



Source Identification and Pollution Factors of Elements in PM_{2.5} Samples Obtained in Akure, Ondo State, Nigeria

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Abstract

Air quality deterioration is a big concern all over the world. It affects both humans and animals in a variety of ways. Air pollution must be quantified to monitor its negative impacts and stakeholders to proffer mitigation options. On this note, our research team has taken measures in Nigeria to monitor and measure PM_{2.5}, its associated elements, as well as local meteorological parameters during sampling period. In addition, enrichment, contamination index, and principal component analysis of associated elements were studied. For ten months (January–October 2018), PM_{2.5} samples were collected at three locations in Ondo State, Nigeria with coordinates (the Federal University of Technology, Akure (FUTA)—low-density residential (LDR), Oba Ile (high-density residential (HDR), and Museum (IND, High density traffic and commercial area) (January–October). The Contamination Factor (CF), Enrichment Factor (EF), and Pollution Load Index (PLI), as well as Principal Component Analysis (PCA) of the samples were determined. Average PM_{2.5} mass concentrations [101 µg/m³ (FUTA); 120 µg/m³ (Oba Ile); and 176 µg/m³ (Museum)] were found to be higher than the WHO (10 µg/m³) and USEPA (15 µg/m³) normal limits. The concentrations of the most prominent elements were in the order; K > Na > Ca > P > Al, while the trace elements displayed Cu > Fe > Zn > Ni > Cr > Mn > Pb. Oba-Ile had the highest metal enrichment in the order: Ti > Mn > Zn > Cu > Ni > Cr. The PCA resolved four factors vis-à-vis vehicular activities, biomass burning, and soil dust as the major PM_{2.5} emission sources. The findings could be useful in the current drive to develop national air quality guideline for PM_{2.5}.

Keywords PM_{2.5} · Trace metals · Air quality index · Enrichment factor · Contamination factor · Pollution load index · Principal component analysis · World Health Organization · United State Environmental Protection Agency

1 Introduction

Urban air pollution is typically caused by a complex mix of gaseous and particulate air pollutants such as nitrogen dioxide (NO₂), sulfur dioxide (SO₂), fine particulate matter (PM_{2.5}), and ground-level ozone (defined as aerodynamic

diameter particulate matter (PM_{2.5}) (Abulude et al. 2021). Atmospheric particulate matter has been linked to negative effects on human health, visibility, and atmosphere, as well as habitats and physical property degradation (UNEP/WHO 1994). The scale of atmospheric aerosols affects human health and the climate. As a result, studies of size-segregated atmospheric particulate matter particularly fine (PM_{2.5}) fractions are often required to gain a better understanding of its sources as well as aids in proffering abatement options. Different sources (natural and anthropogenic) and atmospheric residence periods can exist for PM_{2.5} fraction; however, PM_{2.5} sources are majorly linked to anthropogenic activities such as industrial, biomass and petroleum components combustions, waste incineration, vehicular emissions, and so on (Ezeh et al. 2015; Suriano et al. 2015; Penza et al. 2018; Suriano 2020).

Continuous exposure to PM_{2.5} exposure has a slew of negative health implications. In exposed populations, there have been increase in morbidity and mortality rates resulting

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from infections, cardiovascular, chronic pulmonary, and neurodegenerative diseases, as well as a decrease in life expectancy (Kim et al. 2015). $PM_{2.5}$ can be breathed into the deepest recesses of the lungs due to its vast surface area, small size, and the fact that it contains a significant amount of toxic properties. It settles on the alveoli and also makes its way into the bloodstream, posing a health risk to humans (Zhang et al. 2016). Fe, Co, Ni, Cu, Zn, V, Cr, Mn, As, Pb, and Cd can increase reactive oxygen species production (ROS) whose excess can overpower the body's antioxidant defense mechanism, leading to oxidative stress, inflammation, and disease infections (Sameenoi et al. 2012; Charrier and Anastasio 2015; Park et al. 2018).

Trace elements are efficient atmospheric air pollution tracers (Querol et al. 2007) and are commonly used as input in receptor modeling studies to help in the interpretation of particular emission sources. The Principal Component Factor (PCA), is one of the versatile modeling approaches which efficiently uses elemental concentration data and classifies potential source contributions. The characterization and source detection of trace elements in $PM_{2.5}$ are critical in air pollution prevention and control. These methods have attracted a lot of attention from researchers in recent times, because PMs Study could reveal information regarding emission sources and strength.

To address the problem of air pollution, stakeholders would need to have adequate knowledge of air pollution by particulate matter and also on policies for abatement options. The best tool which is receptor modeling for PMs' source identification and quantification should be applied (Yu et al. 2013; Roy and Singh 2014; Ndamitso et al. 2016; Feng et al. 2007). The application of a multivariate technique to identify and assign sources to pollutants at the receptor locations irrespective of emission time, strength, and transport is known as receptor modeling. In most urban cities in the developing nations, there is very little or no published work on source apportionment and $PM_{2.5}$ and thus this study. Therefore, the objectives of this study are to determine $PM_{2.5}$ mass loads, investigate the relationship between $PM_{2.5}$ and local meteorology, and perform chemical compositions of $PM_{2.5}$ samples as well as the application of principal component analysis technique for source identification and quantification in Akure, South Western Nigeria.

2 Materials and Methods

Akure is the capital of Ondo State, South West and it has a population of about 421,100. Geographically, Akure lies on $t 5^{\circ}12'0''E$, and $7^{\circ}15'0''N$, at a height of 353 m (GeoNames Geographical Database 2012). Akure is a fast-growing city that serves as a trading hub for cash crops such as cocoa, cola nuts, palm oil and kernels, bitter cola citrus fruits, and so on.

Three distinct sampling locations (National Museum and Monuments, Oba-Ile, and the Federal University of Technology—FUTA) were chosen (Table 1 and Fig. 1). These sites represents industrial (IND), high-density residential (HDR), and low-density residential (LDR) site classes. Samplings lasted for at least 8 h (8:00–16:00 h.) for ten (10) months (January–October) of 2018. GPS Map 76CSX (Garmin Ltd, Taiwan) was used to assess the sampling geographical coordinates. At the Observatory Unit of the Federal University of Technology in Akure, Ondo State, Nigeria, wind direction and speed, rain, and relative humidity (RH) were also monitored and measured to aid in the explanation of the influence of local meteorology on $PM_{2.5}$ aerosols.

PM was collected using a Schlumberger Model M250 “Gent” stacked filter unit sampler (Maenhaut et al. 1993). The samples were collected using Whatman nuclepore filters that had been pre-weighed and pre-conditioned, at flow rates ranging from 16 to 18 L min. Before and after exposure, the filters were conditioned for 24 h at about 25 °C and 50% constant humidity. The sampler was positioned at a height of around 1.7 m, so that air circulation around it was not obstructed. To prevent filter clogging and keep the flow rate within the sampler's prescribed limits, the effective sampling time was varied. This ensured accurate size fractionation and efficient selection. Detailed procedure on the use of Gent stacked filter unit sampler for $PM_{2.5}$ collection has been reported (Ezeh et al. 2012). The exposed filters were stored in a desiccator until chemical composition analysis using the XRF technique.

