Journal of Materials and Environmental Science
ISSN: 2028-2508
e-ISSN: 2737-890X
CODEN: JMESCN

J. Mater. Environ. Sci., 2022, Volume 13, Issue 09, Page 1081-1100

http://www.jmaterenvironsci.com

Air pollutant concentrations and health risk assessment around residential areas in Benin city, Nigeria

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Received 18 Sept 2022,
Revised 29 Sept 2022,
Accepted 30 Sept 2022

Keywords
- ✓ *Air pollutants,*
- ✓ *Meteorological parameters,*
- ✓ *AQI,*
- ✓ *Residential areas,*
- ✓ *Health Risks*

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Abstract

The study investigated the variations in air pollutant concentrations and health risks associated with exposure to air pollutants in Benin City, Nigeria. The particulates ($PM_{2.5}$ and PM_{10}) were quantified using Met One AEROCET sampler, while carbon monoxide, nitrogen (iv) oxide, sulphur (iv) oxide, volatile organic compounds, and meteorological parameters were monitored using a multi-Rae PDM analyser and Wind Mate respectively. ArcGIS and SPSS for windows were used for analysing the data obtained. The health risk was obtained by calculating the Air Quality Index (AQI). The average concentrations of CO, NO_2, SO_2, and VOCs were all within the WHO regulatory limits. The concentrations of $PM_{2.5}$ and PM_{10} were above the allowable limits across the sampling locations. The principal component (PC) analysis revealed that air pollutant levels were highly influenced by PM, CO, VOC and NO_2 related activities with high factor loadings of 0.98 in PC1, 0.78 and 0.74 in PC2 and 0.84 in PC3 respectively. There were weak associations between air pollutant levels and the meteorological parameters (R^2 = 2.7 – 15.5%) in the dry and wet seasons. The results of the health risk assessment showed that the AQI ratings of $PM_{2.5}$ ranged between 112 to 185 and 67 to 153 in the dry and the wet seasons, and were generally unhealthy across the study area. This implied that residents could be exposed to a high risk of air pollution-related diseases in the study locations. It is recommended that regular air quality monitoring; the creation of awareness of the impacts of air pollution on health and regular wearing of nose masks against dust should be enforced in the city.

1. Introduction

Air pollution has been reported to be the largest single determinant of environmental health risks in the world. The most pronounced impact of air pollution is in developing countries, and this has been attributed to industrialization, rapid urbanization and increased motorization [1]. The World Health Organization reported that no fewer than 80% of persons residing in urban areas are at risk of air quality levels above regulatory limits [2]. Outdoor air pollutants of importance from a health perspective include particulates ($PM_{2.5}$ and PM_{10}), carbon monoxide (CO), and gaseous pollutants such as nitrogen (iv) oxide, sulphur (iv) oxide, and volatile organic compounds (VOCs) [3]. These pollutants are currently rising to unhealthy levels in developing countries due to an increase in various emissions from different anthropogenic sources in urban centres. Air pollutants such as oxides of

nitrogen, sulphur and soot particles are directly emitted and released into the air via the incomplete burning of fossil fuels [4]. Primary particulate matter is emitted majorly from vehicular road traffic, generation of power especially from generator sets, industrial sources (such as cement, oil and gas), combustion processes in and around residential buildings, and the re-suspension of soil and road dust [5, 6]. Acute and chronic exposure to outdoor atmospheric pollutants continues to pose a dangerous health risk to individuals, particularly in developing countries. This has been attributed to the increase in population with urbanisation and industralisation resulting in densely populated areas with polluted air [7]. Air pollution is the cause of adverse effects on the lungs and the increased factor of many respiratory disorders such as chronic obstructive pulmonary diseases, asthma, and lung cancer [8, 9, 10]. Increased hospital admission for pneumonia and asthma has been correlated with high a concentration of ambient ozone (O_3), NO_2, SO_2 and $PM_{2.5}$ in several studies carried out in Hong Kong [11,12,13]. There is also increasing evidence of an association between air pollution exposure and hypertension, coronary heart diseases, stroke, cancer and myocardial infractions [14,15,16]. The World Health Organisation has established guidelines for annual averages of outdoor air quality for PM_{10}, $PM_{2.5}$, CO, NO_2 and SO_2 as 20, 10, 40 and 20 $\mu g/m^3$, respectively [17]. While the Nigerian ambient air quality standards (NAAQS) permissible limits are 150$\mu g/m^3$, 0.03ppm and 0.03ppm for PM_{10}, NO_2 and SO_2 respectively [18]. Continuous human exposure to air pollutants levels within these regulatory standards could as well be of public health significance, especially in children and people with underlying diseases, since regulatory limits are effective thresholds below which there could be no significant health impacts on the exposed individuals [19]. The United States Environmental Protection Agency (USEPA) has assigned a standardized level of indicator for air pollution, referred to as the Air Quality Index (AQI) [20]. An equation for calculating the AQI based on $PM_{2.5}$, PM_{10}, NO_2, SO_2, and CO was later proposed [21]. Similar sets of class ranges and corresponding AQI categories for these pollutants were outlined to determine the level of health risks the occupants in the study locations are exposed to [21]. These procedures have been employed by several researchers to evaluate the level of health risks posed by air pollutants in different cities in industrialized nations [22, 23].

The place of air quality monitoring in the government agenda is almost nonexistent in Nigeria, as data on air quality are often not available or accessible from government sources. Therefore, urban air pollution currently receives low public attention and it is characterized by a lack of legal framework, funds, incentives, and policy guidelines to help maintain pollutants concentrations within regulatory limits in the region [24]. The enforcement of existing legislation on air pollution, where they are present, is hampered by the absence of political will [25]. Air pollution in developing countries is a complex issue, which has been compounded by the information gaps resulting from the lack of regulations and routine monitoring compared to the developed nations of the world [26]. An understanding of the variability of atmospheric pollutants and their associated health risks can be useful in pollutant hot spot identification and mapping as well as the control and development of appropriate mitigation measures for health risks associated with air pollution. The objective of this study is to investigate the levels of ambient air pollutants around residential areas in the Benin metropolis and evaluate the health risks associated with exposure to the pollutants.

2. Methodology

2.1 Study area

Benin City is a humid tropical urban settlement which comprises Oredo, Ikpoba okha, Egor, Ovia North East and Uhunmwonde Local Councils. It is located within latitudes 6°20′N to 6°58′N and

longitudes 5°35′E to 5°41′E as shown in Figure 1. It broadly occupies an area of approximately 112.552 km^2. The population of the city was estimated at 1,495,800 people. The location of study is situated in a humid tropical environment. Its rainfall element strongly determines the occurrence of the rainy and dry seasons. The total annual rainfall amount recorded in the city ranged between 2,000 and 3,000 mm. The wet season is between April and October with a short dry period in August. The dry season begins in November and ends in April with a humid and dusty harmattan period between December and January. Also, high relative humidity between 75 and 85% is regularly experienced in the area [27]. The descriptions of each sampling area in the study area are presented in Table 1.

