

## Spatial and Temporal Variation of Particulate Matter Around Lagos Environs

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### ABSTRACT

Air monitoring is very essential for characterizing health risks, formulating cost-effective abatement strategies, creating and enforcing appropriate air quality standards, and as well as healthy urban planning. This study investigates the spatial and temporal variation of aerosol pollution in Lagos environs, Nigeria. Selected sampling locations were Computer Village (CV), Oshodi Garage (OG), Magodo Estate (MG), and Caleb International College (CIC). Associated anthropogenic activities were the basis for the selection of the sampling location. Measurements of particulate matters were undertaken by employing the AEROCET 531S device in these selected residential, academic, and commercial environments across Lagos State. The measurements were taken at approximately 2 m from the ground in each sampling location. Data analysis and visualization were executed with python to enhance the visualization of the spatial and temporal distribution of the different particulate matter within and across the locations. A pronounced gradient of the particulate matter concentrations ( $\mu\text{g}/\text{m}^3$ ) was observed across the study area. The study outcome demonstrates that particulate matter distribution is dominated by  $\text{PM}_{10}$  in all locations under consideration. The proportions of fine particles to coarse particles in these environments were low ranging from 0.027 – 0.277 in CV, 0.018 – 0.395 in OG, 0.080 – 0.291 in MG, and 0.028 – 0.272 in CIC. Findings from this study established the dominance of coarse particles assumed to be contributed by cement dust, coal dust, flour, paint spray, pollen, cloud droplets, etc.

**Keywords:** Particulate matter, Lagos, spatial, correlation matrix, heatmaps, python.

### Introduction

#### *Global Assessment of Air Pollution*

Particle pollution, otherwise particulate matter (PM) consists of particles of solids or liquids suspended in the air including dust, dirt, soot, and smoke (CDD, 2021; EPA, 2022). Pollution hurts ozone layer, ecosystems, climate, buildings, and most importantly human health. It is of greater harm when not visible or scented. Despite the reduction in the use of halons and chlorofluorocarbons, they typically remain in the

atmosphere for several decades later (WMO, 2021). Consequently, more chlorine and bromine in the atmosphere negatively impact the ozone at different altitudes (WMO, 2021). Pollution affects biodiversity of the ecosystem, either by shifting species composition or outright loss of sensitive species (EPA, 2021a). Pollution contributes to acidification of lakes, eutrophication of estuaries and coastal waters, and mercury bioaccumulation in aquatic food webs (EPA, 2021a). Particulate

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matter pollution can also lead to changes in rainfall, at regional scale, by multiplying condensation nuclei and in extreme cases, change circulation patterns (EPA, 2021b). Pollution also induce increase in average temperature of the planet due to man-released gases or atmospheric greenhouse gases, GHGs, like carbon dioxide, methane, nitrogen oxides, etc. that increase greenhouse effect (EPA, 2021b).

#### *The Risks of Air Pollution in Lagos*

More than 70% of industries in Nigeria comprising food, beverage, and tobacco; textile; pulp and paper products; chemical and pharmaceutical; wood and wood products; metal; electrical and electronic; plastics; motor vehicle and waste recycling are located in Lagos (Nwagwu and Oni, 2022). Lagos, being the highest consumer of energy, predominantly fossil-based (eg aviation gasoline, jet fuel, white spirit, and special boiling point industrial spirits, coke oven gas, petroleum coke and lubricants), suggestive to state that makes it one of the country's major contributors to carbon-dioxide emissions.

The potential impact of nitrous oxide ( $N_2O$ ), generated also from Waste Water Treatment Plants (WWTPs) is now gaining increased prominence.  $N_2O$  has been considered by Intergovernmental Panel on Climate Change (IPCC) as a greenhouse gas emission facilitating climate change (IPCC, 2013). The procedure of optimization to reduce GHG released from WWTPs among industries in Lagos was set in place in 2012 due to the level of increase (LSME, 2012).

Urban transport is the chief cause of air and noise pollution in Lagos. The study undertaken by Lagos Metropolitan Transport Management Authority (LAMATA) on air quality between 2003 and 2007 showed that vehicles promote approximately 43% of ambient air pollution making them the highest point source contributors

of carbon dioxide, followed by the manufacturing industries (Akanni, 2010). Lagos's transport sector contributes more than 50% of the total GHG in Nigeria (Maduekwe *et al.*, 2020).

Unique features such as high and rapidly increasing population, flat topography, extensive coastal areas, and high water table reaching 0.15 m below the surface in some areas, are predisposing factors that further increase Lagos's vulnerability to climate change impacts (LSME, 2012). The report predicted a temperature increase of 0.04 °C per year until the 2046 – 2065 period, a wetter climate that induces change in annual rainfall, extreme weather, and heat days. Anticipated effects among others include loss of livelihoods, sea-level rise, loss of physical infrastructure, increased risk of water-borne diseases, chronic respiratory illness, corrosion, acid rain and damage to crops.

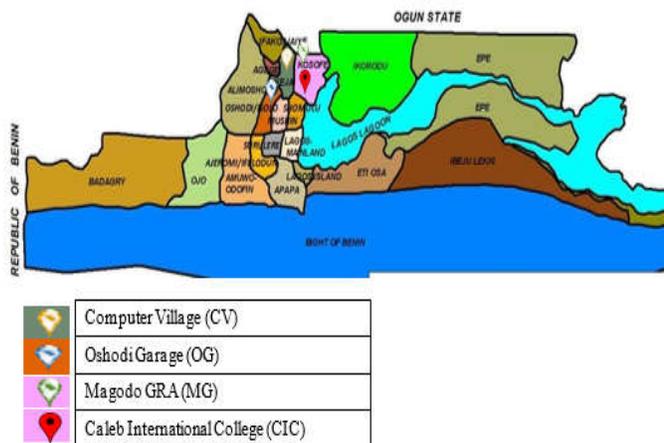
Therefore, air monitoring is of critical importance in characterizing health risks, and planning a healthy urban. More data are required to be strategically communicated, for increased public knowledge as well as effective policymaking. Also, where air quality standards are available, the wilful enforcement may be limited due to lack of adequate air monitoring data. While the challenges may be multifaceted, regular air monitoring remains an effort in the right direction. This study provides current data on the spatial and temporal distribution of aerosol pollution in Lagos environs.

