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THE INFLUENCE OF METEOROLOGICAL PARAMETERS ON THE ATMOSPHERIC PARTICULATE MATTER AROUND AUTOMOBILE WORKSHOPS IN BENIN CITY

***ONAIWU, G. E.,[1] OKUO, J. M.,[2] JONATHAN, E. M.[1] AND OMOROGIUWA, L.[3]**

[1]Department of Physical Sciences, Benson Idahosa University, P.M.B. 1100, Benin City, Edo State, Nigeria

[2]Environmental Analytical Research Laboratory, Department of Chemistry, University of Benin, Benin City, Nigeria

[3]Department of Biological Sciences, Benson Idahosa University, P.M.B. 1100, Benin City, Edo State, Nigeria

*Corresponding author: gonaiwu@biu.edu.ng

ABSTRACT

The effect of meteorological parameters such as air temperature and relative humidity, wind direction, wind speed, atmospheric pressure, ultraviolet radiation, and solar radiation on the concentration of the atmospheric particulate matter had been carried out. This atmospheric particulate matter is also known as suspended particulate matter (SPM) or total suspended particles (TSP) in the atmosphere is investigated in this study. The research was carried out in Benin City between January and December 2019. North West (NW), North East (NE), South East (SE), and South West (SW) are the four zones that make up the city. In both the wet and dry seasons, 180 representative SPM samples were collected from artisans' workshops using an Apex2IS Casella standard pump fitted with a conical inhalable sampling (CIS) head at a flow rate of 3.5L/min for 8 hours. Meteorological parameters were collected at the same time as particulate matter (SPM). In the dry season, SPM/TSP levels ranged from 2,278.02 to 16,458.34 μg/m^3 in the dry season, while in the wet season they ranged between 2313.45 and 12604.16 μg/m^3. The TSP exceeded the World Health Organization (WHO) and National Ambient Air Quality Standard (NAAQS) of 250ug/m^3 which can lead to serious health issues if not mitigated. The meteorological parameters ranged from 27.92 – 33.47^{o}C (temperature), 59.88 – 78.96% (relative humidity), 748.46 – 754.31mmHg (pressure), 2.87 – 6.95km/h (wind speed), 154.96 – 205.46^{o}C (wind direction), 425.19 – 1,073.46W/m^2 (solar radiation), and 717.31 μW/m^2. The correlation of TSP with some meteorological parameters such as atmospheric pressure and solar radiation was found to be highly significant, while others were not within the location of this study. Thus, these findings can be inferred for areas or regions of similar anthropogenic activities and weather conditions.

KEYWORDS: *Air quality, Meteorological parameter, Correlation, Auto-mechanic workshop*

INTRODUCTION

Poor air quality is currently a major environmental issue confronting both developed and developing countries (Munir *et al.,* 2017). It is usually triggered by man-made activities, such as automobile workshop activities. Automobile activities involve working with and spilling fresh and used oils, greases, petrol, diesel, battery electrolyte, paints, welding electrodes, iron filing machines, and other materials which generate organic (PAHs), inorganic (heavy metals), and suspended particulate matter (SPM). These particles are frequently bound to harmful chemicals that are released into the natural environment. Which have impacted negatively on the health of people and other living things, depending on their concentration (Daly and Zannetti, 2007). Epidemiological studies on SPM, in general, have also been published by many authors (Shah *et al.,* 2013; Raz *et al.,* 2014; Kim *et al.,* 2015).

Several of the chemical components associated with SPM have been identified as potential human carcinogens and, if present in high concentrations in the environment can pose a significant risk to humans by entering the bloodstream and lungs and causing cancer and lung diseases (Obioh *et al.,* 2013; Tolis *et al.,* 2014; Adams *et al.,* 2015; Khan *et al.,* 2016; WHO, 2017; Weli and Emenike, 2017). Benzo(a)pyrene, the most studied of the PAHs, is a good example. Increased industrialization, urban growth, and energy usage have all been linked to an increase in air pollution, posing a serious threat to public health (Gulia *et al.,* 2015). Particulates are one of six criteria pollutants identified by the United States Environmental Protection Agency (USEPA) as one of the most dangerous to people's wellbeing (Yusoff *et al.,* 2017). According to a recent University of Chicago study on the Air Quality Life Index, particulate pollution reduces the worldwide average lifespan by an estimated value of 1.8 years for every individual. Thus, making it the world's leading killer (Greenstone and Fan, 2018). It had also been reported that inhaling particles from a polluted environment shortens one's life by more than 1.6 years when compared to first-hand cigarette smokers (Greenstone and Fan 2018). Several studies have found that suspended particulate matter (SPM) has some negative environmental effects, such as reduced visibility (Haze), changes in atmospheric properties, the formation of fog and precipitation, damage to vegetation and materials, and climate change due to changes in solar radiation, wind distribution, and temperature in particular (Masiol and Harrison, 2014; Onuorah *et al.,* 2019). The dispersion and accumulation of suspended particulate matter are primarily influenced by emission sources, meteorological parameters, and local topography (Anake *et al.,* 2016). Particulate matter includes soot, smoke, dust, dirt, and liquid droplets. It is classified primarily based on its size, known as its aerodynamic diameter. Fine particles ($PM_{2.5}$) have a diameter of less than 2.5 µm, whereas coarse particles (PM_{10}) have a diameter of 10 to 2.5 µm. $PM_{2.5}$ particles include soot and smoke from combustion, whereas SPM particles include dust, pollen, mist, mold, fungi, and other microorganisms with $PM_{2.5}$ inclusive (Epa, 2012). The meteorology of a location has a significant impact on the quality of air in that area. Thus, meteorological variables such as air temperature, relative humidity, wind speed, wind direction, atmospheric pressure, ultraviolet radiation, and solar radiation have a significant influence on the rapid diffusion, dilution, and accumulation of atmospheric fine particle pollution (Yang *et al.,* 2011; Liu and Cui 2014. Several studies have shown that high wind speed promotes the attenuation of atmospheric pollutants, whereas low wind speed promotes the accumulation of pollutants. Pollutant dispersion is also aided by wind direction. Wind speed and direction can help to allocate fine particle concentrations to their respective sources.

