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Spatial and Seasonal Influence of Meteorological Parameters on the concentration of Suspended Particulate Matter in an industrial city of Port Harcourt, Nigeria.

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Abstract

Air pollution has been the primary environmental problem in Port Harcourt due to the heavy industrial foundations which are related to the oil and gas industries. This paper examines the spatial and seasonal influence of meteorological parameter on the concentrations of suspended particulate matter 10micron (SPM). Sampling was performed at six different landuse areas with the aid of multi-gas sampler and digital hand held weather tracker during the wet, transition and dry seasons from 2010 to 2011 on the bases of 24-hour continuous measurements. The spatial distribution shows that a comparatively higher concentration of PM_{10} was found at the high density residential and industrial areas which are in the southeastern part of Port Harcourt downwind. The relationship between air pollution and the meteorological factors showed that, air temperature and wind speed accounted for 13.2% and 22% variation in the concentration of PM_{10} at the industrial and high density residential areas during the dry and wet season respectively. The study revealed that there is a weak level relationship between meteorological factors and particulate matter concentrations leading to its enhanced concentrations in Port Harcourt city. The temporal distribution shows a decrease in ambient concentration of PM_{10} from the dry, transition to wet season mainly due to decrease in the values of the meteorological parameters. There is need to put in place policy measures aimed that controlling air pollutant concentrations.

Keyword: meteorological parameters, air pollutant, landuse, particulate matter concentration, industrial city.

1. Introduction

Particulate matter encompasses the small solid or liquid substances that are released into the atmosphere through many activities. For instance, nearly all industrial processes, as well as the burning of fossil fuels, release particulate matter into the atmosphere (Varney and McCormack, 1971, Smith, 1975, Miller, 1994 and Botkin and Keller, 1998). Botkin and Keller (1998) stressed that much particulate matter is easily visible as smoke, soot or dust, and other particulate matter is not easily visible. Included within particulate materials are constituents such as airborne asbestos particles and small particles of heavy metals such as arsenic, copper, lead, and zinc, which are typically emitted from industrial facilities such as smelters.

It was observed that about 10% of the mass of all pollutants is emitted as particles and liquids compared with 90% from gaseous compounds (Miller, 1994 and Botkin and Keller, 1998). Particulate matter embraces a wide range of solid and liquid particles extending from more than 10m in diameter (Varney and McCormack, 1971). Most of the smaller particles, approximately 10µm or less in diameter, are of smoke and are produced by incomplete combustion of fossil fuel (Smith, 1975). Miller (1994) however differs in his explanation. He asserts that suspended particles (oil smoke, 0.8 – 1µm), combustion nuclei (0.01 – 0.1µm), photochemical smog (0.01 - 4µm), metallurgical dust and fumes (0.001 - 100µm), cement dust (0.6 - 100µm) and coal dust (1 - 100µm etc) are found in a wide variety of types and sizes (as indicated above). Smaller particles are more properly referred to as 'aerosols' and exist in the urban tropospheric area for perhaps a week before breaking up and, if introduced into the less turbulent conditions of the stratosphere, this type of particle may persist for years (Junge and Werby, 1985 and Mamane *et al.*, 1982).

Ambient aerosol composition is one of the most noticeable nuisances in polluted urban regions that need to be monitored, but only a few studies have been reported in literature (Yaalon and Ganor, 1979; Mamane et al., 1982 and, Pope et al., 1995). The neglect over the years may be because their measurements are considered to be erratic, selective, non-predictable and usually not replicable (Giever, 1976 and Pope et al., 1995). Giever, (1976) and Pope et al., (1995) therefore called for the regular monitoring and analysis of aerosol in cities to enhance effective information necessary for urban planning and management (United States Global Change Research Programme [USGCRP], 2002). Aerosols are good precursors of condensation nuclei that can lead to heavy downpours, which may result in destructive urban floods.

