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Modeling the Distribution of $PM_{2.5}$ Concentration from 2001-2015 Using Satellite Based Measurement across the Cities of Niger Delta Region, 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. This study used remotely sensed $PM_{2.5}$ to model the the distribution of $PM_{2.5}$ concentration across the cities of Niger delta region of Nigeria using satellite based measurement. $PM_{2.5}$ 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 were obtained from 2001 to 2015 and the boundaries for the cities were created and then the annual average $PM_{2.5}$ distribution for each city from 2001-2015 were calculated. The calculation showed that $PM_{2.5}$ concentration in the Niger delta varied from city to city, and that $PM_{2.5}$ is significantly highest in Yenagoa with 23.29 (µg/m^3), this confirmed Yenagoa having the highest concentration of $PM_{2.5}$, followed by Calabar23.241(µg/m^3)and the lowest $PM_{2.5}$ concentration was Akure15.299(µg/m^3) across the cities of the Niger delta. This means that there is a wide variation in $PM_{2.5}$ concentration over the years across the cities. The effect of $PM_{2.5}$ concentration is higher inYenagoa, and all the state capitals have annual mean values of $PM_{2.5}$ above the WHO guideline value of 10µg/m. $PM_{2.5}$ concentration is increasing with years especially as a result of the illegal refining activities, gas and oil pipeline bombing and gas flaring activities, this implies that $PM_{2.5}$ concentration will continue to increase as long as these activities continues in the Niger Delta region of Nigeria. This situation can lead to adverse health and environmental health effects on human beings with continuous exposure.*

Keywords: *$PM_{2.5}$concentration, cities, satellite platform, Aerosol Optical Depth, Niger delta.*

1. INTRODUCTION

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 (John, Bryan, Darrel, & Christopher, 2014). 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 (Lawal&Asimiea, 2015). It is a mixture with physical and chemical characteristics varying by location. Common chemical constituents of PM includes sulphates, nitrates, ammonium, other inorganic ions such as ions of sodium, potassium, calcium, magnesium and chloride, organic and elemental carbon, crustal material, particle-bound water, metals (including cadmium, copper, nickel, vanadium and zinc) and polycyclic aromatic hydrocarbons (PAH)(WHO, 2013).

There are many sources of PM, they can originate from natural processes, like forest fires, wind erosion, and from human activities like agricultural practices, smoke stacks, car emissions and construction for example, including dust, dirt, soot, soil, and smoke.Airborne (PM) is considered as carcinogenic to humans (WHO, 2013). Particulates are the deadliest form of air pollution due to their ability to penetrate deep into the lungs and blood stream unfiltered causing permanent Deoxyribonucleic acid (DNA) mutations, heart attacks and premature death. The composition of PM varies with place, season and weather conditions.

Particulates that are of particular concern is a class of particles known as fine PM that is 2.5 microns in diameter and less known as $PM_{2.5}$ 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. 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). Adverse health effects have been associated with exposure to $PM_{2.5}$ over both short periods (such as a day) and longer periods (a year or more). It is also responsible for environmental effects such as corrosion, soiling, and damage to vegetation and reduced visibility. The rate at which $PM_{2.5}$is increasing in Niger delta is alarming especially with the increase in oil pipeline bombing and illegal refining of crude oil, this informed the interest of studying the trend or direction in which $PM_{2.5}$concentration is heading.

