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Article

# Diurnal, Monthly and Seasonal Variation in Ambient Air Pollution and Respiratory Conditions in Selected Industrial Locations in Lagos State, Nigeria

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## Abstract

Air pollution levels across industrial clusters are major environmental and health concerns. This study investigated the diurnal, monthly and seasonal concentrations of gaseous and fine particulate matter and respiratory conditions of outdoor workers across selected industrial locations in Lagos State, Nigeria. Field monitoring of air quality and respiratory conditions data for 12 months were used. Diurnal and monthly ambient air quality levels varied over the 12 months. The dry season showed higher pollutants and respiratory conditions than the wet season and the control site. Asthma, Pneumonia, and upper and lower respiratory tract infections accounted for the major outdoor respiratory conditions among under-five and the youths. ANOVA, t-test and multiple regression analyses at  $q < 0.05$  showed significant variation in ambient sulfur(iv)oxide, nitrogen(iv)oxide and fine particulate matters across the study area. A significant relationship was found between carbon(ii)oxide, sulfur(iv)oxide, nitrogen(iv)oxide, fine particulate matter and respiratory conditions across the study area. The quality of both diurnal, monthly and seasonal concentrations of air was higher than the 2021 WHO air quality guidelines. Hence, continuous air quality monitoring, tree planting and greening, development of road infrastructures, use of high-quality fuels and bio-fuels, and mist collectors will significantly improve the air quality levels to the WHO acceptable guidelines across the study area.

**Keywords:** air pollution; respiratory health; industrial workers; environmental quality

## 1. Introduction

Air pollution in urban areas is a dynamic and complex mixture of both man-made (anthropogenic) pollutants and natural sources (Ozlem *et al.*, 2016). Air quality depends on the atmosphere's dynamics amount and intensities of pollutants emissions, types of physicochemical changes, air masses movement and meteorological conditions (Mengesha & Mamo 2006; Cichowicz, *et al* 2017; Iny *et al.*, 2016; Saini *et al.*, 2017; Goyal & Chalapati 2007). Industries are one of the dominant sources of pollution globally and involve the release of atmospheric emissions (such as gases, particulates and volatile organic substances) into the atmosphere from various forms altering the chemical composition of the ambient air and increasing its toxicity to humans and the environment (Mengesha and Mamo 2006). Combustion of non-renewable fossil fuels for electricity generation, transport and industry is responsible for the increased mortality and morbidities from respiratory and cardiovascular diseases (Zhang *et al.*, 2015). Large quantities of pollutants from urban transport, energy production and industries negatively impact human and environmental receptors (Baklanov *et al.*, 2018). There is a huge variation in sources and degree of emission between world geographical regions such that emissions in European and American cities are associated with road use while industrial and biofuel consumption characterized Asian and African cities (Baklanov *et al.*, 2018).

Ambient air pollution (AAP) is more likely to have the largest impact on sites of deposition where doses are highest, such as the upper aerodigestive tract and lungs. Biomarkers that show great potential for the assessment of AAP exposure and respiratory effects are biomarkers in exhaled breath. Such biomarkers include but are not limited to exhaled nitric oxide (FeNO), exhaled breath condensate (EBC) pH, 8-isoprostane, and interleukin 1 $\beta$ . These exhaled biomarkers of airway oxidative stress and inflammation can provide a more reliable indication of a biologically effective dose for respiratory effects (Demetriou & Vineis 2015). Several studies have also investigated the impacts of meteorological conditions on industrial air pollution and human well-being at both city and regional levels (Kakoli & Gupta 2005; Filho *et al.*, 2008; Iny *et al.*, 2016; Cohen *et al.*, 2017; Xiaolin *et al.*, 2017; Oudin, *et al.* 2018; Arias-Ortiz *et al.*, 2018; Dappe, *et al.* 2018) and emphasis is being made on the urgent need for environmental monitoring of stressors, especially amongst urban slums in low and middle-income countries where poverty, deprivation and failing health infrastructures are pervasive (Mustapha, *et al.* 2022).

Industrial pollution sources are mixed with unidentified combustion sources or traffic (Belis *et al.*, 2013) such that proximity to a source of pollution can be a health concern to the inhabitants e.g. roadways and traffic congestion paths and road users (Requia & Koutrakis, 2018). The release of large quantities of pollutants into the ambient air has caused numerous local health problems (WHS, 2018). Past episodes are notable examples; the release of a gas cloud of methylisocyanate at the Union Carbide plants in Bhopal India in 1984 led to the deaths of over three thousand eight hundred people, persistent meteorological conditions kept emissions trapped near the earth's surface and resulted in the deaths of over sixty people and hospitalization of over six hundred people in the Meuse Valley in Belgium in 1930, in 1948 a strong temperature inversion in a nearby factory contaminated the air, annihilated over twenty people and hospitalized fourteen thousand people in Donora Pennsylvania in the United State of America, similar incident also occurred in Poza Rica city of Mexico, the Fog of 1952 and 1962 resulted in premature deaths of over four thousand in London, in Nigeria twenty five students of Ogba junior secondary school Ikeja, Lagos in November 2013 suffered convulsion after inhaling what was presumed to be poisonous fumes from a nearby industrial plant, residents near an Ikeja glass manufacturing factory in 1984 complained of rotten eggs odour coming from a factory workers at a Lagos based company complained of irritation of the eyes, unusual behaviour and loss of appetite due to inhalation of solvent vapours and fumes from their process plants, lowering of pulmonary function symptoms was reported by industrial workers exposed to carbon black concentration of 31.2 + 2.45mg/m<sup>3</sup> within dry cell battery, tyres factories, toluene diisocyanate based polyurethane foam plant and asbestos, textile and toluene diisocyanate foam factories in Ife (Adeyemi 1984; Akeredolu, 1987; Oleru 1980, 1981; see the Guardian Nigeria paper of Saturday 31st October 2015; see the district of Columbia's ambient air quality trends report of October, 2014; Mengesha & Mamo, 2006).

A variety of fatal respiratory diseases are caused by outdoor and indoor air pollution (Saud & Paudel, 2018). Indoor air quality is dependent on the quality of outdoor air (Leung, 2015). Air pollutants from outdoors affected by ambient meteorological conditions can penetrate the indoor environment, natural ventilation is driven by prevailing wind flow and occurs whenever the doors and windows of the room/building are open. Air exchange between indoor and outdoor environments still occurs through cracks and leaks in the building envelope, a process called infiltration, which may be significant for a building with poor sealing (Leung, 2015). The skin is the body's first line of defense against a foreign pathogen or infectious agent and it is the first organ that may be contaminated by a pollutant. The skin is a target organ for pollution, the absorption of environmental pollutants from this organ is equivalent to the respiratory uptake (Ghorani-Azam *et al.* 2016). Studies have established the nexus between exposure to industrial air pollution and increased risk for morbidity and global burden of respiratory, cardiovascular and cerebrovascular diseases e.g. acute respiratory infections, chronic obstructive pulmonary diseases, asthma, lung cancer, recurrent and incidence stroke, cognitive decline, dementia, psychotropic medications in children and adolescents, stress, anxiety, risk of schizophrenia, depression and death (Briere *et al.*

1983; Bickerstaff & Walker 2001; Oberdörster & Utell, 2002; Pedersen *et al* 2004; Leem, 2006; Szyszkowicz *et al* 2010; WHO 2013; Oudin *et al* 2009, 2012, 2016; Power *et al* 2015; 2016; Mehta *et al*, 2015; Cohen *et al*, 2017; Karthik *et al*, 2017; Pun *et al* 2017; Ojekunle *et al*, 2018). Most studies in Nigeria have investigated the influence of meteorological variables on ambient air pollution at roadside corridors with little attention on the influence of industrial air pollution on respiratory conditions (Akanni, 2008, 2010; Gobo, *et al* 2012; Ekpenyong *et al*, 2012; Alfred & Hyeladi, 2013; Weli 2014; Weli & Adegoke, 2016; Asuoha & Osu, 2015; Ojekunle *et al*, 2018) which has necessitated this study.

## 2. Methodology

### 2.1. Study Area

Lagos State is situated in South Western Nigeria at latitudes 6°22'N and 6°52'N and longitudes 2°42'E and 3°42'E. It is bounded to the west by the Republic of Benin, on the southern boundary by a 180 km long Atlantic coastline and on the northern and eastern boundaries by Ogun State. Lagos state has a landmass of 3,671km<sup>2</sup> of which over 35% (787 km<sup>2</sup>) of this are defined by lagoons, creeks and islands (Soladoye & Ajibade 2014; PWC, 2015; NBS 2011). Lagos state has 20 local government areas of which sixteen are metropolitan densely populated areas. The Climate of Nigeria is balkanized into three climate types which are tropical rainforest, montane or highland and tropical savanna climates. The southern region of Nigeria where Lagos is located is defined by the tropical rainforest climate classified according to Koppens as Af, furthermore, it is divided into tropical wet and tropical wet and dry climates characterized by minimal temperature range and convectional storms due to her proximity to the equatorial climate (and the Atlantic) (Ileoje, 2001; Eludoyin, *et al* 2013). The coastal landscape of Lagos state is bifurcated into five geomorphological sub-units, which are; coastal creeks and lagoons, abandoned beach ridge complex, swamp flats, active barrier beach complex and forested river floodplain (Adegoke *et al.* 1980). The topography is flat slightly above mean sea level (Oluwole *et al.* 1994) and is defined by swamp forests of the coastal belt with fresh water, and dry lowland rain forests with patches of vegetation in their natural state. This wetland vegetation is caused by the double maxima rainfall pattern of the region (Adelana & Olasehinde, 2005; Odjugbo, 2010). The geology of Lagos state is made up of the tertiary and quaternary sediments which comprise the Benin formation (Miocene to recent), recent littoral alluvium and lagoon/coastal plain sands of the Dahomey basin (where the sea bed steeply slopes away from shore and stratigraphically consist of Abeokuta and Imo groups and Ilaro Formation) (Soladoye & Ajibade 2014). The Dahomey basin spreads through southeastern Ghana in the west, through southern Togo and southern Benin Republic to southwest Nigeria, the basin is bounded to the west by faults and marked by the Benin hinge line at its eastern limit (Yusuf & Abiye, 2019).

