Chapter

Atmospheric Air Pollution in Nigeria: A Correlation between Vehicular Traffic and Criteria Pollutant Levels

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Abstract

In Nigeria, the rising levels of used/poorly maintained vehicles are contributing to most urban air pollution with possible repercussion on the general public health. This study evaluates the inferences of vehicular traffic surge on outdoor pollutant measurement using Zaria, northern Nigeria, as a case study. The study collected a 1-year time-series dataset for the vehicular count and the respective outdoor criteria pollutant measurements over 19 study sites. The vehicular traffic was categorized into motorcycles (2-W), tricycles (3-W), cars, buses, light-duty vehicles (LDV) and heavy-duty vehicles (HDV). The outdoor pollutants that were measured include carbon monoxide (CO), sulfur dioxide (SO_2) and particulate matter ($PM_{2.5}/PM_{10}$). We utilized validated portable monitors (CW-HAT200 particulate counter and the MSA Altair 5x multigas sensor) for the outdoor measurements during December 2015–November 2016. The observed measurements for the validation procedure were normally distributed [kurtosis (0.301); skewness (−0.334)] and coefficient of determination ($R2 \geq 0.808$). The time-series analysis of particulate matter (PM) measurements displayed alarming concentrations levels. Combined vehicular traffic density analysis revealed significant contribution ($R \geq 0.619$) to the population exposed outdoor pollutant measurements. The 2-W (motorcycle) was found to be the vehicular category that attributed the most significant relationship with observed outdoor pollutant measurements.

Keywords: urban air quality, vehicular traffic, portable sensors, criteria pollutants, Zaria-Nigeria

1. Introduction

In most developing countries, atmospheric pollution continues to affect exposed population health [1–3]. In Africa, air quality studies are devising alternative and reliable means to obtain pollutant measurements for research. The approach

$\mu g\ m^{-3}$	Microgram per meter cube
2-W	Two-wheeler (motorcycle)
3-W	Three-wheeler (tricycle)
CO	Carbon monoxide
HDV	Heavy-duty vehicle
LDV	Light-duty vehicle
$PM_{2.5}$	Particulate matter, with a diameter of <2.5 μm
PM_{10}	Particulate matter, with a diameter of <10 μm
ppm	Parts per million
SO_2	Sulfur dioxide
TSP	Totally suspended particles

Table 1.
List of abbreviations and units.

includes reliable validation of sampling techniques that contribute to the up-to-date understanding of criteria pollutants, maintenance outflow and technical know-how [4].

Nigeria's rising population is escalating anthropogenic activities within its territory without any reliable information on its air quality [5]. The atmospheric air quality of most of its urban cities continues to remain exposed to the growing, poorly managed vehicular traffic from ineffective fuel combustion [6]. The situation is familiar, however, the motivation to address it lingers ambiguously.

The rising levels of used/poorly managed vehicular operations remains an unnoticed contributor to urban atmospheric air pollution. While the literature has established alarming pollutant levels and how they contribute to the respiratory wellbeing of the exposed population [3], there is a need to further establish the relationship between the categories of the existing vehicular traffic surge and corresponding criteria pollutant levels observed. This will facilitate the process of the traffic-related atmospheric air pollution management plan in many Nigerian cities. For familiarity with the terminology, **Table 1** highlights a list of abbreviations and units utilized for this study.

2. Methodology

2.1 Study area

Zaria metropolis described in **Figure 1**, has an estimated area of 296.04 km^2. Its estimated population as reported in 2014 is 938,521. The city climate characteristics are divided into two. The dry season ranges from October to May, and the rainy season ranges from June to September. The altitude is averagely 670 m above mean sea level [7]. Major road intersections are the concept adopted for the selection of the 19 study sites.

2.2 Instrumentation and methods

There is increasing use of portable devices for examining outdoor air (atmospheric) quality. With comparison to established reference devices, their reliability allows for effective real-time data acquisition, especially in limited resource

