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MODELLING THE ANNUAL TRENDS OF $PM_{2.5}$ CONCENTRATION ACROSS THE CITIES OF THE 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 annual trends of $PM_{2.5}$ concentration across the cities of the Niger delta region of Nigeria. Aerosol Optical Depth (AOD) $PM_{2.5}$ data for this study was acquired from remotely sensed satellite data from National Aeronautics and Space Administration (NASA's) earth observing system data and information system from 2001 – 2005. Trend analysis was employed to model the trend of $PM_{2.5}$ concentration and result showed that the annual mean $PM_{2.5}$ concentration from 2001-2015 across the cities of the Niger Delta varied with Akure having the highest concentration in 2005, Asaba 2009, Benin 2005, Calabar 2004 Owerri 2004, Port Harcourt 2004, Umuahia 2008, Uyo 2005 and Yenagoa 2004. This means that there is a wide variation in $PM_{2.5}$ concentration over the years across the cities and there is an increasing trend in $PM_{2.5}$ concentration across the region, 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 situation can lead to adverse health and environmental health effects on human beings with continuous exposure.

Key Words: *$PM_{2.5}$, Modeling, Trend analysis, Niger delta.*

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 *et al*., 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 and 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 *et al*., 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 *et al*., 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 *et al*., 2012). 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) (WHO, 2005) this presents an environmental health burden in relation to potential risk of continuous exposure to dangerous level of $PM_{2.5}$ (Lawal and Asimiea, 2015).

Hu *et al*., (2014) used a new Aerosol Optical Depth (AOD) product with 1km spatial resolution retrieved by the multi-angle implementation of atmospheric correction (MA-IAC) algorithm based on MODIS measurements to model 10- year spatial and temporal trends of $PM_{2.5}$ concentrations in the southeastern US and reported that spatial trends showed that high $PM_{2.5}$ levels occurred in urban areas and along major highways, while low concentrations appeared in rural or mountainous areas. The time-series analysis showed that, for the 10-year study period, the $PM_{2.5}$ levels in the southeastern US have decreased by 20% and annual decrease has been relatively steady from 2001 to 2007 and from 2008 to 2010 while a significant drop occurred between 2007 and 2008. An observed increase in $PM_{2.5}$ levels in year 2005 was attributed to elevated sulfate concentrations in the study area in warm months of 2005. (Ping *et al*., 2015) in their study examined spatial and seasonal variation of $PM_{2.5}$ mass and specie during 2010 in Xi'an, China. $PM_{2.5}$ mass and selected chemical species were measured in 24-h integrated $PM_{2.5}$ samples collected simultaneously at the urban and rural regions of Xi'an (six sites in total) and noted that $PM_{2.5}$ mass and those species measured showed a decreasing trend in $PM_{2.5}$ in comparison with previous studies in Xi'an. Mukhtar *et al*., (2015) studied Long-Term Trend and Seasonal Variability of Horizontal Visibility in four zones Nigerian. Visibility and other meteorological data from NOAA-NCDC and aerosol index data over Nigeria during 1984–2013 were analyzed using time series and simple regression model. The study revealed that there are significant decreasing trends for every region and season during the 30-years period.

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 70,000km^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 (Ekubo and Abowei 2011).

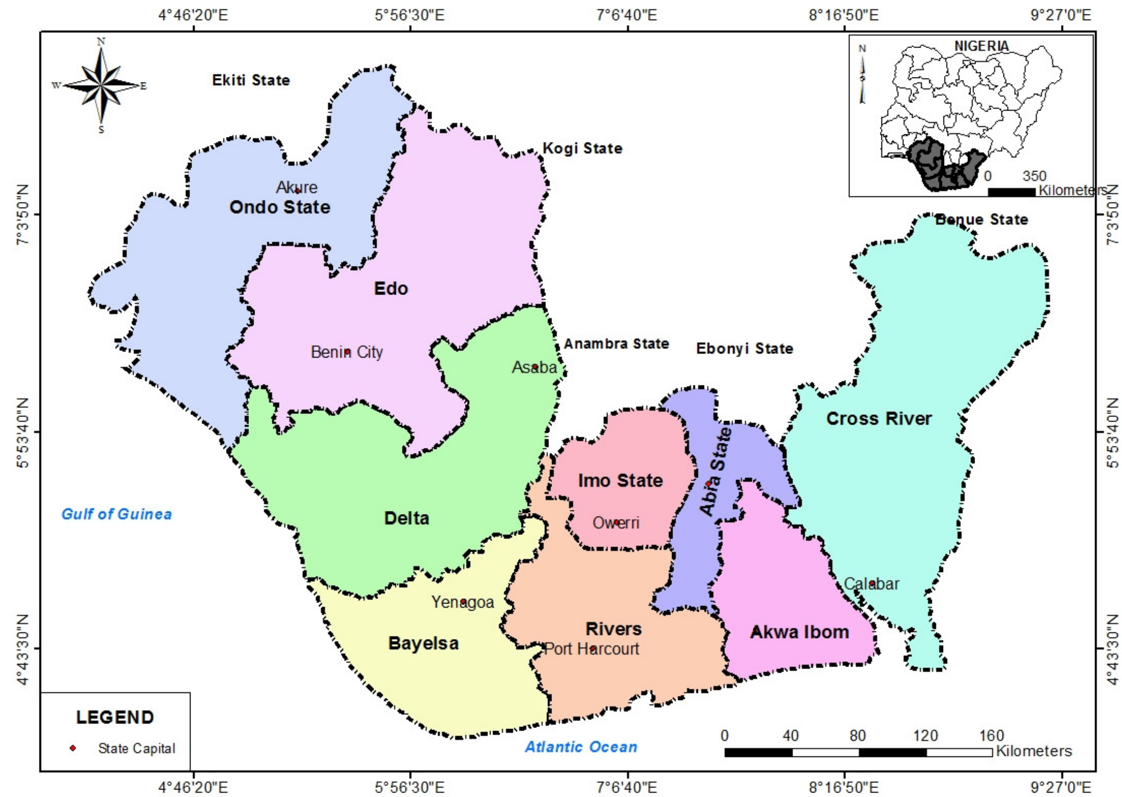

Fig. 1: States across the study area

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℃. 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).