Lagos state accounts for over 60% of the industrial and commercial activities in Nigeria and financially solvent with the capacity of generating over 75% of its revenues independent of federal allocation (LBS, 2015; Ajayi 2007, 2011; SWIFT 2017). According to the Lagos Bureau of Statistics (2015) report on revenue generation, Lagos state had a gross domestic product (GDP) of over 80 billion dollars in 2010 accounting for 36% of Nigeria's GDP and among the largest economy in Africa. Lagos is the highest internal revenue earner in Nigeria recording over 400 billion Naira in 2018 (Oluseun *et al* 2018) and plays the role of both a megacity and a global city with a substantial foreign-born populace and a non-stop flight to hundreds of destinations around the world (Nwagwu & Oni 2015; Soladoye & Ajibade 2014). Lagos State has a projected population of 21 million in 2021 according to the 2006 NPC projection making it the seventh fastest-growing city in the world and the third largest city in Africa (Longe, 2011; Salau, 2016; NPC 2006). It has a population growth rate of 3.2% and is projected to be over 30 million by 2025 (PWC, 2015). Over 80% of the population is domiciled on 37% of the metropolitan landmass where all economic activities are concentrated and driven by a skilled workforce of over 45% with a literacy rate of 92% (Ojeh *et al* 2016; PWC, 2015). The South West Summit Report (2017) on Investment and Exhibition stated that the South West Industrial Region of Nigeria controls 60% of the nation's industrial capacity, three deep sea ports of Apapa, Tin Can Island and Roro, three thermal stations of Egbin, Papalanto and Omotosho and a West Africa

gas pipeline linked industrial estates of Agbara, Ikeja and Ota under the West African Gas Pipeline Plan. The industrial region of South Western Nigeria is located within the industrial conurbation of Ota and Lagos which comprises of states of Ogun, Oyo and Lagos. Most of the industrial clusters are located in Lagos than in Ogun and Oyo states. The industrial estates in Lagos are Ikeja, Agidingbi, Amuwo Odofin, Apapa, Gbagada, Iganmu, Ijora, Ilupeju, Matori, Ogba, Oregun, Oshodi/Isolo/Ilasamaja, Surulere, Odogunya, and Yaba. Others are in Oluyole (Oyo State) and in Agbara-Igbesa industrial estate, Ota industrial estate, Ibeshe-Papalanto-Ewekoro region, Flower Gate industrial estate around the Lagos/Abeokuta interchange and along the Lagos/ Ibadan express from Isheri to Sagamu all in Ogun State (Ajayi, 2007, 2011; Etim, 2012; Ojiodu *et al*, 2013; Mashi *et al*, 2014; Ogun State report on industrial and property development, 2020). Some of these estates are both active and dormant in industrial activities. In terms of their sizes, activeness and intensities of industrial activity, the Ikeja/Ogba, Oshodi/Ilupeju, Apapa, Surulere and Odogunya industrial estates were selected for this study.

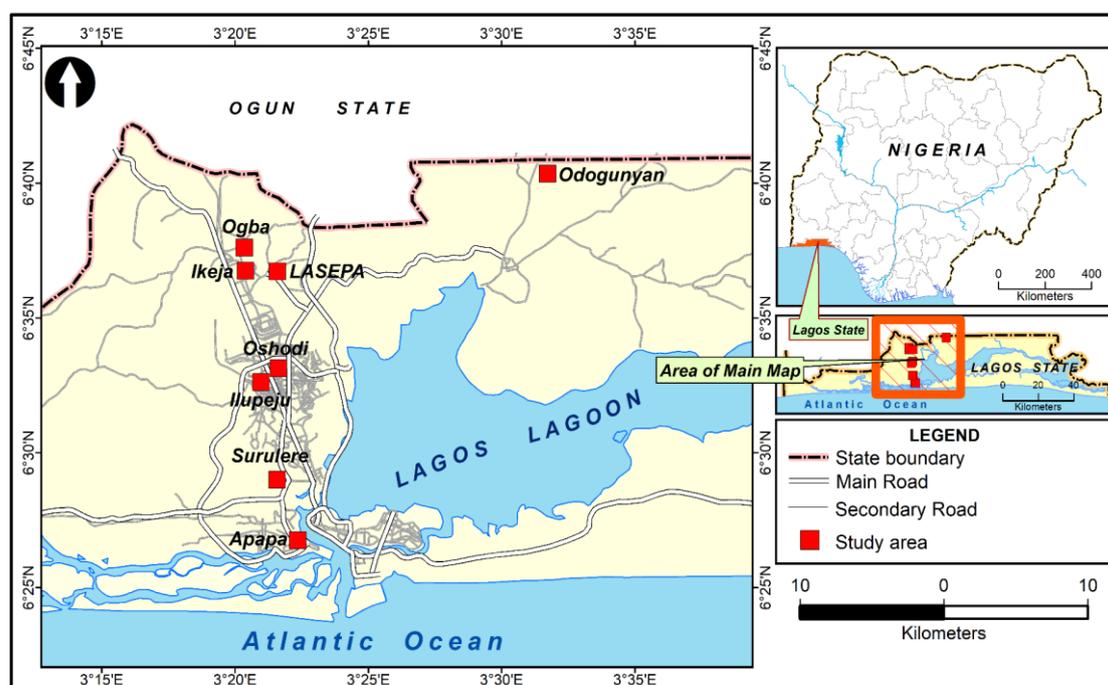
Lagos state is home to over 90% of head offices of many airlines and multinational corporations, expatriates and recently a tourist heaven due to its re-modernization of its city landscape and infrastructures and modification of its entertainment industries in the city e.g., music scenes, movie industries, colourful carnivals etc. (Salau, 2016; PWC 2015; LBS 2015; Nwagwu & Oni 2015). According to the Price Water Copper report (2015) on investment and travel in Lagos, Lagos airport is the busiest airport in West Africa, the fifth busiest in Africa accounting for over six million passengers (i.e., 74% of Nigeria's yearly international passengers) with one in every three international flights into Nigeria bound for the Lagos airport. Also, Lagos serves as a key access point to many markets for both Nigeria and the West African sub-region with the largest markets in Idumota Lagos. Furthermore, it is driven by the Bus Rapid Transit (BRT) system that transports over 200,000 passengers daily equivalent to the New York City transport systems and has Nigeria's first cable-stayed bridge geared towards reducing congestion and travel time between Lekki and Victoria Island by 20 min every day. Lagos state comprises a mainland where a majority of the inhabitants live and the island where the head offices of governmental and commercial establishments are located in addition to a low-density residential area. The two sections are linked by three bridges each forming the end of a major highway (Oluwole *et al*. 1994). Lagos metropolis is located within the Western Nigeria Coastal Zone of coastal creeks and lagoons (Pugh 1954) developed by barrier beaches associated with sand deposition (Hill & Webb 1958). The metropolis is the area of land around the only inlet of the sea into the extensive lagoon system (the Lagos harbour). It includes the islands (Lagos, Ikoyi and Victoria), Apapa, Shomolu, Ikeja, Shasha and Agege.

Table 1. Study area.

| S/n | Industrial estate | Year of est. | Active industrial firm | Size (Ha) | Estate area | Estate type | Industrial nature  |
|-----|-------------------|--------------|------------------------|-----------|-------------|-------------|--|
| 1   | Ikeja/Ogba        | 1959         | 75                     | 180       | Mainland    | IR          | FBT, FM, C&P, DIP, PPP, TW, EE, WH WWG, MVP, CCT, EE, and P. |
| 2   | Oshodi/Ilupeju    | 1962         | 57                     | 330       | Mainland    | IR          | FBT, DIP, PPP, C&P, CP& IT, TW, WWG, MVP, WH and P.          |
| 3   | Surulere          | 1957         | 39                     | 25        | Mainland    | IR          | FBT, WH, M&S, C, PPP, TW, DIP, E/P, EE, NMMP and MV          |
| 4   | Apapa             | 1957         | 31                     | 100       | Coastal     | IR          | FBT, C&P, M&S, PPP, OMC, WH, CCT and TW                      |

|   |                  |      |    |         |          |    |  |
|---|------------------|------|----|---------|----------|----|--|
| 5 | Odogunya         | 1976 | 52 | 1582.27 | Mainland | IR | FBT, C&P, DIP, M&S, PPP, TW, EE, WH, FM, FW and E/P                  |
| 6 | Alausa (control) | 1996 | 0  | 1       | Mainland | GR | LASEPA premises, Government buildings, offices and residential areas |

Source: (Ajayi, 1998; Fagbohunka, 2014; MAN, 2014; LBS, 2016; Field Survey, 2021). Note: IR: Industrial/Residential; GR: Government/Residential. Ha: Hectares; WH: Warehousing. M&S: Metals Iron and Steels Fabrication; C&P: Chemicals and Pharmaceuticals. CP&IT: Computer Parts and Information Technology Equipment; DIP: Domestic/ Industrial Plastics and Nylons, FBT: Food, Beverages, Biscuits and Tobacco; PPP: Paper and Pulp Products, MVP: Motor Vehicle Assembly and Parts; NMMP: Non -Metallic Mineral Products, EE: Electrical and Electronics Products; TW: Textile and Wearing Apparels, WWG: Wood and Wood Goods; CCT: Cement, Clay and Tiles, OMC: Oil Marketing Companies; E/P: Energy/Power, FM: Foam Manufacturing; P: Publishing, C: Carpets; FW: Foot Wears



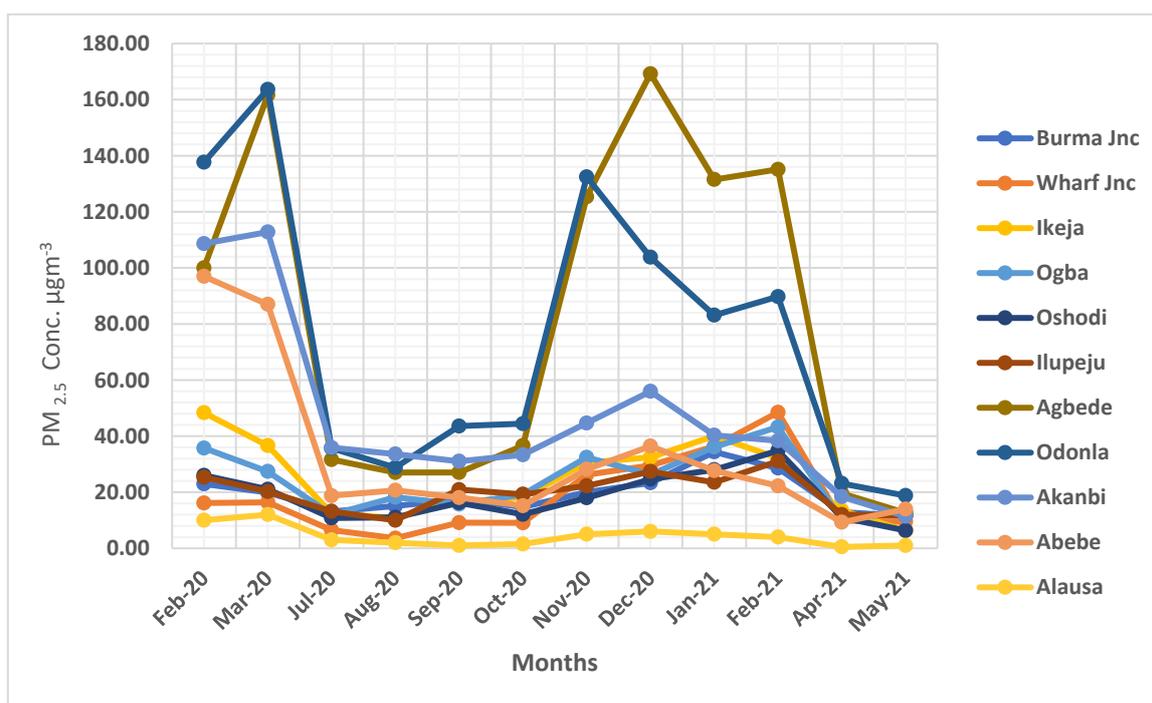
**Figure 1.** Study area showing the sampling points. 2.2 Data Collected.

