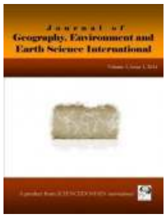

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Seasonal Variations of $PM_{2.5}$ Concentration across the Cities of the Niger Delta Region, Nigeria

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Authors' contributions

This work was carried out in collaboration between both authors. Author VOS designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Author MON managed the analyses of the study and managed the literature searches. Both authors read and approved the final manuscript.

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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 analyze the seasonal variation of $PM_{2.5}$ concentration across the cities of the Niger delta region of Nigeria. $PM_{2.5}$ 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 two-way ANOVA was employed to analyze the seasonal variation of $PM_{2.5}$ concentration. The ANOVA result showed that $PM_{2.5}$ concentration in the Niger delta varied from season to season, and that $PM_{2.5}$ is significantly higher in the dry season 20.72 µg/m^3 than in the rainy season 17.27 µg/m^3 across the cities of the Niger delta with Yenagoa having the highest concentration in dry season (25.5 µg/m^3) with standard deviation of (9.3 µg/m^3) and Calabar having the highest concentration in rainy season (23.4 µg/m^3) with standard deviation of (18.4 µg/m^3). This means that there is a wide variation in

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$PM_{2.5}$ concentration over the years across the cities. The effect of $PM_{2.5}$ concentration is higher in dry season than in rainy season across the region, and all the state capitals have annual mean values of $PM_{2.5}$ above the WHO guideline value of 10 µg/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 in the dry season more than in the rainy season. This situation can lead to adverse health and environmental health effects such as hospital admissions, asthma, cardiovascular or lung disease including premature death on human beings with continuous exposure.

Keywords: $PM_{2.5}$; seasonal variation; two-way analysis of variance; Niger delta.

1. INTRODUCTION

Particulate matter (PM) 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 [1]. 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 [2]. Equally, 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) [3].

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 [3]. 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.

Air pollution has intensified strongly since the industrial revolution, that is, during the epoch known as the Anthropocene [4]. Ground-level fine PM with a diameter of 2.5 microns has increased substantially, not only in most urbanized and industrialized areas but also in rural and even remote regions [5-7]. $PM_{2.5}$ 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 [8,9]. Urban $PM_{2.5}$ exposure is responsible for approximately 712,000 cardiopulmonary disease (CPD) and 62,000 lung cancer deaths in 2000 [10], while anthropogenic $PM_{2.5}$ is associated with 3.5 million CPD and 220,000 lung cancer mortalities annually [7]. 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 [11], 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 [12]. In Nigeria, almost the entire country has $PM_{2.5}$ concentration above the WHO guideline of 25 µg/m^3 (24 hour mean) and 10µg/m^3 (annual mean) [13] which presents an environmental health burden in relation to potential risk of continuous exposure to dangerous level of $PM_{2.5}$ [2]. It has been established that the health effects of atmospheric particulate matter are related to its ability to permeate the respiratory system. It has been generally recognized that, respiratory defense mechanisms have the ability to retain up to 99 percent of particles larger than 10 µm from the inhaled air stream but the smaller particles (2.5µm and less) which are called respirable particles, are highly toxic because of their ability to penetrate deep into the respiratory tract and blood stream where they cause various forms of respiratory and pulmonary diseases. A baseline study of spatial and temporal variation of respirable $PM_{2.5}$ in Isoko Land revealed that dry season $PM_{2.5}$ values were statistically significantly higher than the wet season levels [14].

The composition of PM varies with place, season and weather conditions. The spatial and seasonal variations of PM_{10} and $PM_{2.5}$ concentration in Middle Eastern classrooms and have been studied and observed to be significant for the three seasons [15]. During winter, the mean indoor PM_{10} was 1.30 and 2.50 times higher than fall and spring concentrations respectively. Meanwhile, $PM_{2.5}$ concentration in winter was 3 times higher than fall and spring concentrations. The Characteristics and Seasonal Variations of $PM_{2.5}$, PM_{10}, and TSP Aerosol in Beijing have been found to be most abundant in the spring dust, and the least in summer dust [16]. The average mass ratios of PM>10, $PM_{2.5-10}$, and $PM_{2.5}$ to TSP confirmed that in the spring dust both the large coarse (PM>10) and fine particles ($PM_{2.5}$) contributed significantly. In summer $PM_{2.5}$, $PM_{2.5-10}$, and PM>10 contributed similar fractions to TSP, and in winter much $PM_{2.5}$. The greatest contributors (2%) to atmospheric $PM_{2.5}$ mass concentration were sulfur (S), silicon (Si), chlorine (Cl), aluminum (Al), and iron (Fe) in the spring; S in the summer; and S and Cl in the fall. S, Cl, and Si were the major elements in the winter and there is a significant seasonal difference in $PM_{2.5}$ concentration during the four seasons [17].

