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Evaluation of The Impact of Anthropogenic Emissions on a University's Airshed

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Abstract

The impact of anthropogenic activities in the airshed of a major Nigerian university community was evaluated in this study. Particulate matter ($PM_{1.0}$, $PM_{2.5}$, PM_{10} and TSP) concentration loads were measured in 20 sampling locations and the measured data was correlated with the prevailing microclimatic parameters using Principal Component Analysis (PCA) techniques. A high concentration of PM was measured in locations where the bulk of vehicular movements, and commercial and students activities were considerably high. The university's main entrance was another hotspot for particulate matter emission due to the constant influx of vehicles during peak periods. The 8-hr average concentrations for the TSP, $PM_{1.0}$, $PM_{2.5}$ and PM_{10} in all the sample locations were 210.35, 15.45, 25.10, and 137.09 respectively while the 24-hr average concentrations for the TSP, $PM_{1.0}$, $PM_{2.5}$, and PM_{10} in the same locations were 154.65, 11.36, 18.46, and 100.79 respectively. Exposure to high PM rates was significant especially when there is increased pollution due to exhaust and non-exhaust emissions (like brake wear, dust resuspension, and tyre wear).

Keywords: Particulate Matter, Concentration, University, Correlation analysis, Exposure Assessment

Introduction

Anthropogenic activities have negatively reduced the quality of air in the environment due to a combination of many factors like urbanization, industrialization, and pollution generation in places of work or residences (Adeniran *et al.*, 2017; Pereira *et al.*, 2004). One of the predominant pollutants in the environment from these activities is particulate matter (especially $PM_{2.5}$) (Chen *et al.*, 2015). Particulate matter (PM) comprises a multifaceted mixture of solid and liquid particles of both organic and inorganic substances in the atmosphere with short and long-term exposure linked with severe health problems (EPA, 2015; WHO, 2016; Xue *et al.*, 2019). Particulate matter has been classified under different particle size categories: total suspended particulate, TSP (with a size of about 50 µm), PM_{10} (with particle size less than 10 µm) and $PM_{2.5}$ (with size less than 2.5 µm) (Araújo *et al.*, 2014); PM may also have some other components such as ammonium (NH_4^+), sulphate (SO_4^{2-}), chloride (Cl^-), nitrate (NO_3^-), elemental and organic carbon with soot particles, crustal materials and biological materials. These components' concentration can vary significantly in different urban settings (Fuzzi *et al.*, 2015; Harrison *and* Yin, 2000).

The sources of particulate matter span across various anthropogenic sources such as construction sites (Araújo *et al.*, 2014); manufacturing industries (Adeniran, Yusuf, *et al.*, 2018; Sonibare *et al.*, 2004); combustion of fossil fuels which includes vehicular emissions from internal combustion engines (Abam *and* Unachukwu, 2009; Adeniran *et al.*, 2017; Fakinle *et al.*, 2013), backup generators (Adeniran *et al.*, 2017) and non-exhaust emissions caused by evaporative emissions, tyre wear, brake wear and dust resuspension(Adeniran *et al.*, 2017; Nagpure *et al.*, 2016). The health-related impacts of PM are of paramount importance, especially in Nigeria where air quality standards are rarely implemented. Some researchers have investigated the adverse health challenges of PM which include increased risk of respiratory diseases (Daly and Zannetti, 2007). PM_{10} and $PM_{2.5}$ are inhalable fractions of PM that are capable of causing cardiovascular diseases and asthma(Araújo *et al.*, 2014; Levy *et al.*, 2001; Vallero, 2014).

In recent studies, ground-level measurements of PM out were carried at major intersections of Ilorin city, and the PM concentrations measured were above WHO standards (Adeniran *et al.,* 2017), PM concentration level for $PM_{1.0}$, $PM_{2.5}$, PM_{10} and TSP was also investigated during haze event in the same city and the results revealed that the 24-hr averaging level was above the given standard values (Adeniran, Aremu, *et al.,* 2018). Tertiary institutions in Nigeria are either located in urban areas or in local communities which later on develop into a mini-urban setting. The premises (inside and surrounding environment) of these universities are most densely populated due to the demands for goods and services. This will also necessitate heavy inflow and outflow of humans (students, staff and businessmen/women) for school and commercial activities, use of many vehicles and the use backup electric power generators whenever there is power outage from the national grid. There are challenges in the assessment of the environmental impacts of the tertiary institution (universities) and this is due to the transient and mobile nature of the populace that accounts for a significant portion of its consumption in the environment. University environments in Nigeria have always been challenged by two major manmade pollution sources - mobile (vehicular emission) and stationary (backup generators). Power generation issues have brought about the use of thermal plants for electricity and this means that the environment will be polluted more(Sonibare, 2010). Recent research on the ground level sampling of PMs has majorly focused on urban centres(such as highways, intra-city roads, markets), however, tertiary institution airshed quality has not been properly addressed. Therefore, the main aim of this investigation was carried out to evaluate the impact of anthropogenic PM emissions on a major Nigerian university airshed.

Methodology

Description of the study location

According to the academic record obtained from the academic affairs unit of the University of Ilorin for the 2017/2018 academic session, there were about 56,718 students and 4,376 staff. The University of Ilorin is on latitude 8.4799^{o}N and longitude 4.5418 ^{o}E with an approximate land mass of 5,000 hectares (Fig. 1). From observation, the university has a large influx of both commercial and private vehicles to carry students, staff and goods. There is a high percentage of emission from mobile sources at early resumption hours of 0700 and 0900 and close of work hours of 1500 to 1730. Further, there are provisions of hostels and residents for students and staff, respectively. Movements of staff and students from these facilities to offices and lecture halls are also done using vehicles. This is in addition to the intra-university movements via the only approved commercial means (tricycles) and private vehicles.

The study will be carried out via ground level measurement of PM ($PM_{2.5}$, PM_{10} and TSP) and exposure assessment studies of the PMs emission. The study investigated ground-level sampling of twenty (20) locations(Fig. 2) including the main and intra-university roads while considering major hotspots such as bus stops, commercial stores, staff quarters, bus parks and student areas.

Sampling Method

Ground-level measurement of PM (PM_{10}, $PM_{2.5}$, $PM_{1.0}$and TSP) was carried out using a particle counter Aerocet 531S monitor, with an airflow sampling rate of 2.83 L/min. Aerocet 531S has multiple features which are operated using a rechargeable battery and are capable of measuring six different mass concentrations of PM (PM_{10}, $PM_{4.0}$, $PM_{2.5}$, $PM_{1.0}$ and TSP). The average concentration measured in a run (per minute) for each mass concentration was recorded. In the field campaign, the particle counter was placed just above the breathing zone (approximately 1.5 m height) above the ground level. Within the university community, 20 sampling points (designated as SPs) were carefully selected while maintaining a distance of about 20 - 50 m from the road in each sampling location. Microclimatic conditions such as air temperature, relative humidity, air barometric pressure, wind speed, altitude and dew point temperature were taken for the whole field sampling campaign using the Pocket Weather Tracker (Kestrel 4500).

