Impacts of Covid-19 Lockdown on Concentration Levels of Traffic-Related Air Pollutants in Ibadan -a West African City

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ABSTRACT: Trends and sources of air pollution at twenty-five traffic Intersections (TIs) before and during covid-19 lockdown were investigated in Ibadan, Nigeria. The relationships among climatic parameters, vehicular counts and ten air pollutants which includes particulate matter (PM$_{1}$, PM$_{2.5}$, PM$_{10}$ & Total Suspended Particles-TSP) and gaseous pollutants (CO, NO$_{2}$, SO$_{2}$, NH$_{3}$, total volatile organic compounds-TVOCs, and ground level O$_3$) measured simultaneously at TIs were analysed. Results indicated significant decrease in mean concentrations of all pollutants studied except NO$_2$ with 212% increase during the study period. Concentrations of gaseous pollutants CO, SO$_2$, NH$_3$, TVOCs and ground level O$_3$ reduced by 7.92%, 24.80%, 1.58%, 44.08% and 4.28%, respectively while particulates concentrations of PM$_{1}$, PM$_{2.5}$, PM$_{10}$ and TSP concentrations decreased by 49.64%, 60.79%, 81.21% and 84.17%, respectively during lockdown. An integrated source apportionment approach using Pearson’s correlation, Airflow backward trajectories arriving in the study area and Principal component analysis (PCA) identified vehicular emission as the primary source of studied air pollutants at TIs before and during lockdown in Ibadan. Emission from residences, roadside fuel combustion and local air transport of pollutants from nearby upwind areas with industries and farming activities were identified as secondary sources of air pollution affecting the study area.

KEYWORDS: Covid-19 lockdown, Traffic intersection, Particulates, Gaseous pollutants, Ibadan

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I. INTRODUCTION

Coronavirus disease 2019 (covid-19) is the most precarious worldwide health epidemic of the 21st Century. Covid-19 was first detected in December, 2019 at Wuhan City, China. Coronavirus is an acute respiratory ailment that triggers pneumonia with dyspnea (breathlessness), cough and fever symptoms resulting in mortality rate of about 2–3% (Jiang et al.; Rodriguez-Morales et al., 2020). The World Health Organisation (WHO) proclaimed that covid-19 caused by severe acute respiratory syndrome coronavirus 2 (SARS-Cov-2) had reached a global pandemic status on 11th March, 2020. The pandemic compelled nearly all nations of the world to apply deterrent measures to control person-to-person transmission.

In Nigeria, the index case was confirmed on 27th February, 2020. Lockdown protocols were imposed in accordance with global practice on 30th March, 2020 to 15th July, 2020. The nationwide lockdown period encompassed a total lockdown period of 35 days (30th March, 2020 to 3rd May, 2020) and 73 days of gradual lockdown easing up (5th May, 2020 to 15th July, 2020). The federal government of Nigeria enforced severe regulations, curfews and ban on public gatherings in every State and city of the country. These restraints halted virtually all anthropogenic activities that included restrictions on movement of people and vehicles, closure of businesses and industries, shutting down of public and private workplaces such as vehicle parks, banks, airports, government secretariats, churches, mosques, shrines, restaurants, schools and construction projects.

Air pollution is a complex mix of particulates and gaseous pollutants emitted into the atmosphere from human and natural activities (Adeniran et al., 2018; Li et al., 2020b; Odediran et al., 2021). PM$_{10}$, SO$_2$, and NO$_2$ are deemed everyday air pollutants in urban settings. Many researches have exposed the critical health problems that accompanies these pollutants such as sneezing, respiratory and cardiovascular diseases, asthma, and lung cancer (Abou El-Magd & Zanaty, 2020; Adeniran et al., 2017b; Goel et al., 2021). NO$_2$ produced in the atmosphere from anthropogenic processes which are mostly from vehicles, power plants combustion of fossil fuel and natural processes such as volcano and wild fires(Ogen, 2020). WHO reported that over 4.6 million deaths are recorded yearly from air pollution associated illnesses (Cohen et al., 2017). Deaths linked with air pollution comprise of asthma, bronchitis, lung and heart disorders, acute respiratory diseases (Brauer, 2010). The most dangerous pollutant in ambient air quality monitoring is PM$_{2.5}$ (Fenech & Aquilina, 2020; Kamar et al., 2021). Gaseous emissions of SO$_2$ and NO$_2$ are frequently assessed to monitor rate of pollution from burning of fossil fuel and vehicle exhausts. O$_3$ is emitted from the photochemical reactions involving oxides of nitrogen (NOx) and volatile organic compounds (VOCs) under intense solar radiation.
Studies on disease epidemic demonstrated that there is a robust connection between air pollution exposure and high rate of morbidity and mortality from respiratory and cardiovascular ailments (Pope Iii et al., 2002).

Urban air pollution poses a severe threat to human health and the ecosystem, especially in cities of developing countries (Balakrishnan et al., 2019). The primary sources of air pollutants that contribute to air quality deterioration are from local sources (Guttikunda et al., 2019; Ravindra et al., 2020). These local sources of pollutants include: emissions from biomass and coal combustion, residences, industries, construction sites, automobiles and pollutants transport from upwind neighbouring areas (Ravindra et al., 2019). The spatial and temporal study of air pollutants concentrations for the period before and during Covid-19 lockdown will help to understand the primary sources of urban air pollutants and the impacts of restricted anthropogenic activities (lockdown) on air quality of Ibadan, one of the largest cities in Africa.

