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Investigation and evaluation of health hazards associated with smoke emissions from proliferation of generators in Port Harcourt Metropolis

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Abstract

This study measured and evaluated health hazards associated with the proliferation of fossil fuel electric generators in Port Harcourt metropolis in Rivers State. The study employed both field monitoring and social research surveys in data collection and acquisition. The mean concentrations of TSPM, PM_{10}, PM_7, $PM_{2.5}$ and PM_1 obtained around RSUST Business area were 115.4µg/m^3, 103.0µg/m^3, 85.0 µg/m^3, 60.0 µg/m^3 and 48.2 µg/m^3 respectively. The study indicated that the proliferation of generators impacts negatively on human health. It also revealed that there is high level of awareness among generator users on the health effects associated with generator usage. The results showed unhealthy particulate levels in the air around business center which pose significant risk to human health. This implies that workers in business centers are exposed to high concentrations of air pollutants which may adversely affect their health or aggravate their health conditions due to prolonged exposure. The results of social survey showed that proliferation of fossil fuel generators have negative effects on public health. To reduce the proliferation of generators, government should redouble their efforts to ensure that there is constant or steady power supply in the country, regulate the use of fossil fuel electric generators and encourage alternative energy sources. The relevant regulatory agency should conduct public assessment of generators to ascertain the emission status.

Keywords: Proliferation; Generators; Particulates Emissions; Particulate Fractions; Health Hazards; Fossil Fuel

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1. Introduction

Inexpensive and dependable power is vital to contemporary living. It delivers unsoiled, harmless light round the clock. It chills our homes on hot days and warms those cold periods. It also quietly blows life into the digital world we all use through our smart phones and computers (IER, 2014). Fresh air is taken to be a fundamental necessity of life. However, air pollution continues to be a significant danger to health globally. According to a WHO assessment, the burden of disease due to air pollution in 2006 puts more than 2 million premature deaths each year on urban outdoor and indoor air pollution. More than half of this disease burden is borne by the populations of developing countries (WHO, 2006). In Nigeria, power supply is unpredictable and erratic which has culminated in consumers looking for substitutes such as electric generators.

Presently in Nigeria, portable generators are commonly used in business centers, shops and homes to supply electricity. Notwithstanding the numerous benefits, most Nigerians are not aware of the detrimental effect of emissions from generator usage on their health. The operation or running of generators requires the use of fossil fuel such as diesel and petrol. The burning of hydrocarbon fossil fuel (by generators) results in the emission of different fractions of noxious Particulate matter (Respirable $PM_{7\&10}$) and (inhalable $PM_{1\&2.5}$), into the air environment. As a result, the air we breathe is contaminated with these air pollutants which are harmful to human health. The concern for generator emissions in urban areas has been expressed due to the recognition of numerous adverse effects of these particulate emissions on man and the environment. The generators emit hydrocarbons, carbon monoxide, nitrogen dioxide, lead, particulate matter and in strong sunlight, some of these hydrocarbons and oxides of nitrogen may be converted into “photochemical pollutants” of oxidizing nature (Horsfall and Spiff, 1998).

Port Harcourt being one of the fastest growing cities in sub- Saharan Africa in terms of demographics, has also witnessed a direct proportional growth in the demand and purchase of generators which in turn, transcends to increased emissions in the study areas (Clara, 2011). Port Harcourt is a major player in the oil and gas industry and it plays host to most oil companies as well as oil servicing companies. Like other urban centers in Nigeria, it has serious power supply challenges, as almost all companies, homes, businesses, farms, schools, hospitals, etc., have resulted to generating electric power by themselves. At least, one generator set is located at a residential, official, industrial, agricultural, unit as the case may be. An example is the smallest and cheapest generator popularly called “*I better pass my neighbor*”. Most likely, exposure to these generator emissions might have led to the increase in cancer related cases, respiratory disease conditions, etc.; most of which are common to smokers. These are now being observed in non-smoking residences (Pandey, 1998). Also, most of these generators are over aged and poorly maintained and subsequently may generate more particulate emissions (Aaberg, 2007).

In addition, the proliferation of generators in the metropolis has given rise to an increased incidence of fire out breaks due to generator explosion. These cases have been frequent owing to poor housing pattern as most buildings are closely erected, thus fostering poor ventilation and subsequent spread of these fires and difficulty in fighting them. This study is also necessitated by the lack of awareness of potential dangers posed to residence and the populace by the continuous exposure to the harmful fumes released during generator usage. Uncontrolled exposure to these fumes can cause breathing challenges, sore throat, sore eyes (red eyes), nausea, vomiting, light headedness, unconsciousness and in extremely high levels, death to undiscerning users and the general populace (Ubong et al., 2008; CDC, 2011).

Literature sources have shown and established that exhaust fumes, arising from the burning of fuels in automobiles, homes and industries are a major source of air pollution (Gobo et al., 2008). It was also reported that in the past, outdoor air quality was frequently used as an indicator of human exposure but now, it has been discovered that indoor air quality provides a better index for measuring human exposure (WHO, 2006, Ubong, et al., 2008). This has given rise to a lot of indoor air pollution studies (WHO, 2006). Consequently, indoor pollution is a major public health issue, in that most of the urban population spends more time indoors and the various pollutants present in indoor environments may be harmful and responsible for the deteriorating quality of environment and poor human health.

In a related study, Ubong et al. (2015), studied the air quality within Rivers State University of Science and Technology (RSUST) campus air shed, Nigeria. The parameters covered were Respirable Particulate Matter (PM_{10}, PM_7, $PM_{2.5}$, PM_1) and Total Suspended Particulates (TSP) and noise. The results showed that PM1 varied from <1.0-15.0 μg/m^3 across all stations and that the shopping complex had the highest concentration of 15.0 μg/m^3 while the main Library and Technical and Science Faculty air shed had less than 1.0 μg/m^3. Sulphur oxides (SO_X), Nitrogen dioxide (NO_2), Ammonia (NH_3), Carbon Monoxide (CO), Hydrogen Sulphide (H_2S), Methane (CH_4), Volatile Organic Compounds (VOCs) were also determined.

In a related study of indoor air quality and the well-being perception of library attendants, Ubong et al. (2008), made observations that were in line with the study on human response to air quality that the sensory perception to air pollution is a function of concentration of pollutants and dust fall. Interestingly, it was also noted that the micro-climatic conditions perceived were not in agreement with the environmental parameters measured within the same environment. While the high concentration of pollutants noticed in the area may be responsible for SBS (Sick Building Syndrome), the symptoms covered attention difficulty, tiredness, nausea, watery eyes, sore irritation, runny nose, dry throat, skin irritation, breath difficulty, itchy face, headache, skin reddening, asthmatic attack, coughing, etc.

Ede et al. (2013), determined the Emissions from Private Power Generating Equipment, and evaluated the effects of their widespread and submitted that the total emissions for diesel generators were as follows: THC - 26.1 tons, NO_X -362.79 tons, CO- 138.33, PM_{10} - 23.49 tons, and CO_2 - 44800.65 per year; while for THC - 1096.2 tons, NO_X-70.47 tons, CO- 20,175.3 tons, PM_{10}- 93.96 tons and CO_2- 34.718.22 tons for gasoline generators per year. Assuming a steady growth of the economy of Port Harcourt and emission output from various sources, the air quality of the region will greatly deteriorate. Electric generators produce gaseous and noise emissions while in operation, exposing users to variety of health hazards. Other scientists have also carried out studies on the health hazards of fossil fuel Electric generators in Nigeria (Offiong, 2003; Dimari et al., 2007; Stanley, 2011; Mbamali et al., 2012). Their results showed that combustion of fossil fuel in generators causes air pollution which adversely affects human health. The studies further showed that generator operations expose users to harmful gaseous emissions such as nitrogen oxides (NO_x), sulphur dioxide (SO_2), carbon monoxide (CO) and particulate matter as well as high noise levels. Exposure to air pollutants in the range of 150 – 200 ppm has been found to result in bronchiolitis (Dimari et al., 2007).