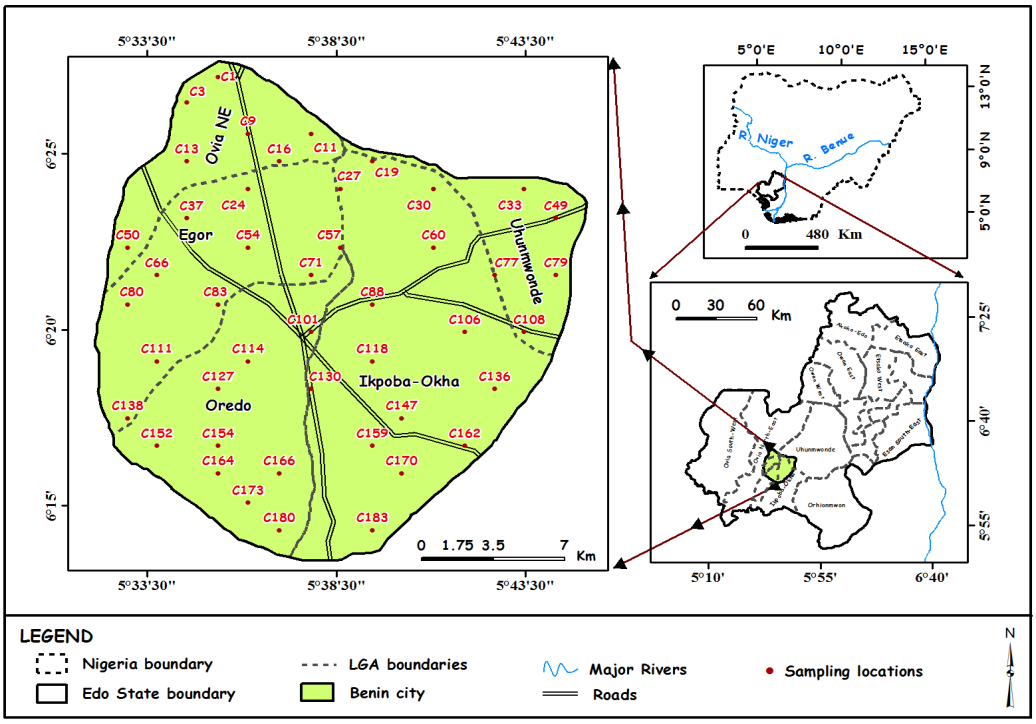

Fig 1: Map of Benin City showing selected sample locations

2.2 Measurement and Sampling of ambient air pollutants

Forty-five cells were randomly selected for outdoor air quality sampling and were grouped into the local council areas as SA1, SA2, SA3, SA4 and SA5 (Table 1). Air sampling was done monthly in triplicates across the locations. A handheld portable gas analyser (multi-Rae PDM-6208 series) was utilised for measurements of CO, NO_2, SO_2, and VOC While $PM_{2.5}$ and PM_{10} were measured with aid of Met One AEROCET series 531 meter. The meter derives the particulate mass concentrations using the stored particulate count and an algorithm. The sensor utilized by the equipment has a prolonged life laser diode, elliptical mirror that efficiently collect light rays and a distinct optics that offers a high concentration limit. Additional component of the equipment includes isokinetic probes that minimise errors occasioned by sample flow velocity. The equipments are characterized with field replaceable infrared, gamma radiation, combustible and electrochemical, and photoionization detector (PID) sensors. The equipment was calibrated before and after use as recommended by the manufacturer. The measurements were all recorded in the windward direction at a height of 2m above ground level to prevent interference of samples with fugitive sand. Measurements were taken in triplicates to guarantee reliability and accuracy in readings.

Table 1: Description of sampling area

SA	Area Council/ Selected Cells	Description
1	**Ovia North East** C1, C3, C9, C11, C13, C16, C19, C24	The houses in this area are relatively new with lots of undeveloped lands with trees around the buildings. The area is characterized with low socio-economic activities with unpaved or untarred roads, although some of the houses are located near highways. There are schools (student hostels), churches and with most of the homes utilizing generator set as power source.
2	**Ikpoba Okha** C27, C30, C50, C88, C106, C118, C147, C159, C162, C170	The sites are predominantly core residential areas with similar pattern of houses. The area is characterized by unpaved roads and without industries. There are lots of markets, lock up stores and small-scale artisans who use fuel powered generators as major source of energy supply. It has the highest population among the local araes in Benin City due to the proximity of rural communities to the local Government which aid migration into the area. Household wastes are openly disposed and generally practiced open waste combustion
3	**Oredo** C57, C71, C101, C127, C130, C136, C138, C152, C154, C164, C166, C173, C180, C183	This is the administrative headquarters of Benin City, with lots of houses converted into commercial buildings. Houses are situated close to tarred roads in the midst of markets, churches, schools filling stations and motor parks. The houses are cited within areas characterized by high level of traffic volume. Waste generated from the areas is combusted openly.
4	**Egor** C37, C54, C60, C66, C80, C83, C111, C114,	Egor araes has predominantly low-cost houses. The area is dominated with artisans and little or no industries due to bad roads. The houses are poorly developed with unpaved roads. Houses in the area generates heat energy locally through continuous domestic activities such as cooking with kerosene stoves, gas and fire wood in some cases.
5	**Uhumwonde** C33, C49, C77, C79, C108,	This location consists newly developed communities with newly built houses and it is an extension of the city. The houses far apart with few occupants. The area is characterized with paved interconnecting roads with relatively few commercial activities.

SA= Sampling location

2.3 Meteorological data

Relative humidity and wind speed were measured in situ at each sampling locations (SA1 - SA5) using Wind Mate (WM 350) equipment. The measurements were recorded every month in triplicates for one year covering wet (April - September) and dry (October - March) seasons between 2019 and 2020.

2.4 Quality assurance of ambient air pollutant data

In situ sampling of meterological parameters and air pollutants was carried out using a calibrated hand-held portable device. Air quality measurements were done daily between 8am to 1pm across the sampling locations according to USEPA standards [26]. Triplicates values of air pollutant concentrations were recorded and in the forty-five cells. The cells that fell into each of the council araes were grouped under each area as SA1, SA2, SA3, SL4 and SL5 for ease of presentation of results. The data recorded daily were used to obtain monthly and seasonal (wet) and (dry) average concentrations. The results obtained were compared with the 24 - hour mean concentrations according to WHO and FMEnv [17, 18].

2.5 Determination of Air Quality Index

The AQI values were calculated for all the sampling sites using the 24-hourly average concentrations of measured air pollutants. Mean levels of each air pollutants were calculated using excel spread sheet. The AQI for the respective air pollutant concentrations (Cs) according to the linear segmented principle was determined as follows;

$$AQI = \frac{Ihigh - Ilow}{BPhigh - BPlow} X\ (Cp - Bplow) + Ilow \qquad \text{(Equation1)}$$

Where: AQI = Index of the pollutant;
Cp = the rounded concentration of pollutant p;
BP_{high} = the breakpoint greater or equal to Cp;
BP_{low} = the breakpoint less than or equal to Cp;
I_{high} = the AQI corresponding to BP_{high};
I_{low} = the AQI corresponding to BP_{low}

2.6 GIS Analysis

The spatial variations of air pollutants parameters were determined by entering the in-situ measurements of air pollutants concentrations into digital map layers. Various sampling locations have been previously identified using the global positioning system (GPS) (GPSMAP 76CSX, Garmin Inc.). The data were processed and entered into Excel sheet and exported to GIS software (ESRI, ArcMap 10.5). Geospatial analysis using Kriging technique was employed to determine the value of each cell at locations without sample data [28]. Air quality index for the selected cells across the sampling locations were used to map the spatial patterns of air pollutant hot spots in the study area using inverse distance.

2.7 Statistical analysis

The concentrations of air pollutants and meteorological parameters were subjected to descriptive and inferential statistics using SPSS for windows (version 22.0). Analysis of Variance (ANOVA) was employed to determine the temporal variations of the air pollutant concentrations across the sampling areas. A paired t-test was employed to compare the measured data sets of outdoor air parameters in the wet and dry seasons. The relationship between the measured air pollutants and the levels of variations that exist among the variables based on the sampling locations was determined using principal component analysis (PCA). Principal component analysis with varimax rotation was conducted to determine how the air pollutants are clustered. Correlation and regression were used to show the associations between the air quality data and in situ meteorological parameters in the study area.

3. Results and Discussion

3.1 Observed meteorological parameters

The mean ambient air temperature and relative humidity were significantly different across the locations in the wet (F= 3.73, p = 0.005; F=143.53, p = 0.001) and dry (F = 38.34 and 40.66, p = 0.001) seasons . The outdoor temperature varied between 30.9 to 32.8°C and 31.2 to 33.6°C, with the highest temperature in SA1 and SA3 and the lowest occurring in SA4 in both seasons (Figure 2). The relative humidity varied from 66.6 to 75.5% and 59.2 to 73.3% in the wet and dry seasons with the highest recorded also around SA4 and the lowest in SA3. The trend of variations in outdoor temperature was found to be inversely related to relative air humidity. Exact patterns of levels of meteorological parameters were reported in the work of [29] who examined the distribution of meteorological parameters in southwestern Nigeria

The observed wind speed also varied significantly across the sampling locations in wet (F= 85.57; p = 0.001), and the dry (F= 160.4; p = 0.001) with the highest speed measured at SA2 (0.96 m/s) in the wet season. The lowest wind speed (0.17 m/s) was recorded in SA1 during the dry season (Figure 2). The wind speed values observed during this study are consistent with the work of [30] who reported that wind speed is generally low throughout the year in Benin City.