Cloudiness promotes the build-up of particulates in the atmosphere, while radiation initiates photochemical reactions with other pollutants (Giri *et al.,* 2008). The air movement is determined by wind speed and direction. The greater the wind speed, the greater the dispersion of pollution and subsequent dilution. Direction is also vital in determining where the polluted air moves and thus controls the downwind or/and upward impacted areas. Temperature, on the other hand, influences atmospheric chemical reactions and tends to stagnate air mass formation, which leads to a higher concentration of particulates formed, and vice versa at higher temperatures.

Weather factors such as still air and temperature inversions (in which cold air is trapped beneath warm air) can slow pollutant removal and amplify the effects of pollution. Furthermore, the effects of high or low relative humidity on particulate levels differ. High relative humidity causes particles to settle on the ground, resulting in a low particle accumulation, and low relative humidity has the opposite effect. Secondary pollutant formation is also aided by relative humidity (Giri *et al.,* 2008). Furthermore, rainy weather condition causes wet particle deposition, which results in the removal of PM from the atmosphere; thus, the rate of precipitation has a significant impact on particle matter concentrations (Megaritis *et al.,* 2014). An investigation into the effects of climatic factors on particulate matter in a coal quarry site in Turkey discovered that an increase in relative humidity tends to increase TSP levels. The study also discovered that increased temperature reduces SPM/TSP accumulation while rainfall reduces TSP concentrations (Tecer *et al.,* 2008; Hernandez *et al.,* 2017). The goal of this study is to look at how meteorological parameters affect TSP concentrations in Benin City, Nigeria. It will also investigate the connection between TSP and meteorological variables. This study will help researchers better understand the factors that contribute to the particle pollution outbreak that has afflicted Benin City and other major cities in Nigeria where similar anthropogenic activities are carried out. It will also assist legislative authorities in developing an effective air quality management plan.

MATERIAL AND METHODS

Study Area

Benin City, the capital of Edo State, lies between latitude 6º23′55″N to 6º27′39″N and longitude 5º36′18″E to 5º44′30″E (Aiyesanmi and Imoisi, 2011). It has a tropical climate, characterised by two distinct seasons, the wet and dry seasons. In this study, the auto-mechanic workshops in Benin City were divided into four zones (NW, NE, SE, and SW) and delineated as shown in Fig.1 and Table 1.