Air pollution has intensified strongly since the industrial revolution, that is, during the epoch known as the Anthropocene (Crutzen, 2002). 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 (Akimoto, 2003; Schulz *et al*., 2006; Anenberg, Horowitz, Tong & West, 2010). $PM_{2.5}$ 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 (Dockery *et al*., 1993; McDonnell, Nishino-Ishikawa, Petersen, Chan & Abbey, 2000). Urban $PM_{2.5}$ exposure is responsible for approximately 712,000 cardiopulmonary disease (CPD) and 62,000 lung cancer deaths in 2000 (Cohen *et al.,* 2004), while anthropogenic $PM_{2.5}$ is associated with 3.5 million CPD and 220,000 lung cancer mortalities annually (Anenberg*et al.,* 2010). The global fraction of adult mortality attributable to the anthropogenic component of $PM_{2.5}$ is 8.0% for CPD and 12.8% for lung cancer (Evans *et al.,* 2012), the global burden of disease for 2010 indicates that outdoor air pollution in the form of fine particles is a much more significant public health risk than previously assumed (Lim, Vos, Flaxman, Danaei& Shibuya, 2012). In Nigeria, almost the entire country has $PM_{2.5}$ concentration above the WHO guideline of $25\mu g/m^3$ (24 hour mean) and $10\mu g/m^3$ (annual mean) (WHO, 2005) this presents an environmental health burden in relation to potential risk of continuous exposure to dangerous level of $PM_{2.5}$ (Lawal&Asimiea, 2015).

Aziakpono, Ukpebor and Ukpebor (2013) studied baseline spatial and temporal variation of respirable $PM_{2.5}$ particulate matter in Isoko, Nigeria, they used Microdust pro real time dust monitor to quantify airborne PM for a year, and they also used ANOVA to determine the distribution of PM. The result showed that there was uniformity in the distribution of respirable $PM_{2.5}$ at the sampling site. Efe (2008) examined the distribution of ambient particulate PM_{10} pollution and its possible health implications in Nigerian cities. He used a total of 102 high-volume (HV) samplers in 17 Nigerian cities to draw a known volume of ambient air at a constant flow rate through a size selective inlet and through filters for a six-year period (2001-2006). He subjected the data to paired t-test, ANOVA and multiple regression statistical analyses. The results showed that the urban corridors of over 70% of Nigerian cities are sites with a high rate of daily mean/annual mean ambient PM_{10} of over $120\mu g/m^3$, while < 30% of Nigerian urban centres had mean annual ambient PM_{10} value of $119.2\mu g/m^3$. Similarly, significant differences exist in PM_{10} concentrations across different land-use types, between the built-up areas and those of the surrounding rural areas. Lawal&Asimiea (2015) studied the spatial modeling of population at risk and $PM_{2.5}$ exposure index in Nigeria using remotely sensed PM data. The result showed that the entire study area has $PM_{2.5}$ concentration above the WHO guideline and change in $PM_{2.5}$ concentration showed that, around 54% of the study area remains the same, 43% improved and the remaining areas showed reduction. Weli (2014) examined the spatial and seasonal influence of meteorological parameter on the concentrations of suspended particulate matter 10micron (SPM) in Port Harcourt. He performed sampling 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 showed 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. DeGaetano and Doherty (2004)measured $PM_{2.5}$ in New York City using a high-density monitoring network of 20 stations and found similarly low spatial variation in concentrations across the city. Site correlations between a central site and all but one of the other sites in lower Manhattan were greater than 0.85.Ye *et al.,* (2003) conducted a 9-month analysis of $PM_{2.5}$ concentrations at two sites in Shanghai that were 4 km apart, yielding low long-term average variations. Average concentrations over the period at the two sites were 67.6 and 64.6 mg/m3 with a high correlation value between sites (r2 ¼ 0:94), suggesting regionally homogeneous sources.Two studies finding homogenous concentrations utilised coefficients of variation in their characterization of uniformity.

2. Materials and Method

Study Area

The study area is the Niger Delta region of Nigeria with latitude 4.05^{O}N to 7.55^{O}N and longitude 4.20^{O}E to 9.30^{O}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(Ekubo&Abowei 2011).

