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Ambient Air Particulate Matter Levels in Selected Urban Centres of Niger Delta Region, Nigeria

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Abstract

This study measured total suspended particulate (TSP) matter load, particulate matter with aerodynamic diameter ten micrometer or less (PM_{10}) and two and half micrometer or less ($PM_{2.5}$) in five urban centres in the Niger Delta region, Nigeria in the dry and wet seasons from December, 2008 to September, 2009 using photometric laser-based particle counter instrument. The results showed that the seasonal mean varied in the range of 72.25±12.32- 320.06±235.42 µg m^{-3} for the TSP in the dry season and 16.31±4.77 – 87.94±27.32 µg m^{-3} for the wet season. The seasonal mean of (PM_{10}) ranged from 42.44±9.74 - 181.38±50.64 and 6.94±2.05 – 59.88±20.89 µg m^{-3} for the dry and wet seasons respectively. Similarly, $PM_{2.5}$ gave 13.56±2.63-55.00±29.45 µg m^{-3} and 1.81±1.11-12.88±3.48 µg m^{-3} respectively for the dry and wet seasons. The annual mean of TSP in all the cities were within World Health Organization (WHO) annual guideline limit of 230-250 µg m^{-3}. Also PM_{10} annual levels exceeded the 20 µg m^{-3} WHO annual guideline limit while $PM_{2.5}$ annual levels in two cities (Uyo and PortHarcourt) exceeded the US annual National Ambient Air Quality Standard (NAAQS) of 15 µg m^{-3}. The F-test statistics revealed statistical significant difference in the dry and wet seasonal means of TSP in Eket and Uyo ($p<0.05$). The PM_{10} dry seasonal level in Eket and Uyo wet seasonal level were significant ($p<0.05$) while $PM_{2.5}$ dry seasonal level in Eket and wet seasonal levels in Uyo and PortHarcourt were statistical significant ($p<0.05$). The study concluded that the high levels of PM_{10} and $PM_{2.5}$ in all the cities monitored especially in the dry season may present a potential public health risk.

Keywords: Ambient air, environmental pollution, fine, coarse, particulate matter, south-south Nigeria.

Introduction

Suspended particulate matter (SPM) is one of the deleterious air pollutants. It is a complex mixture of different particle sizes. Processes that emit particulate matter into the atmosphere include: volcanic eruptions, geochemical sources, windblown dust, soil re-suspension, spray from marine sources, power plant emissions, agricultural and industrial emissions and vehicular emissions[1,2]. Historically, SPM is measured as total suspended particulate (TSP) and it refers to SPM in the air of all sizes. The TSP is an archaic regulatory measure of the mass concentration of SPM and was used by regulatory agencies such as the USEPA until 1987.

Studies involving particle transport and transformation suggest that ambient air SPM commonly occur in two modes namely the fine (aerodynamic diameter two and half or less, $PM_{2.5}$) mode and the coarse (aerodynamic diameter 2.5-10 µm, PM_{10}) mode[3-8]. The fine or accumulation mode (< $PM_{2.5}$) is also referred to as respirable particulate matter because when inhaled, it can penetrates deep into lower region of the human respiratory tract[9,10]. Findings from research on human health effect of SPM have made the health professionals to generally recognize that the particle sizes ten micrometer or less are responsible for many of the significant adverse health effects attributable to particulate matter such as risk of lung cancer, aggravation of respiratory and cardiovascular diseases[11-13]. Studies have correlated PM_{10} and $PM_{2.5}$ to aggravation of asthma attack, pulmonary inflammation, daily mortality and a number of hospital admissions[14-16]. The negative effects of PM also include retardation in growth and yield of plants[17], reduction in visibility[18, 19] and deterioration of the physical environment[20].

The regulatory focus of PM has since changed to reflect the current knowledge with regard to particle size and influence on the adverse health effect caused by particulate. For instance, in June, 1987, the USEPA promulgated a new size-specific air quality standard based on PM_{10} as a measure of the ambient air SPM, hence replacing the hitherto used TSP standard (EPA/625/R-96/010A). The PM_{10} standard for ambient air PM has also been further revised to include the $PM_{2.5}$ as among the criteria pollutants to be monitored and regulated by USEPA. The European communities (EC) has also passed a directive for the PM_{10} and $PM_{2.5}$ to be the regulatory PM standard in their member states with a daily and annual PM_{10} average of 50 µg m^{-3} and annual $PM_{2.5}$ average of 15 µg m^{-3}

Measurements of TSP, PM_{10} and $PM_{2.5}$ in the different regions of developed world are well documented in the literature[21, 22]. In Nigeria, researchers have also reported ambient air TSP and

PM_{10} in few urban cities such as Ile-Ife, Calabar, Warri, Lagos and Abakaliki[23-28]. However, published report on PM monitoring campaign in Nigeria is still limited in scope in terms of the number of cities covered and duration of measurement. This study was aimed at providing an estimate of TSP, PM_{10} and $PM_{2.5}$ concentrations in selected five cities in the South-South (Niger Delta region) Nigeria.