Land Use

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, 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, and backyard farms). At higher levels, resource-exploitation takes the form of profiteering and range from profitable plantation farming to petroleum hydrocarbon exploitation.

Method

Data Collection and Modelling

AOD data was 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), 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. Data for the study area was derived from MODIS sensor, located on the Terra and Aqua satellite platforms, which has 36 spectral channels. 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 (Cao *et al.*, 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 was 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 regression model was used to discern the trend of $PM_{2.5}$ data across the selected cities in the Niger delta.

Results and Discussion

The annual trend of $PM_{2.5}$ showed that almost the entire study area has $PM_{2.5}$ concentration above the WHO guideline of 10µg/m3 across the periods under consideration. This is in line with the observations of (Akimoto, 2003; Schulz *et al*., 2006; Anenberg *et al*., 2010). Works of Hu *et al*., (2014) also corroborate the levels of $PM_{2.5}$ observed from the dataset used for this study. Results of the trend analysis showed that the annual mean $PM_{2.5}$ concentration from 2001-2015 across the cities of the Niger Delta varied with Akure having the highest concentration in 2005, Asaba 2009, Benin 2005, Calabar 2004, Owerri 2004, Port Harcourt 2004, Umuahia 2008, Uyo 2005 and Yenagoa 2007 Table 1.

Table 1: Annual mean of $PM_{2.5}$ from 2001-2015 across the cities of Niger delta.

	PM2.5 (µ/m3)								
Year	Akure	Asaba	Benin	Calabar	Owerri	PH	Umuahia	Uyo	Yenagoa
2001	15.38	14.86	13.47	28.65	16.85	20.30	16.08	18.69	18.63
2002	10.57	20.05	14.63	21.22	13.96	15.98	17.60	15.84	20.58
2003	14.80	15.94	14.99	18.93	15.96	16.87	18.23	20.00	17.52
2004	17.92	18.17	18.27	29.25	22.21	28.40	17.52	30.32	32.39
2005	20.81	20.88	22.44	25.19	20.86	17.09	19.16	34.77	28.50
2006	14.42	23.26	17.40	25.04	21.38	31.77	14.35	20.71	26.96
2007	16.12	17.39	16.89	21.06	17.76	24.43	15.04	15.39	36.28
2008	16.33	15.96	21.27	26.36	15.13	19.03	27.66	21.04	27.15
2009	12.83	23.31	17.81	13.89	16.72	11.97	17.00	17.67	19.74
2010	18.68	16.25	16.31	17.29	11.34	11.81	19.85	13.83	28.82
2011	12.53	19.17	14.68	22.81	17.87	16.24	13.55	14.52	25.51
2012	16.61	16.23	17.58	27.49	13.01	27.46	17.70	20.08	19.71
2013	11.54	16.17	14.07	25.05	20.27	16.85	18.14	16.08	15.82
2014	14.47	15.91	17.02	17.96	14.19	20.25	16.17	20.48	16.76
2015	17.24	15.94	15.70	25.58	15.78	22.25	15.96	17.97	32.28

There is an increasing trend of $PM_{2.5}$ across the cities under study from 2014 especially with menace of pipeline bombing and illegal refining of crude oil that is prevalent in this region.

The spatial distribution and the trend showed that almost the entire study area has $PM_{2.5}$ concentration above the WHO guideline of 10µg/m. This is in line with the observations of Efe (2008), the author examined the spatial distribution of particulate air pollution in Nigeria cities and reported that 70% of the cities studied have values above the daily and annual mean recommended by WHO. There are serious implications for human health with this level of ambient air quality, especially since $PM_{2.5}$ has been implicated in many pulmonary and cardiovascular problems.