Nigeria is among the countries with the most polluted air in the world (Polk, 2019). The largest cause of children mortality in Nigeria is lower respiratory infections (LRI) attributed to ambient PM$_{2.5}$ which is largely from vehicular traffic (McDuffie et al., 2021).

Several studies have reported that covid-19 lockdown had caused a considerable decline in urban air pollution of many cities around the world (Abdullah et al., 2020; Abou El-Magd & Zanaty, 2020; Bao & Zhang, 2020; Biswal et al., 2020; Chauhan & Singh, 2020; Dantas et al., 2020; Davidović et al., 2021; Goel et al., 2021; Li et al., 2020a; Mor et al., 2021; Otmani et al., 2020; Singh et al., 2020a; Zambrano-Monserrate et al., 2020).

Mor et al. (2021) studied the variation in ambient air quality during covid-19 lockdown in Chandigarh, India and identified vehicular emission as major source of air pollution while regional dispersion of pollutant emissions from coal-burning and refuse burning were identified as secondary sources of air pollution during different phases of lockdown studied. Wang et al. (2021) reported that NO$_2$ in China decreased by 42% and 26% in February and March 2020 due to covid-19. According to Sulaymon et al. (2021) concentrations of NO$_2$, PM$_{2.5}$, PM$_{10}$, and CO decreased by 50.6%, 41.2%, 33.1%, and 16.6%, respectively, while O$_3$ increased by 149% during the lockdown. Similarly, Chen et al. (2021) found out that restriction policy for local fuel vehicles and the restriction policy based on the last digit of license plate numbers had reducing effect on urban air pollution in forty-nine cities selected from four provinces of China. Furthermore, Yuan et al. (2021) reported significant improvement of Hangzhou city’s air quality with 80% reduction of NOx and double increase of O$_3$ during the covid-19 lockdown period in China. Otmani et al. (2020) revealed that covid-19 countermeasures in Sale City, Morocco contributed to reduced concentrations of all pollutants but with significant differences among them. Consequently, concentrations of PM$_{10}$, NO$_2$ and SO$_2$ decreased by more than 50% in the covid-19 lockdown period in the city.

Limited data exists on the status of air quality during lockdown activities in Africa. In this study, the impacts of covid-19 lockdown on the ambient concentration levels of traffic related air pollutants at TIs in Ibadan, a West African City were investigated. Concentration trends of air pollutants before and during the lockdown were compared. The potential sources of air pollutants were classified by applying trajectory analysis of air masses arriving in Ibadan, correlation analysis and principal component analysis (PCA). This study will provide information that could help to comprehend and ascertain sources of particulates and gaseous pollutants during the lockdown period.

II. METHODOLOGY

A. Study Area

Ibadan, the Oyo State capital in Nigeria, is one of the largest cities in Africa (Figure 1). It is located between geographical longitudes 7°2'E and 7°40'E and latitudes 3°35'N and 4°10'N (Ajayi et al., 2012). Ibadan is densely inhabited by over 3.8 million residents with overall population density of 586 persons per km$^2$ (NPC, 2006). Ibadan municipal is comprised of 11 local government areas with 5 in the inner city and 6 in the outer areas. Ibadan has a tropical climate of rainy season (March-October) and dry season (November-February). Ibadan overall precipitation is 1420.06 mm, dropping in about 109 days. According to Odediran et al. (2021), the average ambient temperature varied from 20.1°C to 40°C, atmospheric pressure extends from 754.6 mmHg to 762.3 mmHg and the relative humidity varied between 49.2% and 83.58%.

The city has a 12 kilometres land radius with altitudes stretching from 152 to 213 m. The wind speed varies from 1.1 to 17 km/h with lowest and highest values observed during dry season. Over the years, Ibadan has remained a major trade hub experiencing continuous major infrastructural developments attributable to various commercial, agricultural, educational, industrial and construction activities within the city. The anthropogenic activities in the city have become a major air pollution source. Particulates and gaseous emissions are daily released from heavy vehicular traffic and high usage of diesel and petrol powered electricity generators, serving as alternative to the insufficient and unstable power supply in Nigeria.

B. Sampling Protocol

The ambient concentration levels of six gaseous pollutants (CO, NO$_2$, SO$_2$, NH$_3$, TVOCs, and Ground-level O$_3$) and particulate matter (PM$_1$, PM$_{2.5}$, PM$_{10}$ and Total Suspended Particles -TSP) were investigated at twenty-five major traffic hotspots in the study area. PM$_1$, PM$_{2.5}$, and PM$_{10}$ are airborne particulates with diameters that are less than 1, 2.5 and 10 µm, respectively. Selected sampling sites were the major Traffic Intersections (TIs) evenly and spatially distributed within Ibadan metropolis. The geographical details of the 25 selected TIs such as name, site code, category, coordinates and surrounding features were presented in Table 1. In addition to vehicular (traffic) counts recorded at all traffic intersections, average climatic parameters of study area such
as atmospheric pressure, ambient temperature, relative humidity, wind speed and wind direction were monitored for the entire study duration using Kestrel 4500 Weather Tracker. This study compared 5-day mean pollutants concentration levels, average climatic data and vehicular counts observed before covid-19 lockdown period (2nd-6th March, 2020) and during lockdown period (8th-12th June, 2020) in Ibadan.

Six gaseous pollutants were sampled with portable, handheld Aeroqual S500 (Aeroqual Limited, Auckland, New Zealand) monitors and six sensors’ heads of CO (ECN, range 0–100 ppm), NO₂ (ENW, range 0–1 ppm), SO₂ (ESP, range 0–10 ppm), NH₃ (NH, range 0–1000 ppm), VOCs (VP, range 0–500 ppm), and metal-oxide semiconductor O₃ (EOZ, range 0–10 ppm). The relatively compact and lightweight Aeroqual S500 monitors were battery powered at the selected TIs, interchanging the semiconductor and electrochemical sensor, permitting continuous monitoring of the range of selected gases at low mixing ratios (Lin et al., 2017).

