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Relationship between $PM_{2.5}$ and Climate Variability in Niger Delta, Nigeria

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Abstract Fine particulate matter $PM_{2.5}$ has attracted much attention both scientific and public, due to its effects on human health as meteorological conditions serves as one of the factors that have important effect on $PM_{2.5}$ mass concentration. The study examined the relationship between certain meteorological elements and $PM_{2.5}$ concentration in selected cities of the Niger delta region of Nigeria. Meteorological data were obtained from the Nigerian Meteorological Agency. $PM_{2.5}$ data that was used for this study was Aerosol Optical Depth (AOD), it was acquired from remotely sensed satellite data from National Aeronautics and Space Administration (NASA's) earth observing system data and information system, $PM_{2.5}$ concentration data and meteorological monthly data were obtained from 2001 to 2015 and multiple regression analysis was employed to test the relationship between $PM_{2.5}$ concentration and the meteorological elements (Temperature, Rainfall, Relative Humidity and Wind Speed). The correlation analysis result showed that temperature had a positive correlation, rainfall had a negative correlation and wind speed also had a positive but low correlation. This has an effect on $PM_{2.5}$ concentration because as temperature increases and rainfall decreases with low wind speed, $PM_{2.5}$ concentration increases and this can lead to adverse health effects on human beings.

Keywords: *Niger delta, climate variability, $PM_{2.5}$, multiple regression*

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1. Introduction

Weather and climate elements are steadily changing. Variations in these elements can be day to day for weather, and over seasons and years for climate; this can serve as the main drivers of climate-induced changes in particulate matter (PM). Climate Variability refers to variations in the mean state of the climate on all temporal and spatial scales beyond that of individual events. The time scale could be in months to years [1]. Particulate matter is a complex mixture of anthropogenic, biogenic, and natural materials, suspended as aerosol particles in the atmosphere with major components as sulphate, nitrate, ammonium, organic carbon, elemental carbon, sea salt, and dust [2]. PM is a primary air pollutant and includes all solids and/or liquids suspended in the atmosphere and may or may not be visible as soil particles, soot and lead [3]. $PM_{2.5}$ or respirable particles because they are small enough to be inhaled and have the potential to cause health effect; they penetrates the respiratory system further than larger particles, it is made up of sulphate and nitrate particles, elemental and organic carbon and soil. $PM_{2.5}$ material is primarily formed from chemical reactions in the atmosphere and through fuel combustion (motor vehicles, power generation, industrial facilities, residential fire places, wood stoves and agricultural burning). Exposure to fine PM has been associated with hospital admissions, asthma, cardiovascular or lung disease including premature death.

Many aspects of climate variability have the potentials of influencing PM, air pollution and its implications for environmental management in Niger delta Nigeria over the coming decades. The varying climate may affect PM directly through changing meteorology and circulation patterns, and indirectly by affecting wildfires, dust suspension, biogenic emissions [4]. Changes in human activities and the energy generation mix will also affect PM concentrations, through emissions of PM and its precursors, and also through changes to the natural systems that will alter emissions [4]. Climate variability could affect local to regional air quality directly through changes in chemical reaction rates, boundary layer heights that affect vertical mixing of pollutants, and changes in synoptic airflow pattern that govern pollutant transport [5]. Indirect effects could result from increasing or decreasing anthropogenic emissions via changes in human behavior or from altering the level of biogenic emissions because of higher temperatures and land cover change; higher temperatures can increase emissions of isoprene (a volatile hydrocarbon emitted by many woody plant species).

Air pollution has intensified strongly since the industrial revolution, that is, during the epoch known as the Anthropocene [6]. Ground-level fine PM with a diameter of 2.5 micron has increased substantially, not only in most urbanized and industrialized areas but also in rural and even remote regions [7,8,9]. $PM_{2.5}$ can have serious health impacts by causing cardiovascular and respiratory disease and lung cancer, and especially chronic exposure is associated with morbidity and premature mortality [10,11]. Urban $PM_{2.5}$ exposure is responsible for approximately 712,000 cardiopulmonary disease (CPD) and 62,000 lung cancer deaths in 2000 [12], while anthropogenic $PM_{2.5}$ is associated with 3.5 million CPD and 220,000 lung cancer mortalities annually [9].