The objectives of this study were to: characterize and quantify generator exhaust emissions in selected air sheds of Port Harcourt; identify and evaluate air pollutant levels emanating from generator usage in residential and business areas; identify levels of public awareness on the effects of generator fumes; determine mitigating measures to ameliorate negative impacts and carry out an area contour mapping of some particulates' fraction in selected areas. The study was carried out in four selected sampling sites namely: Shopping complex (business center of the Rivers State University (RSU); Le' Meridien Hotel, New GRA; Some Residential homes, within Pentagon Estate, Elelenwo and Agricultural farm (control environment in the Rivers State University (UST), Port Harcourt, Nigeria.

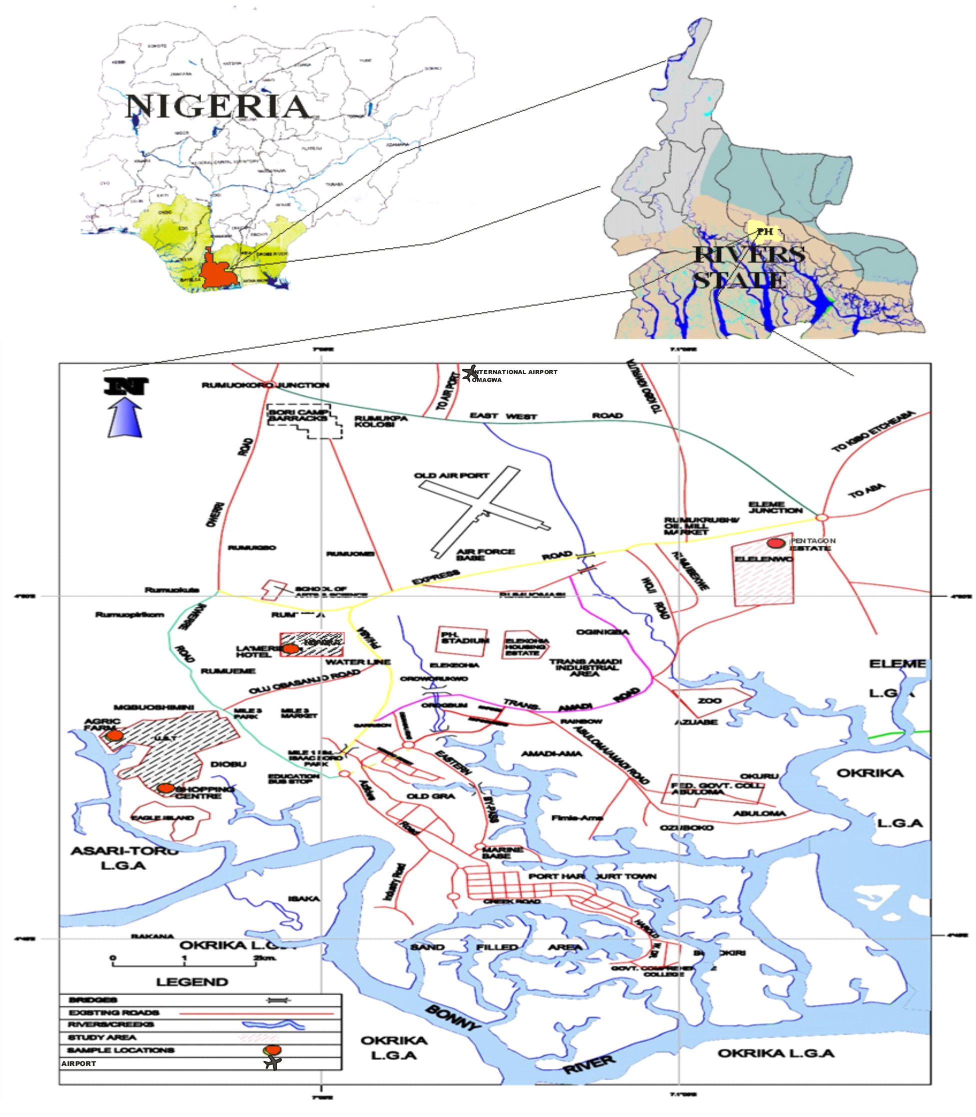

Figure 1. Map of Nigeria, Niger Delta and Port Harcourt Metropolis Showing the Sample Sites (Source: Survey Division, Ministry of Lands and Survey, Port Harcourt).

The study area was Port Harcourt City, which is and has been the capital of Rivers State and a Port town in the southern part of Nigeria (Figure 1). It lies along the Bonny River (and eastern tributary of the Niger Delta), 41 miles (66 km) upstream of the Gulf of Guinea. Its geographical coordinates are Longitudes 007° 01'469" East and Latitude 04° 49'881" North (Gobo et al., 2014). Rapid urban development and increasing land use changes due to increasing population and economic growth is being witnessed in Port Harcourt and cities in other developing countries. The metropolitan nature of Port Harcourt city has undergone changes during the last decades. Port Harcourt had been a colonial city, which had been clearly demarcated in its boundaries and has grown and continues to grow into the adjoining landscape, enveloping more villages, coastlines, and previously reserved landscape, changing into an ever- increasing urban conglomerate. After 1980s, mass development of more cities which had a catalytic impact on reshaping of the economic landscape in metropolitan areas which has drawn much attention (Hackworth, 2005). In the last quarter of the twentieth century, Port Harcourt witnessed transforming change in structure due to population and economic growth and development of its transportation and communication systems and the impact of globalization (Obinna et al., 2010). Much of this growth is unplanned and unregulated (Owei et al., 2008).

Port Harcourt climate falls within the sub equatorial climate belt. Temperature and humidity are high throughout the year. The area is marked by two distinct seasons –the wet and the dry seasons – with 78 percent of the annual rains falling between April and August, while 22 percent is spread in the three months of September to November. The driest months are from December to March (Ayotamuno and Gobo, 2004).

The conceptual framework for the study is presented (Figure 2). The population and pollution model (Popullution Model), shows in simple and relatable terms the strong correlation between industrialization (technological advancement), population growth (man's quest for better life) and pollution. People move from rural to urban areas in search of a better life (Urban/Rural drift). Through this process, strain is created on the existing amenities leading to wear and tear for instance, the epileptic services experienced in the power sector in Nigeria. In a bid to generate electrical power, people design, develop, deploy and purchase generators to various locations for use. The end point is destruction of the environment arising from the emission of gaseous, particulate pollutants and noise. Consequently, people end up breathing in highly polluted air and hearing extremely high noise. These substances pose a serious threat to public health.

2. Materials and methods

Ambient air quality measurement, meteorological and noise surveys were conducted in July and September, 2013 of selected study areas within Port Harcourt Metropolis. The monitoring locations are shown in Table 1 along with their Coordinates detected by a GPRS. For the air quality parameters, the following parameters were measured during the exercise using suitable equipment: Total Suspended Particulate Matter (TSPM) (Met One Instrument Aerosol Mass Monitor), PM_{10}, PM_7, $PM_{2.5}$ and PM_1 (using the Air Metrics Mini-Volume Particulate Sampler); The meteorological parameters were: Temperature, Relative Humidity, Wind Speed, Wind direction using a multi-purpose digital Kestrel 4500 digital Anemometer.

