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

[Received Apr. 28, 2022; Revised Jul. 14, 2022; Accepted Jul. 19, 2022] Print ISSN: 0189-9546 | Online ISSN: 2437-2110

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 from 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; Kumar 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 (NO_x) and volatile organic compounds (VOC_s) under intense solar radiation.

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doi: http://dx.doi.org/10.4314/njtd.v19i3.3

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 762.3mmHg 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, $TVOC_s$, 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

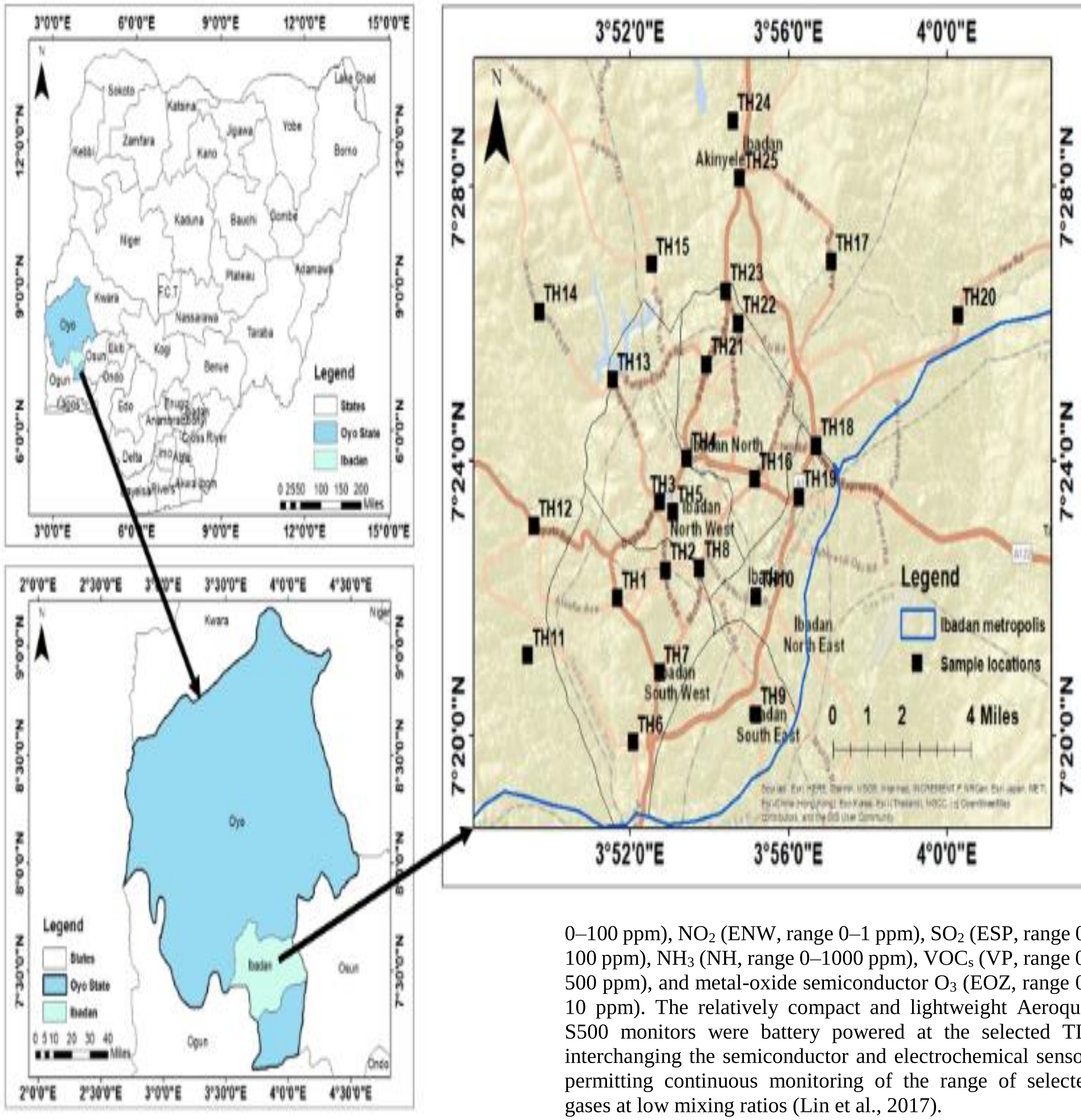


Figure 1: Study area map.

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), NO_2 (ENW, range 0–1 ppm), SO_2 (ESP, range 0–100 ppm), NH_3 (NH, range 0–1000 ppm), VOC_s (VP, range 0–500 ppm), and metal-oxide semiconductor O_3 (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 PM_1, $PM_{2.5}$, PM_{10} & 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 (PM_1, $PM_{2.5}$, PM_4, PM_7, PM_{10} 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

Table 1: Geographical information of the sampling sites (this study).