Reconnaissance was carried out on all 15 industrial estates situated in twelve local government areas of Lagos state in August 2019 to ascertain the number of active industrial estates, the nature of industrial activities and the delineation of sampling points. Ranking and regrouping of the industrial estates was done based on the scale of industrial activities. Government hospitals were identified during the survey for the collection of available respiratory hospital visitation records for morbidities from 2016 to 2021. Primary data collected are monthly air quality levels of sulfur (iv) oxide (SO<sub>2</sub>), nitrogen (iv) oxide (NO<sub>2</sub>), carbon (ii) oxide (CO), and fine particulate matter (PM<sub>2.5</sub>) for a period of 12 months (February 2020 to May 2021) obtained through field recording using an air metric embedded with a Teflon filter for fine particulate matter (PM<sub>2.5</sub>), a vvae multi-detector for nitrogen (iv) oxide (NO<sub>2</sub>) and sulfur(iv)oxide (SO<sub>2</sub>), and a tecto 315-2 carbon(ii)oxide detector with (serial no-02343074/204) for carbon(ii)oxide. The secondary data is monthly records of respiratory conditions obtained from the medical statistics unit of Lagos State University Teaching Hospital (LASUTH) and General hospitals in Isolo, Apapa, Ikorodu and Randle from 2016 to 2021 across the study area

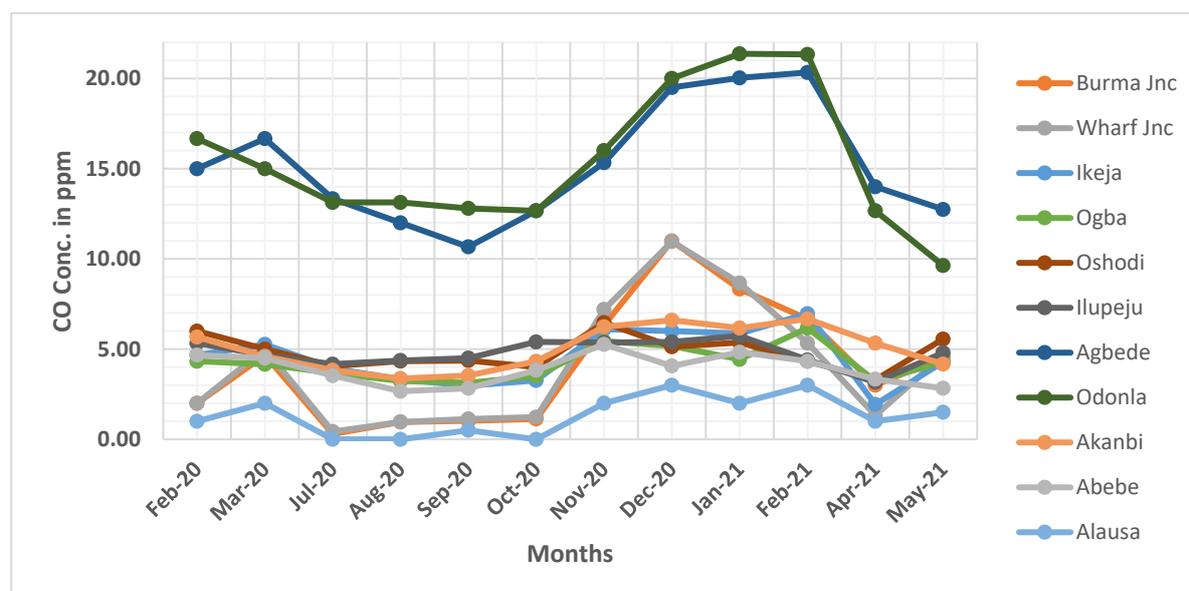
### 3. Results and Discussion

#### 3.1. Variation in Ambient Monthly Gaseous and Particulate Pollutant Levels

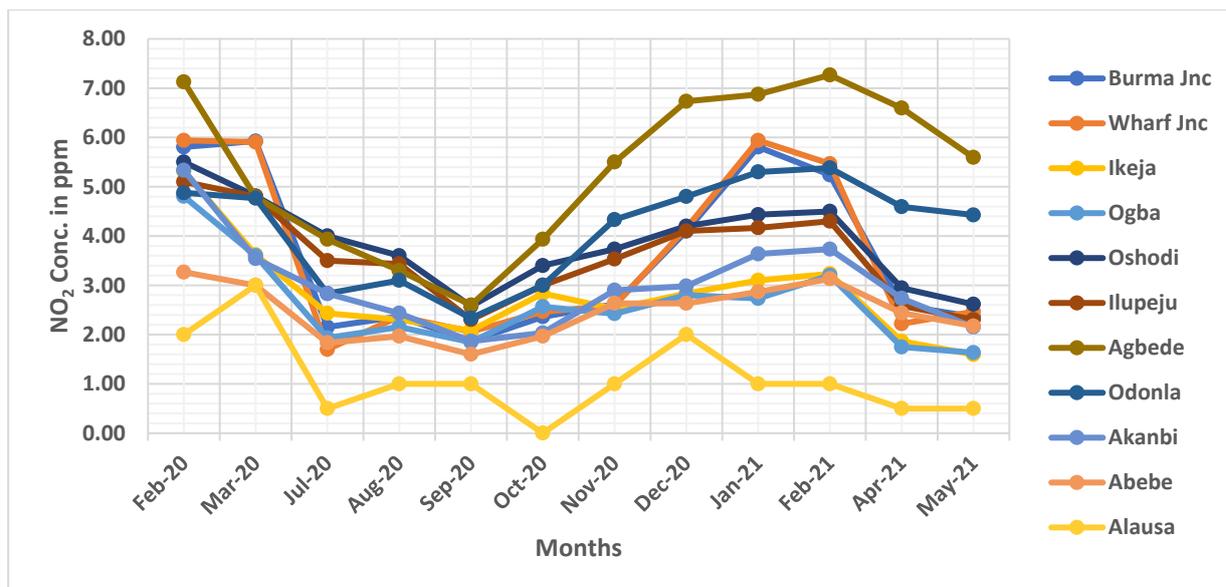
Data analysis revealed varying monthly levels of both gaseous and fine particulate matter concentration across the industrial estates with minimal concentration at the control site. Fine particulate matter (Figure 2) ranged between  $3.61\mu\text{g}\text{m}^{-3}$  to  $169.23\mu\text{g}\text{m}^{-3}$ , while gaseous carbon(ii)oxide (Figure 3) ranged between 0.33ppm to 21.37ppm, nitrogen(iv)oxide (Figure 4) ranged between 0.5ppm to 7.27ppm and sulfur(iv)oxide (Figure 5) ranged between 0.80ppm to 4.41 across the industrial estates and the control site over the 12 months of monitoring.



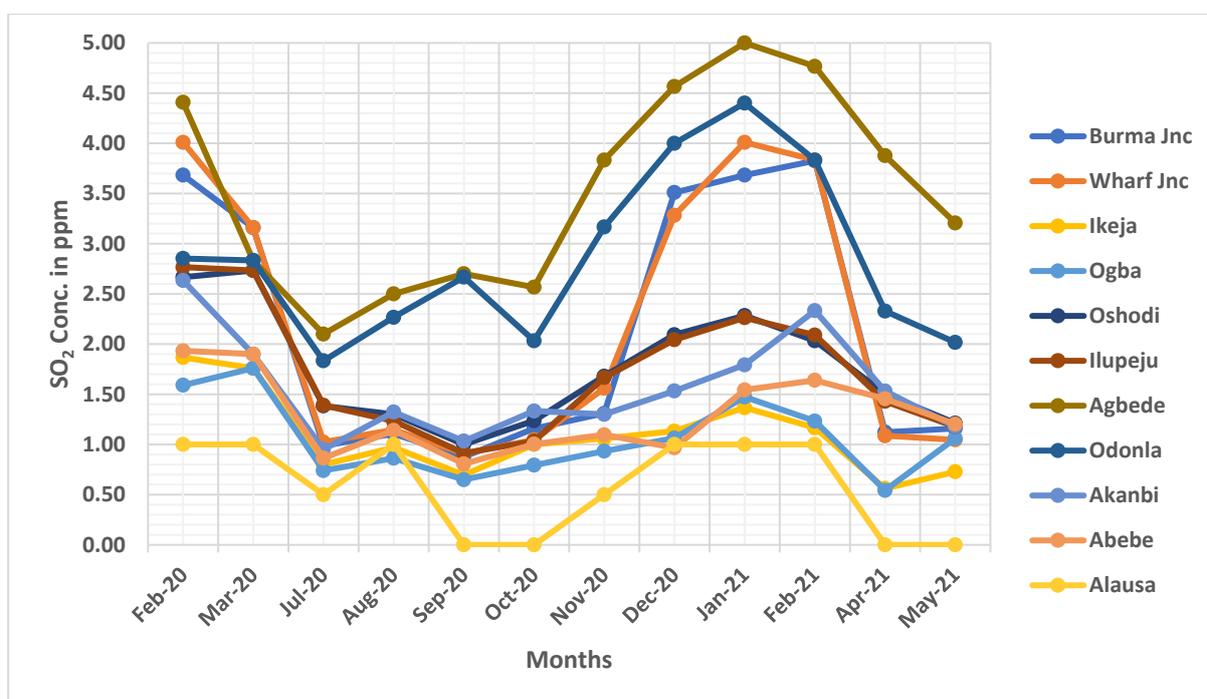
**Figure 2.** Monthly variation in fine particulate matter across selected industrial locations in Lagos state. Source: Field Survey (2021).



**Figure 3.** Monthly variation in carbon(ii)oxide levels across selected industrial locations in Lagos state. Source: Field Survey (2021).



**Figure 4.** Monthly variation in nitrogen(iv)oxide levels across selected industrial locations in Lagos state Source: Field Survey (2021).



**Figure 5.** Monthly variation in sulfur(iv)oxide level across selected industrial locations in Lagos state. Source: Field Survey (2021).

One-way analysis of variance (Table 2) was used to analyze the monthly variation in the ambient pollutant levels over the 12 months of the study. The unit of analysis is the months over which the pollutant levels were recorded.  $\text{SO}_2$  was significant across the study area and period of study at  $q < 0.05$ ;  $F(11, 108) = 5.103$ ,  $q = 0.000$ . The mean square ( $\eta^2$ ) value of 0.853 indicates an  $\text{SO}_2$  variation of 85.3% across the study area. Hence, there is a significant variation in  $\text{SO}_2$  levels across the study area and period of study.  $\text{NO}_2$  was significant across the study area and period of study at  $q < 0.05$ ;  $F(11, 108) = 8.805$ ,  $q = 0.000$ . The mean square ( $\eta^2$ ) value of 1.142 indicates a  $\text{NO}_2$  variation of 14.2% across the study area. Hence, there is a significant variation in  $\text{NO}_2$  levels across the study area and period of study. CO was insignificant across the study area and period of study at  $q > 0.05$ ;  $F(11, 108) = 1.320$ ,  $q = 0.223$ . The mean square ( $\eta^2$ ) value of 23.502 indicates a CO similarity of 50.2% across the study

area. Hence, there is no significant variation in CO levels across the study area and period of study. PM<sub>2.5</sub> was significant across the study area and period of study at  $Q < 0.05$ ;  $F(11, 108) = 3.897$ ,  $Q = 0.000$ . The mean square ( $\eta^2$ ) value of 1047.117 indicates a PM<sub>2.5</sub> variation of 11.7% across the study area. Hence, there is a significant variation in PM<sub>2.5</sub> levels across the study area and period of study.