Ambient PM sizes of PM₁₀, PM₂.₅, PM₁₀ & TSP were measured with Aerocet 531s particle counter/mass monitor, placed within breathing zone of 1-1.5m above the ground level at the selected TIs. This battery operated, handheld Met One Instruments, USA measured concurrently six mass concentration ranges (PM₁, PM₂.₅, PM₅, PM₁₀ and TSP) or five particle count sizes (0.3, 0.5, 1.0, 5.0 and 10 μm). Data sample history were displayed on the screen in either mode after capturing of particles. For the entire study period, monitoring of selected particulate matter (PM) and gaseous pollutants were carried out simultaneously in all the TIs during...
| S/N | Sampling Site | Site Code | Category | Latitude | Longitude | Surrounding Features |
|-----|---------------|-----------|----------|----------|-----------|---------------------|
| 1   | Mobil         | TH1       | Industrial and Commercial | 7.3666   | 3.8612 | Industrial buildings, Filling Stations, Commercial Buildings, Vehicular Movement, Bike, Tricycle and Taxi Parks, Banks, Eateries |
| 2   | Olyolye       | TH2       | Commercial | 7.3735   | 3.8815 | Filling Stations, Commercial Buildings, Vehicular Movement, Bike and Taxi Parks |
| 3   | Oke Adu       | TH3       | Commercial | 7.3900   | 3.8788 | Commercial Buildings, Vehicular Movement, Police Station, Bike and Taxi Parks |
| 4   | Roundabout    | TH4       | Commercial | 7.4006   | 3.8902 | Market, Filling Stations, Commercial Buildings, Vehicular Movement, Bike and Taxi Parks, Banks |
| 5   | Oguncpa       | TH5       | Commercial | 7.3875   | 3.8844 | Market, Commercial Buildings, Vehicular Movement, Police Station, Bike, Tricycle, Taxi and Bus Parks |
| 6   | New Garage Challenge Roundabout | TH6 | Residential | 7.3317 | 3.8768 | Filling Stations, Residential Buildings, Vehicular Movement, Bike, Tricycle and Taxi Parks |
| 7   | Oja-Oba       | TH8       | Residential and Commercial | 7.3741   | 3.8958 | Agricultural produce Market, Filling Stations, Residential Buildings, Vehicular Movement, King’s Palace, Bike and Tricycle, Taxi Parks, Mosque |
| 9   | Olomi         | TH10      | Residential and Commercial | 7.3385   | 3.9194 | Agricultural produce Market, Filling Stations, Residential Buildings, Vehicular Movement Bike Park |
| 10  | Orita Aperin  | TH11      | Residential and Commercial | 7.3669   | 3.9194 | Market, Filling Stations, Residential Buildings, Vehicular Movement Bike Park, Schools |
| 11  | Elebu         | TH12      | Residential and Commercial | 7.3528   | 3.8234 | Agricultural produce Market, Filling Stations, Residential Buildings, Vehicular Movement Bike and Tricycle Park, Church |
| 12  | Apata Eleyele Roundabout | TH13 | Residential | 7.4198 | 3.8593 | Roadside Shops, Residential Buildings, Vehicular Movement, Bike, Taxi and Bus Parks |
| 14  | Ologuneru Apete-Ijokodo | TH14 | Residential | 7.4363 | 3.8284 | Roadside Shops, Residential Buildings, Vehicular Movement, Bike and Taxi Parks |
| 15  | Gate          | TH15      | Residential and Commercial | 7.4478   | 3.8756 | Roadside Shops, Residential Buildings, Vehicular Movement, Bike and Taxi Parks |
| 16  | Akobo         | TH16      | Commercial | 7.3956   | 3.9190 | Market, Roadside Shops, Residential Buildings, Vehicular Movement, Bike, Tricycle, Taxi and Bus Parks, Post Office On-going Road construction, Market, Filling Station, Roadside Shops Residential Buildings, Vehicular Movement, Bike, Taxi and Bus Parks |
| 17  | Iwo Road      | TH17      | Residential and Commercial | 7.4485   | 3.9513 | Market, Roadside Shops, Commercial Buildings, Vehicular Movement, Filling Stations, Police Post, Bike, Tricycle, Taxi and Bus Parks |
| 19  | Old Ife Road  | TH19      | Residential and Commercial | 7.3913   | 3.9376 | Roadside Shops, Residential Buildings, Vehicular Movement, Bike Parks |
| 20  | Olando Sango Elewu | TH20 | Residential and Commercial | 7.4355   | 4.0045 | Roadside Shops, Filling Station Residential Buildings, Vehicular Movement, Filling Stations, Bike and Tricycle Parks, Roadside Shops, Filling Station Residential Buildings, Vehicular Movement, Filling Stations, Bike, Tricycle, Taxi and Bus Parks |
| 21  | Bodijia       | TH21      | Residential and Commercial | 7.4234   | 3.8897 | Market, Roadside Shops Commercial Buildings, Banks, Vehicular Movement, Filling Stations, Police Post, Bike, Tricycle, Taxi and Bus Parks |
| 22  | UI-Agbowo     | TH22      | Commercial | 7.4355   | 3.9119 | Ibadan University Gate, Roadside Shops, Commercial Buildings, Banks, Vehicular Movement, Filling Stations, Banks, Bike, Tricycle, Taxi and Bus Parks, Hospitals |
| 23  | Shasha Ojoo    | TH24      | Residential and Commercial | 7.4827   | 3.9098 | Agricultural produce and Livestock Market, Residential Buildings, Vehicular Movement, Bike, Taxi, Bus and Trailer Parks, Mosque |
| 25  | Roundabout    | TH25      | Commercial | 7.4686   | 3.9127 | Market, Roadside Shops, Commercial Buildings, Banks, Vehicular Movement, Filling Stations, Police Station, Bike, Tricycle, Taxi and Bus Parks |
present in Figure 2c.