In Nigeria, almost the entire country has $PM_{2.5}$ concentration above the WHO guideline of 25µg/m^3 (24 hour mean) and 10µg/m^3 (annual mean) [13] this presents an environmental health burden in relation to potential risk of continuous exposure to dangerous level of $PM_{2.5}$ [3].

[14] applied a multiple linear regression model to understand the relationships of $PM_{2.5}$ with meteorological variables, They found strong positive correlations of $PM_{2.5}$ components with temperature in most of the US.

[15,16,17] investigated the relationship between $PM_{2.5}$ and climate variables and reported that temperature, rainfall, wind speed and relative humidity have a clear influence on $PM_{2.5}$ concentration and distribution; and the effects of increased temperature were an increase in $PM_{2.5}$ concentrations.

The relationship between $PM_{2.5}$ and climate variables leads to the prevailing increase in temperature over the other climate variables confirmed that $PM_{2.5}$ was rather uncomfortable at certain times of the year (dry season), and that temperature mostly influenced the formation of $PM_{2.5}$ while wind speed also influenced the transportation of winds. People with prolonged exposure or activities under this condition are in danger of health hazards. [18] used Statistical Regressions to identify factors influencing $PM_{2.5}$ concentrations in the Pittsburgh supersite as a Case they found that temperature, relative humidity, their squared terms, and their interactions explain much of the variation in airborne concentrations of $PM_{2.5}$ in the city. [19] investigated the influence of present climate on $PM_{2.5}$ concentrations over Europe by representing it using a weather regimes/types approach. They started by exploring the relationships between classical weather regimes, meteorological variables and $PM_{2.5}$ concentrations over five stations in Europe, using the EMEP air quality database. The pressure at sea level was used in the classification as it effectively describes the atmospheric circulation. The result showed that rain rate is the variable that impacts $PM_{2.5}$ concentrations the most.

2. Study Area

The study area is the Niger Delta region of Nigeria with latitude 4.05°N to 7.55°N and longitude 4.20°E to 9.30°E (Figure 1). The area around this coastline is interrupted by series of distributaries that form the Niger Delta swamp at the middle where the lower Niger River system drains the waters of Rivers Niger and Benue into the Atlantic Ocean. This delicate mangrove swamp of the Niger Delta covers a coastline of over 450km, about two-thirds of the entire coastline of Nigeria and the wetland in this region is traversed and criss-crossed by a large number of rivers, rivulets, streams, canals and creeks. The Niger Delta is a rich mangrove swamp in the southernmost part of Nigeria within the wetlands of 70,000km² formed primarily by sediment deposition. It is the largest mangrove swamp and wetland in Africa, maintaining the third largest drainage basin in the continent, and is also the third largest wetland in the world after Holland and Mississippi [20].

