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Seasonal and Multivariate Characteristics of Atmospheric Gases, Particulate Matter and Heavy Metals in Lagos-Suburban

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Aim: Insufficient data on atmospheric pollution research exists in Lagos-suburban areas, and in some cases, studies are yet to be carried out. The aim is to study criteria pollutants seasonal characteristics, suspended particulate matter, and particulate heavy metal concentrations interactions in the Lagos suburban by multivariate techniques

Methodology: Assessment of 3 criteria pollutants, suspended particulate matter (SPM), and 6 particulate heavy metal concentrations, at 10 different suburban locations in Lagos was performed and interpreted by multivariate analysis to determine their sources, distribution, and pollution status. AQI values indicated a non-hazardous environment that is moderately unhealthy and sensitive to vulnerable populations.

Results: Values of CO among the 10 sites ranged from 468-1350 µg/m^3 during the wet season, and 447-1864 µg/m^3 during dry seasons and both exceeded World Health Organization (WHO), and Nigerian Federal Ministry of Environment (FMEnv) regulations. NO_2 concentration exceeded the FMEnv standard and suggest the likelihood of health challenges to the unsuspecting population. Cl^- anion accounts for 85% of the total anion concentrations, and others had low standard deviations < 5%. A correlation of (Na^+ and SO_4^{2-}), (Ca^{2+} and NO_3^-), (K^+ and SO_4^{2-}) showed active atmospheric water chemistry in the study locations. Determined levels of Cd and Ni particulate did not exceed WHO guidelines, while only Alagbado and Surulere were the major Pb hotspots. Pearson

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correlation showed the heavy metals differ from each other during each season, but Zn/Zn and Fe/Fe showed a strong link between the metal concentrations and the seasons. Peripheral component analysis indicated that Cd and Cu particulate matter accounts for 75% of the variance, while cluster analysis showed the similarity of relationship in terms of concentration for the wet season.

Conclusion: The findings of the present study provided invaluable data on atmospheric pollution and the development of improved protocols for pollution guidelines in suburban Lagos.

Keywords: Particulate matter; ambient air; seasonal variation; air pollution; air quality.

1. INTRODUCTION

Air pollution is the emission of pollutants that are harmful to the climate human health and other living organisms. It has continued to impact greatly on the climate, agriculture, ecosystem, and human health because they cannot be effectively removed by the carbon cycle or the nitrogen cycle [1]. The continuous industrialization and active civilization of developing nations have contributed in no small measure to the increased levels of ambient air emissions via automobiles, agricultural activities, factories and industries, mining activities, and even domestic sources [2]. As a consequence, developing nations are beleaguered with the frequent challenge of controlling the atmospheric air pollution for the most part in the megacities; and strikingly little or no research efforts are concerted toward Suburbans of megacities in the world [3]. These efforts are expected to attract current attention, owing to a reported outbreak of cardiovascular diseases, pulmonary disease, and respiratory disease, increased mortality, acid rain, and frequent citing of haze [4]. Then again, studies in suburban regions are yet to capture suspended particulate matter and heavy metal particulates with ambient air gases [5]. Thus there is a need to study the pollutants concentration levels.

Gaseous atmospheric pollutants such as CO, NO_2, SO_2, SPM, have a severe negative impact on human health and contribute greatly to the disruption of the environment and atmospheric balance. The SO_2 and NO_2 undergo different chemical reactions in the atmosphere that leads to the formation of acid that ends up settling on the surfaces of water bodies (rivers, seas, and Oceans) [6]. Researchers are also of the opinion that with the rising cost of natural gases and renewable energy, consumption of fossil fuels and even wood-burning is far from being over. As a result, increased levels of SO_2, NO_2, CO, and even SPM are expected to continue to fluctuate at higher seasonal variations in suburban cities, while promoting climatic change and undesirable human health consequences [7]. Hence there is a genuine need to determine the emissions levels in suburban cities.

Interestingly, NO_2, CO, SO_2 are principal contributors of suspended particulate matter, and more often, the source, size, origin, and composition of suspended particulate matter determine the characteristics of the total particulate matter (TPM) and the emission factor [8]. Suspended particulate matter (SPM) is the sum of all particulate matter of solid and liquid particles that are suspended in the air and are also responsible for several health effects due to poor air quality, and these effects depend on local air quality [9]. For instance, PM10 and PM2.5 have long been associated with epidemiological studies and correlated to higher concentration levels of inhalable particles. Likewise higher morbidity and mortality owing to higher levels of SPM is a primary concern because the effect on the immune system is a leading cause of immune toxicity and increased risk of a range of diseases [10], given the vast composition and interaction of SPM with the human body, its mechanism remains. Subsequently, it is also unclear if synergistic effects among variables also induce health effects and that the observed effects are contributed partially by pollutants that co-occur in the ambient air [11]. These questions warrant the further investigation of SPM and particulate heavy metal pollutions around areas with little data output.