2.5

and TSP of 142.82 µg/m

Likewise, mean concentration of PM

12.10 µg/m

during the lockdown period.

1.58

Lockdown was 5.81µg/m

These may be attributable to the partial compliance with covid

declined during the lockdown at all 25 TIs in Ibadan

indicated that mean concentration levels of nearly all pollutants

Traffic related air pollutants, averaged traffic counts and climatic data

Comparison of the concentration levels of particulates

Aerocet 531s particle counter are detailed in other studies

procedure for correlating PM data obtained from HazdustTM

calibration, adjustment of PM values for relative humidity and

heavy traffic (rush hour) and light vehicular traffic (non-rush

hour) periods. Information on equipment operation and calibration, adjustment of PM values for relative humidity and procedure for correlating PM data obtained from HazdustTM sampler and gravimetric analysis with results obtained from Aerocet 531s particle counter are detailed in other studies (Adeniran et al., 2017a; Adeniran et al., 2018).

III. RESULTS AND DISCUSSION

This study presents comprehensive details on the impacts of on-road vehicles and climatic parameters on the variations in concentration levels of traffic-related air pollutants (TRAPs) at traffic hotspots before and during the covid-19 lockdown period in addition to the identification of potential sources of TRAPs. Table 2 presented the mean concentrations of TRAPs, vehicular counts and climatic data during the study period.

Comparison of the concentration levels of particulates

(PM1, PM2.5, PM10 & TSP) and gaseous pollutants (CO, NO2, SO2, NH3, TVOCs, and Ground level O3) observed in this study indicated that mean concentration levels of nearly all pollutants declined during the lockdown at all 25 TIs in Ibadan metropolis. Nevertheless, there were rise in the concentrations of CO, NO2, SO2, NH3, ground level O3 and PM1 at few TIs. These may be attributable to the partial compliance with covid-19 lockdown protocols in some areas within Ibadan where markets, shops, banks, vehicle parks, some private and public offices remained opened for business.

A. Variation in Particulate (PM1, PM2.5, PM10, TSP) Concentrations

The mean concentration of PM1 for a 5-day period before lockdown was 5.81µg/m3 which decreased to 2.93µg/m3 during lockdown period. PM2.5 mean concentration decreased from 12.10 µg/m3 to 4.74µg/m3 during the lockdown period. Likewise, mean concentration of PM10 declined from 142.82 µg/m3 to 26.83 µg/m3 in the lockdown period while TSP concentration level fell from 312.23 µg/m3 to 49.38 µg/m3 during the study period. The average concentrations of PM10 and TSP of 142.82 µg/m3 and 312.23 µg/m3 were above 50 µg/m3 and 250 µg/m3 which are the corresponding ambient air quality limits of World Health Organization (WHO) and National Environmental Standards and Regulations Enforcement Agency (NESREA) of Nigeria (NESREA, 2020; WHO, 2006).

Pollution concentration reduction of 49.64%, 60.79%, 81.21% and 84.17% for PM1, PM2.5, PM10 & TSP, respectively were observed at TIs in Ibadan during the lockdown in relation to the period before lockdown (Table 2). The decline in particulate concentration levels are attributed largely to the huge reduction of vehicular traffic, construction works, industrial and roadside commercial activities that were the major particulate sources in the ambient air of urban environments (Adeniran et al., 2017b; Mor et al., 2021; Singh et al., 2020a). Figures 2a, 2b, 2c and 2d showed the variations in concentrations of particulates (PM1, PM2.5, PM10 & TSP) at 25 TIs before and during lockdown periods in Ibadan. In the study period, PM2.5 (24h) concentration limits set by WHO (25 µg/m3); and NESREA (35 µg/m3) were not breached at any of the 25 TIs before and during the lockdown in Ibadan City (Figure 2b), PM10 limit (150 µg/m3) set by NESREA in Nigeria was breached at 5 TIs (TH2, TH5, TH9, TH15 and TH17) in the period before lockdown as presented in Figure 2c. Likewise, TSP concentrations were above NESREA limit (250 µg/m3) at 10 TIs (TH2, TH3, TH5, TH8, TH9, TH11, TH15, TH17, TH18 and TH19) during the pre-lockdown period (Figure 2d).

B. Variation in Gaseous Pollutants (CO, NO2, SO2, NH3, TVOCs, and Ground level O3) Concentrations

The 5-day mean concentration levels of CO, NO2, SO2, NH3, TVOCs, and ground level O3 before lockdown were 3.21, 0.01, 0.45,17.47,44.48 and 0.036 ppm, respectively (Table 2), these were below the ambient recommended limits of NESREA (Nigeria) and WHO. During the lockdown, the mean concentrations were documented as 2.95, 0.03, 0.34, 17.19, 24.87 and 0.034 ppm for CO, NO2, SO2, NH3, TVOCs, and ground level O3, respectively. Comparison of gaseous pollutants concentrations before and during lockdown periods indicated mean concentration reductions of 7.92% for CO, 24.80% for SO2, 1.58% for NH3, 44.08% for TVOCs and 4.28% for ground level O3.