## **Materials and Methods**

### ***Study Area***

The study area lies within Lagos state, the most populated city in Nigeria; it is regarded as the economic capital and commercial center of Nigeria (Lagosstate, 2022). Lagos state covers an area of 351,861 hectares and is well-known as the megacity which has the fourth-highest GDP in Africa (Lagosstate, 2022). National Population

Commission (NPC, 2016) estimated Lagos State's population to be approximately 9 million.



**Figure 1:** Map of Local governments in Lagos State

Commercial activities in all the Local Government Areas (LGAs) have grown over the years, especially in the selected sampling areas (Figure 1). The transport system within Lagos is mostly by road and fairly by water. Train service within the state is under upgrade and thus automobile stands the greatest means of intra and inter-transport. This has resolved into a series of daily dense traffic with huge numbers of inhabitants and automobiles competing for space within the city. The road transportation system encompasses private cars and commercial automobiles, buses, taxicabs, trucks, vans, trailers, tankers, etc., irrespective of the vehicle's health status.

### Sampling Locations

The selection of sampling location was based on the associated anthropogenic activities, the major factor responsible for air pollution in this environment. One of the sampling areas was the Computer Village (CV; (lat: 6.596377013948662, long: 3.3396727454945716) located in Ikeja, the home base of computers, phones, other electronics, and accessories. The second sampling area was Oshodi Garage (OG; lat: 6.562210010039824, long: 3.336861560212539),

known for its large market sites for various goods and services and also an important adjoining garage for intra and inter-state transports. Another sampling location was Magodo GRA (MG; lat: 6.61818627836619, long: 3.3772229795970556) Phase 2 estate, a planned, well-structured residential estate and one of the cultured areas on the Lagos Mainland: A serene, well-coordinated neighborhood with well-paved streets, adequate waste management, low rowdiness, and good traffic flow. The estate has its private shuttle buses, security patrol team, electricity substation, some hospitals/health centers, schools, and religious centers. An educational environment, Caleb International College (CIC; lat: 6.604359772217539, long: 3.3779394003758734), C.M.D Road Ikosi, was the fourth sampling location. The school is a clean conducive environment with a tarred road, good waste disposal, and well-coordinated activities within the premises. Notable spots around this environment are the MILE 12 market, Ketu market, and Olusosun landfill.

### Particulate Matter (PM) Measurement

The device employed for measurements was AEROCET 531S with an iso-kinetic probe for reducing count errors due to mismatched sample flow velocity. The device comprises a plug universal AC to DC converter module to charge the internal battery and an adjustable LCD. The device is a combined mass profiler and particle counter in a small, handheld, battery-operated, and completely portable unit that provides visual real-time count data in two channels LCD. The AEROCET 531 provides a fast indication of PM concentration for each cubic foot of sampled air for coarse particle  $PM_{10}$ ,  $PM_7$ ,  $PM_4$ , fine particles  $PM_{2.5}$ , ultrafine particle  $PM_1$ , with aerodynamic diameters respectively  $<10 \mu m$ ,  $<7 \mu m$ ,  $<4 \mu m$ ,  $<2.5 \mu m$ ,  $<1 \mu m$  and total suspended particle (TSP) which are the most regularly investigated particle size fractions when used as a Mass Profiler.

The device utilizes the stored particle count data from eight different particle size ranges (High sensitivity: 0.3  $\mu\text{m}$ , 0.5  $\mu\text{m}$ , 1.0  $\mu\text{m}$ , 5.0  $\mu\text{m}$ , and 10  $\mu\text{m}$ ; Low sensitivity: 0.5  $\mu\text{m}$ , 1.0  $\mu\text{m}$ , 5.0  $\mu\text{m}$ , and 10.0  $\mu\text{m}$ ) and a proprietary algorithm in obtaining the mass concentration for an aerosol sample. It also has a sensor that incorporates a long-life laser diode (90 mW, 780 nm), an efficient light-collecting elliptical mirror, and unique optics to provide a high concentration limit ranging from 0 – 3,000,000 particles per cubic foot at a size accuracy of  $\pm 10\%$  and 0.1 cfm (2.83 lpm) flow rate. The AC adapter/ charger is a Li-ion battery charger, 100 – 240 VAC, 50/60 Hz, 0.2 A. The device weighs 0.9 kg and it is 15.9 cm in height, 10.2 cm in width, and 5.4 cm in thickness. The sampling time for this device is 1 minute. The AEROCET 531S device was selected because of its availability and ease of operation.

Measurements were taken within the breathing level at an approximate distance of 2 meters (Abodunrin *et al.*, 2020) from the ground. The AEROCET 531S Particle Mass Profiler & Counter unit sampler was used in this work to measure the concentrations of PM<sub>1</sub>, PM<sub>2.5</sub>, PM<sub>4</sub>, PM<sub>7</sub>, and PM<sub>10</sub> and evaluate the size-segregated fractions of these atmospheric aerosols. The size absorptions of isolate aerosols (PM<sub>1.0</sub>, PM<sub>2.5</sub>, PM<sub>4</sub>, PM<sub>7</sub>, and PM<sub>10</sub>) were measured at the selected sampling locations during the rainy season. Measurements were taken at 8 am, 11 am, 2 pm, and 5 pm daily in each sampling location.