The urban environments of Nigeria are characterized with increased particulate matter (PM10). Most commuters and urban dwellers are constantly exposed to the hazard of particulate matter, most especially motorbike (Okada) and tri-cycle (keke) riders and their passengers, and those who live close to the traffic clogged areas. Thus, urban inhabitants are typically plagued by a series of complaints including eye irritations and respiratory problems. To cope with this hazard, most commuters now resort to covering their nostrils and mouth with handkerchiefs at major junctions; and some drivers wind up their car windows in these areas. The effects of particulate matter on vertebrate animals include impairment of the respiratory system, damage to eyes, teeth, and bones, increased susceptibility to disease, pests or other stress – related environmental hazards, and reduced ability to reproduce (Injuk et al., 1995; Pope et al., 1995; and Blake and Rowland, 1995). Similarly, other effects of suspended particles have been noted (see Smith, 1975; Botkin and Keller, 1998 and Efe, 2005). For instance, (Miller, 1994) stressed that suspended particles aggravate bronchitis and asthma. Particulate matter associated with large construction projects may kill organisms and damage large areas, changing species composition, altering food chains and generally affecting the ecosystem (Botkin and Keller, 1994). It should be noted that these problems are not unique to Nigerian cities. In London, United Kingdom during 1952, atmospheric pollution and smog resulted in between 3,000 and 4,000 deaths; caused 20,000 other inhabitants to be sick, and shortened the lives of thousands more (Botkin and Keller, 1994 and Efe, 2005 and 2006).

Various studies however, have been carried out to establish the linkage between air pollution and weather pattern and/or meteorological parameters in different parts of the world. For example studies completed in Donora (Harold et, al, 1949), Nashville (Turner, 1961), Stockholm (Bringfielt, 1971), Bangi, Malaysia (Sani, 1987), California (Chow et al, 1998), Turkey (Tayanc, 2000), Ahmedabad, India (Lal et al, 2005), Hongs Kong (Chan et al, 1997; Chan and Kwok, 2000), and Phoenix, AZ (Ellis et al, 1999, 2000), demonstrate some linkage between different meteorological factors and air pollution. Among the meteorological parameters, wind speed can be effective in decreasing pollutant concentration.

In Nigeria, the effect of particulate matter on human health has been noted by several scholars, for instance Ossai *et al.*, (1999), Okecha (2000) and Efe (2005) asserted that high rates of respiratory diseases occasioned by increased PM_{10} concentrations were experienced by residents of most urban areas, but the relationship between meteorological parameters and the concentration of particulate matter has not been given due attention in the industrial city of Port Harcourt. This is the gap which this paper intends to fill in the study area.

2. Methodology

Air quality was measured in the stations stated below reflecting the major and different land use types in the city. The eTrex Venture Garmin GPS which display transect movements: waypoints, latitude and longitude grids was used to determine the X and Y coordinates of selected monitoring sites .The Kestel 400 version 3.00; hand held weather tracker was used to obtain the elevation above mean sea level of each sample station. The X, Y coordinates and the elevation (Z) data was used to produce a map showing area of equal concentrations of pollutants in the city (an Isopleths). The collection of air quality and meteorological data for this study commenced from 2nd August to 18th September, 2010 reflecting the wet season; transition period of October 4th to November 20th, 2010 and dry season period of January 3rd to February 19th 2011. The choice of these seasons is based on rainfall distribution of Port Harcourt. This covered about 126 days (42 days each of the three seasons). The transition period of rainfall represents the period when rainfall begins to recede giving way to the dry season. It is also a period between the wet season and the dry season. These steps were taken in order to capture the fluctuations in PM_{10} concentrations in all the stations for all the seasons. In order to select the sample points which will serve as air quality monitoring stations, a land use map of the study area with the scale 1:1,000 was gridded 500m x 500m. All the squares were coded in their respective land use type and selection was made without replacement to obtain two monitoring stations representing a specific landuse to obtain twelve stations of the five major land use types in the city of Port Harcourt. A Met One Instrument, Inc. Aerosol Mass Monitor Mode GT-321 was used to measure the concentration of PM10. This Ambient Particulate was collected and recorded as “real-time” information on airborne particulate concentration in addition to providing continuous particle monitoring. A laser optical sensor for detecting and measuring particulate concentrations up to 1 milligram per cubic meter was included. A waterproof enclosure contains the laser sensor, flow system and digital recorder. Other features include an 8 x 40 character LCD, password protection and automatic alarms that alert one to hazardous conditions. This portable mass monitor is ideal for filter testing, work place monitoring emissions sampling and air quality surveys. The monitor uses light scatter to measure individual particles instead of clouds like other monitors. At each station, the following parameters were recorded: Exact location using GPS, rainfall, air temperature, humidity, wind speed, prevailing wind direction. Specifically, at the industrial land use areas sampling was taken at a height of 10m, in opens land clear of any localized emissions, e.g. from stacks, flares or vents. This is because pollutants are released in three layer, the primary, secondary and tertiary layers. At industrial areas, it becomes pertinent to capture pollutants at the secondary layer at a height of 10m. Sampling and determinations of the various parameters in other landuse areas was obtained at a height of 2m.

