

## Geospatial and Geostatistical Analyses of Particulate Matter (PM<sub>10</sub>) Concentrations in Imo State, Nigeria

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**ABSTRACT.** Geospatial and geostatistical analysis of particulate matter (PM<sub>10</sub>) variation in Imo State, Nigeria was carried out. The objectives of the study were to determine and analyze the variation in concentration of ambient PM<sub>10</sub> level in Imo State, Nigeria. Air quality sampling was conducted within November 2014 and June 2015, in wet and dry seasons three times daily using Haze Dust Particulate Monitor (10µm). The mean concentration of PM<sub>10</sub> level observed in the study varied from 5.22 - 6.63mg/m<sup>3</sup> in wet season and 5.80 - 8.38 mg/m<sup>3</sup> in dry season. Coefficient of variation (CV %) revealed that the variability of PM<sub>10</sub> level ranged between little and moderate variations in both wet and dry season. Analysis of variance (ANOVA p<0.05) showed statistically significant variation in the mean PM<sub>10</sub> level in the study locations. Box and Whisker plots confirmed variation of PM<sub>10</sub> in the morning, afternoon and evening. The GIS plots revealed the spatial attributes of the air pollutant in the study locations. Time series plots indicate that the air pollutants fluctuated throughout the study duration. The Wind Rose suggests that the prevailing wind speed and wind directions were responsible for the dispersal migration of the air pollutant in the study area. The highest seasonal mean values were observed in Egbema and Okigwe area in both dry and wet season. The seasonal mean values recorded in the study exceeded the Nigerian National Ambient Air Quality Standards. This calls for urgent response to prevent further air quality deterioration and its negative effects on man and the environment.

## INTRODUCTION

Pollution of the ambient environment could be due to gaseous or particulates matter. Atmospheric pollution has been persistent as a result of continuous mixing, transformation and trans-boundary transportation of atmospheric pollutants that deteriorates the air quality of an area and makes it difficult to predict [1]. These atmospheric pollutants especially the particulate matter (PM<sub>10</sub>) has been increasingly unabated due to population growth, urbanization, industrialization, increase in vehicular traffic and wrong implementation of strict environmental regulations, which could contribute significantly to reduction of air quality standards [2].

Particulate matter (PM<sub>10</sub>) is one of the air pollutants emitted into the atmospheric environment by anthropogenic and natural sources which may impact negatively to air quality of the surrounding environment [3]. Pollution of the atmospheric environment due to particulate matter could be regarded as a very important air pollutant and one of the most significant sources of atmospheric pollution. This owns to the complex composition of particulate matter in the environment. Elevated levels of As, Pb, Cd, and Fe has been reported in samples of suspended particulate matter [4]. Similarly, Chiemeka reported significant levels of Ca, K, Mg, Fe, Zn, Mn, Cu, Ni, Cr, Cd, and Pbin atmospheric aerosol samples [5]. In addition, Majewski et al reported presence of As, Cd and Ni in samples of particulate (PM<sub>10</sub>) matter in Warszawa, Poland [6].

Particulates, such as dust, soot, or smoke, are sizable or dark enough to be observed with human naked eye [7]. PM<sub>10</sub> are atmospheric particles which could be liquid or solid, organic or inorganic particulate contaminants ranging from 0.001 to 10 µm [8 - 10]. These particles are usually suspended in the atmospheric environment close to sources of air pollution like in urban atmosphere, highways, windblown dust, industrial plant vicinity, power plants, mining sites, volcanic eruption, bush burning and from agricultural practices [11 - 15].

Atmospheric pollutants such as particulate matter is one of the foremost environmental concern before developing and developed countries due to its effects on air quality standard and human health which could be acute or chronic [16,17]. Atmospheric particulates, due to their considerable environmental significance pose serious threat clean air and environmental health, the basic requirements of human existence [18, 19]. Pollution of the atmospheric environment by particulate pollutants has been linked to numerous health concerns which can worsen respiratory and cardiovascular diseases [20 -24], reduction in growth of plant and yield [25], distortion and reduction of visibility [26,27], including deformation of the esthetic and natural beauty of the environment [28].

The level of atmospheric pollution could vary due to changes with different locations and time resulting from changes in meteorological and topographical conditions. This arises due to the concentration of air pollutants depend not only on the quantities that are emitted from air pollution sources but also on the ability of the atmosphere to either absorb or disperse these emissions [29]. Variation in air pollution concentration is hinged on the space variation of sources as well as atmospheric gradients which results in diffusion and transportation to areas outside the source of the air pollution [30]. Fluctuations in time of the year or seasons have been reported to affect the observed air quality as this could influence dispersal of air pollutants by either decreasing or increasing their concentration in the atmosphere[31]. Difference in the ambient temperature, relative humidity and wind speed including wind direction could also vary the concentration of atmospheric pollutants over the seasons [32].

PM<sub>10</sub> is one of the criteria pollutants that are regulated and monitored. It is among the air pollutants commonly employed in the determination of the air quality index /air pollution index (AQI/API) [33,34]. The problem of particulate matter in the atmospheric environment calls for serious concern in Nigeria especially in Imo where there are a lot of factors that could generate the particles. Majority of the roads even in the urban areas are not asphalted, this is in addition to frequent bush burning that enables the emission of this pollutant. Also, in this part of the world with two distinct seasons this atmospheric pollutant may be significant during dry season when the relative humidity is moderately low with a higher wind velocity [35 - 37]. Air pollution events such as dust storms, biomass combustion, and firework displays, which take place on many occasions in certain periods, could impact negatively to the air quality [38].

The need for this research was necessitated by the fact that Nigeria like most developing countries lack continuous air quality monitoring stations, hence unavailability of air quality data base. This is in addition to paucity of air quality reports on PM<sub>10</sub> in the study area.

## MATERIALS AND METHODS

**Study Area.** The study was carried out in Imo State (figure 1). Imo State is located in the tropical rainforest zone climate, within the coordinates 5.4833°N, 7.0333°E. The area is dominated by plains with elevation ranging from 50-200m above sea level. The annual rainfall is about 2400mm to 4000mm, which is concentrated almost entirely between April and October, with average relative humidity of about 80% and up to 90% occurring during the wet season. The maximum air temperature ranges from 28 to 38°C, while the minimum air temperature range from 19°C to 24°C [39 - 41].