## Results and Discussion

The measured values were structured with excel. Python codes were written to access the pandas, NumPy, Scipy, matplotlib, and seaborn libraries, to assess the significance of the measured data. The temporal variations of the particulate matter in each sampling location are represented with scattergrams of the collocated pairs (Figures 2 – 5) and heatmaps (Figures 6 – 9). The null data (NaNs) in the data specified in MG were identified, counted, and dropped by parsing the

necessary line codes. The Figures represent the data plots and output of Spearman correlation coefficients of the PMs concentrations by location. A pronounced gradient of the particulate matter variation ( $\mu\text{g}/\text{m}^3$ ) was observed across the study area. The strength of the correlation between fine particles, PM<sub>1</sub> and PM<sub>2.5</sub>, in each location is either moderate or very strong; 0.89 in CV, 0.57 in OG, 0.53 in MG, and 0.88 in CIC. The fractional difference PM<sub>1</sub>/PM<sub>2.5</sub> range from 0.15 – 0.70 in CV, 0.08 – 1.00 in OG, 0.13 – 0.63 in MG and 0.29 – 0.70 in CIC. Though the variability in fine particles is dominated by PM<sub>2.5</sub>, ultrafine particles, PM<sub>1</sub>, generally comprising automobile emission, combustion particles, cigarette smoke, bacteria, and viruses at varying degrees have contributed to the total fine particles distributed over these environments. The ratio (PM<sub>1</sub>+PM<sub>2.5</sub>)/(PM<sub>4</sub>+PM<sub>7</sub>+PM<sub>10</sub>) range from 0.027 – 0.277 in CV, 0.018 – 0.395 in OG, 0.080 – 0.291 in MG and 0.028 – 0.272 in CIC. This demonstrates that the proportion of fine particles to the coarse particles in these environments is low. The temporal variation of the measured PMs concentration in this study reveals higher distributions of inhalable coarse particles compared to fine particles in the air (Haoran *et al.*, 2022).

Except for OG, similar variation patterns were observed within the study area with a positive correlation among all PMs. The fine particles' concentrations increased as the inhalable coarse particles' concentrations increased. Barring PM<sub>4</sub>, the strength of this relationship accent from very weak to strong; 0.48 and 0.37 in CV, 0.01 and -0.028 in OG, 0.6 and 0.54 in MG, 0.26 and 0.18 in CIC. There was a high rate of construction of roads and buildings cum industrial activities in OG during the period of measurements and observably, the environment was hazy. PM<sub>4</sub> exhibits a moderate to very strong positive correlation relative to fine particles distributions but for OG where a very weak relation was observed with PM<sub>1</sub>. The fractional difference,

(PM1+PM2.5)/PM4, exceed unity: 0.24 – 1.12 in CV, 0.16 – 1.50 in OG, 0.39 – 1.32 in MG, and 0.30 – 1.02 in CIC, sufficient to state that the data from this study could not satisfactorily establish the contribution of fine particles to PM4 distribution in each environment. The coarse particles PM7 and PM10 distributions are of a very strong relation with correlation coefficients of either 0.99 or 1, indicating a high degree of spatial uniformity. PM7/PM10 ratio is 0.51 – 0.98 in CV, 0.52 – 0.97 in OG, 0.60 – 0.92 in MG and 0.51 – 0.93 in CIC showing that the proportion of PM7 to PM10 distribution is less than unity. The statistical analyses of these data demonstrate that the variability in coarse particles is lower than that of fine particles. The correlation matrices were generated and presented as heatmaps in Figures 6 – 9. The lighter the color, the stronger the strength of the relationship.

The spatial variations of particular PM across the sampling locations are presented with scatter plots in Figures 10 – 15 and heatmaps in Figures 16 – 21. The variation of PM concentrations appears more significant across the study area than within each sampling location. The data points spread out, and demonstrate no trend or very weak correlation between PM1 from one location to the other. The distribution of PM1 in any of the sampling locations does not statistically represent the distribution across the study area. PM2.5 follows the same trend. The gradient is deeper for the coarse particles and more pronounced with PM10 and TSP. More dark boxes appeared on the heatmaps for PM10 and TSP demonstrating very weak or no relationship across the study area. Suffice to say that the data for any of these locations do not statistically represent the entire study area implying high temporal and spatial variation across the study area.

In locations with a high distribution of coarse particles and low distribution of fine particles, the coarse component may impel the variations in PM10. In places where fine and coarse PM

distributions are analogous, the variability of PM10 will reveal the aggregate of the fine and coarse particle variability. However, except fine and coarse particles are highly correlated, which is unusual, the variability of PM10 will be less than that of other components. Hence, separate measurements of fine and coarse particles would better assess the statistical correlation between PM parameters and health outcomes (William and Helen, 1997).

The spatial and temporal variation of PMs in the study area demonstrates that the highest distributions occurred in OG with the exemption of PM2.5 which peaked in CV. PM10 distribution is the highest in all the locations with the peak observed in OG. The least PM distributions occurred in MG but PM7 was observed in CIC. Distribution of PM in CIC, though an academic environment, may have been influenced by activities in MILE 12 market, Ketu market, and Olusosun landfill lying in proximity. The peak TSP was observed in OG; OG is a commercial environment with dense traffic most time, high level of construction and industrial activities may inform the level of pollution observed in this study and connote high risk to the health of occupants.