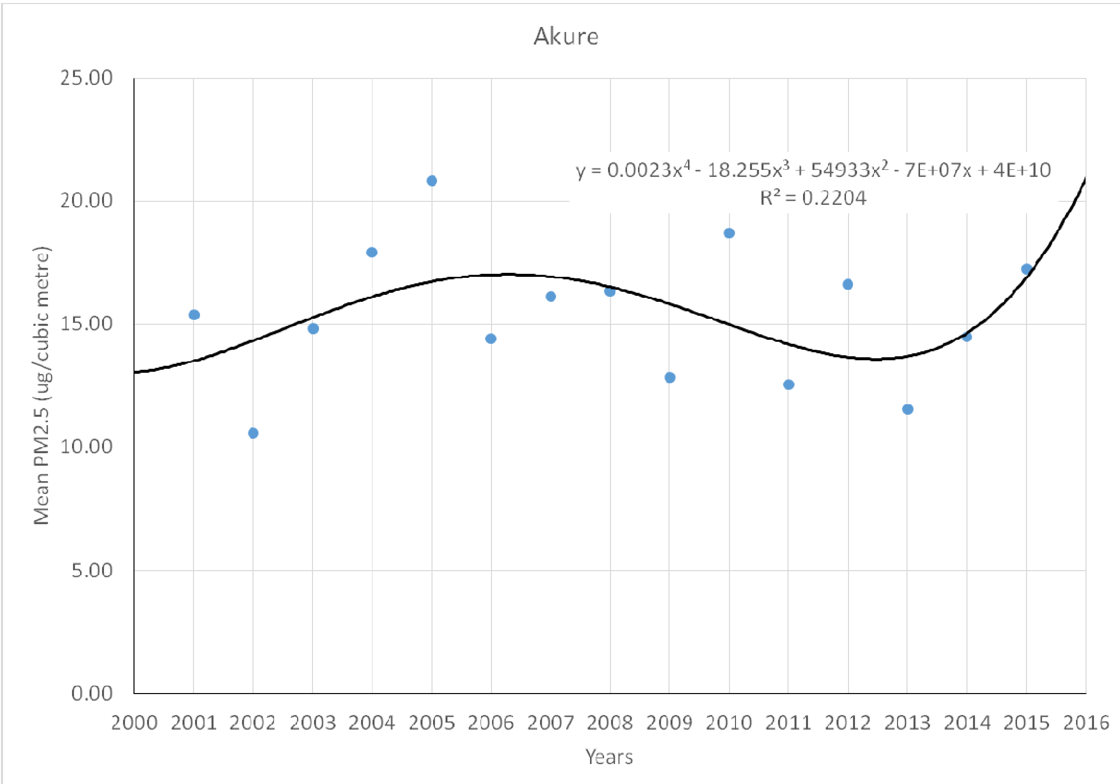

Fig. 2: Trend analysis of $PM_{2.5}$ across the year over the city of Akure

Across Akure, there is a wide variation over the year (Figure 2). Fitting a polynomial of the 4^{th} order to the trend was only able to capture about 22% of the variation across the years (R^2 = 0.22). From 2000 the trend appreciated up to 2005 where it had the peak; it then depreciated from 2009 to 2014 with deep trough and then started appreciating till 2015. This showed that in Akure the $PM_{2.5}$ concentration was very high at the peak in 2005, dropped very low in 2009 and started increasing towards 2015 with the highest outlier 2005 and the lowest in 2002.

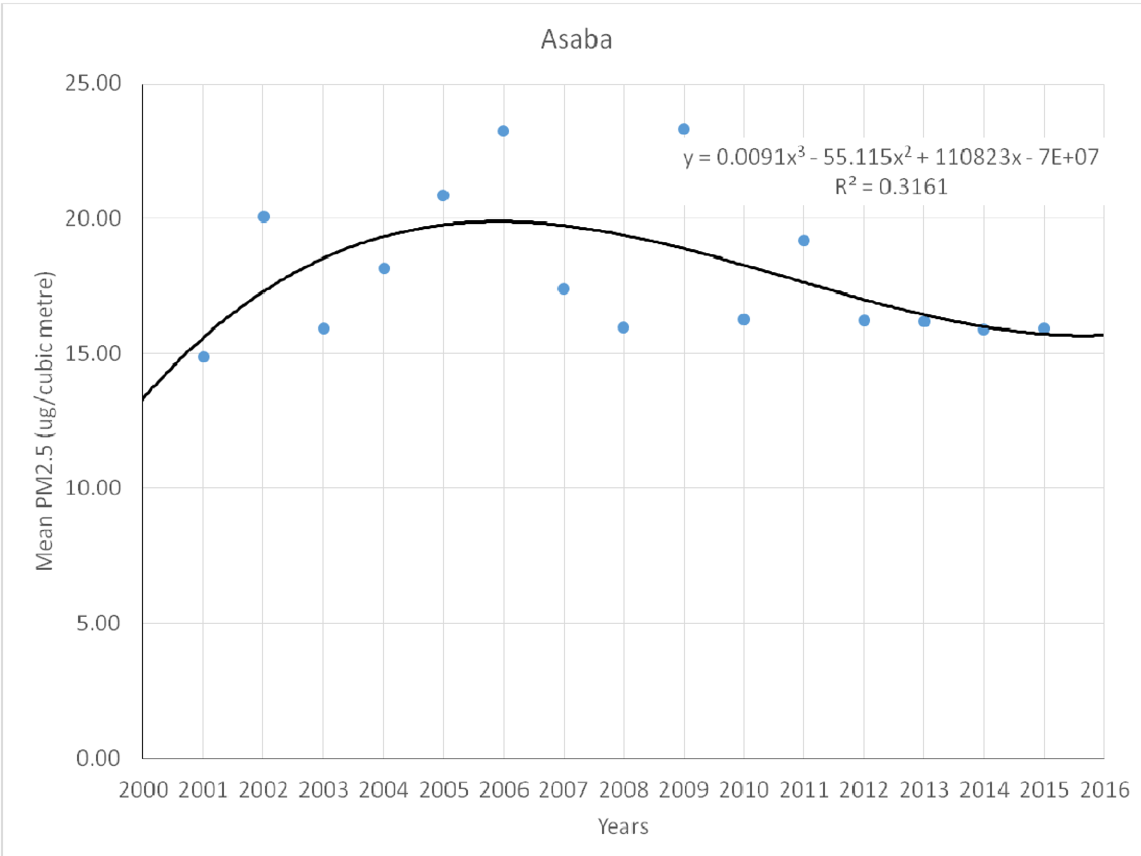

Fig. 3: Trend analysis of $PM_{2.5}$ across the year over the city of Asaba

Across Asaba, there is a wide variation over the year (Figure 3). Fitting a polynomial of the 3rd order to the trend was only able to capture about 32% of the variation across the years (R^2 = 0.32). From 2000 the trend appreciated up to 2006 where it had the peak; it then depreciated slowly to 2015. This showed that in Asaba the $PM_{2.5}$ concentration was very high at the peak in 2006, dropped slowly towards 2015 with the highest outlier in 2009 and the lowest in 2001.

