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**Posted Date:** August 24th, 2026

**DOI:** https://doi.org/10.21203/rs.3.rs-10595310/v1

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**Additional Declarations:** No competing interests reported.

# The Linkages between Air Quality Index, Environmental Quality and Self-Reported Respiratory Conditions. Empirical Evidence from Selected Industrial Locations in Lagos State, Nigeria

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## Abstract

Gaseous and particulate pollutants affect environmental quality, significantly influencing the health of the city's proximate and ambient workers. The development of city infrastructures, industries and transport especially in developing countries has exacerbated air pollution problems and reduced the city's environmental quality. This study assessed the quality of the ambient environmental quality and self-reported respiratory conditions of selected industrial locations in Lagos, Nigeria. Primary data were purposively collected from five active industrial estates (Ikeja/Ogba, Surulere, Odogunyan, Apapa, and Oshodi/Ilupeju), using 10 sampling points and a control (Alausa). Using standard measuring devices, air quality ($SO_2$, $NO_2$, CO, $PM_{2.5}$) parameters were obtained through field monitoring for eight hours in each location, once a month, over 12 months. The United States Environmental Protection Agency Air Quality Index, atomic absorption spectrophotometer, titrimetric analysis and the modified British Research Council Questionnaire were used for this study. The findings revealed; that AQI was very unhealthy at Odogunyan (229±33.73), unhealthy for sensitive groups at Surulere (130±45.23), Oshodi/Ilupeju (129±68.87), Apapa (120±54.97) and Ikeja/Ogba (119±43.87), but was moderate at Alausa (64±18.40), in the dry season. During the wet season, AQI was unhealthy at Odogunyan (161±51.19), moderate at Apapa (86.25±53.61), Ikeja/Ogba (85.00±44.14) and Alausa (52.75±28.39), but unhealthy for sensitive groups at Oshodi/Ilupeju (100.25±55.66) and Surulere (100.5±44.23). Rainwater pH was normal and ranged from 5.7 to 6.9. Soils within the industrial locations are contaminated with cadmium, lead, and arsenic than the control site. Self-reported respiratory symptoms and morbidities were coughing, headache, cold, tiredness, irritation of the eyes, asthma, pneumonia and lung cancer. Gender (OR=1.866), occupation (OR=3.230), housing types (OR=1.575) and cigarette smoking (OR=0.627) significantly influenced respiratory symptoms.

**Keywords:** Air Quality Index, Soil Quality, Respiratory conditions, Heavy Metals etc.

## 1.0 Introduction

The air quality index (AQI) is a health reporting tool used to communicate to the public, the daily level of risk posed by air pollution (Tiwari, 2015; Seth and Purnendu 2024). Air quality index (AQI) is a nondimensional index used to quantitatively describe air conditions through the calculation of the concentration levels of particulate and gases (Pu, *et al.* 2016). The calculated value is the pollutant concentration expressed as a proportion of the threshold value which reduces the complexities associated with pollutant levels for easy interpretation of air quality data (Ghorani-Azam *et al*. 2016; Akinfolarin *et al.* 2017). Countries design their criteria for pollutants ranging from carbon monoxide, particulate, lead, nitrogen dioxide, ozone, sulfur dioxide, particulate matter, etc. They are; the Australian National Environment Protection Ambient Air Quality, the Canadian Air Quality Health Index, the Hong Kong Air Quality Health Index, the Mainland China Ministry of Environmental Protection Air Quality Index, the European Common Air Quality Index, the Indian Air Quality Index, the Mexican Índice Metropolitano de la Calidad del Aire (IMECA), the Pollutants Standard Index of Singapore, South Korean Comprehensive Air Quality Index, the Vietnam Air Quality Index, the United State Environmental Protection Air Quality Index (USEPAQI), the Green Index of 1966, the Shenfeld Ontario Air Pollution Index of 1970, the Oak Ridge Air Quality Index of 1971, the Air Quality Depreciation Index of 1991 and the Factor Analysis based Air Quality Index of 2009 (Ghorani-Azam *et al*. 2016; Tiwari, 2015; Salvador and Salvador, 2012).

AQI is influenced by environmental and economic factors e.g. energy consumption such as coal, oil and gas etc., and varies by season (Jafari *et al* 2017). AQIs have variations in different locations and settings, but most AQI systems have two common characteristics: a table with different levels of air pollution and health risks, ranging from minimal to severe; and colour-coding to distinguish these levels known as breakpoints. The breakpoints distinguishing different AQI levels are tied to scientific and epidemiologic evidence that links air pollution to adverse health effects among specific vulnerable populations (Salvador and Salvador, 2012). Air quality index is usually higher during summer than in the monsoon season (Bhaskar & Mehta, 2010), higher during the dry than in the wet season in the tropics (Akinfolarin *et al.* 2017) and its seasonal variation can be analyzed using the spatial autocorrelation Moran's index (Moran's I) (Pu, *et al.* 2016; Oyebanji, *et al*. 2021;

She *et al.*, 2017). Time series analysis is a forecasting and predicting tool in AQI computation (Abd Rahman *et al*. 2016; Akinfolarin *et al.* 2017).

The United States Environmental Protection Air Quality Index (USEPAQI) focuses on 5 pollutants which are of concern to the health of its populace and they are; Carbon(ii)oxide (CO), Sulfur(iv)oxide ($SO_2$), Nitrogen(iv)oxide ($NO_2$), both fine ($PM_{2.5}$) and coarse ($PM_{10}$) particulate matter and Ozone ($O_3$). These USEPAQI 5 criteria pollutants are regulated under the Clean Air Act and national ambient air quality guidelines set for each of these pollutants and reviewed every 5 years based on evolving air pollution health dynamics.

## 2.0 Statement of the Problem

Ambient air pollution (AAP) is the contamination of outdoor air (WGB, 2020). Globally, AAP accounts for over 3 million deaths annually with the worst hit in South-East Asia and Western Pacific countries (WHO 2016). Over 90% of the world's inhabitants in cities breathe air that is lower than the WHO air quality guidelines (WHO 2016, 2021). Environmental quality is important to the quality of life. Individual reactions to air pollutants depend on the type of pollutant exposed to, the degree of exposure and the individual's health status (Tawari & Abowei 2012; Zagha & Nwaogazie, 2015).

According to the World Health Organization (2010) report on air pollution, air pollutants are linked to respiratory infections, heart disease and lung cancer. Exposure to outdoor air pollution contributes to a broad array of acute and chronic health effects ranging from minor physiological impacts to death from respiratory and cardiovascular diseases (West 2016). Ambient air pollution deaths have been increasing worldwide since the 1990s especially in rapidly industrializing countries (Landrigan, 2017). There is a marked disparity in mortality cases recorded from non-communicable diseases (NCD) between developed (12%) and low- and middle-income countries (21% and 23%) (WHS, 2018). The health effects caused by short and long term exposure and inhalation of gases, fumes and particulates are difficulty in breathing, wheezing, stroke, anaemia, cancer, emphysema, etc. which result in increased medication use, increased doctor or emergency room visits, more hospital admissions and premature death (Asuoha & Osu, 2015; Demetriou

& Vineis 2015; Guillerm & Cesari, 2015; Ediagbonya *et al,* 2016; Landrigan, 2017; Senaul & Singh, 2017; State of Global Air, 2018).

Impacts are both direct and indirect of which direct impacts are chronic and acute effects on human health, ecosystem damage (massive land degradation and reduction of water quality) and poor visibility while the indirect impacts are acid rain (chemicals released into the atmosphere) and climate change caused by the warming of the atmosphere (Hutton, 2011; Surinder & Verma, 2016). According to the UNEP report on the emission gap (2016), global carbon (iv) oxide ($CO_2$) emissions from fossil fuels and industries account for 68% of total global greenhouse gas emissions and also an excess of sulfur and nitrogen compounds emissions is responsible for the widespread acidification of soils and water and eutrophication in nutrient-poor ecosystems (Rogers, 2017). The WHO Report on Climate and Clean Air Coalition (2018) identified that nine out of ten people are exposed to poor air quality with an alarming death toll of 7 million annually.

Air pollution studies in Nigeria focused on the diurnal, weekly and seasonal variation in air pollution with little attention on the soil and rainwater pH of the area(Akanni 2008, 2010; Asibioju, 2016; Alfred & Hyeladi, 2013; Gobo, *et al* 2012; Nwachukwu *et al,* 2012; Ekpenyong *et al,* 2012; Umoh *et al,* 2013; Asuoha & Osu 2015; Zagha & Nwaogazie, 2015; Tawari & Abowei, 2012; Ana, 2011; Ojo & Awokola, 2012; Ipeaiyeda & Adegboyega, 2017; Ogwu *et al,* 2015; Weli 2014; Weli & Adegoke, 2016; Ojekunle *et al,* 2018; SWIFT, 2017; Mustapha *et al.* 2022). This has necessitated the investigation of the nexus between air pollution, soil and rainwater pH, and self-reported respiratory conditions across industrial locations in Lagos, Nigeria's most industrialized state.

## 3.0 Materials and Methods

### 3.1 Study Area

Lagos State is situated in South Western Nigeria at latitudes $6^0$22'N and $6^0$52'N and longitudes $2^0$42'E and $3^0$42'E. It is bounded to the west by the Republic of Benin, on the southern boundary by a 180 km long Atlantic coastline and the northern and eastern boundaries by Ogun State. Lagos state has a landmass of 3,671km$^2$ of which over 35% (787 km$^2$) 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 the tropical rainforest, montane or highland and the tropical savanna climates (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 defined by swamp forest of the coastal belt with fresh water, and dry lowland rain forest with patches of vegetation in their natural state. These wetland vegetation is caused by the double maxima rainfall pattern of the region (Adelana *et al.* 2005; Odjugbo, 2010). The geology of Lagos state is made up of the tertiary and quaternary sediments which comprises of 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 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 projected to be over 30 million by 2025 (PWC, 2015). Over 80% of the population are domiciled on 37% of the metropolitan landmass where all economic activities are concentrated and driven by a skilled work force of over 45% with a literacy rate of 92% (Ojeh *et al* 2016; PWC, 2015). 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. (Ajayi, 2007, 2011; Etim, 2012; Ojiodu *et al,* 2013; Mashi *et al,* 2014). Some of these estates are both active and dormant in industrial activities. In terms of their sizes, activeness and intensities of

industrial activity, Ikeja/Ogba, Oshodi/Ilupeju, Apapa, Surulere and Odogunyan industrial estates was selected for this study.