S/N	Sampling Site	Site Code	Category	Latitude	Longitude	Surrounding Features
1	Mobil Oluyole	TH1	Industrial and Commercial	7.3666	3.8612	Industrial buildings, Filling Stations, Commercial Buildings, Vehicular Movement, Bike, Tricycle and Taxi Parks, Banks, Eateries
2	Oke Ado	TH2	Commercial	7.3735	3.8815	Filling Stations, Commercial Buildings, Vehicular Movement, Bike and Taxi Parks
3	Dugbe	TH3	Commercial	7.3900	3.8788	Commercial Buildings, Vehicular Movement, Police Station, Bike and Taxi Parks
4	Mokola Roundabout	TH4	Commercial	7.4006	3.8902	Market, Filling Stations, Commercial Buildings, Vehicular Movement, Bike and Taxi Parks, Banks
5	Ogunpa	TH5	Commercial	7.3875	3.8844	Market, Commercial Buildings, Vehicular Movement, Police Station, Bike, Tricycle, Taxi and Bus Parks
6	New Garage	TH6	Residential	7.3317	3.8678	Filling Stations, Residential Buildings, Vehicular Movement, Bike, Tricycle and Taxi Parks
7	Challenge Roundabout	TH7	Commercial	7.3486	3.8790	Filling Stations, Commercial Buildings, Vehicular Movement, Bike and Tricycle Parks, Banks, Eateries
8	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	TH9	Residential and Commercial	7.3385	3.9194	Agricultural produce Market , Filling Stations, Residential Buildings, Vehicular Movement Bike Park
10	Orita Aperin	TH10	Residential and Commercial	7.3669	3.9194	Market, Filling Stations, Residential Buildings, Vehicular Movement Bike Park, Schools
11	Elebu	TH11	Residential and Commercial	7.3528	3.8234	Agricultural produce Market , Filling Stations, Residential Buildings, Vehicular Movement Bike and Tricycle Park, Church
12	Apata	TH12	Residential and Commercial	7.3842	3.8262	Market, Roadside Shops Filling Stations, Residential Buildings, Vehicular Movement, Bike, Tricycle , Taxi and Bus Parks
13	Eleyele Roundabout	TH13	Residential	7.4198	3.8593	Roadside Shops, Residential Buildings, Vehicular Movement, Bike, Taxi and Bus Parks
14	Ologuneru	TH14	Residential	7.4363	3.8284	Roadside Shops, Residential Buildings, Vehicular Movement, Bike, Taxi and Bus Parks
15	Apete-Ijokodo	TH15	Residential and Commercial	7.4478	3.8756	Roadside Shops, Residential Buildings, Vehicular Movement, Bike, Taxi and Bus Parks
16	Gate	TH16	Commercial	7.3956	3.9190	Market, Roadside Shops, Residential Buildings, Vehicular Movement, Bike, Tricycle , Taxi and Bus Parks, Post Office
17	Akobo	TH17	Residential and Commercial	7.4485	3.9513	On-going Road construction, Market, Filling Station, Roadside Shops Residential Buildings, Vehicular Movement, Bike, Taxi and Bus Parks
18	Iwo Road	TH18	Commercial	7.4038	3.9448	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	Olodo	TH20	Residential and Commercial	7.4355	4.0045	Roadside Shops, Filling Station Residential Buildings, Vehicular Movement, Filling Stations, Bike and Tricycle Parks,
21	Sango-Elewure	TH21	Residential and Commercial	7.4234	3.8987	Roadside Shops, Filling Station Residential Buildings, Vehicular Movement, Filling Stations, Bike, Tricycle, Taxi and Bus Parks,
22	Bodija	TH22	Commercial	7.4335	3.9119	Market, Roadside Shops, Commercial Buildings, Banks, Vehicular Movement, Filling Stations, Police Post, Bike, Tricycle, Taxi and Bus Parks
23	UI-Agbowo	TH23	Commercial	7.4412	3.9068	Ibadan University Gate, Roadside Shops, Commercial Buildings, Banks, Vehicular Movement, Filling Stations, Banks, Bike, Tricycle, Taxi and Bus Parks, Hospitals
24	Shasha	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	Ojoo 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

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
NO_2 (ppm)	0.01	0.03	-0.02	212.86
SO_2 (ppm)	0.45	0.34	0.11	-24.80
NH_3 (ppm)	17.47	17.19	0.28	-1.58
TVOCs (ppm)	44.48	24.87	19.61	-44.08
Ground level O_3 (ppm)	0.0356	0.0341	0.0015	-4.28
PM_1 (μg/m^3)	5.81	2.93	2.88	-49.64
$PM_{2.5}$ (μg/m^3)	12.10	4.74	7.35	-60.79
PM_{10} (μg/m^3)	142.82	26.83	115.99	-81.21
TSP (μg/m^3)	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

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 (PM_1, $PM_{2.5}$, PM_{10} & TSP) and gaseous pollutants (CO, NO_2, SO_2, NH_3, $TVOC_s$, and Ground level O_3) 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, NO_2, SO_2, NH_3, ground level O_3 and PM_1 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.

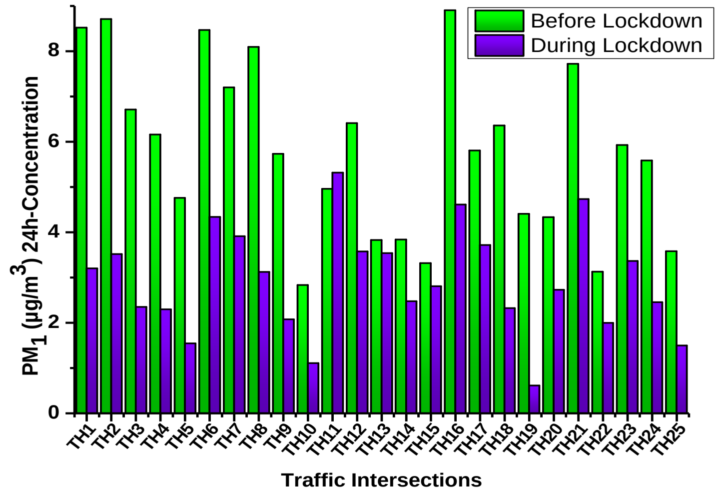
A. Variation in Particulate (PM_1, $PM_{2.5}$, PM_{10}, TSP) Concentrations

The mean concentration of PM_1 for a 5-day period before lockdown was 5.81μg/m^{3}which decreased to 2.93μg/m^3 during lockdown period. $PM_{2.5}$ mean concentration decreased from 12.10 μg/m^3 to 4.74μg/m^3 during the lockdown period. Likewise, mean concentration of PM_{10} declined from 142.82 μg/m^3 to 26.83 μg/m^3 in the lockdown period while TSP concentration level fell from 312.23 μg/m^3 to 49.38 μg/m^3 during the study period. The average concentrations of PM_{10} and TSP of 142.82 μg/m^3 and 312.23 μg/m^3 were above 50 μg/m^3 and 250 μg/m^3 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).