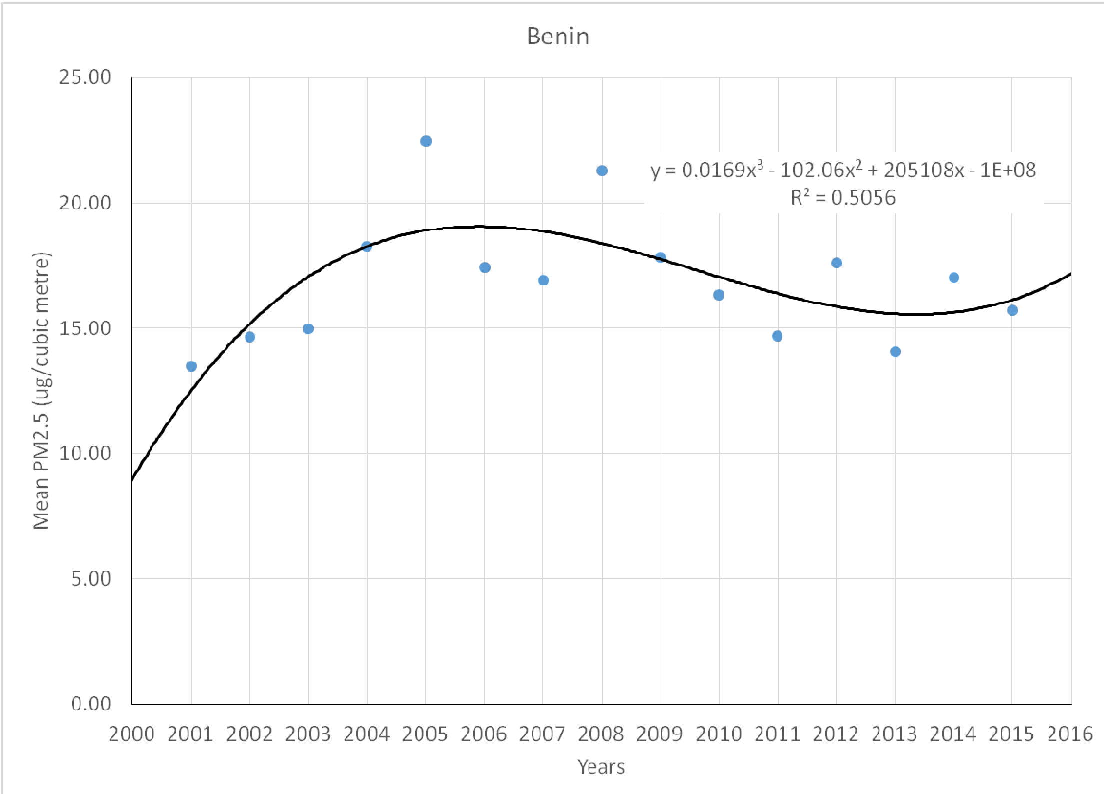

Fig. 4: Trend analysis of $PM_{2.5}$ across the year over the city of Benin

Across Benin, there is a wider variation over the year (Figure 4). Fitting a polynomial of the 3rd order to the trend was only able to capture about 51% of the variation across the years (R^2 = 0.51). From 2000 the trend appreciated up to 2006 where it had the peak; it then depreciated from 2007 to 2013 with trough and then started appreciating till 2015. This showed that in Benin the $PM_{2.5}$ concentration was very high at the peak in 2006, dropped low in 2013 and started increasing towards 2015 with the highest outlier in 2005 and the lowest in 2001.