**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: (Fagbohunka, 2014; MAN, 2014; LBS, 2016; Field Survey, 2021)

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

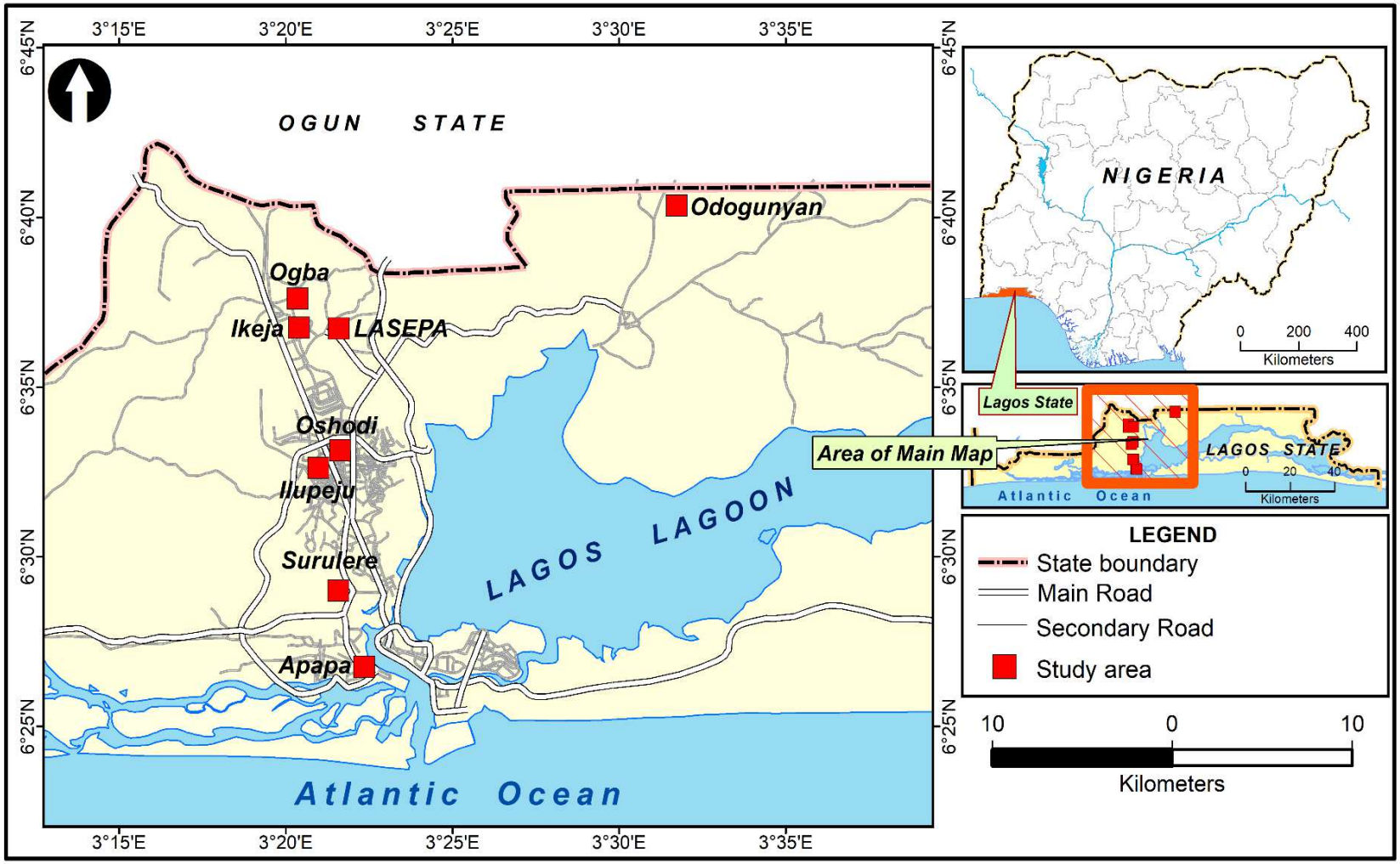



Fig. 1. Study area showing the sampling points

## 3.2 Data Collected

Reconnaissance was carried out on all 15 industrial estates situated in twelve local government areas of Lagos state in the month of 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. Primary data collected are monthly air quality levels of sulfur (iv) oxide ($SO_2$), nitrogen (iv) oxide ($NO_2$), carbon (ii) oxide (CO), and fine particulate matter ($PM_{2.5}$) 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 ($PM_{2.5}$), a vrae multi-detector for nitrogen (iv) oxide ($NO_2$) and sulfur(iv)oxide ($SO_2$), and a tecto 315-2 carbon(ii)oxide detector with for carbon(ii)oxide. Air quality parameters results were used to compute the USEPA Air Quality Index. The USEPAQI is divided into six categories to indicate the level of health concerns and AQI of less than 50 means safe and above 300 is considered unsafe and hazardous to human health. AQI helps to communicate to the public the complexities of air quality in a simplified form using colour to denote the level of risk posed by air pollution and the measures to protect the health of the populace.

Table 1. The United State Environmental Protection Air Quality Index and their Breakpoints (USEPAQI)

| $PM_{2.5}$ (µg/m$^3$) | CO (ppm) | $SO_2$ (ppm) | $NO_2$ (ppm) | AQI Value | AQI |
|---|---|---|---|---|---|
| *Clow – Chigh (avg)* | *Clow – Chigh (avg)* | *Clow – Chigh (avg)* | *Clow – Chigh (avg)* | *Ilow – Ihigh* | Category |
| 0.0–12.0 (24-hr) | 0.0–4.4 (8-hr) | 0–0.280 (8-hr) | 0–0.424 (8-hr) | 0–50 | Good |
| 12.1–35.4 (24-hr) | 4.5–9.4 (8-hr) | 0.288–0.600 (8-hr) | 0.432–0.800 (8-hr) | 51–100 | Moderate |
| 35.5–55.4 (24-hr) | 9.5–12.4 (8-hr) | 0.608–1.480(8-hr) | 0.808–2.880 (8-hr) | 101–150 | Unhealthy for Sensitive Groups |
| 55.5–150.4 (24-hr) | 12.5–15.4 (8-hr) | 1.488–2.432(8-hr) | 2.888–5.192 (8-hr) | 151–200 | Unhealthy |
| 150.5–250.4 (24-hr) | 15.5–30.4 (8-hr) | 2.440–4.832(8-hr) | 5.200– 9.992 (8-hr) | 201–300 | Very Unhealthy |
| 250.5–350.4 (24-hr) | 30.5–40.4 (8-hr) | 4.840–6.432(8-hr) | 10.000– 13.192 (8-hr) | 301–400 | Hazardous |
| 350.5-500.4 (24-hr) | 40.5-100.4 (8-hr) | 6.440–8.032 (8-hr) | 13.200 –16.392 (8-hr) | 401-500 | |

Source: (USEPA, 2021)

Soil samples were collected within the industrial estates at Odogunyan and Ikeja/Ogba and the control sites at Alausa. Five samples were collected at Odogunya and 5 samples at Ikeja/Ogba industrial estates. Samples were not collected at Surulere, Oshodi/Ilupeju and Apapa due to the absence of soils within the estates as the locations are built-up areas. With the aid of a hand trowel and GPS device, top soils and their location were collected. A total of 12 soil samples weighing 2kg each were collected including the control in the month of July 2021. The soils were labelled in a polythene bag and transported to the laboratory for elemental composition analysis.

Direct rainwater was collected at a height of 0.5m in the absence of buildings or trees across the industrial estates and the control. The water was collected during the wet season between the months of July and October 2021 with the aid of a wide bowl on a stand of 0.5m to avoid the influence of rain splash from the ground. The water was poured into a sterilized plastic bottle, labelled according to locations, transported and stored in the laboratory refrigerator to avoid the growth of microorganisms. A total of 6 rainwater samples were collected including the control. The rainwater samples were analyzed for pH using titrimetric analysis. A modified British Medical Research Council Questionnaire was administered to 1067 respondents derived using a Rao soft calculator from the population of the localities. Respiratory conditions data were sourced from general hospitals and teaching hospitals across the study area for a period of 12 months spanning through the wet and dry seasons between 2020 to 2021.

## 4.0 Results and Discussion

### 4.1 Monthly and seasonal variation in AQI for fine particulate matter and gaseous pollutants

Air quality index values for both gaseous and particulate pollutants varied monthly and seasonally across the study area with higher values observed in the dry season than in the wet season across the study area and period of study (Figure 2 to Figure 13). Monthly $PM_{2.5}$ AQI values ranged between 15 to 220, CO between 3 to 240, $SO_2$ between 91 to 311, and $NO_2$ ranged between 122 to 244. Seasonally, $PM_{2.5}$ AQI values ranged between 33 to 95, CO between 18 to 152, $SO_2$ between 111 to 216, and $NO_2$ between 129 to 181 during the

wet season. In the dry season, $PM_{2.5}$ ranged between 78 to 196, CO between 52 to 219, $SO_2$ between 145 to 276 and $NO_2$ between 155 to 225.

Across the study area, $PM_{2.5}$ AQI recorded the highest values in Odogunyan and Surulere industrial estates than in Apapa, Ikeja/Ogba and Oshodi/Ilupeju industrial estates. The reason for such disparity is due to the nature of industrial emissions, the untarred roads and the volume of traffic across the study area. COAQI recorded the highest values in Odogunyan industrial estate than at Apapa, Ikeja/Ogba, Oshodi/Ilupeju and Surulere industrial estates. The reason for such values in Odogunyan is due to the incomplete combustion of the iron and steel companies caused during the valorization of condemned iron into billets. $SO_2$AQI recorded higher values across the study area. The highest values were found in Odogunyan and Apapa than at Oshodi/Ilupeju, Ikeja/Ogba and Surulere. The reason for such disparity is due to the utilization of furnace oil which is rich in sulfur content by most manufacturing companies across the study area. $NO_2$AQI values were high across the study area especially in Apapa and Odogunyan due to the high volume of traffic found in both estates.

AQI was very unhealthy at Odogunyan (229±33.73), unhealthy for sensitive groups at Surulere (130±45.23), Oshodi/Ilupeju (129±68.87), Apapa (120±54.97) and Ikeja/Ogba (119±43.87), but was moderate at Alausa (64±18.40); in the dry season. During the wet season, AQI was unhealthy at Odogunyan (161±51.19); moderate at Apapa (86.25±53.61), Ikeja/Ogba (85.00±44.14) and Alausa (52.75±28.39), but unhealthy for sensitive groups at Oshodi/Ilupeju (100.25±55.66) and Surulere (100.5±44.23).

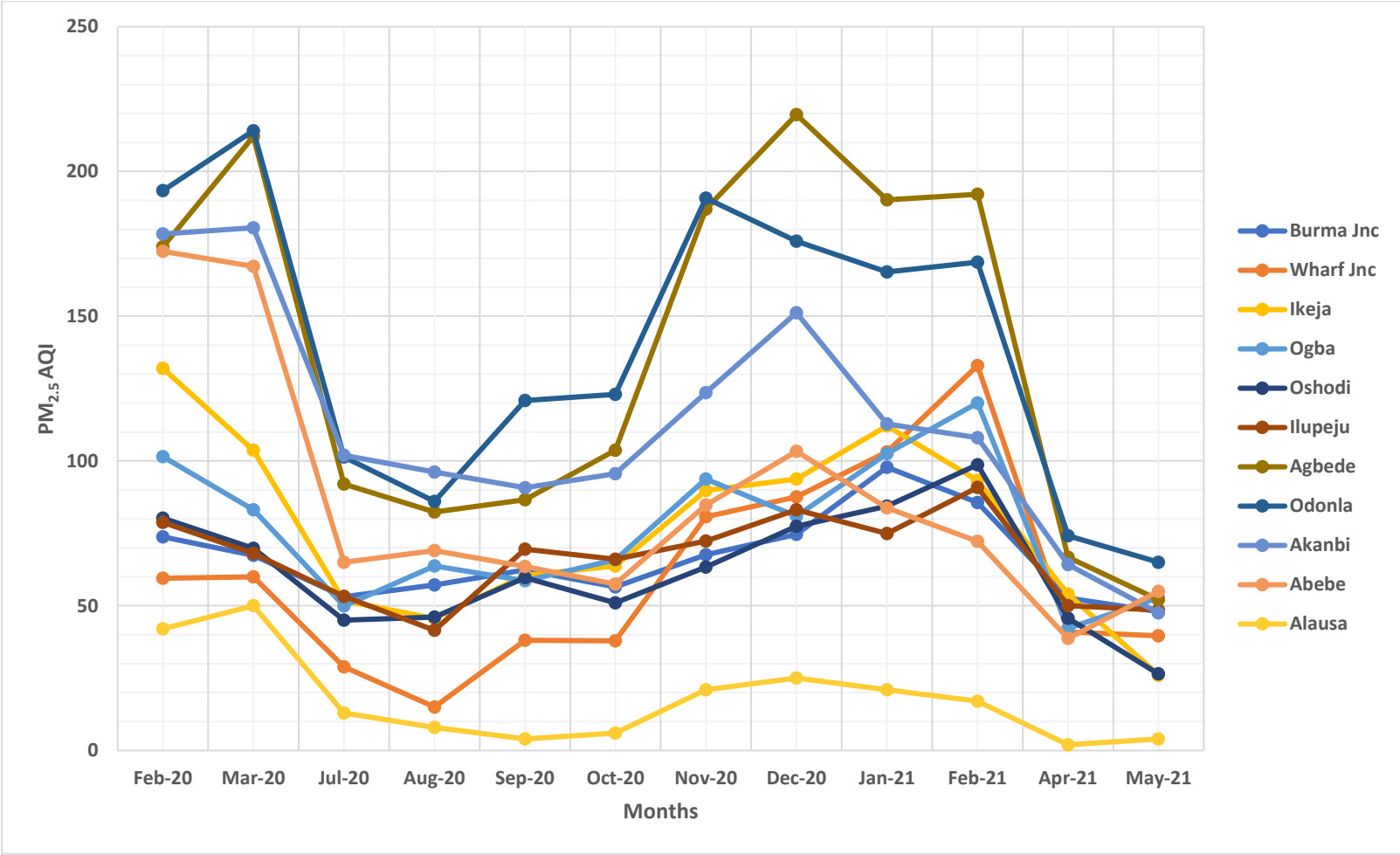



Fig. 2. Monthly variation in AQI for fine particulate matter across selected industrial locations in Lagos state

Source: Field Survey (2021)

