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Measurements of Ambient Air Fine and Coarse Particulate Matter in ten South-East Nigerian cities

Ngele S.O[1*] and Onwu F.K[2]
[1]Department of Industrial Chemistry, Ebonyi State University, P.M.B. 053 Abakaliki, NIGERIA
[2]Department of Chemistry, Michael Okpara University of Agriculture Umudike, P.M.B 7267, Umuahia, Abia State, NIGERIA

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Abstract

This study monitored fine particulate matter (PM) load with aerodynamic diameter ten micrometer or less (PM_{10}) and two and half micrometer or less ($PM_{2.5}$) in ten urban centres in South-Eastern 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 55.81±17.09 to 921.34±532.60 $\mu g.m^{-3}$ for the PM_{10} in the dry season and 14.38±3.01 to 266.06±129.79 $\mu g.m^{-3}$ for the wet season. The seasonal mean of ($PM_{2.5}$) ranged from 21.69±9.93 to 122.88±33.90 and 3.31±2.36 to 11.44±4.57 $\mu g.m^{-3}$ for the dry and wet seasons respectively. Comparatively, the cities' PM_{10} load in the dry season followed the order: Onitsha > Aba > Umuahia > Owerri > Enugu > Nsukka >Abakaliki > Afikpo > Orlu > Nnewi, while the order for dry season means of $PM_{2.5}$ followed: Onitsha> Aba > Owerri > Umuahia > Abakaliki > Afikpo > Orlu > Enugu > Nsukka. The dry seasonal mean of PM_{10} and $PM_{2.5}$ levels in all the cities exceeded the US annual National Ambient Air Quality Standard (NAAQS) of 50 $\mu g.m^{-3}$ and 15 $\mu g.m^{-3}$ respectively. The student t-test statistics revealed significant difference between the dry and wet seasonal means of PM_{10} and $PM_{2.5}$ ($p<0.05$) while correlation matrix showed that the PM_{10} and $PM_{2.5}$ seasonal mean concentrations correlated positively ($p<0.05$). The study concluded that having 100% of these cities in the dry season for PM_{10} and $PM_{2.5}$ and 60 % for PM_{10} in wet season exceeding the recommended annual guideline limit, portends public health risk particularly to people dwelling in the affected cities.

Keywords: Ambient air, environmental pollution, fine, coarse, particulate matter, South-East Nigeria**.**

Introduction

The recent upsurge in the quantum of research in the air environment may stem from increased awareness on the negative consequences of air pollution on public health, biotic and material component of the environment. For instance, air pollution particularly particulate matter has been implicated in the aggravation of respiratory and cardiovascular diseases[1-5], retardation in growth and yield of plants[6], reduction in visibility[7,8] and deterioration of the physical environment[9].

Suspended particulate matter consists of finely divided solids or liquids such as smoke, dust, fumes, mist, smog and sprays[10]. Particulate matter in the ambient air usually consists of discrete particles ranging in size from molecular clusters of 0.005 µm to coarse particles in the order of 100 µm[10,11]. 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[10,12,13]. The south-east Nigerian air environment is characterized by observable high levels of suspended particulate matter in the dry season due to dust//biomass burning, soil re-suspension, wind-blown dust and Sahara dust transport that are prevalent in the dry season. Wet season on the other hand records low PM due to clean up from the rain. For the protection of public health and the sensitive subgroups, measurements of PM_{10} (coarse particulate) and $PM_{2.5}$ (fine particulate) are now among the criteria pollutants that are mandatorily monitored in United States and Europe[14]. Recent research findings have shown that the fine particulate ($PM_{2.5}$) portends more health risk as it penetrates deeper into the lower lung region[1,3,15]. In Nigeria as in many other developing counties, real time continuous monitoring network stations are not yet in place. PM monitoring is still rudimentary, discontinuous, limited in scope and duration. Available data of random sampling by researchers and consultants in some urban centres in Nigeria showed that while some cities such as Lagos, Kano, PortHarcourt, Calabar have PM load above the WHO recommended limit[16-20], other cities such as Abakaliki and Ogoja have PM levels within the limit[21,22]. This study aims at providing baseline data on fine and coarse PM levels in ten major cities in South-Eastern Nigeria.

