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# Remote sensing approach for aerosol optical thickness (AOT) monitoring in relation to the road network in Lagos Metropolis, Nigeria

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**ABSTRACT**

There are knowledge gaps in understanding the dynamics between air quality and road network traffic. This study used Landsat imageries of Lagos Metropolis at two epochs (2002 and 2020) as well as in-situ data to assess the AOT levels and its variation along the road networks of Lagos Metropolis. The python based 6S model was used to simulate AOT using land surface reflectance and top of atmosphere reflectance, and the AOT concentration levels across the road networks were mapped. It was observed that the AOT concentration throughout the study period was higher along the major roads. This can be attributed to the high level of air pollutants released from vehicles, including home/office generators and industries along the road corridors. As a result, the government and air quality agencies should establish more programs or measures to curb this high air pollution concentration.

## 1. Introduction

Lagos State being the fastest-growing urban center in Nigeria, has been experiencing air pollution problems in all its severity over the past decades. This is associated with high density of industries, transport networks, and open waste burning (Njoku et al., 2016). An increase in technological, industrial and agricultural advancement, coupled with increase in population growth, has triggered the deterioration of environmental air quality in Lagos State (Njoku et al., 2016). In Lagos, the socio-economic conditions, traffic congestion, proximity to emission sources and access to healthcare create a differential susceptibility to ill health attributable to air pollution (Komolafe et al., 2014). Daily, more than eight million people, moving in five million vehicles, cram into a very small network of roads every day (CNN Travel, 2019). The Lagos metropolis has been recognized as one of the world's megacities undergoing rapid urbanization and urban sprawl. According to some recent findings on the cost of air pollution in Lagos (World Bank, 2020), it was discovered that ambient air pollution led to premature death and economic loss of $2.0 billion in the state in 2018. In the same year, ambient air pollution led to about 11,200 premature deaths. Notably, the concentration levels of $PM_{2.5}$ recorded in Lagos have exceeded the WHO annual mean concentration guideline. For example, Lagos had recorded levels of 68 $\mu g/m^3$, in the same range as other polluted megacities such as Mumbai (64 $\mu g/m^3$), Cairo (76 $\mu g/m^3$), and Beijing (73 $\mu g/m^3$). The major source of ambient air pollution in the state is due to vehicular emissions. It is noteworthy that each kilometer of the road is clogged by 227 vehicles every day, which is a very high density. Also, most vehicles use old emission technologies and fuel with sulphur levels that are 200 times higher than the standards for diesel in the U.S. Besides, industrial emission is another source of air pollution in Lagos. Industrial and commercial activities in the metropolis have high levels of pollution. Emissions from generators that supply about 50% of the total energy in the state are another major source of air pollution. Consequently, this study monitored the changes in air pollution

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concentration over Lagos metropolis and its relationship with road network traffic over 2 epochs (2002 and 2020).

## 2. Methods

### 2.1. The study area

The study location is Lagos, Nigeria. It is the commercial center and most populous city of the country and Africa's second-largest city, with a total population of 21.3 million people within the Lagos metropolitan area. Lagos Metropolis lies between latitudes 6°20'00''N - 6°42'10''N and longitudes 3°02'30''E - 3°42'40''E. Fifty percent of Nigeria's industrial activities, including 300 industries, are located in this area. With its high rate of urbanization and industrial growth. Lagos is one of the world's most densely populated areas. The area has the highest concentration of economic activities in the country and provides employment to the work force of the country leading to highly trafficked roads. Lagos accounts for about 40% of new vehicle registrations in Nigeria and it is the most industrialized with greenhouse gas emissions.

