$ and PM_{10} (r = 0.97, P < .001). The wind speed significantly influenced $PM_{2.5}$ and PM_{10} concentration with a weak negative correlation (r = - 0.22 and -0.23) respectively at P < .001. Also, $PM_{2.5}$ and PM_{10}

**Corresponding author: Email: ugothorax@yahoo.com;*

concentration exhibited a weak negative but significant correlation with rainfall (r = - 0.05 and - 0.05) and air temperature (r = - 0.12 and -0.14) respectively at *P*< .001. Relative humidity showed a weak negative but not significant correlation with $PM_{2.5}$ concentration (r = - 0.01) while PM_{10} exhibited weak but significant correlation with relative humidity (r = 0.04).

Conclusion: The PM concentration exceedances recorded in month of December could be attributed to dry dusty north east trade wind that comes with harmattan as well as high atmospheric stability which is associated with low wind speed. The study revealed that meteorological parameters such as temperature, wind speed and rainfall plays significant role in the reduction of particulate matter loading through air dispersion, atmospheric instability and washout process while relative humidity increases PM_{10} concentration.

Keywords: $PM_{2.5}$; PM_{10}; particle pollution; particulate matter; meteorological parameter; correlation; Port Harcourt; Nigeria.

1. INTRODUCTION

Air pollution is currently a major environmental challenge facing developed and developing countries world over [1]. It is known as the anthropogenic emission of harmful chemicals that alter the chemical composition of the natural atmosphere which have adverse effects on the health of living things and the environment [2]. Increasing industrialization, growing urbanization and energy consumption were discovered to be responsible for escalated cases of air pollution which poses serious threat to public health [3]. The substances that cause air pollution are called air pollutant. United States Environmental Protection Agency (USEPA) have identified six criteria pollutants as the most health threatening pollutants, of which particulate matter is one of them [4]. A recent study conducted by university of Chicago on Air quality life index revealed that particle pollution reduces global life expectancy by an average of 1.8 years per person, thereby positioning it as the world top killer [5]. It also showed that when particles are inhaled from the polluted atmosphere that it reduces life more than first hand cigarette smokers which shortens life by 1.6 years [5]. Among their main chemical components, are PAHs, ionic species and heavy metals, which are known as potential human carcinogens and if present in elevated concentration in ambient can pose a significant risk to human by finding their way into human blood stream and lungs thereby causing cancer and lungs diseases [6-11]. Several studies have shown that particulate matter ($PM_{2.5}$ and PM_{10}) also has some negative effects on the environment which include reduced visibility (haze), change in atmospheric properties, formation of fog and precipitation, damage to vegetation and materials and change in climate due to alteration of solar radiation, wind distribution and temperature [12,13]. The dispersion and accumulation of particulate matter are predominantly influenced by the emission sources, meteorological parameters and local topography [14]. Particulate matter includes soot, smoke, dust, dirt and liquid droplets. Particulate matter is majorly classified on the basis of their nature and size, referred to as their 'aerodynamic diameter'. Coarse particles (PM_{10}) are those between 10 and 2.5 micrometers (µm) in diameter, while fine particles ($PM_{2.5}$) are smaller than 2.5 µm in diameter. On the basis of their sizes, combustion particles such as soot and smoke belongs to $PM_{2.5}$ while dust, pollen, mist, mold, fungi etc. belongs to PM_{10} fraction [15].

The meteorology of an environment contribute considerably to the quality of air in that locality. Thus, large diffusion, dilution and accumulation of atmospheric fine particles pollution are significantly influenced by meteorological variables such as rainfall, relative humidity, wind speed, wind direction, air temperature, atmospheric pressure and solar radiation [16,17]. Several studies have shown that the attenuation of atmospheric pollutants is a function of high wind speed while low wind speed favours accumulation of pollutants. Wind direction also aid in pollutant dispersion. Wind speed and direction can aid in the apportionment of fine particles concentration to their respective sources. Cloudiness increases the accumulation of fine particles, while radiation sets up photochemical reactions with other pollutants [18]. The movement of air horizontally is a function of wind speed and direction. The higher the wind speed, the greater the dispersion of pollution. Direction is also important as it determines where the pollution moves and hence governs the downwind impact areas.

However, temperature affects ambient chemical reactions and stagnant air masses are formed during low temperatures events, resulting in high particle level and vice versa. Meteorological conditions, such as still air and temperature inversions (where cold air is trapped below warm air), can slow down the removal of pollutants and increase the impacts of pollution.