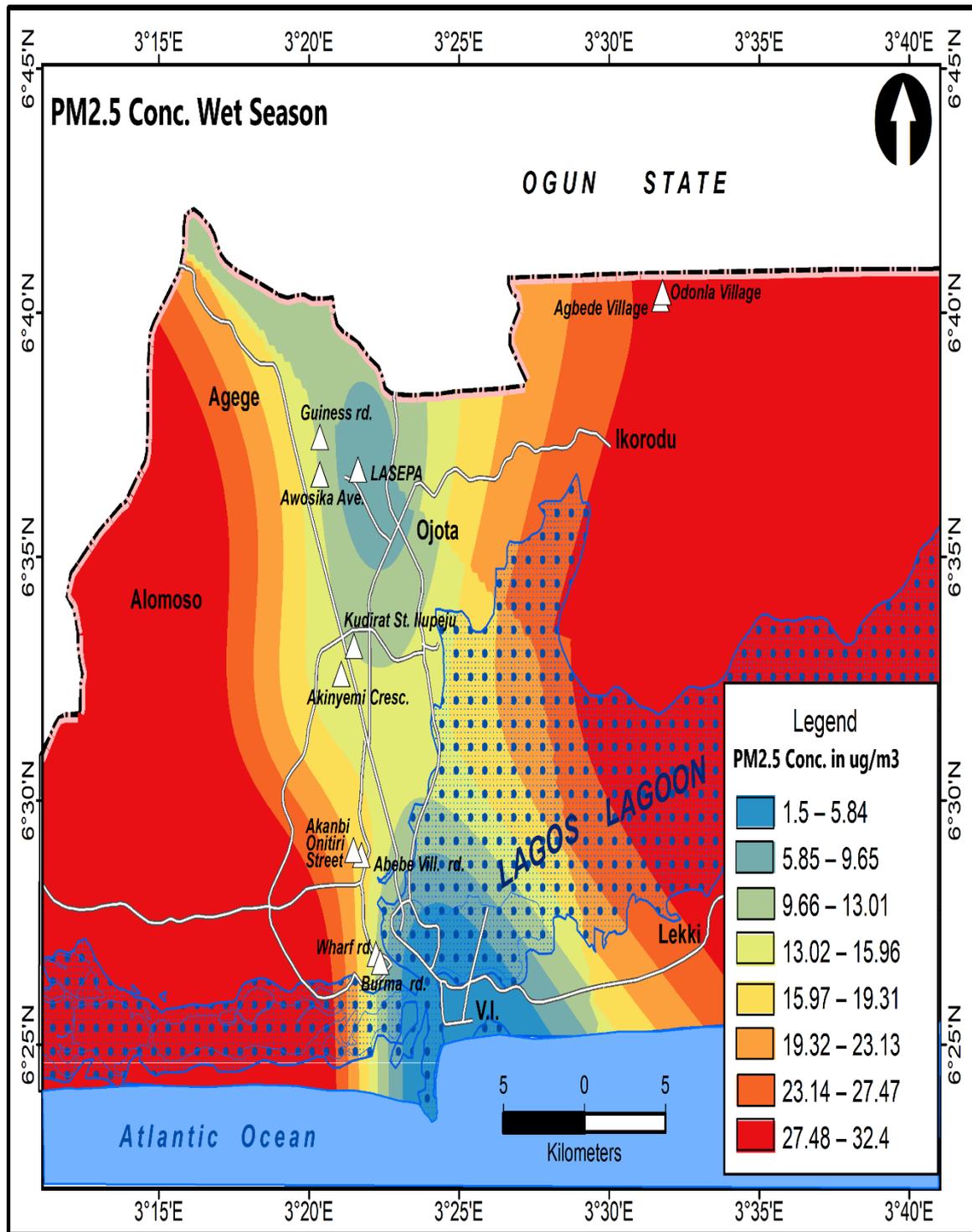
**Table 2.** Monthly variation in ambient air pollutant levels.

|                   |                | ANOVA          |     |             |       |      |
|-------------------|----------------|----------------|-----|-------------|-------|------|
|                   |                | Sum of Squares | df  | Mean Square | F     | Sig. |
| SO <sub>2</sub>   | Between Groups | 47.897         | 11  | 4.354       | 5.103 | .000 |
|                   | Within Groups  | 92.157         | 108 | .853        |       |      |
|                   | Total          | 140.054        | 119 |             |       |      |
| NO <sub>2</sub>   | Between Groups | 110.649        | 11  | 10.059      | 8.805 | .000 |
|                   | Within Groups  | 123.388        | 108 | 1.142       |       |      |
|                   | Total          | 234.036        | 119 |             |       |      |
| CO                | Between Groups | 341.300        | 11  | 31.027      | 1.320 | .223 |
|                   | Within Groups  | 2538.233       | 108 | 23.502      |       |      |
|                   | Total          | 2879.533       | 119 |             |       |      |
| PM <sub>2.5</sub> | Between Groups | 44891.032      | 11  | 4081.003    | 3.897 | .000 |
|                   | Within Groups  | 113088.662     | 108 | 1047.117    |       |      |
|                   | Total          | 157979.695     | 119 |             |       |      |

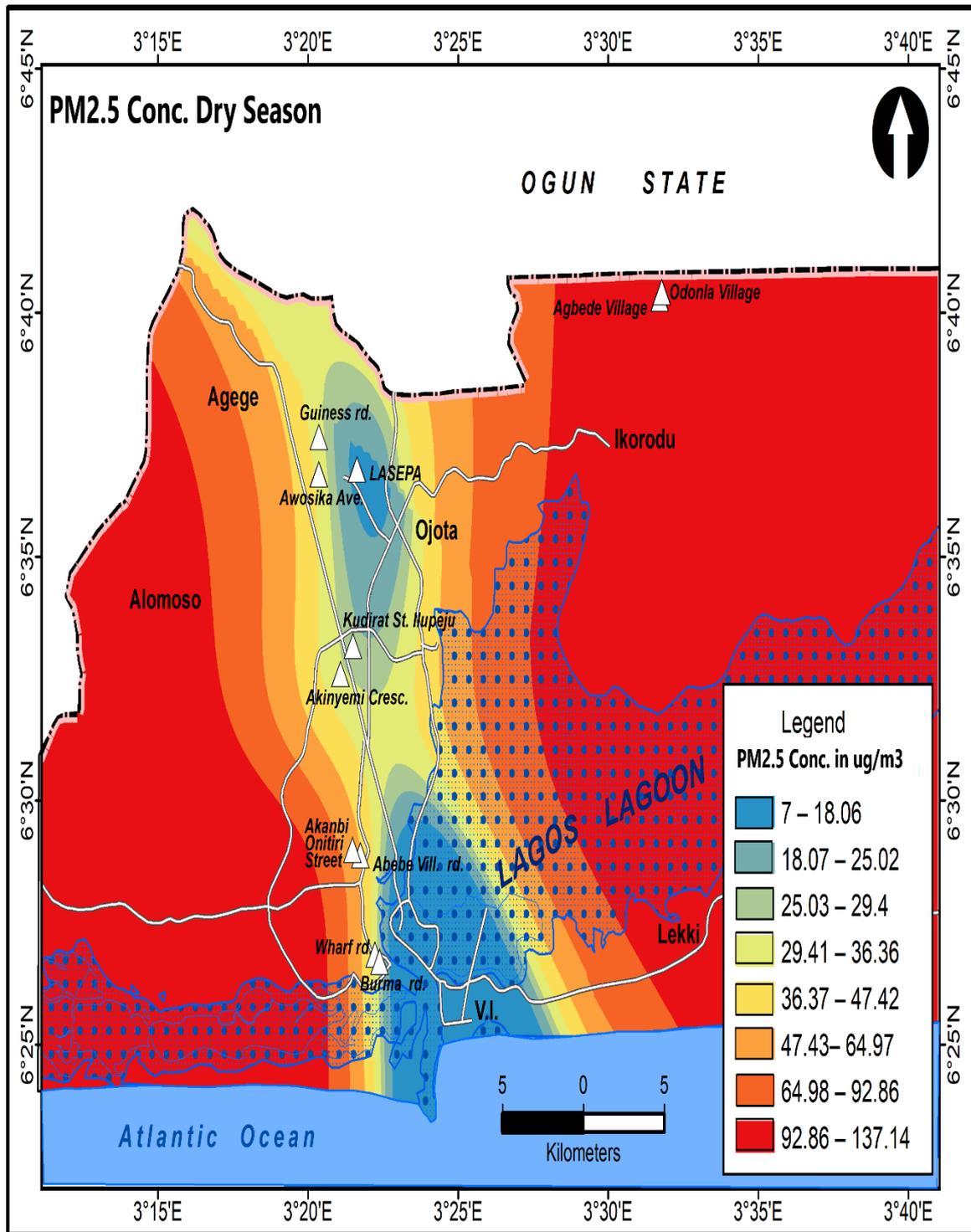
Source: Field Survey (2021).