Material and Methods

The study Area: The study covered five major cities namely Eket, Uyo, Calabar, Ogoja and Port-Harcourt (all in South-South Nigeria). The area is located within latitudes (4º-6.5º) N and longitudes (5º-9º) E. The area has an approximate population of 21,014,675 according to the 2006 census figure. The climatic condition is tropical, characterized by wet and dry seasons. The wet season sets in between April and October while the dry season is usually between November and March. The phenomena and activities in South-South Nigeria that have potential of impacting on the environment (air pollution) include the sea spray, salt volatilization from the ocean, emission of gases from the decaying of organic substance in swampy environment, emissions from the agglomerations of industries (large, medium and small scale) in the area especially in Port Harcourt, emission from the oil exploration and exploitation activities including refinery and gas flaring operations, that are common in the area, emission from vehicular traffic with its preponderance in the state capitals and large commercial cities.

Sampling site selection: In each of the cities monitored, a site was chosen in the 'heart' of the city based on visible human activities, high population density and traffic volume. The coordinates of each site was measured with Garmin global position system, model etrex H (Taiwan).

Table-1
Sampling Location, Name and GPS Coordinates

S/No	City	Site Name	Coordinates
1	EKET	Ataobong junction	$N04^0$ 39.03^1 $E007^0$ 55.63^1
2	UYO	Abak Road by Edrock Junction	$N05^0$ 01.95^1 $E007^0$ 55.28^1
3	CALABAR	EPZ junction	$N05^0$ 01.13^1 $E008^0$ 19.85^1
4	OGOJA	Catheral Round about	$N06^0$ 39.34^1 $E008^0$ 48.45^1
5	PORTHARCOURT	Rumuokwuta Junction	$N04^0$ 50.22^1 $E006^0$ 59.28^1

Monitoring protocol: The concentrations of the suspended particulate matter (TSP, PM_{10} and $PM_{2.5}$) in the ambient air of the monitored sites was determined by means of a digital read out electronic instrument, Aerocet Model 531-9800 Rev. C (Metone Inc. U.S.A). The instrument has in-built particle count data for eight different particle size ranges including total suspended particulate (TSP), PM_{10}, $PM_{2.5}$ and proprietary algorithm to derive the mass concentration for particulate sampled. The sampler was held at a height of 2 m above ground level, the human breathing zone and the ambient air PM concentration reading recorded as displayed on the instrument's screen. Sampling time for each parameter was two minutes (that is time taken from switch on of parameter nub to display of reading on the screen). The frequency of the monitoring was such that a site was monitored one day in a week for twelve hours (6.00 am-6.00 pm) at an interval of thirty minutes for four months (16 weeks) in the dry season, December, 2008 to March, 2009 and four months in the wet season, June-September, 2009. The hourly mean level for the twelve hours per day per week of each parameter was averaged and the mean for the 16 weeks computed to obtain the seasonal mean for the parameters using statistical package for social science (SPSS) software, version 17.

Results and Discussion

The results of the seasonal variations of the mean TSP, PM_{10} and $PM_{2.5}$ are presented in Tables 2, 3 and 4 and their relationships shown in figures-1A, B, C, 2A, B, C and 3A, B and C.

The highest dry season TSP value of 320.06±235.422.36 μg m^{-3} within the period of the study was obtained in Uyo urban while the minimum value of 72.25±12.32 μg m^{-3} was obtained in Ogoja urban. Similarly, in the wet season, PortHarcourt recorded the maximum level of 87.94±27.12 μg m^{-3} while the minimum value of 16.31±4.27 μg m^{-3} was obtained in Calabar. The annual mean TSP levels ranged between 44.35±39.46-195.22±176.55 μg m^{-3} (table-2A). Across the cities, the mean seasonal TSP showed relatively higher levels in more urbanized cities of PortHarcourt and Uyo relative to less urbanized cities of Eket and Ogoja. Calabar displayed an exceptional trend as the measured TSP level does not equate its level of urbanization.

PortHarcourt recorded the highest PM_{10} level of 181.38±50.64 μg m^{-3} in the dry season while the minimum level in the dry season of 42.44±9.74 μg m^{-3} in Ogoja as against the wet season maximum and minimum levels of 59.88±20.89 and 6.94±2.05 μg m^{-3} obtained in PortHarcourt and Ogoja urban respectively. The annual mean PM_{10} levels ranged between 24.69±25.10-120.44±85.64 μg m^{-3} (table-3).

The dry seasonal mean level of $PM_{2.5}$ ranged between 13.56±2.63-55.00±29.45 μg m^{-3} recorded in Ogoja and Uyo urban respectively, while in the wet season the range was 1.81±1.11-12.88±3.48 μg m^{-3} obtained in Calabar and Port Harcourt respectively. Also the annual mean $PM_{2.5}$ levels ranged between 8.66±6.94-29.92±35.47 μg m^{-3} (table-4).