Table 2: Mean concentrations of traffic related air pollutants, averaged traffic counts and climatic data at Ibadan traffic intersections assessed before and during lockdown periods.

| Pollutants       | Before Lockdown | During Lockdown | Difference | Variation (%) |
|------------------|-----------------|-----------------|------------|---------------|
| CO (ppm)         | 3.21            | 2.95            | 0.25       | -7.92         |
| NO2 (ppm)        | 0.01            | 0.03            | -0.02      | 212.86        |
| SO2 (ppm)        | 0.45            | 0.34            | 0.11       | 24.80         |
| NH3 (ppm)        | 17.47           | 17.19           | 0.28       | -1.58         |
| TVOCs (ppm)      | 44.48           | 24.87           | 19.61      | -44.08        |
| Ground level O3 (ppm) | 0.0356          | 0.0341          | 0.0015     | -4.28         |
| PM1 (µg/m3)      | 5.81            | 2.93            | 2.88       | -49.64        |
| PM2.5 (µg/m3)    | 12.10           | 4.74            | 7.35       | -60.79        |
| PM10 (µg/m3)     | 142.82          | 26.83           | 115.99     | -81.21        |
| TSP (µg/m3)      | 312.02          | 49.38           | 262.64     | -84.17        |
| Vehicular count (per hour) | 1162.61        | 1041.74         | 120.87     | -10.40        |
| Temperature (°C) | 31.23           | 27.15           | 4.08       | -13.08        |
| Relative Humidity (%) | 60.72          | 78.84           | -18.12     | 29.84         |
| Pressure (mmHg)  | 758.33          | 759.61          | -1.27      | 0.17          |
| Wind Speed (m/s) | 1.98            | 2.45            | -0.47      | 23.53         |
| Wind Direction (degrees) | 197.10         | 182.70          | 14.40      | -7.31         |
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(a) NESREA Limit

Before Lockdown
During Lockdown

(b) WHO Limit

Before Lockdown
During Lockdown

(c) NESREA Limit

Before Lockdown
During Lockdown

Traffic Intersections

PM$_1$ ($\mu g/m^3$) 24h-Concentration

PM$_{2.5}$ ($\mu g/m^3$) 24h-Concentration

PM$_{10}$ ($\mu g/m^3$) 24h-Concentration
However, NO$_2$ mean concentration rise of 212% was observed during the study period (Table 2). NO$_2$, CO and NH$_3$ are primarily emitted from combustion of fossil fuels at high temperatures (Otmani et al., 2020) resulting particularly from emission of automobiles, industries, fuel powered electrical generators (Tobías et al., 2020), biomass burning and domestic emissions from residences (Mor et al., 2021). NO$_2$ in high concentration could induce acid rain and nitrate aerosol formation which can cause severe health hazards. The rise in NO$_2$ emissions at Ibadan TIs during the lockdown compared to period before lockdown in this study may be largely due to: (1) partial compliance with Covid-19 protocols in some sections of Ibadan city as observed during sampling procedure which resulted in continued vehicular movement, unabated industrial operations and sustained roadside commercial activities in addition to (2) air dispersion of NO$_2$-rich air masses arriving from upwind regions with anthropogenic activities into Ibadan.

CO and NH$_3$ emissions are majorly from emissions of industries, automobiles, biomass burning and agricultural activities (Bhanarkar et al., 2005; Codjo-Seignon et al., 2021).

The NH$_3$ reduction during the study period could result from increased rate of photochemical reaction which enhances formation of secondary aerosols of ammonium nitrate and ammonium sulphate (Bhanarkar et al., 2005; Mor et al., 2021). The major sources of SO$_2$ emission is coal and biomass combustion (USEPA, 2021). The emission reduction of SO$_2$ at TIs could be as a result of fewer wood or coal burning activities from roadside local restaurants; roasted meat and snacks vendors using firewood; and charcoal for cooking, frying, boiling and roasting around TIs in Ibadan.

The fall in concentrations of TVOCs during lockdown may be attributed largely to reduction in vehicle number on the road, decrease in coal and biomass combustion, roadside emissions from food and snacks vendors, reduction in electrical generators emission and decline in industrial activities (Bretón et al., 2017). Two factors that might be responsible for decrease in concentration of ground level O$_3$ at TIs in Ibadan include: (1) the reduction in solar radiation intensity during the lockdown period (rainy season) which reduced photochemical reactions that triggers O$_3$ formation and (2) drop in ozone transport and diffusion from neighbouring upwind regions.

Moreover, Figure 3a revealed that 1h concentrations of CO were above the Nigeria ambient standards (NESREA) limits of 9ppm (1h) at 6 TIs (TH1, TH5, TH6, TH16, TH23, & TH25) before lockdown and 8 TIs (TH2, TH5, TH8, TH11, TH12, TH13, TH16, & TH21) during lockdown. None of the 25 TIs breached the Nigeria NO$_2$ concentration limit of 0.1ppm (1h) throughout the study period as shown in Figure 3b. Ambient concentrations of SO$_2$ and NH$_3$ breached their corresponding NESREA standards of 0.046ppm (1h) and 0.861 ppm (24h) at all the TIs during the study period as presented in Figures 3c and 3d, respectively. Likewise, Figure 3e indicated that 1h concentrations of TVOCs at all the 25 TIs were above the NESREA threshold limit of 1.9 ppm (1h). Figure 3f showed that 0.051ppm (8h) limit of ground level O$_3$ for both WHO and NESREA were breached at 7 TIs (TH6, TH7, TH8, TH16, TH18, TH19 & TH23) before lockdown and 7 TIs (TH2, TH3, TH5, TH7, TH13, TH19 & TH21) during lockdown.