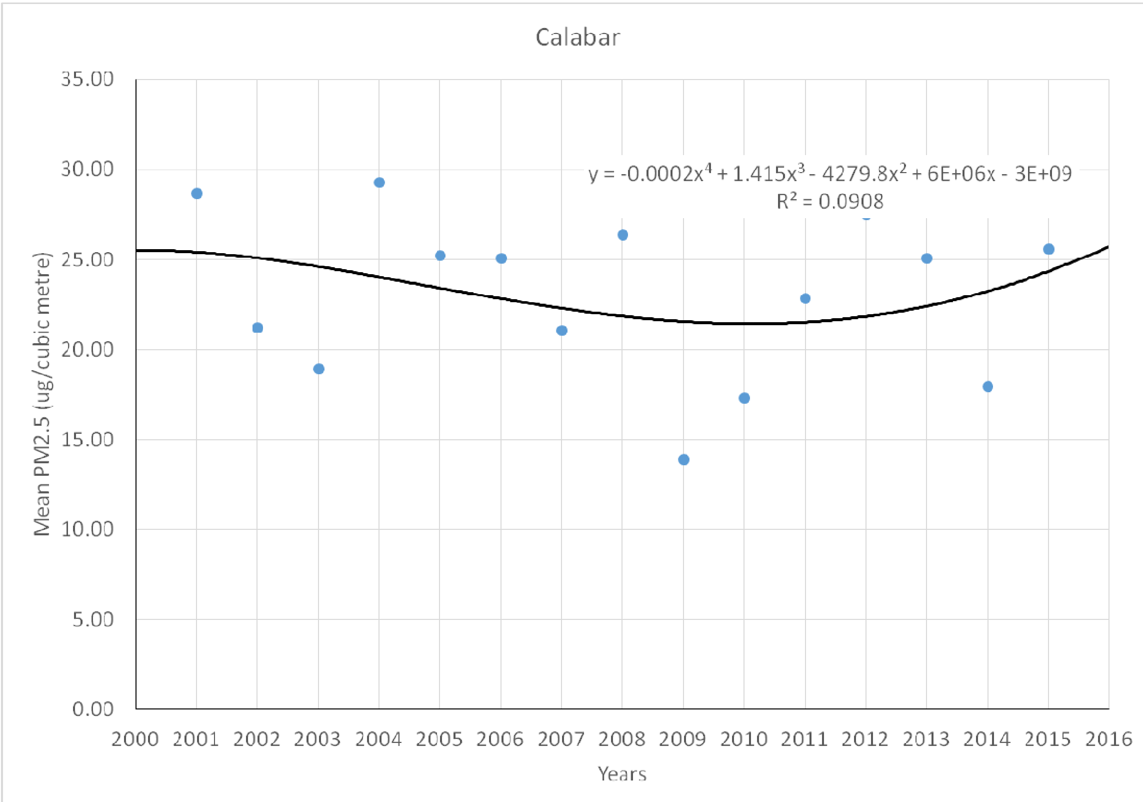

Fig. 5: Trend analysis of $PM_{2.5}$ across the year over the city of Calabar

Across Calabar, there is no wide variation over the year (Figure 5). Fitting a polynomial of the 4th order to the trend was only able to capture about 9% of the variation across the years (R^2 = 0.09). The trend was already high in 2000, started depreciating steadily to 2010 with trough and then started appreciating towards 2015. This showed that in Calabar the $PM_{2.5}$ concentration is very high at the peak in 2001, dropped slowly towards 2010 and started increasing towards 2015 with the highest outlier in 2004 and the lowest in 2009.

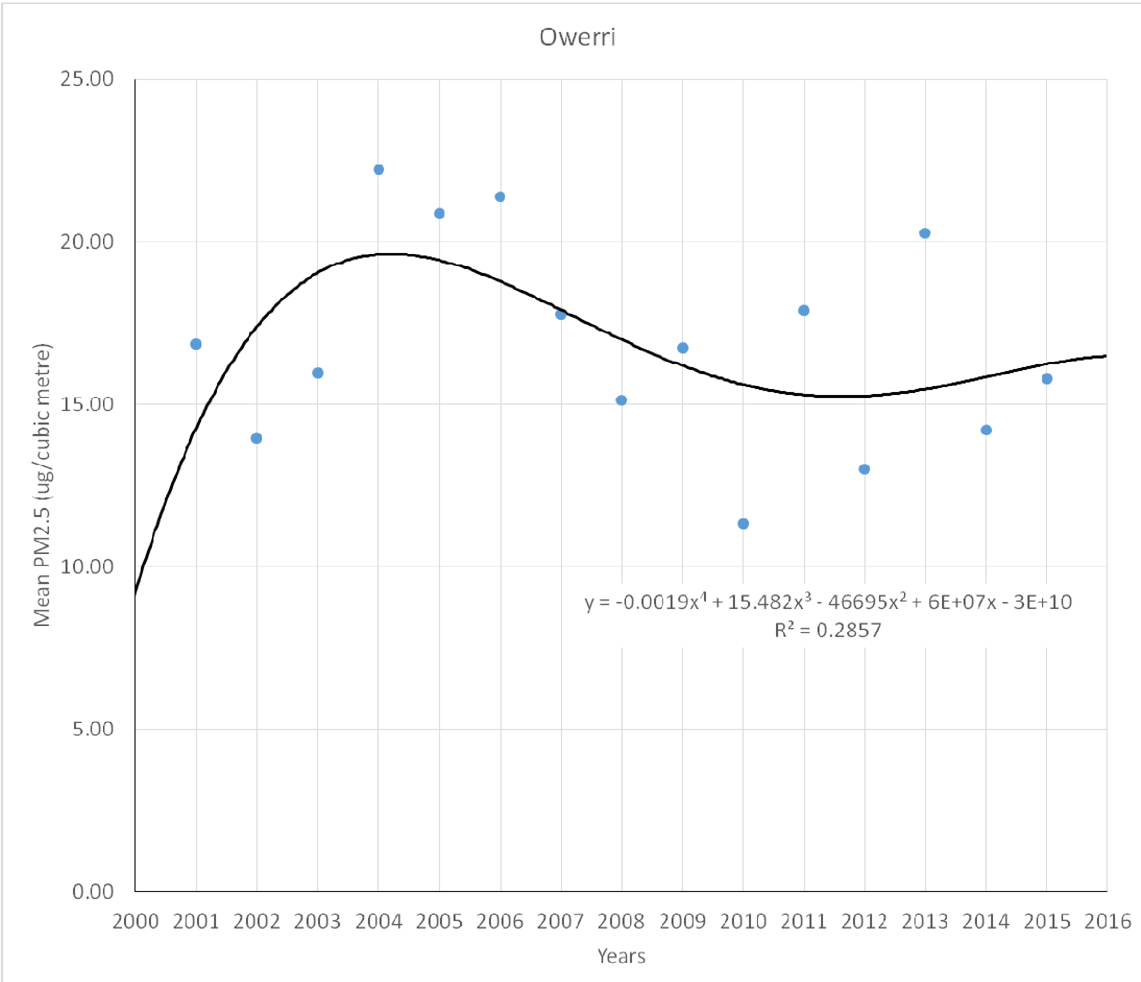

Fig. 6: Trend analysis of $PM_{2.5}$ across the year over the city of Owerri

Across Owerri, there is a wide variation over the year (Figure 6). Fitting a polynomial of the 4th order to the trend was only able to capture about 29% of the variation across the years ($R^2 = 0.29$). From 2000 the trend appreciated sharply to 2004 where it had the peak, it then depreciated from 2005 to 2011 with trough and then started appreciating till 2015. This showed that in Owerri the $PM_{2.5}$ concentration was very high at the peak in 2004, dropped low in 2011 and started increasing towards 2015 with the highest outlier in 2004 and the lowest in 2010.