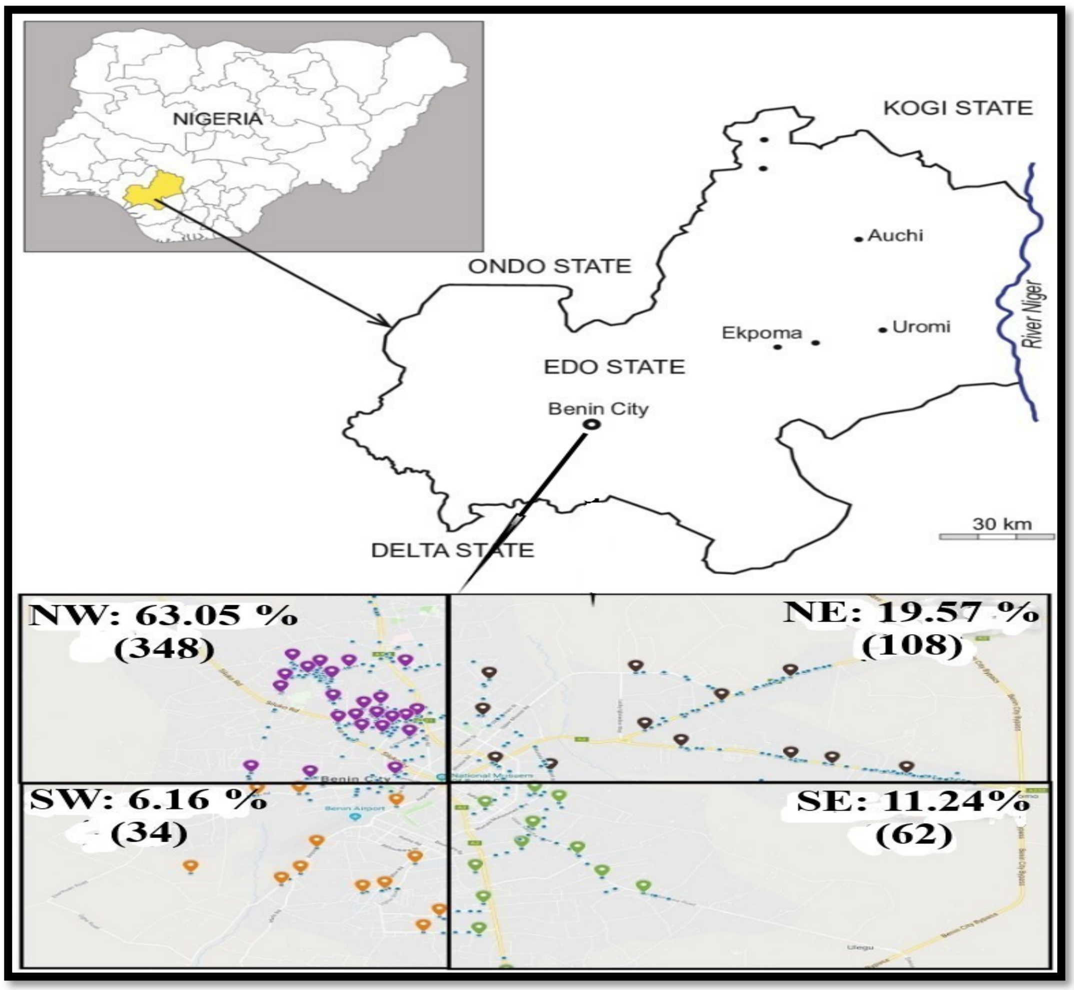

Fig. 1: Map showing the sampling sites of Auto-mechanic workshops in Benin City

Table 1: Description of Site Sampling

S/N	Longitude	Latitude	Elevation	Zones	Description
1	5.59484	6.45752	135.645	NW	Oluku, Benin City
2	5.60849	6.40072	113.925	NW	Usule, Benin city
3	5.62149	6.38072	107.490	NW	Technical college road, Benin city
4	5.62206	6.35947	96.325	NW	Egbede lane, Benin city
5	5.58143	6.33745	82.866	NW	Igbinedion street, Benin city
6	5.58776	6.36940	93.356	NW	Ojo Street, Benin city
7	5.58994	6.37851	104.503	NW	Uwelu, Benin city

8	5.61222	6.36293	96.569	NW	Ogie street, Benin city
9	5.60832	6.35897	92.723	NW	73, Textile mill rd, Benin city
10	5.60744	6.36369	95.011	NW	Ahanor st, Benin city
11	5.59896	6.36576	94.120	NW	65, Uwelu road, Benin city
12	5.60701	6.36082	94.403	NW	Isokpan St, Evbareke, Benin City
13	5.61452	6.35799	90.566	NW	Eguayesonye Street, Benin City
14	5.61255	6.35570	93.816	NW	54 2nd, West-Circular Rd, Benin City
15	5.61156	6.35725	93.138	NW	136 Airhenbuwa St, Benin City
16	5.60510	6.35391	92.026	NW	12 Close 45, Benin City
17	5.60946	6.35349	92.879	NW	Akugbe Streeet, Benin City
18	5.60233	6.37967	107.128	NW	62 Uwasota Rd, Benin City
19	5.60715	6.38086	108.000	NW	Erediawa St, Benin City
20	5.61525	6.35163	92.718	NW	54 W Circular Rd, Benin City
21	5.60005	6.35727	92.074	NW	Siluko Rd, Okhokhugbo, Benin City
22	5.60091	6.34396	87.900	NW	Erhunmwunse, Uzebu, Benin City
23	5.60910	6.36480	94.802	NW	Alimele Street, Use, Benin City
24	5.61221	6.33679	87.093	NW	Plymouth Rd, Benin City
25	5.63231	6.37471	92.183	NE	27, Universal road
26	5.63091	6.36032	81.294	NE	45 Akugbe street, Benin city
27	5.63799	6.35377	56.126	NE	38 Egharevba st, Benin city
28	5.72738	6.33590	85.379	NE	Iguomo before marpet petroleum ltd
29	5.68160	6.34694	84.742	NE	Benin agbor hwy Benin city
30	5.69668	6.34287	91.582	NE	Ogbeson, Benin City
31	5.68192	6.36613	107.163	NE	College road aduwawa Benin city
32	5.66551	6.35448	85.748	NE	Benin Auchi rd, Benin city
33	5.66360	6.37743	107.000	NE	Iguomo before marpet petroleum ltd
34	5.67474	6.37475	108.000	NE	Uselu, Benin city
35	5.64532	6.33821	55.570	NE	75, M.M way, Benin city
36	5.63357	6.34081	91.765	NE	Avbiama, Benin city
37	5.62932	6.29781	68.384	SE	Ogiugo Crescent, Benin City
38	5.62565	6.28215	65.419	SE	33 Godwin Abbe Way, Benin City
39	5.62503	6.27371	64.220	SE	Country Home Rd, Benin City
40	5.63685	6.24119	42.633	SE	Benin-Warri Road, Oka, Benin City
41	5.63916	6.32403	86.328	SE	M.M, Way, Avbiama, Benin City
42	5.64718	6.32550	86.862	SE	Upper Uwa St, Avbiama, Benin City
43	5.64395	6.31942	84.483	SE	Easy Motion Street, Benin City
44	5.64160	6.31519	82.980	SE	Osarogiuwa Street, Benin City
45	5.66523	6.28941	73.075	SE	419 Upper Sakpoba Road, B/City
46	5.63879	6.31093	83.594	SE	St. Maria Goretti Road, Benin City
47	5.63922	6.30717	80.331	SE	Dumez Rd, Benin City
48	5.63576	6.32880	88.221	SE	Uwa Street, Avbiama, Benin City
49	5.60910	6.33186	84.803	SW	Osuma St, Benin City
50	5.59682	6.33238	84.020	SW	Agho St, Benin City
51	5.58073	6.32785	72.361	SW	Ekehuan Rd, Benin City
52	5.60404	6.32996	84.819	SW	6 Joromi, Benin City
53	5.60856	6.32972	84.095	SW	12 Edebiri St, Benin City
54	5.61249	6.32406	80.157	SW	73 Akenzua Off, Airport Rd, B/City
55	5.61132	6.33015	84.636	SW	Osuma St, Ogogugbo, Benin City
56	5.59547	6.30745	70.523	SW	9 Airport Rd, Benin City
57	5.61645	6.30117	69.855	SW	Ugbor Road, Benin City
58	5.61274	6.29111	67.125	SW	Nneka St, Benin City
59	5.60998	6.29089	67.526	SW	Trinity Rd, Benin City
60	5.62166	6.28003	54.145	SW	93 Etete Layout Road, Benin City