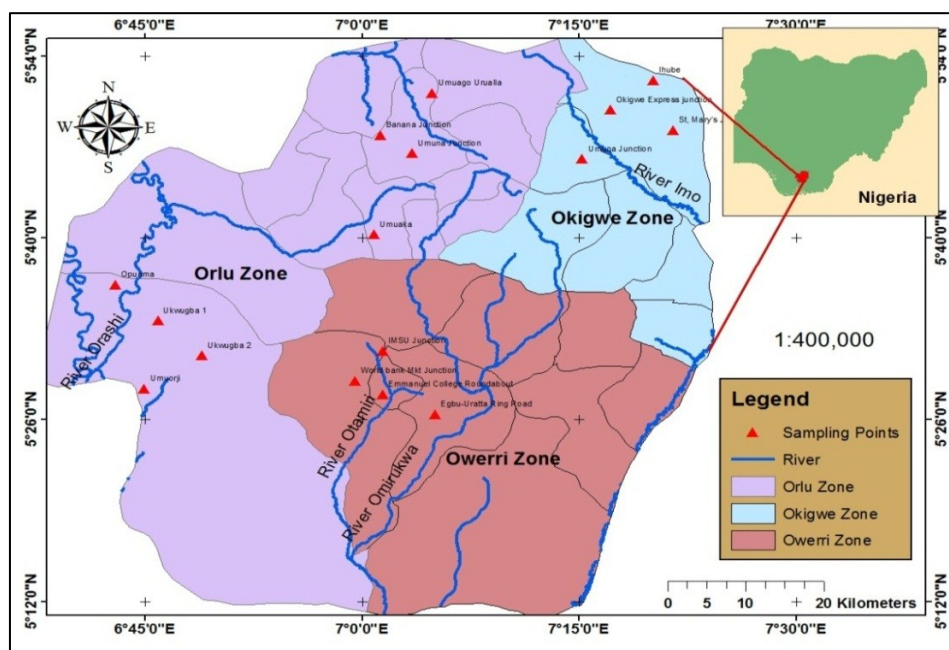


Fig. 1. Map of Imo State showing air pollution monitoring locations

**Description of Study area.** Imo State has a population of about 3,934,899 as at 2006[42]. This figure must have increased tremendously after almost ten years. The presence of stone mining sites in Okigwe and quarrying activities in neighboring towns could be a huge source of particulate matter emission into the ambient environment of the state, and this quarry products or stones are transported to different places by heavy duty trucks that uses diesel which could contribute significantly to air quality deterioration. Orlu city is fast growing with a lot of commercial activities, use of power generators, high volume of vehicular traffic and presence of two stroke engine automobiles like motorcycles and tricycle. Owerri, the capital of Imo State has high population density [42], with a lot of commercial activities, use of power generators, high volume of vehicular traffic and presence of two stroke engine automobiles like motorcycles and tricycles used for transportation, known for their incomplete combustion of fuel which could lead to the emission of noxious atmospheric air pollutants [29]. The State is located in the Niger Delta region of Nigeria blessed with natural resources like natural gas and crude oil mainly within Ohaji, Egbema and Oguta area of the State and most of the oil wells have enormous natural gas associated with them, which has a rough estimated future supply of about 1422 billion cubic meters [43]. Part of this gas has been continuously flared in this region since 1970 [44]. Also, Ohaji, Egbema and Oguta area have enormous farm lands hence most people here are farmers and the type of agricultural practices like bush burning generates much particulate matters. The study therefore was carried out in these areas described above which include Owerri, Orlu, Okigwe and Egbema with a total of four sampling station in each location. This amounts to sixteen (16) air quality sampling stations. Air quality monitoring sites were chosen in these locations for the analysis of particulate matter ( $PM_{10}$ ) variation in the atmospheric environment of Imo State, Nigeria.

**Air quality sampling Procedure.** The air pollutant,  $PM_{10}$ , was sampled three times a day (morning, afternoon and evening) [46], using Haze-Dust Particulate Monitor  $10\mu m$ , model, HD1000, Environmental Device Corporation, USA. The air monitor was calibrated according to the manufacturer's directions before being deployed for the air quality sampling. Sampling was carried out for six month during dry and wet seasons, between November 2014 and June 2015. The air sampling was carried out once a week in each of the 16 air monitoring locations, three times per day, four times a month for a period of twenty four (24) weeks, which was within dry and wet seasons.

**Data interpretation.** Data analysis was done using Microsoft excel 2010, values of all the results from the 16 sampling points in the four locations which were recorded as calculated mean values of the air pollutant concentration in the morning, afternoon and evening hours, indicating minimum,

maximum values and standard deviation (SD). The level of PM<sub>10</sub> variation in (morning, afternoon, and evening) at different locations was determined using variance (VAR) and co-efficient of variation (CV %). This was categorized as little variation (CV % < 20), moderate variation (CV % = 20 – 50) and high variation (CV % > 50) [47]. Contour and 3-D surface plots of the air pollutant concentration were modeled using Surfer 12 software, while the spatial distribution map of PM<sub>10</sub> was modeled with Arc GIS 10.2. Matlab 7.9 version was used to carry out the ANOVA ( $p < 0.05$ ) and time series analysis. Box and Whisker plots were also plotted to further elucidate the variation of this air pollutant at each of the air sampling location in the morning, afternoon and evening, indicating the median, lower and upper quartiles [48].

## RESULTS AND DISCUSSION

**Geospatial Variation of PM<sub>10</sub> in wet season.** The summary of wet season result of PM<sub>10</sub> variation in the atmospheric environment of Imo State is presented in table 1 for wet season. Fig.2 is the contour and 3-D surface plot of PM<sub>10</sub> variation in wet season, while fig. 3 is the spatial variation map of PM<sub>10</sub> in wet season. The result of PM<sub>10</sub> as presented in table 1 for wet season shows that at Owerri, the mean concentration of PM<sub>10</sub> (mg/m<sup>3</sup>) ranged from 5.22 - 6.63. The mean value recorded in Okigwe is between 6.75 - 7.40 mg/m<sup>3</sup>, the value in Orlu ranged from 6.95 - 7.06 mg/m<sup>3</sup>, while in Egbema, the mean PM<sub>10</sub> (mg/m<sup>3</sup>) is between 6.89 - 7.00. In wet season the maximum value was 7.40 mg/m<sup>3</sup> while the minimum value was 4.61 mg/m<sup>3</sup> which were observed in Okigwe and Owerri respectively. The mean PM<sub>10</sub> values obtained from semi- urban and rural areas of Orlu and Egbema respectively are relatively lower when compared with Owerri and Okigwe. Fig. 2 shows the contour and 3-D surface plot of PM<sub>10</sub> variation in the study area in wet season which indicates that elevated values were observed in Okigwe area of the study locations. This is also depicted in the spatial variation map of PM<sub>10</sub> as presented in fig. 3. The order of variation in the morning is Egbema>Okigwe>Orlu>Owerri, while afternoon is Egbema>Owerri>Orlu>Okigwe and evening is in the order; Owerri>Okigwe>Orlu>Egbema. This is also shown in table 1 from the result of coefficient of variation (CV %), which indicates little variation for PM<sub>10</sub> in all the locations. The result of PM<sub>10</sub> obtained in wet season supports the idea of wide-spread, regional pollution of PM aerosols due to long-range transport of particulate and gaseous pollutants as noted by Gomiseck et al [49].

Table 1. Summary of wet season result of PM<sub>10</sub> variation [mg/m<sup>3</sup>]

	Owerri			Okigwe			Orlu			Egbema		
	M	A	E	M	A	E	M	A	E	M	A	E
Max	5.69	6.91	7.32	7.40	6.75	7.02	7.06	6.95	7.01	6.98	7.00	6.89
Min	4.61	5.36	5.91	4.93	5.53	5.60	5.38	5.50	5.49	5.50	5.49	5.49
Mean	5.22	6.14	6.63	6.12	6.03	6.23	6.11	6.13	6.16	6.15	6.17	6.14
Var	0.12	0.21	0.21	0.75	0.13	0.16	0.25	0.17	0.19	0.17	0.18	0.17
SD	0.34	0.46	0.45	0.87	0.36	0.40	0.50	0.41	0.43	0.42	0.43	0.42
CV %	6.51	7.49	6.79	14.22	5.97	6.42	8.18	6.69	6.98	6.83	6.97	6.84

(Where M= morning, A= afternoon and E= evening, Max= maximum value, Min= minimum value Var= variance, SD= standard deviation and CV% = co-efficient of variation)

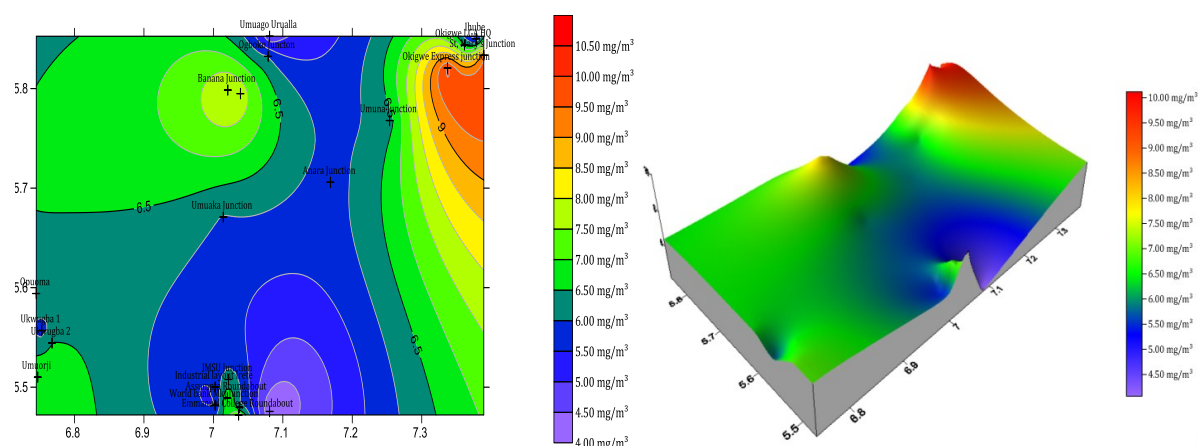


Fig. 2. Contour and 3-D surface plot of  $PM_{10}$  variation in the study area (wet season)