The EDXRF analyses of exposed filters were achieved via a portable facility (model PX 2CR power supply and amplifier for XR-100CR Si-pin Detector) at Centre for Energy Research and Development, Obafemi Awolowo University, Ile-Ife Nigeria. Sample irradiation was done by exposing

Table 1 The sampling locations

S/N	Location	Description of sites
1	Oba Ile (SEDInst) (005 14 29.1 E), (07 16 04.4 N)	HDR
2	The Federal University of Technology, FUTA (Science car park), (005 08 06.5 E), (07 18 07.6 N)	LDR
3	National Museum, (005 11 40.2 E), (07 15 11.6 N)	IND high-density traffic and commercial area

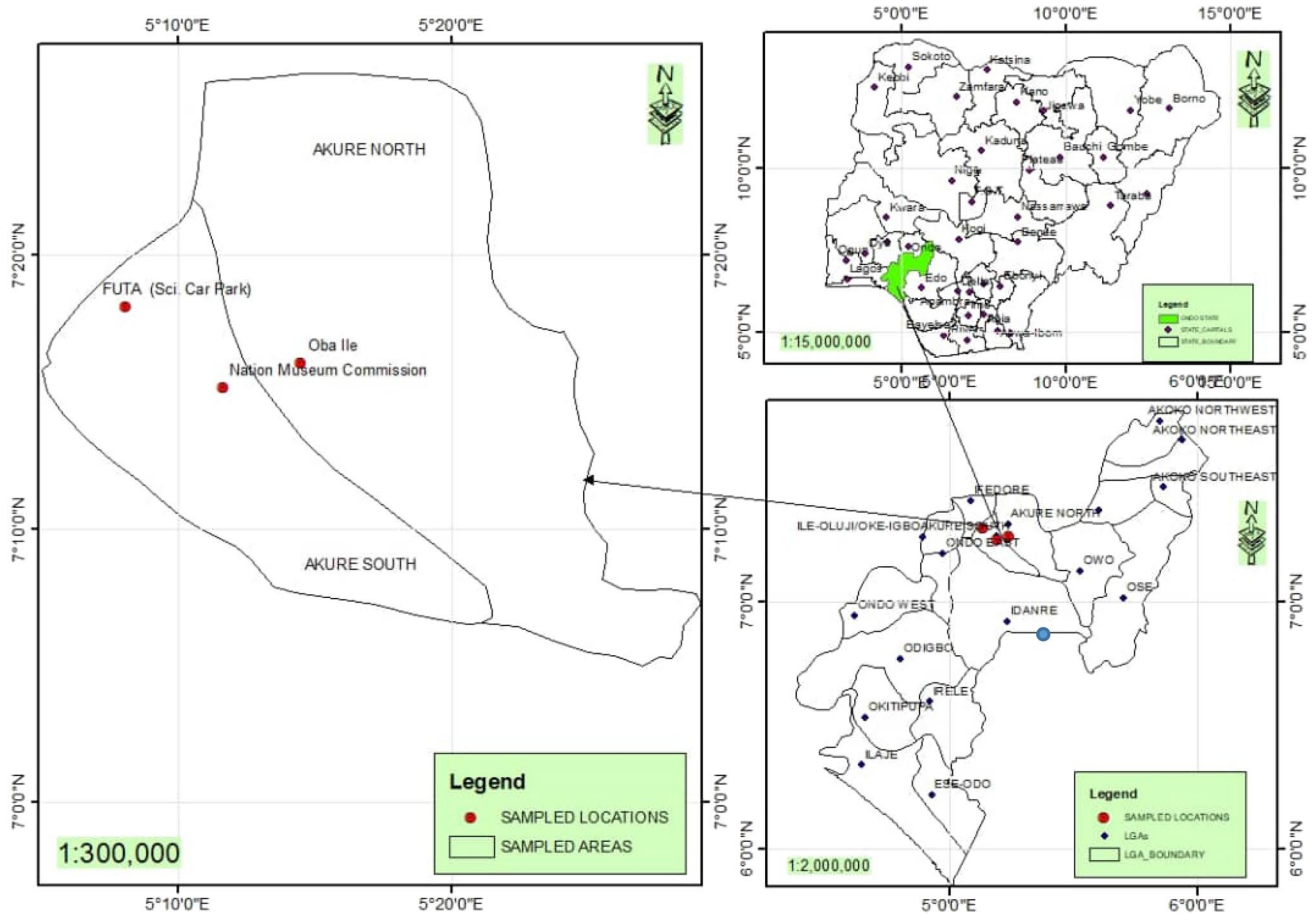


Fig. 1 Akure study areas (Source: Field Work 2018)

the samples for bombardment by silver (Ag) anode X-ray fluorescence spectrometer at a voltage of 25 kV and current of 50 μA for 1200 counts in an external chamber setup. Characteristic X-ray of the sample was detected by the solid-state Si-pin detector system and spectrum acquisition was done using an Amptek model multi-channel analyzer, while elemental analysis was done using the thin target mode of the International Atomic Energy Agency (IAEA) Quantitative Analysis of X-ray Iterative Least (Q-Axil) square software. Prior to the analysis, certified Micrometer[®] thin films (Table 2) were irradiated for calibration purposes.

2.1 Calculation

Concentration (μg^{-3})

$$= \frac{\text{Instrument reading (cm}^2) \times 1000}{\text{Filter area (cm}^2) \times \text{Volume of air sucked (m}^3)} \quad (1)$$

Principal component analysis (PCA) defined by James et al. (2015) was used to classify the sources of the pollutants

Table 2 Results of comparison of observed experimental values with IAEA certified standard reference values thin films

Element	Certified values ($\mu\text{g cm}^{-2}$)	Experimental values ($\mu\text{g cm}^{-2}$)
Ca	47.4	46.5
Fe	46.3	46.1
Pb	52.8	51.3
In	50.2	49.9
Ru	46.1	46.0

(PM, Na, Mg, Al, P, S, K, Ca, Ti, V, Cr, Mn, Fe, Ni, Cu, Se, Zn, and Pb) (2015).

To identify the sources of PM_{2.5} at the study areas, principal component analysis (PCA) with varimax rotation of the components was achieved using Minitab software. Varimax rotation was done to get a clearer pattern of the components without changing their relative positions. Detailed methodology for performing PCA can be found in Jolliffe et al. (2016) and De La Cruz et al. (2019).

The enrichment factor (EF) of the element of interest is the ratio of the element’s concentration to a reference value

(Gonzalez-Macias et al. 2006; Pandey et al. 2015). Fe was often chosen as reference factor, because it is assumed to have only source of crustal material. The enrichment factor (EF) is a tool for assessing whether the source of elements is from crust or human activity (Bhuiyan et al. 2010; Gowd et al. 2010). This factor was used to measure EF:

$$EF = \frac{(C_i/C_{ref})_{\text{sample}}}{(B_i/B_{ref})_{\text{Background}}}, \quad (2)$$

where C_i denotes the concentration of trace elements in the sample, C_{ref} denotes the concentration of the reference element in the sample, B_i denotes the background value of an element of interest, and B_{ref} denotes the background value of the reference element in the study field. The results were categorized into seven classes based on the value of EF: If $EF < 1$ no enrichment, < 3 minor enrichment, $3-5$ moderate enrichment, $5-10$ moderate-to-severe enrichment, $10-25$ severe enrichment, $26-50$ very severe enrichment, and > 50 extremely severe enrichment.