Furthermore, high and low relative humidity situations have different effect on Particulate levels. High relative humidity influences particles to settle down on the ground, causing low accumulation of particles and the reverse applies for low relative humidity. Relative humidity also boosts the formation of secondary pollutant [18]. Also, rainy weather causes wet deposition of particles which results in the removal of PM in the atmosphere; therefore the rate of precipitation has a significant impact on particle matter concentrations [19]. An investigation of the impact of meteorological parameters on fine and coarse particulate matter in a coal mining area in turkey discovered that increase in relative humidity increases episodic values of $PM_{2.5}$ and PM_{10}. The study also revealed that rainfall has a decreasing effect on $PM_{2.5}$ and PM_{10} concentration while increase in temperature decreases PM concentration [20,21]. This study will focus on the analysis of the influence of meteorological parameters on $PM_{2.5}$ and PM_{10} concentration in tropical climate of Woji Port Harcourt, Nigeria. It will also investigate the correlation between $PM_{2.5}$ and PM_{10} with meteorological variables. This study will help to understand the factors that enhances particle pollution episode which has bedeviled the city of Port Harcourt since November 2016. It will also help to understand the sources of pollution and aid legislative authority to develop an effective air quality management plan.

2. METHODOLOGY

2.1 Study Area

The study was carried out at Woji, an urban residential area in Obio-Akpor Local Government Area within Port Harcourt metropolis of Rivers Sate, Nigeria. The town is rapidly undergoing urbanization and development which is characterized with increasing population. It is situated between Latitude 4° 49' 53.80'' N and Longitude 7° 3' 30.94'' E and bounded by Trans-Amadi, Rumurolu, Rumuomasi and Rumuibekwe communities with a total aerial of 5.53 square kilometers. The climate is tropical with two different seasons, wet season (April to October) and dry season (November to March). Port Harcourt on the other hand is the administrative capital of Rivers State with an estimated area of 1811.6 square kilometers with an estimated population of 1,865,000 [1]. The mean monthly rainfall varies between 20.7 and 434.0 mm, with an annual average of 2500 mm. Rainfall is usually at its peak in July and September with December as the driest month of the year. Average temperatures are typically between 25°C- 30°C while the daily relative humidity value ranges from 55% in dry season to 96% in rainy season. The city is a fast growing urban centre with a number of industries such as Notore Fertilizer Company of Nigeria, Eleme Petrochemicals Company Limited, Port Harcourt Refining Company Limited, Shell Petroleum and Development Company and other allied industries within Transi-Amadi industrial layout. Fig. 1 shows the map of the study area with the sampling location.

2.2 Data Collection

The $PM_{2.5}$ and PM_{10} concentration were monitored at Woji monitoring location using handheld particulate matter sampler, Aerocet 531. The equipment has a laser optical sensor for detecting and measuring particulate matter concentration range of 0-1 mg/m^3 and was pre-calibrated before usage to ensure data accuracy throughout the study period. The particulate matter sampling was conducted on one hourly basis for 24 hours from May to December 2018 covering wet and dry season. The sampler which displays real time reading of PM concentration in $\mu g/m^3$ uses light scattering principle with the aid of laser diode was held at the human breathing zone of height 1.5 m above ground level. The PM concentration readings were recorded down on hourly basis for the eight (8) months study period. The meteorological parameters (wind direction, wind speed, ambient temperature, relative humidity and rainfall) were collected from the Misol professional wireless weather station mounted 30 m above ground at the monitoring location. The meteorological data were downloaded from the weather station console at the end of the monitoring period which covers wet and dry season.

2.3 Method of Data Analysis

R-Programming software and its openair package were used to perform data analysis using time variation and correlation matrix plot. The matrix plot gave coefficients which indicates the relationship between meteorological parameters and particulate matter concentration. The analysis revealed how meteorology influences particle pollution in the study area.