### 3.2. Spatial and Seasonal Variation in Gaseous and PM<sub>2.5</sub> Levels

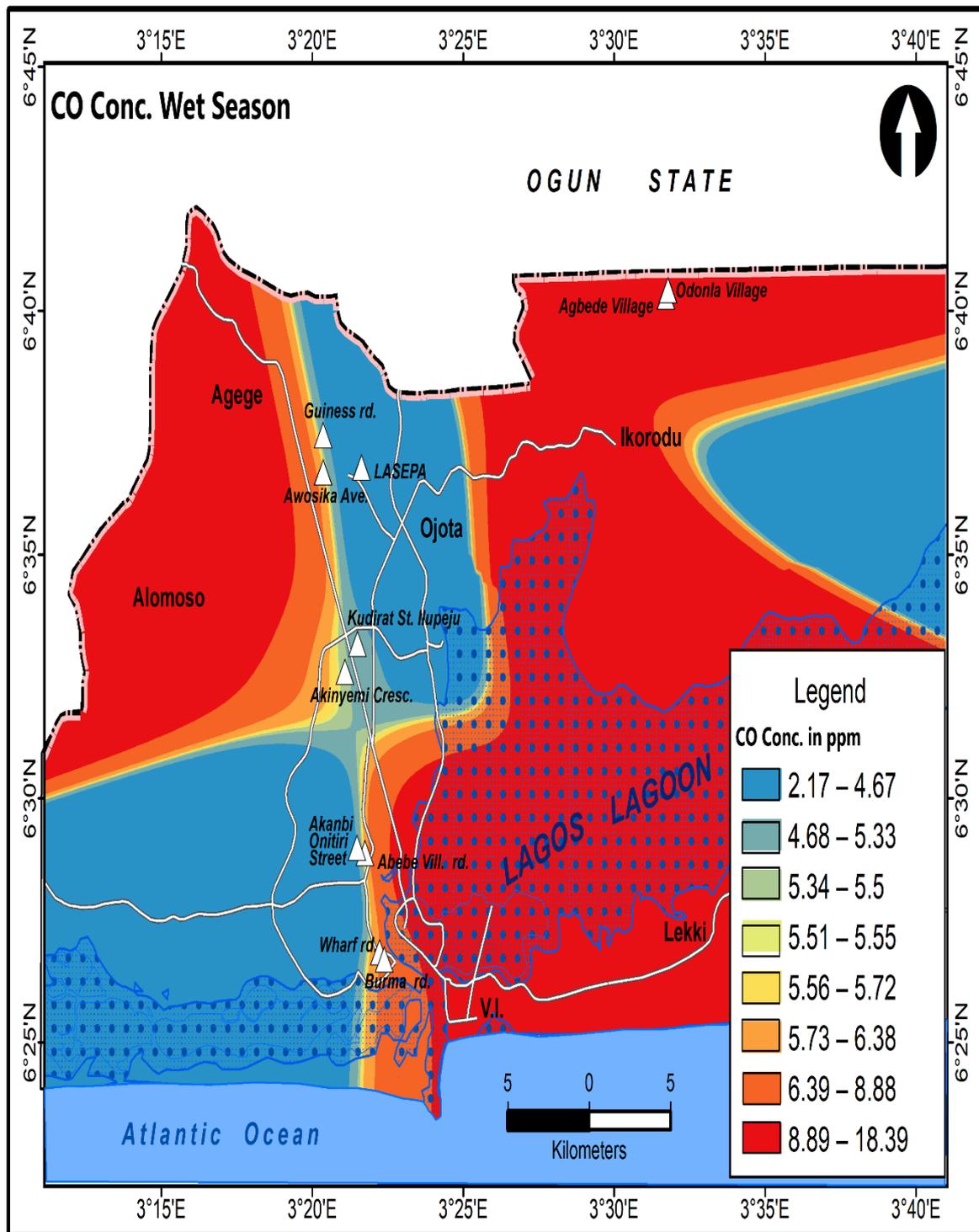
Data analysis revealed varying levels of average gaseous and particulate pollutant concentration across the industrial estates and the control site during the wet and dry seasons. Both gaseous and particulate pollutant concentrations were higher during the dry season than the wet season due to decreased washout from precipitation. The average fine particulate matter level was between 7.94 $\mu\text{gm}^{-3}$  to 32.4 $\mu\text{gm}^{-3}$  (Figure 6), CO was between 1.62ppm to 12.57ppm (Figure 8), NO<sub>2</sub> was between 2ppm to 4.33ppm (Figure 10) and SO<sub>2</sub> was between 0.79ppm to 2.83ppm (Figure 12) during the wet season. During the dry season, fine particulate matter concentration was between 24.55 $\mu\text{gm}^{-3}$  to 137.14 $\mu\text{gm}^{-3}$  (Figure 7), CO was between 4.61 to 18.39ppm (Figure 9), NO<sub>2</sub> was between 2.92ppm to 6.38ppm (Figure 11) and SO<sub>2</sub> was between 1.39 to 4.23ppm (Figure 13).



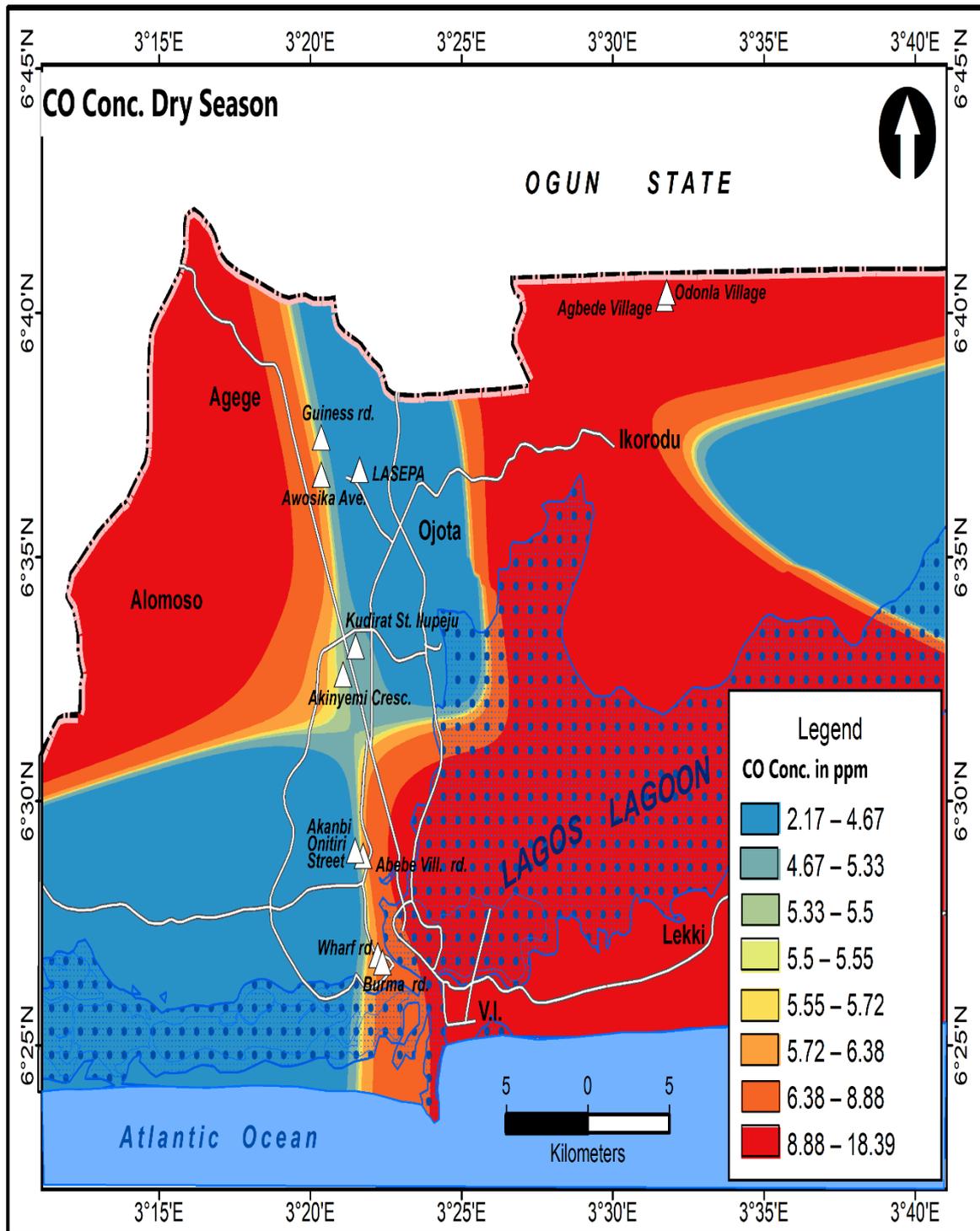
**Figure 6.** Spatial variation in fine particulate matter (PM<sub>2.5</sub>) levels in the wet season across selected industrial locations in Lagos state. Source: Field Survey (2021).



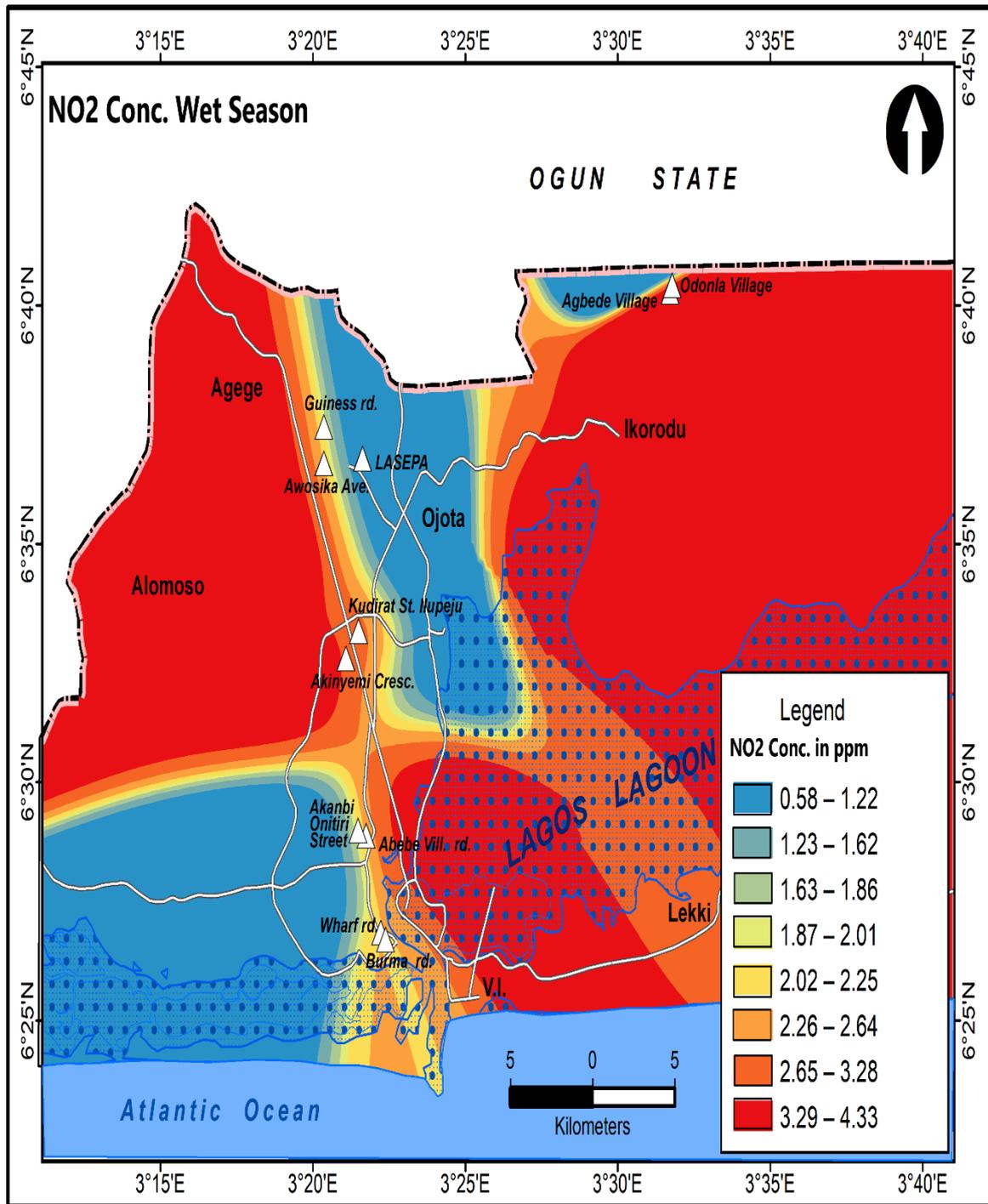
**Figure 7.** Spatial variation in fine particulate matter (PM<sub>2.5</sub>) levels in the dry season across selected industrial locations in Lagos state. Source: Field Survey (2021).