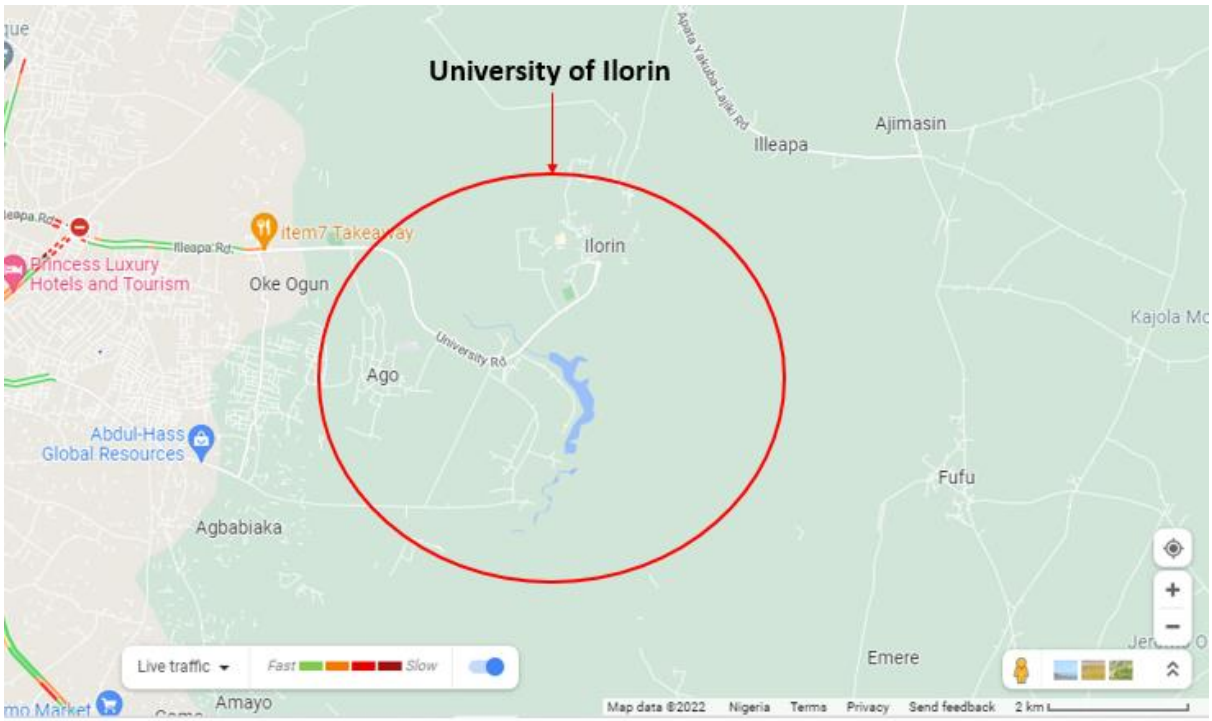


Figure 1: A Google Map View of the University of Ilorin

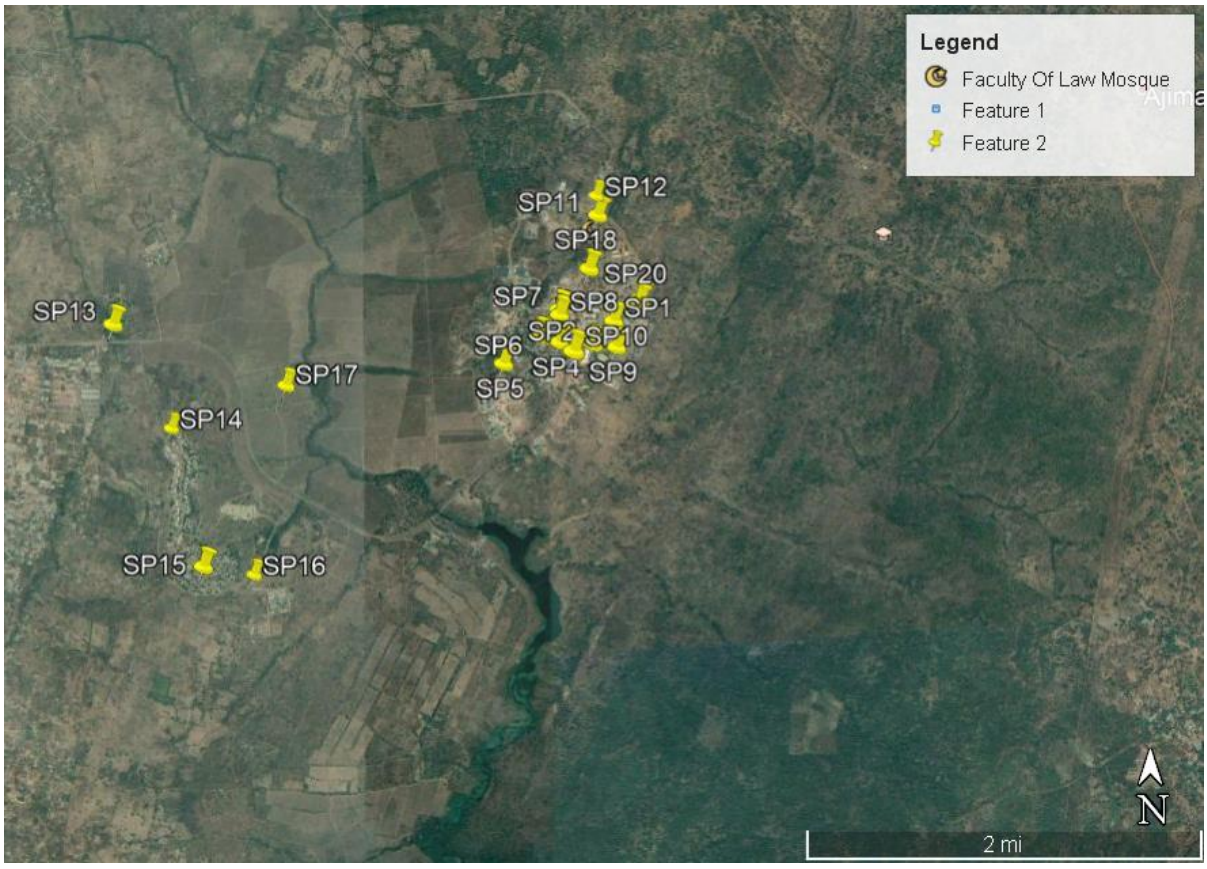


Figure 2: Bird Eye View of the Sampling Points on Google Earth Pro

Equipment Calibration

To ensure the optimal running and error-free count, a zero-count test was done every 1-hr through the zero count filter (PN G3111) as provided with the Aerocet 531S counter. The HazDust^{TM} sampler (47 mm FRM style) was used to calibrate the equipment. PM values obtained using the HazDust^{TM} were correlated using the method described in a previous study (Adeniran *et al.,* 2017) and the calibration was done for all the 20 sampling locations. PM concentration measured were statistically analysed to obtain the average for 1-hr, while the 8 and 24-hr averaging concentrations were estimated using the formula for stability dependent (Adeniran *et al.,* 2017; Adeniran, Aremu, *et al.,* 2018; Al Smadi *et al.,* 2009; MOE, 2004) as given in the equation below:

$$C_0 = C_1 \times F \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where:

C_0 the concentration at the shorter averaging time (ppm or µg/m^3)
C_1 the concentration at the longer averaging time (ppm or µg/m^3)
F the nomenclature to convert from the averaging period of t_1 to the averaging period of $t_0 = (t_1/t_0)^n$
n is the stability-dependent exponent. The stability class include A and B with n = 0.5, C with n = 0.33, D with n = 0.20 and E and F with n = 0.167. We used a stability-dependent exponent of 0.28 as described in the literature (MOE, 2004).

The effect of microclimatic factors such as relative humidity greatly influences the functionality of the particle sampler, hence the possibility of false estimation of particulate matter concentration, therefore the method reported by J. Adeniran et al. (2017) was used. Likewise, it was necessary to ensure that the equipment calibration process was effected in the exposure data to cover for the 4 particle sizes (PM_{10}, $PM_{2.5}$, $PM_{1.0}$and TSP) considered using the method reported by Adeniran, Aremu, et al. (2018).

Assessment of Human Exposure

Assessment of human exposure to PM at the 20 sampling locations was carried out using the total respiratory deposition dose (TRDD) and statutory limit breach (SLB) methods. The TRDD rates for PM_{10}, $PM_{2.5}$, $PM_{1.0}$and TSP were calculated using the method reported by J. Adeniran et al. (2017)in Equation (2):

$$Deposition\ dose\ (region\ of\ thoracic, tracheobronchial, alveolar) of\ PM\ fractions = (V_T \times f) \times DF_i \times PM_i \quad (2)$$

where; V_T is the tidal volume;
f is the breathing frequency;
DF_i is deposition fractions; and
PM_i is the particle size mass concentration in micrometer.