Contamination factor (CF) as defined by Dantu (2009) and Bhuiyan et al. (2010) CFs of the elements of interest was used to calculate the overall contamination of samples by the elements (2010). These figures were calculated by dividing the concentration of the element of interest in the sample by the element's background concentration (Hakanson 1980)

$$CF = C_i/B_i, \quad (3)$$

C_i is the element i 's concentration and B_i is the element's geochemical background value. The pollution values are 0 = none, 1 = none-to-mild, 2 = moderate, 3 = moderate-to-heavy, 4 = strongly contaminated, 5 = strong-to-very strong, and 6 = very strong in increasing order of contamination (Varol 2011).

The pollution load index (PLI) was created after Tomlinson et al. (1980) used Eq. (3) to compare pollution levels at different sites or at the same site over time. The estimation of the concentration factor obtained by dividing the measured concentration of an element with the background concentration of the same element in shale is used to calculate the PLI (Turekian and Wedepohl 1961)

$$PLI = n\sqrt{CF_1 \times CF_2 \times CF_3 \times \dots \times CF_n}. \quad (4)$$

2.2 Calculation of Air Quality Index

An index for any given pollutant is its concentration expressed as a percentage of the relevant standard (Abulude 2016), or

$$\text{Air Quality Index} = \frac{\text{Pollutant concentration}}{\text{Pollutant standard level}} \times 100. \quad (5)$$

One-way analysis of variance (ANOVA) with Duncan Multiple Range test at 95% confidence or $p < 0.05$ was used to analyze the results. The correlation coefficients were determined based on the results. Minitab 16 Statistical Software was used to compute basic descriptions and PCA. Microsoft Excel was used to calculate the enrichment factor, contamination factor, and wind rose.

3 Results and Discussion

The average concentrations of $PM_{2.5}$ measured at the study site classes are presented in Fig. 2. During the sampling periods, mean concentrations of $PM_{2.5}$ ranged from $101 \mu\text{g}/\text{m}^3$ (LDR) to $176 \mu\text{g}/\text{m}^3$ (HDR), while the overall mean stood at $120 \mu\text{g}/\text{m}^3$. Compared with the results obtained elsewhere in some sub-Sahara mega-cities in Nigeria, the concentrations obtained in this study were lower than range of values reported for IND and HDR sites in Lagos (Ezeh et al. 2017). $150-606 \mu\text{g}/\text{m}^3$ (industrial) and $110-460 \mu\text{g}/\text{m}^3$ (high-density residential) reported by Ezeh et al. (2019) However, mean concentration of $PM_{2.5}$ obtained in this study were higher than mean values recorded in China. Acciai et al. (2017) and Huang et al. (2018) equally, higher than values (Gunchin et al. 2019), measured in Ulaanbaatar Mongolia, by 10%, Košetice Czech (Pokorná et al. 2018), by 10%, Terviso Italy (Squizzato et al. 2017), and by 15% and Athens Greece (Grivas et al. 2018) by 20%). Compared to $PM_{2.5}$ guidelines of the WHO and USEPA (Fig. 2), the results obtained in this study were more than three times of both reference values. This scenario is worrisome and could be dangerous for the inhabitants of the study areas.

Considering the US EPA's Air Quality Index (AQI) for reporting air quality (AirNow.gov 2018) deterioration by $PM_{2.5}$; Scale 0–50 is defined as a Good, 51–100 is Moderate, 101–150 is Unhealthy for sensitive groups, 151–200 indicated Unhealthy, 201–300 denoted Very Unhealthily, and 301 and above is classified as Hazardous. In this study, average $PM_{2.5}$ concentrations obtained at LDR and Oba Ile (IND) areas were categorized as Unhealthy for sensitive groups, while AQI for HDR receptor site is categorized as Unhealthy (Table 3). This index implies that members of sensitive groups may experience health effects.

In Table 4, parameters with strong positive correlation are bolded. Although, there was a mild positive association between $PM_{2.5}$ mass concentrations and temperature (Table 4). This means that $PM_{2.5}$ concentration is a function of the ambient temperature. At the HDR, LDR, and IND sampling sites, wind speed (WS) has a significant positive association with $PM_{2.5}$ ($r = 0.87$, $r = 0.61$, and $r = 0.35$), with

the HDR having the strongest connection. The HDR, LDR, and IND had *r* values of 0.59, 0.62, and 0.71 for ambient temperature and PM_{2.5} values, respectively. With *r* values of 0.05 (FUTA), 0.28 (Museum), and 0.31 (FUTA), relative humidity (RH) had a weak relationship with PM_{2.5} mass concentration at IND. It was also discovered that the meteorological parameters had relationships that effects PM_{2.5} mass concentration. Rain (*r*=0.67) was found to be related to wind speed. Wind also had positive (*r*=0.50) relationship with humidity. These positive correlations suggest that

local emission could account for air quality deterioration in Akure by PM_{2.5}.

The summaries of wind directions in percentages and directions as the wind rose are shown in Fig. 3. Each month, the wind directions are denoted by the letters ‘N’ (north) to ‘NNW (north–north–west).’ The percentages represents the number of times each wind direction occurred during the sampling period. The wind blew majorly from the east in January, while in the following months, its directions were predominantly; ESE (February), SW (March), WSW (April), WSW (May), S (June), SSW (July), SW (August),

Fig. 2 Particulate matter concentration

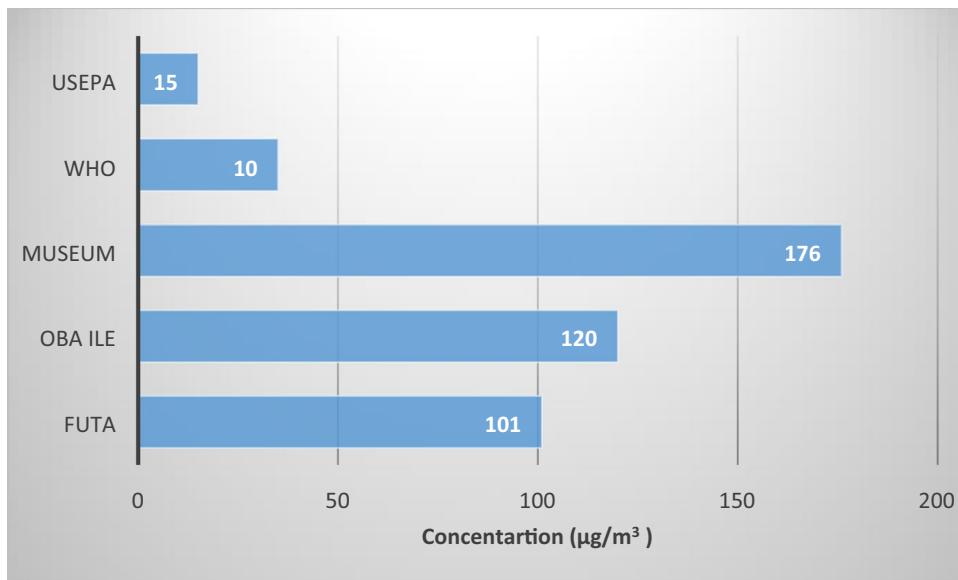


Table 3 Air quality index of the selected sampling locations

Sample Locations	Air Quality Index					
	Good 0 to 50	Moderate 51 to 100	Unhealthy for sensitive groups 101 to 150	Unhealthy 151 to 200	Very Unhealthy 201 to 300	Hazardous 301 and above
LDR	-	-	102.00±30.00	-	-	-
HDR	-	-	-	169.00±40.00	-	-
IND	-	-	120.10±30.00	-	-	-