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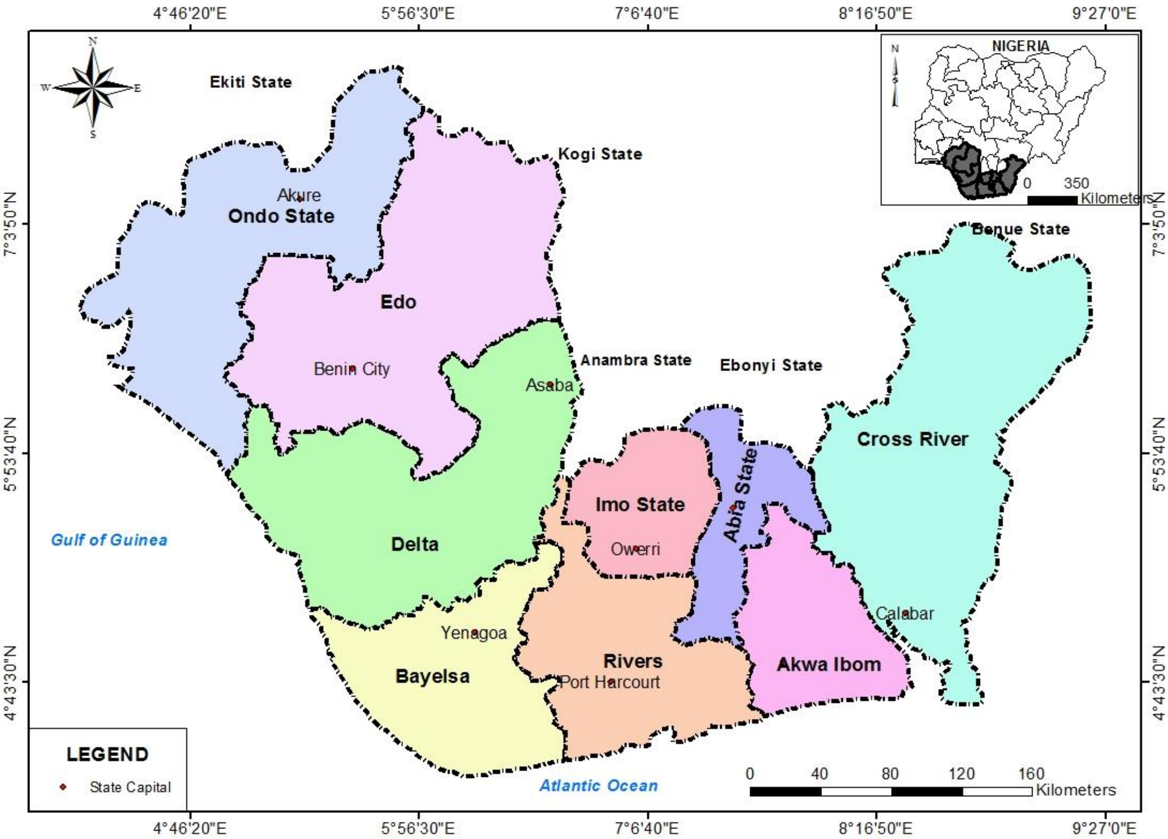

Figure 1. *Niger Delta Region showing States and their Capital Cities*

The Niger delta lies mainly in the wet equatorial climate region (Koppen'sA$_f$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 theonly 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℃. 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 (McGinley, 2014).

The Niger delta is resource-rich and abundantly blessed with expanse of agricultural/aquatic resources and vast reserves of petroleum hydrocarbon (Irikana, 2011). 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(Egberongbe, Nwilo&Badejo, 2006).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(Enemugwem, 2009). 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.

Data Collection and Modelling

Aerosol Optical Depth AOD data were collated on a daily basis and collated for selected cities, namely Akure, Asaba, Benin, Calabar, Owerri, Port Harcourt, Umuahia, Uyo and Yenagoa. Aerosol Optical Depth (AOD), are raster in nature, and were 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. Data for the study area were derived from MODIS sensor, located on the Terra and Aqua satellite platforms, which has 36 spectral channels. AOD, are a measure of light extinction by aerosol in the atmospheric column above the earth’s surface. AOD reflect 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 (Cao, Zheng, & Singh, 2014). 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.