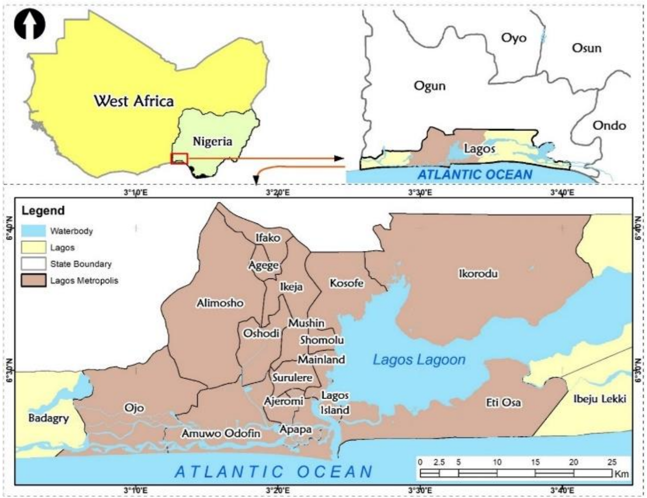


**Figure 1.** Map of the study area

### 2.2. Data acquisition

#### 2.2.1. Satellite imagery

Landsat imagery was used for the AOT retrieval in this study. The Landsat 8 OLI and Landsat 7 ETM+ imagery scenes (Path: 191, Row: 55) covering Lagos metropolis for the year 2002 (28th December) and 2020 (20th January) respectively were downloaded from USGS Earth explorer data archive.

#### 2.2.2. Particulate matter

Particulate matter ($PM_{1.0}$, $PM_{2.5}$, and $PM_{10}$) data were obtained with the ground-based air quality egg instrument. At the selected sites (Ojota, Iwaya, and Mushin), the device was used to acquire the PM data. The data were measured on a weekly basis between 9:00 am and 5:00 pm from February 2019 – July 2019.

#### 2.2.3. Road network

The road network data is readily available on the OpenStreetMap platform, and it can be downloaded for free. The data was downloaded with the BBBIKE web-based tool (https://extract.bbbike.org/) from the OpenStreetMap archive. The downloaded road layer came in different road categories including expressway, main road, minor road, and street. The road type used for this study is the expressway and main road.

### 2.3. Data processing

#### 2.3.1. Surface reflectance

The DDV technique was adopted in this study to estimate the surface reflectance. This was done using the improved dark-pixel method developed by Levy et al. (2010), which is dependent on Normalized Difference Vegetation Index (NDVI) and scattering angle. The equations for determining the surface reflectance are as follows (Luo et al., 2015; Ou et al., 2017):

*Calculating the surface reflectance using Landsat 8 OLI and Landsat 7 ETM*:

$$\rho_{s(0.66)} = f\left(\rho_{s(2.1)}\right) = \rho_{s(2.1)} \times slope_{0.66/2.1} + yint_{0.66/2.1} \quad (1)$$

$$slope_{0.66/2.1} = slope_{0.66/2.1}^{NDVI_{SWIR}} + 0.002 \times \Theta - 0.27 \quad (2)$$

$$yint_{0.66/2.1} = -0.00025\Theta + 0.033 \quad (3)$$

$$slope_{0.66/2.1}^{NDVI_{SWIR}} = 0.48 \qquad (NDVI_{SWIR} < 0.25)$$

$$slope_{0.66/2.1}^{NDVI_{SWIR}} = 0.58 \qquad (NDVI_{SWIR} > 0.75)$$

$$slope_{0.66/2.1}^{NDVI_{SWIR}} = 0.48 + 0.2 \times (NDVI_{SWIR} - 0.25) \quad (NDVI_{SWIR} < 0.25)$$

*Calculating the vegetation index*:

$$NDVI_{SWIR} = \frac{\rho_{TOA(1.6)} - \rho_{TOA(2.1)}}{\rho_{TOA(1.6)} + \rho_{TOA(2.1)}} \quad (4)$$

$$\Theta = \cos^{-1}(\cos\theta\cos\theta_0 + \sin\theta\sin\theta_0\cos(\Delta\varphi)) \quad (5)$$

*Where:*

$\rho_{s(0.66)}$ = red-band surface reflectance (ref)
$\rho_{s(2.1)} =$ *apparent ref, SWIR* 2 (band 7: L8 & band 6: L7)
$\rho_{TOA(1.6)} =$ *apparent ref SWIR* 1 (band 6 - L8 & band 5: L7)
$\rho_{TOA(2.1)} =$ *apparent ref SWIR* 2 (band 7: L8 & band 6: L7)
$\Theta$ = scattering angle
$\theta$ = *sensor zenith angle*
$\theta_0$ = *solar zenith angle*
$\Delta\varphi$ = *relative azimuth angle*
$NDVI_{SWIR}$ = *Normalized difference Vegetation index*

#### 2.3.2. Look-up table

Py6S is a Python interface to the 6S model. In this study, the 6S model was run on the Python interface to simulate the atmospheric properties of the Landsat 8 OLI and Landsat 7 ETM sensor for blue and red bands.