Sampling Strategy for Total Suspended Particles (TSP)

A total of 60 sampling sites were sampled and 180 air particulates (TSP) samples were collected, such that each site was visited three times across the seasons for one year (Table 1). Temperature, relative humidity, pressure, wind speed, wind direction, solar radiation, and ultra-violet radiation were also measured and recorded during samplings using standard methods.

The TSP samples were collected into 37mm diameter quartz filters at a height of 1.5 - 2.0m above the ground using an Apex2IS Casella standard pump, coupled with a conical inhalable sampling (CIS) head at a flow rate of 3.5 litres per minute (LPM) for 8 hrs.

A pre and post-field calibration of the pump was carried out for each field sampling to meet the recommended flow rates of ±10% for each sampling period (Ashley *et al.,* 2017). Prior to sampling time, the 37mm diameter quartz filters were treated at 450-500°C for 4 hrs in a muffle furnace. The quartz filter, inserted inside the cassette was equilibrated in a desiccator for 48 hours to eliminate the effect of humidity and also to obtain accurate TSP measurements before and after sampling. The pre-weighed filters were re-weighed using a four-digit balance with a sensitivity of ±0.1mg (Wu *et al*., 2014; Moldoveanu and David, 2018).

Collection of Meteorological Parameters

Meteorological data such as ambient temperature, rainfall, relative humidity (RH), wind speed (WS), wind direction (WD), solar radiation, and ultra-violet radiation were recorded through an automatic weather monitoring system (Professional weather station: WS-5000-IP) mounted at 2.5 - 3.0m above the ground level at each sampling location closely beside the TSP sampler. It was programmed to collect data for a duration of 8hours with an interval of 5 minutes and store it in memory. The recorded measurements were downloaded to a computer using the weather-Smart app (Liu *et al.,* 2016).

RESULTS AND DISCUSSION

Total Suspended Particles

The values for the TSP mean concentration obtained from the representative sampling locations for the dry and wet seasons in the four-zone within the Benin metropolis are shown below in Fig. 2.

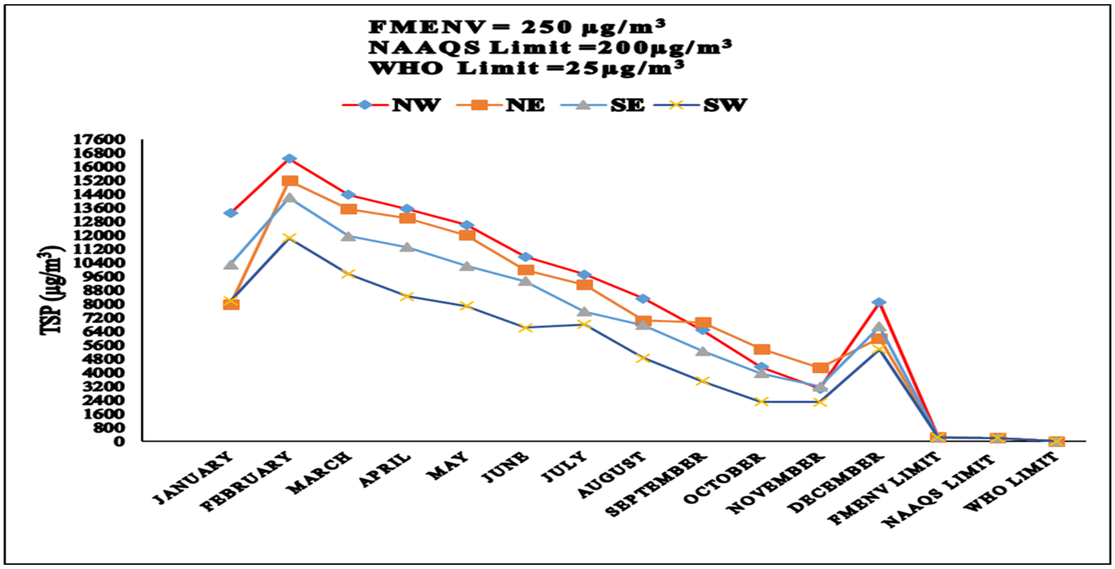

Fig. 2: 8-hours Average TSP Mass Concentrations at Automobile Workshops in Benin City