The table1 below shows areas which constitute the major land use areas and their co-ordinates where monitoring station was cited in order to achieve the objectives of the study.

Table 1: Monitoring stations and their coordinates.

Landuse	Stations	Latitudes (^{0}N)	Longitudes (^{0}E)
Industrial	Eleme	$4^0\,47^1\,29.6^{11}$	$7^0\,6^1\,46.3^{11}$
	Trans-Amadi	$4^0\,48^1\,18.7^{11}$	$7^0\,1^1\,51.8^{11}$
High density residential (HDR)	Diobu	$4^0\,47^1\,32.8^{11}$	$6^0\,59^1\,23^{11}$
	Rumuagholu	$4^0\,52^1\,25.3^{11}$	$6^0\,59^1\,15.2^{11}$
Low density residential (LDR)	GRA	$4^0\,48^1\,26.3^{11}$	$6^0\,59^1\,52^{11}$
	Abuloma housing estate	$4^0\,46^1\,56.5^{11}$	$7^0\,2^1\,46.7^{11}$
Commercial	Mile III Market	$4^0\,48^1\,27.8^{11}$	$6^0\,59^1\,10.6^{11}$
	Creek road market	$4^0\,45^1\,31^{11}$	$7^0\,1^1\,37.5^{11}$
Transport	PH-Aba exprees way	$4^0\,48^1\,19.2^{11}$	$7^0\,0^1\,31.9^{11}$
	Ikwerre road (Rumuokoro junction)	$4^0\,52^1\,2.1^{11}$	$6^0\,59^1\,50.2^{11}$
	PH Int'l Airport	$5^0\,0^1\,52.5^{11}$	$6^0\,57^1\,0.9^{11}$
Rural	Aluu	$4^0\,56^1\,9.3^{11}$	$6^0\,56^1\,54.7^{11}$
	Egbelu-akami	$4^0\,50^1\,56.1^{11}$	$6^0\,57^1\,0.3^{11}$

For all the land use types, effort was made to identify the general direction of wind. This is to enable us identify the down-wind and up-wind direction to enhance the quality and reliability of the data that was collected.

3. Result and Discussion of Findings

The regression result of the concentration of PM_{10} and the meteorological variables at the various landuse areas of Port Harcourt was done to unravel the meteorological condition which will enhance significant concentration of the pollutants for all seasons at the specific landuse. The regression model for the concentration of PM_{10} and the meteorological variables was only produced at the transport landuse area during the wet season, while none was produced during the transition and dry seasons. This is because no variation between PM_{10} and the meteorological parameters was observed during the transition and dry season. However, the correlation matrix of PM_{10} and the meteorological variables revealed that during the wet season rainfall (0.093), air temperature, (.134) and relative humidity (0.382) related directly to the concentration of PM_{10}. But only wind speed (-.048) related inversely to the concentration of PM_{10} at the transport areas of the city. Given an r value of 0.382, r^2 value of 0.146 and coefficient of determination value of 14.6% means that jointly, the meteorological variables accounted for 14.6% variation in the concentration of PM_{10} during wet season(as shown in table 2). The regression equation stating the relationship between the meteorological variables and the concentration of PM_{10} for all the landuse types and seasons is showed in table 3. The r^2 statistics further revealed that relative humidity was the only predictor variable determining the concentration of PM_{10} at the transport areas. This is because it was the only meteorological variable that was significant at 95% level (F-cal. 6.821> F-crit.4.08). This result means that though relative humidity was significant but there is a weak relationship between it and PM_{10} concentration at the transport areas of the city. We therefore conclude that high values of PM_{10} concentration prevailed due to low relative humidity, weak wind and low rainfall. This assertion supports the findings of Sanchez-Ccoyllo and Andrede (2002) in Sau Paulo city; Celik and Kadi (2007) in Karabuk city, Turkey.