Source: AirNow.gov (Accessed 2018).

Table 4 The Pearson correlation (*r*) matrix of the PM and local meteorological data

	FUTA	Museum	Oba-Ile	Rain	Temperature	Wind	Humidity
FUTA	1						
Museum	0.38	1					
Oba Ile	0.20	0.00	1				
Rain (mm)	0.30	0.89	0.78	1			
Temperature (°C)	0.60	0.66	0.72	0.45	1		
Wind (m/s)	0.35	0.84	0.60	0.65	0.171	1	
Humidity (%)	0.05	0.28	0.31	0.37	0.17	0.60	1

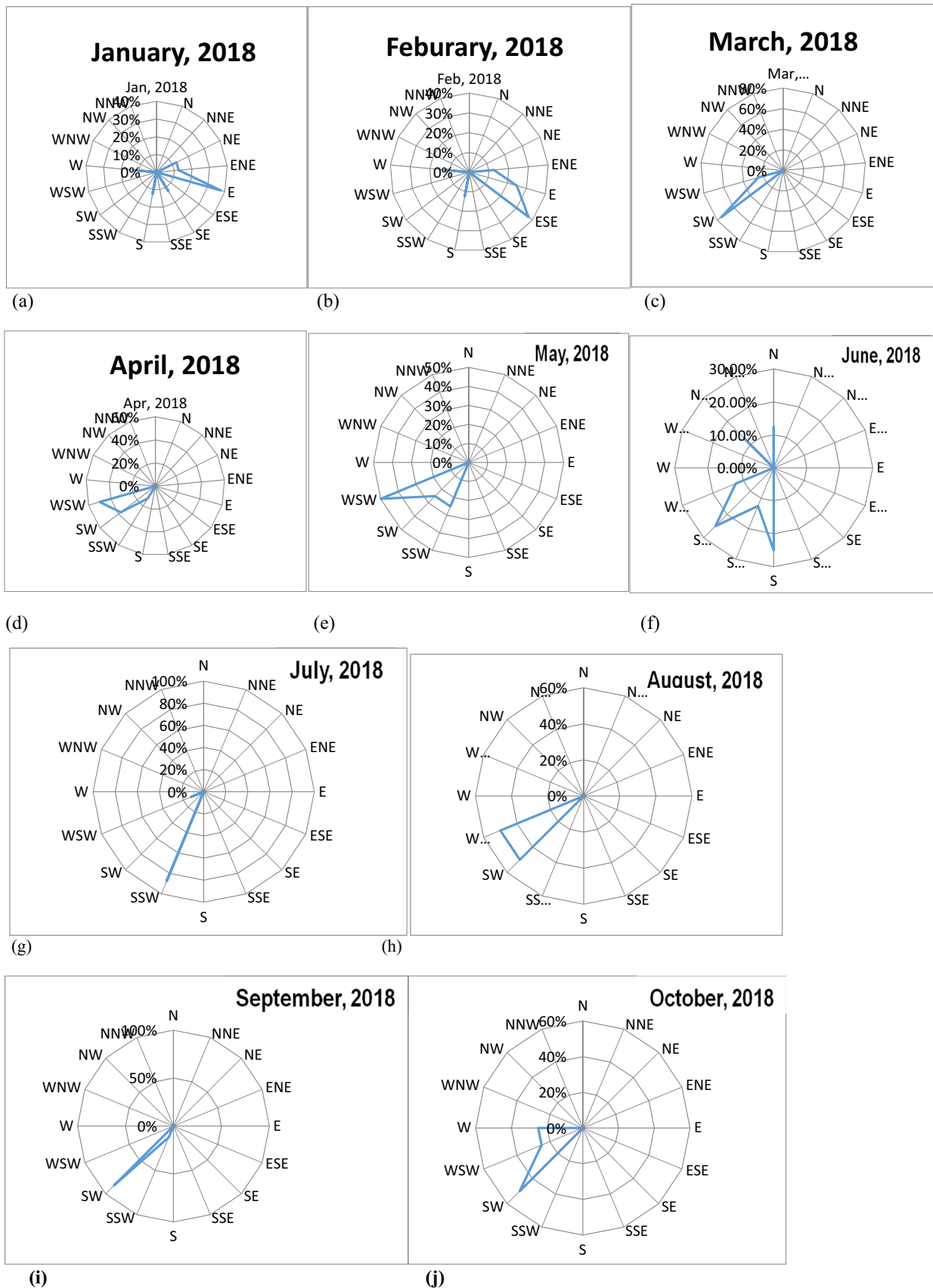


Fig. 3 Wind direction (July–October 2018)

SW (September), and SW (October) (SW). These confirms that the wind direction during sampling were predominantly from the SW and WSW. Table 5 provides average local meteorology data measure during sampling period 3.71 mm, (Rainfall) 26.10 °C, (Temperature) 5.84 m/s (Wind speed), and 77.34% (Humidity). The variance ranged from 1.27 (rain) to 11.54 (humidity). Interestingly, rain had positive values, while others had negatives, according to the skewness results. Negative values were skewed to the left, while positive values were skewed to the right, implying that if the distribution of data is skewed to the left, the mean is less than the median, which is frequently less than the mode. If the data distribution is skewed to the right, the mode is frequently less than the median, which is less than the mean. In addition, the monthly mean wind speed ranged from 4.00 to 7.63 m/s, while that of temperature and humidity ranged from 19.75 to 31.23 °C and 21 to 94.38% respectively. Rainfall ranged from 0 (dry season) to 3.5 mm (wet season).