Table-2
Dry and Wet seasonal mean levels of TSP (µg m^{-3}) in the cities monitored

Week	EKET		UYO		CALABAR		OGOJA		Portharcourt	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
1	81	25	650	82	65	22	80	25	180	160
2	93	30	800	134	83	10	76	20	201	88
3	146	35	720	100	56	15	90	30	191	94
4	87	20	625	75	90	17	72	10	186	53
5	65	21	314	71	120	25	60	16	159	59
6	82	26	290	80	130	20	55	10-	167	80
7	76	22	260	60	104	18	75	15	175	58
8	71	18	245	56	93	15	66	13	160	96
9	107	15	162	50	140	18	75	12	370	100
10	98	17	143	55	120	15	60	10	364	92
11	76	16	157	61	115	17	53	08	367	106
12	80	18	109	58	107	10	67	10	360	122
13	120	26	186	89	120	20	100	25	202	80
14	128	24	153	60	96	14	80	21	180	67
15	135	18	144	40	112	15	75	20	191	88
16	122	18	163	55	77	10	72	18	170	64
$\overline{x}$	97.94	21.82	320.06	70.38	101.75	16.31	72.25	16.44	226.44	87.94
S	25.19	5.52	235.42	23.09	23.42	4.27	12.32	6.58	83.73	27.12
Annual mean ± Std.	59.88 ± 53.83		195.22 ± 176.55		59.03 ± 60.42		44.35 ± 39.46		157.19 ± 97.93	

Table-3
Dry and Wet seasonal mean levels of PM_{10} (µg m^{-3}) in the cities monitored

Week	EKET		UYO		CALABAR		OGOJA		PORTHARCOURT	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
1	60	15	385	30	50	08	60	10	148	40
2	50	10	260	40	60	10	40	08	167	34
3	58	12	238	35	40	06	30	07	158	60
4	40	10	305	32	73	07	32	06	160	26
5	45	08	235	25	80	06	40	08	134	50
6	60	08	186	30	86	06	33	06	158	56
7	55	05	198	22	74	04	46	06	146	80
8	52	08	130	20	65	05	38	05	150	77
9	60	12	80	18	100	15	44	09	293	94
10	66	15	89	16	93	18	40	08	242	82
11	57	12	76	19	80	10	30	06	266	85
12	62	14	72	15	81	08	35	02	254	81
13	80	22	60	14	70	09	60	10	162	35
14	85	20	75	15	64	07	52	08	150	56
15	88	21	70	16	75	05	50	07	156	50
16	82	20	72	12	40	05	49	05	158	52
$\overline{x}$	62.50	13.25	158.19	22.44	70.69	8.06	42.44	6.94	181.38	59.88
S	14.28	5.23	101.86	8.52	17.15	3.79	9.74	2.05	50.64	20.89
Annual mean ± Std.	37.88 ± 34.83		90.32 ± 95.99		39.38 ± 40.29		24.69 ± 25.10		120.44 ± 85.64	

Table-4
Dry and Wet seasonal mean levels of $PM_{2.5}$ (µg m^{-3}) in the cities monitored

Week	EKET		UYO		CALABAR		OGOJA		PORTHARCOURT	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
1	25	10	110	10	15	02	15	06	41	16
2	21	07	90	10	20	02	12	05	42	22
3	26	02	86	06	12	01	16	01	38	11
4	22	02	92	03	14	01	14	01	28	18
5	18	06	80	12	25	03	15	03	33	10
6	15	01	30	04	28	03	12	03	40	14
7	16	02	75	03	18	01	10	03	37	08
8	12	02	63	02	12	01	10	02	39	12
9	20	08	30	08	30	05	13	07	44	14
10	18	06	40	06	20	02	15	05	37	12
11	15	04	42	02	20	02	10	03	41	10
12	22	02	35	01	16	01	12	01	42	12
13	25	06	28	05	18	02	20	08	30	14
14	27	03	34	05	14	01	15	06	26	10
15	26	03	20	01	10	01	15	05	28	12
16	12	02	25	01	08	01	13	01	25	11
$\overline{x}$	20.00	4.13	55.00	4.94	17.50	1.81	13.56	3.75	35.69	12.88
S	5.05	2.68	29.45	3.51	6.23	1.11	2.63	2.29	6.37	3.48
Annual mean ± Std.	12.07 ± 11.22		29.92 ± 35.47		9.66 ± 11.09		8.66 ± 6.94		24.29 ± 16.13	

Table-5
Percentages of fine to coarse fractions of the suspended particulate matter

Parameter	EKET	UYO	Calabar	OGOJA	Portharcourt
% PM_{10}/TSP	63.25	46.99	66.01	55.67	76.62
% $PM_{2.5}$/TSP	20.12	15.56	16.36	19.53	15.45
% $PM_{2.5}$/PM_{10}	31.86	33.13	24.53	35.07	20.17

The percentage of fine to coarse particle was calculated from the annual mean of the TSP, PM_{10} and $PM_{2.5}$. Ogoja, though lowest in PM load relative to the other cities had the highest level of fine particle as can be adduced from the sum of the percentage $PM_{2.5}$/TSP and $PM_{2.5}$/PM_{10}. The PM_{10}/TSP ratio in all the cities except in Port Harcourt lies within 0.4-0.7 (40-70%) estimate of USEPA[1] (table-5). It has been reported that the finer the particle the more hazardous as it penetrates deeper in the lower respiratory tract[9, 29]. The source of the fine particle in this city (Ogoja) may be transboundary as there are no industries in the city that would contribute majorly to the city's ambient air fine particulate level. Gomez *et al.*[1] reported that coarse PM comes from such anthropogenic activities like vehicular traffic, mining/quarry activities, agricultural activities etc while the fine PM comes from secondary source and from metal smelting industries.