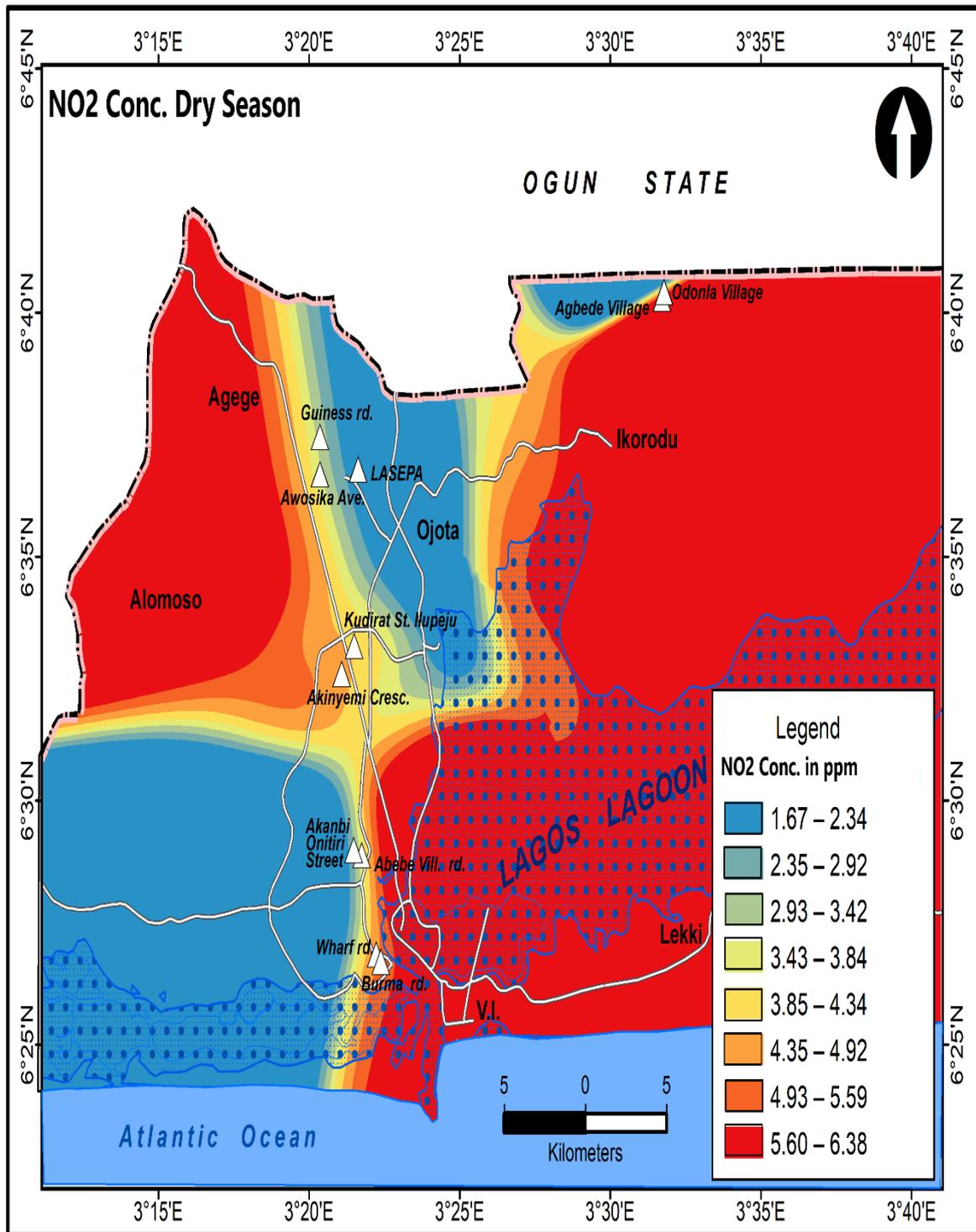
**Figure 8.** Spatial variation in carbon(ii)oxide (CO) levels in the wet season across selected industrial locations in Lagos state. Source: Field Survey (2021)



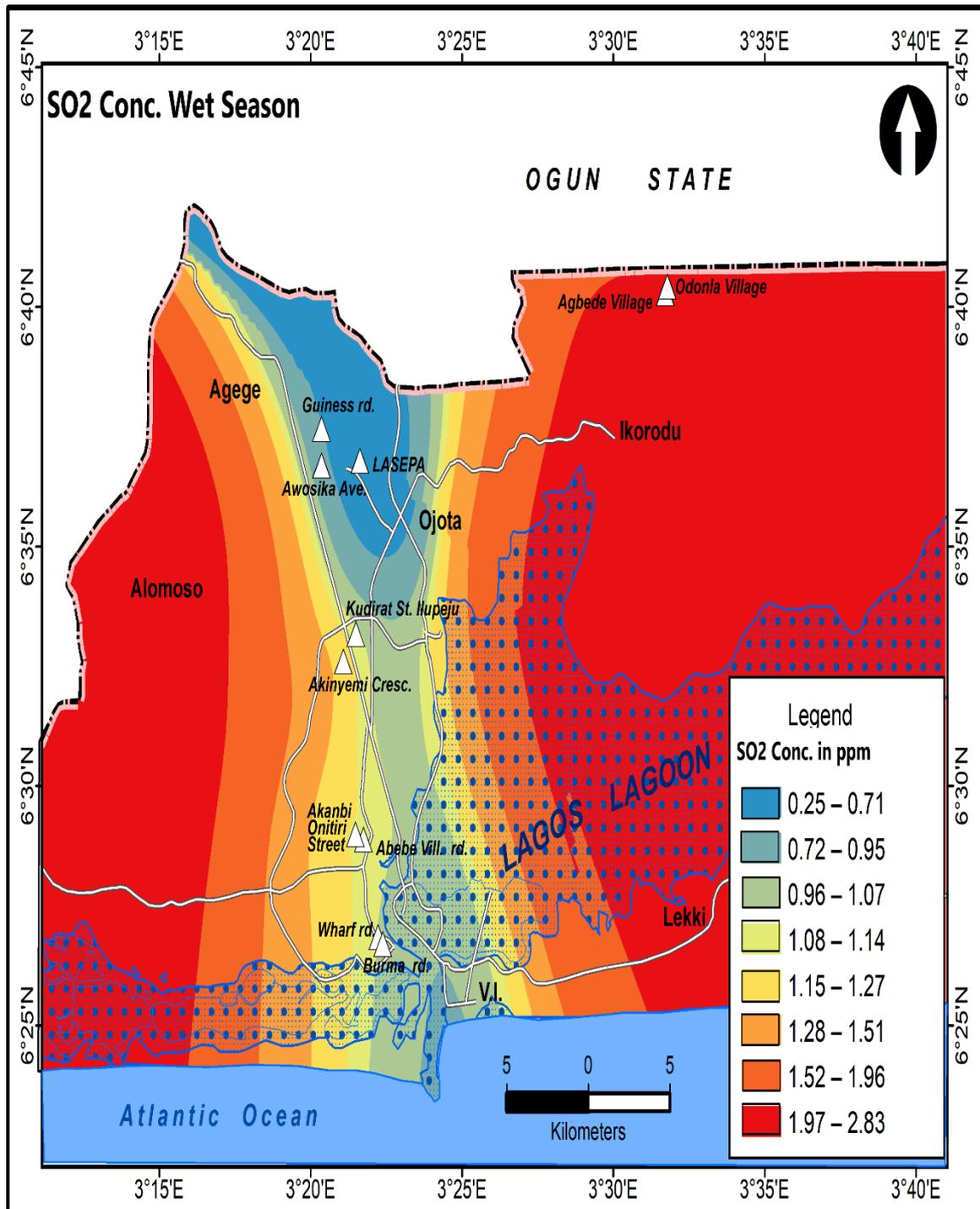
**Figure 9.** Spatial variation in carbon(ii)oxide (CO) levels in the dry season across selected industrial locations in Lagos state. Source: Field Survey (2021).



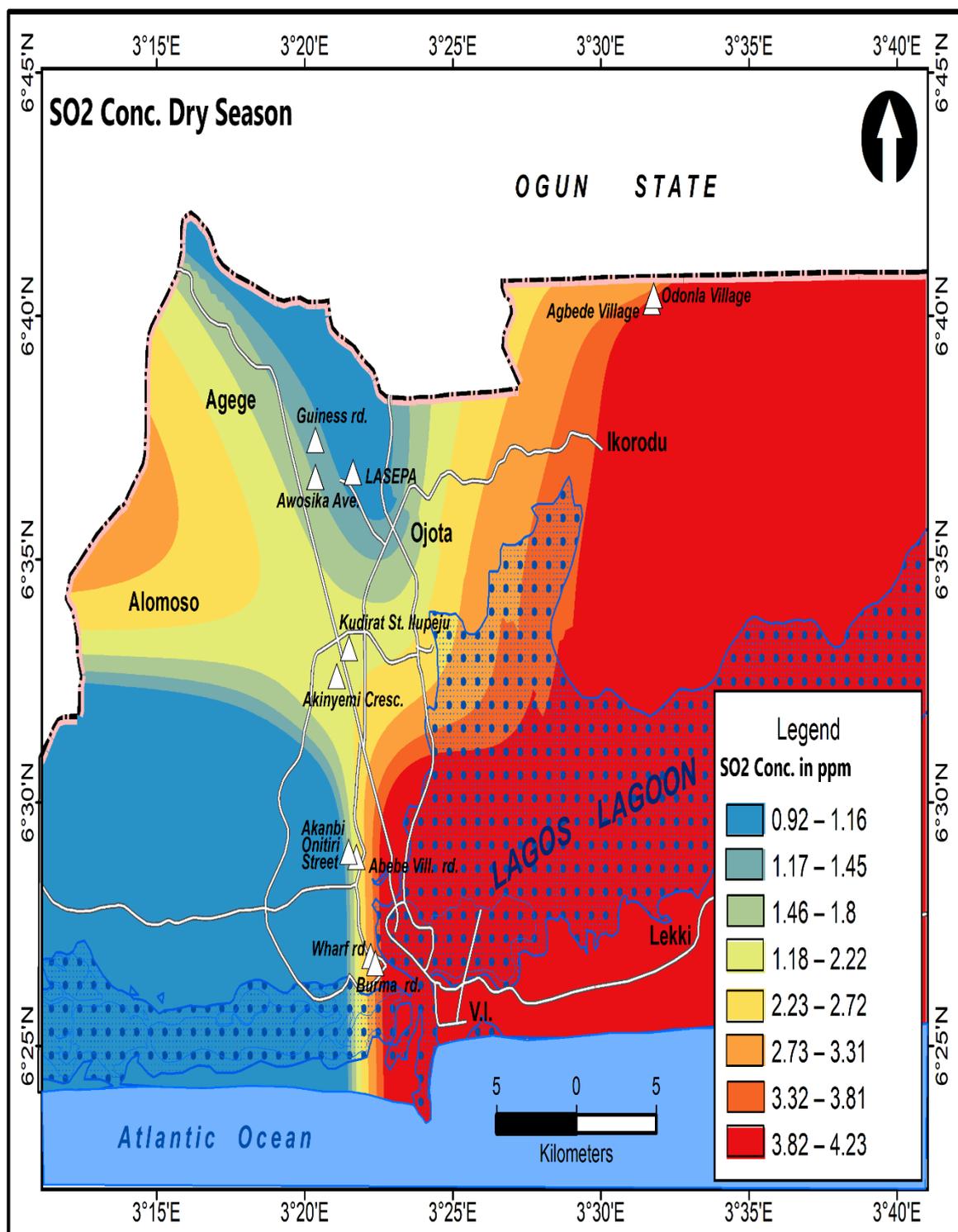
**Figure 10.** Spatial variation in nitrogen(iv)oxide (NO<sub>2</sub>) levels in the wet season across selected industrial locations in Lagos state . Source: Field Survey (2021).