Dry season has been found to be characterized by higher concentration of pollutants, while the rainy season was characterized with less concentration of pollutants implying that seasonality significantly influences the concentration of pollutants [18]. The diurnal and seasonal variation of the $PM_{2.5}$ revealed a strong seasonal and diurnal variations, with higher values observed during the warm season compared to the cold season [19]. [20] An investigation of spatial and seasonal variations of $PM_{2.5}$ mass has shown that it increased in autumn and decreased in winter. Ambient Air Particulate Matter Levels in selected urban cities of Niger were studied and concluded that the high levels of PM_{10} and $PM_{2.5}$ in all the cities monitored especially in the dry season may present a potential public health risk [21].

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 penetrate 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 concentration of $PM_{2.5}$ across cities of the Niger Delta region with regard to seasons.

2. MATERIALS AND METHODS

2.1 Study Area

The study area is the Niger Delta region of Nigeria with latitude 4.05ºN to 7.55ºN and longitude 4.20ºE to 9.30ºE (Fig. 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 450 km, 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 70,000 km^2 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 [22].

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 ℃ . 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 Kanji 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 [23].

The Niger delta is resource-rich and abundantly blessed with expanse of agricultural/aquatic resources and vast reserves of petroleum hydrocarbon [24]. 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 [25]. 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 [26]. At the lowest levels of society, inhabitants of this region eke out their living by subsistent harvesting of natural resources (fishes, forest products, and backyard farms). At higher levels, resource-exploitation takes the form of profiteering and range from profitable plantation farming to petroleum hydrocarbon exploitation.

2.2 Data Collection

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

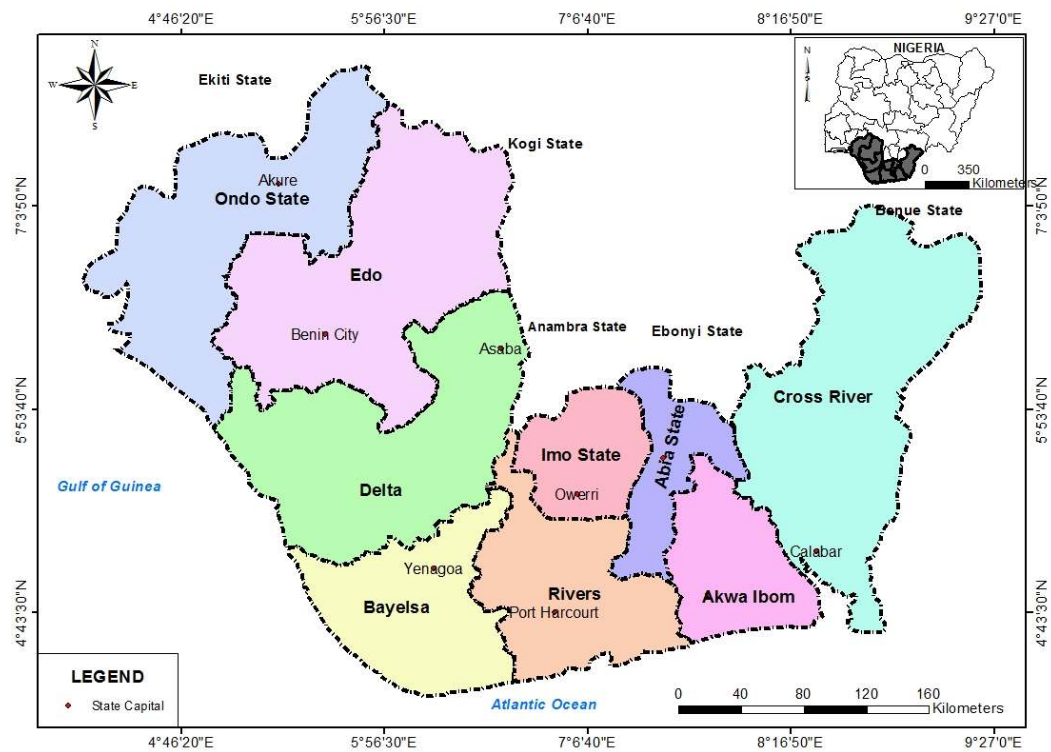

Fig. 1. Niger Delta Region showing States and their Capital Cities

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 [27]. 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 formula ($PM_{2.5}$ = n * AOD) was used to derive the $PM_{2.5}$, where n is (conversion factor) [28]. 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 [29]. The $PM_{2.5}$ data were also summarized for seasons, rainy season from the month of March to October and dry season from the month of November to February. The Two-way analysis of variance (ANOVA) was used to discern the seasonal variation of $PM_{2.5}$ data across the selected cities in the Niger delta.