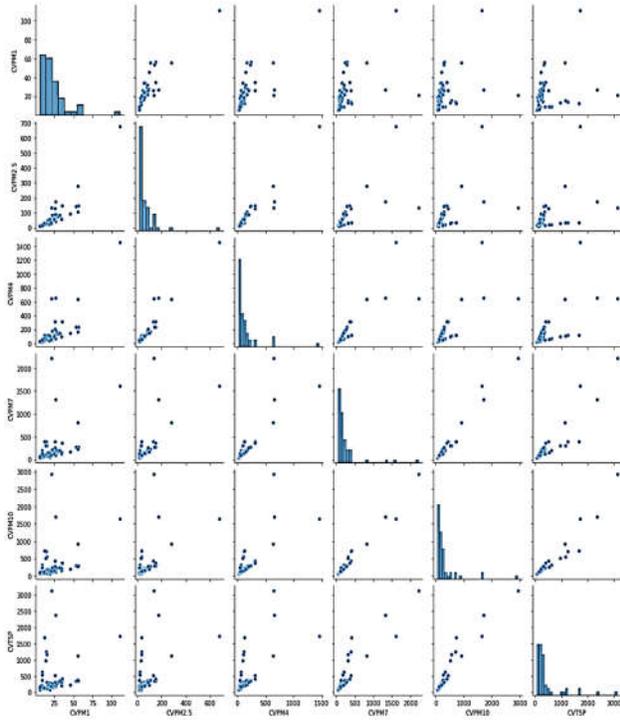


Figure 2: Spatial and Temporal Distribution of PMs in CV

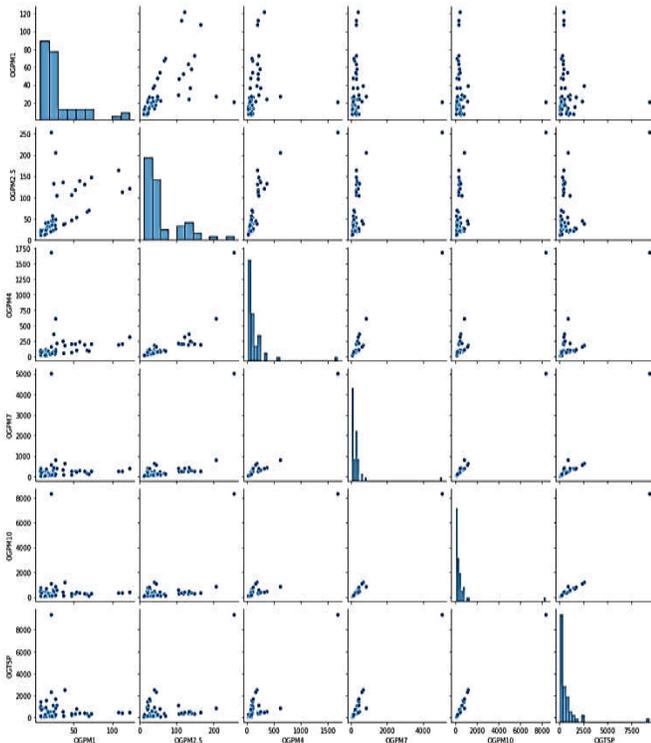


Figure 3: Spatial and Temporal Distribution of PMs in OG

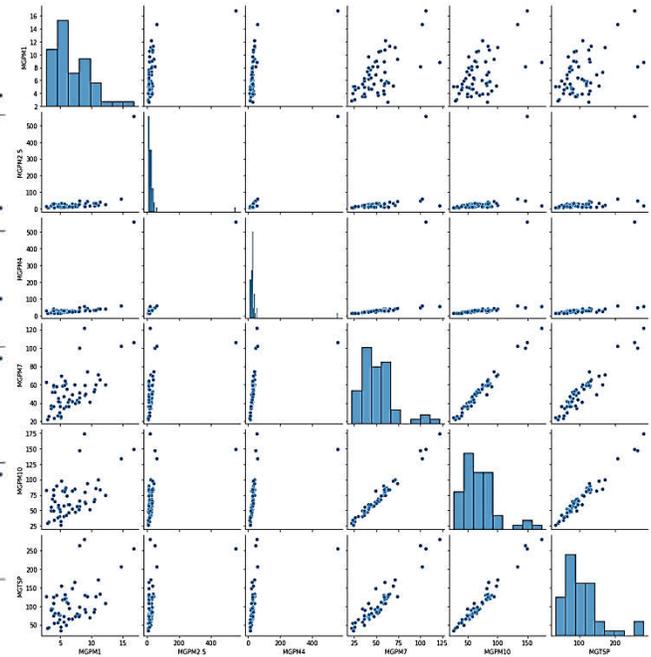


Figure 4: Spatial and Temporal Distribution of PMs in MG

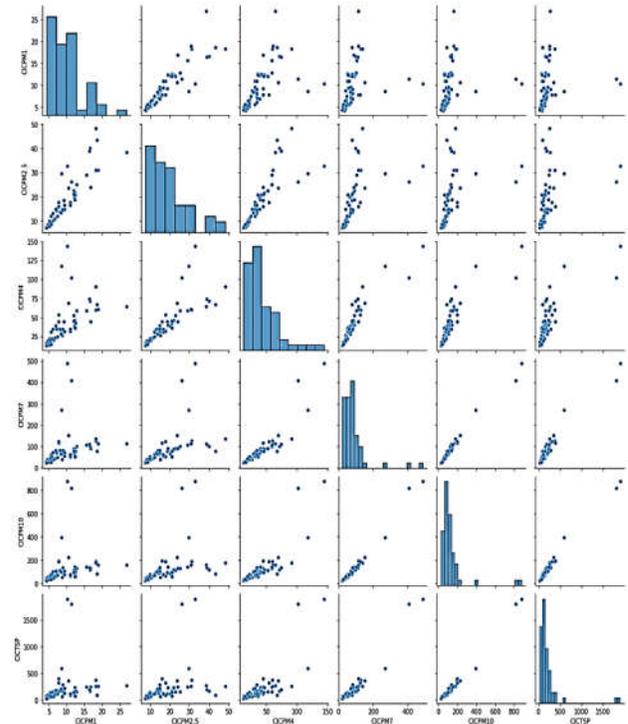


Figure 5: Spatial and Temporal Distribution of PMs in CIC

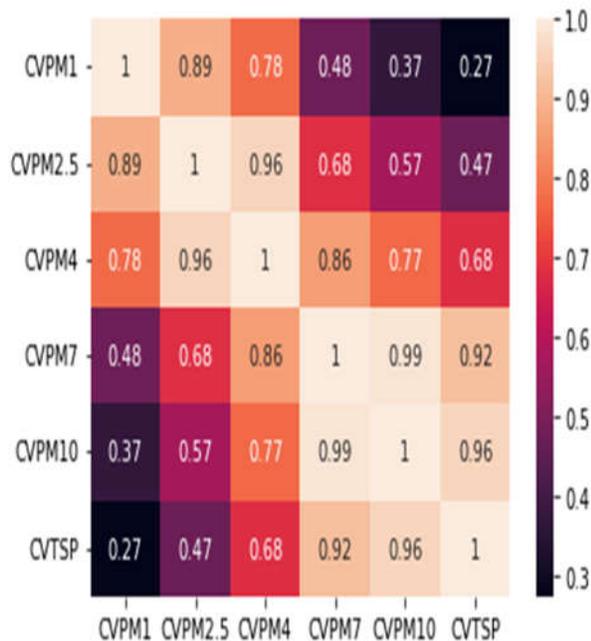