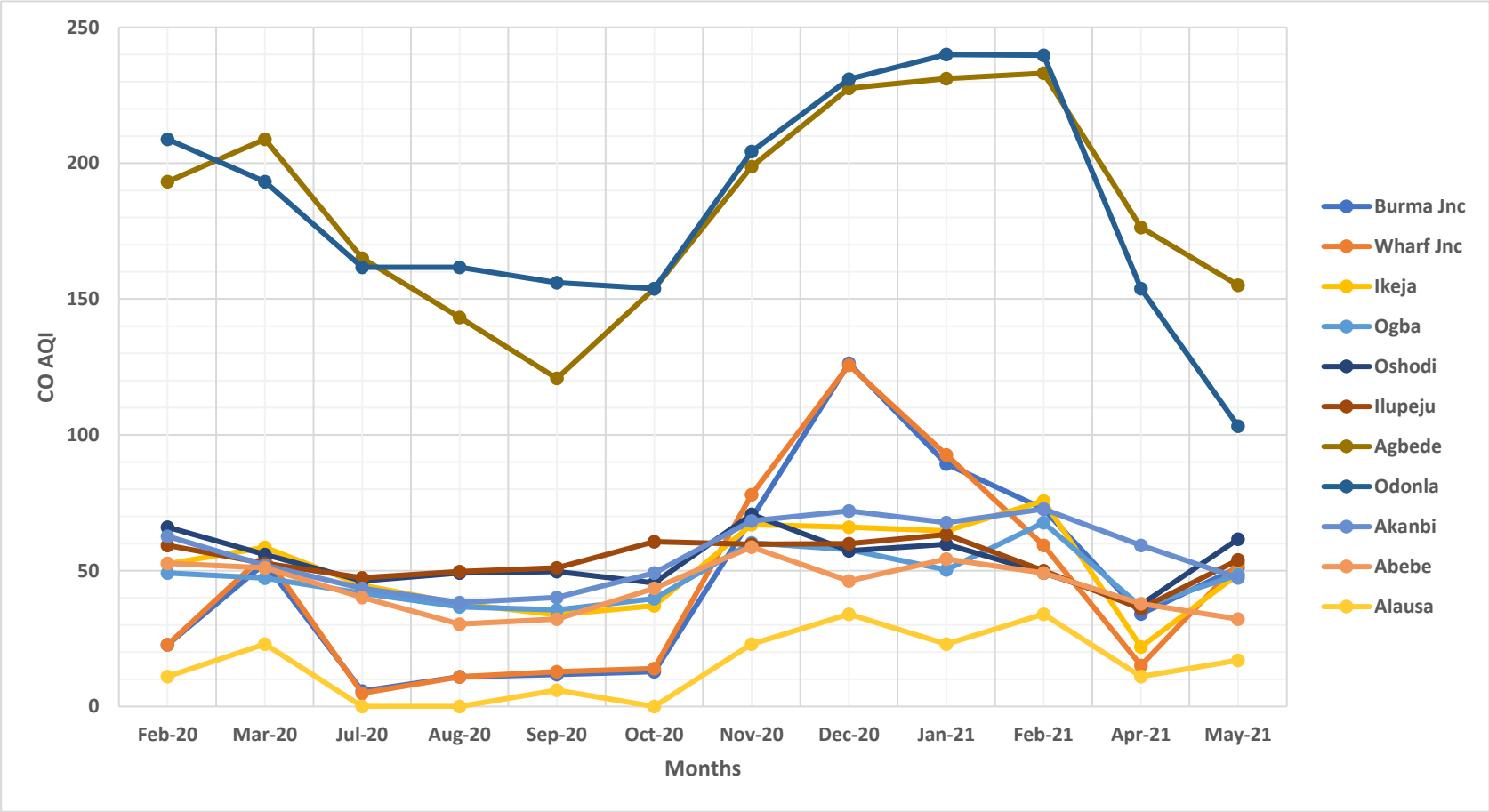



Fig. 3. Monthly variation in AQI for carbon(ii)oxide across selected industrial locations in Lagos state

Source: Field Survey (2021)

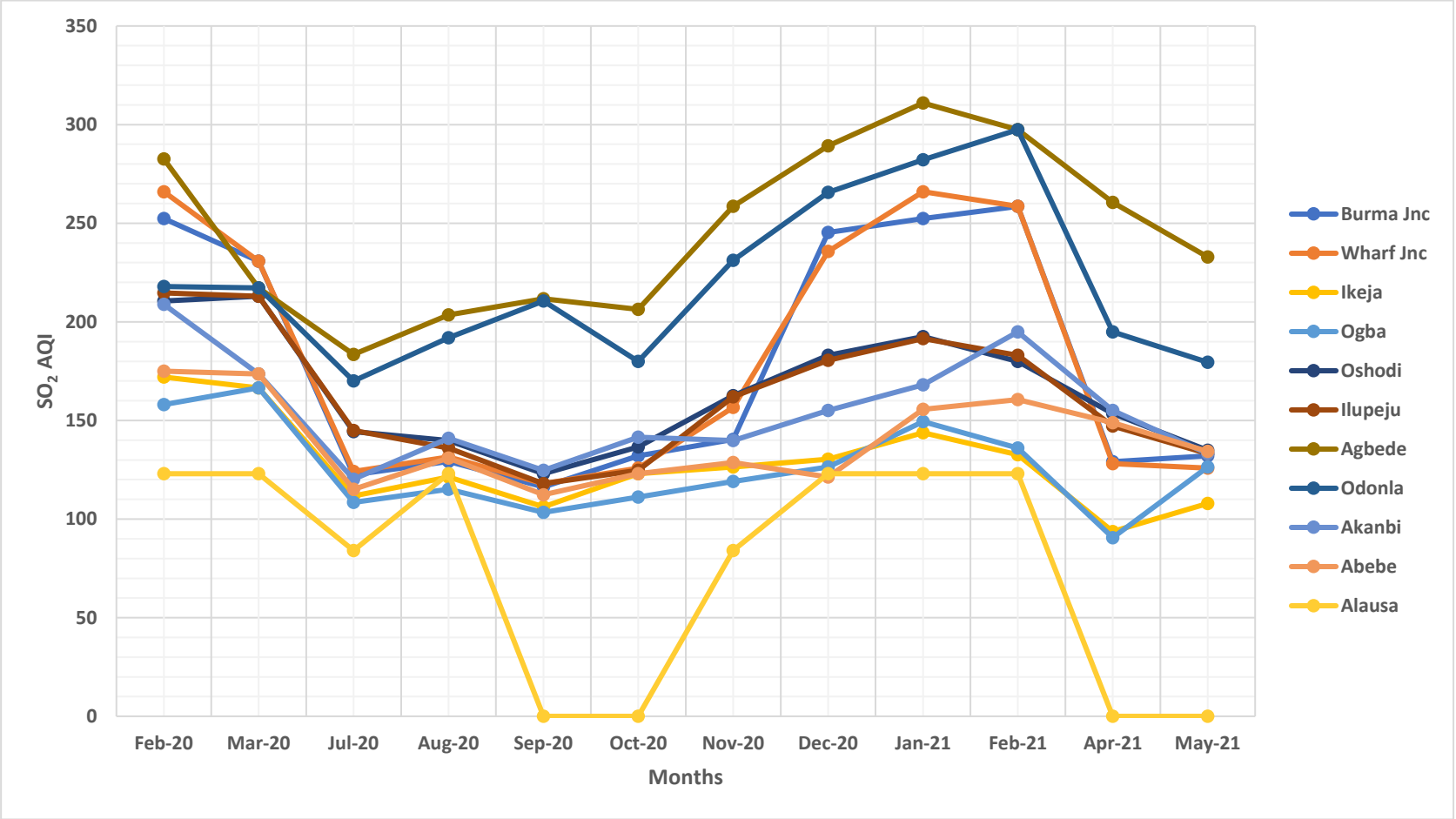



Fig. 4. Monthly variation in AQI for sulfur(iv)oxide ($SO_2$) levels across selected industrial locations in Lagos state

Source: Field Survey (2021)

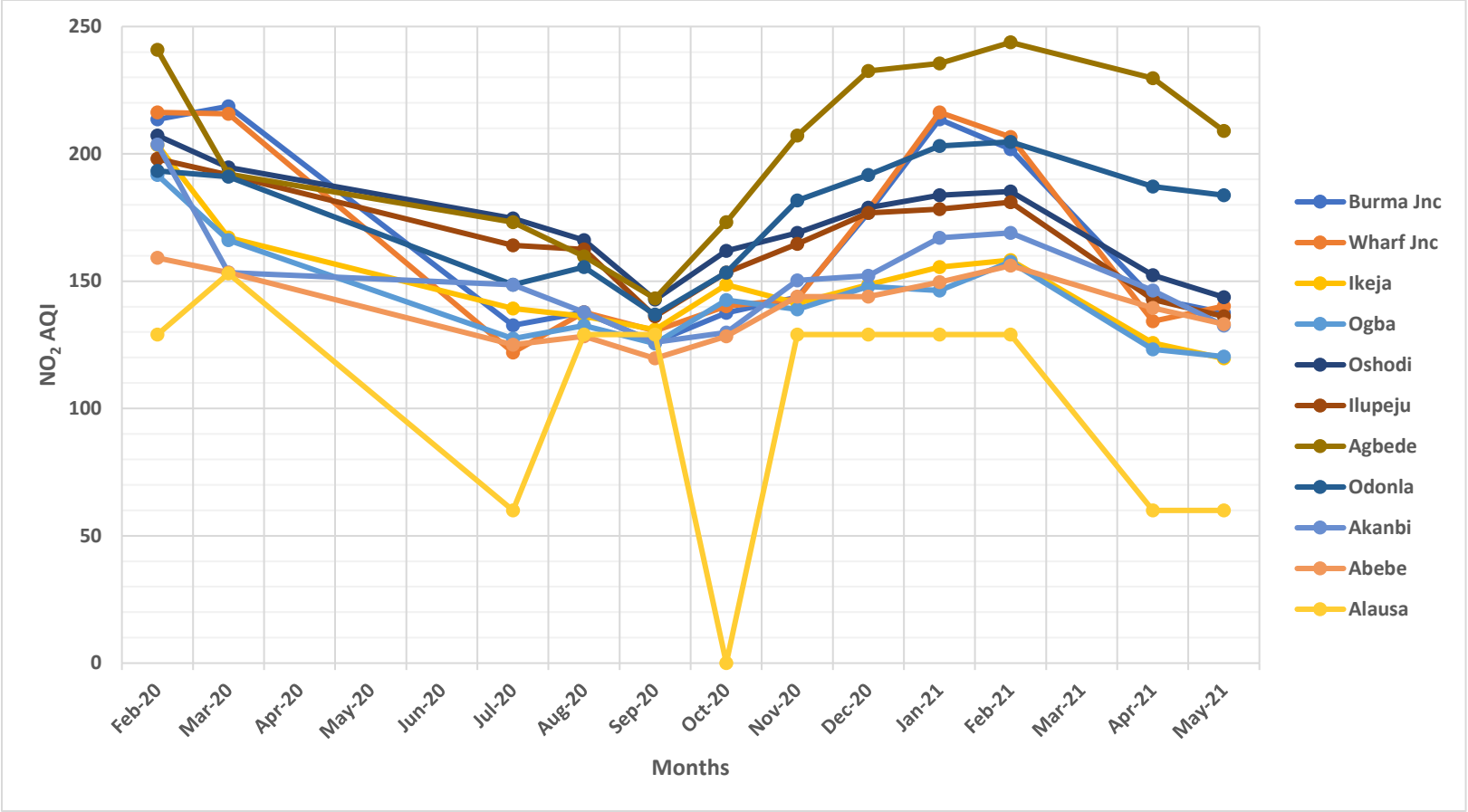



Fig. 5. Monthly variation in AQI for nitrogen(iv)oxide ($NO_2$) across selected industrial locations in Lagos state

Source: Field Survey (2021)