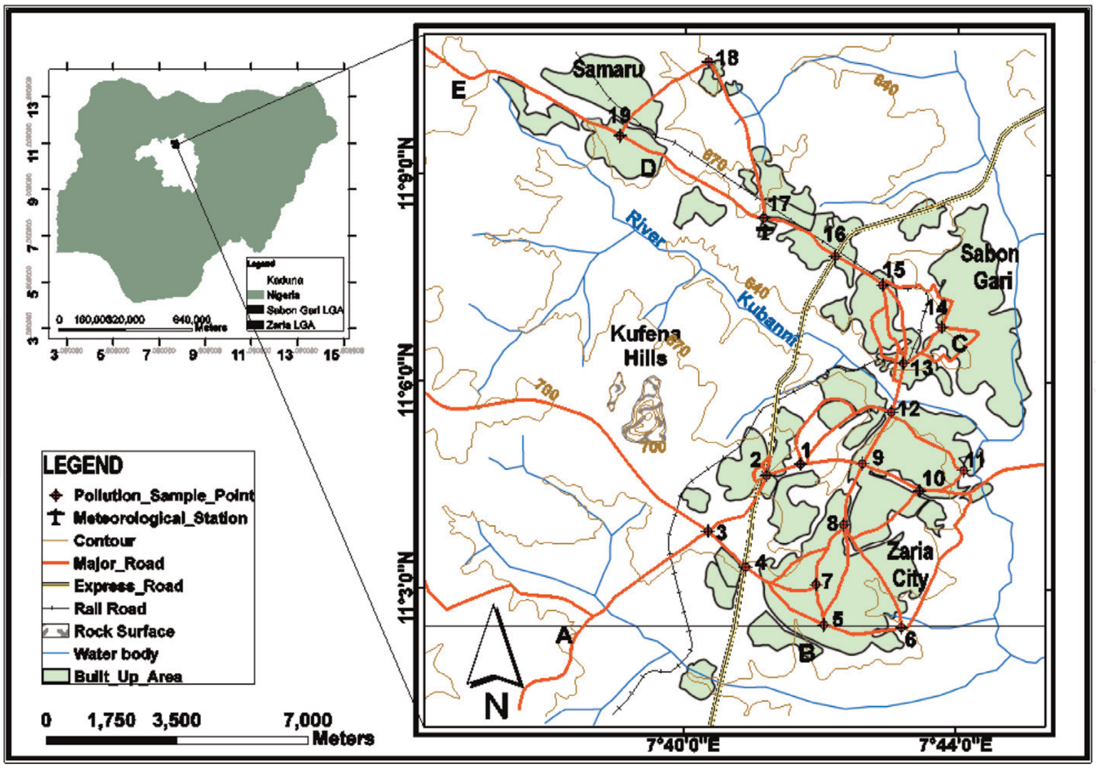


Figure 1.
The 19 study sites adopted for study data acquisition.

environments [8]. This study employed the CW-HAT200 particulate counter and the MSA Altair 5x multi-gas sensor to collect particulate matter ($PM_{2.5}$ and PM_{10}) while the MSA Altair 5x collect carbon monoxide (CO) and sulfur dioxide (SO_2) respectively. The instrument re-calibration was conducted using manufacturer's span calibration mixed gas specifications.

Owing to the unavailability of real-time reference air pollution monitors within the study region, the devices were validated the portable pollutants monitors using the WHO air filter sampling model Eq. (1). To validate the portable devices, total suspended particulates (TSP) were collected at two distinct sample test stations at 1.5 m above the existing ground level. Validation site 1 had dense outdoor traffic activity, while validation site 2 had minimal outdoor traffic activity tagged control site. The validation samples and synchronized portable monitor measurements were obtained across three epochs, that are, morning, afternoon and evening for 17 days. TSP is described as particulate fraction ranging from 0.1 to about 100 μm in size (diameters). Particulates matter $PM_{2.5}$ (diameter < 2.5 μm) and PM_{10} (diameter < 10 μm) fall within the specified range. Based on [9] which identified a significant relationship between total suspended particulates, PM_{10} and $PM_{2.5}$ and [10] which reported that there is a significant correlation among pollutant emissions resulting from a common source, the study validated the portable devices using the WHO air sampling filter technique. Eq. (1) describes the WHO air sample model technique [11].

$$total\ suspended\ particulates\ \left(\mu g\ m^{-3}\right) = \frac{M_S - M_O}{V} \tag{1}$$

where M_O is the filter paper mass without TSP samples, M_S is the filter paper mass with TSP samples, V is the TSP volume. To determine the concentration ($\mu g\ m^{-3}$), model Eq. (1) was divided by the sample time (in hours).

In line with Eq. (1), the validation samples were collected individually on filter papers and collocating pollutant measurements with the portable device over the study duration. The particulate filter samples were processed in the laboratory to obtain their individual concentrations using Eq. (1). They were then compared with the separately recorded collocating pollutant measurements from the portable devices. The collocating measurements were then analyzed using linear regression and bias, for the validation of the portable monitors. The analysis is described in **Figures 2** and **3**. The observed measurements for the validation procedure were normal distributed [skewness (−0.334); kurtosis (0.301)]. The study adopted two performance indicators for the purpose of validating the portable pollutant instrument. The performance indicators are The Bland-Altman agreement plot and the coefficient of determination (R^2). The Bland-Altman plot evaluates the systematic bias between the two measurements techniques, while the coefficient of determination indicates how strongly related the pair(s) of variables are. The Bland-Altman agreement plot can be seen in **Figure 2**.

From **Figure 2**, it can be seen that there is no significant systematic difference in the measurements. Additionally, the coefficient of determination (R^2) across the two test sites showed that the TSP measurements from the WHO model technique and criteria pollutant measurements from the MSA Altair 5x/CW-HAT200 devices were significantly correlated. The linear regression can be seen in **Figure 3**. **Figures 2** and **3** illustrate that the reliability of the portable pollutant monitors has been validated based on [9, 10].