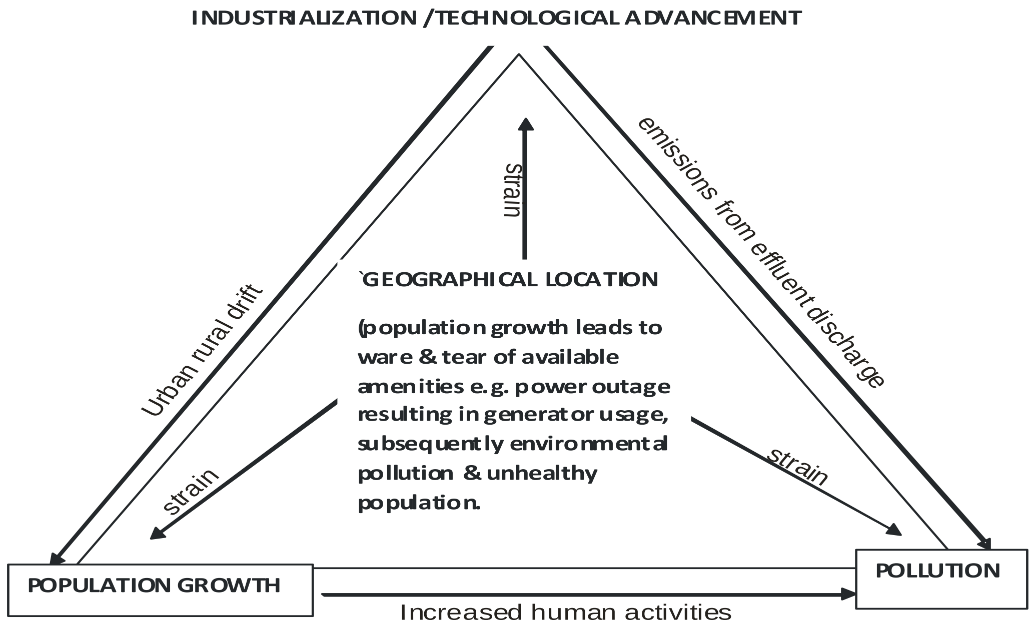

Figure 2. The Popullution Model (Author's Original Work, 2017)

Table 1. Monitoring locations and coordinates

S/No.	Monitoring points	Coordinates
1	Pentagon Estate point 1	E6⁰41'55.037" N5⁰27'39.078"
2	Le Meridien Hotel G R A	E6⁰39'50.730" N5⁰23'28.290"
3	Business Center Area RSU	E6⁰66'85.300" N5⁰39'48.200"
4	Rivers State University (RSU) Agricultural Farm (Control)	E7⁰10'11.106" N4⁰42'9.991"

Rivers State University (RSU)

3. Results and discussions

3.1. Results

3.1.1. Air quality

The results of air quality and meteorology are presented in Tables 2 – 7. The results for Total Suspended Particulate Matter (SPM) for all sites were: Pentagon Estate (26.0-39.0) μg/m^3; Le' Meridien Hotel (26.0-113.0) μg/m^3, RSUST Business Center (12.0-286.0) μg/m^3 and Agricultural Farm (Control point) (28) μg/m^3

(Table 2). The Rivers State University business center had the highest concentration of 286.0 μg/m^3 while the lowest was at Agricultural farm of the same University (28.0) μg/m^3 (Figure 3).

Concentrations of PM_{10} varied thus: Pentagon Estate (24.0-34.0) μg/m^3; Le' Meridien Hotel (21.0-102.0) μg/m^3, RSU Business Center (10.0-248.0) μg/m^3 and Agricultural Farm (Control point) (26) μg/m^3 (Table 3). The Rivers State University business center had the highest concentration of 248.0 μg/m^3 while the lowest was at Agricultural farm of the same University (26.0) μg/m^3 (Figure 4). Concentrations of PM_7 varied thus: Pentagon Estate (21.0-29.0) μg/m^3; Le' Meridien Hotel (15.0-76.0) μg/m^3, RSUST Business Center (6.0-205.0) μg/m^3 and Agricultural Farm (Control point) (18) μg/m^3 (Table 4). The Rivers State University business center had the highest concentration of 205.0 μg/m^3 while the lowest was at Agricultural farm of the same University (18.0) μg/m^3 (Figure 5).

Concentrations of $PM_{2.5}$ varied thus: Pentagon Estate (11.0-25.0) μg/m^3; Le' Meridien Hotel (13.0-64.0) μg/m^3, RSUST Business Center (4.0-127.0) μg/m^3 and Agricultural Farm (Control point) (12) μg/m^3 (Table 5). Like other parameters, the Rivers State University business center had the highest concentration of 127.0 μg/m^3 while the lowest was at Agricultural farm of the same University (12.0) μg/m^3 (Figure 6). PM_1 concentrations ranged thus: Pentagon Estate (6.0-19.0) μg/m^3; Le' Meridien Hotel (7.0-31.0) μg/m^3, RSUST Business Center (2.0-116.0) μg/m^3 and Agricultural Farm (Control point) (8) μg/m^3 (Table 6). Like other parameters, the Rivers State University business center had the highest concentration of 116.0 μg/m^3 while the lowest was at Agricultural farm of the same University (8.0) μg/m^3 (Tables 2-7) (Figure 7).

The $PM_{2.5}/PM_{10}$ ratio varied thus: Pentagon Estate (0.34 - 0.74), Le' Meridien Hotel (0.37-0.63), RSU Business Center (0.36-0.70), Agricultural Farm, Control point (0.46) (Table 6). The highest ratio was at Pentagon estate followed by the University Business center.

Table 2. Ambient Particulate fractions in air shed of Pentagon Estate

Locations	**TSPM (μg/m^3)**	**PM_{10} (μg/m^3)**	**PM_7 (μg/m^3)**	**$PM_{2.5}$ (μg/m^3)**	**PM_1 (μg/m^3)**	**$PM_{2.5}$ / PM_{10} Ratio**
1.	38	32	22	11	9	0.344
2.	26	24	21	13	6	0.542
3.	39	34	29	25	19	0.735
4.	27	25	21	13	8	0.52
Range	26.0-39.0	24.0-34.0	21.0-29.0	11.0-25.0	6.0-19.0	0.34 -0.74
Mean value	32.5	28.75	23.25	15.5	10.5	
Allowable Standards	250$^+$	50.0*	50.0*	25.0*	25.0*	

RSU= Rivers State University, WHO= World Health Organization Standard, FMEnv.$^+$ Limit= Federal Ministry of Environment Limit, Nigeria*

Table 3. Ambient Particulate fractions in air shed of Le' Meridien Hotel

Readings	TSPM (µg/m³)	PM_{10} (µg/m³)	PM_7 (µg/m³)	$PM_{2.5}$ (µg/m³)	PM_1 (µg/m³)	$PM_{2.5}/PM_{10}$ Ratio
Station 1	113	102	76	64	31	0.63
Station 2	68	59	41	22	12	0.37
Station 3	32	29	21	17	11	0.59
Station 4	26	21	15	13	7	0.62
Ranges	26.0-113.0	21.0-102.0	15.0-76.0	13.0-64.0	7.0-31.0	0.37 -0.63
Mean value	59.75	52.75	38.25	29	15.25	
Allowable Standards	250⁺	50.0*	50.0*	25.0*	25.0*	

RSU= Rivers State University, WHO= World Health Organization Standard, FMEnv.⁺ Limit= Federal Ministry of Environment Limit, Nigeria*

Table 4. Ambient Particulate fractions in air shed of RSU Business Center

S/No	TSPM (µg/m³)	PM_{10} (µg/m³)	PM_7 (µg/m³)	$PM_{2.5}$ (µg/m³)	PM_1 (µg/m³)	$PM_{2.5}/PM_{10}$ Ratio
1	14	11	8	4	2	0.36
2	12	10	6	4	3	0.40
3	131	118	105	76	55	0.64
4	286	248	205	127	116	0.51
5	134	128	101	89	65	0.70
Range	12.0-286.0	10.0-248.0	6.0-205.0	4.0-127.0	2.0-116.0	0.36-0.70
Mean value	115.4	103	85	60	48.2	
Allowable Standards	250⁺	50.0*	50.0*	25.0*	15.0*	15*