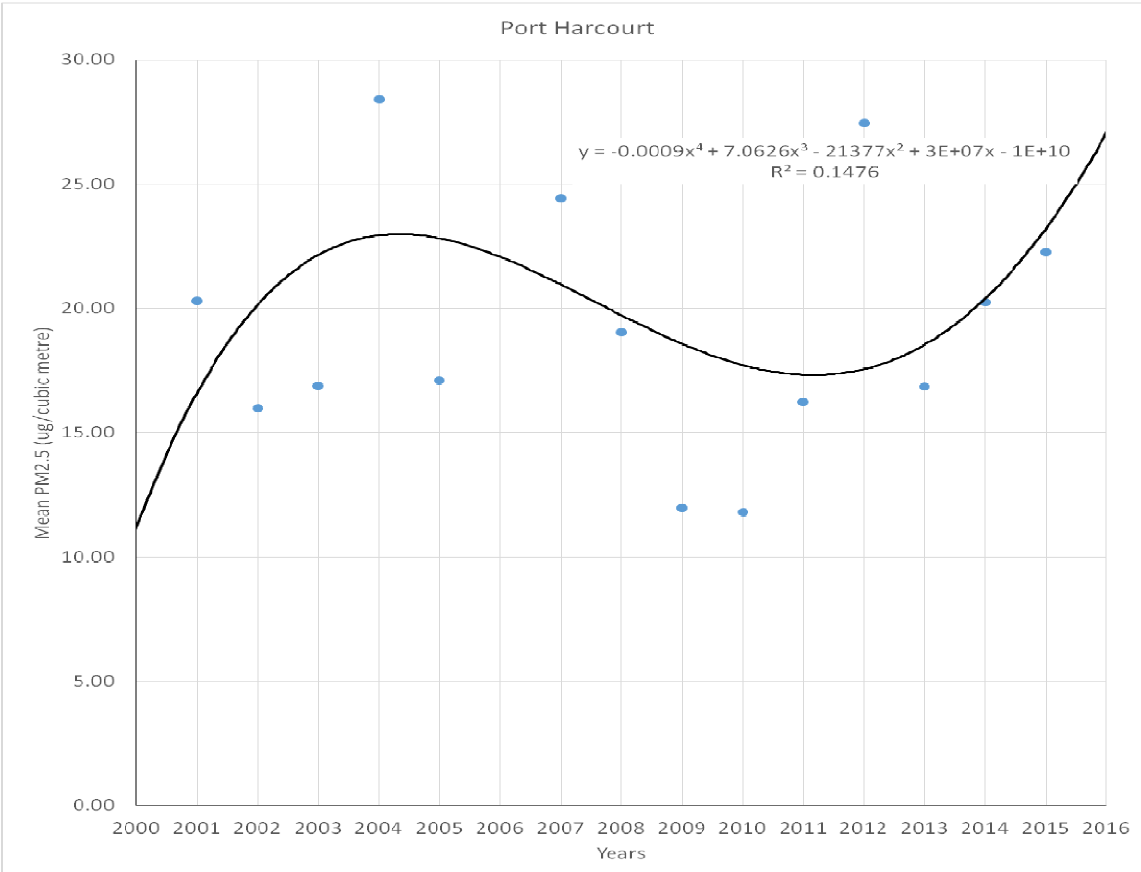

Fig. 7: Trend analysis of $PM_{2.5}$ across the year over the city of Port Harcourt

Across Port Harcourt, there is a wide variation over the year (Figure 7). Fitting a polynomial of the 4^{th} order to the trend was only able to capture about 15% of the variation across the years ($R^2 = 0.15$). From 2000 the trend appreciated sharply to mid 2004 where it had the peak, it then depreciates from 2005 to 2011 with deep trough and then started appreciating sharply till 2015. This showed that in Port Harcourt the $PM_{2.5}$ concentration is very high at the peak in id 2004, dropped sharply till 2011 and started increasing sharply towards 2015 with the highest outlier in 2004 and the lowest in 2010.