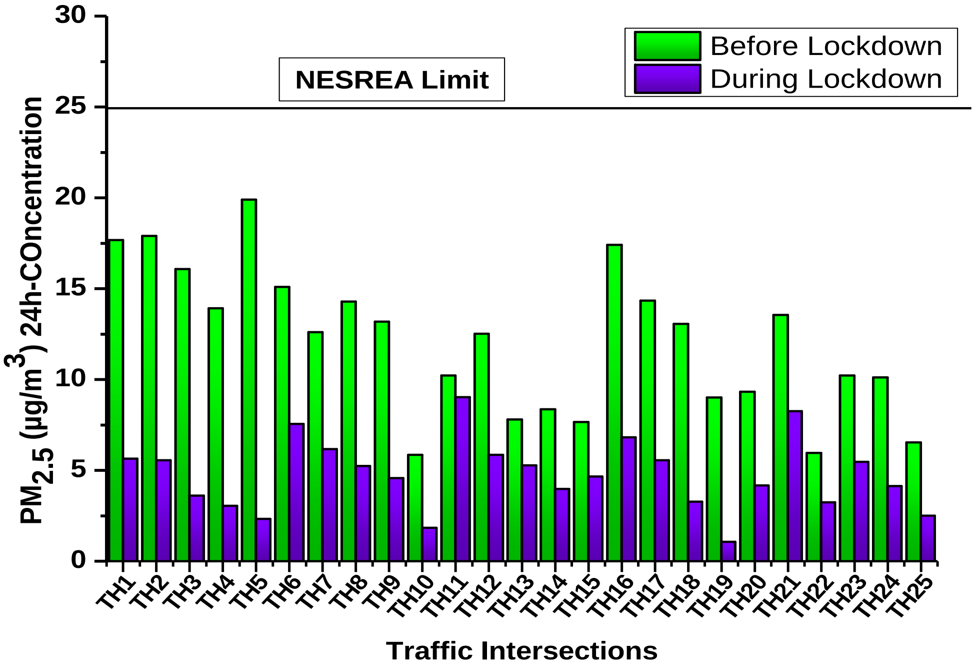
Pollution concentration reduction of 49.64%, 60.79%, 81.21% and 84.17% for PM_1, $PM_{2.5}$, PM_{10} & TSP, respectively were observed at TIs in Ibadan during the lockdown in relation to the period before lockdown (Table 2). The decline in particulate concentration levels are attributed largely to the 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 (PM_1, $PM_{2.5}$, PM_{10} & TSP) at 25 TIs before and during lockdown periods in Ibadan. In the study period, $PM_{2.5}$ (24h) concentration limits set by WHO (25 μg/m^3) and NESREA (35 μg/m^3) were not breached at any of the 25 TIs before and during the lockdown in Ibadan City (Figure 2b). PM_{10} limit (150 μg/m^3) 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/m^3) 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, NO_2, SO_2, NH_3, TVOCs, and Ground level O_3) Concentrations

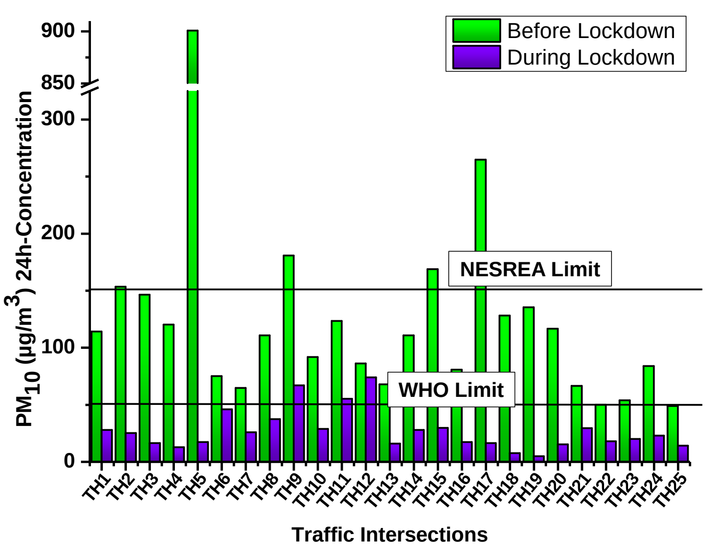
The 5-day mean concentration levels of CO, NO_2, SO_2, NH_3, TVOCs, and ground level O_3 before lockdown were 3.21, 0.01, 0.45,17.47,44.48 and 0.036 ppm, respectively (Table 2), these were below the ambient recommended limits of NESREA (Nigeria) and WHO. During the lockdown, the mean concentrations were documented as 2.95, 0.03, 0.34, 17.19, 24.87 and 0.034 ppm for CO, NO_2, SO_2, NH_3, TVOCs, and ground level O_3, respectively. Comparison of gaseous pollutants concentrations before and during lockdown periods indicated mean concentration reductions of 7.92% for CO, 24.80% for SO_2, 1.58% for NH_3, 44.08% for TVOCs and 4.28% for ground level O_3.


Before Lockdown
During Lockdown
PM1 (µg/m3) 24h-Concentration
Traffic Intersections

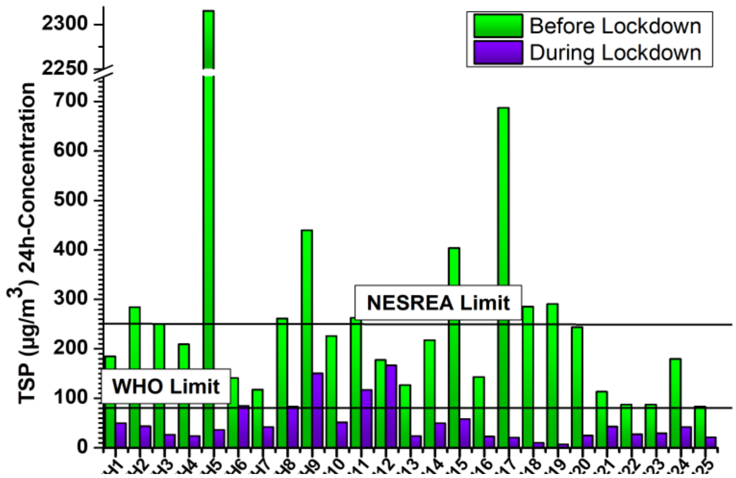
(a)


NESREA Limit
Before Lockdown
During Lockdown
PM2.5 (µg/m3) 24h-COncentration
Traffic Intersections

(b)


Before Lockdown
During Lockdown
NESREA Limit
WHO Limit
PM10 (µg/m3) 24h-Concentration
Traffic Intersections

(c)



(d)

Figure 2: Concentration variations of particulates at 25 TIs before and during lockdown periods in Ibadan (a) PM_1, (b) $PM_{2.5}$, (c) PM_{10}, (d) TSP

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).