Figure 2 shows the observed TSP mass concentrations on a week-to-week basis for the entire sampling period, along with a comparison with the National Ambient Air Quality Standards (NAAQS) (200µg/m^3 for TSP) and the Federal Ministry of Environment (FMENV) (150-250µg/m^3 for TSP) Epa (2012). The 8-hour daily TSP ranged from 3078.74 ± 579.83 to 16,458.34 ± 822.11µg/m^3. The concentrations for the NW, NE, SE and SW were 10,084.20 ± 4,162.50, 9205.15 ± 3540.42, 8390.58 ± 3376.14, 6483.4 ± 2953.96µg/m^3 respectively. The annual mean concentration of TSP in the Benin metropolis was 8540.83 ± 1536.11µg/m^3. The annual TSP concentration was 34.16 times higher than the Nigerian ambient air quality standard set by Federal Ministry of the Environment (FMENV, 1995) standard of 230µg/m^3, the National Ambient Air Quality Standards (NAAQS) (2012) of 200µg/m^3, and the FEPA limit (1991) of 250µg/m^3. This indicates that the PM pollution in the Benin metropolis is of great concern.

Temporal Variation of Total Suspended Particles (TSP)

Figure 3 shows the dry and wet seasons of TSP mass concentrations throughout the sampling period. It is obvious from the figures that the PM concentration revealed significant variations both within the seasons and between the seasons. In the dry season, the average seasonal concentration of TSP was 9,677.28 (ranging from 2,278.02 to 16,458.34µg/m^3), and in the wet season, it was 7,404.39 (ranging from 2,313.45 to 12,604.16µg/m^3).

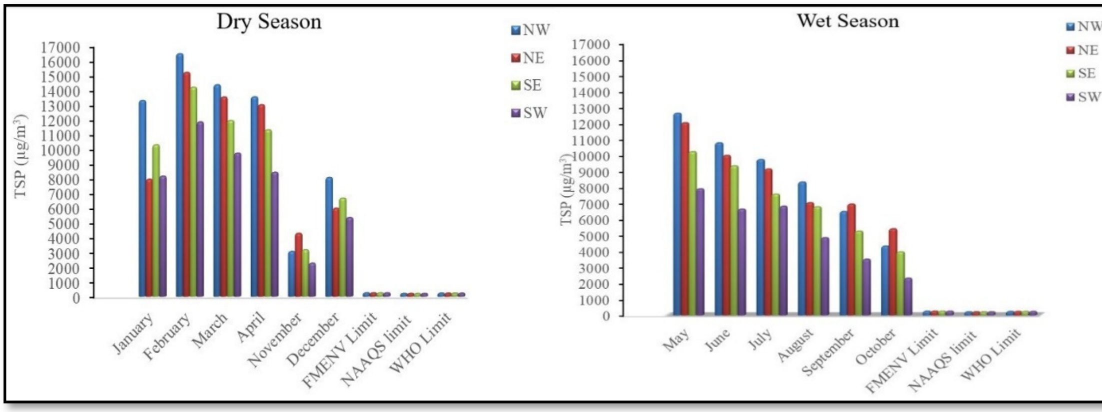

Fig. 3: Mass Concentration in Dry and Wet Seasons for TSP

The values of TSP for both dry and wet seasons exceeded the statutory limits of 250µg/m^3 for particulate matter stipulated by the Federal Ministry of Environment (FMENV, 1995), the 150-230µg/m^3 limit stipulated by the World Health Organization (WHO, 2006), 250 µg/m^3 limit set by the Federal Environmental Protection Agency (FEPA, 1991). The average seasonal concentration of TSP concentrations during the dry (9,677.28µg/m^3) and wet (7,404.39µg/m^3) seasons were 38.71 and 28.70-folds the regulatory body's value of 250µg/m^3, respectively. The reason for the high value of TSP, during the dry season, might be a result of where the samples were obtained from (i.e. auto-mechanic workshops) and its associated activities like repair and maintenance of vehicles, emissions from generators used during welding activities, welding, and motor spray painting. Emissions from vehicles entering and exiting mechanic workshops also play a vital role in increasing the level of TSP obtained. In addition, most of these vehicles, which are either gasoline or diesel, contribute to the high level of TSP during the start-up of the engine during maintenance. All these activities listed above are anthropogenic, so we can say that the variations in anthropogenic activities in the various mechanic workshops could be a major contributing factor to the observed differences in particulate matter levels in the various sites.

For the wet season, TSP value decreases, because the environment can cleanse itself, such that as the rainfall increases, the PM level eventually drops. The values obtained in the four zones during the dry and wet seasons violate the stipulated limit (250µg/m^3) for particulate matter as shown in Table 2. Generally, the high values may also be attributed to local primary emissions aided by meteorological factors such as the frequency in the variation of temperature, rainfall, wind direction, wind speed, and relative humidity coupled with wet and dry depositions which affect the secondary formation of particles. Thus, a clear seasonal pattern in the concentrations of PM was observed in the order of dry > wet (Okuo and Okolo, 2011).