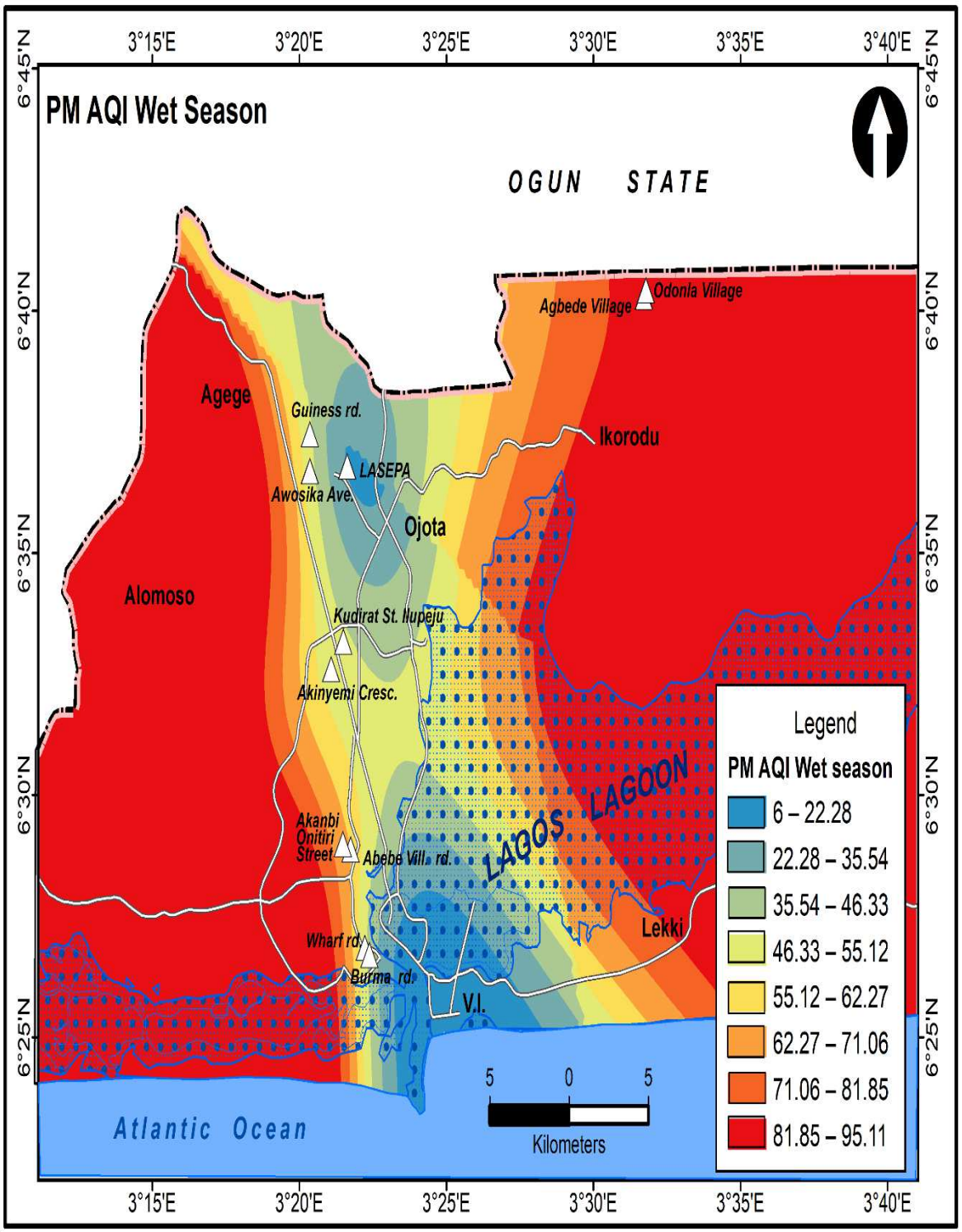



Fig. 6. Spatial variation in AQI for fine particulate matter in the wet season across selected industrial locations in Lagos State

Source: Field Survey (2021)

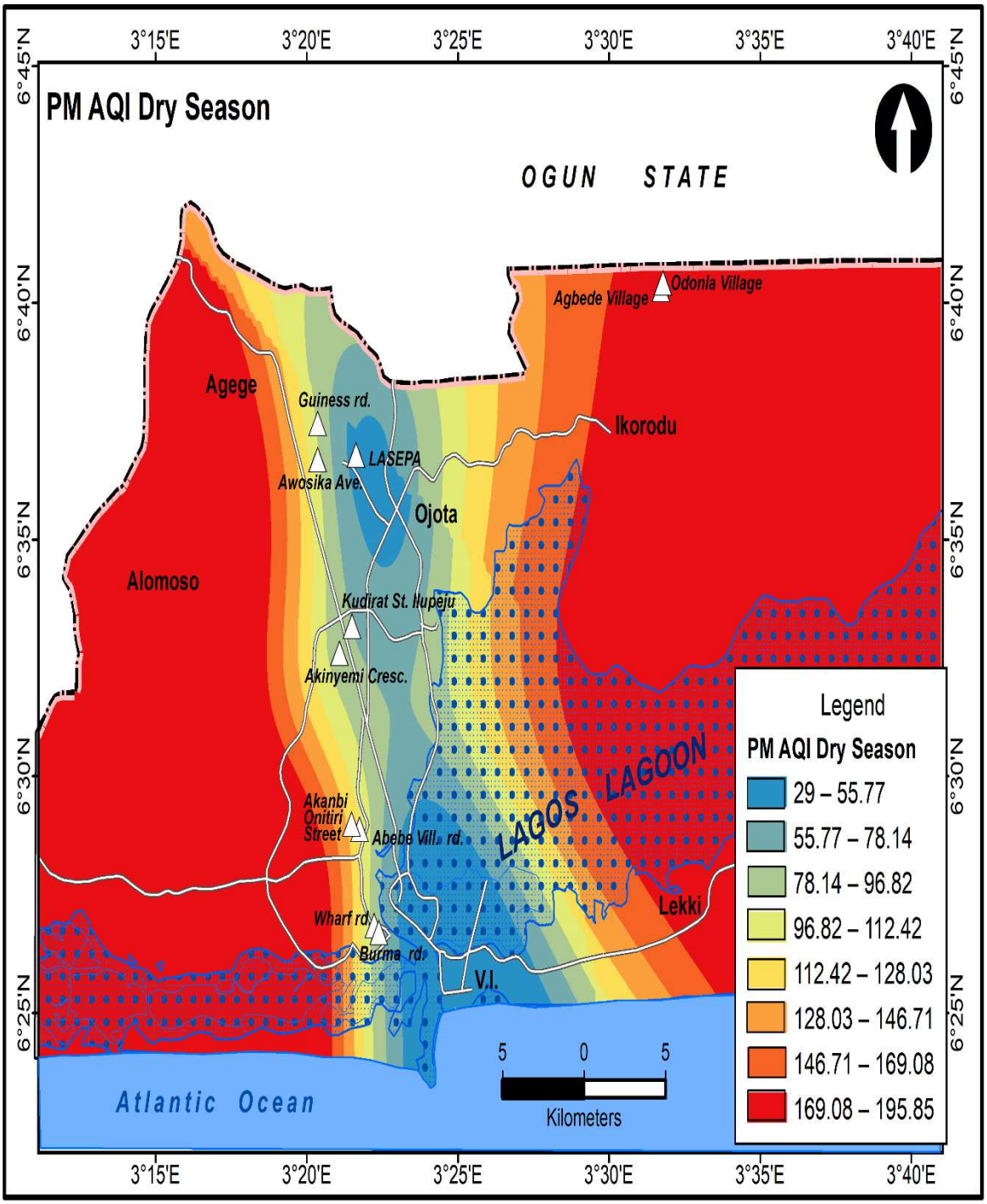



Fig. 7. Spatial variation in AQI for fine particulate matter in the dry season across selected industrial locations in Lagos State

Source: Field Survey, (2021)

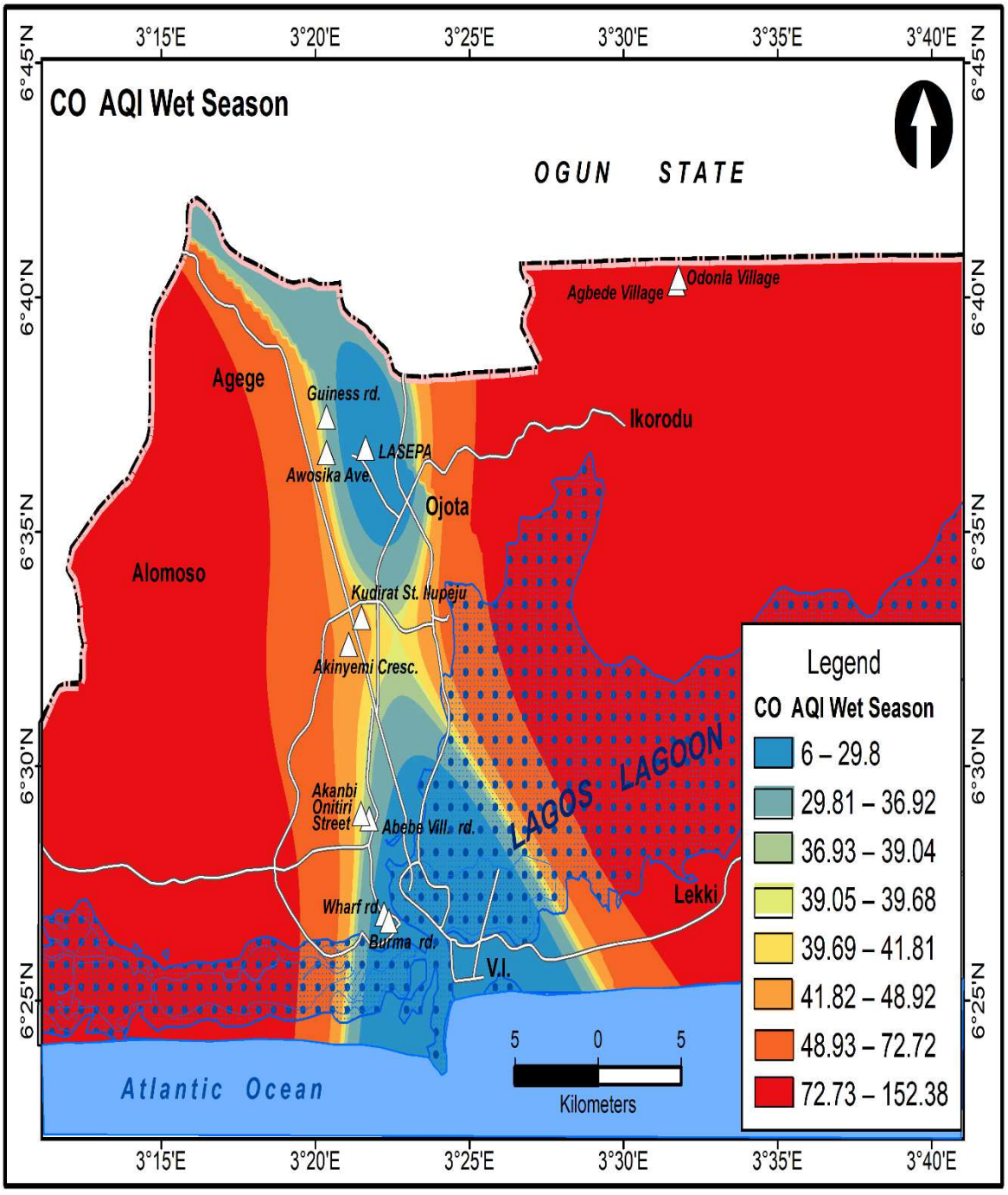



Fig. 8. Spatial variation in AQI for carbon(ii)oxide in the wet season across selected industrial locations in Lagos State

Source: Field Survey, (2021)

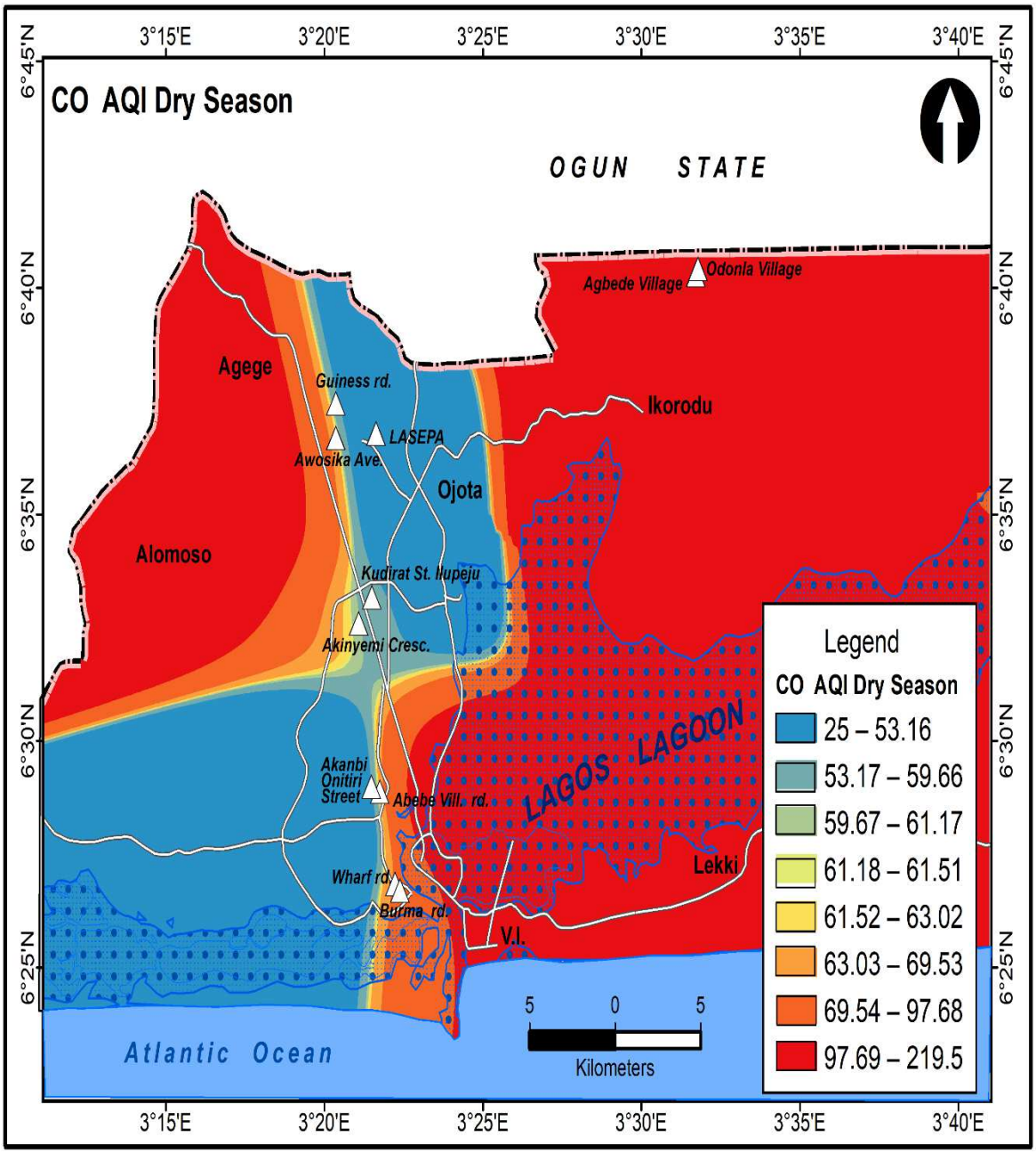



Fig. 9. Spatial variation in AQI for carbon(ii)oxide in the dry season across selected industrial locations in Lagos State