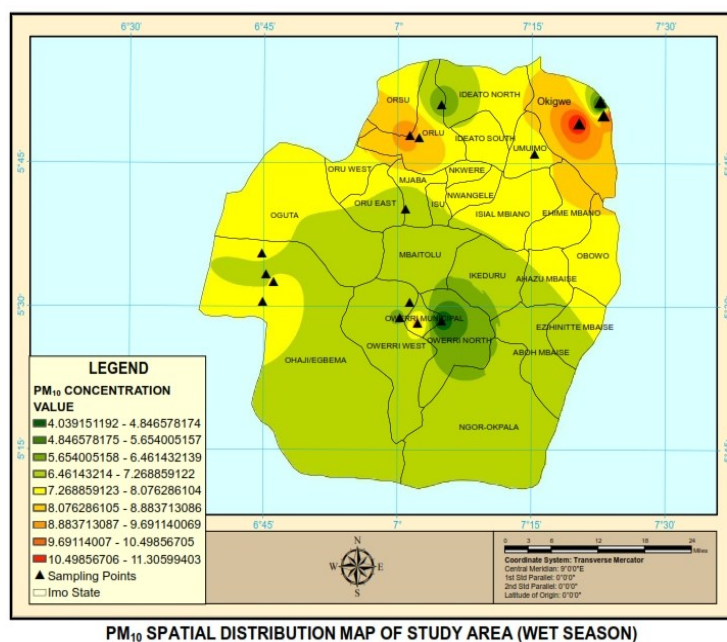


Fig. 3. Spatial variation map of  $PM_{10}$  in wet season

**Geostatistical analysis of  $PM_{10}$  in wet season.** The variation of  $PM_{10}$  in the study locations are presented using Box and Whisker plots as shown in fig.4 – 7. The coefficient of variation (CV%) as shown in table 1 indicates little to moderate variations. Analysis of variance (ANOVA at  $p > 0.05$ ) was also carried out in order to further elucidate the variations in the study locations. Fig.4 is the Box and Whisker plots of  $PM_{10}$  variation at Owerri in wet season. The plot indicates that in the morning, 25% of the data lie above  $4.70 \text{ mg/m}^3$  while 75% lies above  $5.60 \text{ mg/m}^3$ . The afternoon air sampling revealed that 25% lie around  $5.50 \text{ mg/m}^3$  while 75% of the data are within  $6.30 \text{ mg/m}^3$ . In the evening it was observed that 25% of the data were little below  $6.00 \text{ mg/m}^3$  while 75% of the data were within  $6.80 \text{ mg/m}^3$  of the results recorded. In addition ANOVA result ( $F = 13.05$ , sig. value =  $6.6702e^{-5}$ ,  $p > 0.05$ ) shows that there is a significant difference in the mean level of  $PM_{10}$  observed in Owerri in wet season.

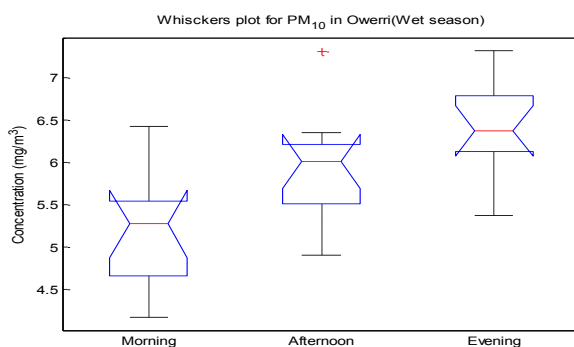


Fig. 4. Box and Whisker plot of PM<sub>10</sub> variation at Owerri (wet season)

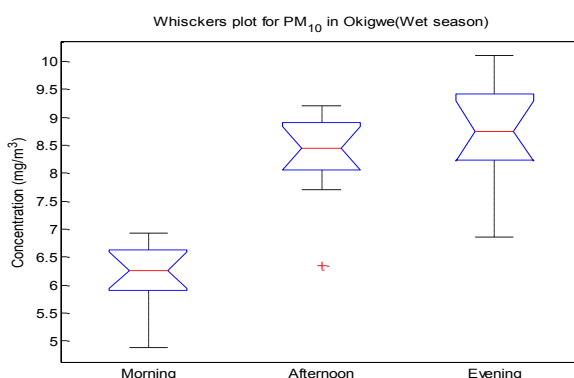


Fig. 5. Box and Whisker plot of PM<sub>10</sub> variation at Okigwe (wet season)

Fig.5 is the Box and Whisker plots of PM<sub>10</sub> variation at Okigwe in wet season. It shows that generally, higher mean values were recorded in the afternoon and evening hours. Fig.5 reveals that 25% of the results are within 5.90 – 8.30 mg/m<sup>3</sup> for morning, afternoon and evening, while 75% of the results are within 6.70 – 9.40 mg/m<sup>3</sup> for the same morning, afternoon and evening. ANOVA result ( $F = 39.65$ , sig. value =  $1.677e^{-9}$ ,  $p < 0.05$ ) indicates that there is a significant difference in the mean PM<sub>10</sub> level observed at Okigwe in wet season.

In the case of Orlu in wet season, fig.6 is the Box and Whisker plots of PM<sub>10</sub> variation in wet season. It revealed that the lower and upper quartile respectively lies within 4.50 mg/m<sup>3</sup> and 5.80 mg/m<sup>3</sup> in the morning, while in the afternoon, 25% and 75% of the results obtained are within 6.30 mg/m<sup>3</sup> and 7.40mg/m<sup>3</sup> respectively. It was observed that in the evening hours, 25% of the results recorded are within 7.20 mg/m<sup>3</sup> while 75% are within 8.10 mg/m<sup>3</sup>. ANOVA result ( $F = 28.78$ ,  $p < 0.05$ ) at a significant value of  $5.8336e^{-8}$  below 0.05 indicating that there is a statistical significant difference in the mean values of PM<sub>10</sub> recorded at Orlu in wet season.

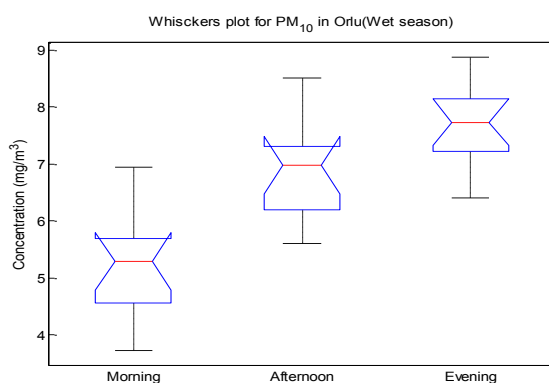


Fig. 6. Box and Whiskerplot of PM<sub>10</sub> variation at Orlu (wet season)

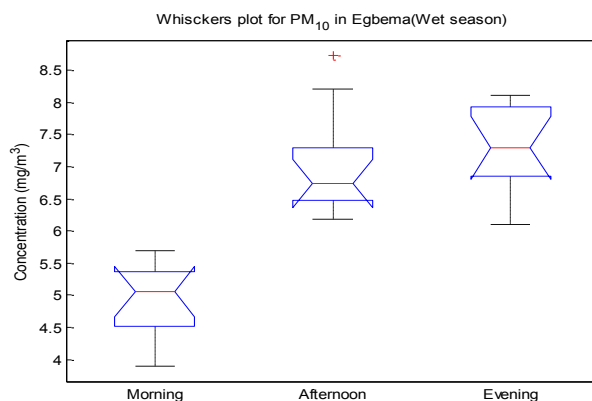


Fig. 7. Box and Whisker plot of PM<sub>10</sub> variation at Egbema(wet season)

Fig. 7 is the Box and Whisker plots of PM<sub>10</sub> variation at Egbema in wet season. Similarly, it was observed that in fig. 7, 25% and 75% of the results are respectively within 4.50 and 5.40 mg/m<sup>3</sup> in the morning, while in the afternoon 25% and 75% of the results are within 6.50 mg/m<sup>3</sup> and 7.30mg/m<sup>3</sup> respectively. It was also observed that in the evening 25% and 75% of the results are respectively within 6.70 mg/m<sup>3</sup> and 7.9 mg/m<sup>3</sup>. ANOVA result ( $F = 46.76$ , sig. value =  $2.3462e^{-10}$ ,  $p > 0.05$ ) shows that there is a statistically significant difference in the mean concentration of PM<sub>10</sub> recorded at Egbema in wet season.