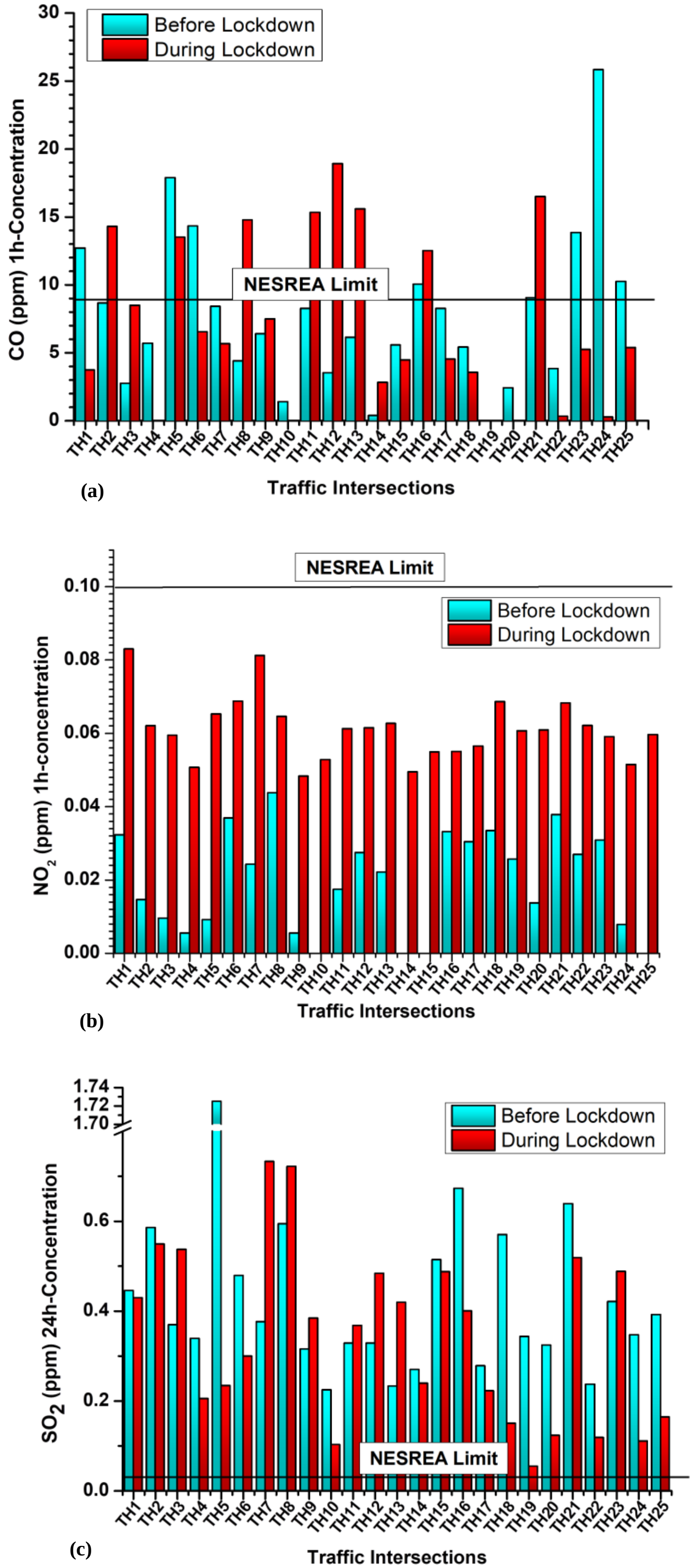
The NH_3 reduction during the study period could result from increased rate of photochemical reaction which enhances formation of secondary aerosols of ammonium nitrate and ammonium sulphate (Bhanarkar et al., 2005; Mor et al., 2021). The major sources of SO_2 emission is coal and biomass combustion (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



Before Lockdown
During Lockdown
NESREA Limit
CO (ppm) 1h-Concentration
Traffic Intersections
(a)
NESREA Limit
Before Lockdown
During Lockdown
NO2 (ppm) 1h-concentration
Traffic Intersections
(b)
Before Lockdown
During Lockdown
NESREA Limit
SO2 (ppm) 24h-Concentration
Traffic Intersections
(c)