Source: Field Survey, (2021)

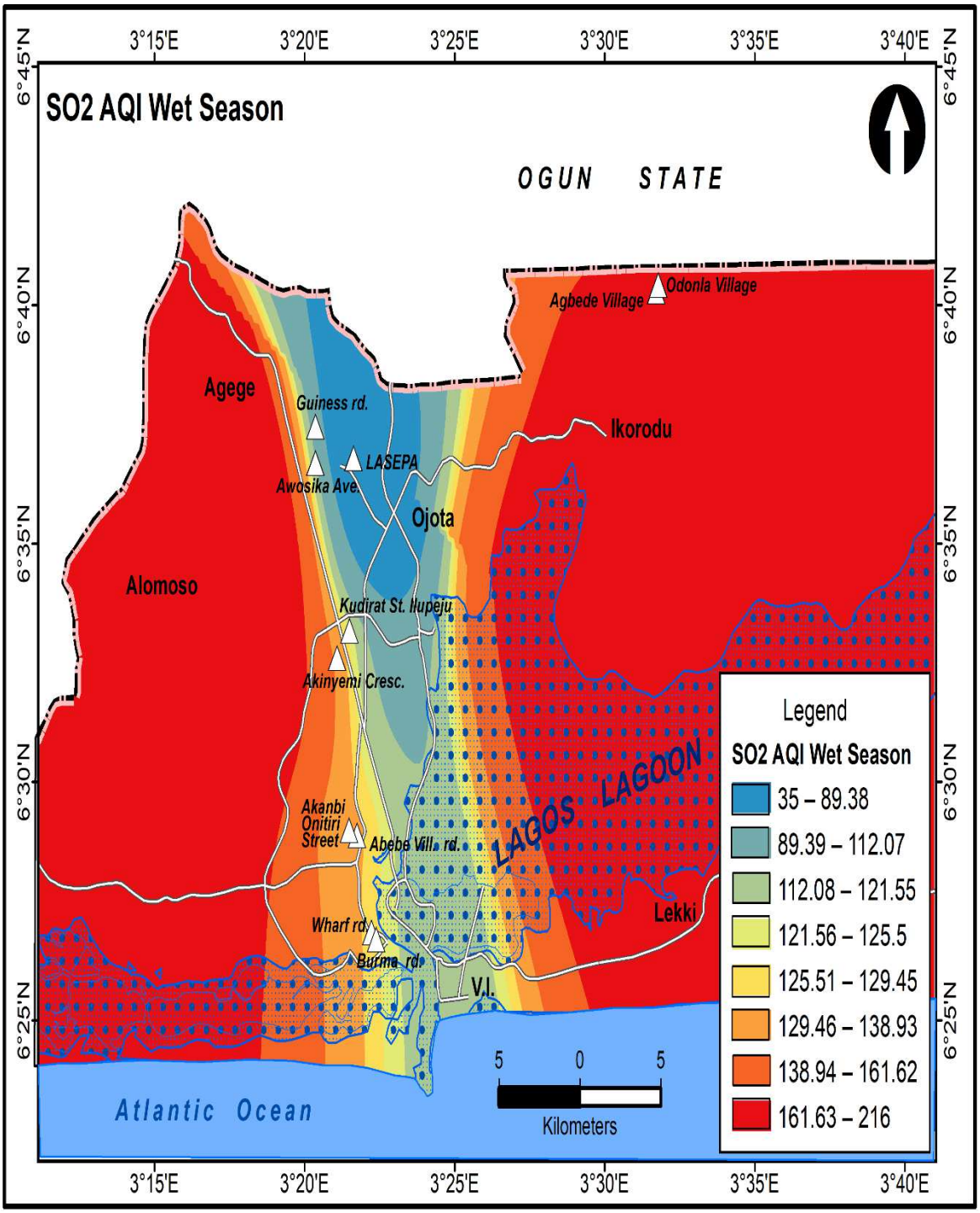



Fig. 10. Spatial variation in AQI for sulfur(iv)oxide in the wet season across selected industrial locations in Lagos State

Source: Field Survey (2021)

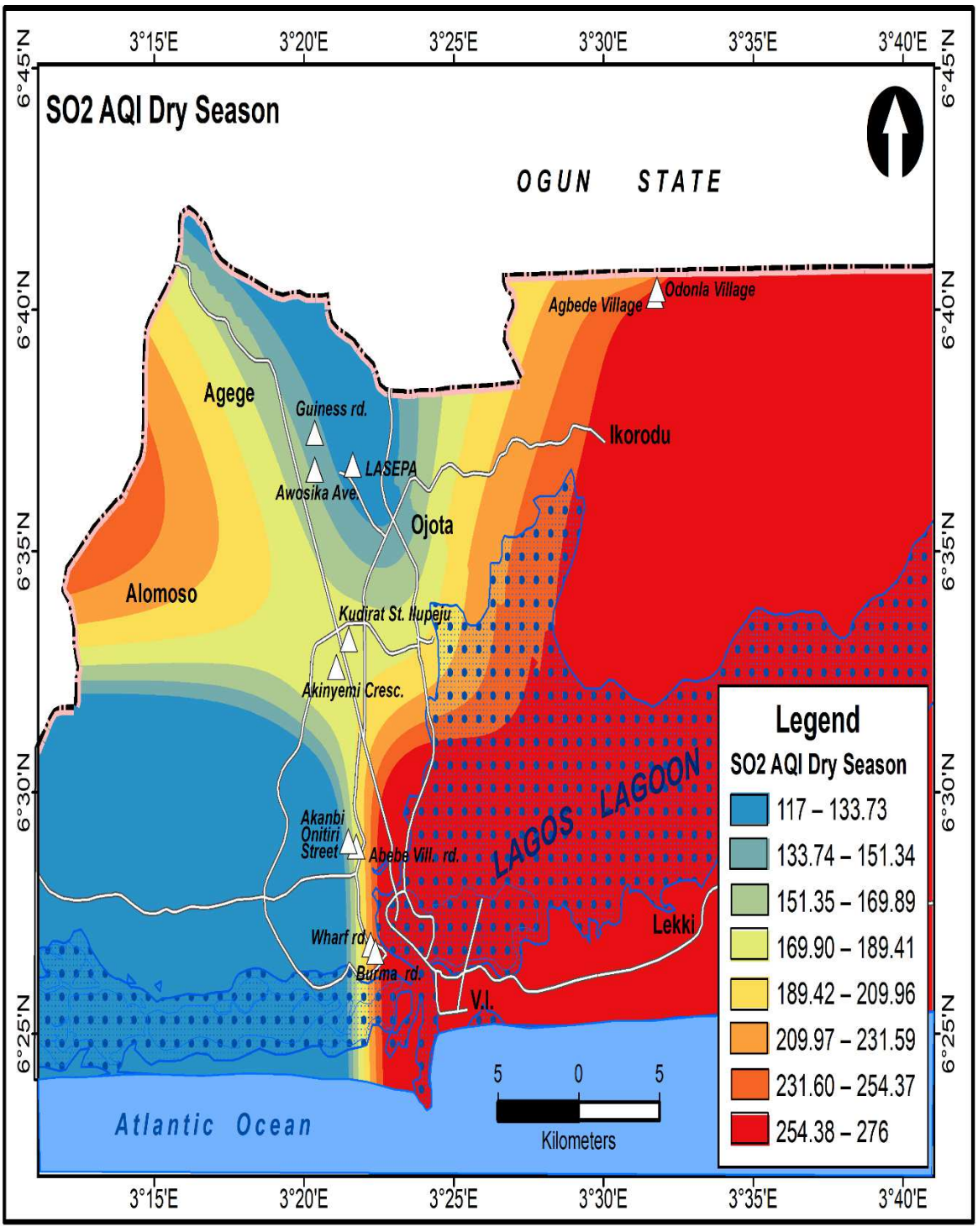



Fig.11. Spatial variation in AQI for sulfur(iv)oxide in the dry season across selected industrial locations in Lagos State

Source: Field Survey (2021)

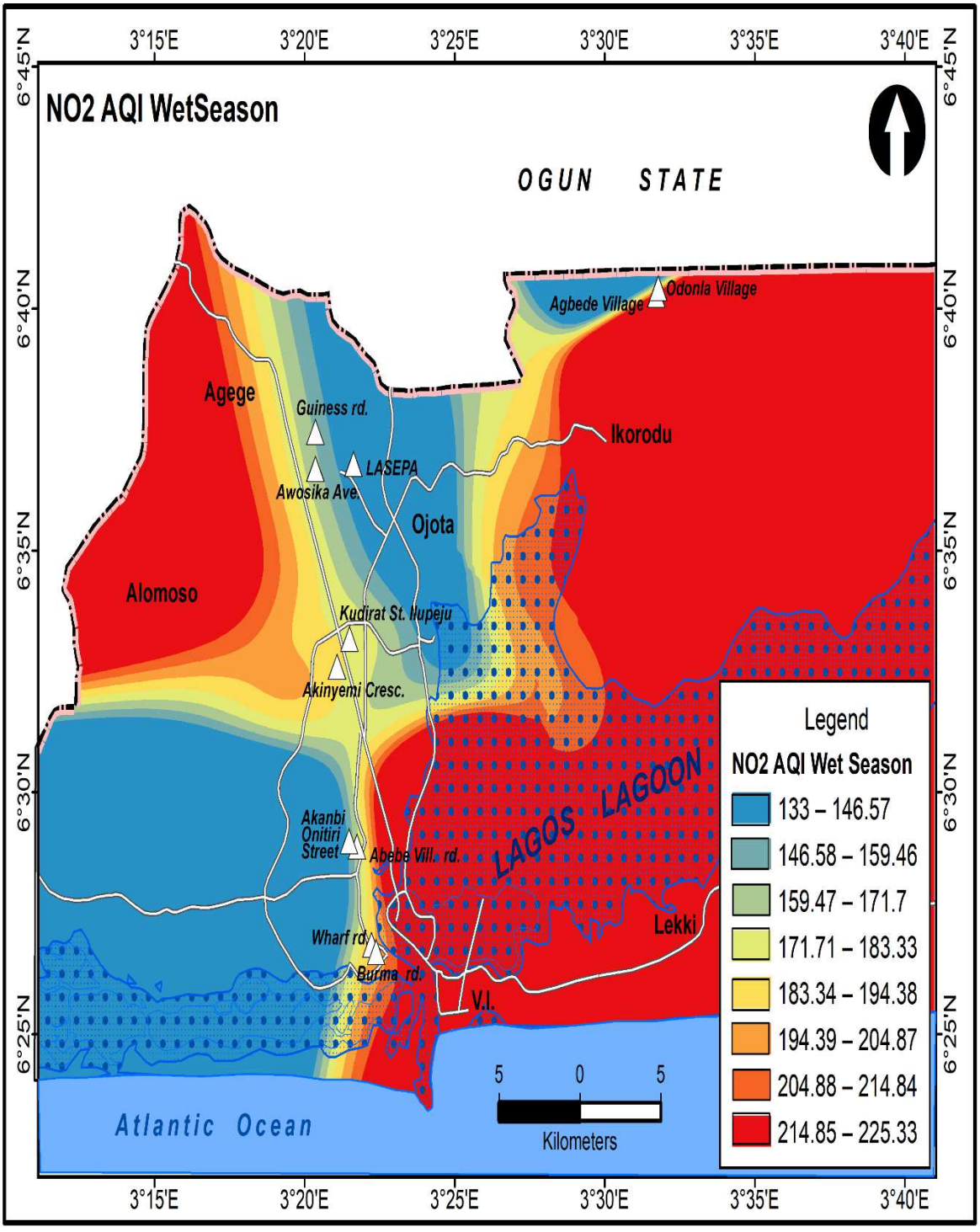



Fig. 12. Spatial variation in AQI for nitrogen(iv)oxide in the wet season across selected industrial locations in Lagos State