The value assumed for V_T and f are 800cm^3 per breath and 0.35 respectively. The values are applicable to light exercise situations by men. To estimate deposition fractions for the PM (TSP, PM_{10}, $PM_{2.5}$, PM_1) an expression was also given as thus (Adeniran, Aremu, *et al.*, 2018):

$$DF = IF \times \left(0.058 + \frac{0.911}{1+exp\left(4.77+ Ind_p\right)} + \frac{0.943}{1+\exp\left(0.508-2.58Ind_p\right)}\right) \quad (3)$$

where; IF is the inhalable fractions and is given by:

$$IF = 1 - 0.5\left(1 - \frac{1}{1-0.00076d_p^{2.8}}\right) \quad (4)$$

In order to estimate the statutory limit breach (SLB) values of the particulate matters, it is expressed as the ratio of ambient PM concentration measured to the statutory limit of ambient concentration, and was calculated for $PM_{2.5}$, PM_{10} and TSP using the expression below:

$$SLB = \frac{M_p}{S_p} \quad (5)$$

where, M_p is the concentration of PM measured mass and S_p is the PM statutory limit. The statutory limits used were from the Federal Ministry of Environment (FMEnv) (FEPA, 1991), World Bank (World Bank, 1998), US Environmental Protection Agency (USEPA, 2012), and World Health Organization (WHO) (WHO, 2006, 2010).

Table 1: Particulate Matter Statutory Limit

Particulates	Concentration µg/m^3			
	USEPA (2012)	(WHO, 2006, 2010)	FEPA (1991)	World Bank (1998)
$PM_{2.5}$	35 (24-hr)	25 (24-hr)	-	-
PM_{10}	150 (24-hr)	50 (24-hr)	-	-
TSP	-	-	250 (24-hr)	80 (24-hr)

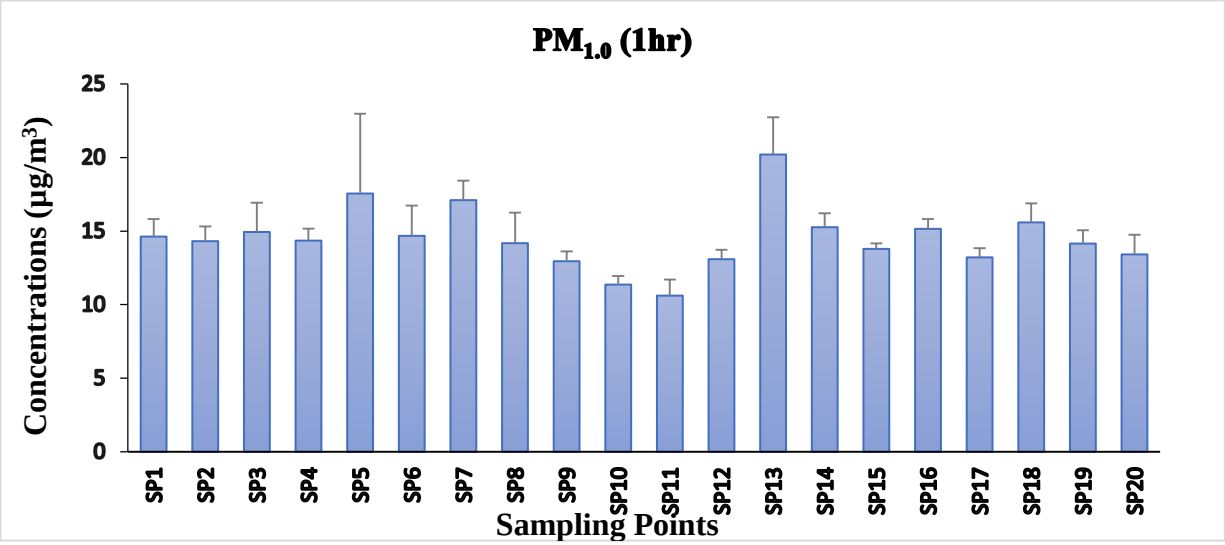
Results and discussions

Microclimatic Factors

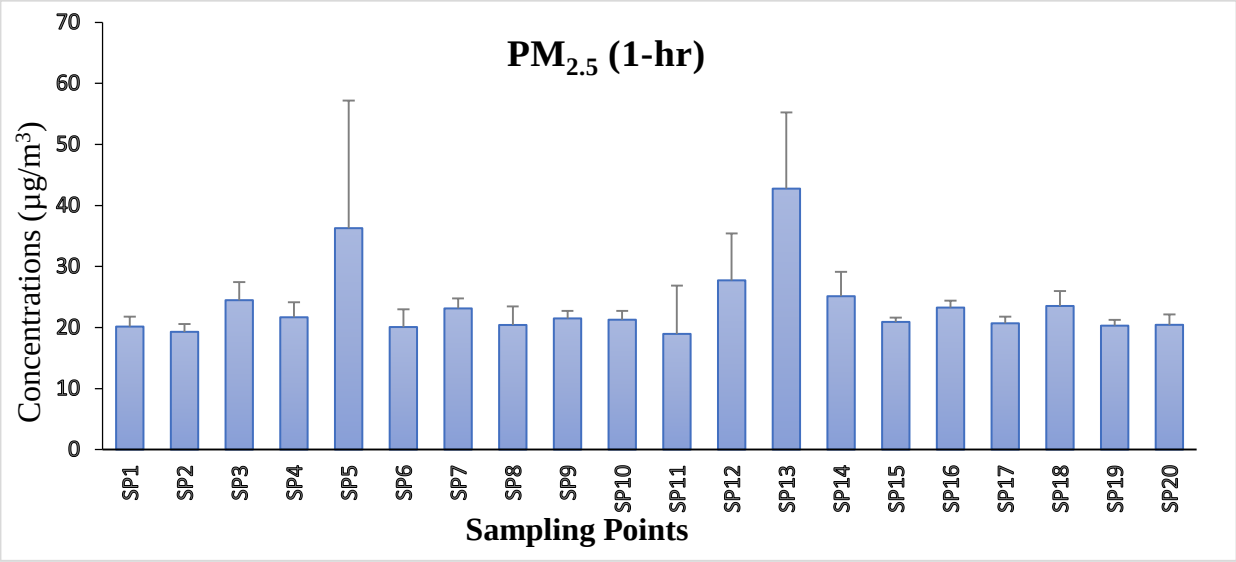
The ambient temperature of the 20-sampling location ranged from 24.40 ^{O}C to 31.51 ^{O}C and the minimum and maximum values for the wind speed are 0.45 m/s and 1.53 m/s. Dew point temperature of the study location also ranged from 22.18 ^{O}C to 24.42 ^{O}C and the relative humidity also ranged from 63.54% to 88.19% while the barometric air pressure has the lowest value as 973.13 hPa and the highest value is 980.56 hPa in all the twenty (20) sampling locations. Finally, the altitude of the study location ranged from 282.50 m to 337.80 m for the sampling points in the university community. The data obtained here for our study was similar to the historical data of the city available in the Lower Niger River Basin Development Authority from 2013 to 2016. Also, in the particulate matter study of the Ilorin metropolis by J. Adeniran et al. (2017), the relative humidity data obtained are consistent with the university sampled data.