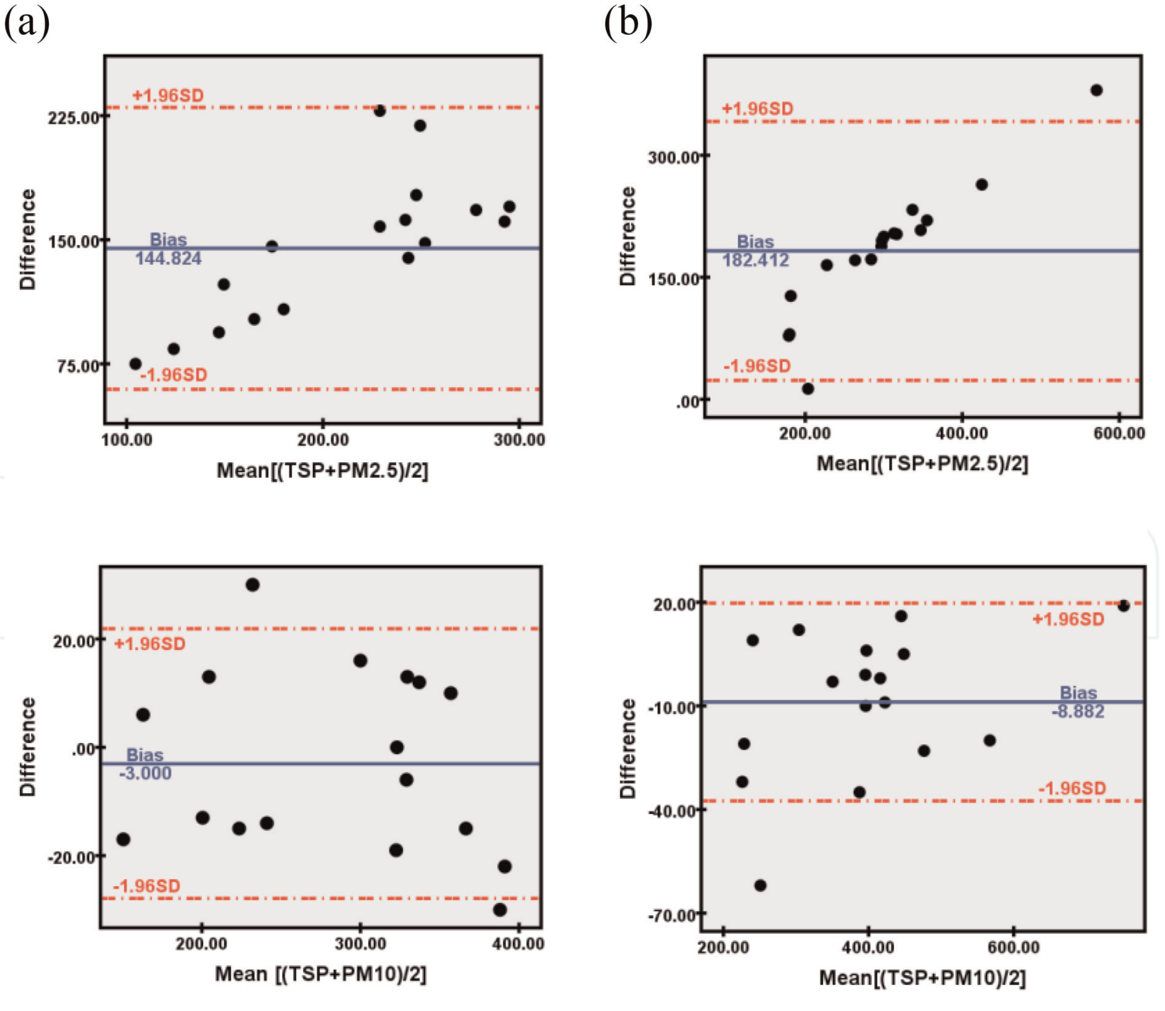


Figure 2.
Bland-Altman bias plot highlighting the agreement of observed validation measurements ($PM_{2.5}$ and PM_{10}) within the 95% confidence interval: (a) less densely populated site and (b) densely populated site.