**Variation of mean PM<sub>10</sub> level across study locations in wet season.** Variation of mean PM<sub>10</sub> values across study locations in wet season is presented in fig.8 which indicates variation of the air pollutant from week one to week twelve. The result indicates that elevated values of PM<sub>10</sub> were recorded in week 4, 9, 10, 11 and 12 at Okigwe. This location in Imo States is known for stone mining and quarry activities within and around the area, which could contribute significantly to the concentration of particulate matter in this area [50]. Also, it could be observed that elevated level of PM<sub>10</sub> was recorded in Egbema. The location is a rural area though with the presence of gas flare starts [51], the observed elevated values of PM<sub>10</sub> could also result from bush burning and other agricultural practices [15].

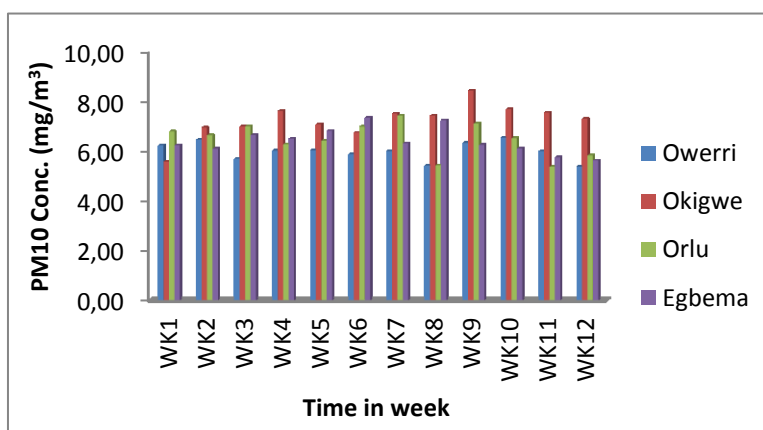


Fig. 8. Variation of mean PM<sub>10</sub> values across study locations in wet season

**Geospatial Variation of PM<sub>10</sub> in dry season.** The summary of dry season variation of PM<sub>10</sub> in the atmospheric environment of Imo State is presented in table 2. Fig.9 is the contour and 3-D surface plot of PM<sub>10</sub> variation in dry season, while fig.10 is spatial variation map of PM<sub>10</sub> in dry season. Table 2 indicates that the mean concentration of PM<sub>10</sub> (mg/m<sup>3</sup>) recorded in Owerri in dry season ranged from 5.80 – 7.28. While the mean PM<sub>10</sub> (mg/m<sup>3</sup>) observed in Okigwe ranged from 6.92 – 7.87. Table 2 also indicates that the mean PM<sub>10</sub> value recorded at Orlu in dry season ranged from 6.72 – 7.77 (mg/m<sup>3</sup>). The mean value of PM<sub>10</sub> (mg/m<sup>3</sup>) recorded in Egbema ranged from 7.42 –



8.38. The highest PM<sub>10</sub> mean value of 8.38 mg/m<sup>3</sup> was observed at Egbema in the afternoon while the lowest mean value of 5.80 mg/m<sup>3</sup> was recorded at Owerri in the morning in dry season as shown in table 2. It has been earlier noted that Egbema is a rural area though with gas flare stacks within and around the area [51]. Also as noted earlier agricultural activities in this area could have contributed significantly to the observed PM<sub>10</sub> level. This is supported by the fact that agricultural activities is responsible for ~18% of PM<sub>10</sub> emissions arising from wind erosion, tillage operations, animal movement and others as reported by Rhonda [52], again other agricultural practices such as bush burning may have contributed to the PM<sub>10</sub> level in this area [15]. Apart from Egbema, elevated value of PM<sub>10</sub> was also observed in Okigwe area which could be due to quarry and stone mining activities in this area. This is agreement with Nartey et al who noted that dust emission is one of the major effects of quarrying activities [53]. Variation of PM<sub>10</sub> in dry season is also illustrated with contour, 3-D surface plots and spatial distribution map as shown in fig.9 and 10. The order of mean PM<sub>10</sub> variation in the morning is Egbema > Okigwe > Orlu > Owerri. The order of PM<sub>10</sub> variation in the afternoon is the same as in the morning, while in the evening, the mean PM<sub>10</sub> level is Egbema > Orlu > Okigwe > Owerri. The result of coefficient of variation (CV %) range from little to moderate variation as shown in table 2. In both morning, afternoon and evening as earlier noted elevated levels of PM<sub>10</sub> was observed in Egbema while lower values was recorded in Owerri. The result in table 2 indicates that elevated values of PM<sub>10</sub> was observed in the afternoon and evening hours than in the morning. This observation agrees with earlier report in a related study [46].

Table 2. Summary of dry season result of PM<sub>10</sub> variation [mg/m<sup>3</sup>]

	Owerri			Okigwe			Orlu			Egbema		
	M	A	E	M	A	E	M	A	E	M	A	E
Max	9.09	10.94	9.62	9.97	11.72	10.74	8.79	10.02	9.18	9.93	10.63	10.15
Min	4.79	5.53	5.73	3.13	4.73	4.73	4.92	6.02	6.43	6.00	6.38	6.08
Mean	5.80	7.25	7.28	6.92	7.87	7.52	6.72	7.77	7.53	7.42	8.38	7.88
Var	1.48	2.11	1.31	3.78	4.74	3.64	1.07	1.77	0.94	1.35	2.14	2.16
SD	1.22	1.45	1.15	1.94	2.18	1.91	1.03	1.33	0.97	1.16	1.46	1.47
CV%	21.03	20.00	15.80	28.03	27.70	25.40	15.33	17.11	12.90	15.63	17.42	18.65

(Where M= morning, A= afternoon and E= evening, Max= maximum value, Min= minimum value Var= variance, SD= standard deviation and CV% =% co-efficient of variation)