### C. Effect of Climatic Parameters

Pollutant dispersion in air is affected by important climatic parameters such as atmospheric temperature, relative humidity, atmospheric pressure, wind speed, and wind direction (Cichowicz et al., 2020). Figures 4a, 4b, 4c, 4d and 4e showed the variation patterns of climatic parameters (Temperature, Relative Humidity Atmospheric Pressure & Wind Speed) and vehicular counts at TIs in Ibadan before and during lockdown phases. With average temperature of 31.23°C, relatively high ambient temperature were experienced in Ibadan before lockdown (March, 2020) in Ibadan because it was the peak of dry season with high intensity of solar radiation (Table 2 and Figure 4a). Increase in solar radiation directly reduces atmospheric stability by raising
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(a) CO (ppm) 1h-Concentration

(b) NO₂ (ppm) 1h-concentration

(c) SO₂ (ppm) 24h-Concentration
Figure 3: Concentration variations of gaseous pollutants at 25 TIs before and during lockdown periods in Ibadan (a) CO, (b) NO₂, (c) SO₂, (d) NH₃, (e) TVOCs, (f) Ground level O₃.
ambient temperature in the environment, intensifying photochemical reaction in air and increasing pollutants mixing height in the troposphere (Cichowicz et al., 2020; Ravindra et al., 2019). The average temperature during lockdown in June, 2020 (a rainy season period) was 27.15°C having a percent temperature reduction of 13.08% when compared with period before lockdown. Decrease in atmospheric temperature could be responsible for a small fraction of the total reduction in pollutants concentration in the lockdown period. The removal of a number of atmospheric pollutants is achieved by a fundamental phenomenon called Rain scavenging (Ravindra et al., 2008; Shukla et al., 2008). Yoo et al. (2014) explained that rain intensity is directly proportional to the pollutants rate of removal and study established that the removal rate of PM10 was the highest followed by gaseous pollutants SO2, NO2, CO and ground level O3.

The variation patterns of pollutants concentrations at TIs shown in Figures 2 and 3 suggests rain scavenging of both particulates and gaseous pollutants with the exception of NO2 in Ibadan. Notably, little or insignificant rainfall was recorded during the study period before lockdown as compared to the lockdown period which was predominantly rainy season. The daytime concentrations of ground level O3 was presented in Figure 3f. O3 were formed from photochemical reactions occurring due to intense radiation from the sun before lockdown in March 2020.

Pollutants accumulation rates are affected by relative humidity (Lou et al., 2017). Munir et al. (2017) investigated the links between particulate deposition and relative humidity (RH) and obtained similar results. Lou et al. (2017) explained that very dry RH (less than 45%), dry RH (45% -60%) and low RH (60%-70%) enhanced the PM2.5 rate of accumulation in ambient air while RH of 40±5% favours the accumulation of NO2, SO2 and PM10. RH increased during the study period and persisted in the range which favoured largely the accumulation of PM2.5, PM10 and TSP with percentage reduction of 60.79%, 81.21% and 84.17%, respectively (Table 2 and Figure 4b). Concentration of TRAPs at TIs in Ibadan demonstrated large fluctuations due to instability of pollutants sources resulting in rapid change in pollutants accumulation rates.

Atmospheric pressure increased from 758.33 mmHg to 759.61mmHg over the study duration (Figure 4c). Correspondingly, mean wind speed during the study period increased from 1.98 m/s before lockdown to 2.45 m/s during the lockdown period (Figure 4d). Dispersion of air pollutants at TIs was aided by increase in wind speed. The assessment of pollutants variation patterns and mean wind speed at TIs during the study presented in Table 2 indicated a decline in the concentrations of all studied pollutants except NO2. PM1 had the least concentration decline among the particulates studied that could be because of increased wind speed and road dust resuspension (Adeniran et al., 2017b; Lawrence et al., 2013; Singh et al., 2020a).
Vehicular counts at 25 TIs observed during the study period showed that the average on-road vehicles reduced by 10.40% (Table 2 and Figure 4e) during lockdown when compared with the period before lockdown. Pollutants diurnal variation at TIs was principally controlled by local emissions, meteorological situations and atmospheric chemistry of the daytime and night time (Singh et al., 2020b). The decline in the vehicle numbers at TIs in Ibadan during lockdown reduced suspension and re-suspension of particulates caused by fast moving vehicles compared with period before lockdown. Covid-19 lockdown protocols permitted haulage trucks and lorries than cars, buses and motorcycles for transportation of goods and services to residents. The reduced number of on-road vehicles guaranteed less congestion at TIs resulting in reduction of vehicular exhaust and non-exhaust emissions.

E. Identification of Sources

The possible sources of traffic related pollutants at TIs in Ibadan were identified and quantified by combining backward trajectories analysis of airflow arriving in Ibadan, Pearson correlation technique and Principal Component Analysis (PCA). This integrated approach was employed due to the constraints of specific source makers and speciation details.

1) Analysis of backward trajectories of air masses

Hybrid Single-Particle Lagrangian Integrated Trajectory Model (HYSPLIT) was used to investigate backward trajectories of air masses arriving in Ibadan for the study period before and during lockdown. Results of backward trajectories presented in Figure 5 revealed that air masses originating from south west direction was predominant for period before lockdown (Figure 5a) while the prevailing air masses during lockdown in Ibadan came from both north-west and south-west directions (Figure 5b). For study period before lockdown, Figure 5a revealed that pollutants were transported from the upwind region that is comprised of gulf of guinea (Atlantic Ocean), Lagos and Ogun States to Ibadan. Residents and the entire ecosystem are potentially at risk of air pollutants from industries, residences and other pollution activities from Lagos-Ogun-Ibadan upwind region sited within 32km of aerial distance from Study Area (Figure 5a). Furthermore, Figure 5b shows that Ibadan was affected by regional transport of pollutants during lockdown from nearby Ogun, Kwara, Niger, Zamfara and Kebbi States together with neighbouring countries location to its west (Benin, Togo and Ghana) and northeast (Chad and Sudan).