The concentrations of major and trace elements in the PM_{2.5} were calculated and are presented in Table 6. In addition, the results were compared to values reported for other cities in Nigeria and beyond. The overall summation of the elemental concentrations (Fig. 4) varied throughout the study sites, with the highest observed at the HDR site, followed by IND and LDR, respectively. The heavy human and vehicular traffic at the HDR location could led to the high concentrations of major and trace elements found there. Main and trace elements were classified into two groups based on their temporal and spatial variation; group 1 consists of Na, Mg, Al, K, Ca, Ti, V, P, Cr, Mn, Ni, Zn, and Fe, while group 2 consists of S, K, and Cu. Copper was found in high concentrations in the IND and HDR regions, while S and K were found in high concentrations in all the sites. The mean concentration of V (15–28 ng m⁻³), Mn (13–25 ng m⁻³), Ni (15–28 ng m⁻³), and Pb (ND) were all within the limits set by the World Health Organization (WHO; 1000, 150, 25, and 500 ng m⁻³ for V, Mn, Ni, and Pb, respectively), the European Air Quality Directive (EU Directive 2007/107/EC; 20 and 500 ng m⁻³ for Ni and Pb, respectively), and the National Ambient Air Quality Standard (NAAQS) of China (500 ng m³ for Pb) (Liu et al. 2020).

The enrichment factor, or EF, is a tool for assessing the chemical structure of airborne particulate matter. It explains the relationship between the concentrations of an element (X) in the air and the concentration of a crustal element (such as Al, Ti, or Fe) in the typical continental crust (Hoffmann et al. 1972; Wedepohl 1971; Zoller et al. 1983). The crustal composition (Taylor 1964) and Fe as the normalizing factor were used to measure EFs for each element. Since Fe is a crustal variable with less anthropogenic impact, it is a good option for a normalizing agent. Elements with an EF close to unity have strong natural source, while those with a high EF may be anthropogenic aerosols. In Fig. 5, the enrichment factor for PM_{2.5} associated elements is shown and most elements were not enriched, since their EF values were less than five. For instance, respective EF values were 0.67–1.02 (Na), 0.08–0.14 (Al), 3.05–3.39 (S), 1.6–3.52 (K), 1 (Fe), 1.33–2.69 (Cr), and 1.23–2.69 (V) while Se and Pb had zero enrichment factors. Low enrichment factors could indicate that the pollutants could be from natural source, especially sea spray and soil dust components.

The pollution load index (PLI), which had values ranging from 0.1 to 1.2, was also used to categorize ecological risk. The mean PLI value (0.1) in this analysis was much smaller than the threshold (1) and suggested that there were no baseline contaminants or loads similar to background levels (Tomlinson et al. 1980). Because of the low PLI values, no drastic abatement measures are needed at the study areas; however, continued air quality deterioration by PM_{2.5}. The findings showed that ecological risk assessment approaches can be used as decision-support mechanisms or instruments for determining the priority of air quality assessment studies.

Across the sites, Contamination Factor (CF) value for V, Cr, Mn, Fe, Ni, Cu, Zn, and Mn ranged from 0.11 to 0.21, 0.12 to 0.28, 0.26 to –0.5, 1, 0.2 to 0.37, 3.82 to 3.96, and 0.39 to 0.5, respectively. Other less significant CF values include Na (0.001), Mg (0.001), Al (0–8.61E–05), P (0.01–0.017), S (0.28–0.32), K (0.003–0.004), Ca (0.001), and Ti (0.001). (0.003–0.08). Of all the heavy metals, Cu had the highest value at IND and HDR locations, while Cr had the lowest value (0.12) at LDR. Figure 4

Table 5 Average weather data in the study periods

	Rain (mm)	Temperature (°C)	Wind speed (m/s)	Humidity (%)
Mean	3.71	26.10	5.84	77.34
SE mean	2.62	1.27	0.35	6.81
Std Dev	1.27	4.01	1.12	11.54
Coef var	223.02	15.36	19.13	27.85
Minimum	0.00	19.75	4.00	21.25
Maximum	27.10	31.23	7.63	94.38
Skewness	3.08	–0.25	–0.22	–2.28
Kurtosis	9.63	–1.50	–0.44	5.93

Table 6 Elemental concentrations compared with other countries

Element	Typical crustal rock*	This study (ng/m ³)								
		FUTA	Oba Ile	Museum	Saudi Arabia ^a	Nigeria ^b	Czech Republic ^c	China ^d	Taiwan ^e	China ^f
Na	28,300	20 (2)	17 (2)	27 (2)	ND-700	22–2087	–	–	1708.06–1772.9	–
Mg	20,900	11 (3)	14 (2)	17 (3)	ND-2479	39–1518	12.4–299	–	42.80–46.32	–
Al	81,300	6 (3)	7 (2)	11 (3)	ND-3572	300–21,511	10.2–392	–	23.22–39.19	–
P	1050	11 (5)	14 (5)	18 (4)	ND-61.3	89–1457	–	–	–	–
S	260	72 (3)	73 (2)	83 (4)	ND-2608.3	2–264	–	–	–	–
K	25,900	82 (5)	88 (5)	76 (4)	ND-47.5	54–3250	–	489.51–20,311.00	–	390
Ca	36,300	17 (2)	24 (2)	18 (2)	ND-783.5	159–796	50.1479	136.22–11,187.00	–	190
Ti	4400	14 (2)	26 (3)	35 (4)	–	22–2042	–	–	0.8–0.98	–
V	135	15 (5)	27 (5)	28 (5)	–	133	–	0.00–58.63	1.35–1.73	26
Cr	100	12 (2)	28 (2)	24 (3)	–	125	4.2×10 ⁻¹ –10.4	0.29–103.51	0.55–0.87	4.5
Mn	50	13 (2)	17 (2)	25 (3)	ND-3.2	2–249	–	9.17–293.69	3.90–4.96	32
Fe	50,000	45 (5)	52 (5)	47 (4)	ND-79.7	194–15,903	50.1–456	247.71–7,685.00	66.08–69.6	410
Ni	75	15 (1)	22 (2)	28 (3)	ND-25.9	114	–	0.13–30.09	0.78–0.9	6
Cu	55	210 (8)	218 (8)	218 (8)	ND-0.4	125	2.2–15.6	3.88–191.63	3.92–5.17	12
Zn	70	27 (4)	31 (5)	35 (5)	ND-2.2	7–431	–	54.13–3,867.00	6.00–24.66	120
Se	0.05	ND	ND	ND	–	–	–	1.03–44.11	–	2.6
Pb	13	ND	ND	ND	–	169	–	25.06–598.02	–	–
Total		570	658	690	–	–	–	–	–	–

ND not detected

^aRushdi et al. (2013) (Saudi Arabia)

^bEzeh et al. (2019) (Nigeria)

^cJandacka and Durcanska (2019) (Czech Republic)

^dAcciai et al. (2017) (China)

^eHuang et al. (2018) (Taiwan)

^fChang et al. (2018) (China)