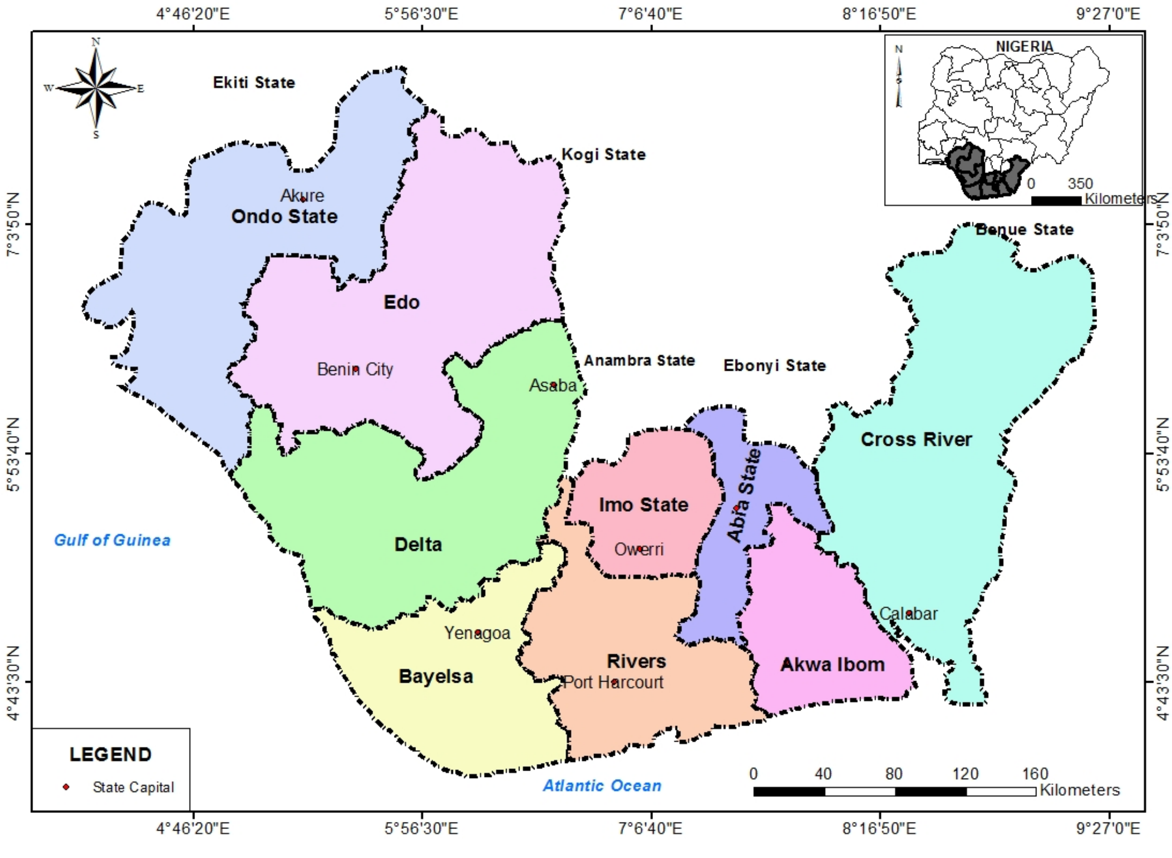

Figure 1. Niger Delta Region showing States and their Capital Cities

2.1. Climate

The Niger delta lies mainly in the wet equatorial climate region (Koppen's A_f climate) but in the northern extremities, the climate is tropical wet-and-dry climate (Koppen's A_w climate). As a result of the nearness of this region to the equator, cloud cover is very high, sunshine hours are low and the air is damp for most of the year due to the very high relative humidity of the air. The climate of the Niger delta is characterized by a long rainy season from March-April through October. Precipitation increases from the north of the delta (with an average of 2,500 millimeters) to the coastal area where mean annual rainfall averages around 4,000 millimeters (mm), making it one of the wettest areas in Africa. The wet season peaks in July, and the only dry months are January and February. However, even during this dry period an average monthly mean of 150 mm rainfall is recorded. Relative humidity rarely dips below 60% and fluctuates between 90% and 100% for most of the year. During most of the rainy season cloud cover is nearly continuous resulting in 1,500 mean annual sunshine hours and an average annual temperature of approximately 28°C. The most important determinant of biological variation in the delta is its hydrology. In addition to precipitation, the major variation in the hydrological regime comes from the Atlantic Ocean's tidal movements and the Niger River flood. This flood begins toward the end of the rainy season in August, peaks in October, and tapers off in December. Some fluctuation in flow is determined by the yearly variation in rainfall, but after the completion of the Kainji dam on the Niger at Bussa in 1968 the timing and level of flooding is also determined by the opening and closing of the dam's sluices [21].

2.2. Land Use

The Niger delta is resource-rich and abundantly blessed with expanse of agricultural/aquatic resources and vast reserves of petroleum hydrocarbon [22]. Most of Nigeria's more than 600 oil fields are in the Niger delta (60% onshore), with a proven oil reserve of over 35 billion barrels and production rate of 2.5 million barrels a day [23]. Over time, this region has played important roles in the global economy (through palm oil trade and now fossil fuels export) and documented human economic activities in the Niger delta dates back to more than a century [24]. At the lowest levels of society, inhabitants of this region eke out their living by subsistent harvesting of natural resources (fishes, forest products, backyard farms). At higher levels, resource-exploitation takes the form of profiteering and range from profitable plantation farming to petroleum hydrocarbon exploitation.