Table 2: R^2 Statistics for PM_{10} concentration during the wet, transition and dry season

LANDUSE	SEASON	R	R^2	F	P - VALUES	CRITICAL F-VALUES	Variables in the equation	SSE
Transport	Wet	0.382	0.146	6.821	0.013	4.08	PM10/RHUM**	21.56
	Transition	-	-	-	-		-	-
	Dry	-	-	-	-		-	-
Industrial	Wet	-	-	-	-		-	--
	Transition	-	-	-	-		-	-
	Dry	0.362	0.131	6.048	0.018	4.08	PM10/TEMPT	139.83
Commercial	Wet	-	-	-	-		-	-
	Transition	-	-	-	-		-	-
	Dry	-	-	-	-		-	-
High density residential	Wet	0.469	0.220	11.299	0.002	7.31	PM10/WS**	21.35
	Transition	0.398	0.158	7.529	0.009	7.31	PM10/RFALL**	37.33
	Dry	0.323	0.105	4.670	0.037	7.31	PM10/RFALL	49.20
Low density residential	Wet	0.418	0.267	8.460	0.006	7.31	PM10/WS &RHUM**	9.77
	Transition	0.369	0.136	6.293	0.016	4.08	PM10/TEMPT*	39.86
	Dry	0.352	0.124	5.669	0.022	4.08	PM10/RHUM*	55.65
Rural	Wet	-	-	-	-		-	-
	Transition	-	-	-	-		-	-
	Dry	0.428	0.183	8.967	0.005	7.31	PM10/RHUM**	96.02

**Significant at 95%, ** Significant at 99%, - No Variance and /or Pollutant not detected. RHUM-Relative Humidity, WS- Wind Speed, TEMPT-Temperature, RFALL – Rainfall.*

At the industrial area, the regression model (table 3 below) was produced during the dry season only. The correlation matrix values of PM_{10} and the meteorological variables revealed that during the dry season rainfall (0.027), related directly to the concentration of PM_{10}. But, air temperature, (-0.362) relative humidity (-0.160) and wind speed (-0.152) related inversely to the concentration of PM_{10} at the industrial areas of the city. Given an r value of 0.362, r^2 value of 0.131 and coefficient of determination value of 13.1% means that jointly, the meteorological variables accounted for 13.1% variation in the concentration of PM_{10} during dry season. The R^2 statistics revealed that air temperature was the only predictor variable determining the concentration of PM_{10} at the industrial areas of the city. This is because it was the only meteorological variable that was significant at 95% level (F-cal. 6.048 > F-crit.4.08).The study showed that air temperature was significant but had a weak relationship with PM_{10} concentration at the industrial area.