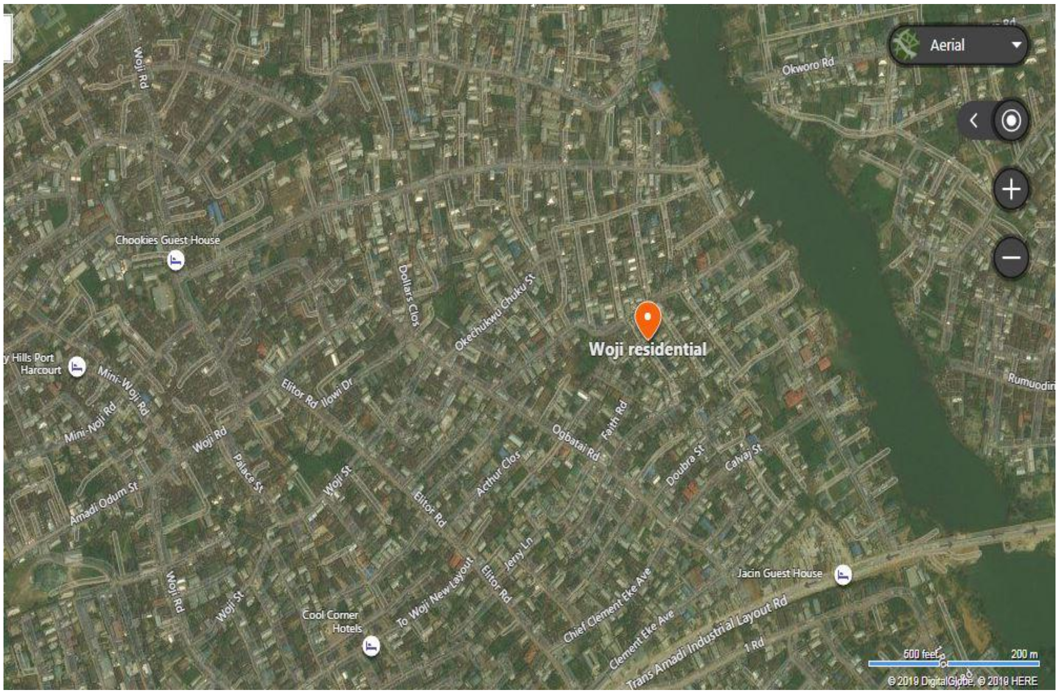

Fig. 1. Map of the study area showing sampling location

3. RESULTS AND DISCUSSION

3.1 PM Concentrations and Meteorological Parameters

The summary results which includes $PM_{2.5}$, PM_{10} and meteorological variables {rainfall, wind speed, temperature, wind direction, relative humidity} for the study period are presented in Table 1. The monthly variation of the particulate matter and meteorological parameters are presented in Table 2.

The result from (Fig. 2) showed that the monthly average $PM_{2.5}$ and PM_{10} concentration for the study period exceeded WHO 24-hr guideline ($PM_{2.5}$ = 25 µg/m³, PM_{10} = 50 µg/m³) with exception to the month of October which recorded mean $PM_{2.5}$ of 22.55 µg/m³. Also the PM concentration for all the months under study were below USEPA 24-hr standard ($PM_{2.5}$ = 35 µg/m³, PM_{10} = 150 µg/m³) except the month of December which experienced particle pollution exceedances as a result of dry dusty north east trade wind that comes with harmattan as well as high atmospheric stability which is associated with low wind speed. The result also revealed that month of December experienced the highest PM pollution followed by the month of July with $PM_{2.5}$ concentration of 38 µg/m while the lowest concentration for the study period was experienced in October (Fig. 2). This finding will aid the Nigerian environmental regulatory authorities in development of effective air Quality management plan that will help to protect the environment and public health from harmful impact of particle pollution.

3.2 Influence of Meteorological Parameters on PM concentration

The degree of particle pollution in a given area tends to vary widely with meteorological variations in the area. This study analyses the effect of meteorological variables on ambient PM_{10} and $PM_{2.5}$ level at Woji Port Harcourt. Hourly measurements of PM_{10} and $PM_{2.5}$ were made from May 2018 to December 2018. The impact of meteorology on PM concentration at different season was understood through analysis of data generated.

3.2.1 Rainfall

Fig. 3 is a plot showing variation in $PM_{2.5}$ & PM_{10} concentration against rainfall within the study period. The scavenging effect of rainfall in reducing concentration of PM is presented in Fig. 3. The inverse relationship between rainfall and particulate matter concentration revealed that at lower rainfall we observed a higher $PM_{2.5}$ and PM_{10} concentration. The month of December had the highest $PM_{2.5}$ and PM_{10} concentration of 58.79 µg/m^3 and 164.69 µg/m^3 respectively with the lowest rainfall (See Table 2 & Fig. 3). It is clearly shown in Fig. 3, that when rainfall is around 0mm, the PM concentrations were at maximum but when the rainfall increases, the PM level sharply declined. Also from Table 2 we can see that the dry season is associated with high PM level than wet season.