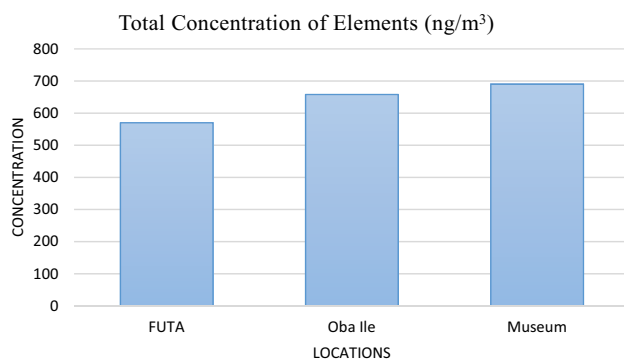


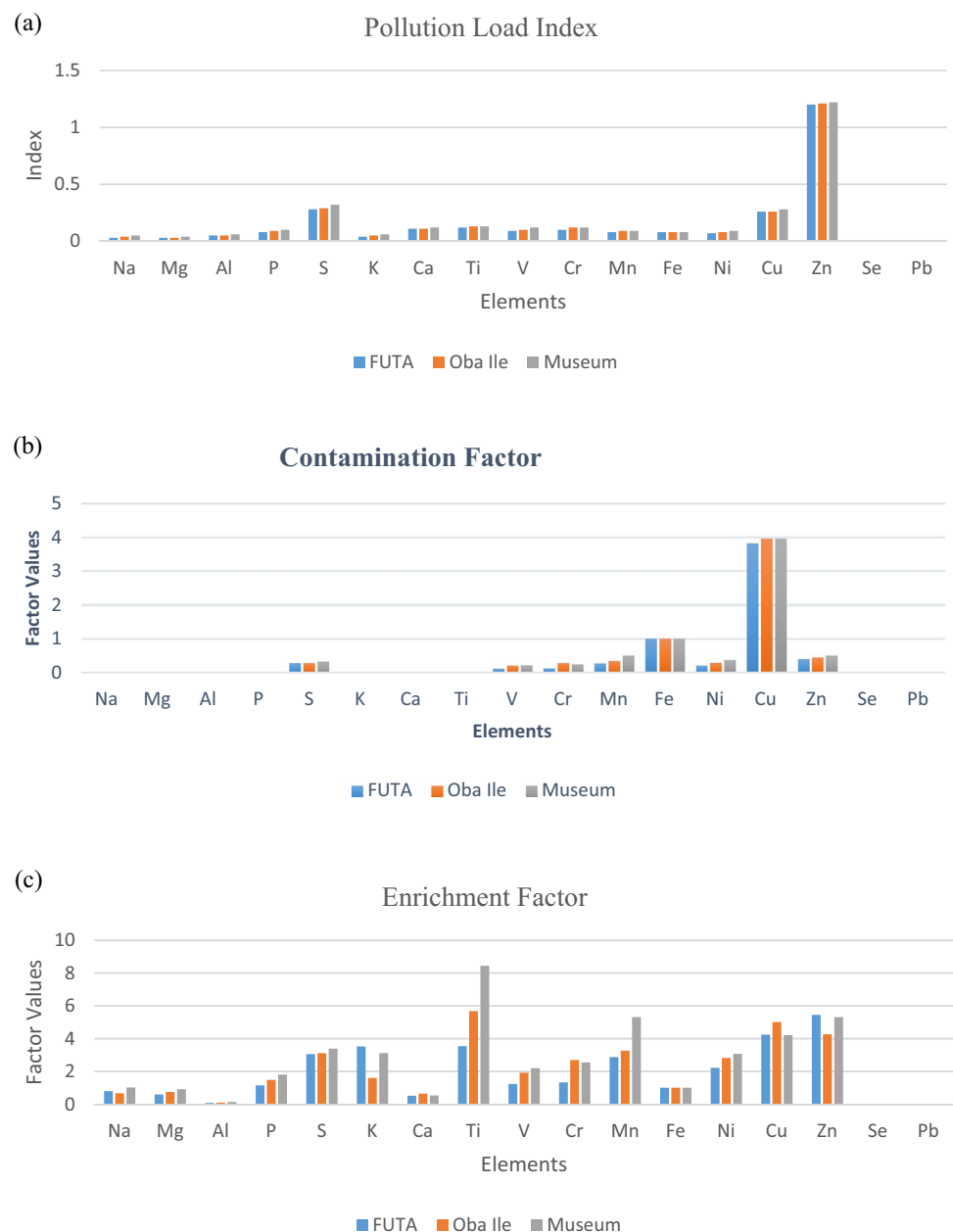
Fig. 4 Total concentration of elements at the different sites (January–October)

depicts the average CF values for each metal in the order: Cu > Zn > Mn > Ni > Cr. There are six categories of CF: 1–2 denotes depletion to minimal enrichment, 2–5 means moderate enrichment, 5–20 depicts significant enrichment, and 20–40 represents extremely high enrichment, while > 40 denotes extremely high enrichment (Sutherland 2000). The

results obtained in this study suggests that the CF is somewhere between minimal and moderate enrichment category which implies that the samples from the locations are not contaminated.

For source apportionment and identification, PCA resolved five distinct factors with their corresponding components (Table 7). Factors 1, 2, 3, 4, and 5 had 65.5, 65.3, 32.7, 23.2, and 11.5% average variation, respectively. Factor 1 revealed significant loading for Mg, P, Ca, Cr, Fe, Ni, and Zn, indicating input from the burning of automotive fuels, wastes, and tobacco smoke in and around the museum district, due to the high volume of vehicular traffic and waste generation generated by the market within the area. Without a doubt, there are a lot of smokers in the city, and a lot of people trade their hobbies. This aggravates the danger to the environment. Suffocation and worsening of asthma and chronic bronchitis, as well as respiratory inflammation, eye and mouth pain, and premature death, are all possible health effects. P, Fe, Cu, and K, as well as their sources, which were mostly parented rock material, dust, soil, and fertilizer, were all

Fig. 5 Plots showing the Pollution Load Index, Contamination Factor, and Enrichment Factor of element concentrations in $PM_{2.5}$ at different sites



present in VF2. However, these metals are also used in liming processes, which can result in respiratory problems, metallic dust poisoning, pulmonary fibrosis, lung cancer, dizziness, headaches, bronchitis, stomachaches, diarrhea, vomiting, loss of appetite, kidney and liver damage, and death (Wei et al. 2010). Cu, Ti, and Na loadings were highest in VF3, suggesting biomass combustion, diesel and residual oils, tobacco smoke, and steel non-ferrous alloys manufacturing. In the tannery industry, manganese is used in the form of salts $[MnCO_3]$ and $Mn(SO_4)_2$ (Tariq et al. 2006). Ca sources from the PM were illustrated by VF4. Plants and animals, as well as the skeletons of animals,

teeth, egg shells, coral, and many soils, are major sources of Ca in current PM. Calcium chloride is present in some water, especially seawater, at a concentration of 0.15%. Calcium does not occur in nature on its own. Calcium is mainly present in the form of limestone, gypsum, and other minerals. Significant loadings for S were found in VF5, indicating sources related to anthropogenic activities, specifically tire vulcanization. Many vulcanizers work along the streets in these neighborhoods, especially in the Oba Ile and Museum areas. Zinc is a vital trace element in living organisms, but it is insoluble and extremely rare in nature (Alloway 1990).