The regression statistics model was produced at the high density residential areas for the wet, transition and dry seasons. The predictive models for the concentration of PM_{10} for all the land use types and seasons are shown in table 3. High values of PM_{10} prevailed because temperature values were relatively low, rainfall was almost absent and wind was calm. These findings are in consonance to studies conducted by Ahrens, (1991), Pepper et al, (1996) and Oren (2001). These studies posit that pollution is poorly dispersed at reduced air temperature levels especially when the atmosphere is calm (low wind speed), clear and stable (low temperature) where turbulent movement of pollution upward is slow or nearly nonexistent. These findings revealed that stagnation of PM_{10} is likely going to occur at the industrial landuse areas during the dry season. This result implies that during the wet season, rainfall amount, wind speed and relative humidity values were very low and therefore enhanced the concentration of PM_{10} rather it was only air temperature whose values were high enough to encourage dispersal, but when it is low, the concentration of PM_{10} will be high, hence an inverse relationship. But during the transition period, air temperature and relative humidity values enhances the concentration of PM_{10} when they are low and disperses the concentration of PM_{10} when they are high. For the dry season, all the metrological variables were low and that made PM_{10} concentration to prevail at the high density residential areas. The r^2 statistics table (table 2) showed that the r values were 0.46, 0.39 and 0.32 for the wet, transition and dry seasons respectively. And the r^2 values also were 0.220, 0.15 and 0.10 for the met, transition, and dry seasons respectively. Given the above R^2 values, the coefficient of determination revealed that meteorological variables accounted 22%, 15.8% and 10.5% of the variation in the concentration of PM_{10} during the wet, transition and dry season respectively.

Table 3: Predictive Model Summary of PM_{10}

MODEL S/N	LANDUSE	PREDICTION MODEL
1	Transport (wet)	$PM_{10\ Conc.} = -91.927 + 0.638_{(RHUM)} + 21.56$
2	Industrial (dry)	$PM_{10\ Conc.} = 1889.110 – 39.714_{(TEMPT)} + 139.82.$
3	High density Residential (Transition)	$PM_{10\ conc.} = 165.837 + 0.561_{(RFALL)} + 37.33$
4	High Density Residential (dry)	$PM_{10\ conc.} = 287.237 + 4.243_{(RFALL)} + 49.20$
5	High Density Residential (wet)	$PM_{10\ conc}. =19.357 + 35.537_{(WS)} + 21.35$
6	Low Density Residential (wet)	$PM_{10\ Conc}. = -13.815 + 0.0436_{(WS)} +0.304_{(RHUM)} +9.32$
7	Low Density Residential (transition)	$PM_{10\ Conc}. = 106.589 + 0.814_{(TEMPT)} + 39.86$
8	Low Density Residential (dry)	$PM_{10\ Conc}. = -56.631 + 5.909_{(RHUM)} + 55.65$
9	Rural (dry)	$PM_{10\ Conc}. = -678.011 + 19.214_{(RHUM)} + 96.02$