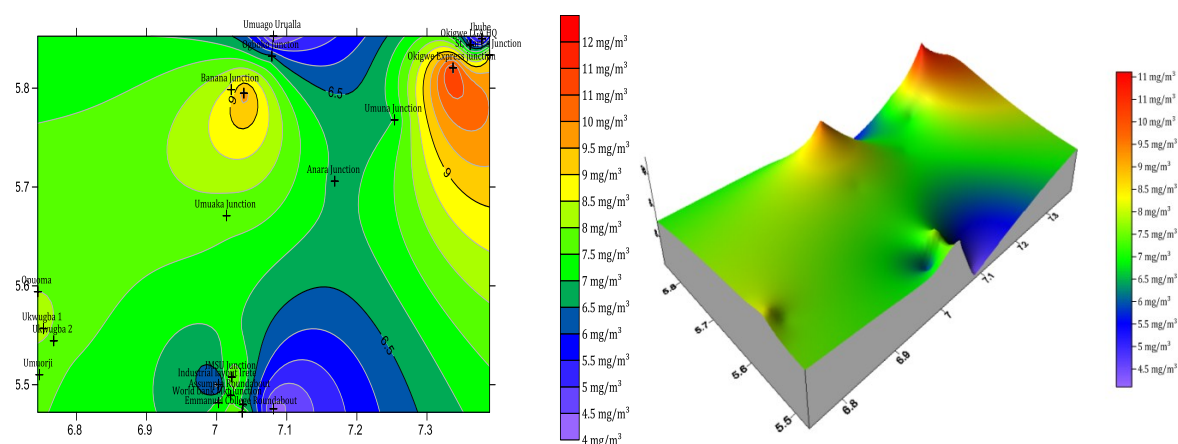


Fig. 9. Contour and 3-D surface plot of PM<sub>10</sub> variation in dry season



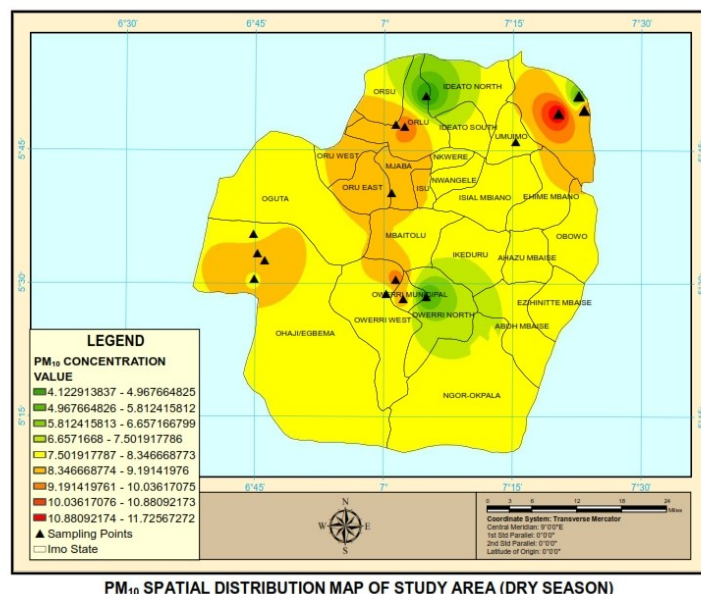


Fig. 10. Spatial variation map of PM<sub>10</sub> in dry season

**Geostatistical analysis of PM<sub>10</sub> in dry season.** Box and Whisker plots were employed to explain the dry season variation of PM<sub>10</sub> in each of the air quality sampling location as shown in fig.11 to 14. Fig.11 is the Box and Whisker plot of PM<sub>10</sub> variation at Owerri in dry season. Fig. 11 shows that 25% and 75% of PM<sub>10</sub> values recorded at Owerri in the morning during dry season are within 5.00 mg/m<sup>3</sup> and 5.90 mg/m<sup>3</sup> respectively. In the afternoon, the Box and Whisker plot indicates that 25% and 75% of the results recorded lies respectively within 6.50 mg/m<sup>3</sup> and 7.80 mg/m<sup>3</sup>. On the other hand, in the evening it was observed that 25% and 75% of the PM<sub>10</sub> values obtained are within 6.70 mg/m<sup>3</sup> and 8.20 mg/m<sup>3</sup> respectively. Furthermore, ANOVA result ( $F = 7.03$ , sig. value = 0.0029) indicates that there is a statistically significant difference in the mean level of PM<sub>10</sub> recorded at Owerri in dry season.

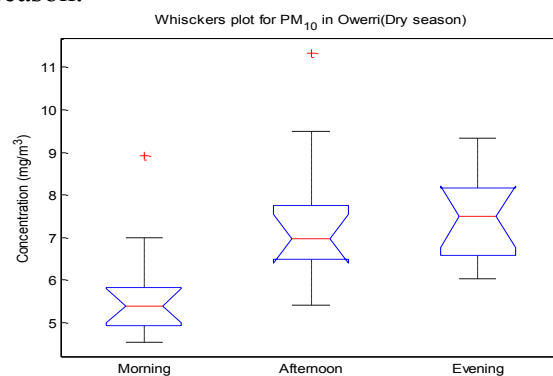


Fig. 11. Box and Whisker plot of PM<sub>10</sub> variation at Owerri (dry season)

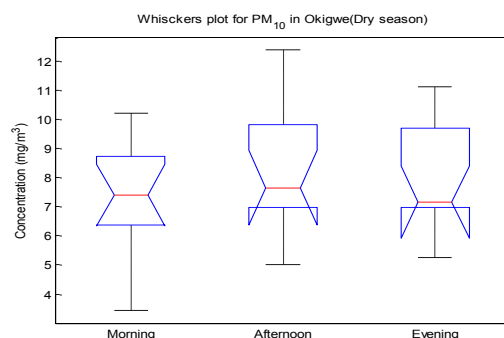


Fig. 12. Box and Whisker plot of PM<sub>10</sub> variation at Okigwe (dry season)

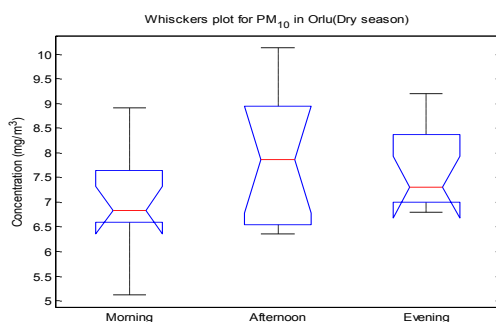


Fig. 13. Box and Whisker plot of PM<sub>10</sub> variation at Orlu (dry season)

The dry season variation of PM<sub>10</sub> at Okigwe is presented in table 2 and fig12. Table 2 indicates that the mean PM<sub>10</sub> recorded in the morning, afternoon and evening do not differ significantly as the CV% for morning, afternoon and evening are between 25.40 – 28.03%, which is an indication of moderate variation. Fig.12 is the Box and Whisker plot of PM<sub>10</sub> variation at Okigwe in dry season. It indicates that 25% and 75% of the result recorded in the morning are respectively within 6.40 mg/m<sup>3</sup> and 8.80 mg/m<sup>3</sup>, while in the afternoon, 25% and 75% of the value recorded are within 6.90 mg/m<sup>3</sup> and 9.90 mg/m<sup>3</sup> respectively. In a similar way, 25% and 75% of the results recorded in the evening at Okigwe in dry season are respectively within 7.00 mg/m<sup>3</sup> and 8.20mg/m<sup>3</sup>. Analysis of variance (ANOVA at  $p > 0.05$ ,  $F = 0.65$ , sig. value = 0.5295) shows no statistically significant difference in the mean value of PM<sub>10</sub> observed at Okigwe in dry season.

Furthermore, the variation of mean PM<sub>10</sub> values in Orlu is presented in table 2 and fig.13. Little variation was recorded in the morning, afternoon and evening hours as indicated by the CV% values presented in table 2. Fig.13 is the Box and Whisker plot of PM<sub>10</sub> variation at Orlu in dry season. It shows that 25% and 75% of the results recorded in the morning are within 6.70 mg/m<sup>3</sup> and 7.70 mg/m<sup>3</sup> respectively. Similarly, in the afternoon, 25% and 75% of the values are within 6.60 mg/m<sup>3</sup> and 8.90 mg/m<sup>3</sup> respectively. It was observed that in the evening, 25% and 75% of the results are respectively within 7.00 mg/m<sup>3</sup> and 8.40 mg/m<sup>3</sup>. The result of ANOVA ( $F = 2.08$ , sig. value = 0.1414,  $p > 0.05$ ) shows that there is no statistically significant difference in the mean concentration of PM<sub>10</sub> values observed at Orlu in dry season.

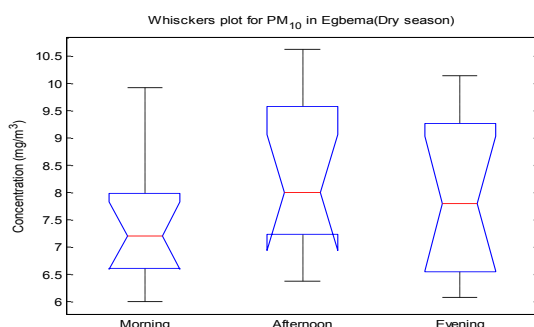


Fig. 14. Box and Whisker plot of PM<sub>10</sub> variation at Egbema (dry season)

The PM<sub>10</sub> variation in dry season at Egbema is presented in table 2 and fig.14. Table 2 shows that the mean PM<sub>10</sub> level at Egbema is in the order morning > afternoon > evening. The values of CV% indicate little variation within the air quality sampling locations. Fig.14 is the Box and Whisker plot of PM<sub>10</sub> variation at Egbema in dry season. The result indicates that in the morning, 25% and 75% of the PM<sub>10</sub> values are respectively within 6.60 mg/m<sup>3</sup> and 8.00 mg/m<sup>3</sup>, while in the afternoon 25% and 75% of the result are within 7.30 mg/m<sup>3</sup> and 9.70 mg/m<sup>3</sup> respectively. In the evening, 25% and 75% of the PM<sub>10</sub> values recorded in dry season are within 6.50 mg/m<sup>3</sup> and 9.40 mg/m<sup>3</sup> respectively. ANOVA result ( $F = 13.05$ , sig. values =  $6.6701e^{-5}$ ) indicates that there is a significant difference in the mean level of PM<sub>10</sub> concentration observed at Egbema in dry season.