Table 7 Principal component analysis (PCA) of the samples

	PCA 1	PCA 2	PCA 3	PCA 4	PCA 5
FUTA	0.79	0.45	0.43	0.06	0.23
Oba Ile	0.68	0.64	0.45	0.07	0.05
Museum	0.67	0.52	0.34	0.77	0.07
Na	0.32	0.44	0.55	0.05	0.05
Mg	0.56	0.45	0.34	0.05	0.04
Al	0.23	0.43	0.23	0.23	0.07
P	0.65	0.51	0.12	0.34	0.04
S	0.26	0.32	0.23	0.09	0.62
K	0.43	0.55	0.33	0.08	0.05
Ca	0.97	0.48	0.45	0.5	0.06
Ti	0.23	0.18	0.51	0.09	0.02
V	0.47	0.41	0.05	0.06	0.05
Cr	0.79	0.62	0.08	0.09	0.03
Mn	0.32	0.55	0.45	0.44	0.04
Fe	0.64	0.64	0.47	0.47	0.03
Ni	0.55	0.34	0.34	0.23	0.04
Cu	0.23	0.56	0.6	0.5	0.04
Zn	0.88	0.65	0.44	0.34	0.03
Se	0	0	0	0	0
Pb	0	0	0	0	0
Eigen value	6.2	3.9	2.4	2	1.57
Total variance (%)	65.6	56.3	32.7	23.2	11.5

Bold values indicate the data represent correlation of variables when the absolute value > 0.5

4 Conclusion

The PM_{2.5} levels found in this study were higher than those recorded by the WHO, the World Health Organization, and the US Environmental Protection Agency, and some countries in Asia, Europe, and the United States. The PM is dangerous for sensitive groups, according to the AQI of the places. PM_{2.5}'s effect on trace and heavy element enrichment, source apportionment, and pollution load index was also investigated. In contrast to previous research on PM performed elsewhere, measured concentrations of macronutrients and heavy metals were higher or lower. Cr, Ni, Cu, Mn, and Zn were added to the PM. Pollution was minimal in the elements. Anthropogenic and non-anthropogenic origins of PM were identified through multivariate analysis. Metals in the air can be apportioned at the source, which can aid decision-makers in developing management strategies to minimize pollution. The climate should be continually and properly controlled in the locations under study.

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Declarations

Conflict of Interest No potential conflict of interest was reported by the authors.

References

- Abulude FO (2016) Particulate matter: an approach to air pollution. Preprints. <https://doi.org/10.20944/preprints201607.0057.v1>
- Abulude FO, Damodharan U, Acha S, Adamu A, Arifalo KM (2021) Preliminary assessment of air pollution quality levels of Lagos, Nigeria. *Aerosol Sci Eng*. <https://doi.org/10.1007/s41810-021-00099-1>
- Acciai C, Zhang Z, Wang F, Zhong Z, Lonati G (2017) Characteristics and source analysis of trace elements in PM_{2.5} in the urban atmosphere of Wuhan in spring. *Aerosol Air Quality Res* 17:2224–2234
- AirNow.gov (2018) The USEPA air quality index basics. <https://www.airnow.gov/aqi/aqi-basics>. Accessed 7 April 2018
- Alloway BJ (1990) Heavy metals in soils. Wiley, New York
- Bhuiyan MAH, Parvez L, Islam MA, Dampare SB, Suzuki S (2010) Heavy metal pollution of coal mine-affected agricultural soils in the northern part of Bangladesh. *J Hazard Mater* 173:384–392
- Chang Y, Huang K, Xie M, Deng C, Zou H, Liu S, Zhang Y (2018) First long-term and near real-time measurement of trace elements in China's urban atmosphere: temporal variability, source apportionment and precipitation effect. *Atmos Chem Phys* 18:11793–11812. <https://doi.org/10.5194/acp-18-11793-2018>
- Charrier JG, Anastasio C (2015) Rates of hydroxyl radical production from transition metals and quinones in a surrogate lung fluid. *Environ Sci Technol* 49:9317–9325
- Dantu S (2009) Heavy metals concentration in soils of the southeastern part of Ranga Reddy district, Andhra Pradesh, India. *Environ Monitor Assess* 149:213–222
- De La Cruz AH, Roca YB, Suarez-Salas L, Pomalaya J, Tolentino DA, Gioda A (2019) Chemical characterization of PM_{2.5} at rural and urban sites around the metropolitan area of Huancayo (Central Andes of Peru). *Atmosphere* 10:21. <https://doi.org/10.3390/atmos10010021>
- Ezeh GC, Obioh IB, Asubiojo OI, Abiye OE (2012) PIXE characterization of PM 10 and PM particulates sizes collected in 2.5 Ikoyi Lagos, Nigeria. *Toxicol Environ Chem* 94:884–894
- Ezeh GC, Obioh IB, Asubiojo OI (2015) Multi-elemental analysis and source apportionment of urban aerosols in a low density residential area: a case study of Ikoyi Lagos Nigeria. *IFE J Sci* 17(2):415–427
- Ezeh GC, Abiye OE, Obioh IB (2017) Elemental analyses and source apportionment of PM_{2.5} and PM_{2.5-10} aerosols from Nigerian urban cities. *Cogent Environ Sci* 3:1323376
- Ezeh GC, Obioh IB, Asubiojo O, Abiye OA, Onyeuwaoma ND (2019) A study of PM_{2.5-10} pollution at three functional receptor sites in a sub-Saharan African megacity. *Aerosol Sci Eng* 3:65–74. <https://doi.org/10.1007/s41810-019-00044-3>
- Feng Y, Xue Y, Chen X, Wu J, Zhu T, Bai Z, Fu S, Gu C (2007) Source apportionment of ambient total suspended particulates and coarse particulate matter in urban areas of Jiaozuo, China. *J Air Waste Manage Assoc* 57:561–575