Materials and Methods

The study Area: The study covered two major cities each in Anambra, Enugu, Ebonyi, Abia and Imo States (all in South-East Nigeria). The area is located within latitudes (4º-6.5º) N and longitudes (5º-9º) E. The area has an approximate population of 16,382,029 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[23].

Table-1
Sampling Location, Name and GPS Coordinates

S. No	City	Site Name	Coordinates
1	Aba	Osisioma junction	N05^0 07.05^1 E007^0 19.81^1
2	Umuahia	Gate by Warri Street	N05^0 32.06^1 E007^0 29.65^1
3	Nnewi	Izuchukwu junction	N06^0 01.10^1 E006^0 55.09^1
4	Onitsha	Upper Iweka	N06^0 08.04^1 E006^0 47.48^1
5	Abakaliki	Akanu Ibiam Roundabout	N06^0 18.58^1 E008^0 05.41^1
6	Afikpo	Eke Market	N05^0 52.96^1 E007^0 56.18^1
7	Enugu	Chris Chemist/Ogbete market Junction	N06^0 26.32^1 E007^0 29.24^1
8	Nsukka	Peace Mass Park, Nsukka	N06^0 50.92^1 E007^0 23.90^1
9	Orlu	Owerri Road by International Market junction	N05^0 47.33^1 E007^0 01.90^1
10	Owerri	Govt House by Modotel Junction	N05^0 30.54^1 E007^0 02.18^1

Sampling site selection: In each of the States, two major cities were selected for study. The cities studied were Abakaliki and Afikpo (Ebonyi State), Enugu and Nsukka (Enugu State), Onitsha and Nnewi (Anambra State), Owerri and Orlu (Imo State), Umuahia and Aba (Abia State). In each of the cities, 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).

Monitoring protocol: The suspended particulate matter (SPM) (PM_{10} and $PM_{2.5}$) mass concentrations 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 2m above ground level, the human breathing zone[12] 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 (6.00am-6.00pm) 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 PM_{10} and $PM_{2.5}$ are presented in table-2 and 3 and their relationships shown in figures-1A, B, C and 2A, B and C.

The highest dry and wet seasonal mean PM_{10} concentrations of 921.34±532.60 and 266.06±129.79 $\mu g.m^{-3}$ were recorded in Onitsha Urban while the minimum levels of 84.38±16.03 and 14.38±3.10 $\mu g.m^{-3}$ were obtained in Nnewi and Orlu respectively (table-2). The dry seasonal mean in this study is above the annual mean of 123.6 $\mu g.m^{-3}$ obtained in a similar study in Nigerian cities[24]. Across the cities, the seasonal mean varied variously with the relatively more urbanized cities of Onitsha, Aba, Umuahia, Owerri and Enugu taking the lead in PM level while Orlu, Afikpo and Nnewi which are relatively less urbanized ranking lower in their PM load (figure-1A). The trend of the PM_{10} concentrations in the dry and wet seasons were depicted in Figs.1B and C respectively. The PM_{10} levels were relatively higher in the first ten weeks of the study in the dry season and peaking within the fourth to sixth week then dipping as the dry season progressed (figure-1B). The peaking within the fourth to sixth week corresponds to the peaking of harmattan in the South –Eastern States of Nigeria when the trans-boundary transportation of PM from the Sahara desert is mostly aided by North-East trade wind that is prevalent within this period. Other researchers have observed the elevation in PM_{10} and $PM_{2.5}$ mass concentrations in the Mediterranean region as result of Sahara desert episodic dust event and its subsequent trans-boundary transportation across the Mediterranean[25-27]. In figure-1C, the PM_{10} levels were higher in the first few weeks of commencement of the measurement and then decreases afterward. This again is expected as the ambient air PM level decreases with the progression of the rainy season due to wet precipitation (atmosphere clean-up by rain).

The seasonal mean PM_{10} levels in all the cities (except Orlu wet season) exceeded the WHO annual average guideline value of 20 $\mu g\ m^{-3}$. The range of PM_{10} levels in this study was above the values reported for various European Countries[28] but within the 24-hours mean levels of 149-340 $\mu g.m^{-3}$ reported for cities in Pakistan[29] and 170-260 $\mu g.m^{-3}$ reported in Calabar, Cross River State, Nigeria[30].