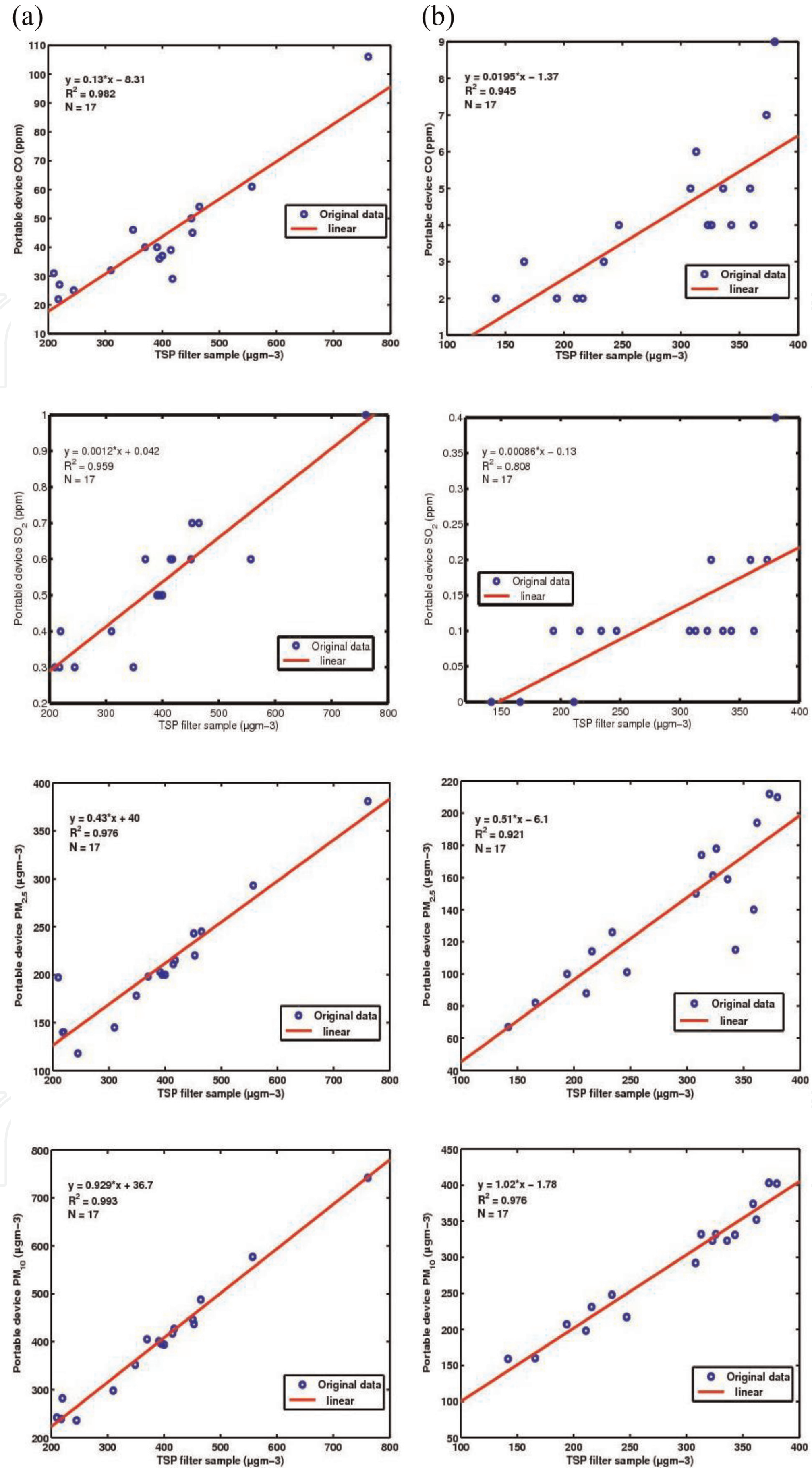


Figure 3.
Scatter plots showing the linear regression and coefficient of determination between the TSP and the portable monitor samples: (a) densely populated site and (b) control site.

Study sites	s1	s2	s3	s4	s5	s6	s7	s8	s9	s10	s11	s12	s13	s14	s15	s16	s17	s18	s19
s1	1	0.997	0.878	0.998	0.983	0.858	0.997	0.999	0.995	0.997	0.986	0.994	0.996	0.988	0.994	0.995	0.989	0.960	0.995
s2		1	0.907	0.993	0.992	0.888	0.989	0.998	0.985	**1.000**	0.993	0.984	0.987	0.974	0.988	0.985	0.994	0.977	0.997
s3			1	0.851	0.951	0.997	0.841	0.895	0.834	0.910	0.906	0.837	0.847	0.797	0.833	0.826	0.897	0.961	0.897
s4				1	0.971	0.828	0.998	0.994	0.995	0.992	0.983	0.993	0.994	0.993	0.999	0.998	0.989	0.950	0.993
s5					1	0.938	0.967	0.989	0.963	0.993	0.982	0.964	0.969	0.944	0.961	0.959	0.982	0.988	0.986
s6						1	0.820	0.878	0.815	0.892	0.881	0.820	0.829	0.775	0.808	0.803	0.873	0.944	0.875
s7							1	0.994	0.999	0.989	0.975	0.998	0.998	0.997	0.996	0.999	0.980	0.937	0.987
s8								1	0.991	0.999	0.985	0.992	0.993	0.982	0.990	0.990	0.990	0.968	0.996
s9									1	0.985	0.967	0.999	**1.000**	0.997	0.992	0.998	0.973	0.928	0.982
s10										1	0.991	0.985	0.988	0.974	0.987	0.985	0.993	0.978	0.997
s11											1	0.963	0.968	0.957	0.980	0.971	0.995	0.981	0.992
s12												1	0.999	0.996	0.990	0.997	0.971	0.928	0.981
s13													1	0.994	0.990	0.996	0.973	0.933	0.983
s14														1	0.993	0.998	0.965	0.909	0.974
s15															1	0.997	0.988	0.943	0.991
s16																1	0.979	0.931	0.985
s17																	1	0.981	0.998
s18																		1	0.978
s19																			1

Table 2.
Pearson's correlation coefficient matrix of seasonal pollutant measurement across the 19 study sites (significant at 0.01 levels).

With the above-described validation, the portable instruments were utilized to commence the measurement of ground level roadside pollution concentrations. The duration of the sampling measurement was from 01 December 2015 to 30 November 2016. The outdoor concentration levels were observed using the approach described in [12, 13]. The vehicular traffic count was also conducted to obtain the volume of vehicles contributing to the outdoor air pollution across the sampling sites. The vehicular count was obtained to determine the contributory level of vehicular density to outdoor air pollution. The vehicles are categorized as follows: motorcycles (2-W), tricycles (3-W), cars, buses, light-duty vehicles (LDV) and heavy-duty vehicles (HDV). The study analysis was performed using software: SPSS, Microsoft Excel and MATLAB.

3. Results and discussion

Table 2 highlights the dispersal relationship of the observed CO, SO_2, $PM_{2.5}$ and PM_{10} across the 19 study sites. This was achieved using Pearson's correlation coefficient. The inter-study-site correlation matrix (**Table 2**), showed that the relationship of the measured pollutants was significant at the 0.01 level across all the study sites. And only study site 6 (a control site) revealed lower coefficient values in comparison to the remaining study sites. From **Table 2**, study sites 2 and 9 produced a perfect relationship with site 10 and site 13, respectively.