- GeoNames Geographical Database (2012) Population of Akure, Nigeria. <http://population.mongabay.com/population/nigeria/2350841/akure>. Retrieved 9 January 2016
- Gonzalez-Macias A, Schifter I, Lluch-Cota DB, Mendez-Rodriguez L, Hernandez-Vazquez S (2006) Distribution, enrichment and accumulation of heavy metals in coastal sediments of Salina Cruz Bay, Mexico. *Environ Monit Assess* 118:211–230
- Gowd SS, Reddy MR, Govil PK (2010) Assessment of heavy metal contamination in soils at Jajmau (Kanpur) and Unnao industrial areas of the Ganga Plain, Uttar Pradesh, India. *J Hazard Mater* 174:113–121
- Grivas G, Cheristanidis S, Chaloulakou A, Koutrakis P, Mihalopoulos N (2018) (2018) Elemental composition and source apportionment of fine and coarse particles at traffic and urban background locations in Athens, Greece. *Aerosol Air Qual Res* 18:1642–1659
- Gunchin G, Manousakas M, Osan J, Karydas AG, Eleftheriadis K, Lodoysamba S, Shagjjamba D, Migliori A, Padilla-Alvarez R, Strelci C et al (2019) Three-year long source apportionment study of airborne particles in Ulaanbaatar using X-ray fluorescence and positive matrix factorization. *Aerosol Air Qual Res* 19:1056–1067
- Hakanson L (1980) An ecological risk index for aquatic pollution control; a sedimentological approach. *Water Res* 14:975–1001
- Hoffmann GL, Duce RA, Hoffman EJ (1972) Trace metals in the Hawaiian atmosphere. *J Geophys Res Atmos* 77:5322–5329
- Huang J, Pan X, Guo X, Li G (2018) Impacts of air pollution wave on years of life lost: A crucial way to communicate the health risks of air pollution to the public. *Environ Int* 113:42–49
- James G, Witten D, Hastie T, Tibshirani R (2015) An introduction to statistical learning. In: Olkin GCSFI (ed) With applications in R, vol 6. Springer, New York, NY, USA. ISBN 9781461471370
- Jandacka D, Durcanska D (2019) Differentiation of particulate matter sources based on the chemical composition of PM10 in functional urban areas. *Atmosphere* 10:583. <https://doi.org/10.3390/atmos10100583>
- Jolliffe IT, Cadima J, Cadima J (2016) Principal component analysis: a review and recent developments. *Philos Trans Roy Soc A374:20150202*. <https://doi.org/10.1098/rsta.2015.0202>
- Kim K-H, Kabir E, Kabir SA (2015) review on the human health impact of airborne particulate matter. *Environ Int* 74:136–143
- Liu L, Liu Y, Wen W, Liang L, Ma X, Jiao J, Guo K (2020) Source identification of trace elements in PM_{2.5} at a rural site in the North China Plain. *Atmosphere* 11:179. <https://doi.org/10.3390/atmos11020179>
- Maenhaut W, Francois F, Cafmeyer J (1993) The “Gent” stacked filter unit sampler for the collection of atmospheric aerosols in two size fractions: description and instructions for installation and use. Coordinated Research Programme, CRP E4 International Atomic Energy Agency, Vienna
- Ndamitso MM, Abdulkadir A, Abulude FO (2016) Total atmospheric deposit source apportionment: a review. *Environ Skept Crit* 5(4):63–78
- Pandey B, Agrawal M, Singh S (2015) Ecological risk assessment of soil contamination by trace elements around the coal mining area. *J Soils Sediments*. <https://doi.org/10.1007/s11368-015-1173-8>
- Park J, Park EH, Schauer JJ, Yi S-M, Heo J (2018) Reactive oxygen species (ROS) activity of ambient fine particles (PM_{2.5}) measured in Seoul, Korea. *Environ Int* 117:276–283
- Penza M, Suriano D, Pfister V, Prato M, Cassano G (2018) Wireless sensors network monitoring of Saharan dust events in Bari, Italy. *Proceedings* 2:898. <https://doi.org/10.3390/proceedings2130898>
- Pokorná P, Schwarz J, Krejci R, Swietlicki E, Havránek V, Ždímal V (2018) Comparison of PM_{2.5} chemical composition and sources at a rural background site in central Europe between 1993/1994/1995 and 2009/2010: effect of legislative regulations and economic transformation on the air quality. *Environ Pollut* 241:841–851
- Querol X, Viana M, Alastuey A, Amato F, Moreno T, Castillo S, Pey J, de la Rosa J, Sánchez de la Campa A, Artíñano B et al (2007) Source origin of trace elements in PM from regional background, urban and industrial sites of Spain. *Atmos Environ* 41:7219–7231
- Roy D, Singh G (2014) Source apportionment of particulate matter (PM₁₀) in an integrated coal mining complex of Jharia coalfield, Eastern India. A review. *Int J Eng Res Appl* 4(4):97–113
- Rushdi AI, Al-Mutlaq KF, Al-Otaibi M, El-Mubarak AH, Simoneit BRT (2013) Air quality and elemental enrichment factors of aerosol particulate matter in Riyadh City, Saudi Arabia. *Arab J Geosci* 2013(6):585–599. <https://doi.org/10.1007/s12517-011-0357-9>
- Sameenoi Y, Koehler K, Shapiro J, Boonsong K, Sun Y, Collett J, Volckens J, Henry CS (2012) Microfluidic electrochemical sensor for on-line monitoring of aerosol oxidative activity. *J Am Chem Soc* 134:10562–10568
- Suriano D (2020) Sentin air system software: a flexible tool for data acquisition from heterogeneous sensors and devices. *SoftwareX* 12:100589. <https://doi.org/10.1016/j.softx.2020.100589>
- Suriano D, Prato M, Pfister V, Cassano G, Camporeale G, Dipinto S, Penza M (2015) Stationary and mobile low cost gas sensor systems for air quality monitoring applications. Conference Paper. <https://doi.org/10.5162/4EuNetAir2015/15>
- Sutherland RA (2000) Bed sediment-associated trace metals in an urban stream, Oahu, Hawaii. *Environ Geol* 39:611–637
- Squizzato S, Cazzaro M, Innocente E, Visin F, Hopke PK, Rampazzo G (2017) Urban air quality in a midsize city—PM_{2.5} composition, sources and identification of impact areas: from local to long range contributions. *Atmos Res* 186:51–62
- Tariq SR, Shah MH, Shaheen N, Khalique A, Manzoor S, Jaffar M (2006) Multivariate analysis of trace metal level in tannery effluents in relation to soil and water: a case study from Peshawar Pakistan. *J Environ Manag* 79:20–29
- Taylor SR (1964) Abundance of Chemical elements in the continental crust; a new table. *Geochim Cosmochim Acta* 28(8):1273–1285
- Tomlinson DL, Wilson JG, Harris CR, Jeffrey DW (1980) Problems in the assessment of heavy metal levels in estuaries and the formation of a pollution index. *Helv. Geol. Jahrb.* 33:566–575
- Turekian KK, Wedepohl KH (1961) Distribution of the elements in some major units of the earth’s crust. *Bull Geol Soc Am* 72:175–192
- United Nation Environment Programme/World Health Organization (UNEP/WHO) (1994) GEMS/AIR methodology reviews 1, suspended particulate matter in ambient air. WHO/EOS/94.3, UNEP/GEMS/94.A.4, UNEP, Nairobi, Kenya
- Varol M (2011) Assessment of heavy metal contamination in sediments of the Tigris River (Turkey) using pollution indices and multivariate statistical techniques. *J Hazard Mater* 195:355–364
- Wedepohl KH (1971) *Geochemistry*. Holt Rinehard and Winston Inc, New York, p 65
- Wei B, Jiang F, Li X, Mu S (2010) Heavy metal induced ecological risk in the city of Urumqi NW China. *Environ Monit Assess* 160:33–45
- Yu L, Wang G, Zhang R, Zhang L, Song Y, Wu B, Li X, An K, Chu J (2013) Characterization and source apportionment of PM_{2.5} in an urban environment in Beijing. *Aerosol Air Qual Res* 13:574–583
- Zhang T, Gao B, Zhou Z, Chang Y (2016) The movement and deposition of PM_{2.5} in the upper respiratory tract for the patients with heart failure: an elementary CFD study. *Biomed Eng* 15:138
- Zoller WH, Parrington JR, Phelankotra JM (1983) Iridium enrichment in airborne particles from Kilauea Volcano: January 1983. *Science* 222:1118–1121