3. Materials and Method

3.1. Climate Data

The data for climatic variables was obtained from the Nigerian Meteorological Agency (NIMET), Oshodi, Lagos which is the sole custodian of climate data of Nigeria. The climate data that was used for this study are Air Temperature, Rainfall, Relative Humidity and Wind Speed from 2001 to 2015. The choice of these climatic variables that were used as drivers was based on their importance and effectiveness in the formation, concentration, transportation and variability of particulate matters.

3.2. $PM_{2.5}$ Data

The type of $PM_{2.5}$ data that was used for this study was Aerosol Optical Depth (AOD), it is raster in nature, this dataset was acquired from remotely sensed satellite data from National Aeronautics and Space Administration (NASA's) earth observing system data and information system, this dataset was used because it is readily available and has global coverage. This dataset represents latest advances in the field of remote sensing and environmental modeling. Data for the study area was derived from this dataset and MODIS sensor, located on the Terra and Aqua satellite platforms, which has 36 spectral channels. This MODIS instrument onboard the NASA's Terra satellite global observations of AOD, is a measure of light extinction by aerosol in the atmospheric column above the earth's surface. AOD reflects aerosol optical extinction of the total column; High AOD values imply very high levels of air pollution and associated negative impact on human health, while low AOD values represent good air quality [25]. MODIS is a multi-spectral radiometer, designed for the retrieval of aerosol microphysical and optical properties over land and ocean, it was also designed to provide a wide variety of information about land, ocean and atmospheric conditions, MODIS has good spatial and temporal resolutions; it has a large number of spectral bands and has the ability to use this spectral information to derive biogeophysical results. Other data required were obtained from journals, textbooks and other relevant literatures.

The Satellite $PM_{2.5}$ data that was used for this study is a new technology; this dataset provides higher accuracy, longer temporal range and higher resolution. The data was from collection 6 and it is level 2 Aqua Terra MODIS collected at 5 minutes interval daily, this was averaged to obtain monthly averages for each year. The global annual average $PM_{2.5}$ gridded datasets from MODIS from 2001-2015 was downloaded from SEDAC, the $PM_{2.5}$ that was used for the study was a finer resolution of 3km because the study is on a regional scale not on a global scale but both algorithms are similar. A Python script was written to extract the monthly averages across the study area over the years after downloading the data.

The [26] formular ($PM_{2.5}$ = n * AOD) was used to derive the $PM_{2.5}$, so we divided the satellite derived AOD by the SEDAC $PM_{2.5}$ values which gave us n (conversion factor). To get a long term average we computed 10 year mean and used the value to compute the $PM_{2.5}$ for the study area. The Niger Delta annual average $PM_{2.5}$ gridded datasets for the period 2001-2015 were extracted by ArcGIS software and were transformed to the same coordinate system as the meteorological datasets. ArcGIS 10.2 software was preferred for this analysis because of its versatility, functionality in the sense that it has some extensions that are operational which are not found in ArcGIS 9 versions, its inter operationality which means it can accept data from other softwares like Ms Access and Ms Excel (Data Integration) and its robustness.

Multiple regression analysis was used to model the relationship between $PM_{2.5}$ and the four climatic variables. This was used to quantify the relationship between climatic variables and $PM_{2.5}$ across the selected cities of the Niger Delta which was concerned with measuring the effect of numerous independent variables on a single dependent variable. Multiple Regression analysis was used for this study to know the influence of temperature, wind speed, rainfall and relative humidity on $PM_{2.5}$ to see which of these parameters relate more with or have more influence on $PM_{2.5}$ concentration and then possible autocorrelation.

$$Y = a + b_1 X_1 + b_2 X_2 + b_3 X_3 + b_n X_n + e \qquad (1)$$

a = Intercept on Y- axis
b_1, b_2, b_3…...bn = the regression coefficients of independent variables.
X_1 X_2 X_3…...X_n = the independent variables
Where: X_1 = Temperature, X2 = Precipitation, X_3 = Relative Humidity, X4 = Wind Speed.
e = the residual or random error term.

4. Results and Discussion

It has been shown in Table 1 that across the cities of the Niger Delta from 2001-2015, the mean Temperature is 27.5°C, mean Rainfall is 123.5mm, mean Relative Humidity is 78.6% and Wind Speed is 3.5m/s, also it was identified that rainfall has the highest mean (123.526mm)/standard error (4.198), standard deviation (119.780) and variance (14347.228).