The data were from collection 6 Terra MODIS collected at 5 minutes interval daily, this was averaged to obtain monthly averages and subsequently annual average. The Van Donklaar et al., 2010 formula ($PM_{2.5}$ = n * AOD) was used to derive the $PM_{2.5}$, where n is (conversion factor). The n was derived from data obtained from $PM_{2.5}$ dataset from Socioeconomic Data and Applications Center (SEDAC). The annual average $PM_{2.5}$ for the selected cities for the period 2001-2015 were extracted using ArcGIS software (ESRI, 2011). The $PM_{2.5}$ data were also summarized for the cities across the Niger deelta for the study period. The Mean and Standard deviation and Bar graph were used to discern the distribution of $PM_{2.5}$ data across the selected cities in the Niger delta.

The Distribution of $PM_{2.5}$ Concentration across the cities of Niger delta from 2001-2015.

Table 1. *Distribution of $PM_{2.5}$ Concentration (µg/m^3)*

CITY_NAME	Mean $PM_{2.5}$ (µg/m^3)	No. of Cases or Count	Standard Deviation	Std. Error	95% Confidence Interval Lower Bound	Upper Bound
Akure	15.299	143	10.852	1.047	13.497	17.606
Asaba	17.864	110	12.650	1.178	15.537	20.163
Benin	16.757	138	9.656	1.063	14.983	19.156
Calabar	23.241	57	11.918	1.901	19.563	27.025
Owerri	16.994	121	11.666	1.124	14.839	19.250
Port Harcourt	20.195	98	14.731	1.252	17.718	22.634
Umuahia	17.432	110	11.388	1.178	15.120	19.745
Uyo	19.875	87	15.066	1.340	16.612	21.871
Yenagoa	23.849	73	16.006	1.498	20.323	26.202

The mean in table 1 revealed that Yenagoa had the highest $PM_{2.5}$ concentration (23.849µg/m^3), followed by Calabar(23.241µg/m^3).The next was Port Harcourt (20.176µg/m^3), then Uyo (19.2242µg/m^3) and the lowest was Akure (15.551µg/m^3). The lower bound and upper bound of 95% confidence level shows that Calabar ranged between 19.563 and 27.025 confidence level. Yenagoa was between 20.323 and 26.202, Port Harcourt was between 17.718 and 22.634. Uyo was between 16.612 and 21.87, Asaba was between 15.537 and 20.163. Umuahia was between 15.120 and 19.745, Benin was between 14.983 and 19.156. Owerri was between 14.983 and 19.156 while Akure was between 13.497 and 17.606 respectively. The standard error shows that Calabar had the highest standard error while Akure had the lowest standard error. The standard deviation revealed that the data are clustered closely around the mean, the data were not dispersed.