Onitsha Urban had the highest mean dry seasonal $PM_{2.5}$ value of 122.88 ± 33.39 $\mu g.m^{-3}$ while the highest wet seasonal value of 11.44 ± 4.57 $\mu g.m^{-3}$ was obtained in Aba. The least dry and wet mean $PM_{2.5}$ values of 21.69 ± 9.93 and 3.31 ± 2.36 $\mu g.m^{-3}$ were obtained in Nsukka and Owerri urban respectively (table-3). The seasonal mean variation of $PM_{2.5}$ followed the pattern of the PM_{10} with relatively less urbanized cities having least in PM levels as against higher values for relatively more urbanized cities (figure-1A).

Table-2
Dry and Wet seasonal mean levels of PM_{10} (µg.m^{-3}) in the cities monitored

WK	Aba		Umuahia		Nnewi		Onitsha		Abakaliki		Afikpo		Enugu		Nsukka		Orlu		Owerri	
	D	W	D	W	D	W	D	W	D	W	D	W	D	W	D	W	D	W	D	W
1	604	106	376	120	106	44	1320	427	107	82	128	60	247	46	170	60	105	12	110	120
2	678	124	481	134	122	51	1460	408	100	73	100	64	253	48	200	71	100	10	121	100
3	727	117	810	106	87	24	1600	419	148	76	136	61	270	48	206	80	120	14	136	102
4	711	121	840	100	98	30	1433	400	155	68	140	58	308	60	220	68	102	14	160	102
5	901	107	889	90	96	31	1283	383	158	48	142	54	309	51	200	62	120	18	158	101
6	975	106	720	60	89	34	1109	375	147	41	152	50	233	40	210	65	90	15	171	90
7	811	120	911	80	96	29	1175	364	123	64	102	52	207	42	286	60	88	12	280	83
8	846	100	387	60	78	30	1086	208	126	60	96	48	362	30	301	40	86	18	310	86
9	684	90	312	70	73	28	1101	276	128	58	95	47	172	29	254	36	86	14	323	82
10	637	83	354	75	78	25	896	235	120	45	90	42	162	30	100	32	80	15	286	76
11	580	83	287	66	76	24	982	211	115	41	84	38	108	20	100	30	80	12	260	85
12	564	87	248	60	80	28	960	136	106	40	76	29	107	18	120	42	60	20	277	75
13	498	79	172	51	70	26	96	121	112	39	72	32	152	20	190	28	70	18	240	98
14	367	75	180	85	74	25	88	101	82	38	70	24	90	18	180	27	68	16	236	90
15	470	89	243	72	63	23	81	98	120	36	56	25	75	16	110	23	80	10	285	85
16	335	66	271	53	64	21	81	95	117	29	52	21	96	18	146	21	86	12	244	78
$\overline{x}$	649.25	97.06	467.56	80.13	84.38	29.56	921.34	266.06	122.75	52.38	99.44	44.06	196.94	33.38	187.06	46.56	88.81	14.38	224.81	90.81
S	181.47	18.04	269.08	24.32	16.03	7.87	532.60	129.79	20.78	16.36	31.67	14.29	89.77	14.46	61.75	19.51	17.09	3.01	70.90	12.13