RSU= Rivers State University, WHO= World Health Organization Standard, FMEnv.⁺Limit= Federal Ministry of Environment Limit, Nigeria*

Table 5. Mean and Ranges of air pollutants in all sampling locations

S/ No.	Locations	SPM (µg/m³)	PM_{10} (µg/m³)	PM_7 (µg/m³)	$PM_{2.5}$ (µg/m³)	PM_1 (µg/m³)	PM 2.5/PM 10 Ratio
1.	Pentagon Estate Mean Range	32.5 26.0-39.0	28.75 24.0-34.0	23.25 21.0-29.0	15.5 11.0-25.0	10.5 6.0-19.0	(0.54) 0.34 -0.74
2.	Le' Meridien Hotel Mean Range	59.75 26.0-113.0	52.75 21.0-102.0	38.25 15.0-76.0	29.00 13.0-64.0	15.25 7.0-31.0	(0.55) 0.37-0.63
3.	RSU Business Center Mean Range	115.40 12.0-286.0	103.00 10.0-248.0	85.00 6.0-205.0	60.00 4.0-127.0	48.20 2.0-116.0	(0.58) 0.36-0.70
4.	Agric Farm (Control point)	28	26	18	12	8	0.46 (0.46)
Allowable Standards		250⁺	50.0*	50.0*	25.0*	25.0*	

RSU= Rivers State University, WHO= World Health Organization Standard, FMEnv. ⁺ Limit= Federal Ministry; () = mean of Environment Limit, Nigeria*

3.1.2. Isopleths mapping

The result of isopleths mapping is presented in Figures 3 and 4 for the total Suspended Particulate Matter and PM 10 respectively.