Figure 6: Heatmap Showing the Correlation Matrix in CV

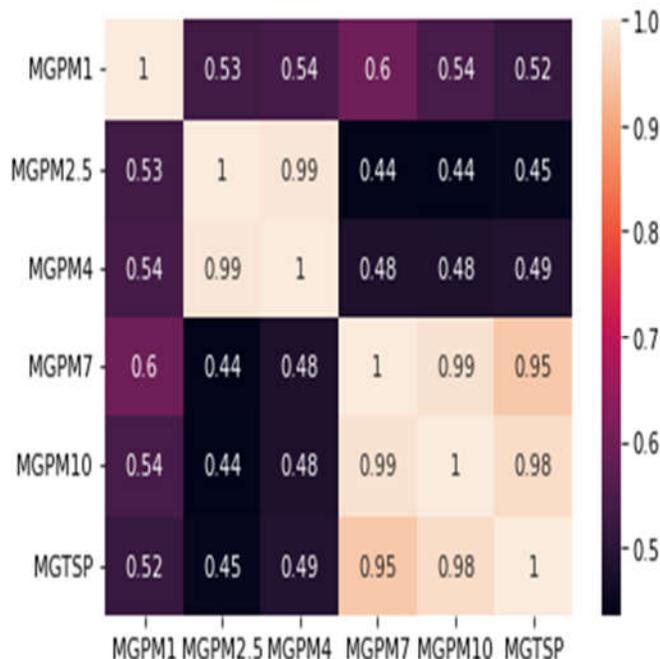


Figure 8: Heatmap Showing the Correlation Matrix in MG

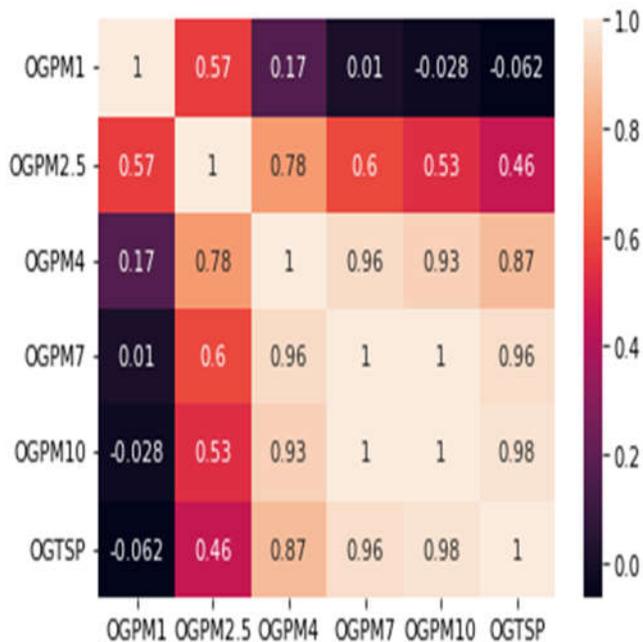


Figure 7: Heatmap Showing the Correlation Matrix in OG

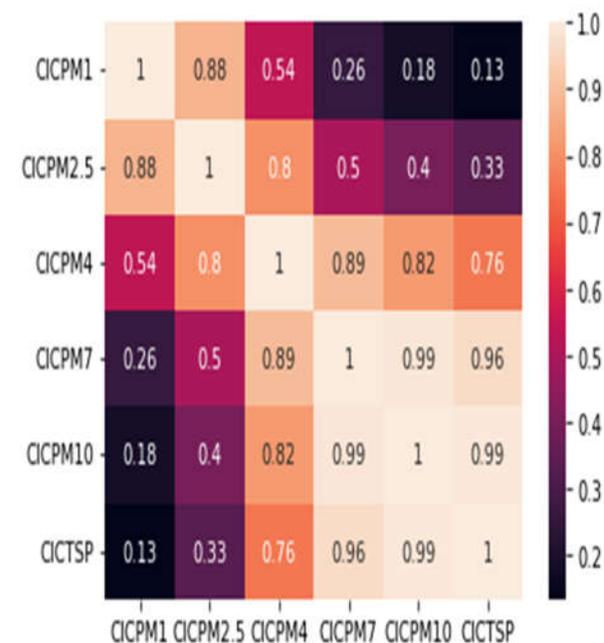


Figure 9: Heatmap Showing the Correlation Matrix in CIC

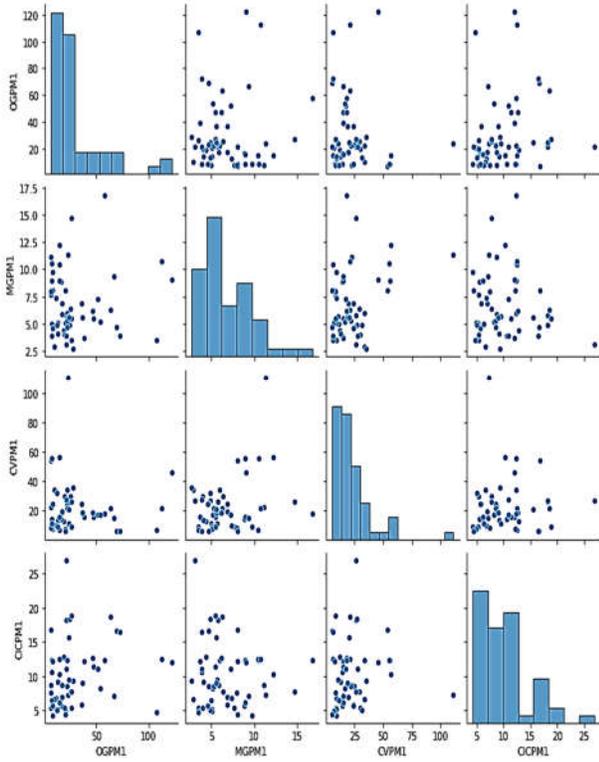