Particulate Matter Concentration

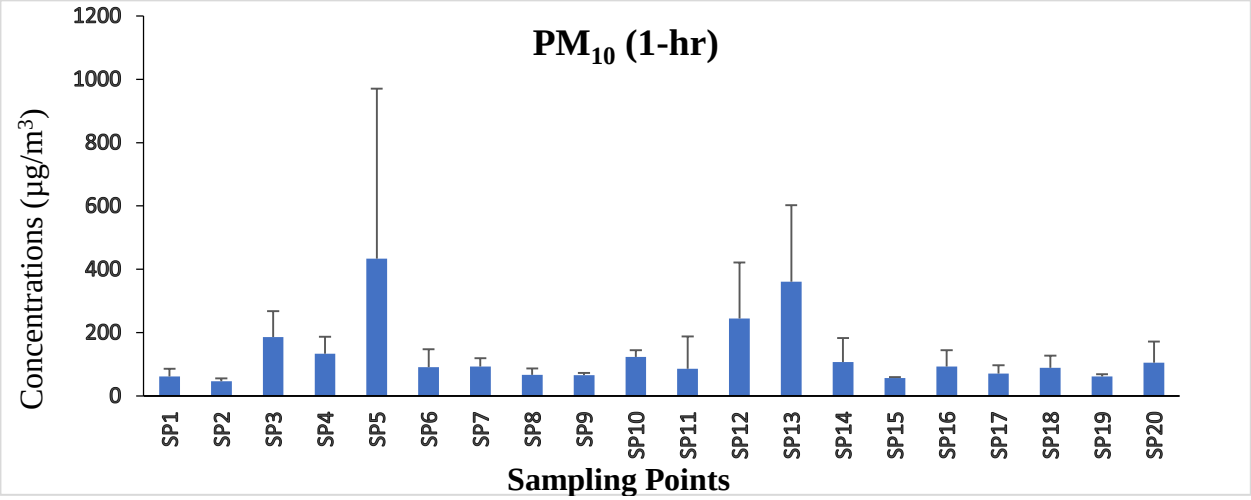
Particulate matter mass concentration is presented in the descriptive statistic for PM_{10}, $PM_{2.5}$, $PM_{1.0}$ and TSP in Figure 3a – d.



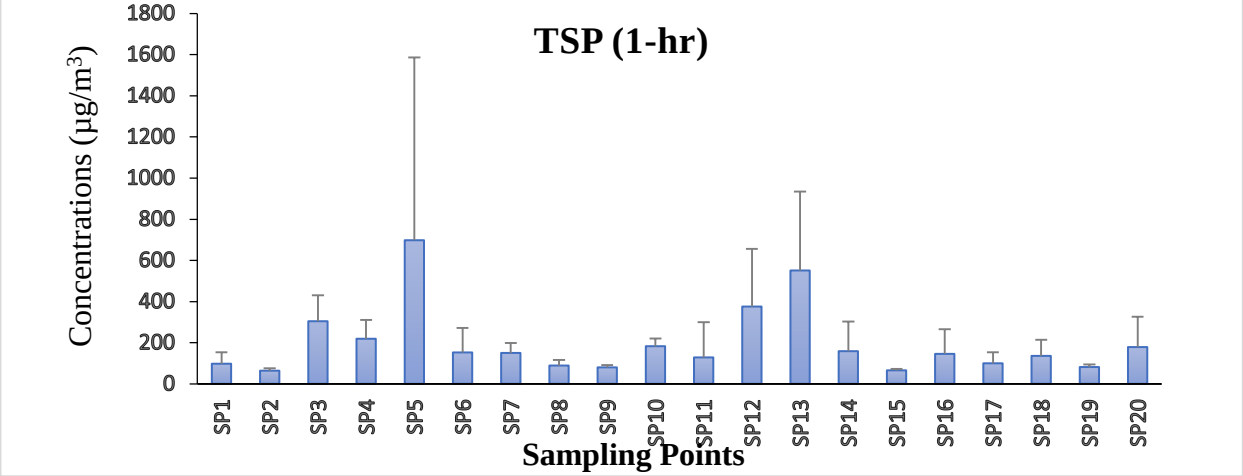
(a) Concentration levels of $PM_{1.0}$



(b) Concentration level of $PM_{2.5}$



(c) Concentration level of PM_{10}



(d) Concentration level of TSP

Figure 3: (a) $PM_{1.0}$Concentration levels **(b)** $PM_{2.5}$Concentration levels **(c)** PM_{10}Concentration levels **(d)** TSPConcentration levels

Concentration level for $PM_{1.0}$ have values ranging from 10.61 to 20.20 µg/m^3 obtained in SP11 and SP13 respectively; concentration level for $PM_{2.5}$ ranged from 18.95 to 42.75 µg/m^3 in SP11 and SP13; PM_{10} concentration level ranged from 47.04 to 433.39 µg/m^3 and the concentration level for TSP ranged from 63.78 to 697.51 µg/m^3. Sampling points with the highest TSP concentration are SP5, SP13, SP12, SP3 and SP4 with 697.51 (± 888.73) µg/m^3, 550.59 (± 383.33) µg/m^3, 375.28 (±281.35) µg/m^3, 304.01 (±126.94) µg/m^3 and 218.89 (±91.48) µg/m^3 respectively. For PM_{10}, the same trend was observed as the TSP concentration, SP5, SP13, SP12, SP3 and SP4 has the highest concentration levels with 433.39 (± 537.03) µg/m^3, 361.16 (± 241.0) µg/m^3, 244.23 (± 177.54) µg/m^3, 185.60 (± 82.66) µg/m^3 and 133.78 (± 53.31) µg/m^3, respectively. $PM_{2.5}$ and $PM_{1.0}$highest concentration level was observed in SP13, SP5, SP12, SP14 and SP3 with 42.75 (± 12.50) µg/m^3, 36.28 (± 20.92) µg/m^3, 27.73 (± 7.68) µg/m^3, 25.13 (± 3.98) µg/m^3 and 24.48 (± 2.99) µg/m^3 respectively; and SP13, SP5, SP7, SP18 and SP14 with 20.20 (± 2.53) µg/m^3, 17.55 (± 5.42) µg/m^3, 17.10 (± 1.32) µg/m^3, 15.59 (± 1.30) µg/m^3 and 15.26 (± 0.94) µg/m^3 respectively.

Estimated 8 hourly and daily averaged concentration levels of PM_{10}, $PM_{2.5}$, $PM_{1.0}$ and TSP are shown in Table 2a – b, respectively. The values for 8-hr $PM_{1.0}$ average have ranged from 5.93 to 11.28 µg/m^3; $PM_{2.5}$ values ranged from 10.59 to 23.88 µg/m^3; PM_{10} values ranged from 26.28 to 242.09 µg/m^3 and TSP values ranged from 35.62 to 389.63 µg/m^3. (Tables 2a-b)The highest values for the TSP were observed in SP5 and SP13 with 359.63 (± 496.44) and 307.56 (± 214.13) µg/m^3; the highest values for PM_{10} were also observed in SP5 and SP13 with 242.09 (± 299.98) µg/m^3 and 201.75 (± 134.62) µg/m^3, this followed the same trend as the total suspended particulate measurements. For $PM_{2.5}$ and $PM_{1.0}$, the highest values are 23.88 (± 6.98) and 20.26 (± 11.69) µg/m^3 and 11.28 (± 1.42) and 9.80 (± 3.03) µg/m^3 in SP13 and SP5, respectively. The 8-hr average concentrations for the $PM_{1.0}$, $PM_{2.5}$, PM_{10} and TSP in all the sample locations were 15.45, 25.10, 137.09 and 210.35 respectively.

The values for 24-hr average for $PM_{1.0}$ ranged from 4.36 to 8.30 µg/m^3; $PM_{2.5}$ values ranged from 7.78 to 17.56 µg/m^3; PM_{10} values ranged from 19.32 to 177.99 µg/m^3 and TSP values have minimum and maximum values as 26.19 µg/m^3 and 286.47 µg/m^3, respectively. The highest values obtained from TSP in the 24-hr average are from SP5 and SP13 with 286.47 (±365.0) and 226.13 (± 157.43) µg/m^3, respectively and the highest values for PM_{10} followed the same trend with 177.99 (± 220.56) and 148.33 (± 98.98) µg/m^3 from SP5 and SP13, respectively. For $PM_{2.5}$ and $PM_{1.0}$, the highest values were observed in SP13 and SP5, following the same trend as in the 8-hr average with 17.56 (± 5.14), 14.90 (± 8.59); and 8.30 (± 1.04) and 7.21 (± 2.23) µg/m^3, respectively. The 24-hr average concentrations for the $PM_{1.0}$, $PM_{2.5}$, PM_{10} and TSP in all the sample locations were 11.36, 18.46, 100.79 and 154.65 respectively.