**Variation of mean PM<sub>10</sub> level across study locations in dry season.** Fig.15 is the variation of mean PM<sub>10</sub> values across study locations in dry season. This shows the variation of the air pollutant from week one to week twelve in dry season. The result indicates that elevated values PM<sub>10</sub> were recorded in week 4,5 and 6 at Egbema. While in week 8 higher PM<sub>10</sub> values were observed in all the locations as shown in fig.15. This supports the idea of wide-spread, regional pollution of PM aerosols due to long-range transport of particulate and gaseous pollutants earlier noted [49]. Also in week 9, 10 and 11 higher concentrations of PM<sub>10</sub> were observed in Okigwe. This is not out of place, Okigwe area is known for stone mining and quarrying activities which could contribute significantly to PM<sub>10</sub> as earlier remarked. Reports has it that mining activities could constitute fugitive dust sources which may influence air quality levels in the urban areas around the quarries [54]. Though the amount and composition of fugitive dust emanating from quarrying and mining activities is cumbersome to assess, the US emission factors for mineral handling, quarrying and mining range from 0.007 to 0.119 kg/ton of waste produced [55]. It has been reported that PM<sub>10</sub> could increase the seriousness of asthma attacks, exacerbate bronchitis and other lung diseases, which could weaken the body's capability to fight infections [56,57].

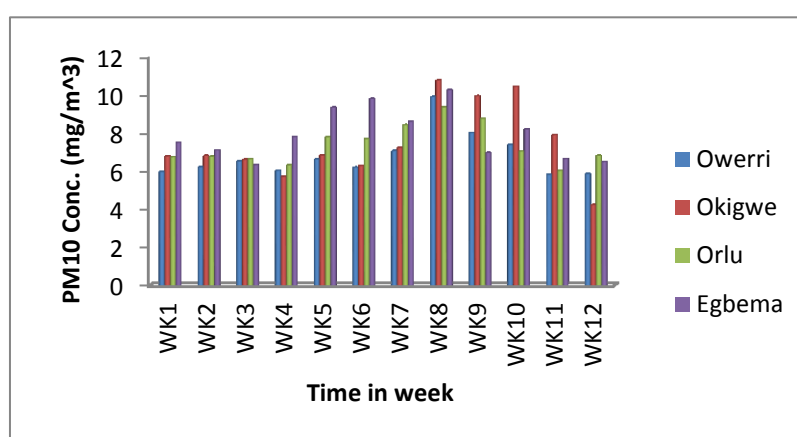
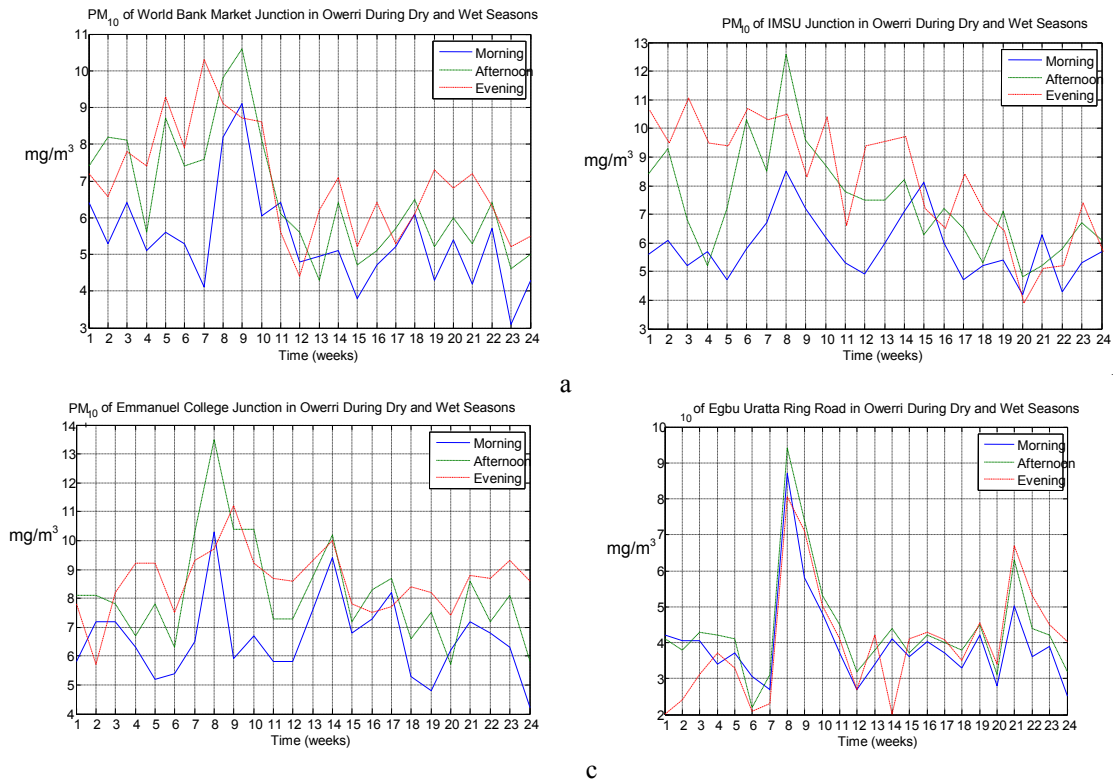
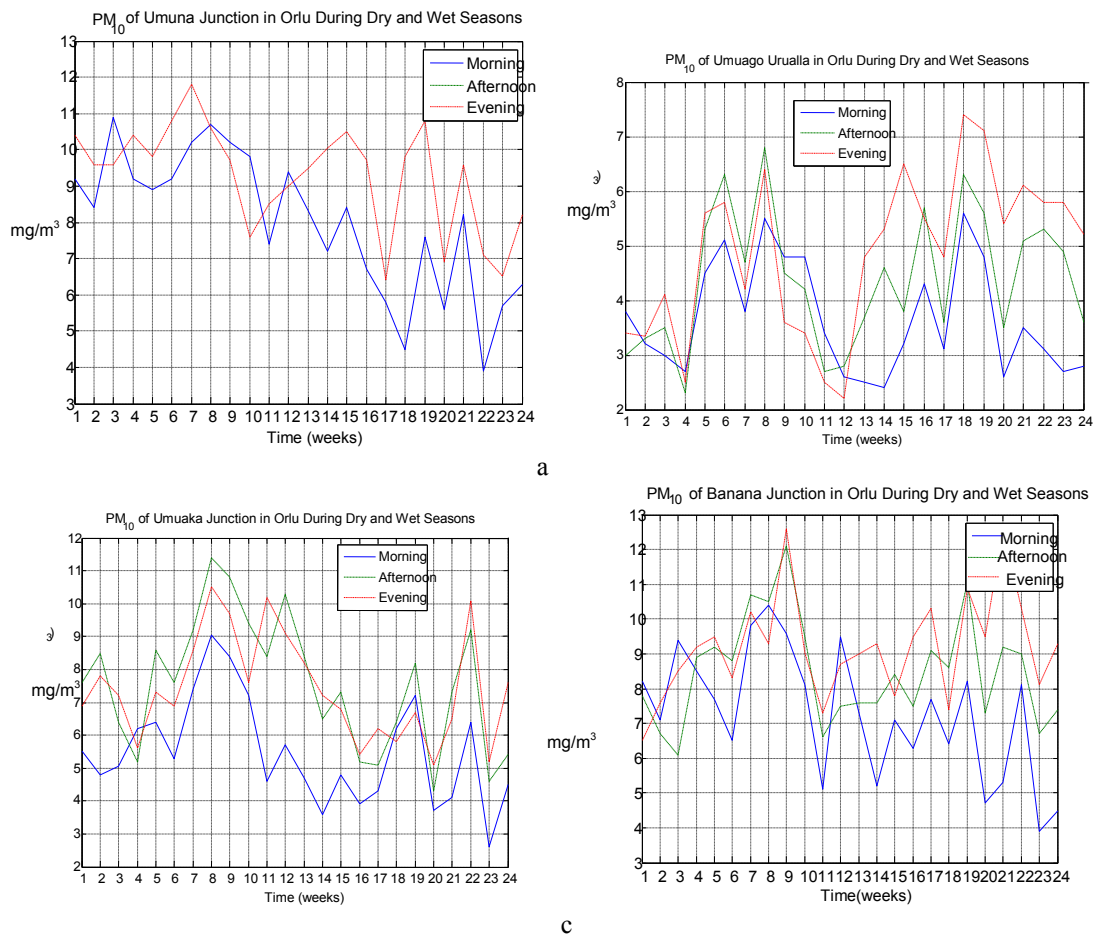
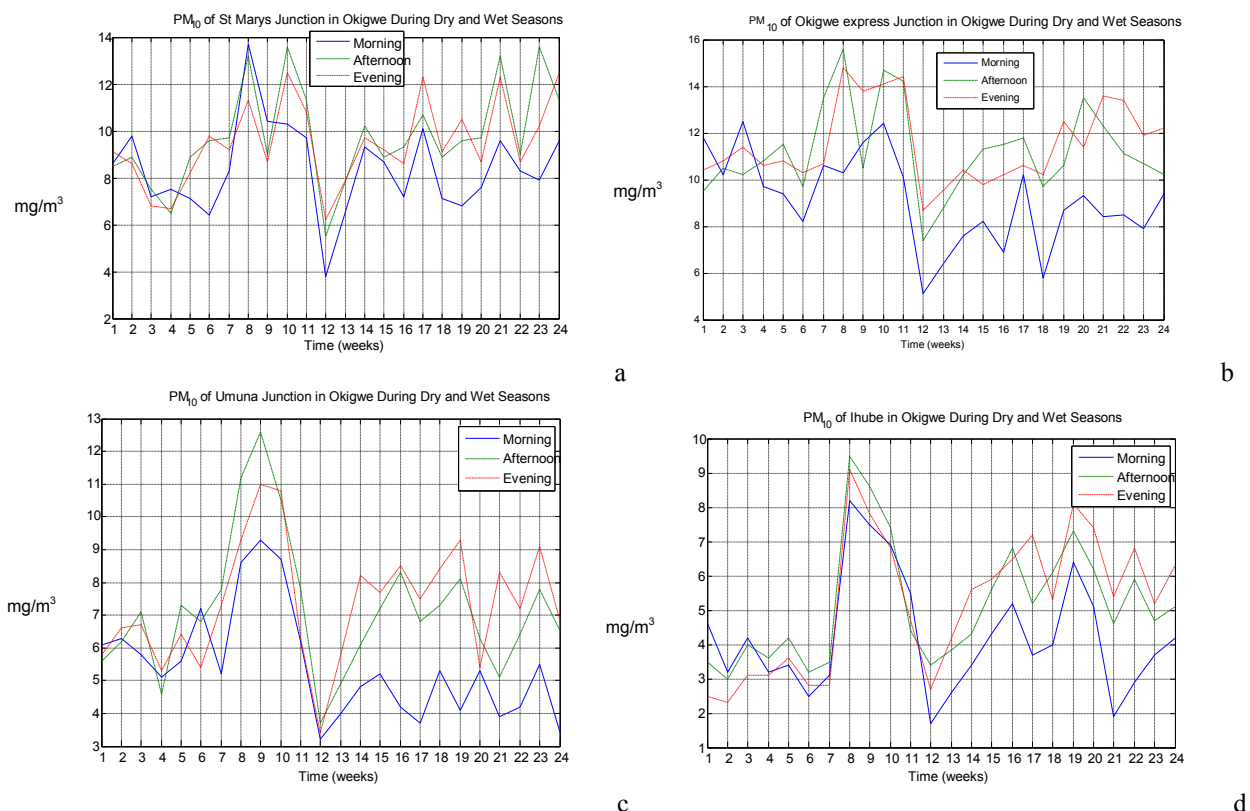
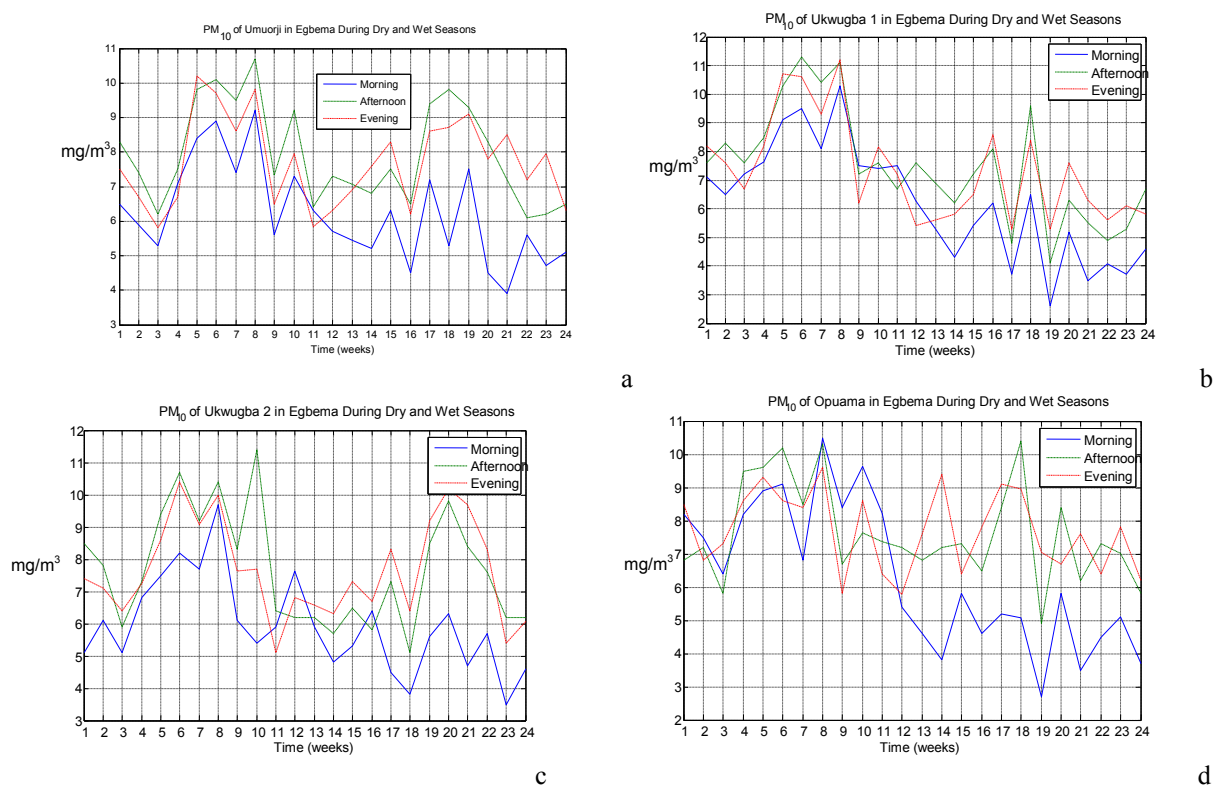