Source: Field Survey (2021)

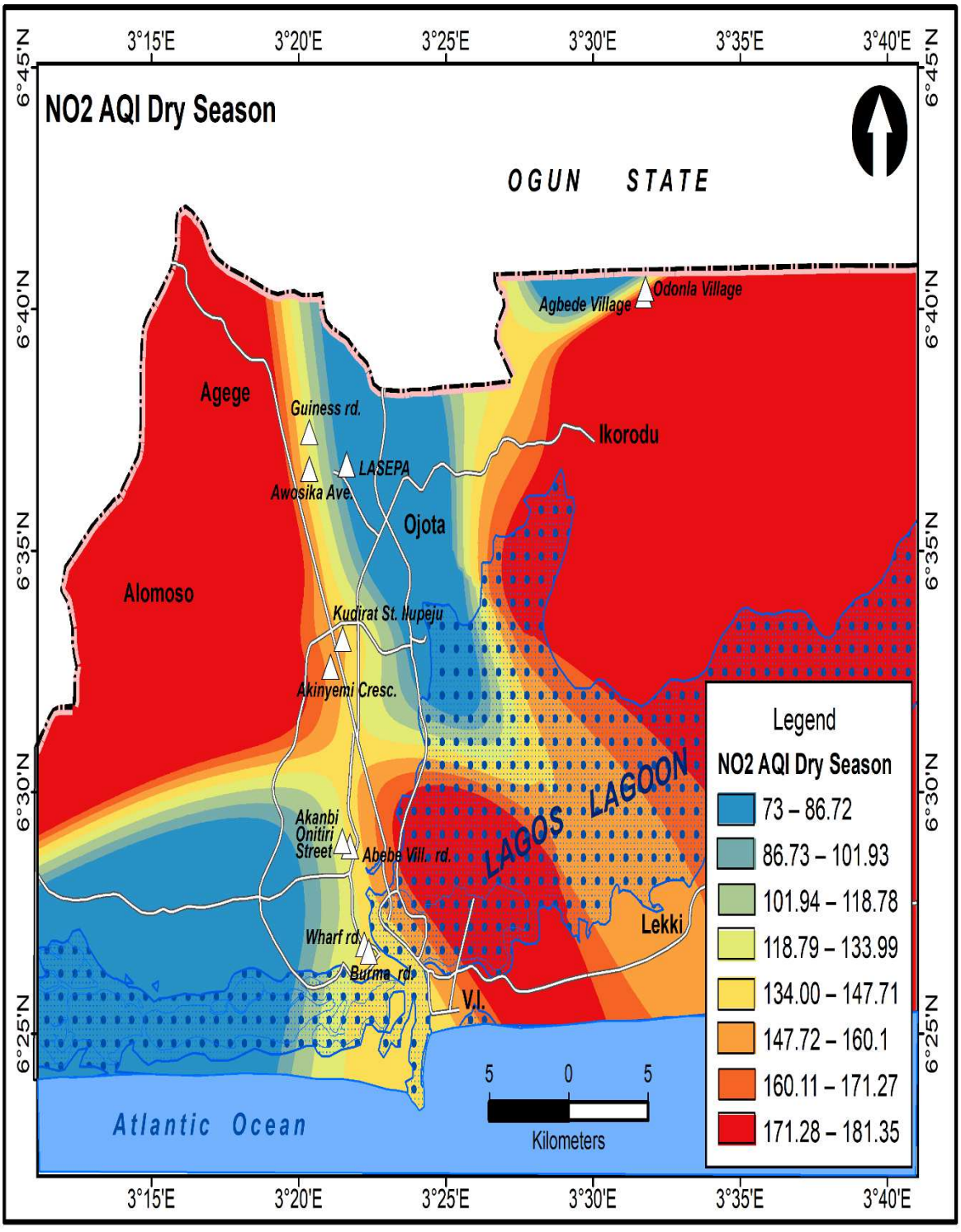



Fig. 13. Spatial variation in AQI for nitrogen(iv)oxide in the dry season across selected industrial locations in Lagos State

Source: Field Survey (2021)

Multiple linear regression was employed to test for the relationship between monthly AQI and monthly hospital-based respiratory conditions (Table 2). The dependent variable (hospital-based respiratory conditions (HBRS) was regressed with monthly air quality index for ($PM_{2.5}$, $NO_2$, CO, and $SO_2$). The independent variables significantly influenced monthly hospital-based respiratory conditions, $F(4,115) = 21.708$, $\rho=0.000$, which indicates that the independent variables under study have a significant influence on monthly hospital-based respiratory conditions. Moreover, the $R^2=0.430$ depicts that the model explains 43% of the monthly variation in hospital-based respiratory conditions. Additionally, the coefficients were also assessed to ascertain the influence of the air quality index values (for $PM_{2.5}$, $NO_2$, CO, and $SO_2$) on monthly hospital-based respiratory conditions. $SO_2$AQI did not significantly influence monthly hospital-based respiratory conditions ($\beta=0.738$, $\rho=0.107$). $NO_2$AQI significantly reduced monthly hospital-based respiratory conditions by 2.8% ($\beta = -2.028$, $\rho= 0.003$). COAQI did not significantly influence monthly hospital-based respiratory conditions ($\beta=0.481$, $\rho=0.061$) while $PM_{2.5}$AQI significantly increased monthly hospital-based respiratory conditions by 35.1% ($\beta=1.351$, $\rho=0.000$).

**Table 2. Relationship between monthly AQI and monthly respiratory hospital visitation**

| Predictors | β | t | ρ- value | Results |
|---|---|---|---|---|
| $SO_2$ AQI | .738 | 1.624 | .107 | Not supported |
| $NO_2$ AQI | -2.028 | -3.083 | .003* | Supported |
| CO AQI | .481 | 1.896 | .061 | Not supported |
| $PM_{2.5}$ AQI | 1.351 | 4.916 | .000* | Supported |
| ANOVA | F (4,115) | 21.708 | 0.000* | |
| $R^2$ | 0.430 | | | |

ρ < 0.05*; Dependent variable: Hospital-based respiratory conditions

Regression weight; Weighted by months
Source: Field Survey, (2021)

Air quality index values were higher in the dry season than the wet season due to high pollutants and gases across the study area. A study by Kebe *et al* (2021) in Dakar Senegal investigated the AQI for $PM_{2.5}$ from Hlm and Yoff industrial sites and found an AQI of 497 which indicates a very unhealthy and hazardous environment. Lower AQI values during the wet season is due to the remediating role of precipitation which reduces pollutants from the atmosphere through wet deposition, rain out and precipitation scavenging. This process helps in the cleaning of the atmosphere and in the improvement of the quality of air. This is consistent with a study by Oyebanji, *et al* (2021) who employed the USEPA air quality index and the inverse distance weighting interpolation method to investigate the spatial variation in the concentration levels of air pollution between the wet and dry seasons across eight farm settlements in Ogun state, Nigeria and concluded that $NO_2$ (10.14 – 107.07 and 10.84 – 72.88), CO (71.98 – 238 and 88.85 – 220.93) and $PM_{2.5}$ (12.90 – 70.85 and 12.56 – 54.02) were higher than the acceptable air quality index levels for both wet and dry seasons across the farm settlements. Hypothesis results revealed that not all AQI revealed a strong relationship with monthly respiratory conditions. While the AQI for $NO_2$ and $PM_{2.5}$ showed a strong significant relationship, COAQI and $SO_2$AQI showed no significant relationship with monthly respiratory conditions.

## 4.2. Self-reported respiratory symptoms and morbidity

Survey analysis of self-reported respiratory disorders (Figure 14) majorly complained across the industrial estates were coughing, headache, cold/catarrh, sweating, tiredness, irritation of the eyes, nose and throats and dizziness while minimal cases reported were decreased lung function, chest tightness and convulsion amongst respondents. Similarly, asthma and pneumonia (Figure 15) were also majorly reported amongst respondents across the study area. Across the study area, Odogunyan, Surulere and Apapa had more cases of respiratory disorders than Ikeja/Ogba and Oshodi/Ilupeju. This could be due to the intensity of and nature of exposure of workers to industrial ambient air pollution across the areas.

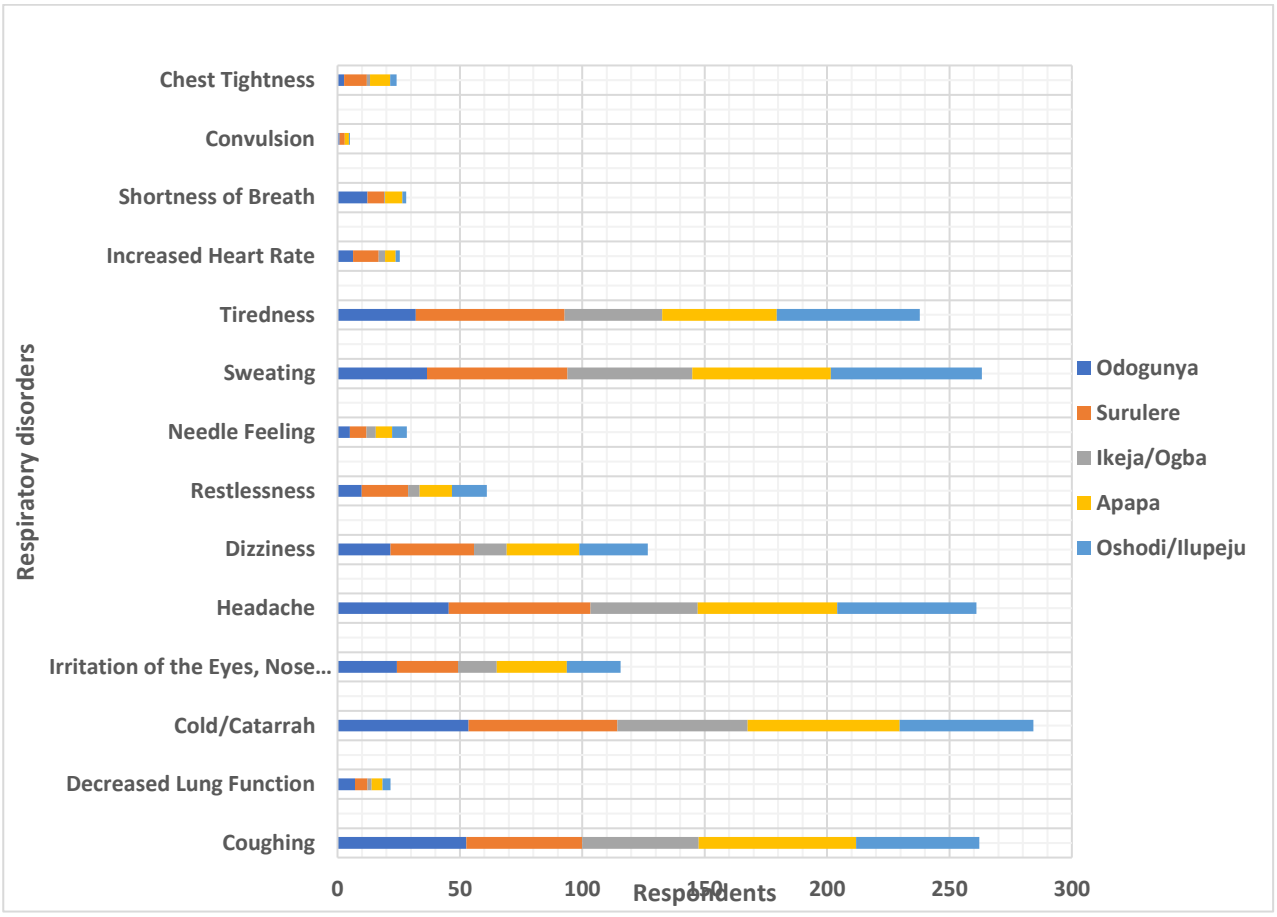



Figure 14. Respiratory disorders amongst respondents in the last 6-12 months

Source: Field Survey (2021)