$PM_{1.0}$ and $PM_{2.5}$ have two major spots with the highest pollutants, SP13 and SP5. The two locations are characterized by lots of vehicular movements and commercial activities. The vehicular count process depicts the nature of how busy the roads are. For instance, SP13 has a vehicular movement rate of about 17 vehicles per minute and SP5 has a rate of about 16 vehicles per minute. The locations are also characterized to have road dust which is always on resuspension during vehicle and human movements and may have contributed to the increased PM concentrations. $PM_{2.5}$ at the 24-hr average level in these hotspots does not exceed the 35 µg/m^3 guidelines by EPA (2014) and the 25 µg/m^3 by WHO (2010). PM_{10} values in six (6) sampling locations breached the WHO standards of 50 µg/m^3 and one (1) location breached the USEPA standards of 150 µg/m^3.

Table 2a: Eight-hourly Average of PM

Location	$PM_{1.0}$ (µg/m^3)				$PM_{2.5}$ (µg/m^3)				PM_{10} (µg/m^3)				TSP (µg/m^3)			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
SP1	8.17	0.67	7.15	9.11	11.26	0.92	9.66	12.46	34.64	13.62	20.78	60.27	54.51	31.44	27.93	116.36
SP2	7.99	0.56	7.43	9.11	10.77	0.72	9.89	11.95	26.28	4.68	21.17	35.14	35.62	6.73	28.27	48.43
SP3	8.34	1.11	7.71	11.0	13.67	1.67	11.62	16.70	103.68	46.17	43.96	159.09	169.82	70.91	73.85	256.51
SP4	8.02	0.46	7.49	8.83	12.11	1.39	10.73	14.80	74.73	29.78	38.04	118.53	122.27	51.10	51.73	192.77
SP5	9.80	3.03	7.26	14.64	20.26	11.69	11.00	38.93	242.09	299.98	37.93	889.51	389.63	496.44	57.42	1483.25
SP6	8.20	1.15	7.15	10.73	11.21	1.62	9.72	13.91	50.87	31.46	27.09	122.28	85.12	66.59	38.88	237.57
SP7	9.55	0.74	8.66	10.73	12.92	0.92	11.56	14.24	52.05	14.36	35.36	71.33	83.78	27.47	52.12	123.06
SP8	7.92	1.16	5.64	9.33	11.40	1.70	7.54	13.07	37.29	11.20	19.77	52.73	49.58	15.29	29.05	72.28
SP9	7.23	0.38	6.76	7.88	12.00	0.70	11.06	13.02	36.77	3.63	30.11	41.06	44.58	6.53	35.42	52.84
SP10	6.35	0.32	5.92	6.98	11.88	0.83	10.17	12.96	68.97	11.95	48.60	84.29	102.04	21.55	68.09	135.40
SP11	5.93	0.61	5.25	7.26	10.59	4.42	8.10	21.39	48.01	56.88	22.01	187.86	71.62	96.38	27.54	309.02
SP12	7.31	0.36	6.65	7.71	15.49	4.29	11.06	24.63	136.42	99.17	25.19	326.61	209.63	157.16	31.06	496.43
SP13	11.28	1.42	9.89	13.80	23.88	6.98	16.98	37.37	201.75	134.62	73.12	467.10	307.56	214.13	92.0	705.68
SP14	8.53	0.52	7.60	9.22	14.03	2.22	12.40	19.33	60.08	42.03	31.17	159.31	88.54	81.09	36.42	279.41
SP15	7.70	0.21	7.43	8.10	11.68	0.39	11.00	12.29	31.39	2.05	27.99	34.41	36.54	4.69	30.39	45.53
SP16	8.46	0.37	7.88	8.88	12.99	0.63	12.12	14.08	52.16	28.81	30.22	120.21	81.24	67.46	34.58	240.42
SP17	7.38	0.35	6.81	7.88	11.56	0.62	10.22	12.12	39.58	14.90	25.42	68.60	55.66	30.62	29.16	117.25
SP18	8.71	0.72	7.93	10.11	13.14	1.38	11.45	16.09	49.72	21.71	28.77	93.57	75.75	44.04	35.58	169.48
SP19	7.90	0.50	7.26	8.71	11.34	0.55	10.61	12.07	34.24	4.14	29.66	39.72	45.48	7.10	39.77	60.05
SP20	7.49	0.75	6.65	8.66	11.42	0.94	10.33	13.07	58.77	37.18	32.12	144.40	99.69	82.66	45.86	293.77

Table 2b: Twenty-four Hourly Average of PM

Location	$PM_{1.0}$ (µg/m^3)				$PM_{2.5}$ (µg/m^3)				PM_{10} (µg/m^3)				TSP (µg/m^3)			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
SP1	6.01	0.49	5.26	6.69	8.28	0.67	7.11	9.16	25.47	10.01	15.28	44.31	40.07	23.12	20.54	85.55
SP2	5.88	0.41	5.46	6.69	7.92	0.53	7.27	8.79	19.32	3.44	15.57	25.83	26.19	4.94	20.78	35.61
SP3	6.13	0.82	5.67	8.09	10.05	1.23	8.54	12.28	76.23	33.95	32.32	116.97	124.86	52.14	54.29	188.59
SP4	5.89	0.34	5.50	6.49	8.90	1.02	7.89	10.88	54.94	21.89	27.97	87.15	89.90	37.57	38.03	141.73
SP5	7.21	2.23	5.34	10.76	14.90	8.59	8.09	28.63	177.99	220.56	27.89	654.0	286.47	365.0	42.22	1090.53
SP6	6.03	0.85	5.26	7.89	8.24	1.19	7.15	10.23	37.40	23.13	19.92	89.90	62.59	48.96	28.58	174.67
SP7	7.02	0.54	6.37	7.89	9.50	0.68	8.50	10.47	38.27	10.56	26.0	52.45	61.59	20.20	38.32	90.48
SP8	5.82	0.85	4.15	6.86	8.38	1.25	5.54	9.61	27.41	8.23	14.54	38.77	36.45	11.24	21.36	53.14
SP9	5.32	0.28	4.97	5.79	8.82	0.52	8.13	9.57	27.03	2.67	22.14	30.19	32.78	4.80	26.04	38.85
SP10	4.67	0.24	4.35	5.13	8.74	0.61	7.47	9.53	50.71	8.79	35.73	61.97	75.02	15.85	50.06	99.55
SP11	4.36	0.45	3.86	5.34	7.78	3.25	5.96	15.73	35.30	41.82	16.18	138.12	52.66	70.86	20.25	227.20
SP12	5.38	0.26	4.89	5.67	11.39	3.15	8.13	18.11	100.30	72.92	18.52	240.14	154.13	115.55	22.83	364.99
SP13	8.30	1.04	7.27	10.14	17.56	5.14	12.49	27.48	148.33	98.98	53.76	343.43	226.13	157.43	67.64	518.84
SP14	6.27	0.39	5.59	6.78	10.32	1.63	9.12	14.21	44.17	30.90	22.92	117.13	65.10	59.62	26.78	205.43
SP15	5.66	0.15	5.46	5.96	8.59	0.28	8.09	9.04	23.08	1.50	20.58	25.30	26.86	3.45	22.34	33.47
SP16	6.22	0.27	5.79	6.53	9.55	0.46	8.91	10.35	38.35	21.18	22.22	88.38	59.73	49.60	25.42	176.77
SP17	5.43	0.25	5.01	5.79	8.50	0.46	7.52	8.91	29.10	10.95	18.69	50.43	40.92	22.51	21.44	86.21
SP18	6.40	0.53	5.83	7.43	9.66	1.02	8.42	11.83	36.55	15.96	21.15	68.79	55.69	32.38	26.16	124.61
SP19	5.81	0.37	5.34	6.41	8.34	0.40	7.80	8.87	25.18	3.05	21.81	29.20	33.44	5.22	29.24	44.15
SP20	5.51	0.55	4.89	6.37	8.39	0.69	7.60	9.61	43.21	27.34	23.62	106.17	73.29	60.77	33.72	215.99

SP13 has a very close particle concentration of 148.33 (± 98.98) µg/m^3 to the set limits and could be exceeded in days where there are heavy traffic volumes. TSP concentration for 24-hr average level was more than the Federal Ministry of Environment limit of 250 µg/m^3(FEPA, 1991) in one sampling location, SP5 while SP13 has a value very close to the limit which could be exceeded on high traffic volume days. it was observed that the concentrations obtained in five (5) locations exceeded the limit (80 µg/m^3) established by the World Bank(World Bank, 1998).