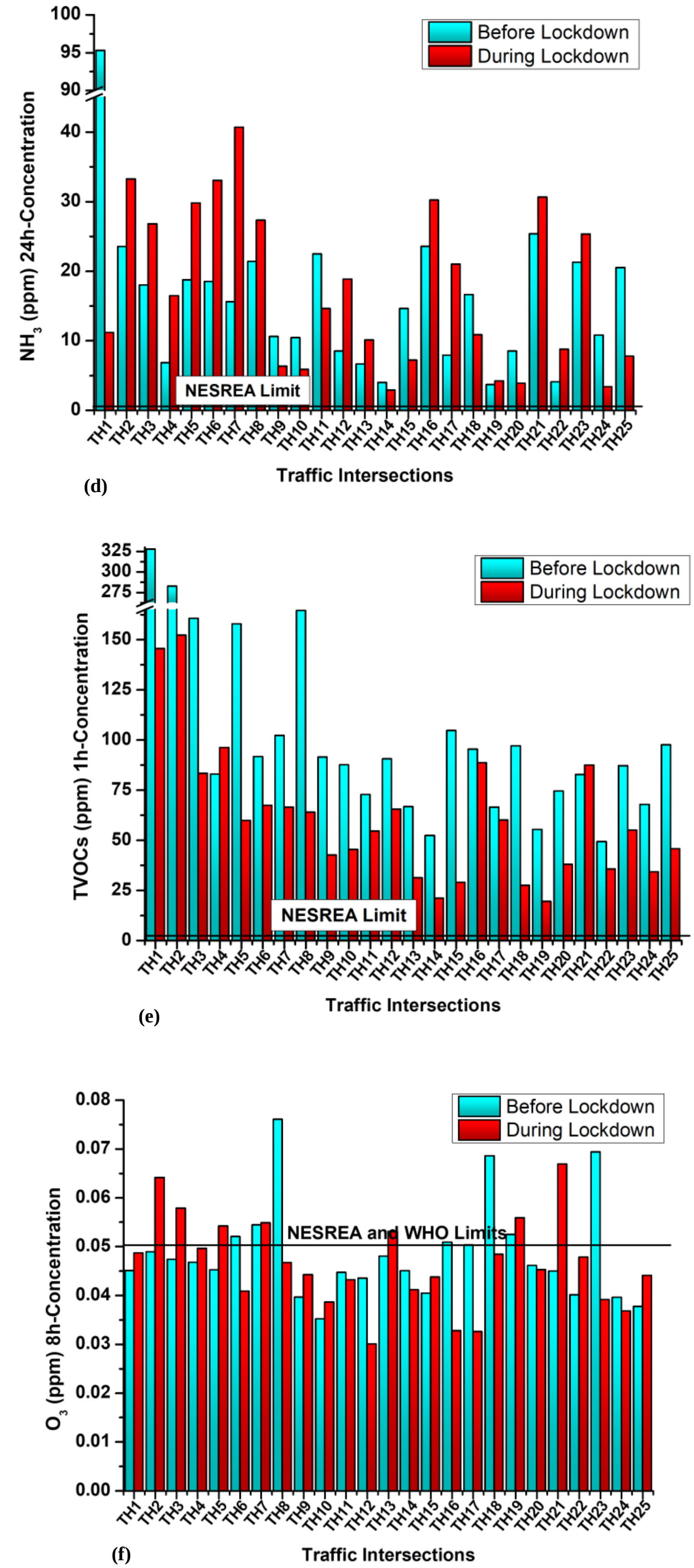


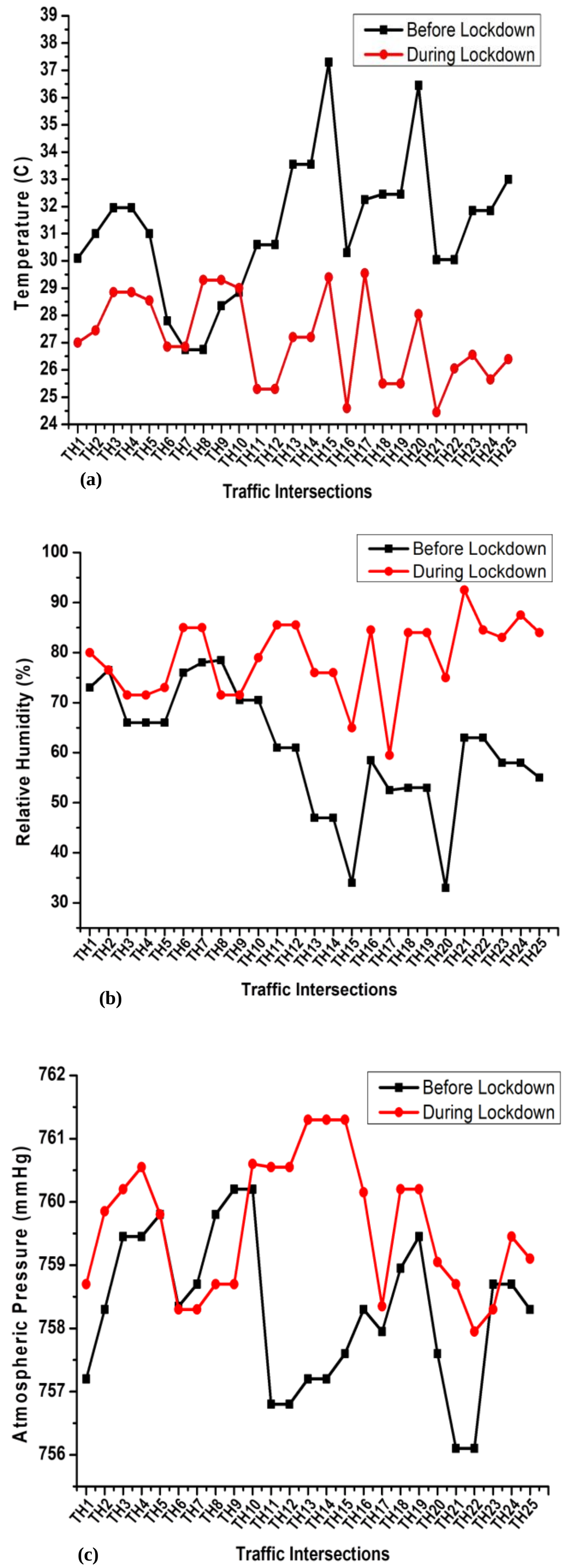
Figure 3: Concentration variations of gaseous pollutants at 25 TIs before and during lockdown periods in Ibadan (a) CO, (b) NO_2 (c) SO_2, (d) NH_3, (e) TVOCs, (f) Ground level O_3.