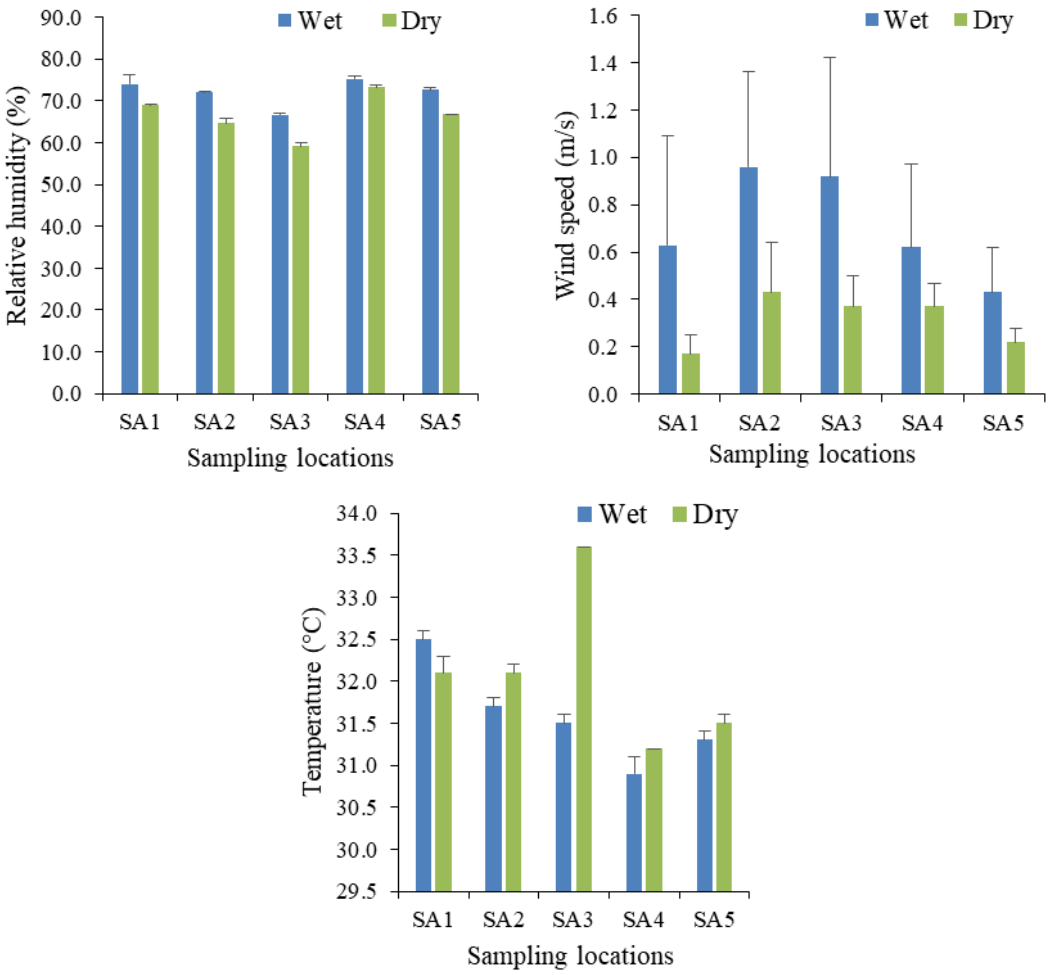

Fig 2: Mean meteorological parameters in the wet and dry seasons at different sampling locations

3.2 Mean concentrations of ambient air pollutants

Outdoor CO concentrations ranged from 1.88 – 3.50 mg/m^3 in the wet season and 2.15 – 4.47 mg/m^3 in the dry periods of the year (Figure 3). The highest ambient CO values were monitored across SA1 at (4.47 mg/m^3) followed by SA3 (2.15 mg/m^3) and the least was recorded in SA2 (1.88 mg/m^3). The relatively high CO levels in SL1 could be due to the predominant use of generator sets occasioned by the constant power outages in the area which is predominantly a student environment. The values of ambient CO varied significantly across the locations in the wet (F=7.23, p = 0.001) and dry (F= 9.82, p =0.001) seasons. The monitored CO values were within the WHO limit of 12.3 mg/m^3 [17]. The continued exposure to low and moderate levels of CO could be dangerous to vulnerable persons, especially children and those with underlying respiratory illnesses. The monitored concentrations of CO observed in this study were similar to the concentrations (1.81 – 4.23 ppm) reported by Ukpebor *et al.* [30] during the geospatial mapping of air pollution in Benin City, Nigeria. However, these values were lower than CO concentrations documented by Balogun and Orimoogunje [31] at several road junctions in Benin City which was attributed primarily to vehicular exhaust.

The concentrations of ambient NO_2 and SO_2 in both seasons were below the detectable limit (0.002 mg/m^3) of the measuring equipment, in most of the locations except at SA2 and SA5 (Figure 3). Outdoor NO_2 concentrations ranged between 0.02 – 0.04 mg/m^3 in the wet season but were higher in the dry season with 0.06 mg/m^3 (Figure 3). On the other hand, the monitored mean SO_2 value was 0.03 mg/m^3 in the wet season and 0.02 mg/m^3 in the dry season (Figure 3). The presence of NO_2 and SO_2 gases around the monitored residential areas could be due to emissions from vehicular traffic since most of the selected areas in SA2 and SA5 are located near the roads. Other possible sources may be due to the use of gasoline-powered generators, which are dominant practices in those areas because of incessant power failure [32]. These findings are in line with the report of Nimyel and Namadi [33]. But the observed values in SA4 and SA5 were greater than those reported by [34] Obanya *et al.* around residential and transportation sector locations in Lagos, Nigeria. Exposure to SO_2 has been correlated with increased respiratory symptoms, and constriction of airways such as the nose, throat and lungs [35]. The concentration of monitored outdoor SO_2 and NO_2 values were within the WHO permissible limits [17].

Generally, the concentrations of particulates ($PM_{2.5}$, PM_{10}) varied significantly across the sample areas in the wet (F=10.86 and 10.89, p = 0.001) and dry (F=31.31 and F=33, p<0.001) seasons. The highest concentrations (54.5 and 63.5µg/m^3) in wet and dry seasons (85.9 and 104.5µg/m^3) of the particulates were recorded at SA2 while SA1 has the lowest values (27.4 and 33.5 µg/m^3) during the wet and dry seasons (45.6 and 54.7 µg/m^3) of monitored particulates. The values of monitored $PM_{2.5}$ and PM_{10} were above the permissible limit prescribed by WHO [17]. The high concentration of outdoor particulates measured across the sampling locations in this study could be largely attributed to the proximity of sites to unpaved roads which was predominantly the case in the Ikpoba Okha area. This observation is similar to Ediagbonya *et al.* [36] who worked on the correlation of meteorological parameters and dust particles in rural areas of Edo state and argued that paved and unpaved roads are contributory sources to particulate matter emissions in different areas. The mean concentrations of VOCs in the wet season ranged from 24.8 – 51.8 mg/m^3 and 27.2 – 50.8 mg/m^3 in the dry season (Figure 3). The sampling area (SA2) has the highest value of monitored VOCs followed by SA5 while the lowest concentration was determined at SA4. Ambient air VOCs also varied significantly across the study locations in the wet (F= 51.06, p = 0.001) and dry (F=23.53, p = 0.001) seasons. The values of monitored VOC were within the FMEnv permissible limit of 160µg/m^3.

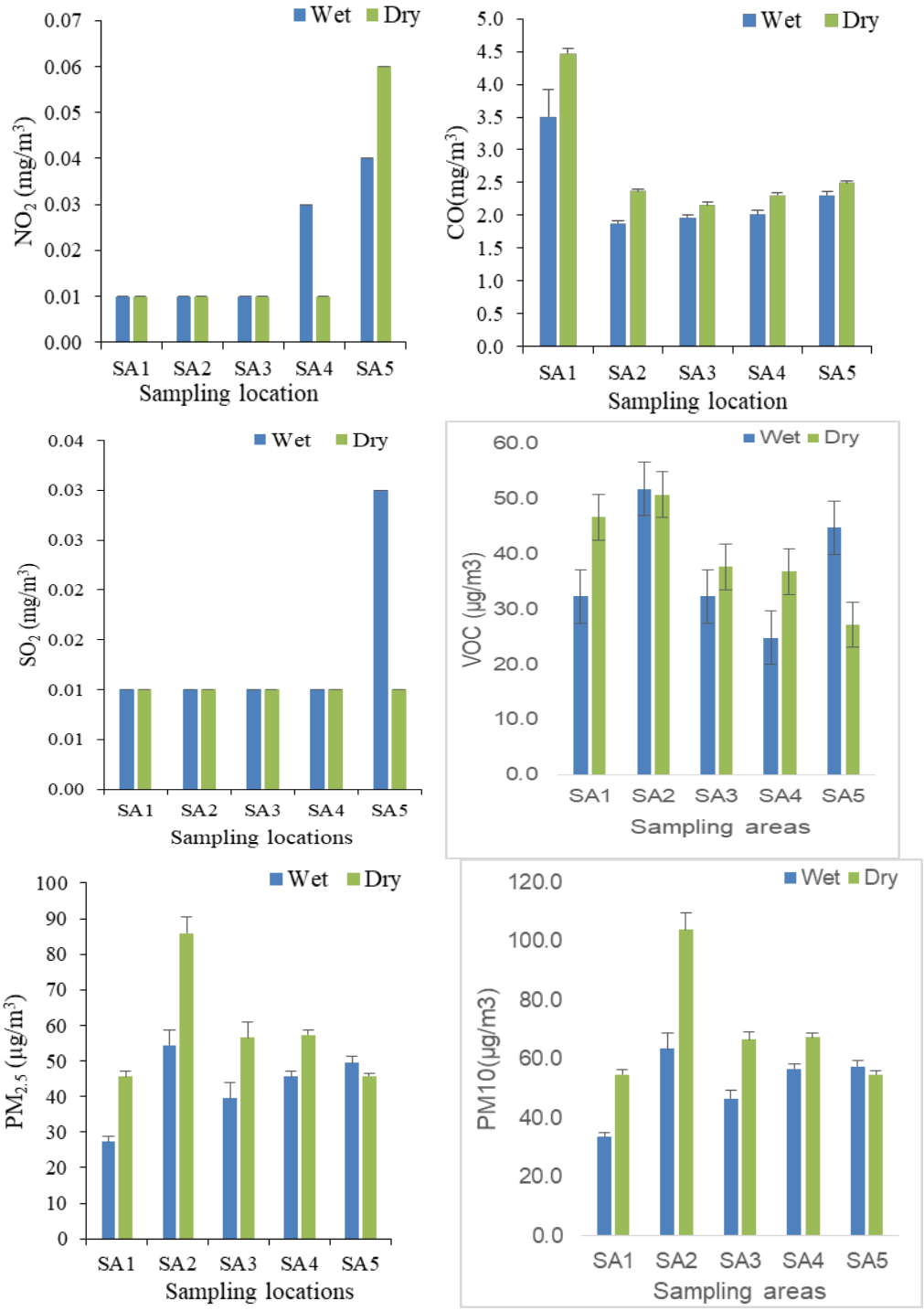

Fig 3: Mean concentrations of outdoor air pollutants at different locations

3.3 Seasonal variations in air pollutants concentrations

Table 2 showed the t-test values of the average levels of measured pollutants and meteorological parameters in the sampling locations during both wet and dry seasons. The temperature in the dry season was remarkably higher than that of the wet season in most of the sites, except in SA4 ($p = 0.032$) and SA5 ($p = 0.241$). The dry season is often characterized by a lack of cloud cover, low humidity and less rainfall which increases solar radiation. In contrast, the low-temperature values observed in the wet season might be due to the dense cloud cover obstructing the incidence of radiation from the sun. Therefore, the energy received by the earth has little or no reflective power hence revolving continuously within the atmosphere as rainfall [37]. On the other hand, outdoor