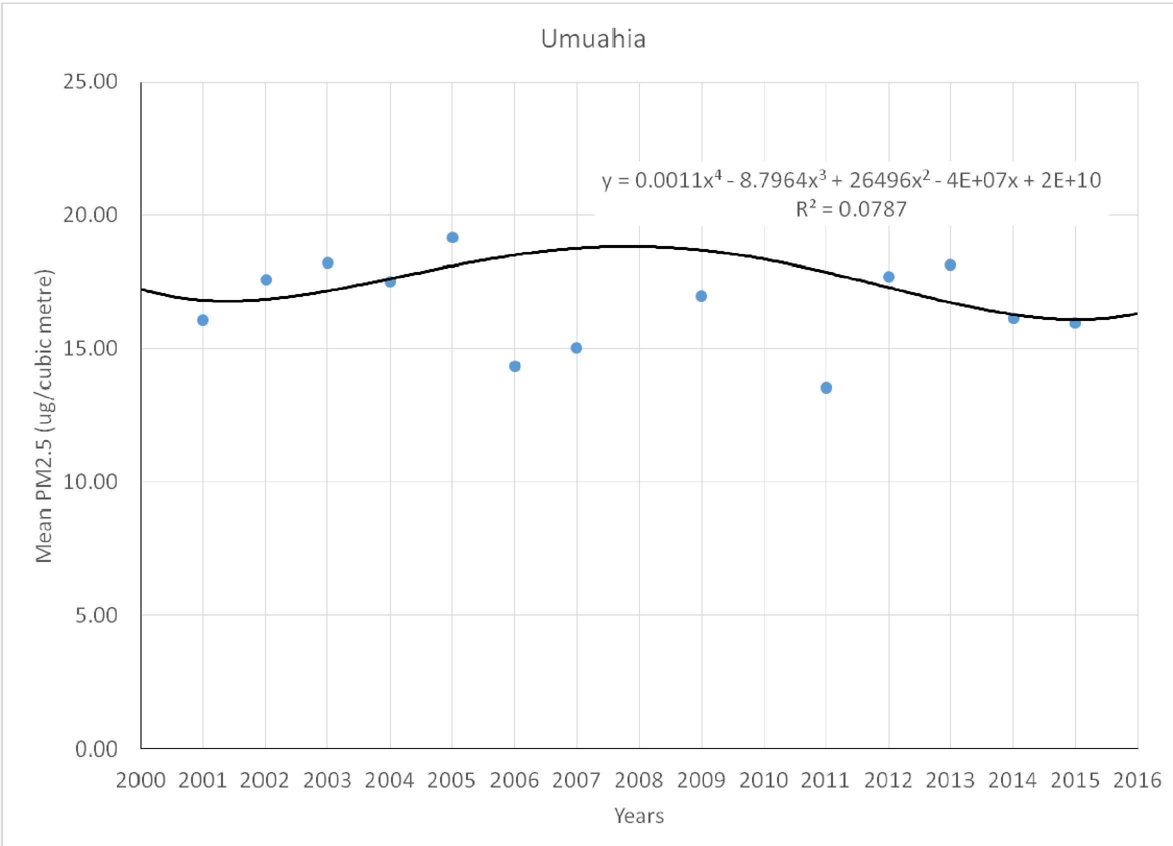

Fig. 8: Trend analysis of $PM_{2.5}$ across the year over the city of Umuahia

Across Umuahia, there is no wide variation over the year (Figure 8). Fitting a polynomial of the 4th order to the trend was only able to capture about 08% of the variation across the years ($R^2 = 0.08$). From 2000 there was a decrease towards 2001 with trough, then a steady increase from 2002 towards 2008 with peak and a steady decrease from 2010 to 2014 with another trough where it started appreciating towards 2015. This showed that in Umuahia the $PM_{2.5}$ concentration was low with trough in 2001, high at the peak in 2008, dropped low in 2014 and started increasing towards 2015 with the highest outlier in 2005 and the lowest in 2011.