2) Pearson Correlation

Tables 3a and 3b presents the relationships among the mean concentrations of studied TRAPs, climatic parameters and vehicular counts before and during lockdown in Ibadan using Pearson’s correlation analysis. For study period before lockdown, the concentrations of CO, NO\textsubscript{2}, SO\textsubscript{2}, NH\textsubscript{3}, TVOCs, Ground level O\textsubscript{3}, PM\textsubscript{1}, and PM\textsubscript{2.5} at TIs showed negative correlation with atmospheric temperature. PM\textsubscript{1} exhibited the highest coefficient of correlation (r = -0.517) followed by NO\textsubscript{2}, PM\textsubscript{2.5}, ground level O\textsubscript{3}, NH\textsubscript{3}, TVOCs and CO. However, PM\textsubscript{10} and TSP had weak but positive correlations with temperature. Before lockdown period, PM\textsubscript{10} and TSP had positive correlation with atmospheric pressure. All the studied pollutants gave negative correlations with atmospheric pressure except CO and TSP showed positive but weak correlation during lockdown.

The relationship between wind speed (WS) and all studied pollutants were positive prior to lockdown indicating that all
Figure 5: Backward trajectories arriving at Ibadan (a) before lockdown and (b) during lockdown.
pollutants were from similar sources except NO$_2$ that had negative correlation with RH. The negative correlation between NO$_2$ and WS signifies the dilution of NO$_2$ by wind. Likewise, all studied pollutants exhibited negative relations with WS during lockdown except ground level O$_3$, PM$_{10}$ and TSP. The positive correlation between WS and ground level O$_3$ signifies that regional transport of O$_3$ that was higher before lockdown than during lockdown. Observations showed that positive correlation existed between WS and ground level O$_3$ with $r = 0.131$ and $r = 0.07$ for periods before and during lockdown, respectively. Correlation between atmospheric temperature and ground level O$_3$ were negative with $r = -0.285$ and $r = -0.88$ for periods before and during lockdown, respectively. This implies ground level O$_3$ at TIs in Ibadan were from regional air transport while temperature or solar radiation acted as reducing agent. PM$_{10}$ and TSP exhibited relatively strong correlations with Wind direction during lockdown only. PM$_1$ had the highest positive correlation with vehicular count before lockdown while vehicular count demonstrated highest positive and negative correlations with NH$_3$ and TSP, respectively during lockdown period.

3) Principal component analysis (PCA)

Using SPSS software, PCA was employed in this study for source apportionment of air pollutants at TIs in Ibadan. PCA technique converts and reduces large variable dataset with multidimensionality into small interpretable dataset capable of representing or describing the old large dataset in a linear relationship and having new set of components or factors arranged in accordance with the calculated percentage variances (Ravindra et al., 2016; Ravindra et al., 2008). PCA method is used extensively to identify sources of pollutants in air, soil and water (Cruz et al., 2020; Hoang & Tran, 2021; Kong et al., 2015; Lovrić et al., 2021; Masum & Pal, 2020; Pal & Masum, 2021; Ravindra et al., 2008; Shen et al., 2021). In this study, factor analysis was achieved by using the varimax rotation and kaizer normalization techniques. All factors with eigenvalues > 1 were retained. Three factors indicated the highest variance for the study period before lockdown in Ibadan with a cumulative variance of 79.67% as presented in Table 4. Factor 1 revealed a 38.29% variance with significant factor loadings for SO$_2$, PM$_{10}$ and TSP. SO$_2$ is indicative of emission from vehicles and biomass near TIs (Wang et al., 2013). PM$_{10}$ and TSP from road dust suspension and re-suspension were aided by regional wind transport and vehicular movement (Ahmad et al., 2021; Chen et al., 2018).

Factor 2 was composed of NH$_3$, TVOCs, PM$_1$, and PM$_{2.5}$ explaining 27.63% variance. Pollutants from vehicle exhausts, roadside fuel combustion activities and regional transport from upwind areas may be responsible for factor 2 (Gallego et al., 2008; Lawrence et al., 2013; Ravindra et al., 2020). Pollutants from neighbouring upwind area may be released from industrial, agricultural and residential sources or combination of these sources. Factor 3 indicated 13.74% variance for NO$_2$ and ground level O$_3$ factor loadings. NO$_2$ is indicative of fuel combustion sources (Marković et al., 2008) from vehicles and other roadside activities while ground level O$_3$ with high factor loading of 0.86 suggests photochemical production from oxides of Nitrogen (NOx) through solar radiation during the study period (Johnson, 2017; Marković et al., 2008) in addition to O$_3$ regional air transport.