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

Wk	Aba		Umuahia		Nnewi		Onitsha		Abakaliki		Afikpo		Enugu		Nsukka		Orlu		Owerri	
	D	W	D	W	D	W	D	W	D	W	D	W	D	W	D	W	D	W	D	W
1	100	12	80	14	40	09	105	18	47	20	20	16	15	06	14	06	15	09	70	04
2	106	15	77	12	55	08	129	14	54	16	40	16	18	10	16	10	20	06	76	08
3	80	12	78	10	68	06	153	12	56	16	41	18	21	10	25	12	25	06	96	06
4	140	14	106	10	60	04	165	12	51	14	43	15	28	10	23	06	22	06	104	06
5	145	21	140	08	68	08	136	10	60	16	60	14	55	06	36	06	30	04	102	06
6	94	12	118	08	56	06	145	10	60	06	58	13	56	06	40	10	32	05	100	06
7	86	18	80	12	60	06	124	10	72	06	56	10	29	04	30	12	36	02	120	03
8	80	16	77	06	40	06	141	12	71	06	64	10	26	04	32	08	32	03	101	03
9	76	12	62	08	37	03	188	10	66	06	52	10	22	04	30	06	30	02	90	02
10	78	10	55	06	36	02	149	07	35	06	51	06	20	06	20	08	28	10	82	01
11	70	08	49	06	30	02	100	06	31	04	48	05	18	03	23	06	21	06	85	01
12	71	08	46	06	26	02	97	06	30	04	45	04	18	03	17	02	28	03	83	01
13	72	06	45	04	26	02	96	04	33	06	30	01	19	04	15	03	40	01	76	02
14	65	06	50	04	29	02	89	10	36	04	25	01	16	02	10	04	27	02	60	01
15	68	08	48	06	26	01	71	04	23	02	20	01	17	02	06	01	30	01	68	01
16	69	05	42	09	27	02	78	04	41	02	15	02	20	01	10	01	35	01	42	02
$\overline{x}$	87.50	11.44	72.06	8.06	42.75	4.31	122.88	9.31	47.88	8.38	41.75	8.88	24.88	5.06	21.69	6.31	28.19	4.19	84.69	3.31
S	24.48	4.57	28.74	2.93	15.77	2.65	33.39	3.94	15.60	5.85	15.54	6.05	12.62	2.89	9.93	3.55	6.47	2.81	19.43	2.36

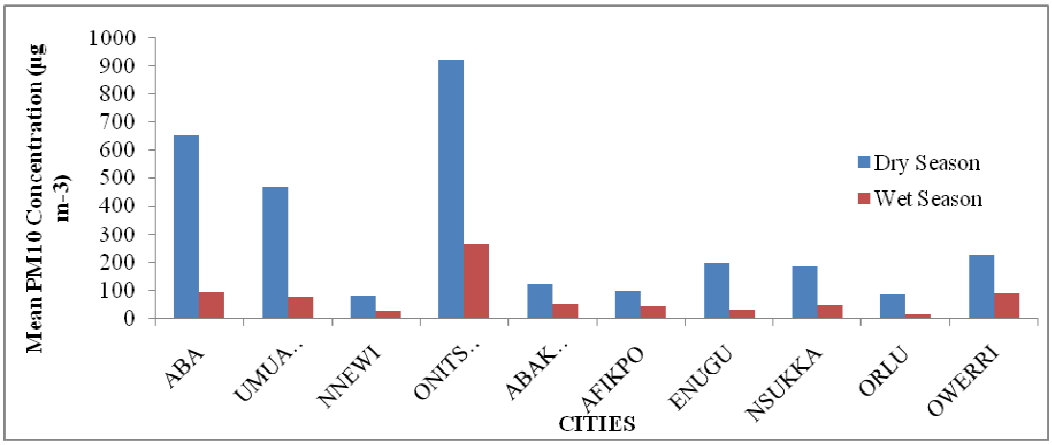

Figure-1A

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

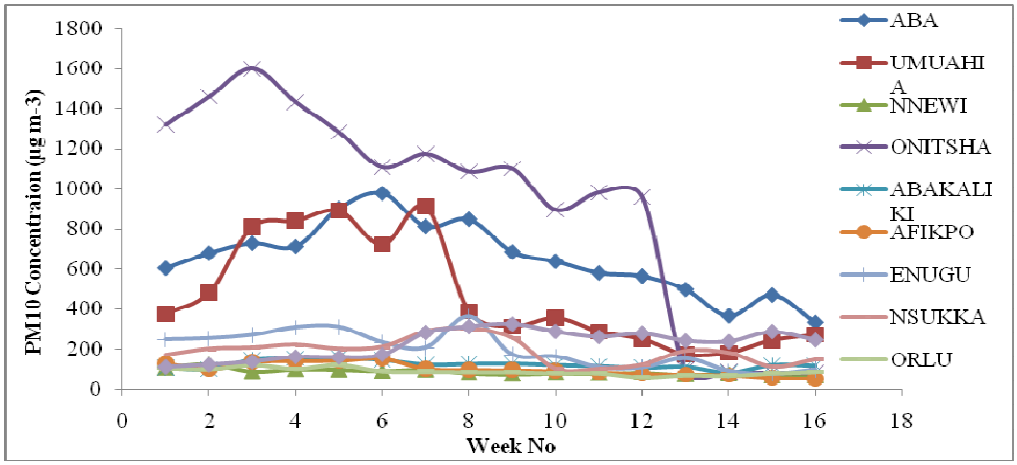

Figure-1B

Comparison of Dry Season PM_{10} concentration within the months of Dec. 2008 to March 2009