Comparatively, the levels of suspended particulate matter (SPM) in the dry season were higher than those of the wet season across the cities monitored. Furthermore, SPM levels (TSP, PM_{10}, $PM_{2.5}$) in Uyo and PortHarcourt were consistently higher than those of other cities (figures-1A, 2A and 3A). The higher PM level of Uyo relative to more urbanized PortHarcourt city may be due the various road construction works going on in the city during the monitoring campaign with its attendant dust suspension characteristics.

The trend of the SPM within the dry season showed a slight elevation in the first four weeks of the campaign and a more or less dipping towards the end of the monitoring period in most of the cities with the exception of Uyo and PortHarcourt urban that showed a marked elevation within the few weeks of commencement of the campaign and at the middle of the period (figures-1B, 2B and 3B). The elevation in the first four weeks corresponds to the period of harmattan in the South-South when the ambient air SPM load is usually elevated due to the North-East trade wind laden with dust that is prevalent within this period. Early research works have observed similar SPM level elevation in the harmattan[30, 31]. In the wet season, the trend depicts higher levels at the beginning of the campaign and then gradual dipping due to wet precipitation as the rainy season heightens (figures-1C, 2C and 3C).

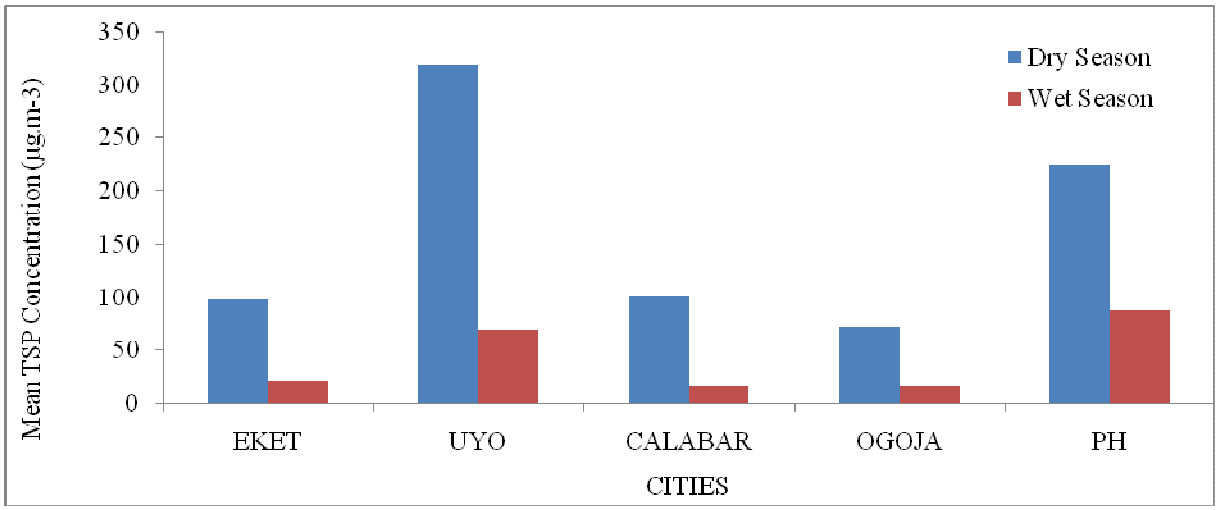

Figure-1A
Variations of TSP concentrations in Ambient Air between the dry and wet seasons across cities in South- South Nigeria

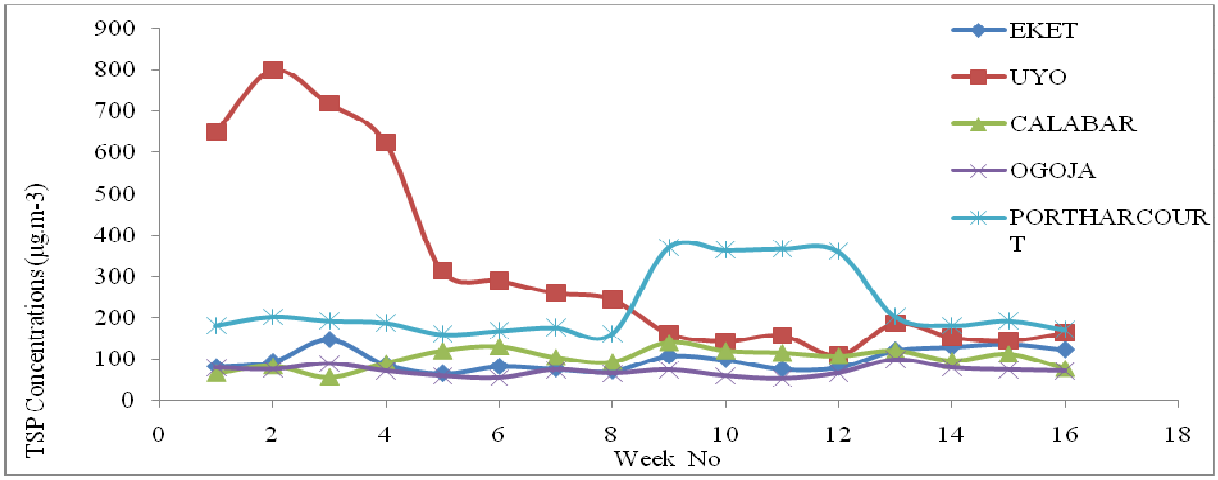

Figure-1B
Trend of Dry season TSP concentrations within the months of Dec. 2008 to March 2009