The coefficients were used to write regression equations for each models as follows:

Model 1: Y = a + bT; where T= Temperature

When the expected Temperature value is 27.461, then the expected $PM_{2.5}$ is

$$Y = -59.76 + 2.83(27.461)$$
$$Y = -59.76 + 77.46$$
$$Y = 17.95.$$

Also, if the expected Temperature value is 30, then the expected $PM_{2.5}$ is

$$Y = -59.76 + 2.83(30)$$
$$Y = -59.76 + 84.9$$
$$Y = 25.14.$$

Model 1 showed that as temperature increases, $PM_{2.5}$ concentration increases across the cities of the Niger delta. Temperature has a high influence on the concentration of $PM_{2.5}$ across the cities Niger delta.

Model 2: Y = a + bT + cR; where T=Temperature, R= Rainfall. When the expected Temperature and Rainfall values are 27.461 and 123.526 respectively. Then the expected $PM_{2.5}$ is:

$$Y = -37.67 + 2.12(27.461) + -0.02(123.526)$$
$$Y = -37.67 + 58.22 - 2.47$$
$$Y = -37.67 + 55.75$$
$$Y = 18.08.$$

Model 2 showed that rainfall had a minimal influence on $PM_{2.5}$ concentration; therefore, an increase in temperature with a decrease in rainfall increases $PM_{2.5}$ concentration.

Model 3: Y = a + bT + cR + dW.; where T= Temperature, R= Rainfall, and W= Wind speed. When the expected Temperature, Rainfall and Wind Speed values are 27.46, 123.526 and 3.518 respectively. Then the expected $PM_{2.5}$ is

$$Y = -36.36 + 1.92(27.46) + -0.02(123.526) + 1.15(3.518)$$
$$Y = -36.36 + 52.723 - 2.47 + 4.046$$
$$Y = -36.36 + 54.299$$
$$Y = 17.94.$$

Model 3 showed that an increase in temperature increases $PM_{2.5}$ concentration, a decrease in rainfall increases $PM_{2.5}$ concentration and an increase in wind speed increases $PM_{2.5}$ concentration. This confirmed that temperature is most significant in $PM_{2.5}$ concentration.

Table 1. Summary Statistics of the Parameters used for the Analysis

Parameters	N	Minimum	Maximum	Mean (Std. Error)	Std. Deviation	Variance	Skewness (Std. Error)	Kurtosis (Std.Error)
Mean Temperature	829	24.00	33.4	27.461 (0.043)	1.239	1.535	0.126 (0.085)	0.471 (0.170)
Mean Rainfall	814	0.00	539.80	123.526 (4.198)	119.780	14347.228	1.051 (0.086)	0.451 (0.171)
Mean R/Humidity	829	40.00	98.00	78.578 (0.286)	8.245	67.971	-1.499 (0.085)	2.882 (0.170)
Mean W/Speed	829	1.10	8.40	3.518 (0.034)	0.990	0.980	0.643 (0.085)	1.600 (0.170)
MEAN PM25	937	1.55	120.12	18.370 (0.414)	12.681	160.808	2.539 (0.080)	11.976 (0.160)

Table 2. R Square Value for the Three Models Identified by Stepwise Techniques

	R	R Square	Adjusted R-Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change
1	.283[a]	.080	.079	11.893	.080	70.853	1	812	.000
2	.343[b]	.118	.116	11.655	.038	34.568	1	811	.000
3	.355[c]	.126	.123	11.608	.008	7.470	1	810	.006

5. Conclusion

The increase in rate of $PM_{2.5}$ concentration and high temperature had its attending effect on both the environment and the health of residents thereby causing hospital admissions, asthma, cardiovascular or lung disease including premature death. People with asthma, cardiovascular or lung disease, as well as children and elderly people, are considered to be the most sensitive to the effects of fine (PM).

The general air temperature and $PM_{2.5}$ concentration confirmed that Niger delta region is rather uncomfortable at certain times of the year, and people in this region will be in danger of hospital admissions, asthma, cardiovascular or lung disease including premature death with prolonged exposure or activity under this condition. Adequate space management and planning is therefore sure for averting $PM_{2.5}$ related disasters in the cities. This is particularly important as the issues of global warming are at the front burner of environmental sustainability.

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