Table 1. Summary of meteorological parameters and pollutants hourly data from May to December 2018

Metrics	PM_{10} (µg m^{-3})	$PM_{2.5}$ (µg m^{-3})	$PM_{2.5}/PM_{10}$ Ratios	Wind speed (m s^{-1})	Wind direction (degrees)	RH (%)	Temp. (°C)	Rainfall (mm)
Minimum	2.0	1.00	0.1739	0.00	25.0	10.00	20.90	0.00
1st Quartile	42.0	11.00	0.2500	1.70	180.0	72.00	25.00	0.00
Median	77.0	21.00	0.2667	1.40	225.0	86.00	26.50	0.00
Mean	109.1	33.91	0.2843	1.62	230.6	80.03	27.04	0.31
3rd Quartile	135.0	41.00	0.3004	2.40	315.0	92.00	28.70	0.00
Maximum	776.0	337.0	0.5533	7.10	360	98.00	36.30	37.50

Table 2. Meteorological parameters and pollutants average monthly data

Monthly mean	May	June	July	August	September	October	November	December
Temp.(°C)	27.83	27.15	26.15	25.92	25.99	26.96	27.72	28.88
RH (%)	80.35	82.11	84.72	83.74	85.55	82.40	81.20	60.68
Wind speed (ms^{-1})	1.82	1.83	1.65	1.81	1.61	1.59	1.35	1.38
Wind direction (degree)	230.36	238.70	235.81	236.90	225.96	224.95	221.45	228.59
Rainfall (mm)	0.276	0.405	0.277	0.467	0.561	0.244	0.149	0.084
$PM_{2.5}$	27.36	26.05	38.02	32.42	28.67	22.55	33.12	58.79
PM_{10}	86.69	99.21	131.10	99.90	91.02	75.99	114.42	164.49
$PM_{2.5}/PM_{10}$ Ratio	0.287	0.261	0.272	0.279	0.278	0.271	0.270	0.349

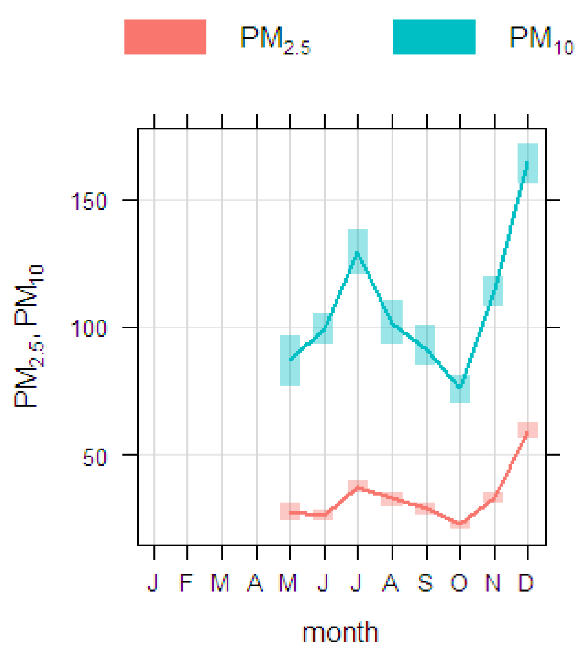

Fig. 2. Time variation plot showing monthly variation of $PM_{2.5}$ & PM_{10} concentrations

The finding shows that rainfall reduces PM concentration due to the scavenging mechanism of precipitation [22]. According to USEPA rainfall was discovered among the meteorological parameters to have the greatest effect on particulate matter concentration in the atmosphere. This is because rainfall has the effect of reducing re-entrainment of particle and washing them out of the air. This finding concluded that increase in precipitation reduces particulate matter concentration in the study area through wet deposition. This finding is collaborated by these researchers [23-25].

3.2.2 Wind speed

The daily wind speed ranges from 0 m/s to 7.1 m/s with the highest monthly mean wind speed of 1.83 m/s in June and lowest in November (1.35 m/s) as shown in Tables 1 & 2. Fig. 4 presents a plot showing how PM_{10} and $PM_{2.5}$ concentration varies with wind speed for the study period. High wind speed transport large amount of particles to far distance thereby reducing PM concentration. Our finding as depicted in Fig. 4 confirmed that increase in wind speed reduces PM concentration due to wind dispersion which transports particles away from the study area. At calm condition when the wind speed is at 0 m/s, we had the highest Particulate matter concentration due to stable atmosphere which impedes particle dispersion. Table 2 also showed that the month of November and December which had the lowest wind speed of 1.35 m/s and 1.38 m/s for the study period tend to experience the highest PM_{10} of 114.42 μg/m^3 and 164.49 μg/m^3 respectively. PM concentration in wet season is lower due to higher wind speed as compared with dry season which had lower wind speed as shown in Table 2.

This is in agreement with the finding of other researcher, which showed that low wind speed increases PM level while increase in wind speed lowers PM concentration through wind dispersion and dry deposition [23,26].