Figure 10: Spatial and Temporal Distribution of PM1 across the Study Area

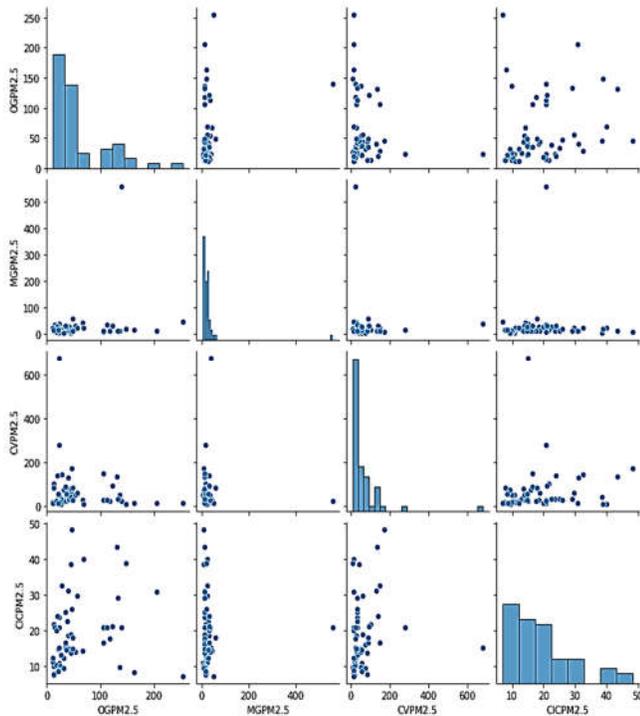


Figure 11: Spatial and Temporal Distribution of PM2.5 across the Study Area

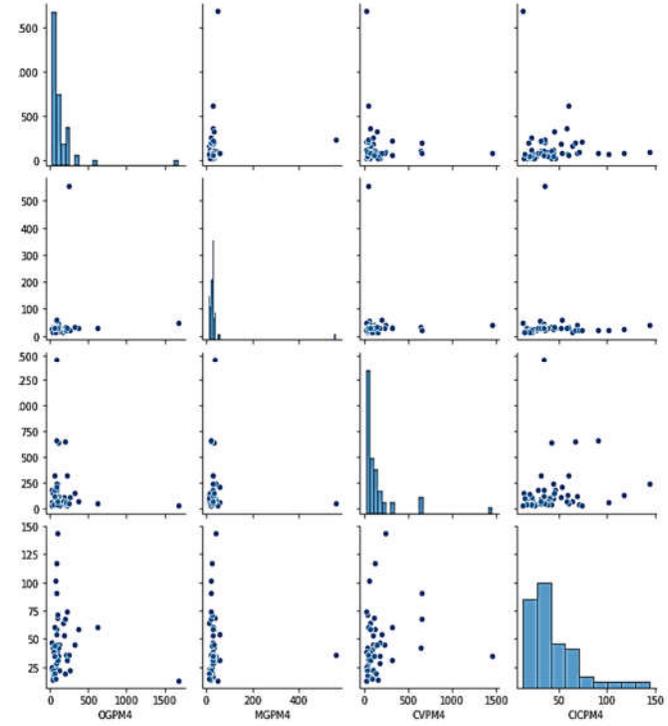


Figure 12: Spatial and Temporal Distribution of PM4 across the Study Area

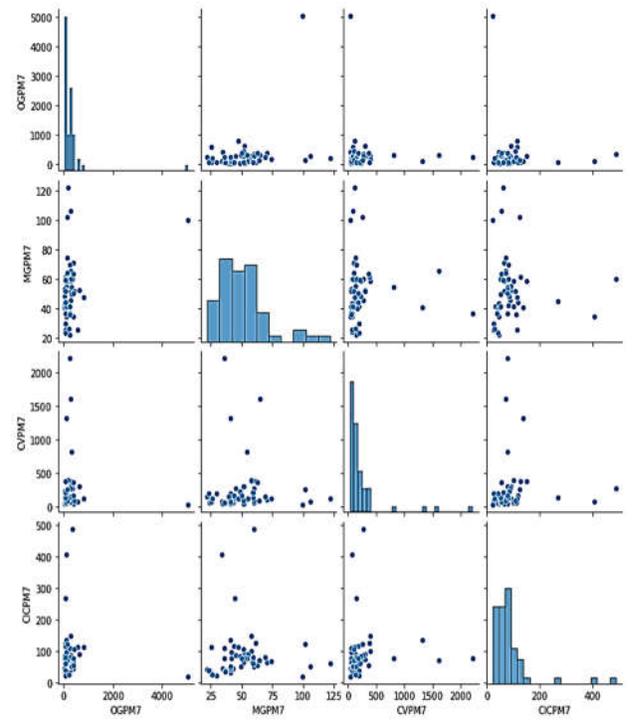
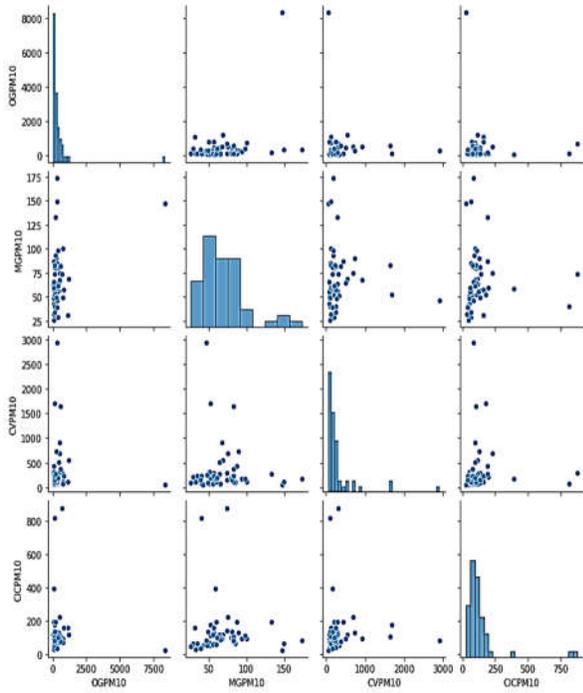
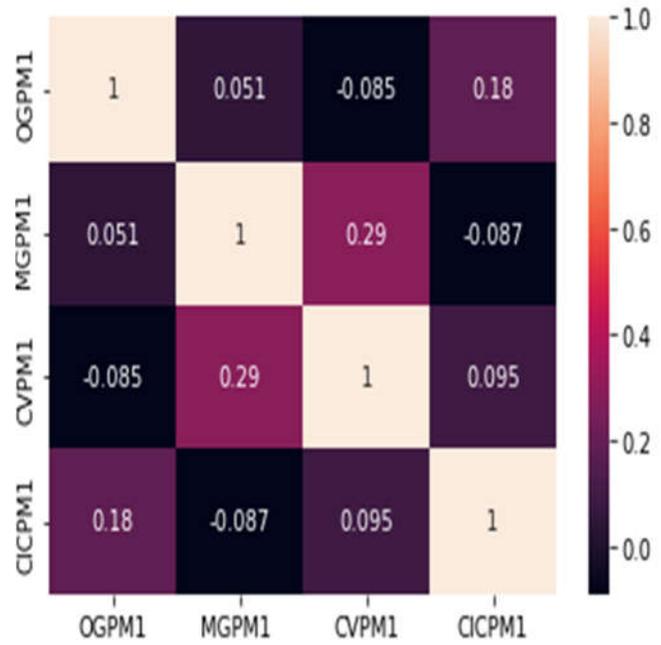