3. RESULTS AND DISCUSSION

Results of the ANOVA showed that the annual mean $PM_{2.5}$ concentration from 2001-2015 across the cities of the Niger Delta varied with Yenagoa having the highest concentration in dry season (25.5 µg/m^3) with standard deviation of (9.3 µg/m^3) and Calabar having the highest concentration in rainy season (23.4 µg/m^3) with standard deviation of (18.4 µg/m^3). The average $PM_{2.5}$ concentration for the entire Niger delta is (20.7 µg/m^3) during dry and (17.3 µg/m^3) during rainy season respectively.

Fig. 2 also showed that Yenagoa had the highest $PM_{2.5}$ concentration (25.5 µg/m^3) during the dry season and Calabar had the highest $PM_{2.5}$ concentration (23.4 µg/m^3) during rainy season confirming the previous result. This could be as a result of the wind direction towards Calabar during the rainy season.

The result of the ANOVA in terms of seasonal variation in Table 2 showed that there is a significant difference in $PM_{2.5}$ concentration among the seasons since the F calculated is (15.585) and its p-value (0.000) which is less than the Sig. value of 0.05. It has been shown in table 1 results above that the dry season has the highest $PM_{2.5}$ across the cities.

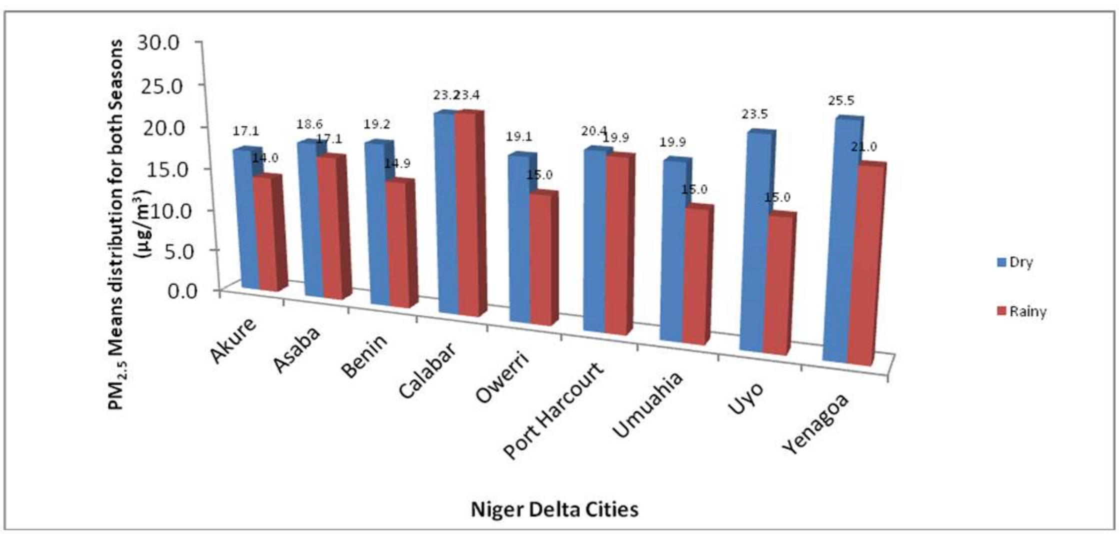

Fig. 2. $PM_{2.5}$ mean distribution for dry and rainy season

Table 1. Annual seasonal mean of $PM_{2.5}$ ($\mu g/m^3$) from 2001-2015 across the cities of Niger Delta