relative humidity was significantly higher in the wet season compared to the dry season across forty per cent of the locations. Although the wind speed measured across the sampling sites was generally low, it was observed that the mean wind speed recorded during the wet periods was significantly higher ($p = 0.001$) compared to the values observed in the dry months.

There was a significant increase in ambient CO concentrations was significantly in the dry months compared to the wet periods of the year in all the locations, except for SA1, where the difference was not statistically significant ($p = 0.47$). The higher values of outdoor CO in the dry season observed in this study were similar to the reports from several studies on ambient air pollution [30,38,39]. Dry seasons are characterized by high temperatures and low humidity in Nigeria, while the opposite is the case for wet seasons [38]. The high outdoor concentrations obtained for all the gaseous pollutants in the dry season are further supported by Jacobson [40] who reported that increased levels of ambient pollutants monitored during the dry season were attributed to high temperatures leading to the downward movement of pollutants and higher ground-level concentrations. The higher the plume rises, the higher the rate of dispersion of gaseous pollutants from its source before it reaches the ground-level. On the other hand, pollutant gas concentrations on the ground level would increase if the temperature of the ambient air is higher [40]. The values of outdoor VOCs in the dry season were significantly ($p<0.001$) higher than in wet months in all the monitored sites.

The average concentrations of the monitored ambient air particle metrics ($PM_{2.5}$ and PM_{10}) were significantly higher in the dry season than in the wet season at all sampling sites. This is similar to the report of [41]. The higher concentration of particulates had been associated with the increase in atmospheric temperature that characterizes dry seasons in Nigeria [32]. The rise in ambient temperature increases the reactivity of gaseous constituents in the environment thereby causing an increase in the rate of production of particulate matter through photochemical reactions [36]. Contrary to this finding, Onuorah *et al.* [42] reported a decrease in PM concentration due to an increase in atmospheric temperature. The relatively low concentrations of particulate matter in the wet season could be linked to the increase in relative humidity due to high rainfalls that enhance the adsorption of water vapour onto the particles leading to settling and dry deposition of particulates [42].

Table 2: Seasonal Variations of outdoor air quality and meteorology parameter

Sampling Locations		Temp (°C)	R/H (%)	WS (m/s)	CO (mg/m)	VOC (µg/m^3)	$PM_{2.5}$ (µg/m^3)	PM_{10} (µg/m^3)
SL1	t value	2.66	-2.45	16.9	-2.00	-6.67	-10.1	-8.90
	sig	0.01	0.02	0.00	0.47	0.00	0.00	0.00
SL2	t value	-2.22	6.28	23.5	-9.37	0.35	-5.16	-5.29
	sig	0.03	0.00	0.00	0.00	0.00	0.00	0.00
SL3	t value	-13.1	9.07	22.4	-2.76	-4.54	-4.15	-5.02
	sig	0.00	0.00	0.00	0.01	0.00	0.00	0.00
SL4	t value	-2.15	1.13	10.6	-5.07	-6.71	-6.72	-5.36
	sig	0.03	0.26	0.00	0.00	0.00	0.00	0.00
SL5	t value	-1.18	0.38	11.0	-2.55	6.39	2.12	1.42
	sig	0.24	0.71	0.00	0.01	0.00	0.00	0.16

Temp: Temperature; R/H: Relative Humidity; WS: Wind speed; CO: Carbon monoxide; VOC; Volatile Organic compounds.

3.4 Principal component analysis (PCA) for air pollutants

In this study, six parameters were subjected to PCA. The first three components with eigenvalues greater than 1 were considered [43]. In the wet season, the three components accounted for 71.6% of the entire dataset (Table 3). The first, second and third components explained 35.46% (98% of the

data sets), 19.04% (78% of the data sets) and 17.26% (88% of the data sets) respectively in the wet season. These components are predominantly influenced by the particulates ($PM_{2.5}$ and PM_{10}), CO and VOCs. In the dry season, the three components also accounted for 72.4% of the total data sets. The three components accounted for 34.56 (48% of the data sets), 21.11% (68% of the data sets) and 16.7% (84% of the data sets) in the dry season (Table 3), respectively and were strongly influenced by CO, NO_2 but weekly dominated predominated in the dry season. This result implies that particulate matter ($PM_{2.5}$ and PM_{10}) being grouped in one component with the highest positive loadings, emanated from the same source. The likely sources include vehicular emissions, open waste burning, re-suspension of road dust and other human activities related to unplanned urbanization in the area. This study is in tandem with the reports of Oyebanji *et al.* [44]. Carbon monoxide and VOC grouped in component two with high positive loadings could also be from similar sources in the wet season.

Table 3: Rotated component matrix for wet and dry seasons

	Components					
	Wet			**Dry**		
	1	2	3	1	2	3
CO	-0.01	**0.78**	-0.19	-0.03	**0.68**	-0.19
NO_2	-0.08	-0.03	**0.88**	-0.12	-0.03	**0.84**
SO_2	0.35	0.07	**0.47**	0.12	0.03	0.41
VOC	0.08	**0.74**	0.23	-0.02	0.63	0.20
$PM_{2.5}$	**0.98**	0.04	0.06	**0.48**	-0.02	-0.04
PM_{10}	**0.98**	0.02	0.05	**0.48**	-0.04	-0.06
Eigenvalues	2.06	1.16	1.08	2.07	1.27	1.01
% Variance	35.46	19.04	17.26	34.56	21.11	16.78
% Cumulative	35.46	54.45	71.76	34.56	55.67	72.45

Significant values with loadings greater than 0.45 are in bold

3.5 Correlation among air pollutant concentrations

A weak negative correlation was found between VOCs and NO_2 (-0.173), $PM_{2.5}$ and NO_2 (R = -0.123) during the dry season (Table 4). This implies that an increase in one air parameter results in a decrease in the other. A significant positive correlation exists between PM_{10} and VOCs (R = 0.200), PM_{10} and $PM_{2.5}$ (R = 0.779). An increase in the concentration of PM_{10} leads to a corresponding increase in VOC and $PM_{2.5}$ concentrations. There was a significant positive correlation between the pollutants across the sampling locations during the wet periods of the year (Table 4). Sulphur (iv) oxide was associated positively with NO_2 (R = 0.204), VOC and NO_2 (R = 0.150), VOCs and SO_2 (0.116), PM_{10} and SO_2 (0.213), PM_{10} and $PM_{2.5}$ (0.929), with the implication that a decrease in one parameter leads to a corresponding decrease in another parameter. The observed correlations among the air pollutants particularly VOCs, NO_2, and $PM_{2.5}$ In the wet season and SO_2, NO_2, VOCs and PM_{10} during the dry season could be attributed to a relatively similar source. The relative humidity observed in this study is considered high (59.2 to 73.3%) across both seasons, hence under high humid conditions, semi-volatile substances and aerosols are readily absorbed resulting in increasing temperature inversion [45]. This prevents the vertical diffusion of air pollutants through the stabilization of atmospheric stratification [46]. The correlation between PM_{10} and $PM_{2.5}$ (R = 0.779; R = 0.929) was positively strong at both seasons. However, the relationship was stronger in the dry season. This implies that increase in the concentrations of $PM_{2.5}$ results in an increase in PM_{10} levels in both seasons.

Table 4: Correlation among air pollutants in dry and wet season

Parameter	CO-dry	NO_2-dry	SO_2-dry	VOC-dry	$PM_{2.5}$-dry	PM_{10}-dry
CO-dry	1					
NO_2-dry	-0.020	1				
SO_2-dry	-0.048	**0.376****	1			
VOC-dry	0.053	**-0.173****	-0.104	1		
$PM_{2.5}$-dry	-0.086	**-0.123****	-0.026	**0.221****	1	
PM_{10}-dry	-0.055	-0.091	-0.009	**0.200****	**0.779****	1
Parameter	CO-wet	NO_2 wet	SO_2 wet	VOC-wet	$PM_{2.5}$ wet	PM_{10}-wet
CO-wet	1					
NO_2-wet	-0.061	1				
SO_2-wet	0.074	**0.204****	1			
VOC-wet	0.061	**0.150****	**0.136****	1		
$PM_{2.5}$-wet	-0.029	0.025	**0.223****	0.116**	1	.
PM_{10}-wet	-0.048	0.006	**0.213****	0.073	**0.929****	1

**=Correlation is significant at p<0.01

3.6 Relationship between air quality and meterological parameters

The correlation results are presented in Table 5. The result showed that a weak negative correlation existed between NO_2, SO_2 and temperature (R = -0.211 and -0.144) in the dry season while temperature correlated negatively weak with CO and VOC (R = -0.236 and -0.181) in the wet season. This suggests that during a low-temperature regime, the concentrations of NO_2 and SO_2 increase. This study is similar to the reports of [47, 48], who observed negative relationships between ambient air temperature and gaseous pollutant concentrations in Abeokuta and Lagos during the wet and dry seasons [49].