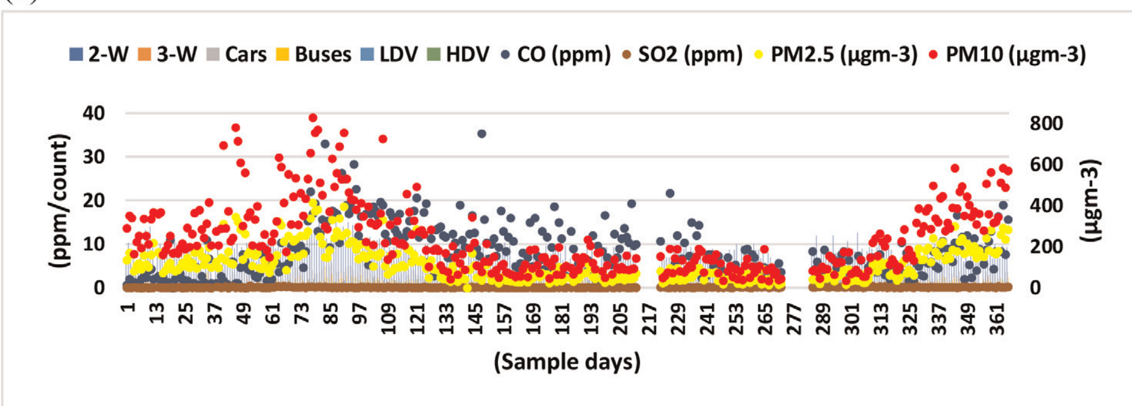
Study site	2-W	3-W	Car	Bus	LDV	HDV
1	16,034 ± 17	3186 ± 4	10,242 ± 11	5613 ± 6	958 ± 1	1417 ± 2
2	15,111 ± 16	2955 ± 4	8443 ± 9	4971 ± 6	643 ± 1	1204 ± 2
3	8554 ± 8	888 ± 1	3021 ± 3	1177 ± 1	2571 ± 1	641 ± 1
4	19,948 ± 22	3731 ± 4	11,785 ± 12	7279 ± 8	1561 ± 2	3444 ± 4
5	11,688 ± 12	2063 ± 2	2960 ± 4	1418 ± 2	340 ± 1	571 ± 1
6	5602 ± 6	615 ± 1	1585 ± 2	542 ± 1	241 ± 1	412 ± 1
7	18,012 ± 18	3954 ± 5	4045 ± 5	6656 ± 7	502 ± 2	442 ± 1
8	17,069 ± 17	3556 ± 4	5153 ± 5	6353 ± 7	428 ± 1	211 ± 1
9	27,008 ± 27	5529 ± 7	16,307 ± 17	9352 ± 10	1495 ± 2	1628 ± 2
10	14,870 ± 15	3575 ± 4	8628 ± 9	3667 ± 5	784 ± 2	1320 ± 1
11	14,453 ± 16	4446 ± 6	7089 ± 8	2321 ± 3	296 ± 1	369 ± 1
12	27,058 ± 28	5720 ± 6	15,746 ± 17	9643 ± 10	1436 ± 2	929 ± 2
13	22,012 ± 23	4982 ± 6	9559 ± 10	8551 ± 9	919 ± 2	537 ± 1
14	28,897 ± 29	6205 ± 7	5123 ± 6	6797 ± 8	897 ± 2	500 ± 1
15	17,482 ± 18	3736 ± 5	11,748 ± 13	6761 ± 7	1343 ± 2	899 ± 2
16	20,678 ± 22	4672 ± 6	22,656 ± 24	13,050 ± 14	2405 ± 3	2666 ± 4
17	11,167 ± 12	2241 ± 3	12,647 ± 13	6447 ± 8	1013 ± 2	1131 ± 2
18	6710 ± 7	756 ± 1	4194 ± 5	2528 ± 3	364 ± 1	713 ± 1
19	10,529 ± 11	2048 ± 3	9781 ± 10	6063 ± 7	872 ± 2	896 ± 2
Total	**312,882**	**64,858**	**170,712**	**109,189**	**19,068**	**19,930**

Table 3.
Vehicular traffic density (total ± average per 3 min) across the 19 sampling sites in the study.

The traffic count for the individual sampling site per epoch was computed based on the vehicular category, as shown in **Table 3**. In general, the study site with the highest weighted average of the criteria pollutants measured over the 19 study locations is study site 14. The reason for the high measurements is because the site is within the study area's main market (Sabon-Gari market) with the highest average count of 2-W and 3-W vehicle density (**Table 3**). The traffic volume was determined by direct counting the traffic during the daily sampling epoch for the study period (1 year).