Conc. - Concentration

Findings also shows that wind speed, and rainfall with an F-calculated values (11.29 and 7.52) greater than the critical F-value (7.31) respectively was significant at 99% and therefore had significant impacts on levels of PM_{10} concentration during the wet season, and transition periods respectively. But during the dry season, rainfall was the variable that significantly impacted on levels of PM_{10} concentration at 95% significant level (F-cal.4.67 > F-crit.4.08). This result indicates that rainfall was able to scavenge about 22% and 10.5% of PM_{10} during the transition and dry season (see Greenfield, 1957; Kupchella and Hyland 1989, Pepper et al 1996). Wind speed also was responsible for the concentration of PM_{10} during the wet season (see Pepper et al 1996, Oren 2001; Hung et al. 2005; Tsai et al 2004; Chiu et al 2005; Wan-Li, 2001 Rouse and McCutchen 2008). At the low density residential area, regression models were produced for all the seasons. The correlation matrix revealed that during the wet season, rainfall (-0.094), had an inverse correlation with PM_{10} concentration while the correlation values of air temperature (0.040) wind speed (0.418) and relative humidity (0.278) had a direct correlation with PM_{10} concentration. But during the transition period, all the variables correlated directly with the concentration of PM_{10} (rainfall 0.225; air temperature 0.369; wind speed 0.0; relative humidity 0.160). During the dry season, both rainfall (-0.184) and wind speed (-0.190) correlated inversely to the concentration of PM_{10} while air temperature (0.171) and relative humidity (0.352) correlated directly to the PM_{10} concentration. This means that during the wet season, rainfall amount was high and led to the scavenging of more of PM_{10} particulates but wind speed, air temperature and relative humidity values were very low to impact PM_{10} concentration. During the transition period, all the meteorological variables had very low values and therefore aided the concentration of the pollutant (see Hung et al 2005; Tsai et al 2004). During the dry season, rainfall and wind values were high enough to scavenge and disperse PM_{10} respectively in the atmosphere of the low density residential areas of the city. The r^2 statistics table showed that r values were 0.41, 0.36 and 0.35 for the wet, transition and dry seasons respectively. And the r^2 values also were 0.17, 0.13 and 0.12 for the wet, transition and dry seasons respectively. With the r^2 values above, the coefficient of determination revealed that the meteorological variables accounted for 26.7%, 13.6% and 12.4% of the variation in the concentration of PM_{10} during the wet, transition and dry season respectively at the low density residential areas of the city. Result indicates further that wind speed (F-cal 7.08 > F-crit. 5.18), air temperature (F-cal.6.29 > F-crit.4.08) and relative humidity (F-cal.5.66 > F-crit.4.08) were significant at 99%, 95% and 95%. During the wet, transition and dry seasons respectively. This means that wind speed and relative humidity; air temperature; relative humidity levels had significant impact on the concentration of PM_{10} during the wet, transition and dry seasons respectively. At the rural areas, both air temperature (-0.019) and wind speed (-0.108) correlated inversely to the concentration of PM_{10}. This means that the values of wind speed and air temperature were high enough to encourage the dispersal of PM_{10} at the rural areas of Egbelu-Akami and Aluu sampled in this study but rainfall (0.258) and relative humidity (0.428) correlated directly to PM_{10} concentration. This is because, rainfall was almost absent and relative humidity value was very low and therefore enhanced the concentration of PM_{10} at the rural areas during the dry season. Result shows that relative humidity was significant in determining the concentration of PM_{10} at 99% significant level. This is because, in the absence of rainfall, the wind from the Rivers and creeks criss-crossing the entire length and breadth of the city of Port Harcourt blows in more humid air thereby contributing to the concentration of pollutants in the city.

Below are the maps showing the Spatial and seasonal relationship between meteorological parameters and PM_{10} concentration in the city of Port Harcourt.