Season	Parameters	Akure	Asaba	Benin	Calabar	Owerri	Port Harcourt	Umuahia	Uyo	Yenagoa	Niger Delta
Dry	Mean	17.1	18.6	19.2	23.2	19.1	20.4	19.9	23.5	25.5	20.7
	std. deviation	7.3	8.4	7.6	9.2	9.3	7.5	8.3	16.0	9.3	
Rainy	Mean	14.0	17.1	14.9	23.4	15.0	19.9	15.0	15.0	21.0	17.3
	std. deviation	12.7	16.0	10.6	18.4	13.3	20.3	13.4	12.3	23.4	

Footnote: Std. is standard deviation

Table 2. Two-way Anova values for univariate tests for Seasonal variation of $PM_{2.5}$ concentration across the Niger Delta

	Sum of squares	Df	Mean square	F	Sig.	Partial eta squared
Contrast	2379.844	1	2379.844	15.585	.000	.017
Error	140334.343	919	152.703			

The increase in rate of $PM_{2.5}$ concentration during the dry season 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 [30]. With this understanding there is a need to develop policies which are geared towards reducing the exposure and improving air quality across urban areas. These will consequently reduce environmental health burden and contribute to sustainable development.

4. 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 seasonal variation 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 seasonal variation of $PM_{2.5}$ concentration observed revealed that $PM_{2.5}$ concentration in the Niger delta varied from season to season and that $PM_{2.5}$ is significantly higher in the dry season than in the rainy season across the cities of the Niger delta, this is in line with [14,18]. This implied that the effect of $PM_{2.5}$ concentration is higher in dry season than in rainy season 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 $PM_{2.5}$ across the Niger delta in the dry season creates a significant burden on the national health infrastructure and contribute to great risks to human and sustainable development. $PM_{2.5}$ is highest in Yenagoa in and lowest in Akure in dry season, while it was highest in Calabar and lowest in Akure in rainy season, this revealed that Yenagoa and Calabar and their environs are prone to health effect of $PM_{2.5}$ during the dry and rainy seasons. 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.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. John PD, Bryan JB, Darrel AW, Christopher PW. Understanding the meteorological drivers of U.S. particulate matter concentrations in a changing climate. Journal of American Meteorological Society. 2014;521-532.
2. Lawal O, Asimiea AO. Spatial modelling of population at risk and $PM_{2.5}$ exposure index: A case study of Nigeria. Ethiopian Journal of Environmental Studies & Management. 2015;8(1):69-80.
   ISSN: 1998-0507.
3. WHO. Health Effects of Particulate Matter. Policy implications for countries in Eastern Europe, Caucasus and central Asia. WHO Regional Office for Europe UN City, Marmorvej 51 DK-2100 Copenhagen O, Denmark; 2013.
   ISBN: 978 92 890 0001 7
4. Crutzen PJ. Geology of mankind. Nature. 2002;415:23.
5. Akimoto H. Global air quality and pollution. Science. 2003;302:1716-1719.
6. Schulz M, Textor C, Kinne S, Isaksen ISA, Iversen T, Koch D, Kirkevag A, Liu X, Montanaro V, Myhre G, Penner JE, Pitari G, Reddy S, Seland O, Stier P, Takemuna T. Radiative forcing by aerosols as derived from the AeroCom present day and pre-industrial simulations. Atmos. Chem. Phys. 2006;6:5225-5246.
   DOI: 10.5194/acp-6- 5225
7. Anenberg SC, Horowitz LW, Tong DO, West JJ. An estimate of the global burden of anthropogenic ozone and fine particulate matter on premature human mortality using atmospheric modeling. Environ. Health Persp. 2010;118:1189-1195.
8. Dockery DW, Pope CA, Xu X, Spengler JD, Ware JH, Fay ME, Ferris Jr, BG, Speizer FE. An association between air pollution and mortality in six U.S cities. N. Engl. J. Med. 1993;329:1753-1759.
9. McDonnell WF, Nishino-Ishikawa N, Petersen FF, Chan LH, Abbey DE. Relationships of mortality with the fine and

coarse fractions of long-term ambient PM_{10} concentrations in nonsmokers. J. Expo. Anal. Env. Epid. 2000;10:427-436.