Okimiji *et al.* [48], suggested that the conversion of gaseous pollutants into ozone in addition to the relatively increased temperature under the vertical dispersion regime could be responsible for the inverse relationship. However, Nwosisi *et al.* [50], reported a positive relationship between in situ temperature and NO_2 in Delta States, Nigeria, and attributed this to the role of temperature during the photochemical reactions undergone by gaseous pollutants. In the wet season, RH correlated positively with CO, NO_2 and SO_2 (R = 0.298, 0.127 and 0.33I).

The relationship between the ambient relative humidity and CO, $PM_{2.5}$ and PM_{10} (R = -0.103, -0.238 and – 0.174) was weakly negative but positive with NO_2 and SO_2 in the dry season (Table 5). The inverse relationship between RH and CO and particulates implies that an increase in ambient relative humidity indicates a decrease in air pollutants [50] also observed that high relative humidity which is indicative of high rainfall could result in a scavenging effect of atmospheric pollutants, hence reducing their concentrations in the air. A decreasing trend between the ground level concentration of particulates and increasing relative humidity has been reported by [51]. Afrin *et al.* [52] reported that the growth and posterior wet precipitation of particles were caused by the inverse associations between ambient relative humidity and $PM_{2.5}$ in Dhaka. The correlation between wind speed, CO and VOC (R = -0.208; -0.251) was weakly significantly positive in the dry season. This implies that an increase in wind speed will reduce the pollutant concentrations from the emitting source due to dispersion towards the up-wind direction.

Generally, there were poor associations between the air pollutant concentrations and the meteorological parameters in this study. Filonchyk and Yan [43] suggested that increased atmospheric

air pollutants are not always determined by in situ weather conditions but could be influenced by the prevailing weather conditions in the nearby areas.

Table 5: Correlations between meteorological parameters and air pollutants levels

Parameter	Temp	RH	Wind speed
CO-dry	0.030	**-0.103****	**-0.208****
NO_2-dry	**-0.211****	**0.125****	0.014
SO_2-dry	**-0.144****	**0.107****	0.021
VOC-dry	0.081	-0.066	**-0.251****
$PM_{2.5}$-dry	-0.055	**-0.238****	0.088
PM_{10}-dry	-0.029	**-0.174****	0.082
CO-wet	**-0.236****	**0.298****	**0.161****
NO_2-wet	0.048	-0.014	**0.122****
SO_2-wet	**0.069***	**0.127****	0.075
VOC-wet	**-0.181****	**0.332****	-0.063
$PM_{2.5}$wet	0.076	0.013	0.009
PM_{10}-wet	-0.098	0.025	-0.059

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

3.7 Explanatory factors of air pollutant concentrations

The contributions of temperature, relative humidity and wind speed on air pollutant concentrations were examined for both dry and wet seasons using multiple regression analysis. The results presented in Table 6 revealed that the coefficient of determination (R^2) of in situ meteorological parameters with monitored air pollutant concentrations ranged from 2.7 to 15.5% in both the dry and wet seasons. This implies that the meteorological parameters contributed less than 20% of the concentrations of air pollutants in the study areas and therefore, have low predictive power for the air pollutant concentrations. This study is at variance with the reports of Okimiji *et al.* [48] who observed higher predictive powers of temperature, atmospheric pressure and relative humidity in coastal slum settlements in Lagos, Nigeria.

Table 6: Explanatory factors of air pollutant concentrations

Regression Model Parameter (Dry season)	**R**	**R^2**	**R^2 (%)**	**Std. error of the estimate**	**Sig. F**
Y_{CO} = 2.453 + 0.011Temp - 0.006RH – 1.069WS	0.243	0.059	5.9	0.690	0.001
Y_{NO2} = 0.087 – 0.0020Temp + 0.000054RH + 0.0.08WS	0.221	0.049	4.9	0.019	0.001
Y_{VOC} = 24 .305+0.237Temp + -0.062RH + 40.117WS	0.026	0.065	6.5	23.621	0.001
$Y_{PM2.5}$ = 207.005 -- 3.665 111Temp -0.644RH +18.883WS	0.313	0.098	9.6	26.477	0.001
Y_{PM10} = 215.964 – 3.608Temp - 0.664RH + 24.422WS	0.227	0.052	5.2	39.409	0.001
Regression Model Parameter (Wet season)					
Y_{CO} = -2.746 + 0.128Temp + 0.012RH + 0.201WS	0.394	0.155	15.5	17.931	0.001
Y_{SO2} = -0.064 - 0.001Temp + 0.0017RH + 0.001WS	0.177	0.031	3.1	0.021	0.001
Y_{VOC} = 68.435 -1.690Temp + 0.222RH + 5.323WS	0.022	0.050	5.0	24.529	0.001
$Y_{PM2.5}$ = -24.447 + 0.520Temp + 0.639RH – 1.471WS	0.226	0.051	5.1	17.753	0.001
Y_{PM10} = -13.849 – 0.532Temp - 0.607RH - 2.458WS	0.182	0.033	3.3	21.526	0.001

Temp=Temperature; RH=Relative humidity; WS=Windspeed R^2=Coefficient of determination

3.8 Health Risk analysis using AQI index

The AQI spatial and seasonal maps for CO across the sampling locations are presented in Figure 4. The AQI for CO varied from 17 to 125 and 21 to 133 in the dry and wet seasons respectively. The AQI score for CO was good in most of the sampling locations except in C13 (123) in the dry season and 133 (wet season).

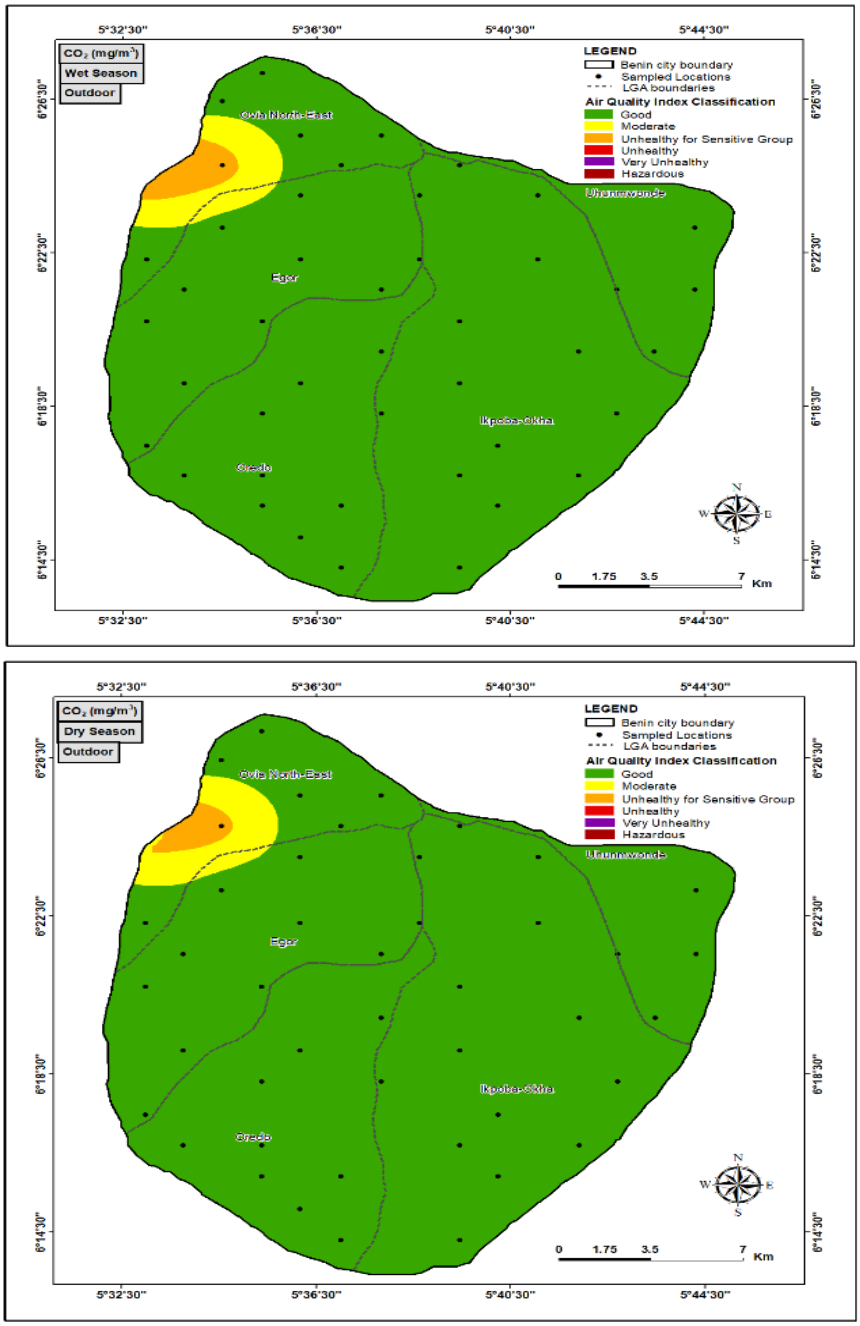

Fig 4: AQI of ambient CO in the wet and dry seasons

These areas have an AQI rating of unhealthy for sensitive group status. Sampling location C113 is the Ekosodin area in Ovia north. It is mainly occupied by students who predominantly utilize generators as a power source which is the major source of unhealthy levels of carbon oxide in the area. [53] reported that persistent exposure to moderate levels of carbon (II) oxide often causes clinical manifestations such as headache, fatigue, dizziness and nausea. However, at elevated levels, CO can react with haemoglobin forming carboxyl haemoglobin and resulting in hypoxia and cardiovascular