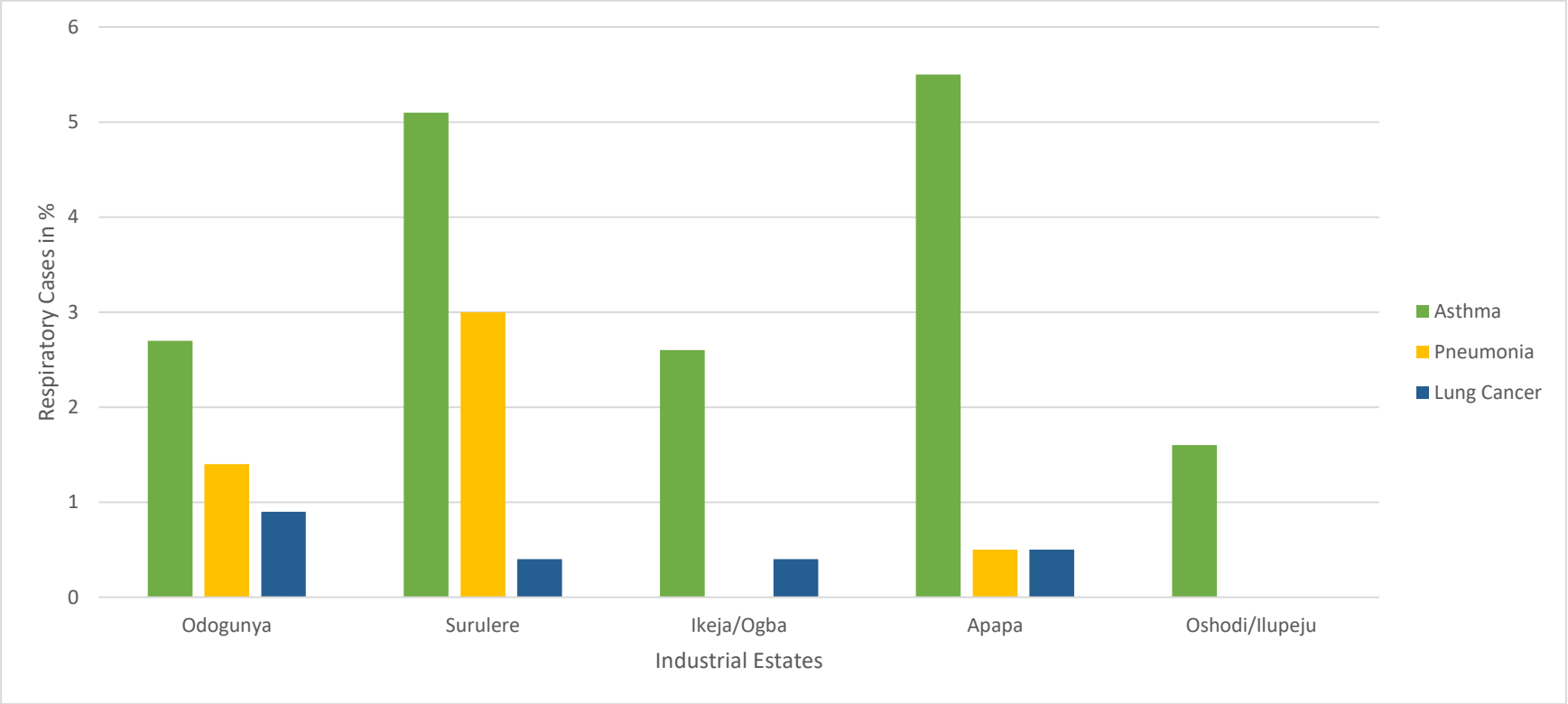



Fig. 15. Respiratory morbidity amongst respondents

Source: Field Survey, (2021)

### 4.4. pH of rain and soils, and elemental composition of soils during the study period

Laboratory analysis results (Fig. 16) of rainwater revealed a pH of between 5.7 to 6.95 across the study area. The soil pH (Fig. 17 and Fig. 18) ranged between 7.1 to 8.64 while elemental soil composition analysis revealed (Fig. 19 and 20) a high concentration of chromium, lead and nickel within the industrial estates than the control site due to the intensity of industrial and traffic pollution within the industrial estates.

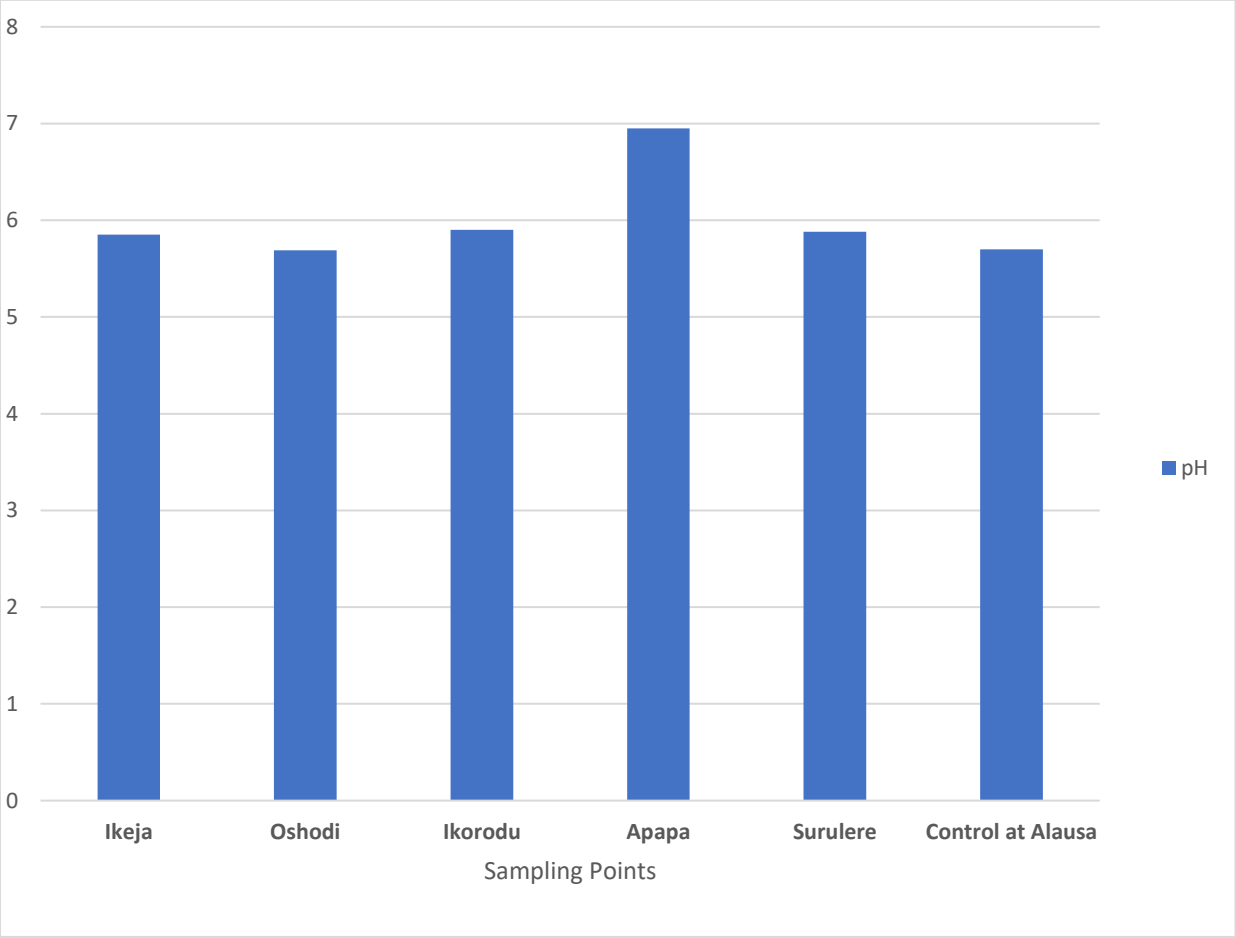



Fig. 16. pH of the rain across the industrial estate during the study period

Source: Field Survey, (2021)

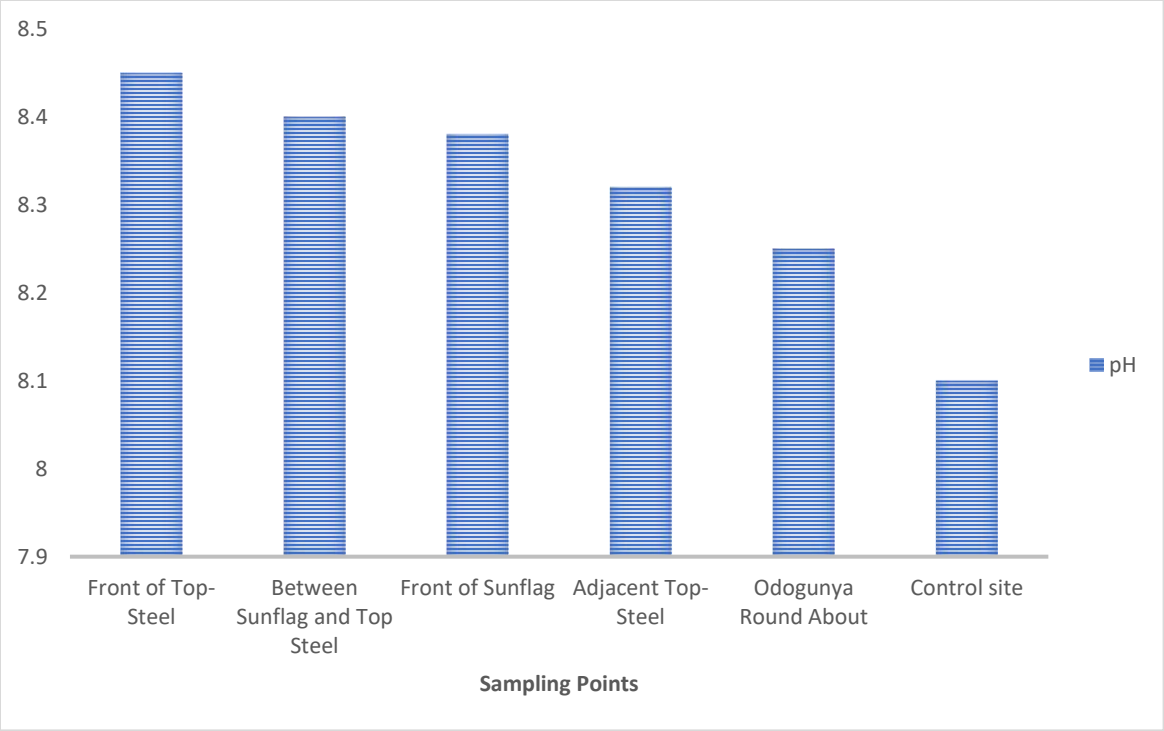



Fig. 17. pH levels across sampling points in Odogunya industrial estate

Source: Field Survey, (2021)

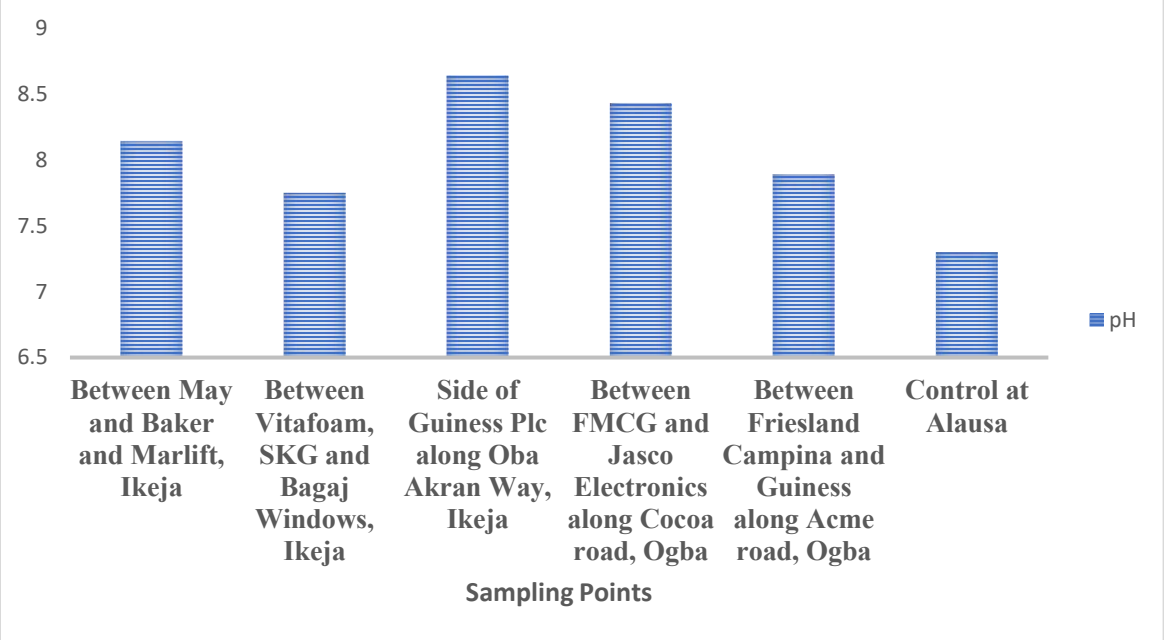



Fig. 18. pH levels across sampling points in Ikeja/Ogba industrial estate

Source: Field Survey, (2021)

Apapa, Surulere and Oshodi are built-up areas with road networks within the estates which made it difficult for soil samples to be collected.