**Figure 11.** Spatial variation in nitrogen(iv)oxide (NO<sub>2</sub>) levels in the dry season across selected industrial locations in Lagos state. Source: Field Survey (2021).



**Figure 12.** Spatial variation in sulfur(iv)oxide (SO<sub>2</sub>) levels in the wet season across selected industrial locations in Lagos state. Source: Field Survey (2021) .



**Figure 13.** Spatial variation in sulfur(iv)oxide (SO<sub>2</sub>) levels in the dry season across selected industrial locations in Lagos state. Source: Field Survey (2021).

The independent sample t-test was employed (Table 3) to quantify the seasonal difference in ambient levels of pollutants. SO<sub>2</sub> significantly varied between the wet and the dry season ( $t(18) = 3.013$ ,  $\rho = 0.007 < 0.05$  significant interval). NO<sub>2</sub> significantly varied between the wet and the dry season ( $t(18) = 4.042$ ,  $\rho = 0.001$  significant interval). PM<sub>2.5</sub> also significantly varied between the wet and the dry season ( $t(18) = 2.798$ ,  $\rho = 0.012$  significant interval). CO did not significantly vary between the wet and the dry season ( $t = 1.432$ ,  $\rho = 0.169$  significant interval).

**Table 3.** Seasonal variation in ambient pollutant levels.

|                                |                         | t-test for Equality of Means |    |                 |                 |                       |   |          |
|--------------------------------|-------------------------|------------------------------|----|-----------------|-----------------|-----------------------|---|----------|
|                                |                         | t                            | df | Sig. (2-tailed) | Mean Difference | Std. Error Difference | 95% Confidence Interval of the Difference |          |
|                                |                         |                              |    |                 |                 |                       | Lower                                     | Upper    |
| <b>SO<sub>2</sub> Season</b>   | Equal variances assumed | 3.013                        | 18 | .007            | 1.14500         | .38006                | .34652                                    | 1.94348  |
| <b>NO<sub>2</sub> Season</b>   | Equal variances assumed | 4.042                        | 18 | .001            | 1.65200         | .40866                | .79344                                    | 2.51056  |
| <b>CO Season</b>               | Equal variances assumed | 1.432                        | 18 | .169            | 3.00300         | 2.09720               | -1.40304                                  | 7.40904  |
| <b>PM<sub>2.5</sub> Season</b> | Equal variances assumed | 2.798                        | 18 | .012            | 36.91900        | 13.19497              | 9.19741                                   | 64.64059 |

Source: Field Survey, (2021).

### 3.3. Monthly and Seasonal Variation in Gaseous and Particulate Pollutants

Monthly variation in gaseous and particulate emissions stems from both industrial and traffic sources which are a combination of fumes from industries, cars, bikes, forklifts, and heavy-duty vehicles. The utilization of furnace oil in the powering of industries is also a major source of sulfur (iv) oxide while biomass burning, thermal power plants and fossil fuel combustion from vehicles are major emitters of nitrogen (iv) oxide (Saadat, *et al.* 2021). Natural and anthropogenic sourced PM<sub>2.5</sub> from airborne dust particles, sea salts, pollens, industries, bush/forest/wood/incinerator burning, power plants, fumes from heavy-duty vehicles, cars and forklifts, construction sites, and untarred roads are responsible for the variation in fine particulate matter levels across the industrial estates. Fumes from cars and heavy-duty vehicles, combustion (gas turbines and furnaces), non-combustion processes (raw materials treatments), transportation and offloading of dusty industrial raw materials, and traffic particulate matter were identified as the major causes of gaseous and particulate emission in cities (Owoade *et al.* 2013; Samek, *et al.* 2017; Ojekunle *et al.* 2018; Kanu *et al.* 2021; Ezeugoh, *et al.*, 2020). Across arctic countries, energy, industry, transport and agricultural sectors are significantly responsible for SO<sub>2</sub>, NO<sub>2</sub>, PM<sub>2.5</sub> and CO emissions (Moore, *et al.* 2021) which influences the quality of the ambient environment (Marinello *et al.* 2021). According to Karagulian *et al.*, (2015), 10% of PM<sub>2.5</sub> levels in Africa originate from industrial activities where the intensity of emission affects the variation in concentration levels across the city. The reduction in air quality in low- and middle-income countries is primarily caused by the rapidity in urbanization and economic development characterized by the reliance on the burning of fossil fuels with minimal efforts for emission reduction and control (Croitoru, *et al.* 2020). The WHO (2021) report on air quality guidelines described air pollution as the single biggest environmental threat to human health due to its contribution to the global disease burden. The report identified six classical pollutants of concern to human health and wellbeing which are; fine particulate matter, coarse particulate matter, sulfur(iv)oxide, nitrogen (iv) oxide, carbon (ii) oxide and ozone. Kislitsyna *et al.*, (2021) identified criteria pollutants in an ideal industrial estate as; soot, inorganic dust, carbon(ii)oxide, nitrogen(ii)oxide, sulfur(iv)oxide and nitrogen(iv)oxide.

The hypothesis result revealed that SO<sub>2</sub>, NO<sub>2</sub>, and PM<sub>2.5</sub> exhibited significant variation over the 12 months across the study area. While CO did not reveal any significant variation in monthly concentration level during the study period. Seasonally, both gaseous and fine particulate matter values were higher during the dry season than the wet season across the study area and the control site. The reason for such differences is the remediating role of precipitation which removes both gaseous and particulate from the atmosphere through precipitation scavenging, gravitational settling and wet deposition (Oke, 1987). Both particulate and gaseous monthly pollutants levels were higher than the WHO air quality standard of 0.013ppm (25µgm<sup>-3</sup>) for NO<sub>2</sub>, 3.49ppm for CO, 0.015ppm (40µgm<sup>-3</sup>) for SO<sub>2</sub> and 15µg/m<sup>3</sup> for PM<sub>2.5</sub>. Air quality across seasons revealed a marked variation

between the wet and dry seasons in the tropics and in the summer, autumn, and winter months in the temperate region (Gobo, *et al* 2012; Hongliang *et al.* 2016; Weli & Adegoke, 2016; Saud & Paudel, 2018; Wei *et al.*, 2015; Ikamaise, *et al.* 2001; Weli, 2014; Oyebanji, *et al.* 2021). Weather variables and topography have proven to help in the sequestration and chemical transformation of pollutants in space and over time (Juřík and Braathen, 2021) which in turn reduces the risk posed by elevated pollutants on the vulnerable segment of the populace in the city (Brauer *et al.* 2021; Ming-Lun *et al.* 2021). Globally, air quality has increased the burden on respiratory, cardiovascular, and nervous system damages, and eye irritation (Rai, *et al.* 2021). Human mortality due to ambient air pollution in East Asia (35%) and India (33%) accounted for more deaths than in Africa (11%) (Silva, *et al.* 2016). Hypothesis results revealed that SO<sub>2</sub>, NO<sub>2</sub>, and PM<sub>2.5</sub> exhibited significant seasonal variation throughout the study than CO which did not show any significant seasonal variation.

Multiple linear regression was utilized to statistically investigate the relationship between seasonal hospital-based respiratory conditions, seasonal air pollutant concentration and meteorological parameters. The dependent variable (hospital-based respiratory conditions (HBRS)) was regressed with seasonal meteorological parameters (wind speed, temperature, precipitation, and relative humidity) and pollutants concentration (Table 4). The independent variables significantly influenced hospital-based respiratory conditions,  $F(8,11) = 3.652$ ,  $q = 0.025$ , which indicates that the independent variables under study have a significant influence on seasonal hospital-based respiratory conditions. Moreover, the  $R^2 = 0.726$  depicts that the model explains 72.6% of the seasonal variation in hospital-based respiratory conditions. Additionally, the coefficients were also assessed to ascertain the influence of meteorological parameters (wind speed, temperature, precipitation, and relative humidity) and pollutant concentration on hospital-based respiratory conditions. SO<sub>2</sub> has no significant influence on hospital-based respiratory conditions ( $\beta = 140.133$ ,  $t = 0.309$ ,  $q = 0.763$ ). NO<sub>2</sub> has no significant influence on hospital-based respiratory conditions ( $\beta = -303.075$ ,  $t = -0.929$ ,  $q = 0.373$ ). CO significantly increased hospital-based respiratory conditions by 83.4% ( $\beta = 217.834$ ,  $t = 2.568$ ,  $q = 0.026 < 0.05$ ). PM<sub>2.5</sub> has no significant influence on hospital-based respiratory conditions ( $\beta = -2.577$ ,  $t = -0.293$ ,  $q = 0.775$ ). Ambient temperature has no significant influence on hospital-based respiratory conditions ( $\beta = -318.472$ ,  $t = -1.629$ ,  $q = 0.132$ ). Relative humidity significantly reduced hospital-based respiratory conditions by 30.8% ( $\beta = -11.308$ ,  $t = -2.220$ ,  $q = 0.048$ ). Precipitation has no significant influence on hospital-based respiratory conditions ( $\beta = 65.217$ ,  $t = 1.478$ ,  $q = 0.167$ ). Wind-speed has no significant influence on hospital-based respiratory conditions ( $\beta = 33.584$ ,  $t = 0.186$ ,  $q = 0.856$ ).

**Table 4.** Relationship between seasonal ambient air pollutant concentration, meteorological parameters, and seasonal hospital-based respiratory conditions.

| Predictors        | $\beta$  | t      | q-value | Results       |
|-------------------|----------|--------|---------|---------------|
| SO <sub>2</sub>   | 140.13   | .309   | .763    | Not supported |
| NO <sub>2</sub>   | -303.07  | -.929  | .373    | Not supported |
| CO                | 217.83   | 2.568  | .026*   | Supported     |
| PM <sub>2.5</sub> | -2.577   | -.293  | .775    | Not supported |
| Temperature       | -318.47  | -1.629 | .132    | Not supported |
| Relative Humidity | -11.308  | -2.220 | .048*   | Supported     |
| Precipitation     | 65.217   | 1.478  | .167    | Not supported |
| Wind Speed        | 33.584   | .186   | .856    | Not supported |
| ANOVA             | F (8,11) | 3.652  | 0.025*  |               |
| R <sup>2</sup>    | 0.726    |        |         |               |

$q < 0.05^*$ ; Dependent variable: Hospital-based respiratory conditions. Regression weight; Weighted by season.