3.2.3 Temperature

The change in surface temperature controls the atmospheric convection, which invariably affects pollutant concentration. The daily ambient temperature for the study period varies from 20.9°C (low) to 36.3°C (high) with an average cumulative value of 27°C (See Table 1). The wet season ambient temperature observed at study area varied from 20.9°C (low) to 34.9°C (high) with cumulative mean value of 26.6°C while dry season temperature ranged from 22.2°C to 36.3°C with a cumulative mean of 28.3°C. The month of December experienced the highest mean temperature of 28.9^{o}C with the lowest in August (25.9°C) for the study period (See Table 2). The influence of temperature on ambient $PM_{2.5}$ and PM_{10} concentration is depicted by the scatter plot in Fig. 5. The inverse relationship between temperature and PM concentration revealed that increase in temperature reduces particle pollution level and vice versa. The results of this study agreed with the findings of other

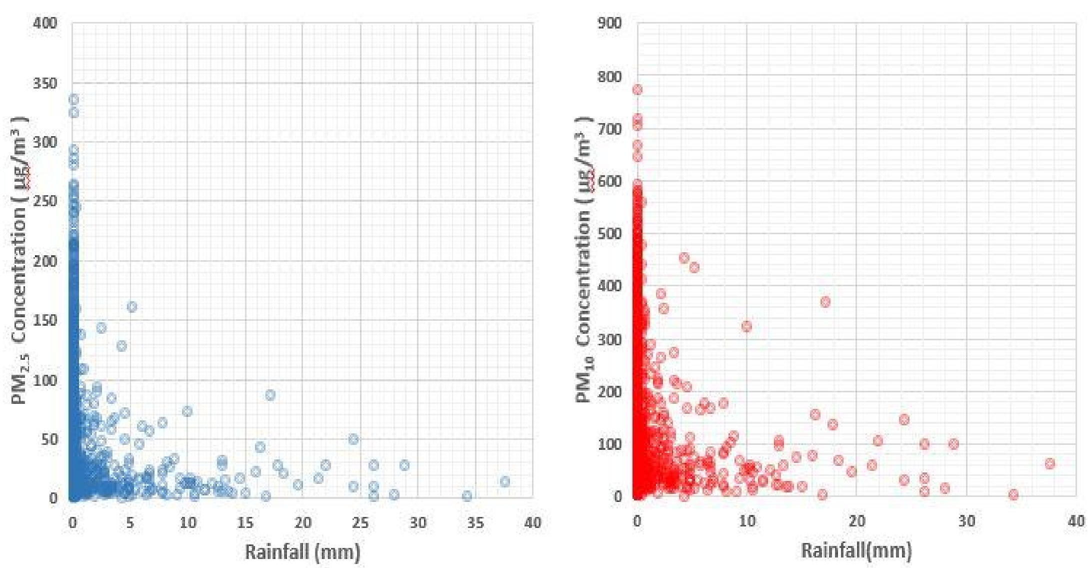

Fig. 3. Temporal variation of $PM_{2.5}$ & PM_{10} concentrations against rainfall

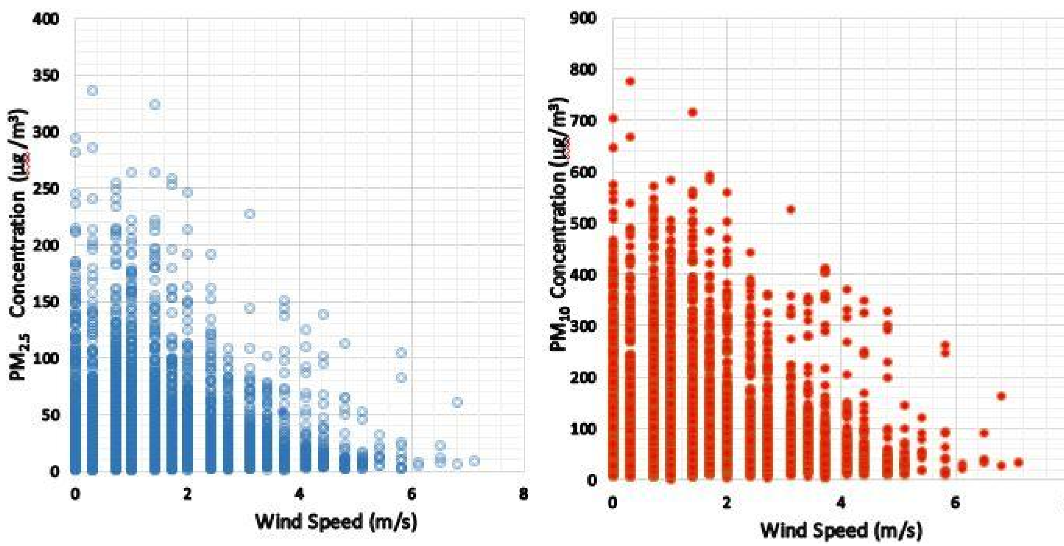

Fig. 4. Temporal variation of $PM_{2.5}$ & PM_{10} concentrations against Wind speed