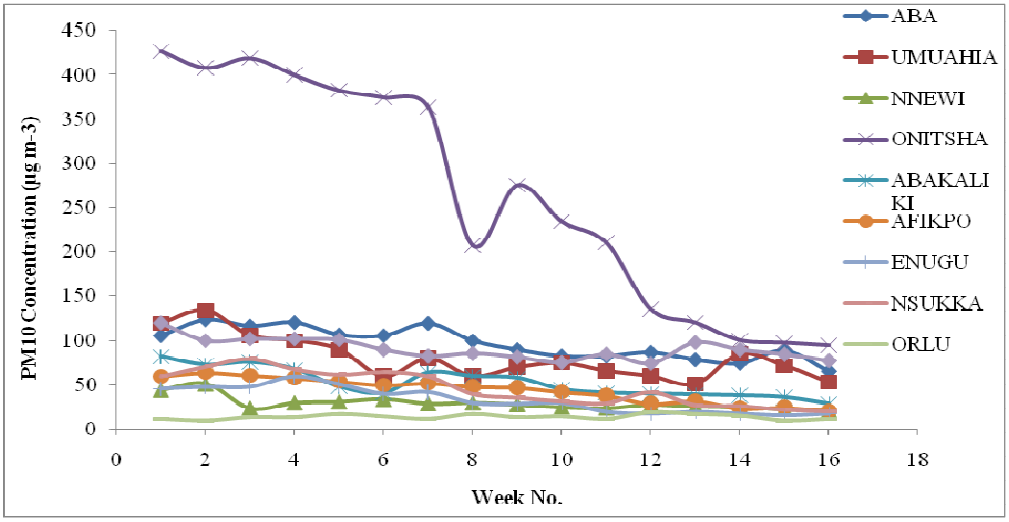

Figure-1C

Comparison of Wet Season PM_{10} concentration within the months of June –September, 2009

The $PM_{2.5}$ concentrations trend followed the seasonal pattern exhibiting normal curve shape of gradual increase at the beginning of dry season, peaking at the middle and deceases afterwards (figure-2B) while the wet season pattern showed initial higher values and dipping afterwards (figure-2C). The $PM_{2.5}$ concentrations recorded in this study is within the time weighed average minimum and maximum values of 10-340 $\mu g.m^{-3}$ by Shendell and Naeher[11] in a monitoring of three sites in the summer in urban Guatemala.

All the cities studied had their wet season mean concentration within the USEPA recommended annual average limit of 15 $\mu g.m^{-3}$ for $PM_{2.5}$ but the dry season mean levels exceeded this limit. The dry and wet seasonal levels of PM_{10} correlated significantly with $PM_{2.5}$ ($P< 0.05$) in all the cities monitored while the student t-test showed significant difference between the dry and wet seasonal mean of PM_{10} and $PM_{2.5}$.