Figure 4 displays the time-series plots of vehicular traffic count and resulting criteria pollutants measurements collected over selected study sites 3, 9 and 15. It can be observed that the study sites 3 which is a control site, did have the majority of its pollutant concentration levels below 40 ppm, 0.6 ppm, 300 μg m^{-3} and

(a)



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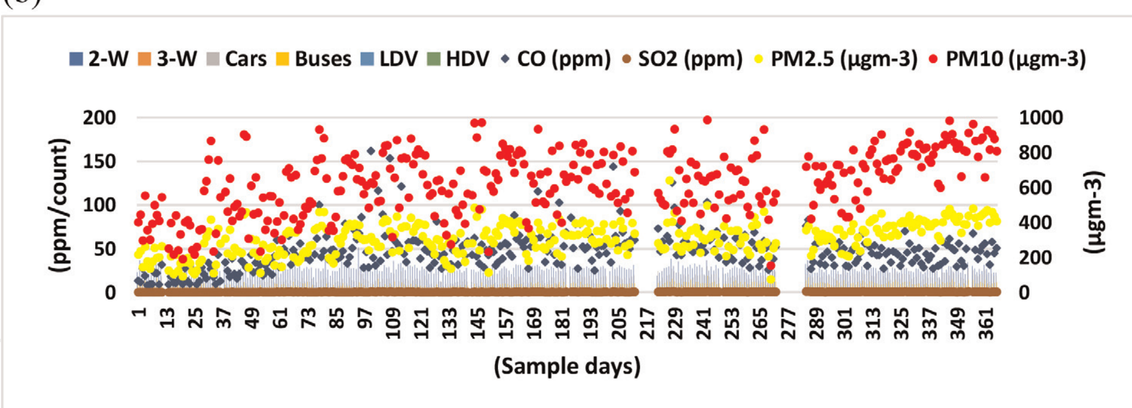

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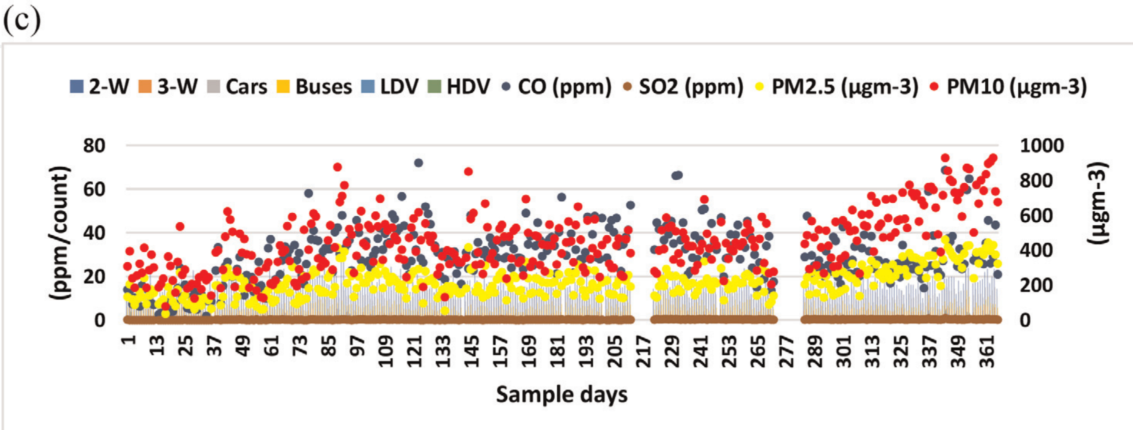

Figure 4.
Time-series of the weighted average for the vehicular traffic count against the measured criteria pollutants over randomly selected sites 3, 9, and 15 for the 366 days duration: (a) Study site 3, (b) Study site 9, and (c) Study site 15.

600 μg m^{-3} for CO, SO_2, $PM_{2.5}$ and PM_{10} respectively. Except for PM during the Harmattan season which falls between sample days 1–91. For sites 9 and 15, the majority of the observed criteria pollutant measurements were above the earlier described values.

Table 4 presents the computed 1-year weighted average of the measured criteria pollutants concentrations across the 19 study sites [14]. Study sites 3 and 6 recorded the least pollutant measurements CO/SO_2 and $PM_{2.5}$/PM_{10}. This could attribute to minimal population activities at the sites. The sites 3, 6 and 18 were actually selected to serve as control sites for the study. From **Table 4**, the weighted average of the observed criteria pollutants for the study area is deduced as CO (29.220 ppm), SO_2 (0.319 ppm), $PM_{2.5}$ (219.729 μg m^{-3}) and PM_{10} (451.958 μg m^{-3}).

Additionally, the weighted average computed for the observed criteria pollutant was compared against the stipulated guidelines in the WHO air quality document [15]. The comparison revealed that the weighted average of criteria pollutants observed over the 19 study sites did exceed the WHO stipulated threshold (blue line across bar charts) for SO_2, $PM_{2.5}$ and PM_{10} in all the study sites, except for CO, whose weighted average stayed within the stipulated limits only in sites 3, 6 and 18. This is illustrated in **Figure 5**.

Pearson's correlation matrix was utilized to investigate the seasonal level of association between measured criteria pollutants and traffic activities within the 19