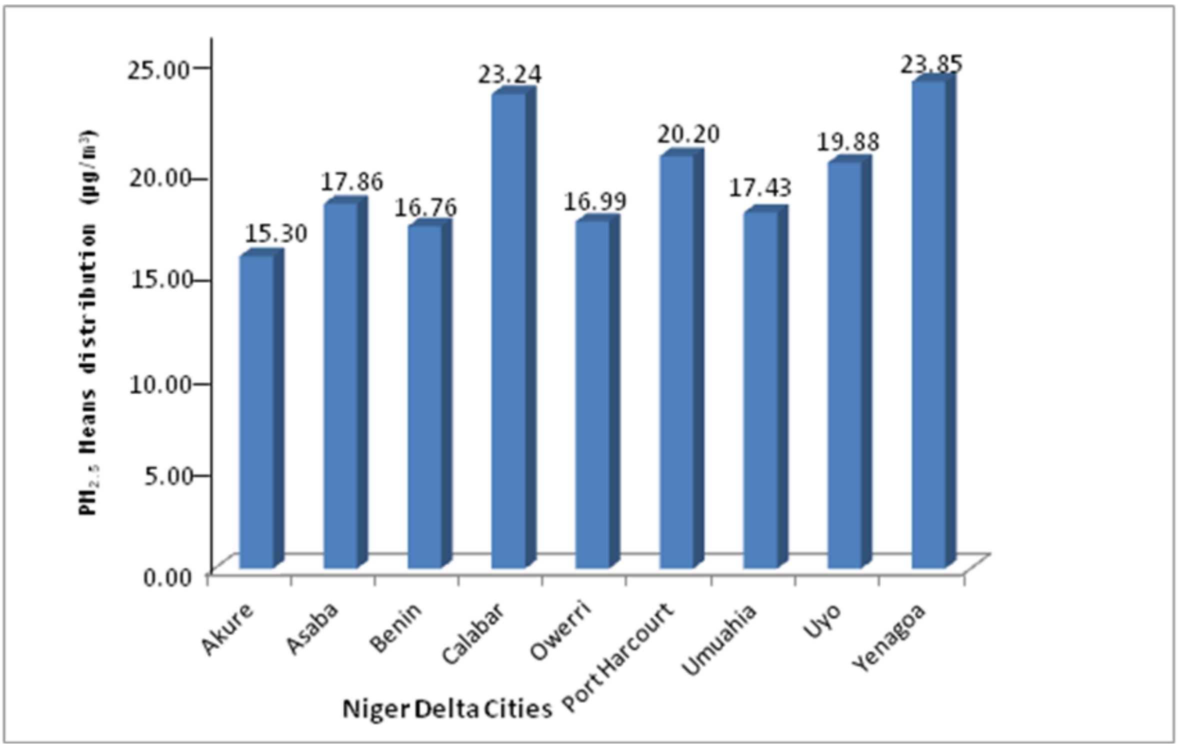

Fig. 2. *$PM_{2.5}$ Means distribution (µg/m^3) for 2001-2015.*

The distribution of $PM_{2.5}$ across the cities of the Niger Delta in figure 2 showed that Yenagoa had the highest $PM_{2.5}$ with 23.29 (µg/m^3)across the cities, this confirmed Yenagoa having the highest concentration of $PM_{2.5}$, followed by Calabar and the lowest $PM_{2.5}$ concentration was Akure in table 1.

3. CONCLUSION

The study presents a method which could be used for regional or national planning for environmental and health policy decision making. To achieve this, the study revealed the distribution of $PM_{2.5}$ concentration across the Niger delta from 2001 and 2015. The results showed that across the region, all the state capitals have annual mean values of $PM_{2.5}$ above the WHO guideline value and large numbers of vulnerable people are exposed to these dangerous levels of air quality. The distribution of $PM_{2.5}$ concentration observed revealed that $PM_{2.5}$ concentration in the Niger delta varied from city to city, and that $PM_{2.5}$ is significantly higher in the Yenagoa and lowest in Akure across the cities of the Niger delta, this means that there is variation in $PM_{2.5}$ concentration across the region and this is in line with Weli, 2014; Lawal&Asimiea, 2015. This implied that the effect of $PM_{2.5}$ concentration is higher inYenagoa, Callabar and their environ than in Akure across the region, therefore, there should be guideline values which are meant to provide targets and thus promote movement towards a lower PM concentration both in the dry and rainy seasons. The rate of increase in $PM_{2.5}$concentration across the Niger delta creates a significant burden on the national health infrastructure and this contributes to great risks to human and sustainable development. $PM_{2.5}$is highest in Yenagoa, Calabar and Port Harcourt while it was lowest in Akure, this revealed that Yenagoa, Calabar, Port Harcourt and their environs are prone to health effect of $PM_{2.5}$concentration. This result highlights the importance of monitoring and the need to improve urban area's air quality. Rural areas should also not be neglected, but urban areas need to take precedence due to the higher risk to a large number of people.

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