Figure-2A

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

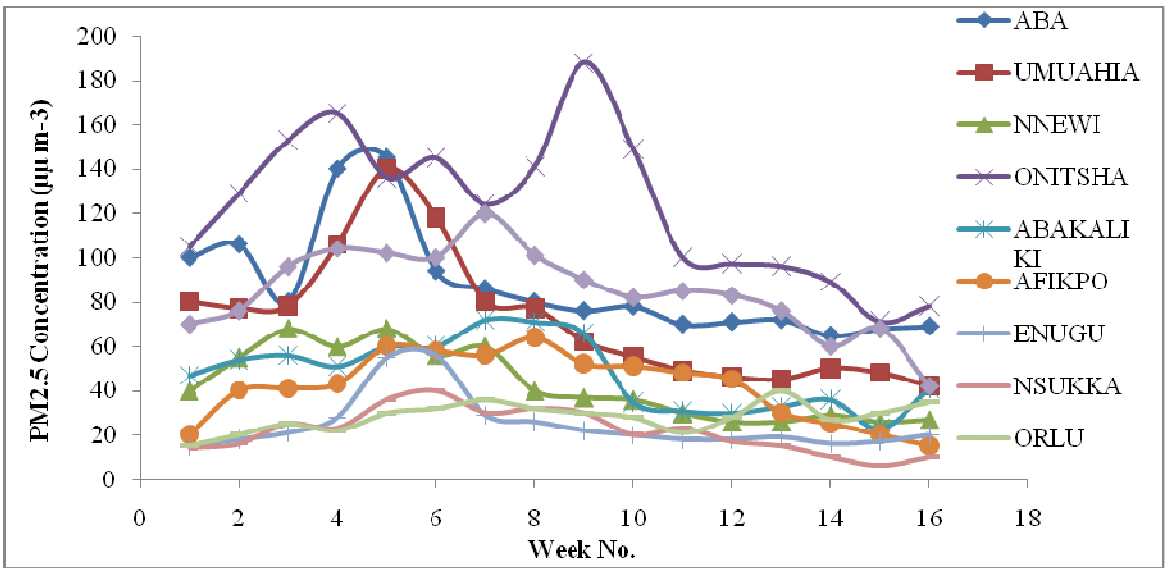

Figure-2B

Comparison of Dry Season $PM_{2.5}$ concentration within the months of Dec. 2008 to March 2009

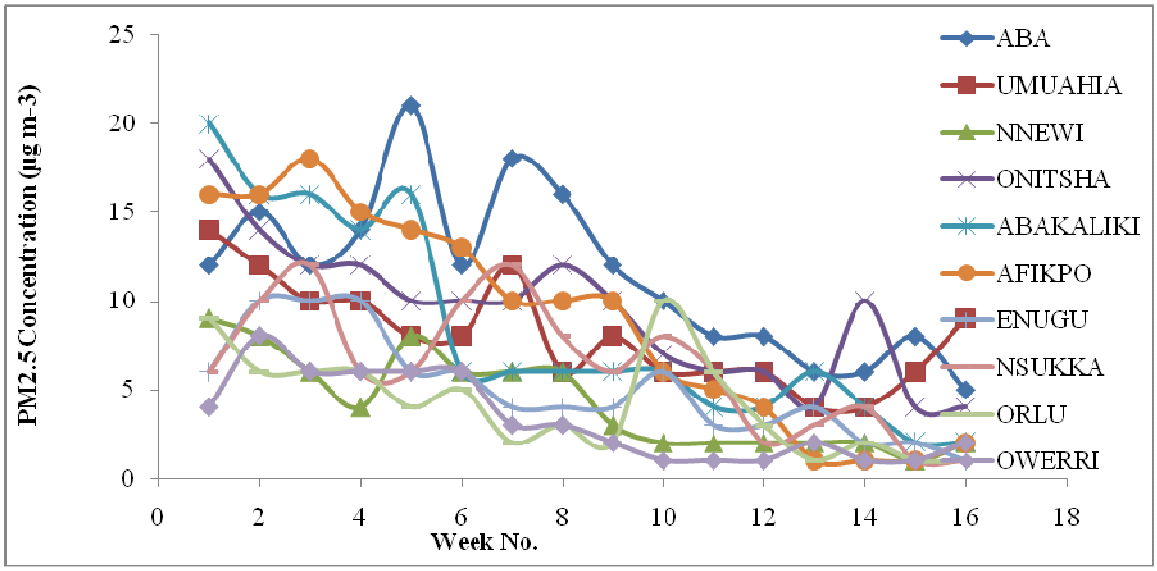

Figure-2C
Comparison of Wet Season $PM_{2.5}$ concentration within the months of June –September, 2009

Conclusion

This study was conducted to assess the ambient air level of coarse and fine particulate in ten urban cities in South-East Nigeria. It was found that within the period of the study, Onitsha urban relative to other cities studied had the highest ambient air seasonal mean concentrations of both the coarse and fine particulate. In addition, the PM load across the cities varied according to the level of urbanization and season. It can be concluded that all the cities studied had dry seasonal mean PM_{10} and $PM_{2.5}$ load that were above the guideline limit and this calls for concern in view of the human health risk associated with particulate matter pollution.

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