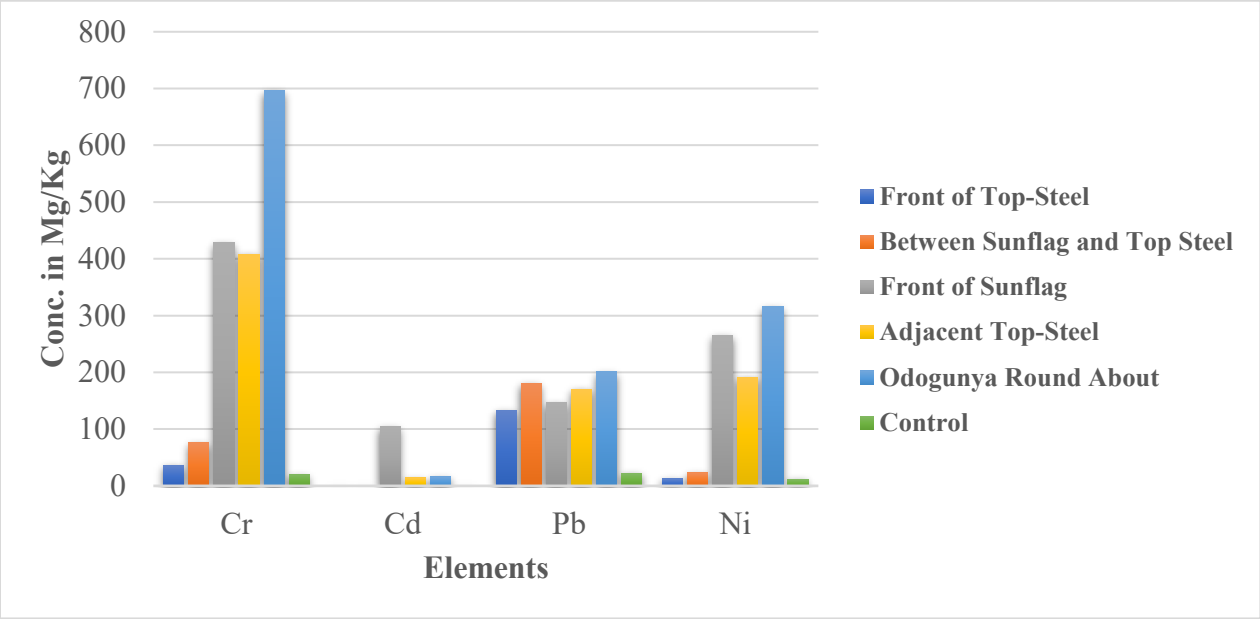



Fig. 19. Elemental composition of soil samples in Odogunya industrial estate
Source: Field Survey, (2021)

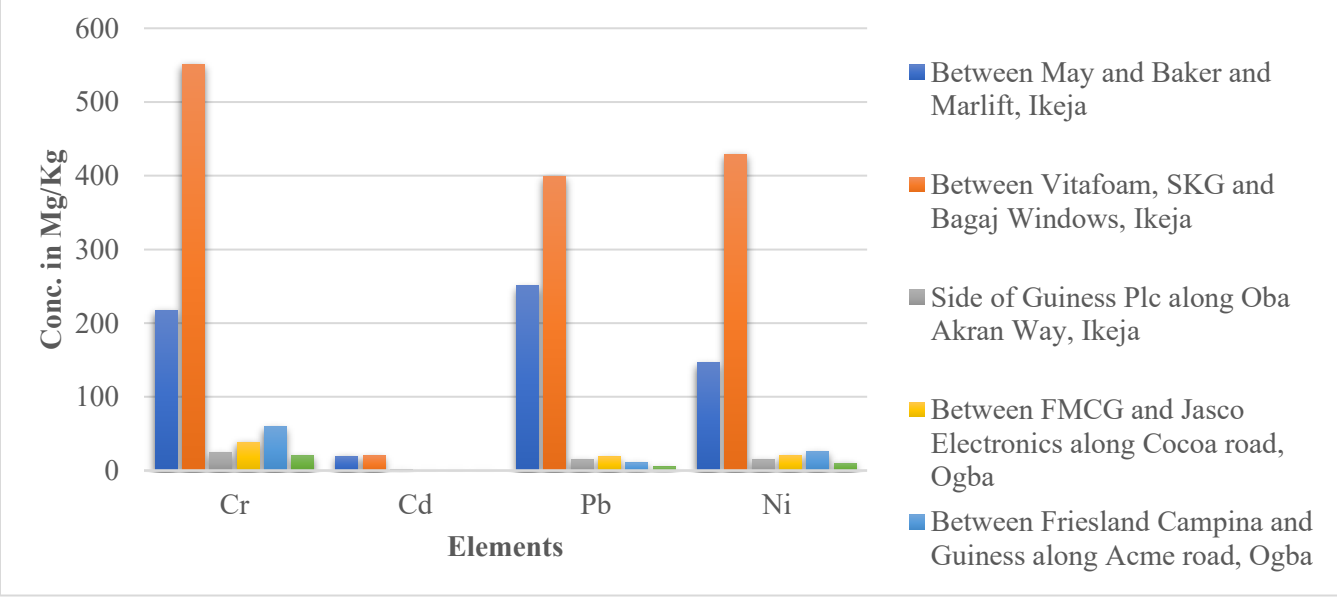



Fig. 20. Elemental composition of soil samples in Ikeja/Ogba industrial estate
Source: Field Survey, (2021)

Industrial pollutants released into the ambient environment impact the soils through gravitational settling, dry deposition and precipitation scavenging. Soils within industrial areas are enriched with toxic elements due to the nature and activities of manufacturing industries. This is consistent with several studies which found a mark distinction in soil enrichment between industrial and control sites (Njoku *et al.*, 2013; Fakayode and Onianwa, 2002; Okolo *et al*., 2016; Alkhdhairi, *et al.,* 2018; Qiao, *et al.* 2021, Oghenetega, *et al.* 2021 and Jian, *et al.* 2022). Pollutants released into the ambient environment always enrich, acidify, and contaminate soils and water bodies (Juřík and Braathen, 2021). The pH of the rainwater was normal which is consistent with the pH of rain water in its purest form at 5.6. Rain water pH that is acidic must be between 4.2 to 4.4 which is non-existent across the study area. The industrial pollutants did not reveal any influence on the pH of the rain as all rainwater samples were between 5.6 to 5.9. The pH of the rain did not influence the acidification of the soil as other factors such as the geology of the area, organic matter buildup, flooding, native vegetation, soil texture, nature of soil colloids, use of nitrogenous fertilizers, use of urea on the soil etc. are other determining factors that influence the pH of the soil. The result is consistent with similar studies globally, which found minimal influence of industrial emission on rain water pH (Ogolo *et al.,* 2018; Jing *et al.,* 2022; and Siti, *et al* 2022).

## 5.0 Conclusion

Industrial ambient air pollution is one of the single biggest threats to the environment and human health. It negatively impacts on the environment reducing the quality of air, water and ecosystem sustainability. The United States Environmental Protection Agency Air Quality Index used in this study also revealed varying levels across the state. Lower index values which translate to good air quality was averagely recorded during the wet season than the dry season. Industrial areas such as Ikeja/Ogba, Oshodi/Ilupeju, Surulere and Apapa recorded good air quality during the wet season than in the dry season while Odogunya industrial estate revealed poor air quality and higher index values both during the wet and dry seasons.

Both industrial and traffic sources of air pollution characterized the industrial estates across the state. Pollutants sources are dominantly intertwin by the varying nature of industrial production and vehicle types. The quality of soils across Ikeja/Ogba and Odogunya industrial estates revealed higher levels of elemental contaminants than the control sites. This is an indication of significant enrichment of toxic elements in the soils largely due to industrial ambient air pollution. Rainwater

pH across the industrial estates was normal at 5.7 to 6.5 which revealed a minimal influence of industrial ambient air quality on rainwater pH. The WHO standard for acid rain is a pH of between 4.2 to 4.4. The pH of the rain across the study area was largely benign with no evidence of acid rain across the state. The pH of the soils in Ikeja/Ogba and Odogunya was alkaline which did not reveal a nexus between the pH of the rain and the soils. Other factors like the geology of the area, vegetation, fertilizer application, quality of soil etc. also determine the pH of soils.

The study outcome revealed that the quality of ambient air across the study area is poor, especially during the dry season which negatively impacts the quality of the environment and the health of the residents and industrial workers. The United Nations Sustainable Development Goals (UNDP) adopted in 2015 enumerated 17 goals which call on government at all levels to end poverty, and hunger and the sustainable management of the environment. The outcome of this study will inform policymakers in Nigeria on the need to achieve goals 9 and 11 by 2030 which focuses on building safe, resilient, inclusive and sustainable cities with resilient infrastructure that promotes innovation and sustainable industrialization, especially in developing countries.

### 5.1 Recommendation

Air beam sensor, a wearable air monitor that maps, graphs, and crowd sources $PM_{2.5}$ exposures in real-time (1-second readings) via an air casting android app and measures $PM_{2.5}$ by utilizing a light scattering method or a detector to measure and estimate the number of particles in the air can be adopted for use across the industrial estates, especially amongst front line workers like factory workers and folklife operators to monitor pollutants levels in real time (Ezeugoh *et al*., 2020). These will help in ascertaining the risk and vulnerability of the workers and ensure a favourable occupational safety for the workers.

Citizen science is an effective strategy against air pollution and clean energy use at the grassroots through the use of smartphones for targeted engagement and a channel between the government and the people at individual and community levels. A multidisciplinary approach involving the public, pressure groups, businessmen and researchers, community groups and artists can effectively drive the awareness process to the grassroots. Public attention is an alternative solution that can help in the reduction of air pollution through constant complaints to the government on the need to safeguard the health of the inhabitants and the environment. For example, public attention is being used in China to awaken the government to prioritize the importance of air

quality and its implications for the health of the citizens. In the global south or developing economies, public attention is yet to be explored as a viable option by the populace to awaken the government to prioritize the need for constant monitoring of air quality (Xing *et al*. 2022).

Tree planting and green spaces should be enforced around all manufacturing companies to help in the bio-filtering and reduction of pollutants in the ambient environment. Tree planting can be achieved through high-density street vegetation, green facades, and green walls which will help in the purification of urban atmospheric aerosol pollutants into crowded and densely populated areas. Sufficient green spaces and green infrastructures modify the microclimate of the immediate environment by purifying the ambient air, reducing air temperature, and increasing oxygen within the immediate environment.

A good road network and drainage channels should be provided as a matter of urgency in Odogunya and Apapa industrial estates to reduce the level of dust particulate caused by the brakes of heavy-duty vehicles during the dry season. The quality of the fuel used in the powering of manufacturing industries and transport across the industries should be clean and efforts should be made to transition from the current utilization of fossil fuels to the use of eco-friendly sources of energy e.g., biofuels (ethanol, jatropha), biotechnology, solar power, windmills etc. which are cleaner, noiseless and less harmful to human wellbeing and the sustenance of environmental quality. The use of cleaner fuel with low sulfur content, and the implementation of the Nigerian industrial standards for fuel revised in 2017 which placed the sulfur content for diesel at 50ppm, gasoline and kerosene at 150ppm will significantly reduce transport emissions on our roads. Most of the cars traded in Nigeria are used cars with old emission control technology and over 50% of such sales occur in Lagos, the importation of vehicles with more advanced Euro standard emission control technology coupled with the use of low sulfur and nitrogen(iv)oxide content fuel will reduce the air pollution in the city and ensure a cleaner passenger fleet.

Aggressive adoption of renewable cleaner energy and the consequent reduction in fossil fuels has significantly increased the life expectancy of citizens and improved the environmental quality of 29 European cities (Rodriguez-Alvarez, 2021). Nigerians' biofuel resource is a major substitute for energy needs as it contributes an average of 78% of the primary energy supply needs of Nigeria annually with huge potentials yet to be tapped for maximum utilization, they include; forest resources, animal wastes, crops, crop residues and municipal solid wastes. With the preconditions for the development of the capacity for biofuel production still in its infancy, there is a need for

huge investments in agriculture and the requisite types of machinery for the production of biofuels in Nigeria which will reduce over-dependence on fossil fuels and conserve scarce foreign exchange from the importation of refined petroleum products (Sokan-Adeaga and Ana 2015).

### 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.

## 5.3 Authors Declaration

There is no conflict of interest

### 5.4 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.

### 5.5 Funding

This research did not receive any funding or support of any kind.

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