disorders in exposed individuals [54]. The AQI values ranged between 112 to 185 and 67 to 153 in the dry and wet seasons respectively (Figure 5). The spatial map also showed that the AQI status for $PM_{2.5}$ in both seasons was generally moderate to unhealthy for sensitive individuals and unhealthy. The air quality status of respirable PM prevalent in the sampling locations is of public health significance as it can pose varying undesirable health effects on the residents.

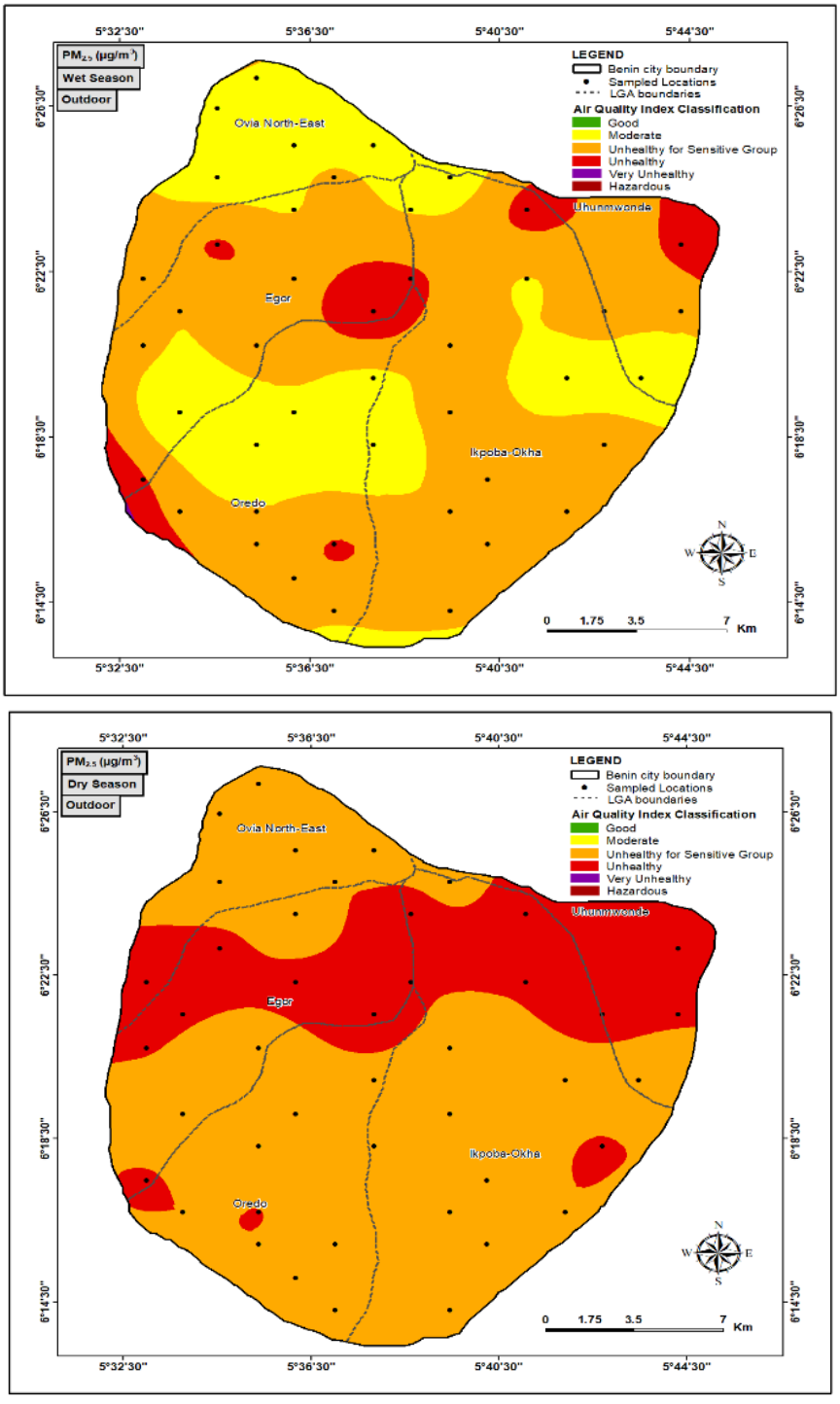

Fig 5: AQI of ambient $PM_{2.5}$ in the wet and dry seasons

Possible sources of unhealthy levels of $PM_{2.5}$ across the sampling areas may be attributed to vehicular exhaust due to relatively dense traffic on major roads and within the streets which are prominent across the areas. High density-built environment and increased human activities could also be the

reason for unhealthy concentrations of $PM_{2.5}$ in the sampling locations. $PM_{2.5}$ can induce various symptoms of pulmonary inflammation and structure impairment. Studies have shown that there is a link between increased and long-term exposure to increased levels of $PM_{2.5}$ [55, 56]. The AQI for PM_{10} at wet and dry seasons ranged between 23 to 89 and 47 to 93 in the dry season (Figure 6). The AQI status for PM_{10} across the sampling locations was good and moderate. The AQI scores of PM_{10} were higher in the dry season across the locations than in the wet season. The unplanned urban expansion characterized by so many unpaved roads could be one of the sources of coarse particulates in Benin City. Epidemiological studies have shown that increased exposure to PM_{10} concentrations is associated with the rate of death from cardiovascular and respiratory illness [57, 58].