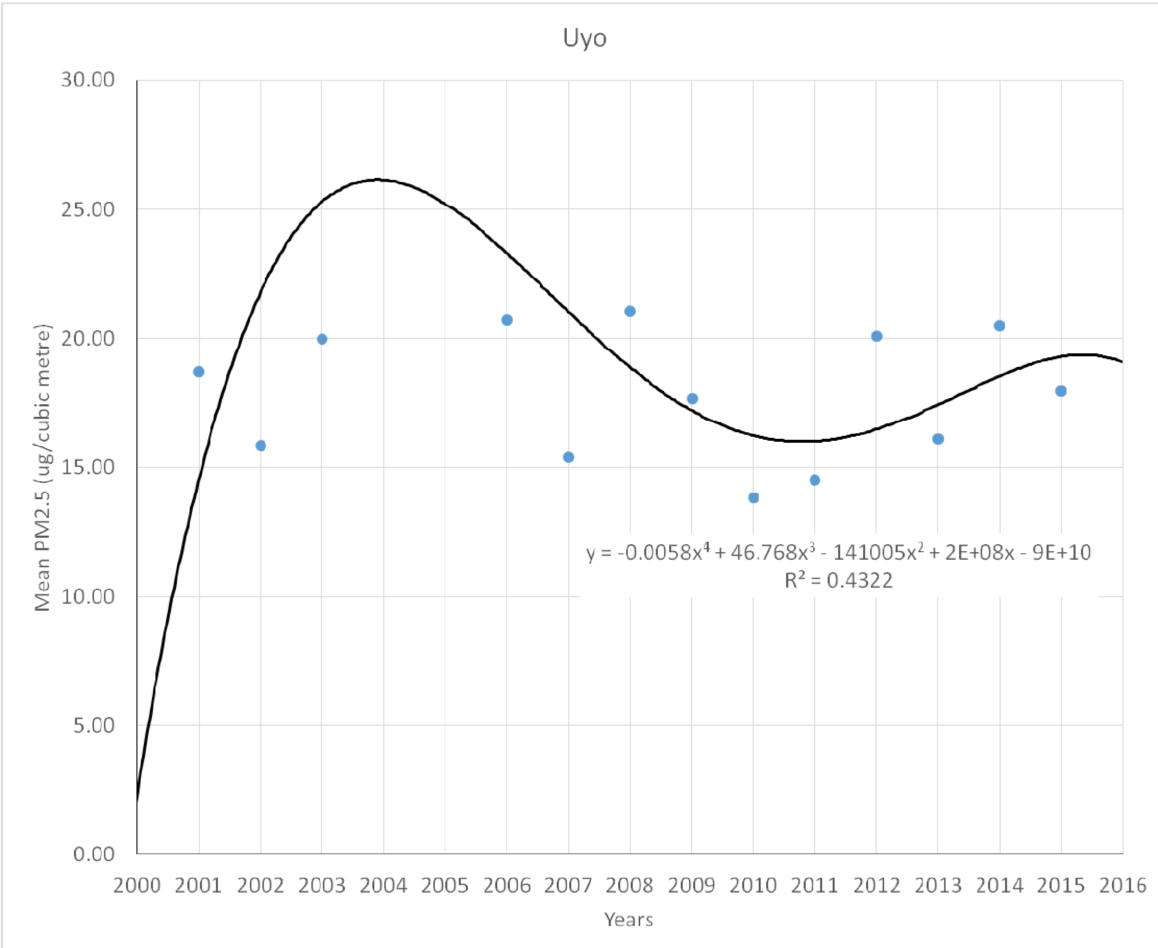

Fig. 9: Trend analysis of $PM_{2.5}$ across the year over the city of Uyo

Across Uyo, there is a wider variation over the year (Figure 9). Fitting a polynomial of the 4th order to the trend was only able to capture about 43% of the variation across the years (R^2 = 0.43). From 2000 the trend appreciated sharply to 2004 where it had the peak, it then depreciated from sharply from 2005 to 2010 with deep trough and then started appreciating from 2012 to 2015 with another trough. This showed that in Uyo the $PM_{2.5}$ concentration is very high at the peak in 2004, dropped sharply in 2010 and started increasing towards 2015 with the highest outlier in 2008 and the lowest in 2010.

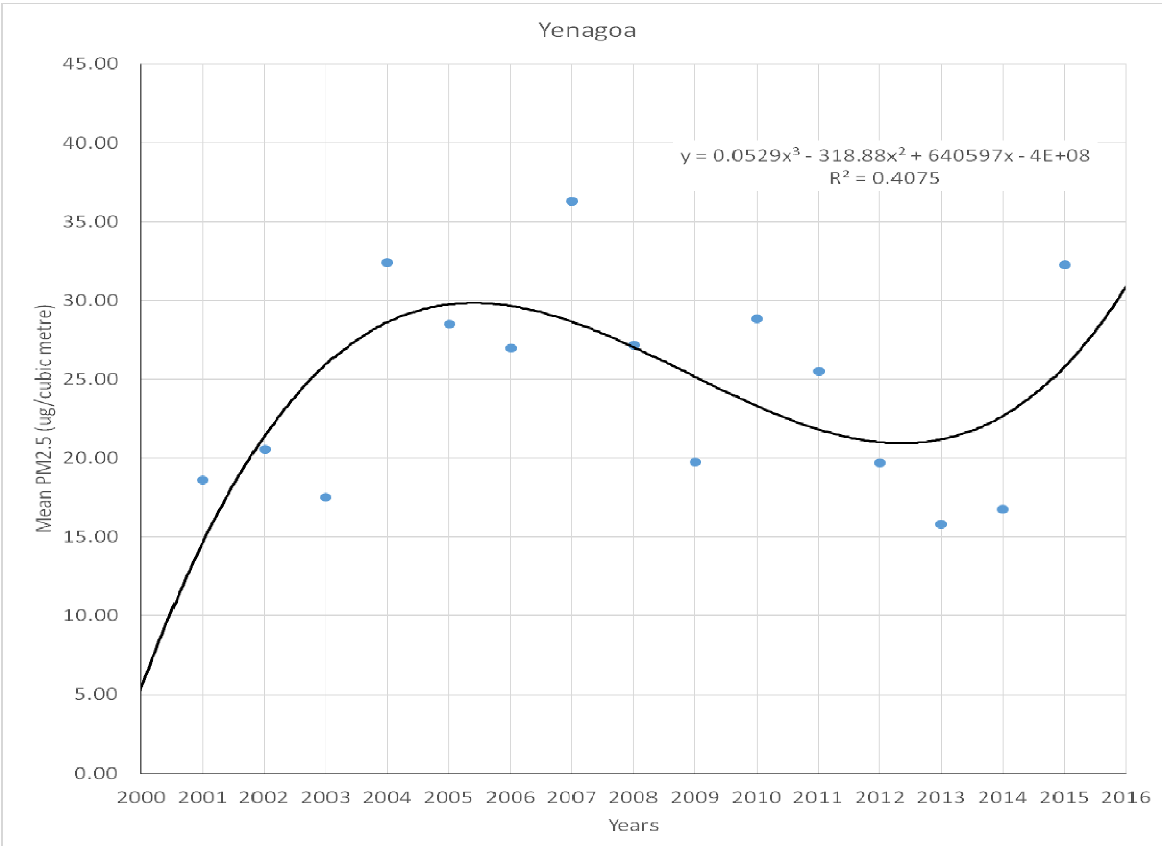

Fig. 10: Trend analysis of $PM_{2.5}$ across the year over the city of Yenagoa

Across Yenegoa, there is a wider variation over the year (Figure 10). Fitting a polynomial of the 3rd order to the trend was only able to capture about 41% of the variation across the years ($R^2 = 0.41$). From 2000 the trend appreciated sharply to 2005 where it had the peak, it then depreciated from 2006 to 2012 with deep trough and then started appreciating till 2015. This showed that in Yenagoa the $PM_{2.5}$ concentration was very high at the peak in 2005, dropped very low in 2012 and started increasing towards 2015 with the highest outlier in 2007 and the lowest in 2013.

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, The work of (Lawal and Asimiea, 2015) in Nigeria corroborated this study which revealed that the increase in rate of $PM_{2.5}$ concentration 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. The increasing trend of $PM_{2.5}$ has a significant global and regional effects on people with asthma, cardiovascular or lung disease, as well as children and elderly people that are considered to be the most sensitive to the effects of fine (PM) (Anenberg *et al.,* 2010; Evans *et al.,* 2012; Lim *et al.*, 2012) 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.

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 trend of the mean annual concentration of $PM_{2.5}$ 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 general trend of $PM_{2.5}$ concentration observed revealed that there is an increase in $PM_{2.5}$ concentration across the region; therefore, there should be guideline values which are meant to provide targets and thus promote movement towards a lower PM concentration. The rate of increase in $PM_{2.5}$ across the Niger delta creates a significant burden on the national health infrastructure and contributes to great risks to human and sustainable development.

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