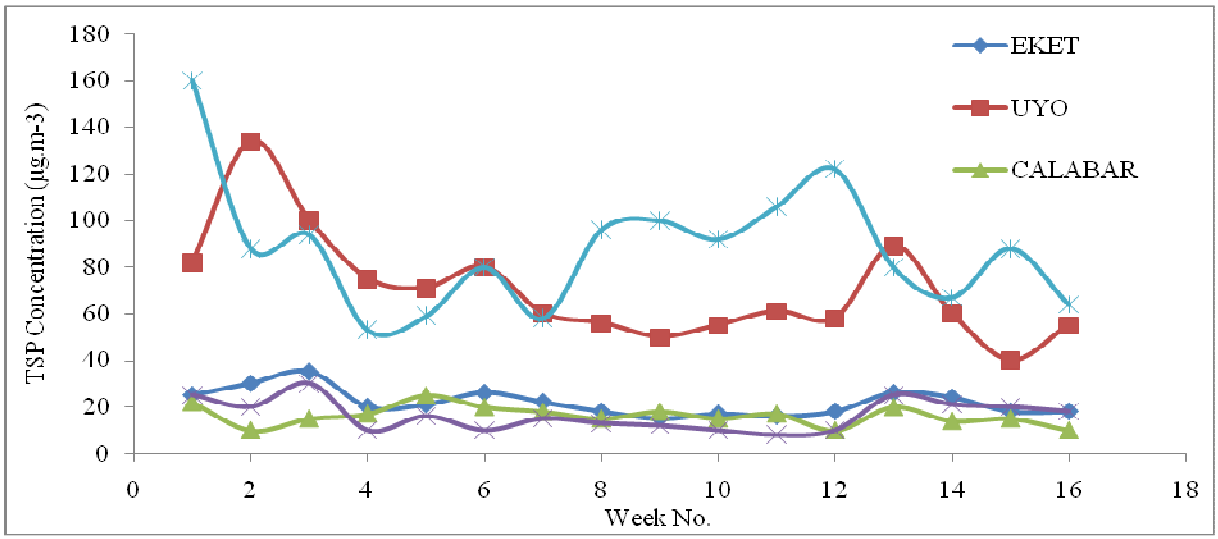

Figure-1C
Trend of Wet season TSP concentrations within the months of June –September, 2009

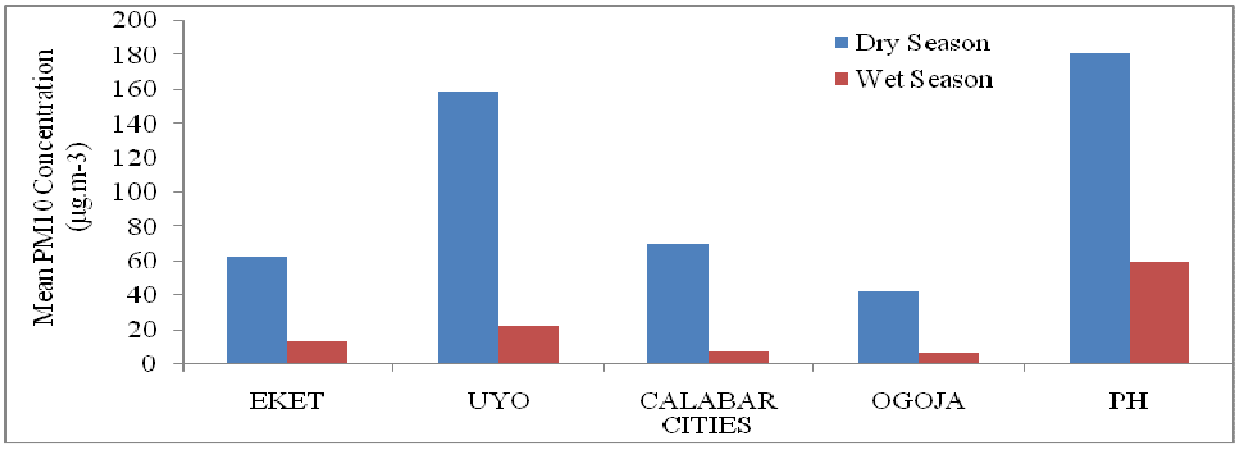

Figure-2A

Variations of PM_{10} concentrations in Ambient Air between the dry and wet seasons across cities in South-South Nigeria