## 3. Results

This section presents the results of the different processing and analysis carried out in this study. These include the AOT maps, Road network-AOT maps, and analysis of the relationship using correlation coefficient (r), between PMs, AOT and the road networks. These are presented in Figures 2 and 3 and Tables 1 and 2 respectively. These results are discussed in Section 4.

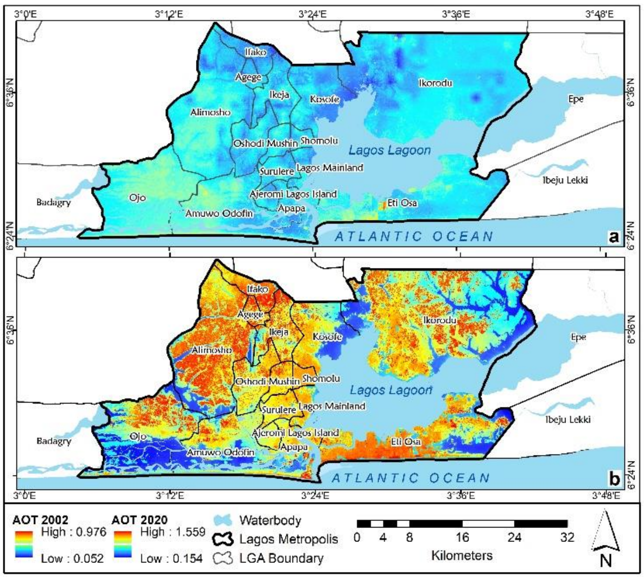


**Figure 2.** AOT distribution map in Lagos metropolis - (a) 2002 (b) 2020

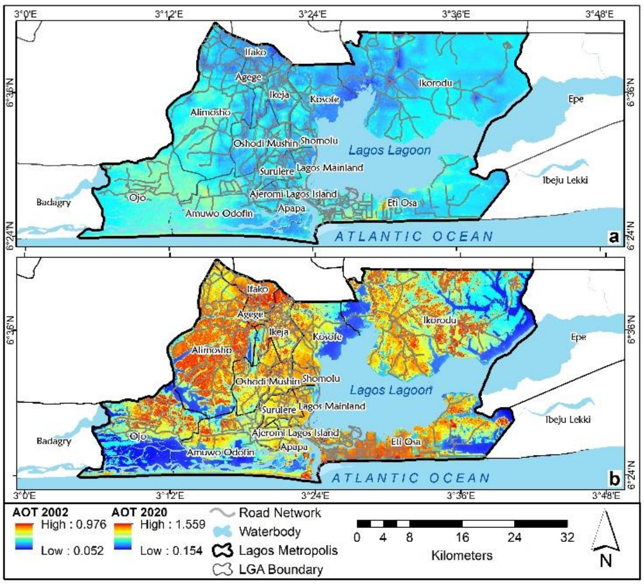


**Figure 3.** AOT distribution along Lagos road network – (a) 2002 (b) 2020

**Table 1.** Coefficient of correlation (r) between imagery-derived AOT for year 2020 and in-situ PM data at three locations in Lagos Metropolis

| Location | | $PM_1$ | $PM_{2.5}$ | $PM_{10}$ | AOT |
|---|---|---|---|---|---|
| Ojota | $PM_1$ | 1.000 | 0.999 | 0.996 | -0.616 |
| | $PM_{2.5}$ | 0.999 | 1.000 | 0.997 | -0.616 |
| | $PM_{10}$ | 0.996 | 0.997 | 1.000 | -0.669 |
| | AOT | -0.616 | -0.616 | -0.669 | 1.000 |
| Iwaya | $PM_1$ | 1.000 | 0.994 | 0.989 | 0.256 |
| | $PM_{2.5}$ | 0.994 | 1.000 | 0.996 | 0.284 |
| | $PM_{10}$ | 0.989 | 0.996 | 1.000 | 0.285 |
| | AOT | 0.256 | 0.284 | 0.285 | 1.000 |
| Okobaba | $PM_1$ | 1.000 | 0.9865 | 0.977 | 0.705 |
| | $PM_{2.5}$ | 0.987 | 1.000 | 0.999 | 0.726 |
| | $PM_{10}$ | 0.977 | 0.999 | 1.000 | 0.728 |
| | AOT | 0.705 | 0.726 | 0.728 | 1.000 |