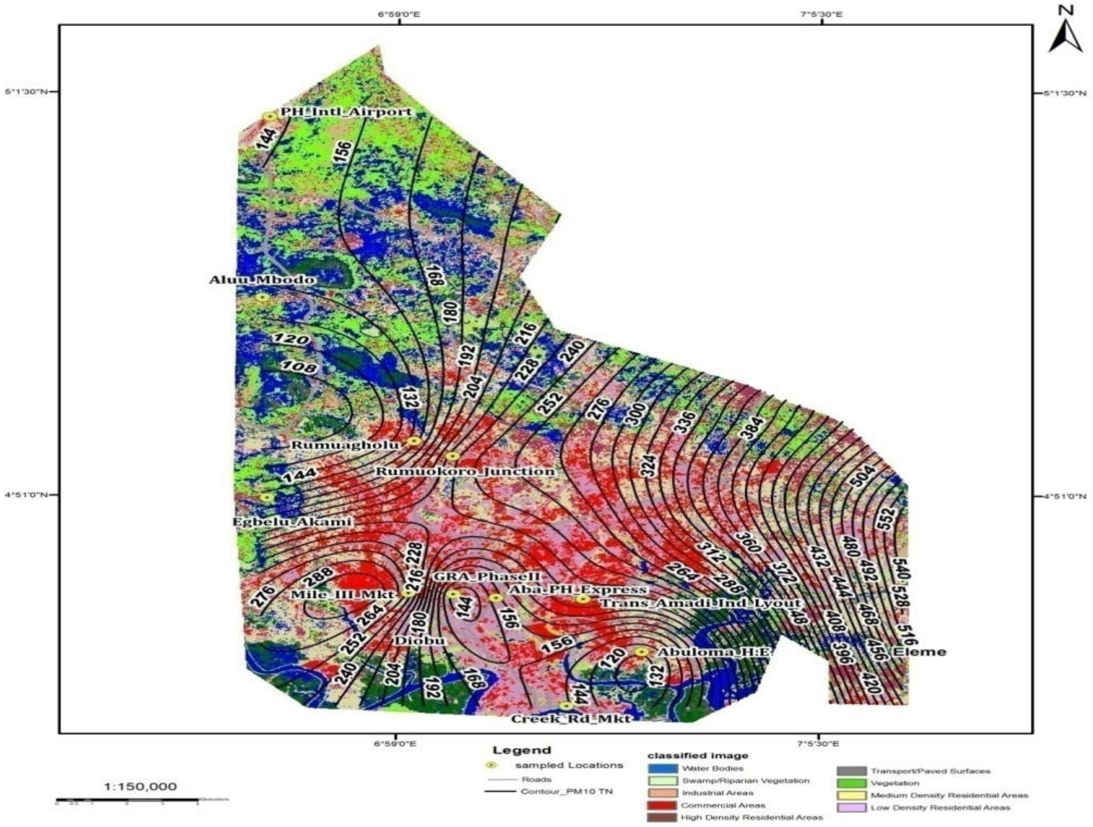

Fig. 1: Particulate matter (10 micron) concentration (in μg/m^3) during transition period (October- November, 2010).

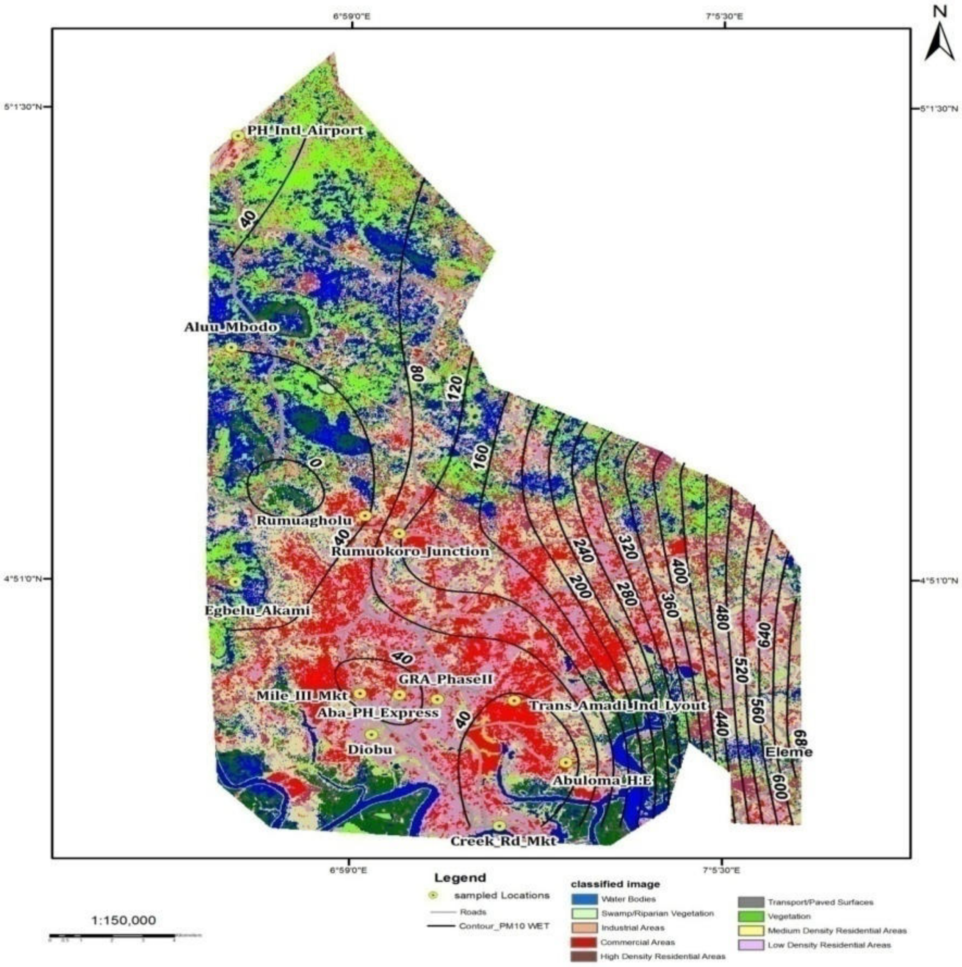

Fig. 2: Particulate Matter (10 micron) concentration (in μg/m^3) during wet season (August-September, 2010).