Source: Field Survey, (2021).

Multiple linear regression was utilized to statistically investigate the relationship between monthly hospital-based respiratory conditions, monthly air pollutants concentration and monthly

meteorological parameters. The dependent variable (hospital-based respiratory conditions (HBRS)) was regressed with monthly meteorological parameters (wind speed, temperature, precipitation, and relative humidity) and pollutants concentration (Table 5). The independent variables significantly influenced monthly hospital-based respiratory conditions,  $F(8,111) = 8.315$ ,  $q = 0.000$ , which indicates that the independent variables under study have a significant influence on monthly hospital-based respiratory conditions. Moreover, the  $R^2 = 0.375$  depicts that the model explains 37.5% of the monthly variation in hospital-based respiratory conditions. Additionally, the coefficients were also assessed to ascertain the influence of meteorological parameters (wind speed, temperature, precipitation, and relative humidity) and pollutant concentration on monthly hospital-based respiratory conditions.  $SO_2$  has no significant influence on monthly hospital-based respiratory conditions ( $\beta = 25.777$ ,  $t = 1.049$ ,  $q = 0.297$ ).  $NO_2$  significantly reduced monthly hospital-based respiratory conditions by 87.4% ( $\beta = -48.874$ ,  $t = -2.835$ ,  $q = 0.005$ ).  $CO$  has no significant influence on monthly hospital-based respiratory conditions ( $\beta = 6.0454$ ,  $t = 1.627$ ,  $q = 0.107$ ).  $PM_{2.5}$  significantly increased monthly hospital-based respiratory conditions by 36.1% ( $\beta = 1.361$ ,  $t = 2.998$ ,  $q = 0.003$ ). Ambient temperature has no significant influence on monthly hospital-based respiratory conditions ( $\beta = 7.036$ ,  $t = 1.128$ ,  $q = 0.262$ ). Relative humidity significantly increased monthly hospital-based respiratory conditions by 21.4% ( $\beta = 6.214$ ,  $t = 4.395$ ,  $q = 0.000$ ). Precipitation has no significant influence on monthly hospital-based respiratory conditions ( $\beta = -0.082$ ,  $t = -0.730$ ,  $q = 0.467$ ). Wind-speed significantly reduced monthly hospital-based respiratory conditions by 37.9% ( $\beta = -21.379$ ,  $t = -2.384$ ,  $q = 0.019$ ).

**Table 5.** Relationship between monthly ambient air pollutant levels, meteorological parameters, and monthly hospital-based respiratory conditions.

| Predictors        | $\beta$   | t      | q-value* | Results       |
|-------------------|-----------|--------|----------|---------------|
| $SO_2$            | 25.777    | 1.049  | .297     | Not supported |
| $NO_2$            | -48.874   | -2.835 | .005*    | Supported     |
| $CO$              | 6.045     | 1.627  | .107     | Not supported |
| $PM_{2.5}$        | 1.361     | 2.998  | .003*    | Supported     |
| Temperature       | 7.036     | 1.128  | .262     | Not supported |
| Relative Humidity | 6.214     | 4.359  | .000*    | Supported     |
| Precipitation     | -.082     | -.730  | .467     | Not supported |
| Wind Speed        | -21.379   | -2.384 | .019*    | Supported     |
| ANOVA             | F (8,111) | 8.315  | 0.000*   |               |
| $R^2$             | 0.375     |        |          |               |

$q < 0.05^*$ ; Dependent variable: Hospital-based respiratory conditions. Regression weight; Weighted by month.

Source: Field Survey, (2021).

Hypothesis result revealed varying significant relationships between seasonal pollutants, meteorological variables and respiratory hospital visitation. Only seasonal ambient  $CO_2$  levels and relative humidity showed a strong influence on seasonal respiratory hospital visitation. This is consistent with the findings of Rajendra, *et al.* (2021) who investigated the impacts of mixture of pollutants on hospital visits for respiratory morbidity in Canada and found that  $CO$ ,  $PM_{2.5}$ ,  $NO_2$ , or Ozone had a stronger impact on respiratory hospital visitation during the warm season than a combination of pollutants. Monthly ambient  $NO_2$ ,  $PM_{2.5}$ , relative humidity and wind-speed levels showed a strong significant influence on monthly respiratory hospital visitation across the study area and period of study. This result is consistent with the findings by Hsu *et al.*, (2017) who investigated ambient  $PM_{2.5}$  levels in residential areas near industrial complexes in Central Taiwan and found that daily exposure to  $PM_{2.5}$  by  $10\mu g m^{-3}$  resulted to an increase in respiratory physician visits for elderly aged  $\geq 65$  years in winter by over 2%. Zhaohui, *et al.* (2021) also investigated the nexus between air pollutants exposure and the risk of pulmonary embolism hospitalization in Beijing China and found a positive association between elevated levels of  $PM_{2.5}$ ,  $O_3$ ,  $CO$  and  $PM_{10}$  on pulmonary embolism

hospitalization (3500 cases in three years at 6.5 per 1000 population) among women ages 65 and above.

#### 4. Conclusion

This study investigated the quality of ambient industrial air pollution and human health in Lagos state and found a considerable decline in the quality of air during the dry season than the wet season and control site. The results revealed varying monthly and seasonal variations in the concentration levels of both fine particulate matter and gaseous pollutants across the state. Meteorological variables like precipitation, wind speed, relative humidity and temperature significantly influenced the concentration levels of both fine particulate matter and gaseous pollutants across the state. Specifically, wind speed, relative humidity and precipitation recorded higher levels during the wet season than during the dry season and significantly played remediating roles in the reduction of the concentration levels of both fine particulate matter and gaseous pollutants across the state. More respiratory hospital visitations were found during the dry than the wet season due largely to poor ambient air pollution concentration levels. For example, pneumonia, asthma, upper and lower respiratory tract infections, chronic obstructive pulmonary diseases (COPD) and lung cancer were majorly reported across the state than laryngitis, tonsillitis, and emphysema especially among under 5 and post-natal outdoor patients. A significant monthly and seasonal variation in both gaseous and fine particulate pollutant levels was found across the study area.

#### 5. Recommendation

There is an urgent need for the development of a master plan and infrastructures for the sitting and continuous monitoring of ambient air quality across the industrial estates in Lagos states, especially in Odogunya, and Apapa. Efforts to reduce air pollution levels is dependent on the resources deployed for air quality infrastructural development in the city. For example, the Romanian implementation of the EU acquis helped in the development of monitoring and reduction approach capacity for major air pollutants levels in the country, in the Czech Republic, air pollution tax imposition on industries was used as a measure for reducing emission concentration limits in the city, in China, government embarked on a national action plan to reduce air pollution in 2013 across the country with specific focus on the most industrialized regions of Beijing-Tianjin-Hebei, Yangtze River Delta and Pearl River Delta regions. The plan committed over 390 billion US dollars by both the central and the Beijing city governments. The plan's objective centered on the provision of incentives for pollution reduction across all levels of government in China, replacement of coal power plants with natural gas and increase in renewable energy production and generation, reduction and shutting down of the iron and steel production capacity of the country, reduction of vehicles on the road and installation of over 5000 air quality monitoring stations across the country. The results in 2021 revealed a decline in fine particulate matter concentration by 39.6% across all cities in China and a gain in life expectancy of 2 years, a 48.8% reduction and an increase in life expectancy by 4.1 years in the Beijing-Tianjin-Hebei region, 20% reduction in the Pearl River Delta region and a 15% decline in the Yangtze River Delta region of China. In Bogota, Columbia, the government plans to reduce air pollution by 10% by 2024 through the electrification of its public buses and metro stations. The Breathe Warsaw initiative in Poland is transitioning from coal heating to cleaner energy sources and installing 165 sensors for the monitoring of air quality. In Seoul, South Korea, the government is working towards the eradication of diesel-powered cars and mass transit fleets from all public spaces by 2025. In Bangkok, Thailand, the Green Bangkok 2030 project is working towards increasing green spaces and footpaths to reduce dependence on private transportation. The Breathe Life campaign project in Accra, Ghana is poised to sensitize and educate the populace on the health risks of exposure to indoor cooking stoves and waste burning. Such global approaches are aimed at reducing air pollution in cities and can be planned and implemented across the city of Lagos and the industrialized regions of Nigeria which will build a stronger voice for the prioritization of air

pollution in the development agenda of low- and middle-income countries (Sánchez-Triana, *et al.* 2021).

There is an urgent need for the enforcement and installation of air quality control devices such as mist collectors, scrubbers, incinerators, air filters, electrostatic precipitators, cyclones, biofilters, and catalytic reactors in all manufacturing companies across the industrial estates, to filter and prevent obnoxious and poisonous gases and particulate from the ambient environments. Air quality sensors should be enforced and installed in all manufacturing industries to monitor the quality of both indoor and outdoor pollutant levels. An outdoor solar-assisted large-scale cleaning system is being used in Xi'an China to reduce the level of fine particulate matter in the city. These can be adopted and deployed as a matter of urgency to areas like Odogunyan, Apapa and Surulere industrial estates where the level of both fine particulate matter and gaseous pollutants are unacceptably high.

Regular power supply should be provided to reduce the use of generators which pollute the environment. Waste management practices and evacuation should be intensified across the industrial estates, especially in Apapa where both industrial wastes and human excreta are pervasive due to inadequate mobile toilets and irregular waste evacuators along Wharf and Burma Roads. Regular sanitation should be enforced in Apapa and Odogunyan industrial estates for the timely evacuation of wastes generated from the industries. Decommissioning of industrial facilities can be carried out by the government especially the iron steel companies in Odogunyan which have failed to make corporate social responsibility a priority in their host communities and have failed to also reduce the poisonous soot and obnoxious gases released into the ambient environment.

### 5.1. Limitation of the Study

Studies on air quality and respiratory conditions require funding to access scarce air quality monitoring equipment and respiratory data. Air quality monitoring infrastructures are inadequate in Nigeria due to limited government and private sector support for air quality research. Access to respiratory data across government hospitals was cumbersome and need to be accessible to researchers. This study was funded by the researchers and that affected the number of monitoring points designed for this study. With the right funding support in future studies, more sampling points can be covered to improve on the quality of air quality research outcomes.

### 5.2. Ethical Approval

Ethical approval for this study was granted by the University of Ibadan Social Science Ethics Committee with Number: **UI/SSHREC/2019/0038**, Lagos State Ministry of Health, and the Lagos State Health Service Commission.

**Authors Contribution:** PNA and IOA conceived the topic and both developed the study design. PNA collected the data and analyzed it while IOA developed the study content and supervised the development of the manuscript. Both PNA and IOA read and agreed on the final research output. .

**Conflicts of Interest:** PNA and IOA declared a conflict of no interest.

**Data Availability declaration:** The air quality, meteorologic and respiratory data used for this research are readily available for your elucidation.

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