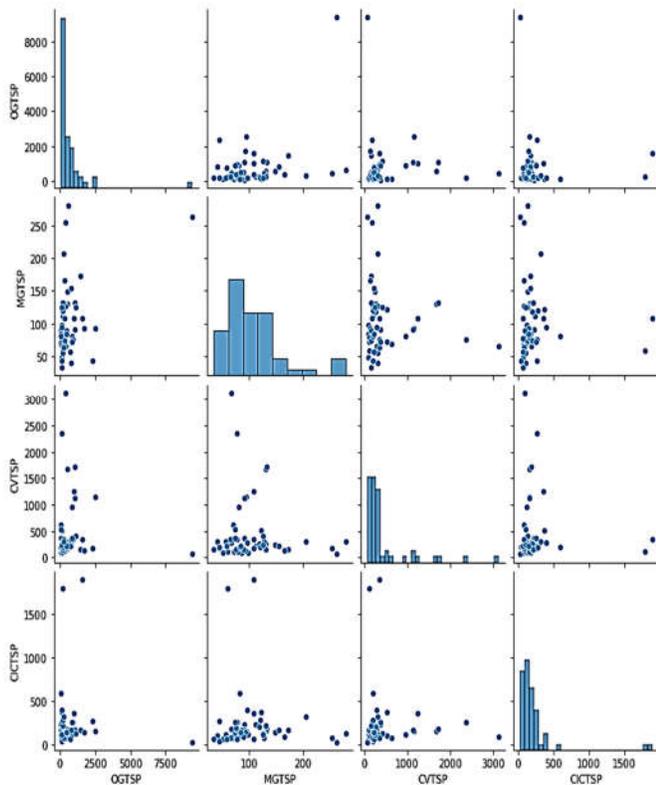
Figure 13: Spatial and Temporal Distribution of PM7 across the Study Area



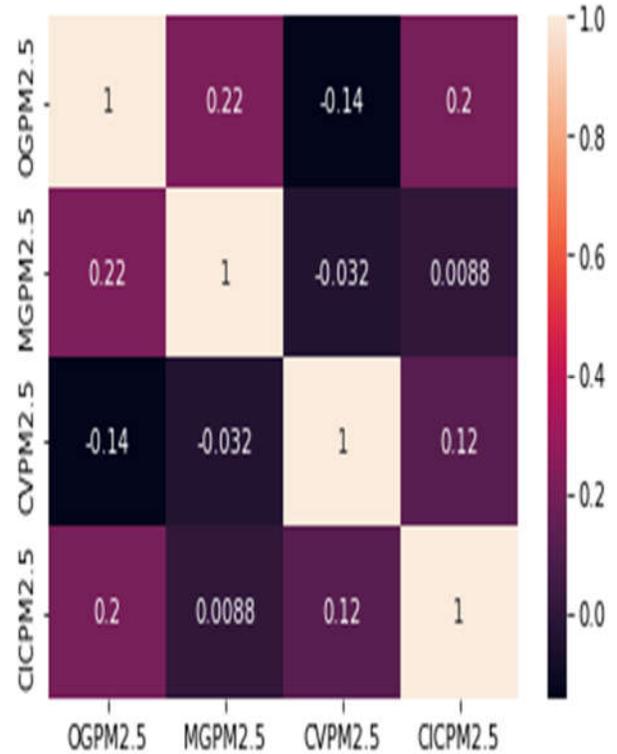
**Figure 14:** Spatial and Temporal Distribution of PM10 across the Study Area



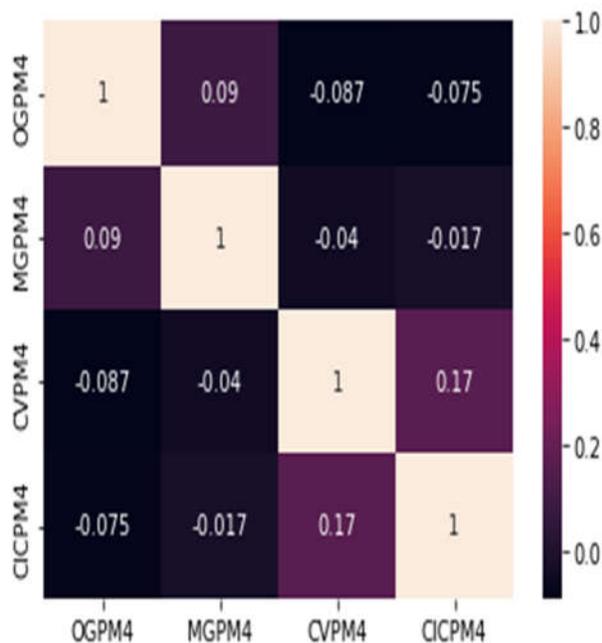
**Figure 16:** Heatmap Showing the Correlation Matrix of PM1 across the Study Area