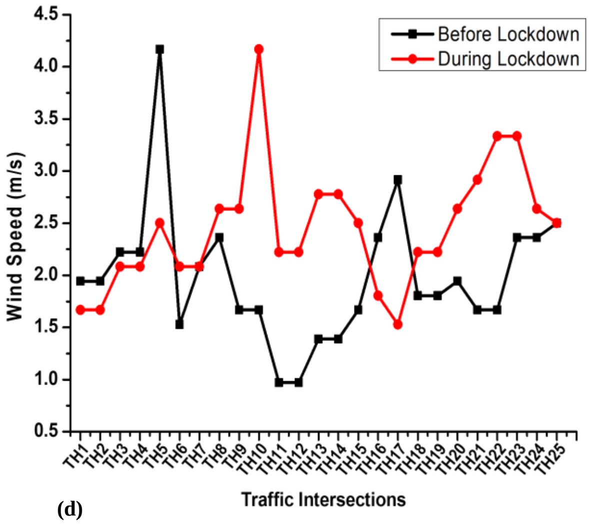
ambient temperature in the environment, intensifying photochemical reaction in air and increasing pollutants mixing height in the troposphere (Cichowicz et al., 2020; Ravindra et al., 2019). The average temperature during lockdown in June, 2020 (a rainy season period) was 27.15˚C having a percent temperature 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 SO_2, NO_2, CO and ground level O_3.

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 NO_2 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 O_3 was presented in Figure 3f. O_3 were formed from photochemical reactions occurring due to intense radiation from the sun before lockdown in March 2020.

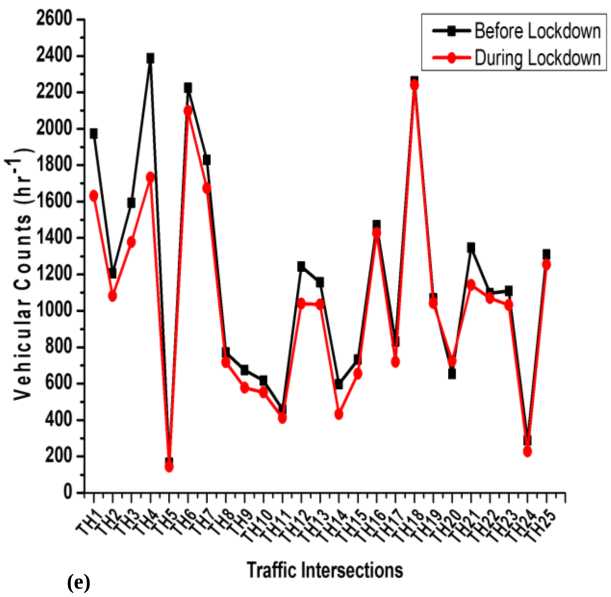
Pollutants accumulation rates are affected by relative humidity (Lou et al., 2017). Munir et al. (2017) investigated the links between particulate deposition and relative humidity (RH) and obtained similar results. Lou et al. (2017) explained that very dry RH (less than 45%), dry RH (45% -60%) and low RH (60%-70%) enhanced the PM2.5 rate of accumulation in ambient air while RH of 40±5% favours the accumulation of NO_2, SO_2 and PM_{10}. RH increased during the study period and persisted in the range which favoured largely the accumulation of $PM_{2.5}$, PM_{10} 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 NO_2. PM_1 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).





(d)



(e)

Figure 4: Trends of climatic data and vehicular counts at 25 TIs before and during lockdown periods in Ibadan
(a) Temperature, (b) Relative Humidity, (c) Atmospheric Pressure (d) Wind Speed, (e) Vehicular Counts.

D. Effect of On-Road Vehicles

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.

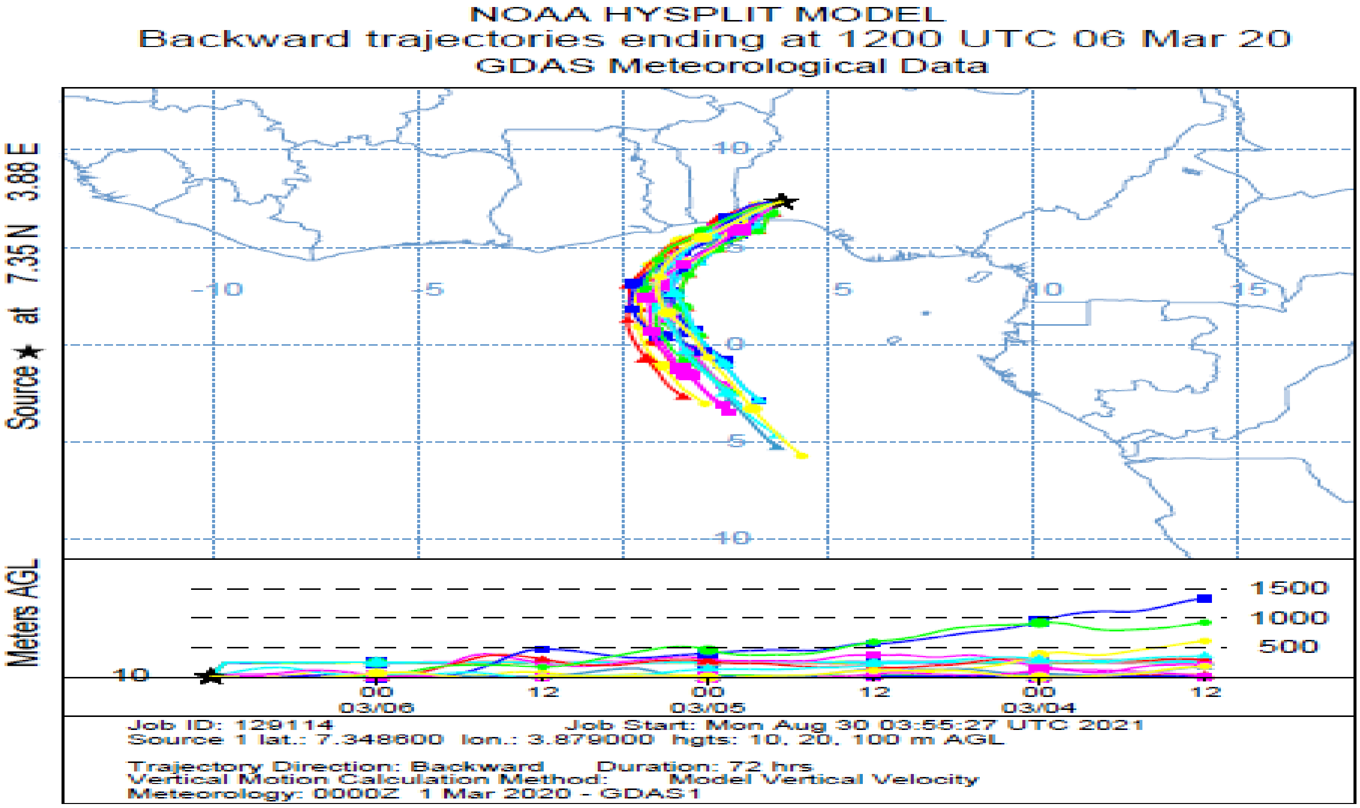
1) Analysis of backward trajectories of air masses

Hybrid Single-Particle Lagrangian Integrated Trajectory Model (HYSPILT) 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).