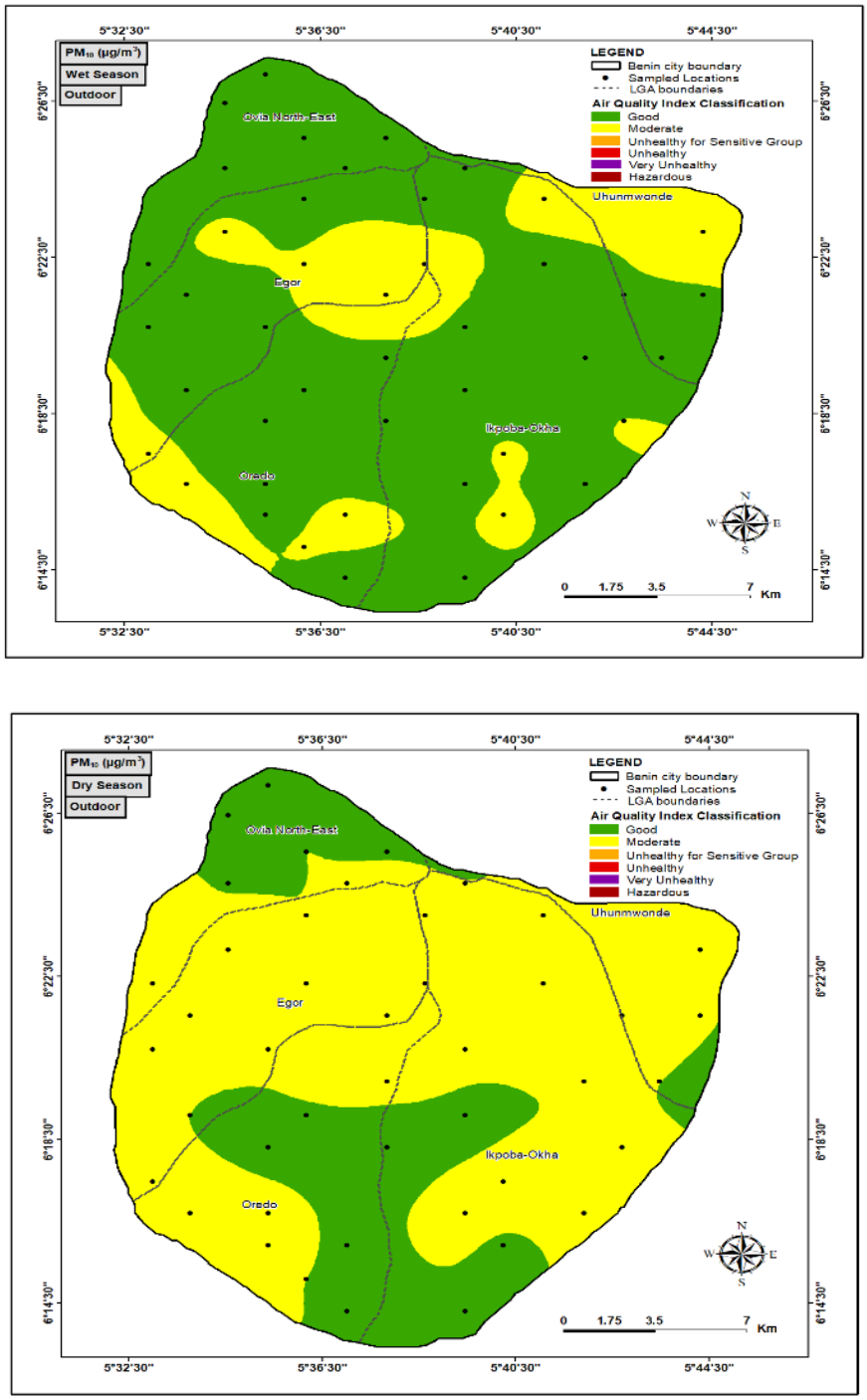

Fig 6: AQI of ambient PM_{10} in the wet and dry season

Conclusion

The seasonal air pollutant levels monitored in Benin metropolis in Nigeria were subjected to statistical and geospatial analysis to examine the variations and their relationships with the prevailing meteorological conditions, during the sampling. The monitored air pollutants (CO, NO_2, SO_2, and VOCs) were all observed within WHO regulatory limits except for $PM_{2.5}$ and $PM_{10,}$ which were higher than the allowable limits. Air pollutants varied significantly across the sampling locations and also with seasons. The PCA revealed the sources of predominated particulate pollution in the study area. The major sources of PM in Benin City include vehicular emissions, indiscriminate burning of refuse, road dust particles and other anthropogenic activities within the area. There were weak positive and negative relationships among air pollutants in both seasons except for $PM_{2.5}$ and PM_{10} (R = 0.779; R = 0.929). Generally, poor associations existed between the air pollutants and the meteorological parameters across the sampling area. This suggests that there could be other unaccounted factors influencing the distribution of air pollutants in the study area. The risk assessment revealed that the AQI status for particulate matter was predominantly unhealthy. This implies that residents around the study area are exposed to unhealthy levels of particulate matter. This study, therefore, underscores the need for routine air quality monitoring in Benin City together with enlightenment and awareness programmes on the health impacts of exposures to air pollutants particularly particulates.

Acknowledgement
The author acknowledges the technical inputs of Mr. Abayode Bamidele of the Department of Chemistry, University of Benin

Disclosure statement: *Conflict of Interest:* The authors declare that there are no conflicts of interest.
Compliance with Ethical Standards: This article does not contain any studies involving human or animal subjects.

References

[1] A.L. Power, R.K, Tennant, R.T, Jones, Y, Tang, J and Du, A.T. Worsley and J. Love. Monitoring Impacts of Urbanisation and Industrialisation on Air Quality in the Anthropogenic Using Urban PondSediments. *Front. Earth Sci*. 6(2018)131. doi: 10.3389/feart.2018.00131

[2] WHO. Methods and data sources for global causes of death 2000-2012. Global Health Estimates Technical Paper WHO/HIS/HSI/GHE/2014.7. 2016, Available: http:// www.who.int/entity/healthinfo/global_burden_disease/Accesse 23 March 2012.

[3] O. Oguntoke, F. O, Emoruwa and A.M. Taiwo. Assessment of air pollution and health hazard associated with sawmill and municipal waste burning in Abeokuta Metropolis, Nigeria. Environ. Sci. Pollut. Res, 26(2019)32708–32722 https://doi.org/10.1007/s11356-019-04310-2

[4] M. Bonzini, A. Tripodi, A. Artoni, L. Tarantini, B. Marinelli, P.A. Bertazzi, P. Apostoli and A. Baccarelli. Effects of inhalable particulate matter on blood coagulation. J. Thromb. Haemost, 8(2010)662–668. https://dx.doi.org/10.1111%2Fj.1538-7836.2009.03694.x

[5] C.O. Akanni. Spatial and seasonal analysis of traffic-related pollutant concentrations in Lagos Metropolis, Nigeria. Afr. J. Agric. Res, 5(2010)1264–1272

[6] A.A. Komolafe, S.A. Adegboyega, A.Y.B, Anifowose, F.O. Akinluyi, D.R. Awoniran. Air pollution and climate change in Lagos, Nigeria: needs for proactive approaches to risk

management and adaptation. *Amos J. Environ. Sci*, 10(4) (2014) 412–423. doi.org/10.3844/ajessp.2014.412.423

[7] M.S. Burroughs Peña and A. Rollins. Environmental exposures and cardiovascular disease: A challenge for health and development in low- and middle-income countries. *Cardiology Clinics*, 35 (2017) 71–86. doi: 10.1016/j.ccl.2016.09.001.

[8] J. Lelieveld, J. Evans and M. Fnais. The contribution of outdoor air pollution sources to premature mortality on a global scale. *Nature*, 525(2015)367–371. https://doi.org/10.1038/nature15371

[9] B. Karimi and B. Shokrinezhad. Air pollution and mortality among infant and children under five-years: a systematic review and meta-analysis. *Atmos. Pollut. Res*. 11(2020) 61–70

[10] A.F. Eghomwanre, O. Oguntoke, A.M. Taiwo. Levels of indoor particulate matter and association with asthma in children in Benin City, Nigeria, *Environ, Monit and Assess* 194(2022) (6),467

[11] F.W. Ko, W. Tam, T.W. Wong, C.K. Lai, G.W. Wong, T.F. Leung and D.S. Hui. Effects of air pollution on asthma hospitalization rates in different age groups in Hong Kong. *Clin. Exp. Allerg,* 37(2007)1312–1319.

[12] M.H. Cheng, C.C. Cheng, H.F. Chiu and C.Y. Yang. Fine particulate air pollution and hospital admission for asthma: A case-crossover study in Taipei. *J. Toxicol. Environ. Health*, 77 (2014) 071–1083.

[13] H. Qiu, L, W. Hian, V.C. Pun, K.F. Ho, T.W. Wong and I.T. Yu. Coarse particulate matter associated with increased risk of emergency hospital admissions for pneumonia in Hong Kong. *Thorax,* 69 (2014) 1027–1033.

[14] M. Franchini and P.M. Mannucci. Thrombogenicity and cardiovascular effects of ambient air pollution. *Blood,* 118 (2011) 2405–2412.

[15] D.E. Newby, P.M. Mannucci, G.S. Tell, A.A. Baccarelli, R.D. Brook, K. Donaldson, F. Forastiere, M. Franchini, O.H. Franco, O.H and I. Graham, Expert position paper on air pollution and cardiovascular disease. *Eur. Heart J.,* 36 (2015)83b–93b.

[16] N. Islam, M.G. Saroar, T. Ahmed. Meteorological influences on atmospheric particles in Darus Salam Area of Dhaka City. In Proceedings of the 4th International Conference on Civil Engineering for Sustainable Development (ICCESD), Khulna, Bangladesh, 9–11 Feb. 2018; pp.1–12. Available online: http://www.iccesd.com/proc_2018/Papers/r_p4167.pdf (accessed March, 2020)

17] World Health Organization. Ambient (Outdoor) Air Pollution. (2018) Available online: https://www.who.int/(Accesed March 24, 2022)

[18] FMEnv. National Emission Standards for Hazardous Air Pollutants for Source Categories. Portland Cements Manufacturing Industry. Federal Register. 1 (1999). Available online: https://www.gpo.gov/fdsys/pkg (accessed on 14 June 2021)

[19] F. Gilbert, N. Serge, N.L. John, L. Samuel. "Air Quality and Human Health Risk Assessment in the Residential Areas at the Proximity of the Nkolfoulou Landfill in Yaoundé Metropolis, Cameroon", J. Chem, 20(2019):19- 29. https//doi.org/10.1155/2019/3021894

[20] USEPA, (2006) "Air Quality Index: A guide to air quality and your health". EPA-456/F-14-002. United States EPA, office of Air quality planning and standards outreach and information division research, Triangle Park, NC, pp1-8.