**Table 2.** Concentration of aerosol optical thickness on road corridors

| Year | Region | Area (km²) | AOT Min | Max | Range | Mean | SD |
|---|---|---|---|---|---|---|---|
| 2002 | ARN | 114 | 0.07 | 0.92 | 0.85 | 0.35 | 0.07 |
| | ORN | 1451 | 0.05 | 0.98 | 0.92 | 0.33 | 0.07 |
| 2020 | ARN | 114 | 0.43 | 1.71 | 1.28 | 1.31 | 0.15 |
| | ORN | 1451 | 0.36 | 1.75 | 1.39 | 1.05 | 0.38 |

*Note: ARN – Along road network; ORN – Outside road network*

## 4. Discussion

### 4.1. AOT distribution

There has been an increase in the AOT levels over Lagos metropolis, and this could be explained by the increasing urbanization in the state (Offor et al., 2016). The pollution from vehicular emissions, population congestion, industrial and commercial activities in Lagos State, and especially the metropolis have a deleterious impact on the wellbeing of residents. Akinyoola et al. (2018) reported that the aerosol loading/concentration is of high increase in Nigeria's south-south and south-western (coastal) region, and this corroborates the generally high aerosol concentration observed in the study area our findings.

### 4.2. Relationship between AOT and PM

Table 1 presents the correlation of ground-based sample PM data and year 2020 AOT concentration at selected locations of Lagos Metropolis. $PM_{2.5}$ and $PM_1$, $PM_{10}$ and $PM_1$ have a high positive association in Ojota. There is a negative association between AOT and PM in Ojota. The association between AOT and PM is positive but not high at Iwaya, but the correlation between $PM_{2.5}$ and $PM_1$, $PM_{10}$ and $PM_1$, $PM_{10}$ and $PM_{2.5}$ is quite strong. In Okobaba, there is a strong positive correlation between AOT and PM. There is also a strong positive correlation between $PM_{2.5}$ and $PM_1$, $PM_{10}$ and $PM_1$, $PM_{10}$ and $PM_{2.5}$. It can be observed that the correlation between AOT and the different sizes of PM in Ojota are negative, possibly due to the evening time of day this data was observed as opposed to the high positive correlation value in Okobaba, which was acquired during the daytime. The values showing the correlation between AOT and PM in Iwaya are positive but less in values compared to that in Okobaba.

### 4.3. Relationship between AOT and Road Network traffic

The concentration of AOT along the major roads in the Lagos Metropolis was also examined. Due to the low spatial variability of aerosol over a small area, a road buffer of 60 meters was used to examine AOT concentration along the road network. From the results, it was observed that the AOT concentration throughout the study period is higher along the major roads. This can be attributed to the high level of air pollutants emitted from vehicles, including home/office generators and industries located along the road corridors. From Table

2, the mean AOT along road network (ARN) is higher than that observed outside road network (ORN) for both years. From Figure 3, it was observed that the AOT concentration is higher along the major roads, especially in the center of the metropolis and over Eti-Osa region, except for the year 2002. The high AOT in these regions can be attributed to daily traffic experienced in the highly urbanized Eti-Osa LGA and the heavy vehicular activities in the metropolis.

## 5. Conclusion

This study has provided evidence of increased AOT levels and deteriorating air quality along major roads in Lagos State. The paucity of ground-based data limited the level of analysis performed to examine the relationship between AOT and particulate matter at a full scale. The lack of clear satellite imagery also limited the study to examine seasonal changes in the AOT concentration.

According to UNEP (2016), Nigeria is one of the countries without Ambient Air Quality Standards and air quality laws and regulations. The high AOT concentration observed in the metropolis necessitates the need to establish Ambient Air Quality Standards by the government. Air quality monitoring and modeling, in addition to the provision of AAQS, are significant instruments for air quality management. However, most countries only monitor air quality on a sporadic basis, if at all. Because there is a scarcity of air quality data, evaluating the potential air quality impacts on a country from multiple sources is challenging. As a result, the government should consider the establishment of multiple air quality monitoring stations to acquire real-time air quality information. The pollution from traffic activities in the metropolis manifested in the AOT concentration observed along the road network. The government should consider exploring clean mobility by creating national electric mobility strategies to reduce vehicular emissions. In addition, the government should enforce proper city planning to manage the urbanization growth in the metropolis.

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