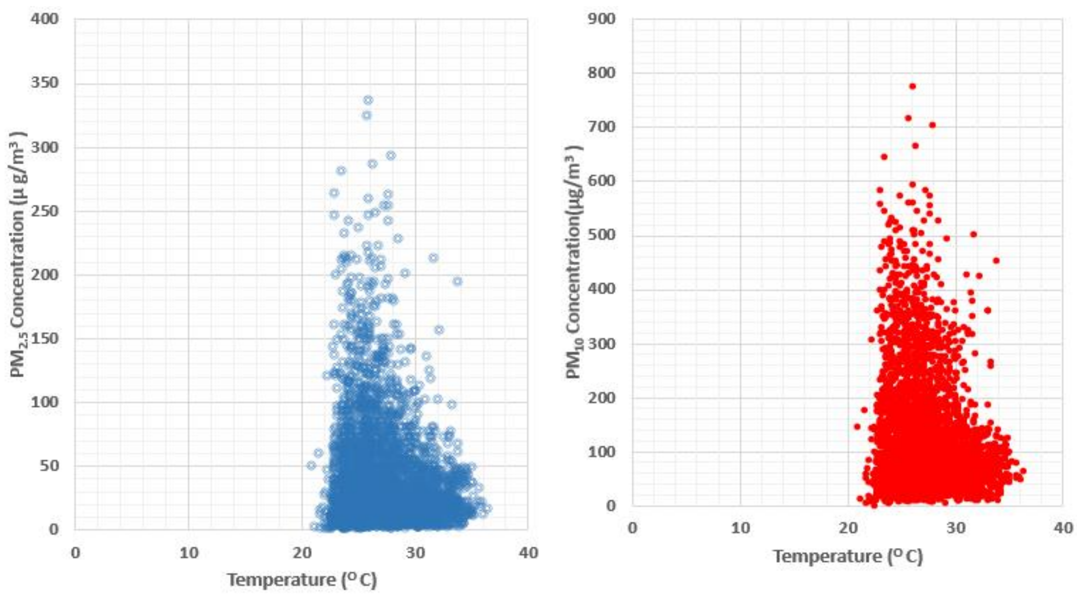

Fig. 5. Temporal variation of $PM_{2.5}$ & PM_{10} concentrations against ambient temperature

researchers which affirms that increase in air temperature helps to reduce PM concentration [21,27]. The PM level reduction could be attributed to thermal convection arising from high temperature that heats up the ground in the day time and increases wind speed and gust leading to increased dispersion of particulate matter. Also, decreasing temperature at night creates a temperature inversion that acts like a cap, thereby inhibiting particulate matter diffusion. It is clear that high temperature contributes to atmospheric instability and air turbulence thus reduction in PM concentration through diffusion. However, it this finding negates the findings of some other researchers whose findings revealed that increase in temperature results to formation of particles through photochemical reaction thus increase in PM concentration [24,25].

3.2.4 Relative humidity

The mean relative humidity observed for the study period as shown in Table 1 was 80% with a range from 10% (low) to 98% (high). The wet season daily relative humidity ranged from 44% (low) to 98% (high) with a cumulative mean of 83.3% while the dry season varied from 10% (low) to 97% (high) with a cumulative mean of 70.7%. The highest monthly mean relative humidity was recorded in the month of September (85.5%) with the lowest in December (60.7%) as shown in Table 2. The influence of relative humidity on ambient $PM_{2.5}$ and PM_{10} concentration as shown in Fig. 6 shows that relative humidity has a negligible or minimal negative effect on $PM_{2.5}$. That shows that increase in relative humidity slightly reduces $PM_{2.5}$ concentration. This slight decrease is attributed to the fact that particles accumulate mass owing to moisture which leads to dry deposition. This results is in conformity with the finding of other researchers [1,26-28]. Also, the PM_{10} concentration was found to increase as the relative humidity increases because of their weak positive relationship.

3.2.5 Wind direction

Fig. 7 presents sixteen (16) wind directions and their individual contribution to Particulate Matter (PM) concentration at the study area. The wind from different direction transport different amount of particulates. The contribution of each wind direction to PM concentration at the study area was determined using average weighted Particulate matter (AWP) by wind speed for different wind direction. The predominant wind direction for the year 2018 was south westerly