Fig. 15. Variation of mean PM<sub>10</sub> values across study locations in dry season

**Time series analysis of PM<sub>10</sub>.** The time series plots of PM<sub>10</sub> are presented in Fig.16 – 19. In order to analyze and characterize the nature of temporal relationship during the air quality sampling, which was three times a day (morning, afternoon and evening) 4 times a month for a period of six months (3 months each for dry and wet season) which implies a total of 24 week. Time series models for each of the air pollutants at the 16 air sampling points were modeled based on weeks and time. Week 1 to 12 represents dry season while wet season is week 13 to 24 as shown in fig. 16 – 19. Time series has been used in air pollution studies to evaluate changes in concentration of atmospheric pollutants [58 - 60]. The time series plots in fig. 16 -19 indicate that the concentration of PM<sub>10</sub> varied remarkably throughout the study period. In most cases elevated concentration of the pollutant was recorded in the afternoon and evening than in the morning hours. Fig 16a to 16d shows that higher concentration of PM<sub>10</sub> was observed in dry season (week 1-12) than in wet season (week 13-24) in Owerri. Fig.17 reveals that the mean level of the pollutant measured in Orlu fluctuated tremendously showing no definite pattern except fig. 17d. Similarly, fig.18 and 19 also showed significant variation in the concentration of PM<sub>10</sub>. The observed variation in concentration of PM<sub>10</sub> as revealed by the time series could be due to changes with different locations and time resulting from changes in meteorological and topographical conditions of the location.