Table 2: Mass Concentration in Dry and Wet Season for TSP

Months	**NW**	**NE**	**SE**	**SW**
	TSP (µg/m³) Dry season			
January	13296.94 ± 1110.41	7964.16 ± 183.28	10293.99 ± 744.73	8168.47 ± 807.94
February	16458.34 ± 822.11	15195.91 ± 575.08	14196.42 ± 799.70	11845.23 ± 673.44
March	14360.11 ± 386.90	13531.91 ± 679.89	11941.96 ± 284.10	9732.14 ± 462.98
April	13541.66 ± 301.55	13008.16 ± 159.11	11309.52 ± 126.26	8437.49 ± 357.76
November	3078.74 ± 1179.83	4297.38 ± 241.26	3187.46 ± 134.24	2278.02 ± 107.89
December	8079.51 ± 591.56	5997.93 ± 36.50	6681.41 ± 83.91	5371.89 ± 121.84
Seasonal average per zones	11469.21 ± 367.68	9999.24 ± 255.10	9601.79 ± 325.24	7638.87 ± 285.21
Overall seasonal average	**9,677.28 ± 48.90**			
	TSP (µg/m³) Wet season			
May	12604.16 ± 593.99	12008.16 ± 159.11	10208.33 ± 21.03	7886.90 ± 168.35
June	10758.91 ± 965.14	9976.78 ± 126.35	9322.90 ± 557.67	6622.02 ± 315.67
July	9722.01 ± 1728.78	9127.52 ± 54.77	7558.29 ± 1122.29	6807.69 ± 286.30
August	8312.29 ± 485.23	7025.87 ± 813.90	6766.76 ± 363.95	4841.36 ± 247.83
September	6477.20 ± 771.82	6935.71 ± 269.06	5256.99 ± 851.92	3496.14 ± 275.19
October	4320.54 ± 1214.06	5392.38 ± 573.92	3963.05 ± 1162.30	2313.45 ± 71.24
Seasonal average per zones	8699.18 ± 458.33	8411.07 ± 297.90	7179.38 ± 448.75	5327.9 ± 91.47
Overall seasonal average	**7,404.39 ± 171.61**			
Annual Average	**8,540.84 ± 1,607.17**			
FMENV Limit (1995)	250	250	250	250
NAAQS limit (2012)	200	200	200	200
WHO Limit (2006)	25	25	25	25

Comparing the results obtained from Benin City with others (Table 3). The results reported among artisans' workshops by Okuo and Okolo (2011) for TSP concentration (583-20,166µg/m³) were higher than the annual mean concentration (8,540.83 ± 1,607.17µg/m³) of this study, as well as the average seasonal concentration (9,677.28µg/m³ and 7,404.39µg/m³) in the dry and wet season respectively.

Table. 3: Comparison of Total Suspended Particulate and $PM_{2.5}$ of this Study with other Studies

S/N	Site/Locations	Values (µg/m^3)	TSP	References
1	Urban/Benin City	583.00 -20,166.67	TSP	Okuo and Okolo, (2011)
2	Urban/Benin City	3,958.33 -7430.56	TSP	Ediagbonya *et al.,* 2016
3	Rural/Calabar	108.98	TSP	Ikamaise *et al.,* 2013
4	Nigeria	1,033 - 40,000	TSP	Offor *et al.,* 2016
5	Urban/Benin City	wet season: 10,758.91-12,604.16	TSP	Current Study
		dry season: 14,360.11-16,458.34	TSP	Current Study

This could be a result of the sampling techniques, the volume of air, the type of sampling head (IOM or CIS) coupled with the filter paper diameter used. This might be a result of the activities being carried out at the various sampling sites. Comparing the results obtained in this study with the work carried out by Ediagboya *et al.* (2016) among welders in Benin City, which reported 7,430.55µg/m^3 as their highest mean concentration for TSP. The TSP reported by Edaigboya *et al.* (2016) was slightly close to the annual mean concentration (8,540.83 ± 1,607.17µg/m^3) but less than the average seasonal concentration (9,677.28µg/m^3) in the dry season and very close to 7,404.39µg/m^3 in the wet season, respectively, in this present study.

The observed high value during the dry season could be a result of accumulated dust in the dry season coupled with the prolonged absence of precipitation. The slightly higher wind speed arising from the harmattan can also be said to contribute to the high value by aiding the circulation of dust in the environment and, as such, increasing particulates in the atmosphere. For the wet season, TSP values, as expected, declined significantly. This is most likely a result of the emergence of the rainy season, which is characterized by heavy precipitation/heavy wet deposition. The precipitation reduces the concentration of air pollutants in the atmosphere, particularly particulate matter. The values obtained in all sites during dry and wet seasons violated the stipulated limit as they were all above the standard permissible limit of 250 µg/m^3, set by recognised regulatory agencies.