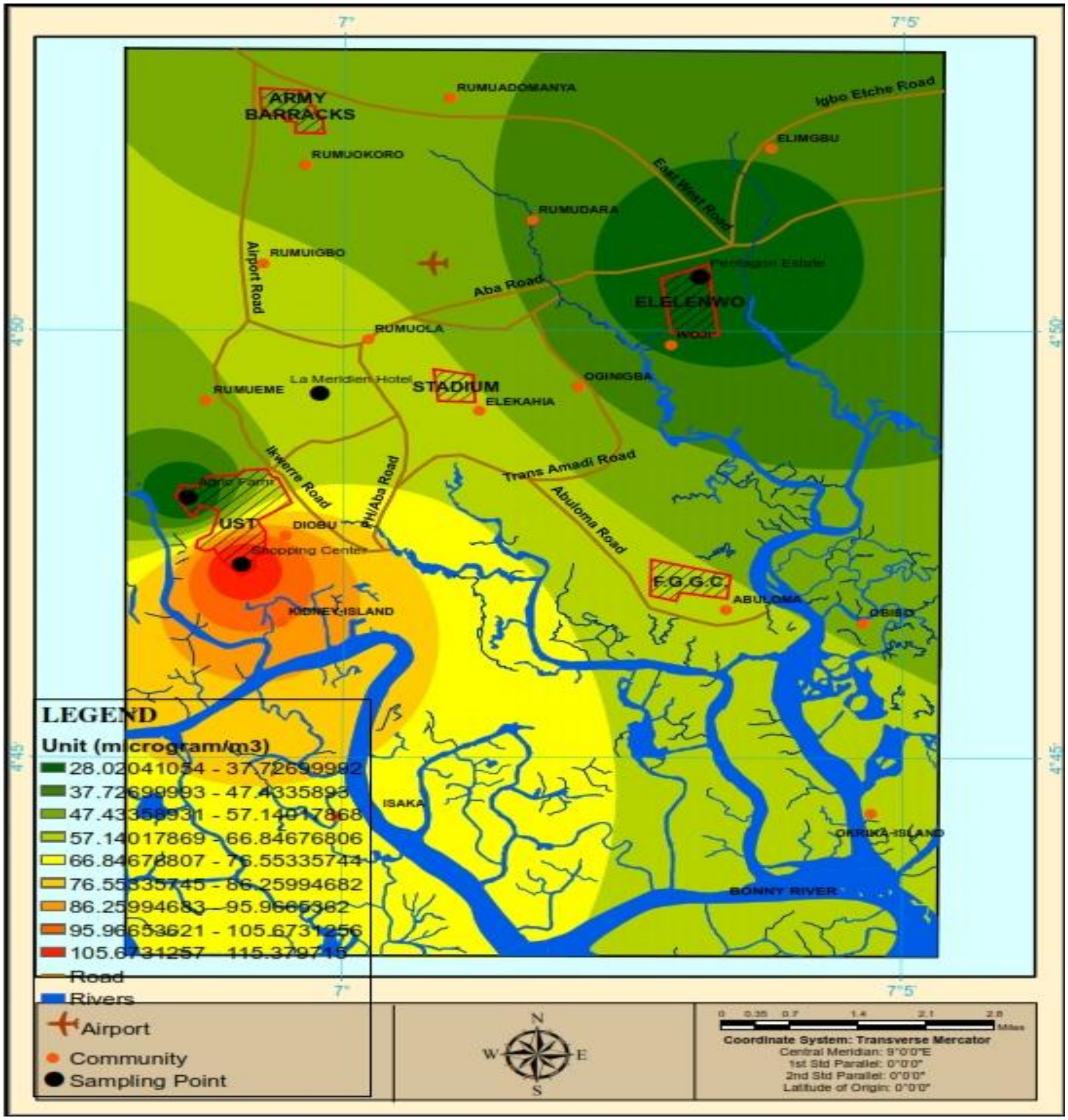

Figure 3. TSPM Isopleths mapping for the study area

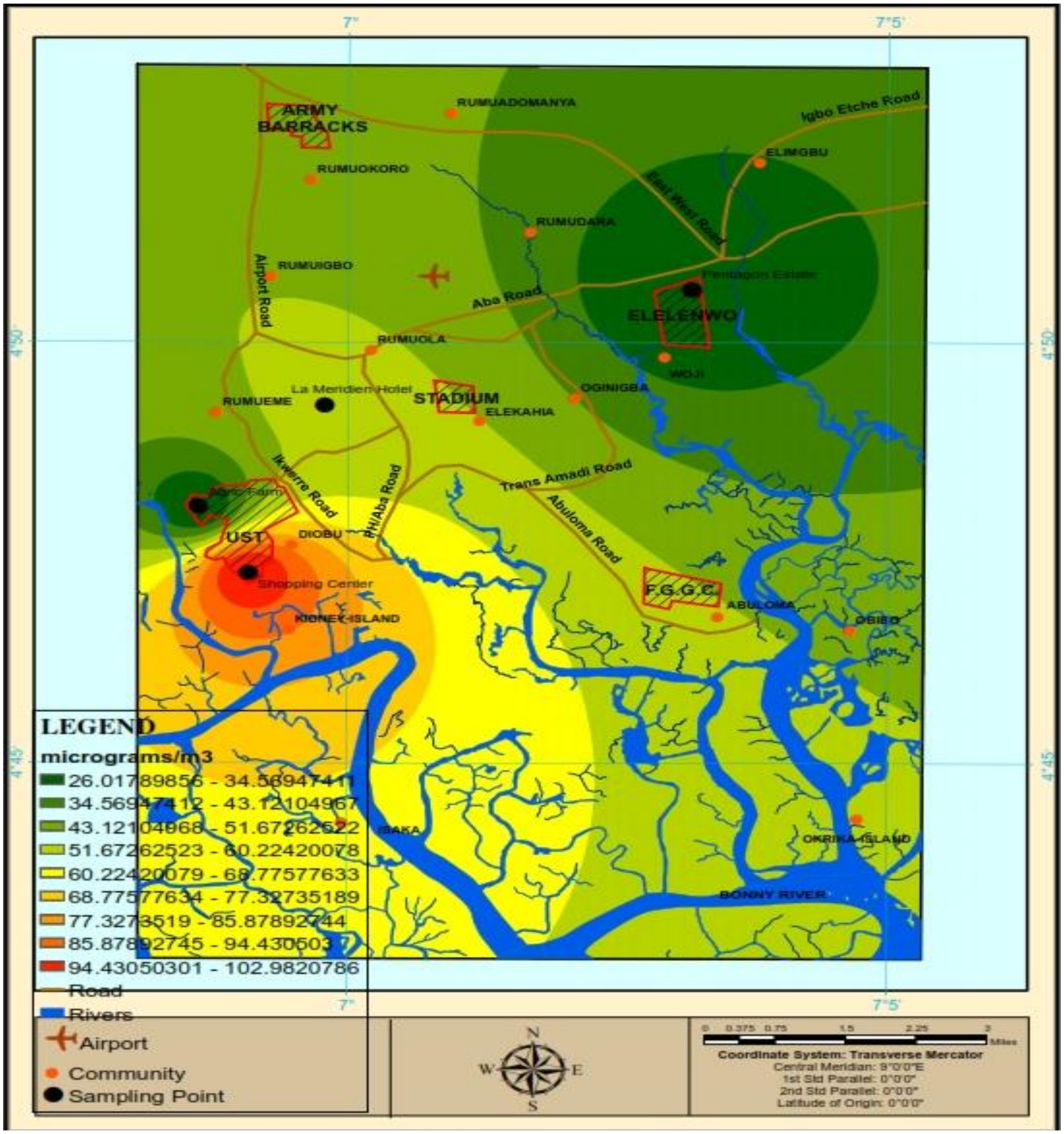

Figure 4. PM_{10} mapping for the Study Area

3.1.3. Meteorology and other issues

The micro-climatic data were: Temperature (26.35-26.675) ^{o}C, Relative Humidity (78-82.75) %, Wind Speed (0.42 - 0.65) m/s and wind that was predominantly South Westerly and South Easterly (Tables 6 and 7). The temperature was not different but similar in all air sheds studied. The Relative Humidity ranged from 78.0 - 82.75 % while the wind speed ranged from 0.43 – 0.80 (m/s). The highest wind speed was obtained from the agricultural farm of the university while the lowest came from the Le' Meridien Hotel air shed and was less than 0.7 m/s. The noise ranged from 49.2 db at the university agricultural farm to 75db at the university business center (Tables 6 and 7).

Table 6. Meteorological Results as Measured in All Air Sheds Studied

Locations	Temp (^{0}C)	Rel. Humid (%)	Wind Speed (m/s)	Wind Direction
Pentagon Estate				
1	25.8	86	0.3	223 S-SW
2	26.5	82	0.5	215 SW
3	27.1	85	0.9	189 SE
4	*27.3*	*78*	*0.9*	*258 SE*
Average value	*26.68*	*82.8*	*0.65*	
Le' Meridien Hotel				
1	25.8	89	0.2	118 SS
2	25.4	87	0.3	106 S
3	27.4	75	0.5	250 SW
4	27.6	77	0.7	189 S-SW
Average value	**26.55**	**82.0**	**0.43**	
RS University Business Area				
1	26.4	75	0.1	023 SS
2	26.1	80	0.2	034 SW
3	26.4	78	0.4	248 SW
4	26.6	76	0.6	203 SS
5	26.3	78	0.9	233 SS
Average value	**26.4**	**78.0**	**0.53**	
University Agric farm (control)	26.5	81	0.80	125 SS

RS= Rivers State

Table 7. Mean Values of Meteorology and Noise at the Sampling Locations

Locations	Tempt (^{0}C)	Rel. Humidity (%)	Wind Speed (m/s)	Noise (dB A)
Pentagon Estate	26.67	82.75	0.65	58.15
Le' Meridien Hotel	26.4	82.0	0.43	67.63
University Business Center	26.35	78.0	0.53	74.95
Agric Farm (Control point)	26.5	81.0	0.8	49.2

3.2. Discussions

3.2.1. Air quality

3.2.1.1. Total Suspended Particulate Matter

The total suspended particulate matter showed varying concentrations and distribution in the air shed. The low concentration at the University Agricultural farm (28.0) µg/m^3 arises from neighborhood domestic emissions vehicular sources, generator emissions, etc. All these contribute to a raised background or baseline. It can be considered as a near baseline value. There is no major activity of air pollution interest that impacts the air shed at the farm hence low reading. The Pentagon Estate (26.0-39.0) µg/m^3 was next in low concentration. This is a residential estate and higher concentration may be attributed to generator emissions from homes, domestic emissions from cooking, barbecue, vehicular sources entering and leaving the estate, etc. Le' Meridien Hotel air shed (26.0-113.0) µg/m^3 was the site with second high concentration (Tables 2-5). This is Government reserved area (GRA) with a road by-pass from the high-way. So apart from emissions from generators that dot homes and the big hotels in the neighborhood, traffic emissions may be second major source contributing to particulate hike in the air shed. Sources of high concentration in the Rivers State University business center with the highest concentration of 286.0 µg/m^3, may be due to many factors including: emissions from generators, traffic, biomass burning, charcoal burning to roast plantain/yam, barbecue, stove for those cooking to either warm food or cook afresh, etc. The business complex is a community in itself with myriads of generators at work most of the times. It is a busy neighborhood with beehives of activities of air pollution interest. In all these activities, emissions are released to the air basin. A look at all sites shows that the university business center had the highest SPM concentration that exceeded the national (Federal Ministry of Environment) allowable standard of 250 µg/m^3 (Figure 3).

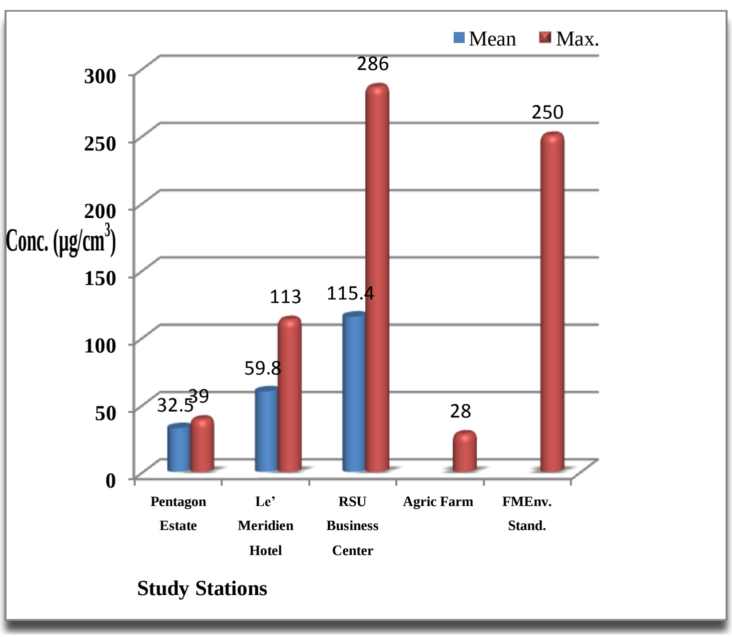

Figure 3. Mean concentrations of SPM in all study Stations

Exceedance observed in the maximum concentration implies that exceedance will cascade down to the least fraction i.e. PM 10, PM 7, PM 2.5 and PM 1 (Table 5).. Levels of SPM reported in this study are about 5 times higher than the ones earlier reported by Ubong et al. (2015), where campus SPM ranged from 27.0-61.0 μg/m^3; with the highest obtained from the shopping complex. Levels obtained depends on the time of year sampling is done.