These locations are predominantly student areas with continuous day-to-day commercial activities that sometimes extend into the night. Vehicle movements by commercial drivers, staff, dust resuspension by passers-by and use of BUGs are also contributory factors that may emit both exhaust and non-exhaust PM(Adeniran, Aremu, *et al.,* 2018; Nagpure *et al.,* 2016). The health implications for short-and-long-term exposure to PM could be a matter of concern considering the population proportion of students at 0.93, aged workers and people suffering from respiratory diseases. These categories are vulnerable and, further exposure may trigger an ailment within the receptor environment.

As part of the human exposure assessment of PM in the study location, the ratio of different particle sizes was estimated, i.e. ratios of $PM_{1.0}/PM_{2.5}$, $PM_{2.5}/PM_{10}$ and PM_{10}/TSP.

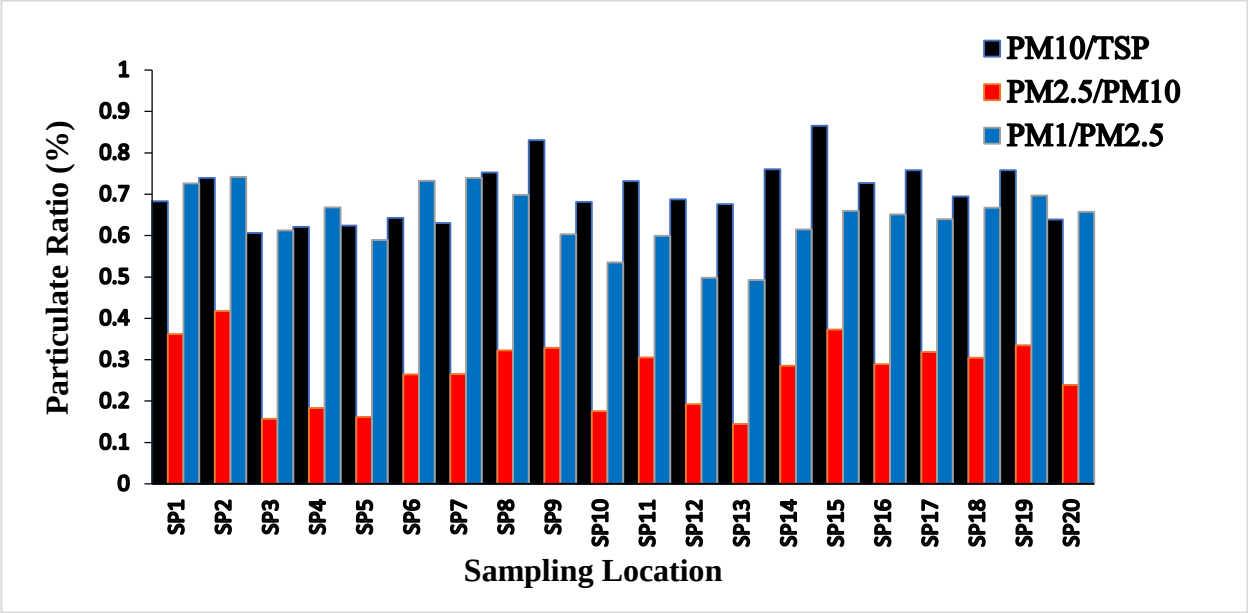


Figure 4: Ratio of Measured Particulate Matters

Fig.4 shows the descriptive statistical representation of the measured PMs ratio for ultrafine particles to respirable ($PM_{1.0}$ to $PM_{2.5}$), respirable fractions to inhalable particles ($PM_{2.5}$ to PM_{10}) and inhalable to TSP (PM_{10} to TSP). The $PM_{1.0}/PM_{2.5}$ values ranged from 0.49 to 0.74; $PM_{2.5}/PM_{10}$ values ranged from 0.14 to 0.42; and PM_{10}/TSP values ranged from 0.61 to 0.87. From the chart (Figure 4), it was evident that the ratios of $PM_{1.0}/PM_{2.5}$ are high which depicts that the concentration of ultrafine particles is high in the respirable fractions and there are fewer concentrations of $PM_{2.5}/PM_{10}$ and this could mean that the respirable fractions are low in the inhalable fractions. The results obtained from these estimates are in total conformity with a previous investigation by Adeniran, Aremu, et al. (2018). In the PM_{10}/TSP ratio, it was observed that there are even more concentrations of inhalable fractions in the total suspended particles (coarse particles). This is in accordance with the processes such as coagulation, agglomeration and formation of secondary aerosols that brought about the increasing particle sizes with increasing PM concentrations.

Correlation analysis

The relationship between particulate matter concentration and microclimatic parameters was carried out using analytical software (SPSS). Table 3 shows the result of the correlation matrix between the measured PM and 6 microclimatic factors such as temperature (Temp), relative humidity (RH), dew point (DP), air pressure (AP), altitude (ALT) and wind speed (WS).

From the results, it is evident that the matrix indicates a moderate correlation between the PM sizes as the values ranged from 0.5 to 1.0. Having this level of correlation could mean that smaller particle sizes are contained in the larger particle sizes which were also confirmed in the PM ratio estimations. Different correlation levels were observed in the relationship between the PM and microclimatic factors, for instance, negative relationships were noticed between the PM, temperature and wind speed. Temperature and wind speed has been classified as the meteorological factor that influences pollutant dispersion (Latini *et al.,* 2002). This relationship indicates that the low values of temperature and wind speed will largely result in an increased PM concentration. The result obtained here conforms with the PM study of the Ilorin metropolis by Adeniran, Aremu, *et al.* (2018), where a strongly negative correlation existed between the microclimatic factor and PMs measured during the haze period.

A slight deviation observed from the PM study of Ilorin metropolis was the negative correlation between PM and other microclimatic conditions such as relative humidity and sunshine hour. In this study, a positive relationship existed between air pressure, dew point and relative humidity and this is in line with a study by Szep *et al.* (2016), where a positive correlation was obtained for relative humidity and dew point with particulate matters. It was posited that at higher RH and dew points, the concentration of PM will be higher. This combined effect as observed in this study could affect the dispersion and chemical transformations of pollutants.

The multivariate analysis was done using the Principal Component Analysis (PCA) techniques assisted in determining the factor loading (using Varimax with Kaiser rotation method), eigenvalue, variance (in percentile) and cumulative percentage which are presented in the supplementary data. For the eigenvalues, a three-factor extraction was done as described by Olajire *et al.* (2011) (i.e. eigenvalues > unity). In Table S1, the first factor has a total variance of 42.763%, factor two has a total variance of 22.566% and factor three accounted for 17.810% of the variance with high loading of $PM_{1.0}$, $PM_{2.5}$ and PM_{10}, respectively. The data in this study has a cumulative percent of 83.140.