[21] USEPA (2015) Air Quality Index (AQI). A Guide to Air Quality and Your Health. Accessed August 2021

[22] Meng X, Wu Y, Pan Z, Wang H, Yin G, Zhao H. (2019) Seasonal characteristics and particle-size distributions of particulate air pollutants in Urumqi. Int. J. Environ. Res, 16:396. https://doi.org/10.3390/ijerph16030396
[23] Z. Bodor, K. Bodor, A. Keresztesi, R. Szép. Major air pollutants seasonal variation analysis and long-range transport of PM in an urban environment with specific climate condition in Transylvania (Romania). *Environ. Sci Pollut. Res* 27. (2020):38181–38199
[23] D. Schwela. Review of Urban Air Quality in Sub-Saharan Africa Region. Reviews of Urban Air Quality in Sub Saharan Africa Region. (2012).
[25] N. Toure, N.D. Guèye, A.M. Diokhane, G. Jenkins, M. Li, M. Drame, K. Coker, K. Thiam Observed and Modeled Seasonal Air Quality and Respiratory Health in Senegal During 2015 and 2016. *GeoHealth,* 3 (2020) 423–442.
[26] P. Knippertz, M.J. Evans, P.R Field, A.H. Fink, C. Liousse, J.H Marsham. The possible role of local air pollution in climate change in West Africa. Nat. Clim. Change, 5(9) (2015) 815–822. doi:10.1038/nclimate2727
[27] P.A. Okhakhu. Meteorological services for disaster risk prevention and mitigation in Nigeria. *Environ. Earth Sci,* 4(8) (2014) 66-76.
[28] H. Adedeji, O. Oluwafunmilayo and T.A.O. Oluwaseun. Mapping of traffic related air pollution using GIS techniques in Ijebu-Ode, Nigeria. *Indones J. Geogr*, 48(1) (2016)73.
[29] A.O Adunola and A. Kolawole. Thermal comfort considerations and space use within residential buildings in Ibadan, Nigeria. Proceedings of 7th Windsor Conference: The changing context of comfort in an unpredictable world Cumberland Lodge, Windsor, UK, 12-15 April 2012. London.
[30] E.E. Ukpebor, J.E. Ukpebor, F. Eromomene, J.I. Odiase and D. Okoro. Spatial and Diurnal Variations of Carbon Monoxide (CO) Pollution from Motor Vehicles in an Urban Space. *Pol. J. Environ. Stud*., 19 (2010) 817-823.
[31] V.S. Balogun and O.I.O. Orimoogunje. Geo-Spatial mapping of air pollution in Benin City, Nigeria, *J. Geo, Environ. Earth Sci Int,* 3(3) (2015)1-17.
[32] M. Taiwo, T.A. Arowolo, K. Abdullahi and O.T. Taiwo. Particulate Matter Pollution In: Nigeria: A review proceedings of the 14th International Conference on environmental science and technology Rhodes, Greece, 3-5 September, (2015) 1-8.
[33] S. Nimyel and M. Namadi. Determination of selected air quality parameters in Zaria and its environs, Kaduna State, Nigeria. J. Appl. Sci. Environ *Manage* 23 (8) (2019) 1505-1510.
[34] H.H. Obanya, N.H. Amaeze, O. Togunde and A.A. Otitoloju. Air Pollution Monitoring Around residential and transportation sector locations in Lagos Mainland. *J. Health Pollut,* 8(19) (2018)180-193.
[35] J.T. Ayodele and F. Abubakar. Sulphur dioxide as indoor pollutant in Kano municipality Kano-Nigeria. *J. Environ. Chem. Ecotoxicol,* 2(1) (2010) 9-13
[36] T.F. Ediagbonya, E.E. Ukpebor and F.E. Okieimen. Correlation of meteorological parameters and dust particles using scatter plot in a Rural community. *Ife J. Sci.* 15(3) (2013) 445 – 453
[37] A.O Adunola and A. Kolawole. Thermal comfort considerations and space use within residential buildings in Ibadan, Nigeria. Proceedings of 7th Windsor Conference: The changing context of comfort in an unpredictable world Cumberland Lodge, Windsor, UK, 12-15 April 2012. London.
[38] V.S. Balogun, O.I.O. Orimoogunje. Geo-Spatial mapping of air pollution in Benin City, Nigeria, *J. Geo. Environ. Earth Sci. Int.* 3 (3) (2015) 1-17
[39] P.N. Ede, D.O. Edokpa. Regional air quality of the Nigeria's Niger Delta. *Open J. Air Pollut,* 4 (2015) 7–15.

[40] M.Z. Jacobson. Fundamentals of atmospheric modeling, 2nd edition, Cambridge University press, New York; (2005)120-125.
[41] A.E. Gobo, T.J.K. Ideriah, T.E Francis and H.O. Stanley, Assessment of air quality and noise around Okrika communities, Rivers State, Nigeria. *J. Appl. Sci. Environ Manage* 16 (1) (2012)75 – 83.
[42] C.U. Onuorah, T.G. Leton and O.L.Y. Momoh. Temporal Variability of Particulate Matter in Urban Area of Port Harcourt, Nigeria. *Asian Journal of Advanced Research and Reports*, *7*(2) (2019)1-7
[43] M. Filonchyk, H. Yan. The characteristics of air pollutants during different seasons in the urban area of Lanzhou, Northwest China. *Environ. Earth Sci,* 77(2018) (22). https://doi.org/10.1007/s12665-018-7925
[44] F.F. Oyebanji, G.R.E.E Ana, O.O. Tope-Ajayi, Y.A. Sadiq and Y. Mijinyawa. Air Quality Indexing, Mapping and Principal Component Analysis of Ambient Air Pollutants around Farm Settlements across Ogun State, Nigeria, *Appl. Environ. Res,* 43(2) (2021)93-105
[45] J. Yang, Z. Ji, S. Kang, Q. Zhang, X. Chen and S.Y. Lee. Spatiotemporal variations of air pollutants in western China and their relationship to meteorological factors and emission sources. *Environ. Pollut,* 254 (2019)112952.
[46] N. Cheng, B. Cheng, S. Li and T, Ning. Effects of meteorology and emission reduction measures on air pollution in Beijing during heating seasons. *Atmos. Pollut. Res.* 10 (2019) 971–979. https://doi.org/10.1016/j.apr.2019.01.005
[47] O. Oguntoke, F.O. Emoruwa, A. M, Taiwo. Assessment of air pollution and health hazard associated with sawmill and municipal waste burning in Abeokuta Metropolis, Nigeria. *Environ Sci Pollut Res* 26(3) (2019) 2708–32722. https://doi.org/10.1007/s11356-019-04310-2
[48] O.P. Okimiji, K. Techato, J.N. Simon, O.O. Tope-Ajayi, A.T. Okafor, M.A. Aborisade and K. Phoungthong. Spatial Pattern of Air Pollutant Concentrations and Their Relationship with Meteorological Parameters in Coastal Slum Settlements of Lagos, Southwestern Nigeria. *Atmosphere*, 12 (2021) 1426
[49] J. Wang, Y. Wang, H. Liu, Y. Yang, X. Zhang, Y. Li, Y. Zhang and G. Deng. Diagnostic identification of the impact of meteorological conditions on $PM_{2.5}$ concentrations in Beijing. *Environ. Int.* 81 (2013) 158–165.
[50] M.C. Nwosisi, O. Oguntoke, A.M. Taiwo, Dispersion and emission patterns of NO_2 from gas flaring stations in the Niger Delta, Nigeria. *Model. Earth Syst. Environ.* 6 (2020) 73–84 https://doi.org/10.1007/s40808-019-00658-z
[51] Y. He, I. Uno, Z. Wang, T. Ohara, N. Sugimoto, A. Shimizu, A. Richter and J.P. Burrows. Variations of the Increasing Trend of Tropospheric NO2 over Central East China during the Past Decade. *Atmos. Environ,* 41 (2008) 4865–4876.
[52] S. Afrin, M. Islam and T. A. Ahmed. Meteorology Based Particulate Matter Prediction Model for Megacity Dhaka. *Aerosol Air Qual Res* 21 (2020) 200-371
[53] A.P. Jones. Indoor Air Quality and Health, In: *Air Pollution Science for the 21st Century*, Austin, J., Brimblecombe, P. and Sturges, W(Eds.), Elsevier Science Ltd., Oxford, United Kingdom, (2002) 57-116.
[54] D.G. Levitt, M.D. Levitt. Carbon monoxide: a critical quantitative analysis and a review of the extent and limitations of its second messenger function. Clinical pharmacology: *Adv. Appl*, 7 (2015) 37–41

[55] C.A. Pope, R.T. Burnett, D. Krewski, M. Jerrett, Y. Shi, E.E. Calle and M.J. Thun. *Cardiovascular Mortality and Exposure to Airborne Fine Particulate Matter and Cigarette Smoke: Shape of the Exposure-Response Relationship. Circulation*, 120(11) (2009) 941–948. doi:10.1161/circulationaha.109.85.

[56] J. Lelieveld, J. Evans, M. Fnais M. The contribution of outdoor air pollution sources to premature mortality on a global scale. *Nature*, 525 (2015) 367–371. https://doi.org/10.1038/nature15371

[57] J.M. Samet, F. Dominici, F.C. Curriero, I. Coursac, S.L Zeger. Fine Particulate Air Pollution and Mortality in 20 U.S. Cities, 1987–1994. *New Eng J. Med,* 343 (2000) (24):1742–1749. doi:10.1056/nejm200012143432401

[58] T. Ma, F. Duan, K. He, Y. Qin, D. Tong, G. Geng, X. Liu, H. Li and S. Yang. "Effects of airborne particulate matter on respiratory morbidity in asthmatic children", *J. Epidemio,* 18(3) (2008) 97-110 http://dx.doi.org/10.2188/jea.JE2007432 JECHDR 0141-7681

(2022) ; http://www.jmaterenvironsci.com