Fig. 16. Time series plots of  $PM_{10}$  at OwerriFig. 17. Time series plots of  $PM_{10}$  at Orlu

Fig. 18. Time series plots of  $PM_{10}$  at OkigweFig. 19. Time series plots of  $PM_{10}$  at Egbema

**Wind rose and dispersal of particulate pollution.** The residence time of atmospheric pollutant such as particulate matter in the ambient environment and the formation of secondary pollutants are not only controlled by the concentration emitted from source of pollution but also by wind speed



and wind direction. Wind speed and direction which make up the wind rose diagram provides real-time information on the migration and dispersal of air pollutant in an area in relationship to sources and pollutant levels [19]. Fig. 20 is samples of some wind rose diagrams obtained during the study which explains the dispersal of particulate matter ( $PM_{10}$ ) emitted in the area. Fig. 20a, b, c and d are respectively the wind rose diagram for IMSU Junction, Owerri, Okigwe Express Junction, Okigwe, Banana Junction, Orlu and Umuorji in Egbema. The wind rose diagram is a summary of the wind speed and wind directions recorded in the morning, afternoon and evening during the  $PM_{10}$  air quality monitoring station in each location.

Results of the wind rose diagrams suggest that the dispersal and migration of  $PM_{10}$  is associated with the prevailing wind speed and wind directions observed in the study locations. The dominant wind speed in Owerri range from 0.9 - 3.5 m/s in NE, SW and NW directions, while in Okigwe area the wind speed is between  $< 0.5$  -  $< 3.5$  m/s in NE, SW and SE directions. In the case of Orlu area, the prevalent wind direction is NE, SW and NW with a wind speed ranging from  $> 0.5$  -  $> 0.35$ . It was observed that in Egbema area, the wind speed range from  $> 0.5$  -  $> 2$  in NW, SE and SW in directions. These predominant wind speeds and wind directions contribute significantly to the dispersal and migration of  $PM_{10}$  emitted in the study locations.

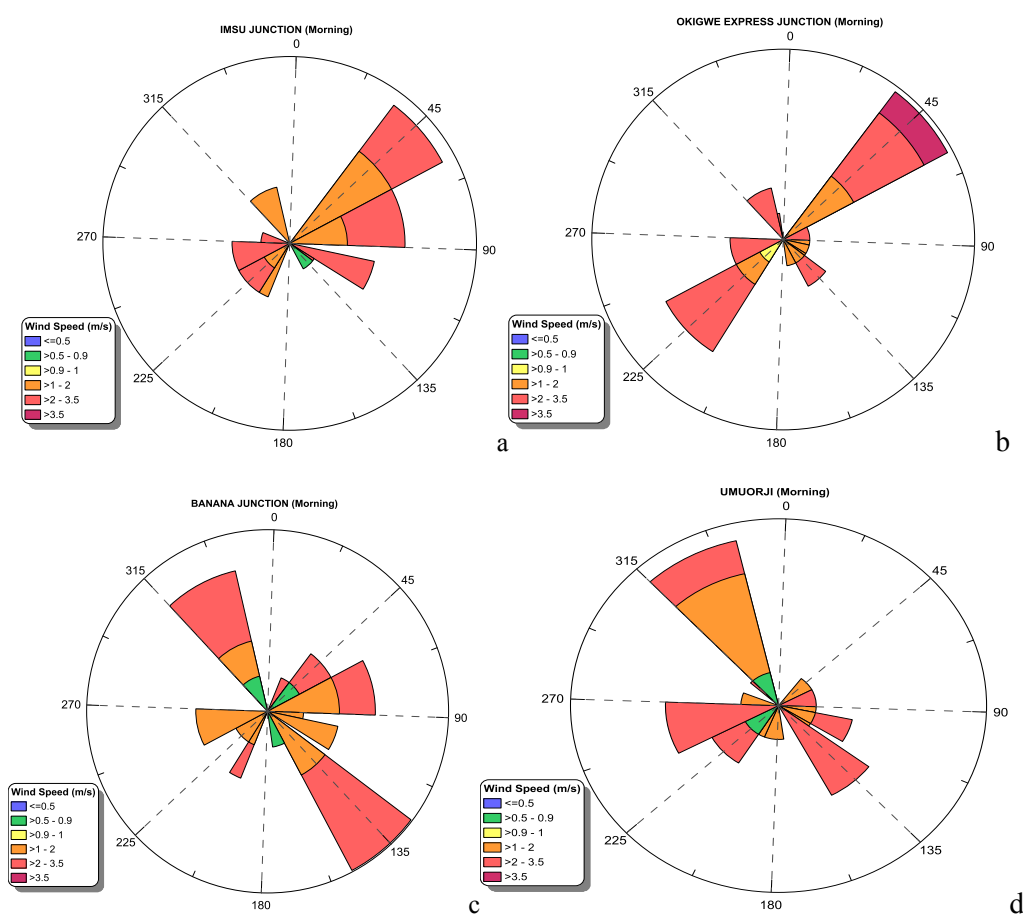


Fig. 20. Samples of some wind rose diagrams obtained during the study.

**Comparison of mean  $PM_{10}$  level across study locations.** Finally, fig.20 is the comparison of mean  $PM_{10}$  variation across study locations in dry and wet season. It indicates that generally higher  $PM_{10}$  values were observed in the dry season than in the wet season with Egbema showing the highest mean value as shown in fig.21. The highest dry seasonal mean ( $7.90 \text{ mg/m}^3$ ) obtain in this study is above that reported in related studies in Nigeria [11,61]. In addition to earlier stated reasons, elevated  $PM_{10}$  levels in this area could be attributed to the episodic dust events of Sahara desert and its associated trans-boundary transportation [62,63].



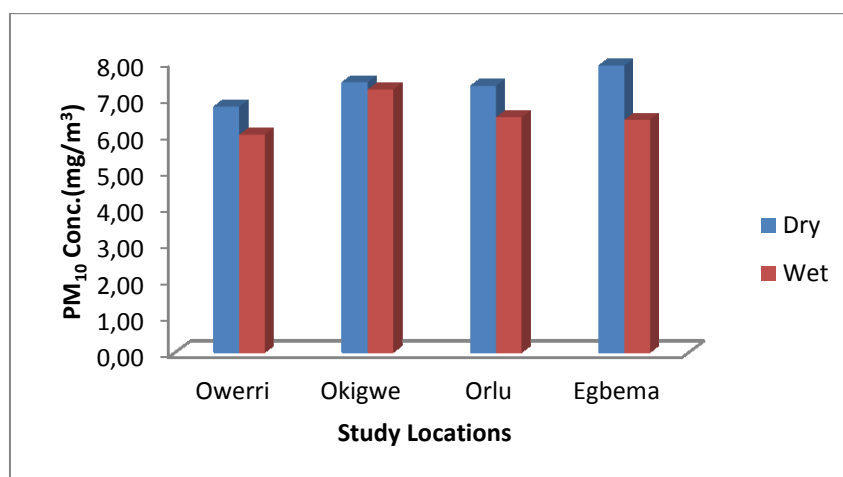


Fig. 21. Comparison of mean  $PM_{10}$  level across study locations (dry and wet season)

This is due to the fact that particles have different capacity to be transported over either short or long distances which depends on the particle size [64]. The mean  $PM_{10}$  levels in both wet and dry season exceeded the annual guide line values ( $120\mu\text{g}/\text{m}^3$ ) ( $0.12\text{mg}/\text{m}^3$ ) of Nigerian National Ambient Air Quality Standards [65].

## Conclusion

The study determined the variation of particulate matter in the atmospheric environment of Imo State, Nigeria. Concentrations of  $PM_{10}$  measured were observed to be affected by either wet or dry season, with the lowest and highest mean values obtained during wet and dry seasons respectively. Results of the study indicates that the variability of the measured  $PM_{10}$  concentration in the study locations ranged between little and moderate variation. The highest seasonal mean values were observed at Egbema and Okigwe area of the State in both dry and wet season. The Box and Whisker plots revealed that higher concentration of  $PM_{10}$  was observed in the afternoon and evening than in the morning in the study location. The study also indicates that the concentration of  $PM_{10}$  obtained in the study varied in different time of day when measurements were conducted. ANOVA,  $p < 0.005$  result indicates that variation within most sampling locations (morning, afternoon and evening) showed statistically significant difference. Time series analysis confirmed that the mean concentration of the atmospheric pollutant fluctuated throughout the study duration. The mean  $PM_{10}$  values obtained within the time of this study exceeded the stipulated guideline values. This therefore implies that the people in this area will have to contend with exposure to particulate matter ( $PM_{10}$ ) at levels above what is considered safe, even though the degree of exposure is yet to be understood.

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