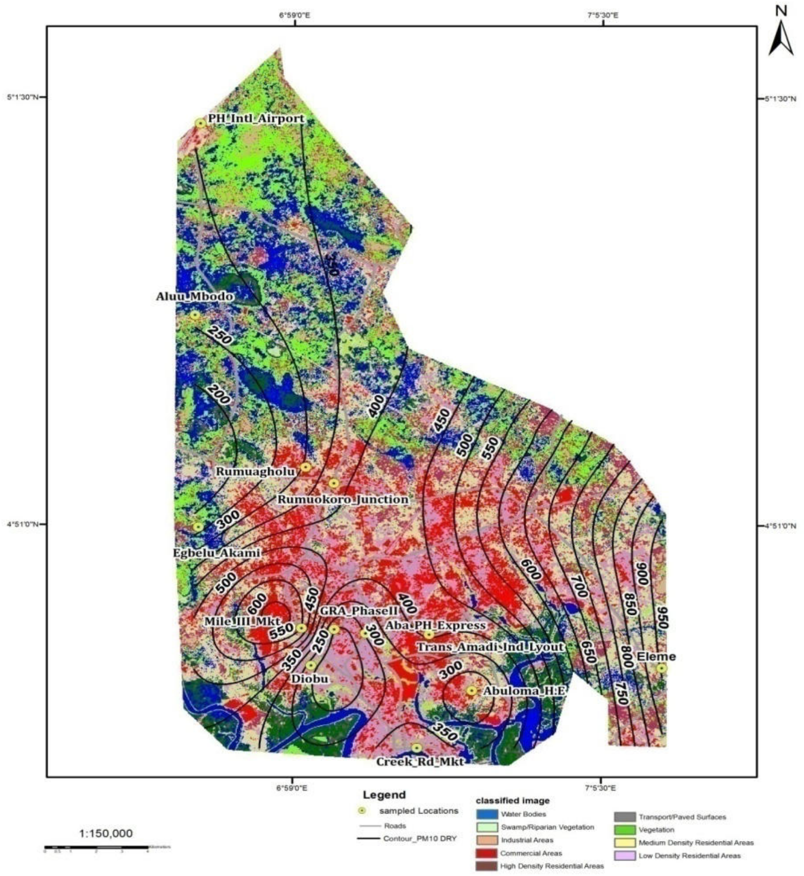

Fig. 3: Particulate Matter (10 micron) concentration (in μg/m^3) during dry season (December, 2010 – January, 2011).

4. Conclusion

The spatial and temporal distribution of PM_{10} concentration in the city of Port Harcourt was found to be dependent on the variation in meteorological variables. However, according to the results obtained from the multiple step-wise regression analysis, there is not a strong relationship between meteorological variables and PM_{10} concentrations in Port Harcourt. Wind speed and relative humidity; air temperature; relative humidity levels had significant impact on the concentration of PM_{10} during the wet, transition and dry seasons respectively across the various landuse areas. During the transition period, all the meteorological variables had very low values and therefore aided the concentration of PM_{10}. But during the dry season, rainfall and wind values were high enough to scavenge and disperse PM_{10} respectively in the atmosphere of the low density residential areas of the city. Similarly, rainfall was also absent and relative humidity value was very low and therefore enhanced the concentration of PM_{10} at the rural areas during the dry season.

The result further showed that during the wet season, rainfall amount was high and led to the scavenging of more of PM_{10} particulates but wind speed, air temperature and relative humidity values were very low to enhance PM_{10} concentration. During the period of investigation, the atmospheric loading of PM_{10} was highest during the dry season, followed by the transition and the wet seasons.

5. Recommendation

There is need for constant monitoring of Particulate matter in the city of Port Harcourt to forestall the potential health challenges arising from the inhalation of the particulate.

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