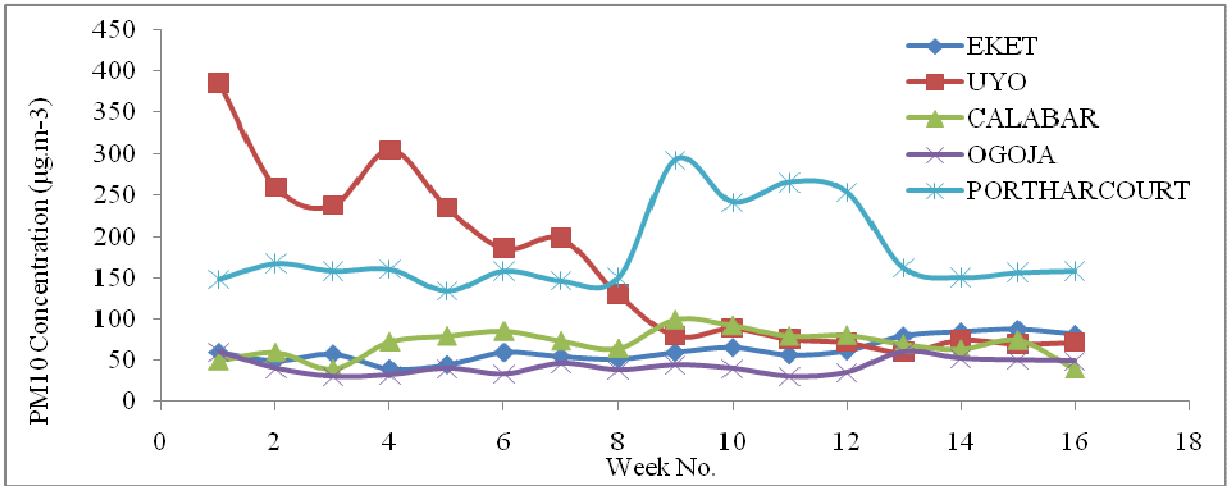

Figure-2B

Trend of Dry season PM_{10} concentrations within the months of Dec. 2008 to March 2009

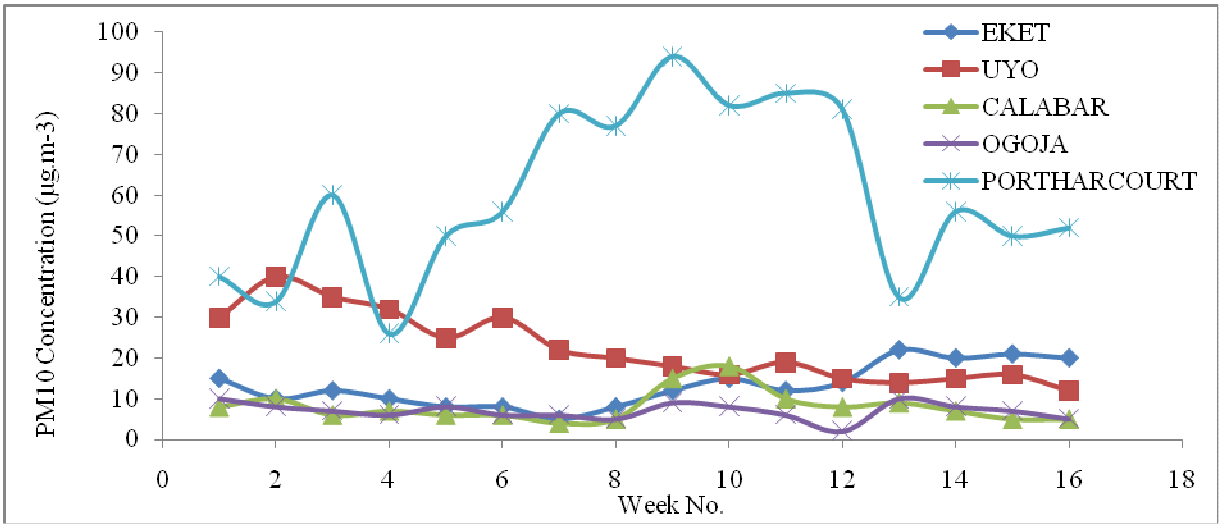

Figure-2C

Trend of Wet season PM_{10} concentrations within the months of June –September, 2009