10. Cohen AJ, Anderson HR, Ostro B, Pandey KD, Krzyzanowski M, Kunzli N, Gutschmidt K, Pope CA, Romieu I, Samet JM. Urban air pollution, Comparative Quantification of Health Risks. 2004;2: 1353-1433.
11. Evans J, Van Donkalaar A, Martin RV, Burnett R, Rainham DG, Birkett NJ, Krewski D. Estimates of global mortality attributable to particulate air pollution using satellite imagery. Environ. Res. 2012;120: 33-42.
12. Lim SS, Vos T, Flaxman AD, Danaei G, Shibuya K. A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990-2010. A systematic analysis for the Global Burden of Disease Study 2010. Lancet. 2012;380:2224-2260.
13. WHO. WHO Air quality guidelines for PM, Ozone, Nitrogen dioxide and Sulphur dioxide: Global Update, Summary of Risk Assessment; 2005.
14. Aziakpono MO, Ukpebor EE, Ukpebor JE. Baseline, spatial and temporal variation of respirable [$PM_{2.5}$] particulate matter in isoko land. Greener Journal of Physical Sciences. 2013;3(7):247-254.

    Available:www.gjournals.org 246

    ISSN: 2276-7851.
15. Maher E, Nor AR, Noor FF, Wesam A. Spatial and seasonal variation of particulate matter PM_{10} and $PM_{2.5}$ in Middle Eastern classrooms. Atmospheric Environment. 2013;80:389-397.
16. Wen-Jie Z, Ye-Le S, Guo-Shun Z, Dong-Qun X. Characteristics and seasonal variations of $PM_{2.5}$, PM_{10}, and TSP aerosol in Beijing. Biomedical and Environmental Sciences. 2006;19:461-468.
17. Choong-Min, K, Young S, HakSung L, Byung-Wook K, Sang-Kwun L. Atmospheric concentrations of $pm_{2.5}$ trace elements in the Seoul Urban Area of South Korea. Journal of the Air & Waste Management Association. 2012;54:432-439.
18. Balogun VS, Orimoogunje OOI. An assessment of seasonal variation of air pollution in Benin City, Southern Nigeria. Atmospheric and Climate Sciences. 2015; 5:209-218.

    Available:http://dx.doi.org/10.4236/acs.2015.53015
19. Zirui L, Dongsheng J, Yonghong W, Mingxing W, Yuesi W. Diurnal and seasonal variation of the $PM_{2.5}$ apparent particle density in Beijing, China. Atmospheric Environment. 2015;120:328-338.
20. Ping W, Jun-ji C, Zhen-xing S, Yong-ming H, Shun-cheng L, Yu H, Chong-shu Z, Qi-yuan W, Hong-mei X, Ru-jin H. Spatial and seasonal variations of $PM_{2.5}$ mass and species during 2010 in Xi'an, China. Science of the Total Environment. 2015; 508:477–487.
21. Ngele SO, Onwu FK. Ambient air particulate matter levels in selected Urban Centres of Niger Delta Region, Nigeria. Int. Res. J. Environment Sci. 2015;4(4): 54-63.

    ISSN: 2319–1414
22. Ekubo A, Abowei J. aspects of aquatic pollution in Nigeria. Research Journal of Environmental and Earth, Sciences. 2011; 3(6):673-693.
23. McGinley M. Conservation biology biodiversity and ecology in the Encyclopaedia of Earth: World Wildlife Fund; 2014.
24. Irikana GJ. Mangrove resources utilization in Nigeria: An analysis of the andoni mangrove resources crisis. Sacha J. Env. Stud. 2011;1(1):49- 63.
25. Egberongbe FOA, Nwilo PC, Badejo OT. Oil spill disaster monitoring along Nigerian coastline. Promoting Land Administration and Good Governance 5th FIG Regional Conference Accra, Ghana, March 8-11; 2006.
26. Enemugwem JH. The development of the Niger Delta of Nigeria, 1900-1966. J. Sust. Dev. Afr. 2009;10(4):162-178.
27. Cao C, Zheng S, Singh, RP. Dust event of April 23-24, 2014 in the Northwest China and Changes in Air Quality, Atmospheric and Meteorological Parameters. American Geophysical Union, Fall Meeting 2014; 2014.
28. Van Donkelaar A, Martin RV, Brauer M, Kahn R, Levy R, Verduzco C, Paul J, Villeneuve PJ. Global estimates of ambient fine particulate matter

concentrations from satellite-based aerosol optical depth: Development and application. Environ Health Perspect. 2010;118(6):847–855.

29. ESRI. ArcGIS Desktop (Version 10). redlands, CA: Enviromental Systems Research Institute; 2011.

30. Shaibu, VO, Weli, VE. Modeling the Distribution of PM Concentration from 2001-2015 Using Satellite Based Measurement across the Cities of Niger 2.5 Delta Region, Nigeria. International Journal of Research in Environmental Science (IJRES). 2017;3(2):1-7.

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