Similarly, three factors explained the cumulative variance of 78.46% for period during lockdown in Ibadan. Factor 1 showed 46.02% variance with substantial factor loading for CO, SO$_2$, NH$_3$, TVOCs, PM$_1$ and PM$_{2.5}$. Sources of these pollutants at TIs may be from vehicle emission (exhaust and non-exhaust), fuel combustion from roadside activities and regional transport of air pollutants from upwind areas with industries, residences and agricultural activities or combination of these sources (Lawrence et al., 2013; Ravindra et al., 2020; Sembhi et al., 2020). Factor 2 comprising PM$_{10}$ and TSP accounted for 21.90% variance. Road dust suspension and re-suspension by movement of vehicles and wind in addition to particulate regional transport are the possible sources of PM$_{10}$ and TSP at TIs in Ibadan (Ahmad et al., 2021; Chen et al., 2018). Factor 3 explained 10.54% with noteworthy loadings for NO$_2$ and ground level O$_3$, signifying that NO$_2$ were emitted from fuel combustion in vehicles and from roadside activities such as electric generators using petrol or diesel, fuel driven motor engines of vulcanizer compressor and fuel driven motor engines of grain and pepper grinders. The possible sources of O$_3$ are from regional air transport and photochemical production of ground level O$_3$ from NO$_2$ during lockdown at TIs (Johnson, 2017; Marković et al., 2008). Furthermore, PCA results in this study showed clearly that vehicle emissions from exhaust and non-exhaust sources at TIs had significant impact on urban air pollution of Ibadan before and during covid-19 lockdown.

IV. CONCLUSION

The lockdown impacts owing to Covid-19 pandemic on the air quality of Ibadan, a West African city were investigated. The comparison of average concentrations of pollutants, climatic parameters and vehicular counts before and during lockdown at twenty-five TIs revealed a considerable decrease in the concentration of all pollutants studied except for NO$_2$ with 212% increase. Concentrations of CO, SO$_2$, NH$_3$, TVOCs and ground level O$_3$ reduced by 7.92%, 24.80%, 1.58%, 44.08% and 4.28%, respectively whereas concentrations of PM$_{1}$, PM$_{2.5}$, PM$_{10}$ and TSP decreased by 49.64%, 60.79%, 81.21% and 84.17%, respectively. Covid-19 lockdown protocol in Ibadan imposed restrictions on movement of vehicles and shutdown industrial and commercial activities resulting in reduction of air pollution at TIs during the lock-down period. Variation in concentrations of particulates, NO$_2$, SO$_2$ and ground level O$_3$ during the study period were considerably influenced by the number of vehicles on the road and climatic parameters at the different sampling sites (TIs).

Results of Pearson’s correlation, backward trajectories of air masses arriving in Ibadan and principal component analysis established exhaust and non-exhaust vehicular emissions as the major sources of air pollution at TIs and identified the contributions of pollutants emanating from roadside fuel combustion and regional air transport from neighbouring upwind areas with industries, agricultural activities and residences. Potential sources of air pollutants during restricted anthropogenic activities were identified and described in this study. Information from this study will help to design and plan...
Table 3(a): Pearson correlation of studied traffic related pollutants, vehicular count and climatic parameters in Ibadan before lockdown

| Ground level | Temperatur e | Rel. Humidity | Atm. Pressure | Wind Speed | Wind Direction | Vehicular Count |
|--------------|--------------|---------------|---------------|------------|----------------|----------------|
| CO           | 1.016        | -0.021        | -0.008        | -0.281     | -0.193         | -0.009         |
| NO₂          | -0.016       | 1.000         | 0.063         | 0.190      | -0.285         | -0.007         |
| SO₂          | 0.038        | -0.012        | 1.000         | 0.190      | -0.285         | -0.007         |
| NH₃          | -0.016       | 0.038         | 0.063         | 1.000      | 0.190           | -0.285         |
| TVOCs        | 0.038        | -0.012        | 0.063         | 1.000      | 0.190           | -0.285         |
| PM₁₀         | 0.038        | -0.012        | 0.063         | 1.000      | 0.190           | -0.285         |
| PM₂.₅        | 0.038        | -0.012        | 0.063         | 1.000      | 0.190           | -0.285         |
| PM₁₀         | 0.038        | -0.012        | 0.063         | 1.000      | 0.190           | -0.285         |
| TSP          | 0.038        | -0.012        | 0.063         | 1.000      | 0.190           | -0.285         |

*Correlation is significant at the 0.05 level (2-tailed). **Correlation is significant at the 0.01 level (2-tailed).

Table 3(b): Pearson correlation of studied traffic related pollutants, vehicular count and climatic parameters in Ibadan during lockdown

| Ground level | Temperatur e | Rel. Humidity | Atm. Pressure | Wind Speed | Wind Direction | Vehicular Count |
|--------------|--------------|---------------|---------------|------------|----------------|----------------|
| CO           | 1.000        | 0.063         | 0.190         | 0.190      | -0.285         | -0.007         |
| NO₂          | -0.016       | 1.000         | 0.063         | 0.190      | -0.285         | -0.007         |
| SO₂          | 0.038        | -0.012        | 1.000         | 0.190      | -0.285         | -0.007         |
| NH₃          | -0.016       | 0.038         | 0.063         | 1.000      | 0.190           | -0.285         |
| TVOCs        | 0.038        | -0.012        | 0.063         | 1.000      | 0.190           | -0.285         |
| PM₁₀         | 0.038        | -0.012        | 0.063         | 1.000      | 0.190           | -0.285         |
| PM₂.₅        | 0.038        | -0.012        | 0.063         | 1.000      | 0.190           | -0.285         |
| PM₁₀         | 0.038        | -0.012        | 0.063         | 1.000      | 0.190           | -0.285         |
| TSP          | 0.038        | -0.012        | 0.063         | 1.000      | 0.190           | -0.285         |

*Correlation is significant at the 0.05 level (2-tailed). **Correlation is significant at the 0.01 level (2-tailed).
an appropriate pollution mitigation strategy to reduce air pollutants from local activities and upwind areas in Ibadan City.

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