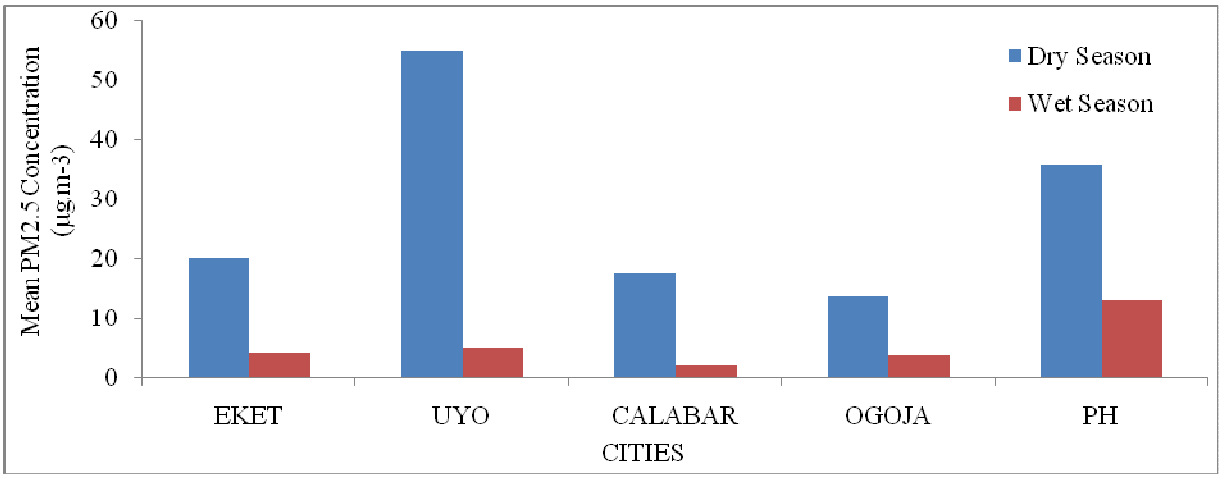

Figure-3A

Variations of $PM_{2.5}$ concentrations in Ambient Air between the dry and wet seasons across cities in South-South Nigeria

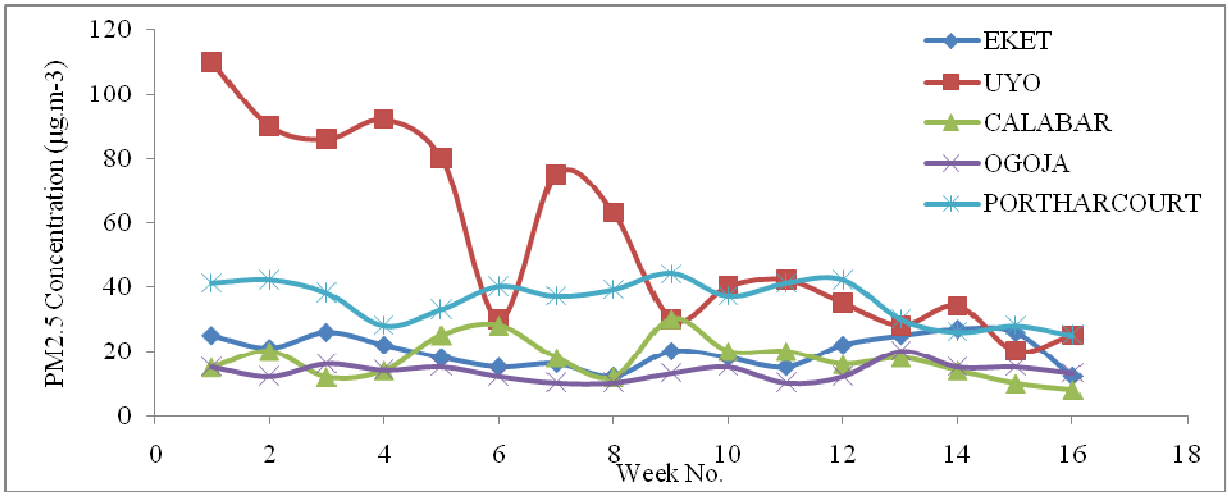

Figure-3B

Trend of Dry season PM2.5 concentrations within the months of Dec. 2008 to March 2009

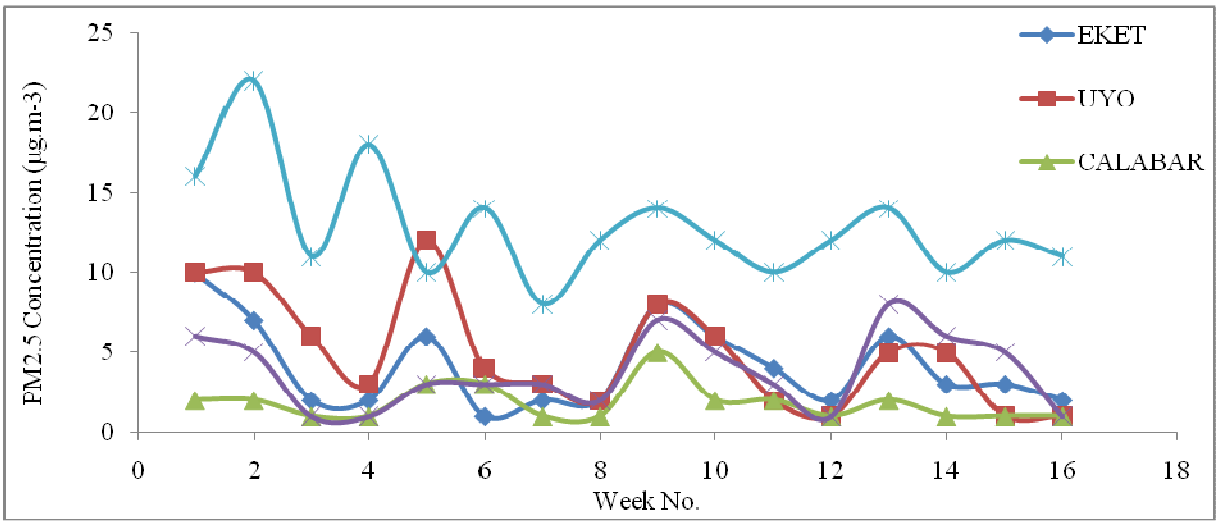

Figure-3C

Trend of Wet Season $PM_{2.5}$ concentrations within the months of June –September, 2009