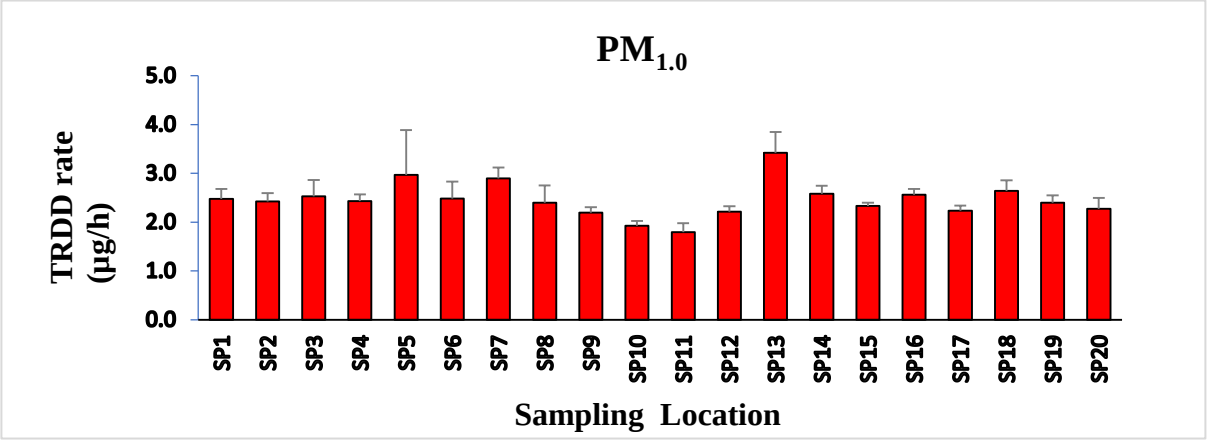
For a better simplification and understanding of the factor loading, Varimax with Kaiser rotation method was applied. This will assist in finding the variables that have the closest relationship in terms of PM concentration level. From Table S2, the correlation loadings showed that the first component (PCA1) has a high and strong correlation with $PM_{1.0}$, $PM_{2.5}$, PM_{10}, TSP; moderate correlations with air pressure (AP), relative humidity (RH) and dew point (DP). This is a clear indication of higher PM concentration at high humidity, dew point and air pressure. The second component matrix (PCA2) has the highest negative correlation with the temperature at -0.918 while the strongest positive correlation existed with RH (0.877) and WS (0.740), at this factor loading, the $PM_{1.0}$, $PM_{2.5}$, PM_{10}, and AP values are moderately correlated while TSP, DP and ALT have negative relationships. The third component (PCA3) almost followed the same trend as the first (PCA1) as altitude, temperature and WS had negative relationships. Air pressure exhibited the strongest positive correlation followed by dew point (DP = 0.518) and other factors such as the PM and RH exhibited moderate relationships. The data analysis may have indicated the conditions that will result in having either higher or lower particulate matter concentrations in different or varying microclimatic conditions.

Table 3: Correlation Matrix for PMs and Microclimatic Parameters

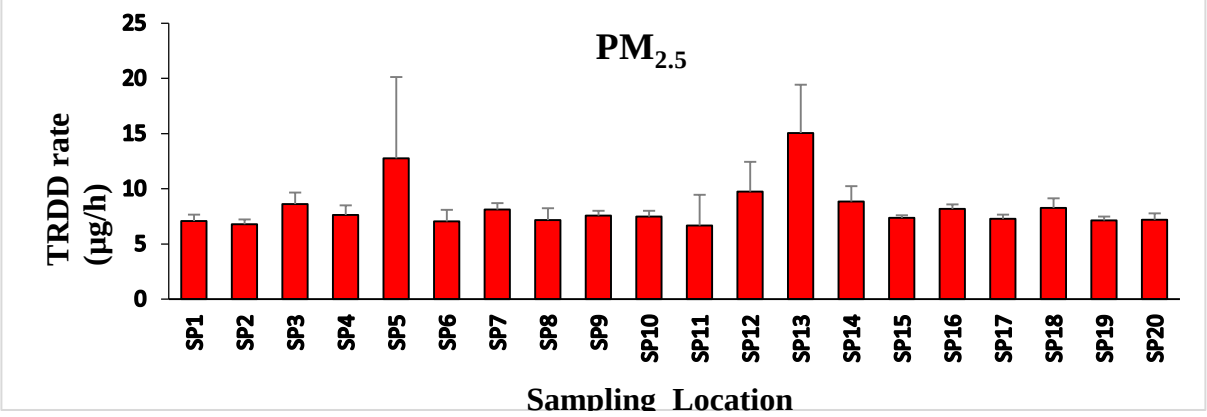
Factor	$PM_{1.0}$	$PM_{2.5}$	PM_{10}	TSP	Temp	WS	AP	RH	DP	ALT
$PM_{1.0}$	1	0.766	0.584	0.584	-0.3	-0.201	0.376	0.257	0.120	-0.386
$PM_{2.5}$		1	0.918	0.900	-0.437	-0.157	0.390	0.428	0.117	-0.391
PM_{10}			1	0.998	-0.289	-0.249	0.215	0.301	0.131	-0.209
TSP				1	-0.256	-0.272	0.194	0.268	0.146	-0.188
Temp					1	-0.480	-0.252	-0.941	0.316	0.265
WS						1	-0.08	0.469	-0.182	0.000
AP							1	0.277	0.304	-0.998
RH								1	-0.150	-0.284
DP									1	-0.296
ALT										1

Total Respiratory Deposition Dose (TRDD)

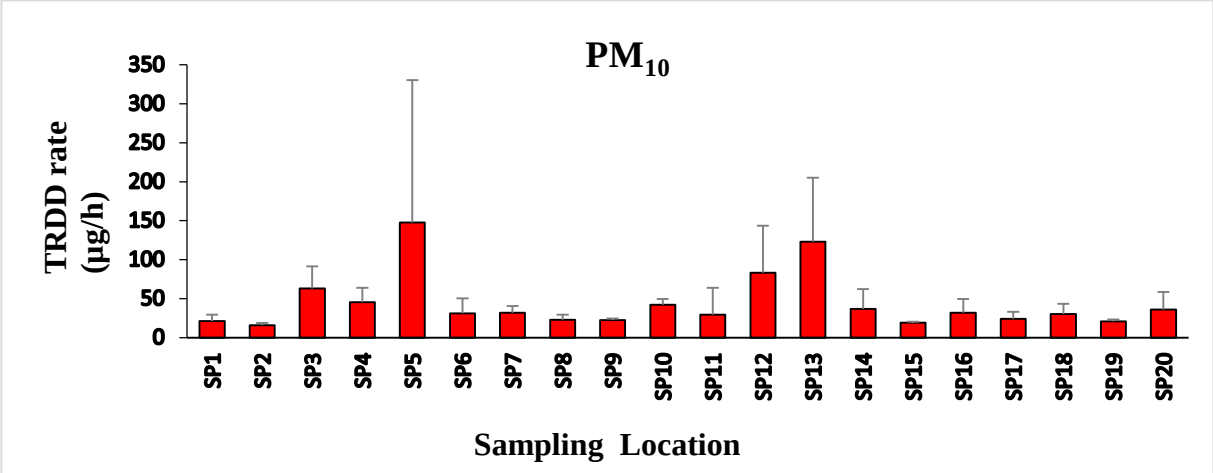
The human exposure assessment was estimated based on the total respiratory deposition dose (TRDD) and statutory limit breach concepts (Fig. 5a-d). The highest TRDD rate for $PM_{1.0}$was obtained in SP13 at 3.42 $\mu gh^{-1,}$ for $PM_{2.5}$' it was obtained in SP13 at 15.04 μgh^{-1}. The highest TRDD rate for PM_{10} was obtained in SP5 at 147.63 $\mu gh^{-1}$and the highest TRDD values for TSP are from major hotspots in the University community like SP5 (140.93 μgh^{-1}), SP13 (111.24 μgh^{-1}), SP12 (75.82 μgh^{-1}) and SP3 (61.42 μgh^{-1}).