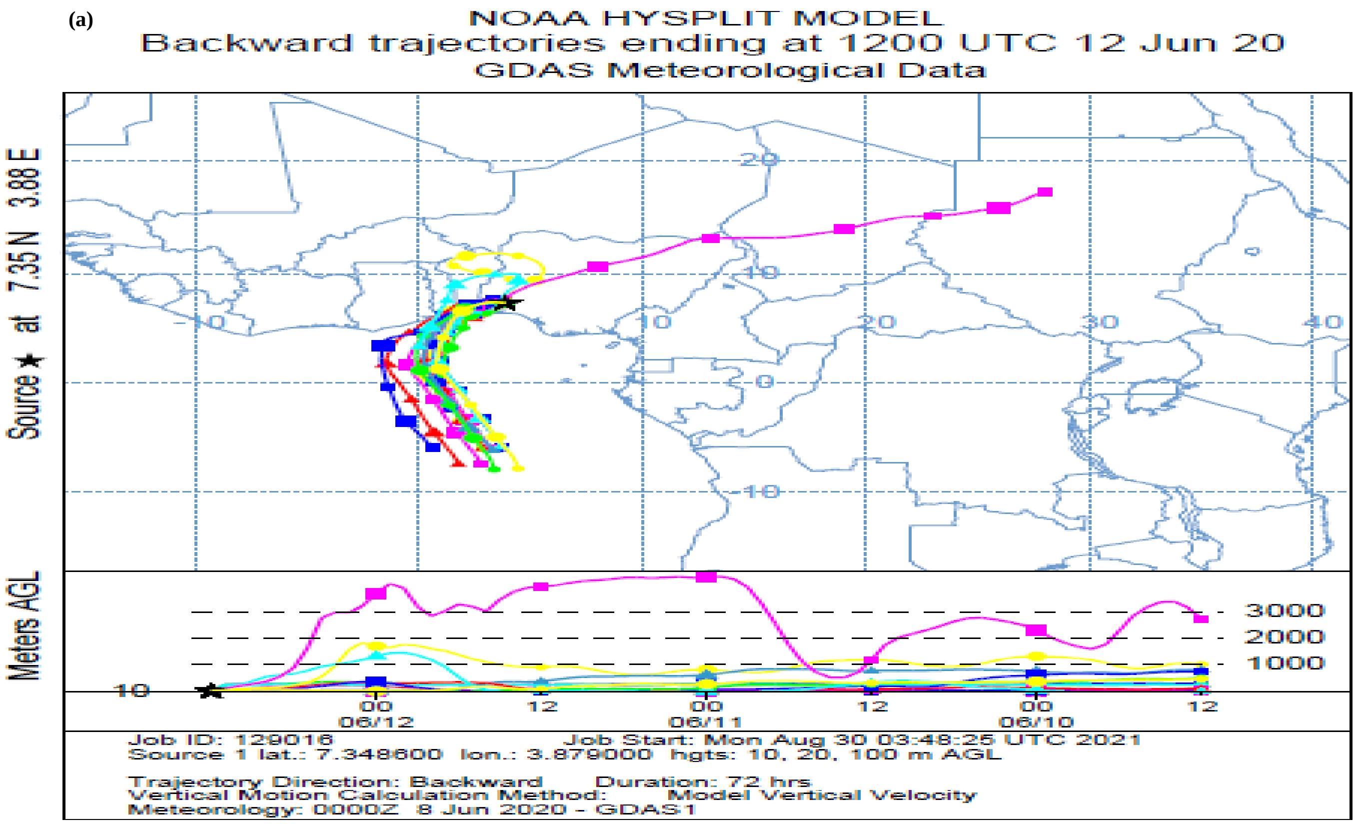
2) Pearson Correlation

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_2, SO_2, NH_3, $TVOC_s$, Ground level O_3, PM_1 and $PM_{2.5}$ at TIs showed negative correlation with atmospheric temperature. PM_1 exhibited the highest coefficient of correlation ($r = -0.517$) followed by NO_2, $PM_{2.5}$, ground level O3, NH3, TVOCs and CO. However, PM_{10} and TSP had weak but positive correlations with temperature. During the lockdown period, atmospheric temperature showed negative but weak correlations with PM_1, $PM_{2.5}$, NO_2, CO, ground level O_3, NH_3 and PM_{10}. Only PM_1 and $PM_{2.5}$ had a positive and relatively strong correlation with RH before lockdown while CO, NO_2, NH_3, $TVOC_s$, ground level O_3, PM_1, $PM_{2.5}$, PM_{10} and TSP demonstrated positive but weak relations with RH during lockdown period. Before lockdown period, PM_{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



(a)



(b)

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 = -285 and r = -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 (NO_x) 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_x 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 lockdown 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