Site	Latitude	Longitude	Description	CO (ppm)	SO_2 (ppm)	$PM_{2.5}$ (μg m^{-3})	PM_{10} (μg m^{-3})
1	11.080	7.695	Kofar Kibo	33.036	0.363	258.873	528.000
2	11.078	7.686	Danmagaji, Wusasa	20.838	0.264	214.720	432.571
3	11.064	7.673	Madaci, Saye	7.994	0.159	117.177	232.246
4	11.054	7.682	Gwargwaje	29.703	0.351	250.294	509.957
5	11.044	7.701	Kofar Gayan	16.811	0.212	182.562	372.982
6	11.041	7.720	Kofar Kona	4.586	0.137	99.068	202.008
7	11.051	7.699	Zaria City market	38.281	0.383	276.448	561.482
8	11.066	7.706	Babban Dodo	27.242	0.290	220.292	448.332
9	11.081	7.710	Kofar Doka	46.844	0.449	312.469	631.429
10	11.074	7.725	Banzazzau	22.880	0.260	208.111	424.255
11	11.079	7.735	FCE/Ungwan Kaya	19.728	0.243	179.426	367.067
12	11.093	7.717	Agwaro, Tudun Wada	55.959	0.525	328.026	662.063
13	11.104	7.721	PZ	38.848	0.399	282.524	573.486
14	11.113	7.730	Sabon Gari market	65.073	0.627	342.588	704.262
15	11.124	7.715	MTD	29.600	0.302	173.255	448.810
16	11.130	7.703	Kwangila bridge	50.130	0.465	282.891	576.923
17	11.139	7.686	Aviation by NITT road	19.180	0.238	167.004	352.324
18	11.177	7.672	Basawa by Hayin Dogo	8.795	0.167	93.807	189.041
19	11.159	7.651	Samaru market	19.652	0.244	185.319	369.965

Table 4.
The 1-year weighted average of the observed pollutants (N = 19, 104).

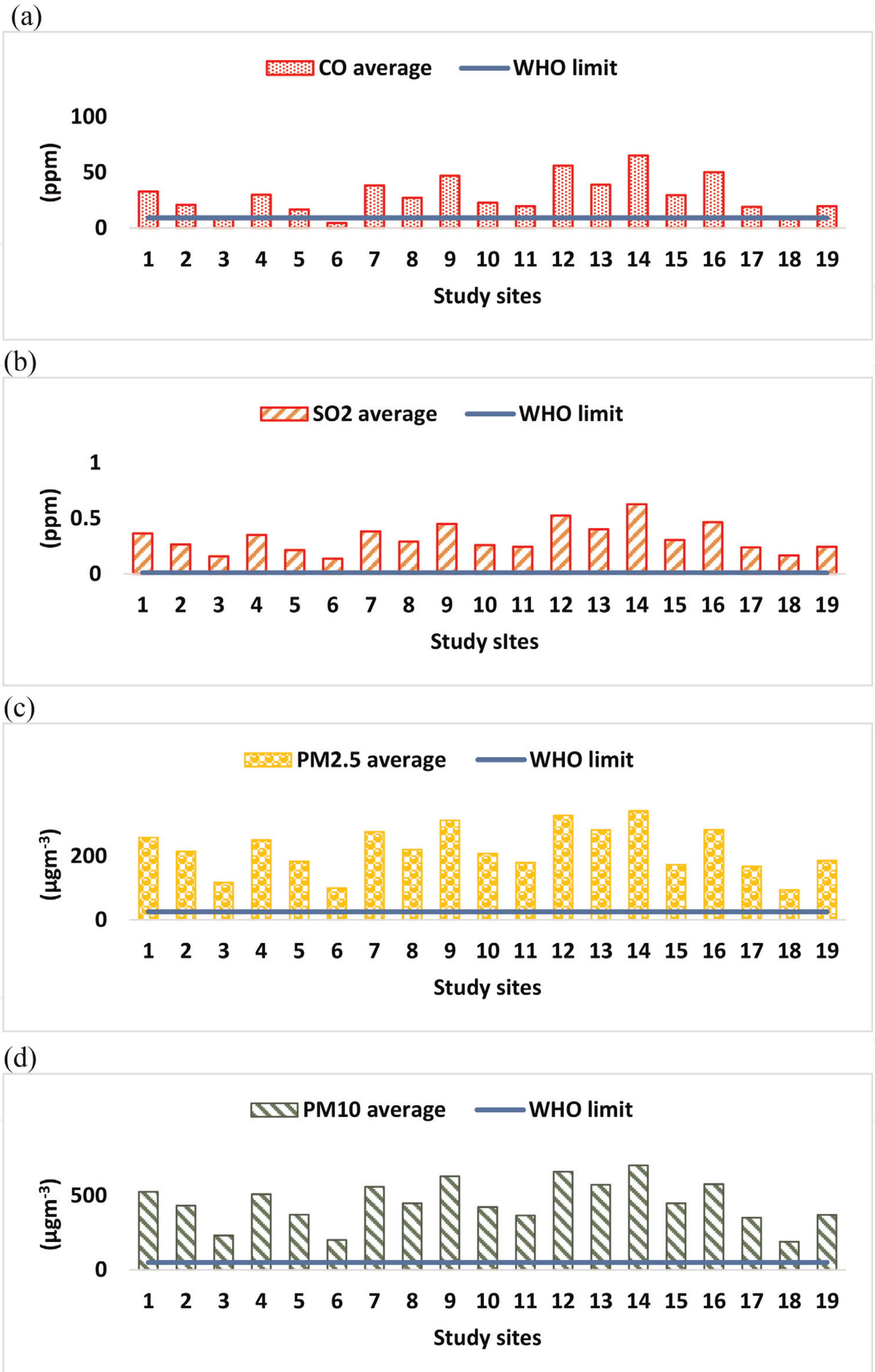

Figure 5.
The comparison of weighted criteria pollutants average: (a) CO; (b) SO_2; (c) $PM_{2.5}$; and (d) PM_{10} against the WHO air quality guidelines.