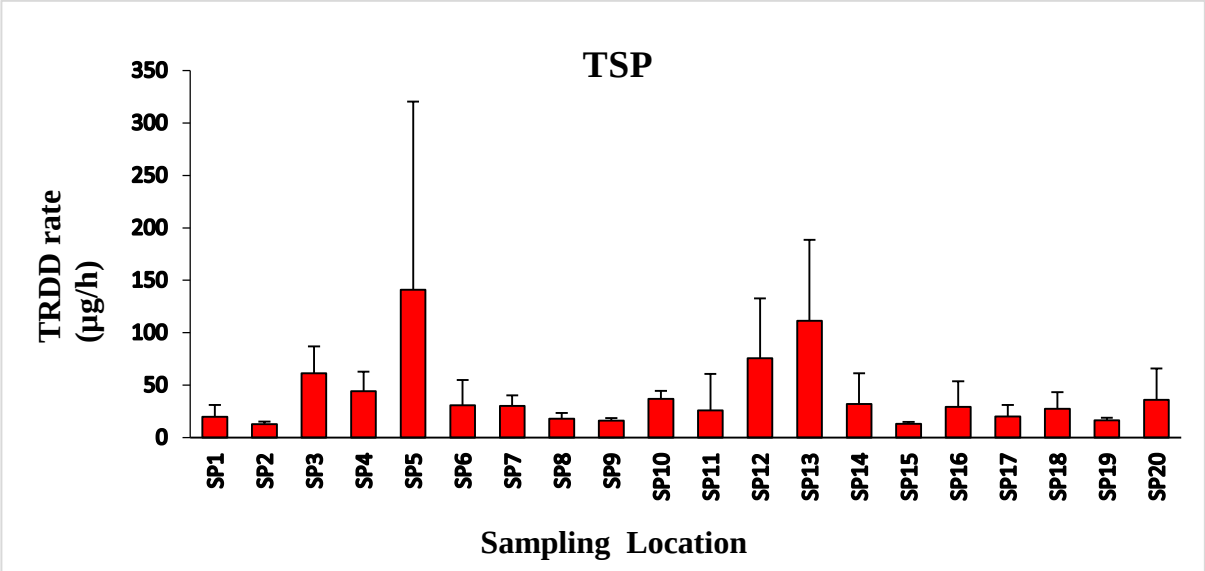
(a) TRDD rate of $PM_{1.0}$



(b) TRDD rate of $PM_{2.5}$



(c) TRDD rate of PM_{10}



(d) TRDD rate of TSP

Figure 5: (a) TRDD rate of $PM_{1.0}$ **(b)** TRDD rate of $PM_{2.5}$ **(c)** TRDD rate of PM_{10} **(d)** TRDD rate of TSP

The sampling points with high TRDD rates are characterized by continuous vehicular movements, commercial activities, and poor road conditions which could lead to dust resuspension and contribute as part of non-exhaust emission to the air quality issues. In this study, the TRDD values evaluated were on daily basis. Recent research had established the detrimental effect of short-term exposure which include asthma, coughing, and sneezing, and in addition can lead to respiratory and cardiovascular diseases (Adeniran *et al.,* 2017). There is also the possibility of long-term exposure, especially by students, staff, and commercial shop owners in most of these hotspots. Particulate matter has adverse health effects, especially the PM_{10} which is often a causative agent of inflammatory ailment (Adeniran, Aremu, *et al.,* 2018); $PM_{1.0}$ and $PM_{2.5}$, because of their sizes can find their way into our alveoli and cause a magnitude of damage to our body system (Adeniran *et al.,* 2017). TSP may contain smaller particles like PM_{10} and

$PM_{2.5}$ that may find their routes to our lungs. TSP, due to its size cannot pass through our nostrils and throats but may cause damage to buildings, clothes, and plants (Araújo *et al.,* 2014).

Statutory Limit Breach

Continuous environmental and health problems have led to the establishment of guidelines by authorities for particulate matter emission. Using the information in Table 1, the statutory limit breach values were estimated for each pollutant concerned (PM_{10}, $PM_{2.5}$and TSP). Table 10 shows the statistical representations of the SLB values for the twenty (20) sampling points of the University community.

Table 4: Average SLB Values for the University Sampling Points

Location	TSP		PM_{10}		$PM_{2.5}$	
	FEPA	WB	USEPA	WHO	USEPA	WHO
SP1	0.16	0.50	0.17	0.51	0.24	0.33
SP2	0.10	0.33	0.13	0.39	0.23	0.32
SP3	0.50	1.56	0.51	1.52	0.29	0.40
SP4	0.36	1.12	0.37	1.10	0.25	0.36
SP5	1.15	3.58	1.19	3.56	0.43	0.60
SP6	0.25	0.78	0.25	0.75	0.24	0.33
SP7	0.25	0.77	0.26	0.77	0.27	0.38
SP8	0.15	0.46	0.18	0.55	0.24	0.34
SP9	0.13	0.41	0.18	0.54	0.25	0.35
SP10	0.30	0.94	0.34	1.01	0.25	0.35
SP11	0.21	0.66	0.24	0.71	0.22	0.31
SP12	0.62	1.93	0.67	2.01	0.33	0.46
SP13	0.90	2.83	0.99	2.97	0.50	0.70
SP14	0.26	0.81	0.29	0.88	0.29	0.41
SP15	0.11	0.34	0.15	0.46	0.25	0.34
SP16	0.24	0.75	0.26	0.77	0.27	0.38
SP17	0.16	0.51	0.19	0.58	0.24	0.34
SP18	0.22	0.70	0.24	0.73	0.28	0.39
SP19	0.13	0.42	0.17	0.50	0.24	0.33
SP20	0.29	0.92	0.29	0.86	0.24	0.34

For coarse particles (TSP) the SLB values ranged from 0.10 to 1.15 using the FEPA statutory limit and 0.33 to 3.58 for the World Bank limit estimation. Particulate matter with aerodynamic diameter < 10µm (PM_{10}) has SLB values from USEPA and WHO as 0.13 to 1.19 and 0.39 to 3.56, respectively and lastly, the $PM_{2.5}$ statutory limit breach minimum and maximum values are 0.22 to 0.50 and 0.31 to 0.70 for USEPA and WHO limits, respectively.

By using the 24-h threshold value to estimate the SLB, it has been reported that an SLB value of 1 is worrying enough to the ambient air quality at which it is obtained (Adeniran, Aremu, *et al.*, 2018; Fakinle *et al.,* 2013). SLB values obtained for $PM_{2.5}$ while referencing both USEPA and WHO are within the set limit of unity, the highest obtained in the two cases ranged from 0.22 to 0.50 and 0.31 to 0.70 respectively. The highest SLB are locations with high PM concentrations attributable to heavy vehicle flow and commercial activities. Values for PM_{10} with USEPA guideline reference point have nineteen (19) sampling points that conformed to the agreeable unity point. The sampling point (SP5) with the highest SLB has a value above unity (SLB = 1.19). This location is one of the busiest areas in the University community characterized by vehicular movements (commercial and private), student movements, commercial activities and heavy road dust particles. The SLB values estimated with the

WHO reference limit show that fourteen (14) locations are within the unity (SLB < 1), while six (6) sampling locations have SLB values that are greater than unity, (SLB > 1). These locations are hotspots that were discussed earlier in the particulate matter sampling of the University community.

Particulate matter (including TSP) has been a major air pollution issue affecting human health and irrespective of their toxicity nature (extrinsic or intrinsic), PMs poses consequential environmental and health hazards to human (Fakinle *et al.,* 2013). The SLB value for TSP considering reference point of FEPA and World Bank shows that nineteen (19) locations have values below unity (i.e. SLB < 1) and one (1) sampling location (SP5) have value above unity (i.e. SLB > 1). While for the SLB value with World Bank limits, fifteen (15) locations conforms to the unity value (SLB < 1) and five (5) sampling points breached (SLB >>1).

As earlier posited, an SLB value above 1 is indeed a danger to the sampling location because of the imminent health issues that students, staff, ,businessmen/women and even children will be exposed to this besmirched air quality. Mitigation approaches required to reduce the PM emission should be implemented. These may include strict emission compliance, prompt road maintenance to minimize road dust, and vehicle maintenance inspection.

Conclusion

In the university study domain, a high-performing particle mass counter was used to sample 20 points for particulate matter emission from vehicles, and major hotspots were identified due to the high concentration of PM observed which is higher than the set guidelines by USEPA, WHO, World Bank and FEPA. Correlation analysis of microclimatic parameters and PMusing PCA revealed the dependable relationship and effect of pollutants concentration. The total respiratory deposition dose and a statutory limit breach were used to evaluate human exposure level and the major hotspots that could harm road users were identified by comparing the results obtained with international standards (WHO, World Bank, and USEPA). This study has established that PM emission from anthropogenic activities in the university impacted negatively on the airshed on the University of Ilorin Campus. The results obtained in this study can be used in future studies that depict the exact correlation between the understanding of pollutant concentration and epidemiological studies within the university community.

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