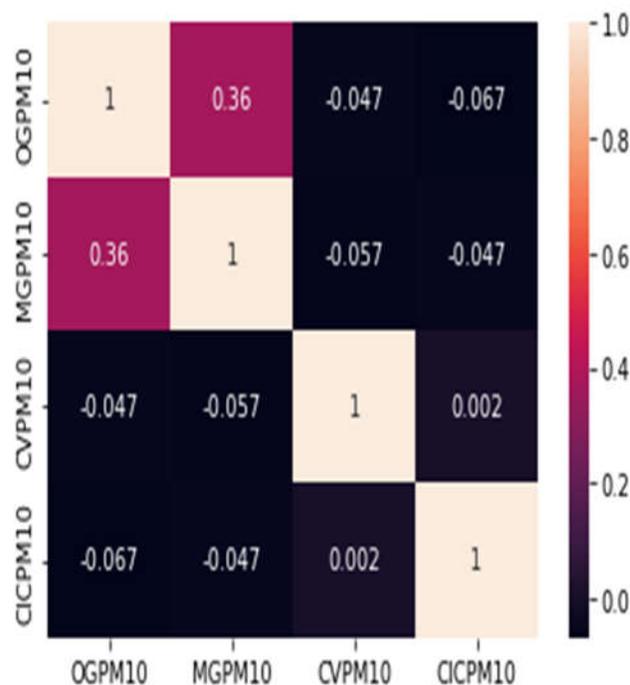
**Figure 15:** Spatial and Temporal Distribution of TSP across the Study Area



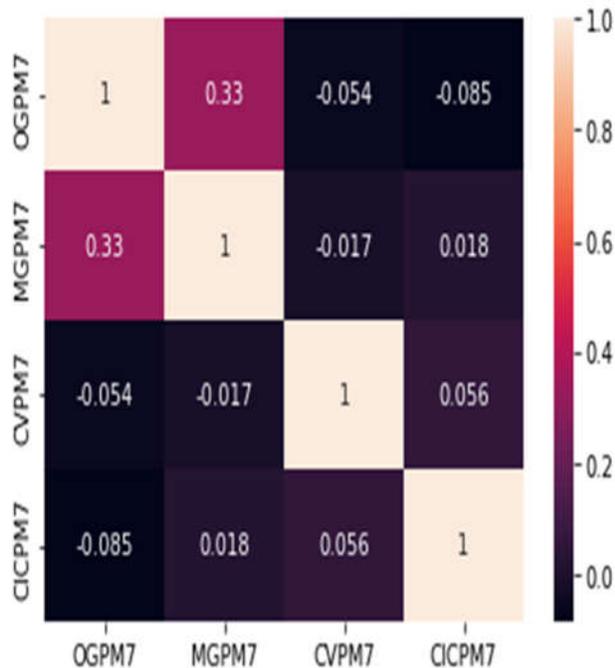
**Figure 17:** Heatmap Showing the Correlation Matrix of PM2.5 across the Study Area



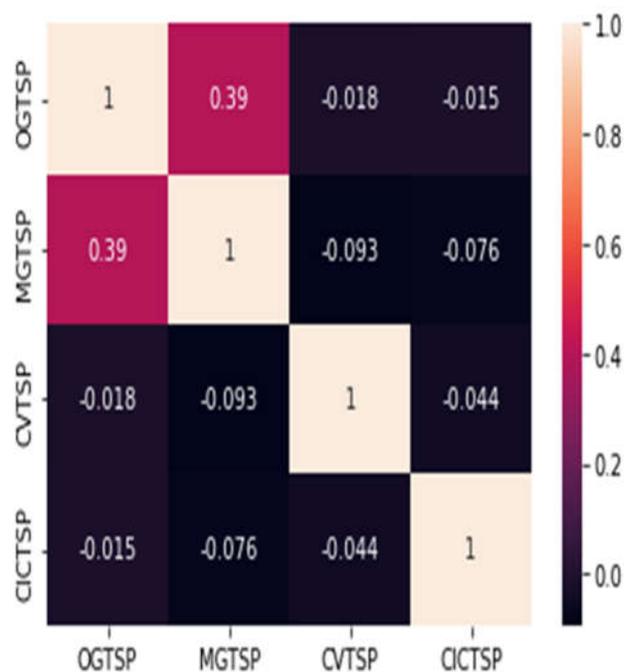
**Figure 18:** Heatmap Showing the Correlation Matrix of PM4 across the Study Area



**Figure 20:** Heatmap Showing the Correlation Matrix of PM10 across the Study Area



**Figure 19:** Heatmap Showing the Correlation Matrix of PM7 across the Study Area



**Figure 21:** Heatmap Showing the Correlation Matrix of TSP across the Study Area

## Conclusion

The spatial and temporal variation of particulate matters in Lagos environs have been investigated and the data have been made available in this study. The combination of ultrafine particles and fine particles into PM<sub>2.5</sub> reduces the daily variability of PM<sub>2.5</sub> and, hence, its effectiveness as a particle indicator for spatial variability of fine particles in each location. Measurements carried out in different locations suggest more spatial non-uniformity of fine particle concentrations relative to coarse particle concentrations. The significance of this is that the daily variability of the ambient fine particle concentrations at one location is not expected to yield a reasonable indication of the variability of the ambient fine particle concentrations across the study area. Similarly, the daily variability of the concentration of coarse particles in one location may not be expected to yield a fairly indication of the variability in the concentration of ambient coarse particles across the study area. Owing to the differences in sources, properties, and composition, coarse and fine particles should be regarded as separate categories of pollutants and measured accordingly. Determination of the geographical distribution of coarse and fine particles is necessary for statistical confidence of representative concentrations of fine or coarse particles across an urban area.

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## Conflict of Interest

The author declares no conflict of interest concerning the publication of this article.

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