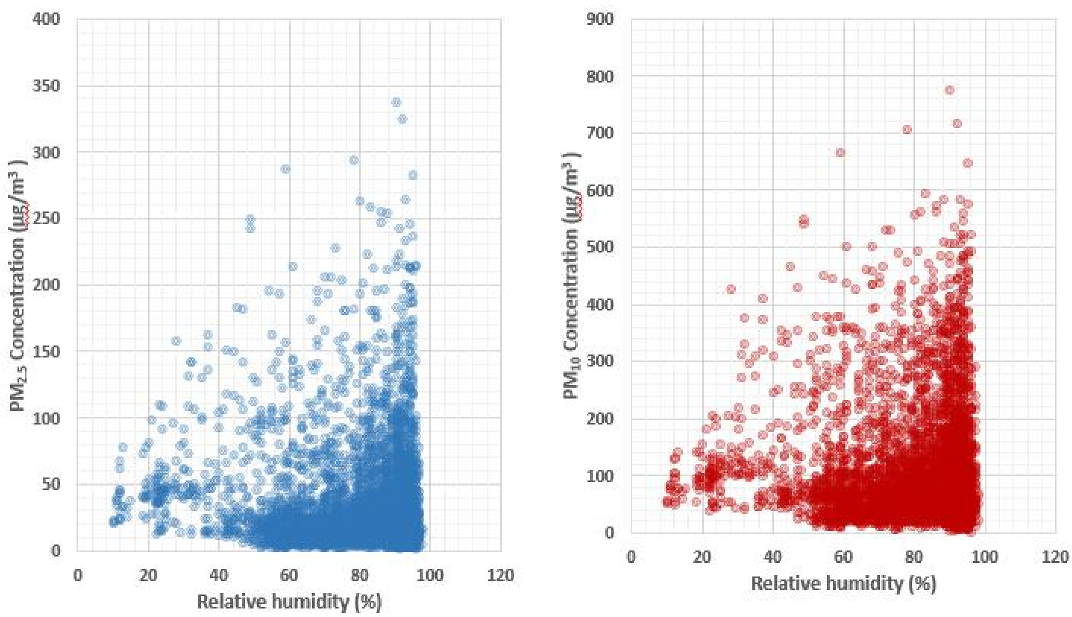

Fig. 6. Temporal variation of $PM_{2.5}$ & PM_{10} concentrations against relative humidity

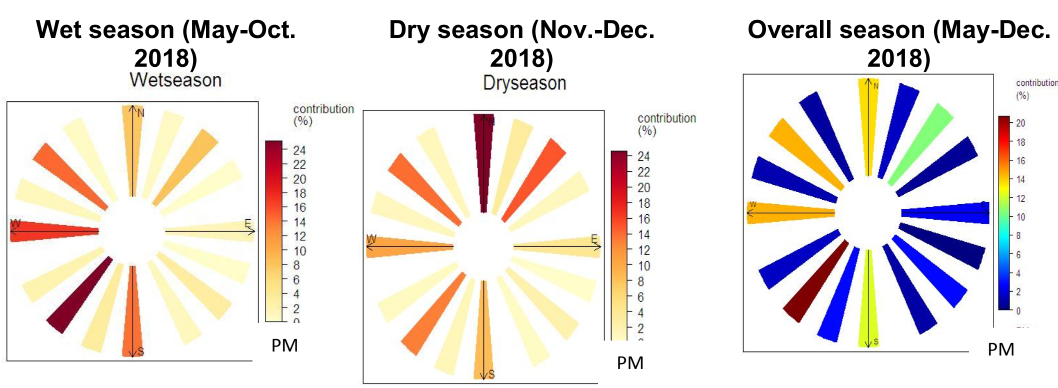

Fig. 7. Temporal variation of PM concentrations against wind direction

which contributed over 24%, which can be attributed to the tropical maritime Air mass (South West trade wind). The south west wind was predominant in the wet season contributing over 25% of PM concentration in the wet season owing to its closeness to Atlantic Ocean while Northerly wind which was predominant in the dry season contributed over 24% to PM concentration in the dry season with north east contributing over 15% (Fig. 7). The finding contradicts the result of other researchers who reported that the predominant direction in the rainy season was north easterly [29]. The wet season PM loading is contributed mostly by the SW, W, NW and S winds than any other wind direction while the dry season particulate matter contribution at Woji was dominated by the N, NW and NE wind direction. The result therefore confirms that wind direction influences particulate matter concentration at Woji, which is in agreement with the findings of these researchers [23,30].