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		CO				SO_2				$PM_{2.5}$				PM_{10}				Traffic count			
Pollutants	Seasons	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON
CO	DJF	1	0.983	0.975	0.940	0.962	0.957	0.963	0.927	0.778	0.951	0.941	0.900	0.779	0.948	0.941	0.910	0.870	0.876	0.837	0.790
	MAM		1	0.992	0.972	0.976	0.984	0.988	0.958	0.782	0.968	0.960	0.916	0.783	0.966	0.960	0.930	0.882	0.898	0.854	0.814
	JJA			1	0.984	0.969	0.976	0.995	0.975	0.780	0.970	0.971	0.934	0.781	0.969	0.971	0.949	0.882	0.898	0.861	0.822
	SON				1	0.946	0.949	0.979	0.992	0.749	0.949	0.958	0.943	0.752	0.951	0.959	0.954	0.894	0.903	0.882	0.860
SO_2	DJF					1	0.985	0.968	0.929	0.747	0.930	0.922	0.879	0.750	0.929	0.922	0.898	0.816	0.837	0.781	0.737
	MAM						1	0.983	0.930	0.751	0.935	0.923	0.861	0.752	0.931	0.923	0.885	0.828	0.842	0.791	0.749
	JJA							1	0.972	0.789	0.966	0.963	0.917	0.790	0.963	0.963	0.933	0.867	0.887	0.845	0.804
	SON								1	0.761	0.955	0.971	0.968	0.766	0.957	0.972	0.975	0.909	0.914	0.891	0.864
$PM_{2.5}$	DJF									1	0.871	0.837	0.778	0.999	0.864	0.836	0.785	0.673	0.691	0.664	0.619
	MAM										1	0.989	0.952	0.871	0.999	0.989	0.960	0.885	0.904	0.858	0.815
	JJA											1	0.977	0.837	0.992	1.000	0.984	0.892	0.911	0.874	0.831
	SON												1	0.783	0.960	0.977	0.996	0.919	0.922	0.896	0.861
PM_{10}	DJF													1	0.864	0.837	0.790	0.676	0.694	0.667	0.622
	MAM														1	0.992	0.967	0.886	0.905	0.861	0.819
	JJA															1	0.985	0.893	0.911	0.875	0.832
	SON																1	0.898	0.903	0.872	0.834
Traffic count	DJF																	1	0.985	0.973	0.955
	MAM																		1	0.986	0.964
	JJA																			1	0.992
	SON																				1

Table 5.
Seasonal correlation of the measured pollutants against the traffic variables (significant at 0.01 levels).

	2-W	3-W	Cars	Buses	LDV	HDV
CO	0.865*	0.793*	0.523	0.665*	0.542	0.433
SO_2	0.710*	0.694	0.422	0.587*	0.458	0.352
$PM_{2.5}$	0.763*	0.719*	0.465	0.593*	0.461	0.361
PM_{10}	0.766*	0.720*	0.468	0.600*	0.462	0.359

**The gradient of the shaded cells highlights (in decreasing order) the ranking of correlation of the various categories of vehicles to the observed criteria pollutants.*

Table 6.
Statistical correlation between vehicular categories collated at the study sites against the criteria pollutant measurements.

sampling locations. The data capture period was categorized into seasons that include December-January-February (DJF); March-April-May (MAM); June-July-August (JJA) and September-October-November (SON). This aims to appraise the environmental implication of road traffic movement to outdoor air pollution in Zaria across the seasons. From **Table 5**, it can be observed that all the measured variables were correlated positively at 0.01 p-levels. The analysis also indicates that the traffic activities (that is, the vehicular counts at the time of criteria pollutant observations) contributed significantly to observed criteria pollutants concentration levels except for the December-January-February (DJF) season. The DJF season (**Table 5**, red text) recorded lower correlation coefficients compared to the remaining seasons. The lower Pearson's coefficients during the DJF season can be attributed to the Harmattan and the holiday season within the study area. The Harmattan season is characterized by natural dusty-windy conditions and low temperatures, while the holiday season attributed to the lesser than usual traffic activities within the study area. From **Table 5**, this study concludes that emissions from vehicular activities are significantly responsible for measured pollutants observations in this study.

The contribution of traffic variables to the outdoor air pollution level is further evaluated with the consideration of the various vehicle categories (2-W, 3-W, cars, buses, LDV and HDV). **Table 6** described the contributory relationship between the observed criteria pollutants and the vehicular category. From **Table 6**, it can be observed that 2-W (motorcycles) counts showed the strongest relationship with the individual criteria pollutants measured, this followed by the 3-W (tricycles) and then buses. These findings confirmed the theory of the terrible state of these categories of the vehicle in the study.

4. Conclusions

Urban air quality management remains a continuous task for Nigerian policymakers. This study assessed the implication of varying categories of vehicular traffic on outdoor air pollution over a developing Nigeria city. This was achieved through day-time primary data capture of vehicular traffic and corresponding criteria pollutant measurements over a period of 1 year (December 2015–November 2016). The result of the criteria pollutant measurements was alarmingly high as confirmed by similar studies. Furthermore, the study concluded that the combined vehicular traffic did contribute significantly ($R \geq 0.619$) to the observed pollutant measurements all through the study. The 2-W (motorcycle) was found to be the vehicular category that attributed the most significant relationship with observed outdoor pollutant measurements. This is followed by the 3-W (tricycles) and buses. The findings of the study will assist Nigerian policymakers on decisive steps for vehicular worthiness to urban air quality management.

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Conflict of interest

The authors declare no conflict of interest.

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