	CO	NO_2	SO_2	NH_3	TVOCs	Ground level O_3	PM_1	$PM_{2.5}$	PM_{10}	TSP	Temperature	Rel. Humidity	Atm. Pressure	Wind Speed	Wind Direction	Vehicular Count
CO	1	-.015	.425*	.311	.192	-.016	.297	.347	.283	.284	-.156	.220	.048	.469*	-.112	-.084
NO_2	-.015	1	-.012	.199	.081	.563**	.552**	.219	-.285	-.277	-.390	.249	-.358	-.233	-.017	.301
SO_2	.425*	-.012	1	.178	.323	.063	.210	.607**	.850**	.841**	-.088	.173	.238	.695**	.007	-.160
NH_3	.311	.199	.178	1	.788**	-.016	.497*	.452*	-.002	-.031	-.199	.333	-.151	.072	.134	.299
TVOCs	.192	.081	.323	.788**	1	.080	.548**	.625**	.190	.149	-.198	.475*	.100	.208	.039	.217
Ground level O_3	-.016	.563**	.063	-.016	.080	1	.397*	.179	-.137	-.123	-.285	.202	.289	.131	-.083	.211
PM_1	.297	.552**	.210	.497*	.548**	.397*	1	.804**	-.102	-.131	-.517**	.588**	.056	.078	-.183	.514**
$PM_{2.5}$	.347	.219	.607**	.452*	.625**	.179	.804**	1	.470*	.435*	-.356	.506**	.233	.456*	-.236	.291
PM_{10}	.283	-.285	.850**	-.002	.190	-.137	-.102	.470*	1	.998**	.049	.040	.316	.716**	-.118	-.375
TSP	.284	-.277	.841**	-.031	.149	-.123	-.131	.435*	.998**	1	.042	.027	.317	.715**	-.123	-.405*
Temperature	-.156	-.390	-.088	-.199	-.198	-.285	-.517**	-.356	.049	.042	1	-.914**	-.265	-.008	.240	-.205
Rel. Humidity	.220	.249	.173	.333	.475*	.202	.588**	.506**	.040	.027	-.914**	1	.341	.110	-.209	.299
Atm. Pressure	.048	-.358	.238	-.151	.100	.289	.056	.233	.316	.317	-.265	.341	1	.469*	-.293	-.023
Wind Speed	.469*	-.233	.695**	.072	.208	.131	.078	.456*	.716**	.715**	-.008	.110	.469*	1	-.342	-.168
Wind Direction	-.112	-.017	.007	.134	.039	-.083	-.183	-.236	-.118	-.123	.240	-.209	-.293	-.342	1	.000
Vehicular Count	-.084	.301	-.160	.299	.217	.211	.514**	.291	-.375	-.405*	-.205	.299	-.023	-.168	.000	1

*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

	CO	NO_2	SO_2	NH_3	TVOCs	Ground level O_3	PM_1	$PM_{2.5}$	PM_{10}	TSP	Temperature	Rel. Humidity	Atm. Pressure	Wind Speed	Wind Direction	Vehicular Count
CO	1	.562**	.629**	.537**	.324	.038	.581**	.586**	.470*	.457*	-.210	.119	.133	-.212	.347	-.091
NO_2	.562**	1	.388	.440*	.311	.420*	.420*	.434*	.269	.249	-.302	.347	-.183	-.148	.294	.266
SO_2	.629**	.388	1	.667**	.461*	.133	.570**	.582**	.363	.330	.091	-.060	-.120	-.238	.434*	.142
NH_3	.537**	.440*	.667**	1	.562**	.196	.549**	.503*	.074	.019	-.058	.097	-.348	-.359	.167	.342
TVOCs	.324	.311	.461*	.562**	1	.335	.382	.367	.072	.033	.012	.006	-.204	-.501*	.281	.337
Ground level O_3	.038	.420*	.133	.196	.335	1	-.126	-.117	-.358	-.365	-.088	.195	-.039	.007	-.008	.260
PM_1	.581**	.420*	.570**	.549**	.382	-.126	1	.976**	.370	.285	-.339	.214	-.144	-.365	.270	.190
$PM_{2.5}$	.586**	.434*	.582**	.503*	.367	-.117	.976**	1	.502*	.415*	-.331	.253	-.211	-.307	.333	.134
PM_{10}	.470*	.269	.363	.074	.072	-.358	.370	.502*	1	.990**	-.005	.097	-.028	.016	.585**	-.204
TSP	.457*	.249	.330	.019	.033	-.365	.285	.415*	.990**	1	.035	.050	.018	.008	.554**	-.236
Temperature	-.210	-.302	.091	-.058	.012	-.088	-.339	-.331	-.005	.035	1	-.894**	.027	.052	.007	-.266
Rel. Humidity	.119	.347	-.060	.097	.006	.195	.214	.253	.097	.050	-.894**	1	-.166	.195	.182	.281
Atm. Pressure	.133	-.183	-.120	-.348	-.204	-.039	-.144	-.211	-.028	.018	.027	-.166	1	.027	.247	-.195
Wind Speed	-.212	-.148	-.238	-.359	-.501*	.007	-.365	-.307	.016	.008	.052	.195	.027	1	.202	-.383
Wind Direction	.347	.294	.434*	.167	.281	-.008	.270	.333	.585**	.554**	.007	.182	.247	.202	1	-.060
Vehicular Count	-.091	.266	.142	.342	.337	.260	.190	.134	-.204	-.236	-.266	.281	-.195	-.383	-.060	1

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

Table 4: Result of PCA for the study duration

Parameters	Before Lockdown			During Lockdown		
	Factor 1	**Factor 2**	**Factor 3**	**Factor 1**	**Factor 2**	**Factor 3**
CO	.380	.396	-.002	.597	.491	.306
NO_2	-.177	.138	.840	.356	.342	.703
SO_2	.916	.220	.101	.726	.259	.257
NH_3	-.058	.910	-.021	.801	-.079	.302
TVOCs	.141	.881	.026	.597	-.105	.398
Ground level O_3	.008	-.066	.862	-.013	-.327	.865
PM_1	.019	.689	.624	.898	.231	-.118
$PM_{2.5}$	.529	.658	.350	.849	.360	-.095
PM_{10}	.968	.025	-.173	.183	.953	-.084
TSP	.969	-.017	-.165	.102	.970	-.068
Eigenvalues	3.829	2.763	1.374	4.602	2.190	1.054
% of total variance explained	38.293	27.632	13.741	46.024	21.900	10.536
Cumulative %	38.293	65.924	79.666	46.024	67.924	78.459

an appropriate pollution mitigation strategy to reduce air pollutants from local activities and upwind areas in Ibadan City.

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