3.3 Correlation between $PM_{2.5}$ and PM_{10} Concentrations with Meteorological Parameters

Fig. 8 is a correlation matrix which provides the visual relationship between pollutants ($PM_{2.5}$ and PM_{10}) and the meteorological parameters in Woji Port Harcourt. The ellipses shows correlation while a line drawn at 45 degree positive slope represents a perfect positive correlation. However, a circle shape represents a zero correlation. The results from Fig. 8 revealed a positively strong correlation between $PM_{2.5}$ and PM_{10} concentration which is statistically significant (r = 0.97, P< .001). The strong positive correlation between $PM_{2.5}$ and PM_{10} shows that increase in $PM_{2.5}$ directly increases PM_{10} concentration. This finding is in agreement with the findings of these researchers [1,26,31,32]. A weak negative correlation was found between particulate matter ($PM_{2.5}$ and PM_{10}) and wind speed which is statistically significant at P< .001. The result shows that increase in wind speed decreases PM concentration. It also shows that wind speed cleanses the atmosphere of PM through atmospheric instability via dispersion and transport of particulates thus reduction in concentration [24]. PM_{10} and $PM_{2.5}$ shows a significant but weak negative correlation with rainfall (r = -0.05, P< .001). The weak negative correlation between $PM_{2.5}$ and PM_{10} with rainfall, shows that increase rainfall give rise to reduction in PM concentration due to its scavenging potential through wet deposition [4,24,25]. Fig.8 also revealed a significant but weak positive correlation between relative humidity and PM_{10} (r = 0.04). The result is in agreement with the findings of some researchers [21]. On the other hand, a very weak negative correlation between

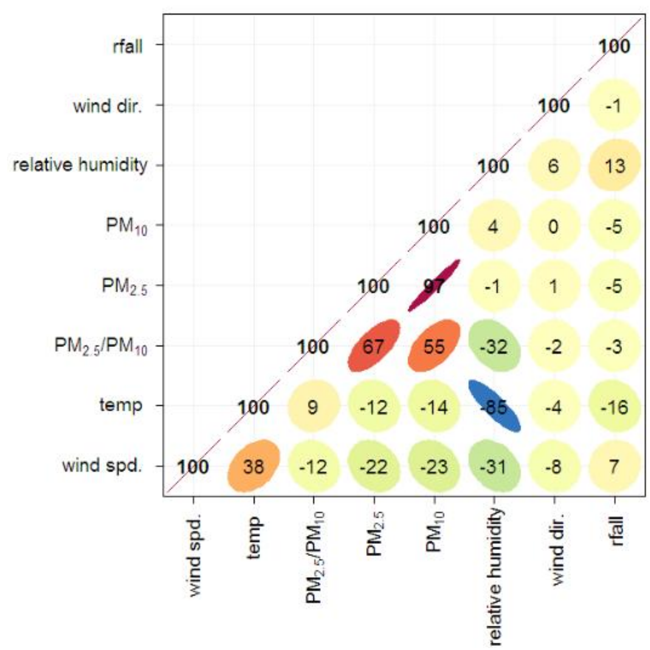

Fig. 8. Correlation plot of $PM_{2.5}$ and PM_{10} with Meteorological parameters for the study period in Woji

$PM_{2.5}$ and relative humidity (r = -0.01) is statistically not significant [4,24,27]. Relative humidity makes the soil humid by hindering the re-suspension of soil dust, thus reducing PM loading in the atmosphere.

A very weak negative correlation exist between air temperature and the particulates ($PM_{2.5}$ and PM_{10}) with a correlation coefficient of -0.14 and -0.12 respectively which is significant at P<.001 [21,33]. The finding shows that decrease in air temperature increases PM concentration at the study area. Decreasing temperature usually enhances temperature inversion which acts as a cap limiting diffusion of $PM_{2.5}$ and PM_{10} most especially at night.

4. CONCLUSION

The following conclusions can be drawn from this study:

1) The study concludes that the monthly average $PM_{2.5}$ and PM_{10} concentration for the study period exceeded WHO 24-hr guideline ($PM_{2.5}$ = 25 µg/m³, PM_{10} = 50 µg/m³) with exception to the month of October which recorded mean $PM_{2.5}$ of 22.55 µg/m³. However, the PM concentration for all the months under study were below USEPA 24-hr standard ($PM_{2.5}$ = 35 µg/m³, PM_{10} = 150 µg/m³) except the month of December which experienced particle pollution exceedances as a result of dry dusty north east trade wind that comes with harmattan as well as high atmospheric stability which is associated with low wind speed.
2) The meteorological parameters plays a prominent role in temporal variation of PM_{10} and $PM_{2.5}$ concentration at Woji Port Harcourt. It was inferred that meteorological parameters such as air temperature, wind speed and rainfall plays significant role in the reduction of particulate matter loading through air dispersion, atmospheric instability and washout process while relative humidity had a minimal influence on PM concentration.
3) The study concludes there is a strong positive correlation between PM_{10} and $PM_{2.5}$.It also concludes there is a weak negative correlation between $PM_{2.5}$ and relative humidity which is not statistically significant but also a weak but statistically significant negative correlation with temperature, rainfall and wind speed. The PM_{10} has a weak negative relationship with wind speed, rainfall, temperature but a weak positive relationship with relative humidity which are statistically significant.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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