Meteorological Parameters

The summary of the meteorological parameters obtained from this study for one year is shown in Table 4. The Table contained summary of the monthly average temperature, relative humidity, pressure, wind speed, wind direction, solar radiation, and ultra-violet radiation observed during the study period with the corresponding values of 29.73 ± 0.83 – 33.47 ± 0.77 (^{0}C); 59.88 ± 2.11 – 78.96 ± 4.50 (%); 748.46 ± 0.60 – 752.91 ± 0.14 (mmHg); 2.87 ± 0.14 – 5.84 ± 0.77 (km/h); 158.55 ± 59.95 – 205.46 ± 12.15 (^{0}); 462.21 ± 36.15 – 1,073.46 ± 97.94 (W/m^2) and 753.14 ± 293.29 – 1,133.78 ± 48.56 (µW/m^2) respectively for the dry season (January – April, November and December). The range of values for the wet season includes 27.92 ± 0.57 – 29.89 ± 0.37 (°C); 72.07 ± 4.26 –78.24 ± 1.95 (%), 749.62 ± 0.78 – 754.31 ± 0.69 (mmHg), 5.21 ± 0.84 – 6.95 ± 0.58 (km/h), 154.96 ± 12.85 – 175.73 ± 16.19 (^{0}), 425.19 ± 38.53 – 571.24 ± 38.74 (W/m^2) and 717.31 ± 133.63 ($\mu W/m^2$) respectively. Temperature is a very critical factor in determining the weather; because it influences or controls other elements such as precipitation, humidity, clouds, atmospheric pressure etc. Its measurement tends to have a great influence on other parameters and their applications (Akhilesh *et al.,* 2015; Ukhurebor *et al.,* 2017).

The temperature increases gradually from January to April and decreases progressively from April to August before increasing slowly again from September to January, depending on the prevailing weather, while the relative humidity follows the opposite trend. The changes in the pressure throughout the sampling period were very placid in the dry season while there was a minor fluctuation in the wet season. The wind was mostly changing directions in the SSW, S, and SSE directions. The wind was relatively low in the dry season compared to the wet season. The solar radiation starts gradually decreasing from January with its peak in April and decreases gradually from April to December. Ultraviolet radiation tends to fluctuate throughout the sampling period, but with its peak in January.

Table 4: Summary of Meteorological Parameters in Benin City

Month	Temperature (°C)	Relative humidity (%)	Pressure (mmHg)	Wind-speed (km/h)	Wind-direction (°)	Solar-radiation (W/m^2)	Ultra-violet radiation ($\mu W/m^2$)
JAN	31.67 ±0.25	71.10 ± 5.64	751.43 ± 1.16	3.76 ± 1.82	158.55 ± 59.95	703.60 ± 208.78	1133.78 ± 48.56
FEB	30.12 ±0.77	73.74 ± 1.55	752.41 ± 1.30	5.44 ± 0.66	160.84 ± 22.41	603.11 ± 50.11	857.87 ± 131.45
MAR	30.78 ±0.38	71.33 ± 2.33	748.66 ± 0.43	5.47 ± 0.45	182.78 ± 39.35	728.65 ± 50.07	970.82 ± 63.61
APR	33.47 ± 0.77	59.88 ± 2.11	748.46 ± 0.60	5.84 ± 0.77	186.49 ± 6.25	1073.46 ± 97.94	1067.52 ± 92.27
MAY	29.89 ± 0.37	72.07 ± 4.26	749.62 ± 0.78	5.21 ± 0.84	169.90 ± 34.57	561.32 ± 30.68	803.88 ± 77.01
JUN	29.43 ± 0.44	72.50 ± 1.95	751.71 ± 1.76	5.87 ± 0.70	169.89 ± 22.32	564.24 ± 42.15	779.84 ± 134.59
JUL	27.37 ± 0.44	82.32 ± 2.06	752.61 ± 1.38	5.54 ± 0.86	179.43 ± 24.42	571.24 ± 38.74	861.85 ± 31.92
AUG	27.92 ± 0.57	78.24 ± 1.95	754.31 ± 0.69	6.36 ± 0.37	154.96 ± 12.85	425.19 ± 38.53	784.49 ± 89.08
SEP	28.72 ± 0.47	86.16 ± 1.04	753.82 ± 0.32	6.95 ± 0.58	174.14 ± 17.38	458.05 ± 81.76	808.46 ± 225.24
OCT	27.87 ± 0.80	78.98 ± 3.13	752.11 ± 0.07	6.84 ± 0.28	175.73 ± 16.19	495.01 ± 80.84	717.31 ± 133.63
NOV	29.73 ± 0.83	78.96 ± 4.50	752.91 ± 0.14	2.99 ± 0.15	205.46 ± 12.15	468.33 ± 54.29	907.55 ± 132.94
DEC	30.06 ± 1.95	67.09 ± 16.88	752.71 ± 0.55	2.87 ± 0.14	179.11 ± 13.23	462.21 ± 36.15	753.14 ± 293.29
Seasonal mean (dry)	30.97 ± 1.43	70.35 ± 4.03	747.77 ± 7.76	4.40 ± 1.34	178.88 ± 17.43	673.23 ± 134.51	948.45 ± 139.32
Seasonal mean (wet)	28.53 ± 0.69	78.38 ± 2.55	752.37 ± 1.67	6.13 ± 0.86	170.68 ± 8.51	512.51 ± 62.30	792.64 ± 47.06
Annual mean value	29.75 ± 1.26	74.36 ± 3.39	750.07 ± 5.87	5.26 ± 1.09	174.78 ± 13.76	592.87 ± 115.46	870.55 ± 128.26

The variation of the measured meteorological parameters was clearly shown using a line graph in Figure 4.