Table-6A
Analysis of variance (ANOVA) of the dry and Wet seasonal mean levels of TSP (µg m^{-3}) data in the cities monitored

Source variables	Mean	std.dev	df	SS	MSE	F ratio	p-value
Eket dry	97.94	25.186	1	17.920	17.920	10.150	0.024
Eket wet	21.81	5.516	1	11.685	11.685	6.618	0.040
Uyo dry	320.06	235.420	1	58.614	58.614	33.198	0.002
Uyo wet	70.38	23.088	1	9.686	9.686	5.486	0.036
Calabar dry	101.75	23.422	1	3.538	3.538	2.004	0.216
Calabar wet	16.31	4.270	1	0.249	0.249	0.141	0.723
Ogoja dry	72.75	12.321	1	0.093	0.093	0.052	0.828
Ogoja wet	15.81	7.626	1	0.308	0.308	0.174	0.694
Port Harcourt dry	226.44	83.730	1	3.054	3.054	1.730	0.246
Port Harcourt wet	87.94	27.123	1	0.015	0.015	0.009	0.929
Constant			1	31.910			
ESS	8.828		5	8.828			

Table-6B
Analysis of variance (ANOVA) of the Dry and Wet seasonal mean levels of PM_{10} (µg m^{-3}) data in the cities monitored

Source variables	Mean	std.dev	df	SS	MSE	F ratio	p-value
Eket dry	62.50	14.283	1	3.765	3.765	5.082	0.024
Eket wet	13.25	5.235	1	1.129	1.129	1.524	0.272
Uyo dry	158.19	101.861	1	2.920	2.920	3.942	0.104
Uyo wet	22.44	8.524	1	8.752	8.752	11.814	0.018
Calabar dry	70.69	17.145	1	0.545	0.545	0.735	0.430
Calabar wet	8.06	3.785	1	0.384	0.384	0.518	0.504
Ogoja dry	42.44	9.743	1	1.545	1.545	2.085	0.208
Ogoja wet	6.94	2.048	1	0.005	0.005	0.006	0.940
Port Harcourt dry	181.38	50.644	1	1.714	1.714	2.313	0.189
Port Harcourt wet	59.88	20.893	1	4.177	4.177	5.638	0.064
Constant			1	12.957			
ESS			5	3.704			

Table-6C
Analysis of variance (ANOVA) of the dry and wet seasonal mean levels of $PM_{2.5}$ (µg m^{-3}) in the cities monitored

Source variables	Mean	std.dev	df	SS	MSE	F ratio	p-value
Eket dry	20.00	5.046	1	0.599	0.599	5.082	0.024
Eket wet	4.13	2.680	1	10.213	10.213	1.524	0.272
Uyo dry	55.00	29.448	1	59.478	59.478	3.942	0.104
Uyo wet	4.94	3.511	1	0.740	0.740	11.814	0.018
Calabar dry	17.50	6.229	1	0.002	0.002	0.735	0.430
Calabar wet	1.81	1.109	1	2.757	2.757	0.518	0.5041
Ogoja dry	13.56	2.632	1	3.108	3.108	2.085	0.208
Ogoja wet	3.75	2.295	1	1.176	1.176	0.006	0.940
Port Harcourt dry	35.69	6.374	1	11.039	11.039	2.313	0.189
Port Harcourt wet	12.88	3.481	1	6.191	6.191	5.638	0.024
Constant			1	81.198			
ESS			5	6.315			

The Fisher test, analysis of variance (ANOVA), for the TSP, PM_{10} and $PM_{2.5}$ in the dry and wet seasons showed that TSP levels in the dry and wet seasons in Eket and Uyo urban were statistically significant as shown by the p-values ($p<0.05$) (Table 6A). For the PM_{10}, the wet season levels in Eket and Uyo were significant ($p<0.005$) (Table 6B). The dry seasonal levels of $PM_{2.5}$ in Eket and wet season concentrations in Uyo and Portharcourt were statistically significant ($p<0.05$).

The TSP, PM_{10} and $PM_{2.5}$ concentrations obtained in this study were lower than those reported for Abakaliki urban, South-East Nigeria[28] and Calabar[25]. The annual mean TSP in all the cities

were below the 230-250 $\mu g.m^{-3}$ WHO annual guideline limit. All the cities had annual PM_{10} concentrations above the WHO 20 $\mu g.m^{-3}$ annual guideline limit. In contrast, only the annual mean $PM_{2.5}$ in Uyo and PortHarcourt exceeded the annual US National Ambient Air Quality Standard (NAAQS) limit of 15 $\mu g\ m^{-3}$

Conclusion

This study has provided baseline data of TSP, PM_{10} and $PM_{2.5}$ levels of the cities monitored. Comparatively, the SPM levels in Uyo and PortHarcourt were relatively higher than those of the other three cities monitored. The study concludes that within the period of the campaign, the TSP levels were within the guideline limit while levels of PM_{10} and $PM_{2.5}$ either exceeded or were very close to the guideline limits in all the cities monitored and hence presents possible public health risk.

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