Clean air is considered to be a basic requirement of human health and well-being. However, air pollution continues to pose a significant threat to health worldwide (WHO, 2005).

3.2.1.2. PM $_{10}$

Particulate matter (PM 10), like SPM, showed varying concentrations and distributions in the air shed (Tables 2-5). The concentration at the University Agricultural farm (26.0) μg/m^3 appears to be a raised baseline due to neighborhood emissions from generators, traffic, biomass burning, etc. The Pentagon Estate (24.0-34.0) μg/m^3 was next in low concentration (Tables 3 and 5). This is a residential estate and higher concentration may be attributed to generator emissions from homes, domestic combustion, vehicles entering and leaving the estate, etc. Le' Meridien Hotel air shed (21.0-102.0) μg/m^3 was the site with second high concentration. This is Government reserved area (GRA) with a road by-pass from the high-way. So apart from emissions from generators that dot homes and the big hotels in the neighborhood, traffic emissions may be another major source contributing to particulate hike in the air shed. Sources of high concentration in the Rivers State University business center with the highest concentration of 248.0 μg/m^3 may be due to many factors including: emissions from generators, traffic, biomass burning, and barbecue, charcoal burning to roast plantain/yam, stove for those cooking to either warm food or cook afresh, etc.

The business complex is a community in itself with myriads of generators at work most of the times. It is a busy neighborhood with beehives of activities of air pollution interest. In all these activities, emissions are released to the air basin (Table 5). A look at all sites shows that the university business center had the highest PM 10 concentration (10.0-248.0) that exceeded the international World Health Organization standard of 50 μg/m^3 (Figure 4). Exceedance observed in the maximum and mean concentrations implies that exceedance will cascade down to the other fractions of PM 7, PM 2.5 and PM 1. Respirable particulate matter reaching 102 and 248.0 μg/m^3 in the air basin, shows very poor air quality which poses a risk to the inhabitants of this area (Figure 4). It shows the finding in this study is four times higher than the control in GRA while university business community is almost ten times higher than the control. The international limit is 50 μg/cm^3 which is exceeded in both GRA and the university business complex air sheds by a factor of 2 and 5 respectively. Levels of PM 10 reported in this study are higher than the ones earlier reported by Ubong et al. (2015), where campus PM 10 ranged from 23-57.0 μg/m^3; with the highest obtained from the shopping complex. Particulate matter is highly seasonal and so levels obtained will depend on the time of year measured.

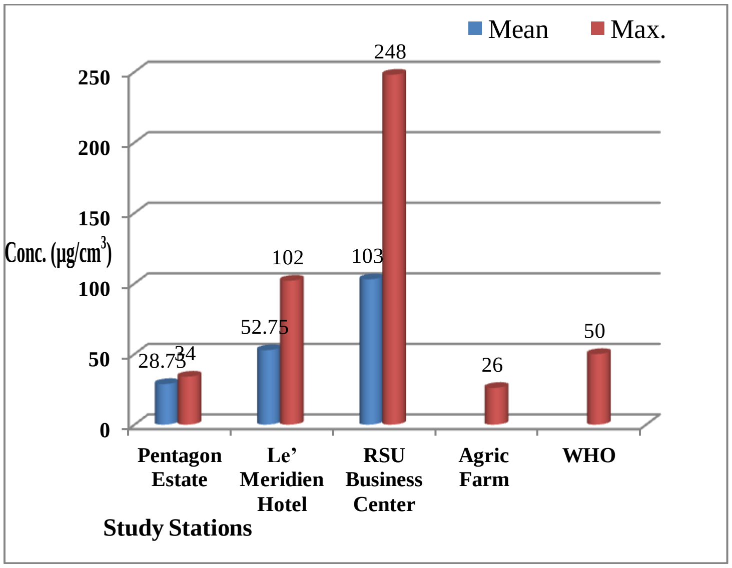

Figure 4. Mean concentrations of PM_{10} in all study Stations

Particulate matter is solid or liquid matter that is suspended in the air (Greenfacts, n.d.; Estokova and Stevulova, 2012). PM_{10} represents the particle mass that enters the respiratory tract (USEPA, 2012). Based on size, particulate matter is often divided into two main groups (Morawska and Salthammer, 2003; USEPA, 2012; Estokova and Stevulova, 2012; Ubong et al., 2015): the coarse fraction which contains the larger particles with a size ranging from 2.5 to 10 µm (PM2.5 - PM10) and the fine fraction which contains the smaller ones with a size up to 2.5 µm (PM 2.5). The particles in the fine fraction which are smaller than 0.1µm are called ultrafine particles (Estokova and Stevulova, 2012; US EPA, 2012; Greenfacts, n.d.). Coarse particles are formed from sources like road dust, sea spray and construction. Fine particles are formed when fuel is burned in automobiles and power plants, originates primarily from combustion sources. Particulate matter that is small enough can enter the lungs and cause health problems. Some of these problems include more frequent asthmatic attacks, respiratory problems, and premature death. In most urban environments, both coarse and fine mode particles are present, but the proportion of particles in these two size ranges is likely to vary substantially between cities around the world, depending on local geography, meteorology and specific PM sources (WHO, 2005). In some areas, the combustion of wood and other biomass fuels can be an important source of particulate air pollution, the resulting combustion particles being largely in the fine ($PM_{2.5}$) mode (WHO, 2005).

3.2.1.3. PM_7

Particulate matter (PM_7), like PM 10, also showed varying concentrations and distribution in the air shed. The low concentration at the University Agricultural farm (18.0) µg/m^3 appears baseline. The Pentagon Estate (21.0-29.0) µg/m^3 was next in low concentration (Table 5). This is a residential estate and higher concentration may be attributed to generator emissions, domestic cooking from homes and vehicular emissions. Le' Meridien Hotel air shed (15.0-76.) µg/m^3 was the site with second high concentration. This is a Government reserved area (GRA) with a road by-pass from the high-way. So apart from emissions from generators that dot homes and the big hotels in the neighborhood, traffic emissions may be another major source contributing to particulate hike in the air shed. Sources of high concentration in the Rivers State University business center (6.0-205.0) with the highest concentration of 205.0 µg/m³ may be due to many factors including: emissions from generators, traffic, biomass burning, charcoal burning to roast plantain/yam, barbecue, stove for those cooking to either warm food or cook afresh, etc. The business complex is a community in itself with myriads of generators at work most of the times. It is a busy neighborhood with beehives of activities of air pollution interest. In all these activities, emissions are released to the air basin. A look at all sites shows that the university business center had the highest PM **7** concentration (6.0-205.0) that exceeded the international World Health Organization standard of 50 µg/m³ (Figure 5). Exceedance observed in the maximum and mean concentrations implies that exceedance will cascade down to the other fractions of PM 2.5 and PM 1. Respirable particulate matter reaching 85 and 205.0.0 µg/m³ in the air basin shows very poor air quality and poses a risk to the inhabitants of these areas (Figure 5). It shows four times higher concentration in GRA than the control while university business community is eleven times higher than the control. The international limit is 50 µg/cm³ which is exceeded in both GRA and the university business complex air shed by a factor of 5 in the case of university business center air basin. The control had 18 µg/m³. Levels of PM 7 reported in this study are far higher than the ones earlier reported by Ubong et al. (2015), where campus PM 7 ranged from 18.0 - 54.0 µg/m³; with the highest obtained from the shopping complex.