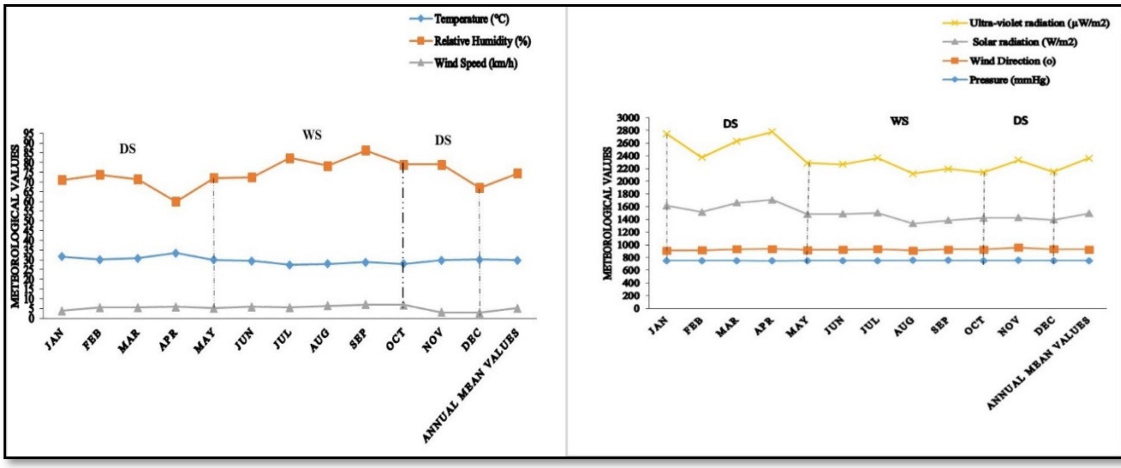

Fig. 4: The line graph shows the meteorological parameters for one year

Relationship between the Meteorological Parameters and Total Suspended Particle (TSP)

A correlation analysis was carried out to determine the relationship between the meteorological parameters and $PM_{2.5}$ and TSP within the sampling period, as shown in Table 5. The result revealed that a positive relationship exists between TSP and solar radiation at $p<0.05$, $r = 0.647$) while with pressure it is negative ($p<0.05$, $r = -0.638$). Within the meteorological parameters, there was a correlation between temperature, relative humidity, pressure, solar radiation, and ultra-violet radiation. Temperature correlated negatively with humidity ($r = -0.84$, $p<0.01$) and pressure ($r = -0.71$, $p<0.05$). While with solar radiation ($r = -0.82$, $p<0.01$) and ultra-violet radiation ($r = -0.76$, $p<0.01$), the correlation was highly positive. Relative humidity correlated positively with pressure ($r = -0.70$, $p<0.05$) and negatively with solar-radiation ($r = -0.72$, $p<0.01$). Pressure correlated negatively with solar radiation ($r = -0.80$, $p<0.01$). Solar radiation correlates positively with ultraviolet radiation.

Table 5 Correlation Matrix between the Meteorological Parameters and TSP

		Temperature (°C)	Relative Humidity (%)	Wind Speed (km/h)	Pressure (mmHg)	Wind Direction (o)	Solar Radiation (W/m^2)	Ultra-violet Radiation ($\mu W/m^2$)	TSP ($\mu g/m^3$)
Temperature (°C)	Pearson Correlation	1	-.839**	-.338	-.708*	.158	.824**	.762**	.575
	Sig. (2-tailed)		.001	.283	.010	.624	.001	.004	.050
Relative Humidity (%)	Pearson Correlation		1	.333	.704*	-.042	-.724**	-.451	-.563
	Sig. (2-tailed)			.291	.011	.896	.008	.141	.057
Wind Speed (km/h)	Pearson Correlation			1	.011	-.351	.055	-.291	.057
	Sig. (2-tailed)				.972	.264	.864	.359	.861
Pressure (mmHg)	Pearson Correlation				1	-.226	-.803**	-.519	-.638*
	Sig. (2-tailed)					.481	.002	.084	.025
Wind Direction (o)	Pearson Correlation					1	.144	.101	-.381
	Sig. (2-tailed)						.656	.754	.222
Solar radiation (W/m^2)	Pearson Correlation						1	.755**	.647*
	Sig. (2-tailed)							.005	.023
Ultra-violet radiation ($\mu W/m^2$)	Pearson Correlation							1	.507
	Sig. (2-tailed)								.092
TSP ($\mu g/m^3$)	Pearson Correlation								1
	Sig. (2-tailed)								

CONCLUSION

Based on TSP levels and the meteorological data obtained in Benin City in the year 2019, this study examined the systematic impact of meteorological factors on TSP variation. Consequently, according to the study, the monthly average TSP concentrations for the study period exceeded the NAAQS and WHO 24-hour guidelines for both wet and dry seasons. Also, depending on the season, it was evident that some meteorological parameters have a significant influence on total particulate matter levels. The funding for this research was provided by the Staff Multipurpose co-operative society of Benson Idahosa University and the University of Benin teaching hospital as a loan coupled with support from the Environmental Research Laboratory (University of Benin).

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