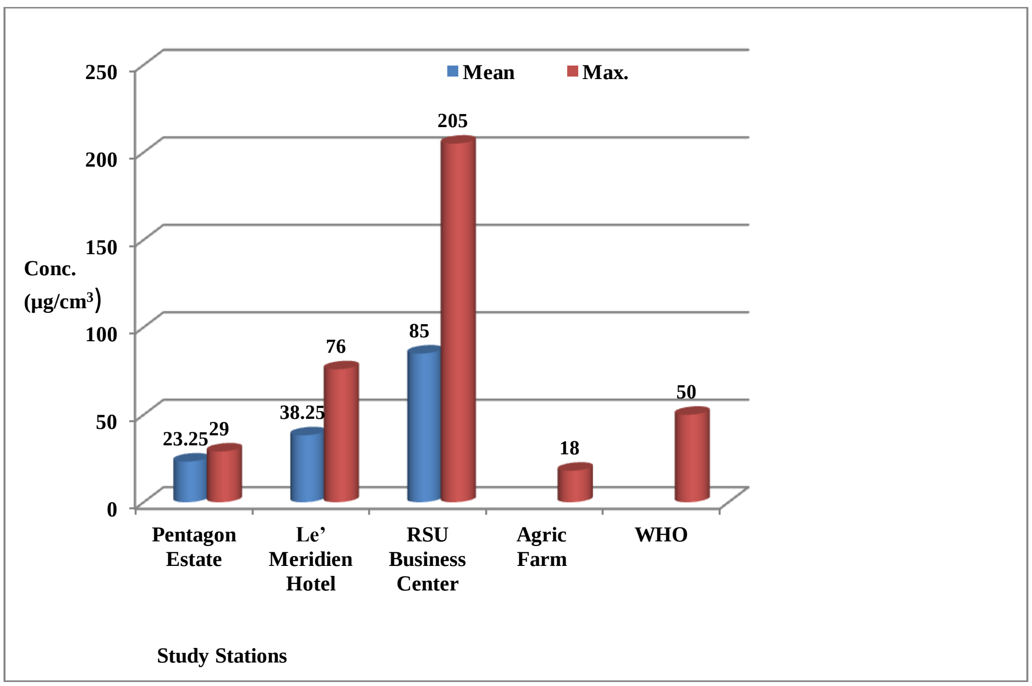

Figure 5. Mean concentrations of PM_7 in all study Stations

3.2.1.4. PM 2.5

The particulate matter, PM **2.5**, like others, had varying concentrations and distribution in the air shed. The low concentration at the University Agricultural farm (12.0) µg/m³ appears baseline. There is no significant activity of air pollution interest that could impact the air shed at the farm hence low reading. The Pentagon Estate (11.0-25.0) µg/m³ was next in low concentration. This is a residential estate and higher concentration may be attributed to generator emissions from homes. Le' Meridien Hotel air shed (13.0-64.0) µg/m³ was the site with second high concentration. This is Government reserved area (GRA) with a road by-pass from the high-way. So apart from emissions from generators that dot homes and the big hotels in the neighborhood, traffic emissions may be another major source contributing to particulate hike in the air shed. Sources of high concentration in the Rivers State University business center (4.0-127.0) with the highest concentration of 127.0 µg/m³ may be due to many factors including: emissions from generators, traffic, biomass burning, charcoal burning to roast plantain/yam, stove for those cooking to either warm food or cook afresh, etc (Figure 6).

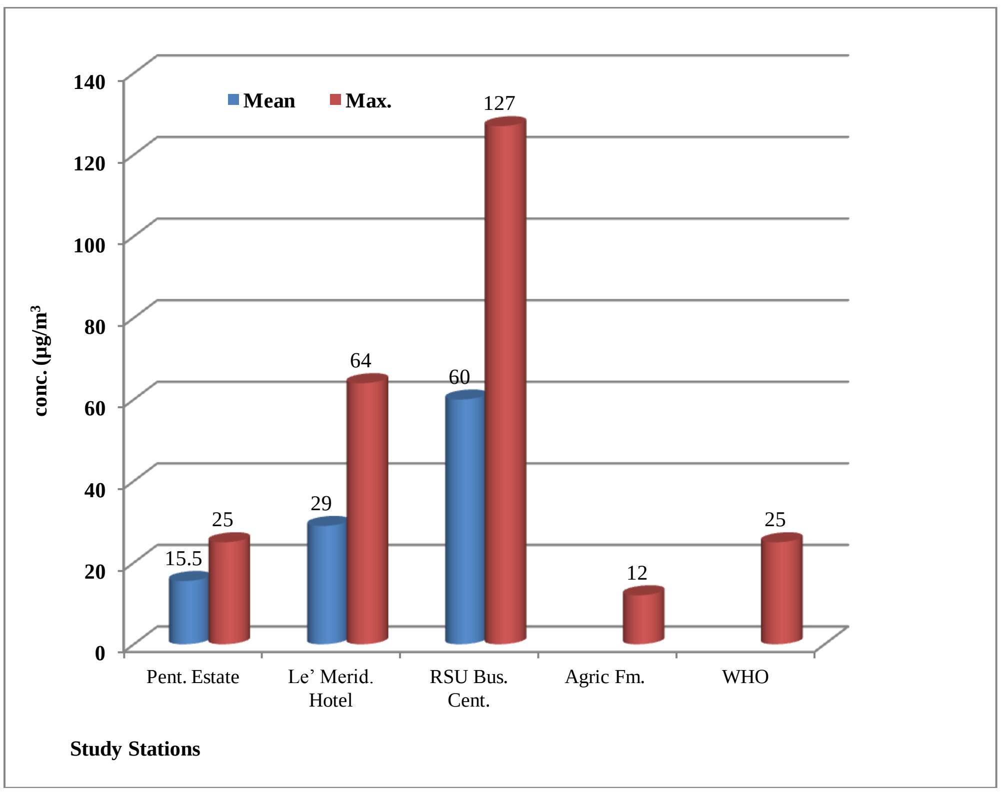

Figure 6. Mean concentrations of $PM_{2.5}$ in all study Stations

The business complex is a community in itself with myriads of generators at work most of the times. It is a busy neighborhood with beehives of activities of air pollution interest. In all these activities, emissions are release to the air basin. A look at all sites shows that the university business center had the highest PM **2.5** concentration (4.0-127.0) that exceeded the international World Health Organization standard of 25 µg/m³

(Figure 6). Exceedance observed in the maximum and mean concentrations implies that exceedance will cascade down to the other fractions of PM 1. Respirable particulate matter reaching 60 and 127.0.0 µg/m^3 in the air basin shows very poor air quality and poses a risk to the inhabitants of these areas (Figure 6). It shows four times higher in GRA than the control while university business community is eleven times higher than the control (12 µg/m^3). The international limit is 50 µg/cm^3**.** This is exceeded in both GRA and the university business complex air shed by a factor of 5, in the case of university business center air basin. The control had 12 µg/m^3. Levels of PM 2.5 reported in this study are far higher than those earlier reported by Ubong et al. (2015), where campus PM 2.5 ranged from 5.0-38.0 µg/m^3. The highest was obtained from the shopping complex.

Ambient particulate matter is responsible for harmful effects on health even in the absence of other air pollutants. Both fine and coarse particles have been shown to affect health in particular the respiratory system.

Fine particles are more dangerous than the coarse particles (Greenfacts, 2017). Apart from the size of the particles, other specific physical, chemical, and biological characteristics that can influence harmful health effects include the presence of metals, polycyclic aromatic hydrocarbons (PAHs), other organic components and certain toxins (Greenfacts, nd). For these study areas, the high concentrations of PM $_{2.5}$ were like raising the flag to show an imminent air pollution problem which is the soot problem now being experienced in the city of Port Harcourt.

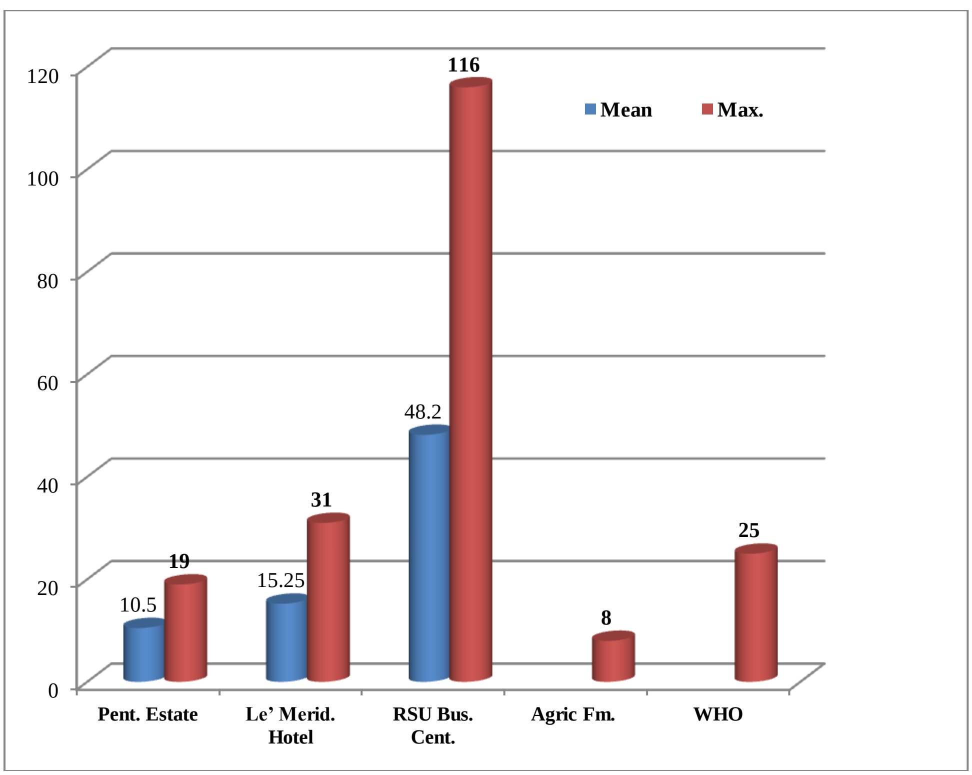

Figure 7. Mean concentrations of PM$_1$ in all study Stations

3.2.1.5. PM_1

The particulate matter, PM_1, like other fractions, showed the non-uniformity of atmospheric composition, with varying concentrations and distribution in the air shed. The low concentration at the University Agricultural farm (8.0) μg/m^3 is baseline. There is no significant activity of air pollution interest that could impact the air shed at the farm hence low reading. The Pentagon Estate (6.0-19.0) μg/m^3 was next in low concentration. This is a residential estate and higher concentration may be attributed to generator emissions from homes. Le' Meridien Hotel air shed (7.0-31.0) μg/m^3 was the site with second high concentration. This is Government reserved area (GRA) with a road by-pass from the high-way. So apart from emissions from generators that dot homes and the big hotels in the neighborhood, traffic emissions may be another major source contributing to particulate hike in the air shed. Sources of high concentration in the Rivers State University business center (2.0-116.0) with the highest concentration of 116.0 μg/m^3 may be due to many factors including: emissions from generators, traffic, biomass burning, charcoal burning to roast plantain/yam, stove for those cooking to either warm food or cook afresh, etc (Figure 7). The business complex is a community in itself with myriads of generators at work most of the times. It is a busy neighborhood with beehives of activities of air pollution interest. In all these activities, emissions are released to the air basin. A look at all sites shows that the university business center had the highest PM **1** concentration (2.0-116.0) that exceeded the international World Health Organization standard of 25 μg/m^3 (Figure7). Respirable particulate matter reaching 48.2 and 116.0.0 μg/m^3 in the air basin shows very poor air quality and poses a risk to the inhabitants of these areas (Figure 7). It shows four times higher in GRA than the control while university business community is eleven times higher than the control (8 μg/m^3). The international limit is 25 μg/cm^3 which is exceeded in both GRA and the university business complex air shed by a factor of 5 in the case of university business center air basin. The control had 8 μg/m^3. Levels of PM 1 reported in this study are far higher than the ones earlier reported by Ubong et al. (2015), where campus PM 1 ranged from <1.0 - 15.0 μg/m^3; with the highest obtained from the shopping complex. These are particulate matter in the fine and ultra-fine particulate mode or category. This constitutes the soot and the soiling effect of air quality in Port Harcourt air basin.

3.2.1.6. $PM_{2.5}/PM_{10}$ Ratios (0.16 – 0.67)

From Table 5, all sites had values much below the lower range observed for developing countries (0.5 - 0.8) (WHO, 2005). In Port Harcourt, the range can be rewritten in the form of 0.3 - 0.7. This means that $PM_{2.5}$ in the air basin ranges from 30 to 70 %. The ratio within the range of 0.5 – 0.8 indicates predominance of PM 2.5 fraction whereas ratio below the range implies predominance of PM 10 fraction. In this study, $PM_{2.5}/PM_{10}$ ratio is given as 0.34 -0.74 which is in agreement with previously reported ratio of (0.16 – 0.67) by Ubong et al. (2015). This means much of the particulate fraction is in the size range of $PM_{2.5}$ hence the soot problem in Port Harcourt City. $PM_{2.5}$ dominated the air basin at 69.2 % (9) of the sites studied while PM 10 dominated 30.8 % (4) of the sites. This means that the predominant fraction is $PM_{2.5}$. The concern for PM **2.5** stems from the fact that these smaller particles are responsible for the most adverse health effects of particulate because of their ability to reach the thoracic or lower regions of the respiratory tract (USEPA, (1990).

3.2.2. Isopleths mapping

Ranges of concentrations of SPM and PM $_{10}$ were plotted being superimposed on the map using their geographical coordinates as shown in Figures 3 and 4. Concentrations of similar locations can be read off from the plots if their coordinates are known.

3.2.3. Meteorology and noise

The range of temperature observed was similar, low and within the range reported for the study area. The low values for temperature will decrease the dispersion potential, mixing and transport of air pollutants. Similarly, the high Relative Humidity does not support the dispersion of air pollutants as well. The wind speed indicated that it was a period of calm which slowed down the dispersion of air pollutants. Hence the high concentrations of particulates measured at various sampling sites. The wind was predominantly southerly (Tables 6 &7). Noise in the study locations was above 45 db (outdoor value for dwelling) whereas dwelling indoor is 35db and school outdoor is 55 db, commercial shopping and traffic areas, indoors and outdoors is 70db (WHO, 1999). The noise exceedance in the Petangon estate and Le' Meridien, all residential areas, may be due to generator noise, vehicular sources, music, etc. That of the university business center is also attributed to a number of factors including myriads of generators in use, vehicular sources, noise of students talking, music, etc. This was also exceeded. The university farm was the only environ that had noise below the guideline value. This corroborated earlier finding reported by Ubong et al. (2016), where campus noise ranged from 67.7 – 75.6 db with a mean of 70.61db. The highest came from the shopping complex.

4. Conclusion

The Shopping Complex air shed had the highest concentration of Particulate Matter of all fractions (PM1 - 10 and TSP); which exceeded allowable limits; However, PM **2.5**, PM**7** & PM **10** showed exceedances over internationally allowable WHO limits. The PM 2.5/ PM 10 ratio showed that 69.2% of the data had particulate matter in the size fractions of PM $_{\mathbf{2.5}}$ microns (soot) whereas 30.8 % of sites showed dominance of the size fractions of PM $_{\mathbf{10}}$ microns. Much work still needs to be done in the area of particulate composition, PAHs and metal determinations.

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