Particulate heavy metal accumulation poses a great potential threat to human health. They are classified as systemic toxicants which can induce multiple organ damage even at low concentrations [12]. Also according to the US environmental protection agency, they have been classified as human carcinogens with increasing ecological and global public health concerns [13]. Although they are an important constituent of biochemical and physiological functions in plants and animals, their atmospheric availability is influenced by sources, temperature, adsorption, and sequestration rate [14]. The heavy metal-induced human toxicity and carcinogenicity consists of several mechanisms which are still poorly understood. Hence assessment of pollution levels of heavy metal particulates is essential in understanding the ambient air relationship [15]. For instance, within the Lagos suburban, suspended heavy metal-induced health-related challenges are rarely reported. On the other hand, each metal makes a unique contribution due to its chemical composition and that confers specific environmental and human health challenges [16]. For instance, the main routes of entry for cadmium (Cd) are inhalation and ingestion of food causes such as abdominal pain, nausea, vomiting, salivation, muscle cramps, shock, loss of consciousness, and even convulsions within 15 to 30 min [17,18].

While lead and copper (Pb and Cu) are associated with impaired neurological behavior, lower intelligence quotient decreased hearing acuity and language handicaps in children. But when in acute exposure causes organ damage, gastrointestinal disease, and disruption n of the central nervous system [19,20] Some trace metals like iron and Nickel (Fe and Ni), because of their presence in trace amounts in various environmental matrices affect thermodynamic equilibrium, complexation kinetics in plants and lipid solubility, and other biochemical processes [21,22]. However, literature is scarce regarding atmospheric particulate metal determinations in suburban Lagos in Nigeria.

Lagos, Nigeria is one of the most densely populated megacities in the world, with about 18 million inhabitants within 1,200 per sq/km having a population density of about 6,500 residences per square kilometer. Lagos is predominantly inhabited by Nigerians but suffers from terrible traffic congestions owing to a large number of automobiles on the roads [23]. A high proportion of atmospheric pollutants is inhaled by the residents and some suburban areas even experience soothe settling on buildings. The high concentration of pollutants from vehicular emission, biomass burning, construction activities, and industrial emissions have also been reported around the Lagos state Nigeria, and are also major contributors to ambient air pollution, total particulate matter, particulate heavy metal particular concentrations at aggravated levels [24]. In addition, despite the unavailability of research data, little or no studies have been done in this region using the application of multivariate statistical methods. Hence, we study the criteria pollutants and their seasonal characteristics (SO_2, NO_2, CO), suspended particulate matter (SPM), and particulate heavy metal concentrations of Cadmium (Cd), Copper (Cu), Zinc (Zn), Iron (Fe), Lead (Pb) and Nickel (Ni) at 10 different suburb locations in the Lagos suburban by multivariate techniques for a significant data reduction and dataset interpretation and interaction.

2. MATERIALS AND METHODS

2.1 Study Area

Lagos is situated in the western part of Nigeria. It is surrounded on the north by Ogun state, east by Ondo state, and on the south is the Atlantic Ocean. Lagos state is known as the center of attraction of Nigeria and is located in the southwestern part of the country. It is geographically located on the narrow flood plain of Bight of Benin. It lies on longitude 3°9′ E - 3°28′ E and latitude 6°23′ N - 6°41′ N and covers about 3577 per sq km which is a fraction of 0.4 % of the landmass in Nigeria. Lagos is the largest urban center in Nigeria with about 24 million people. Lagos state is characterized by heavy traffic congestions, while poor infrastructural development is often seen around the mainland, which is the study location, and air pollution episodes during the wet season and heatwave episodes during the dry season. Study locations were selected to capture the focal points of the suburbs of Lagos. The study sites include: Agege Ojo, Egbeda, Surulere, Gbagada, Obalenle, Iju, Ojodu, Alagbado, and Epe, and with them represent a larger fraction of Lagos (Fig 1). In some areas, wastes are constantly dumped on the streets, while some places have poor toilet facilities and some have a poor infrastructural layout [25].

2.2 Determination of Criteria Pollutant and Particulate Matter

Data acquisition for criteria pollutants (CO, NO_2, and SO_2) were performed within the sampling site. The 10 selected sites (Figure 1) were geo-referenced and 5 points were selected in each sampling location at about 1000 km distance apart. Research activity lasted for 3 months within each season (wet season: May-July and dry season: October-December) at 72 hr intervals measurement respectively. Using real-time in-situ measurement, the air pollutants were measured using Madur GA-21 plus multi-gas monitor (Aeroqual series 200) by electrochemical method [26].

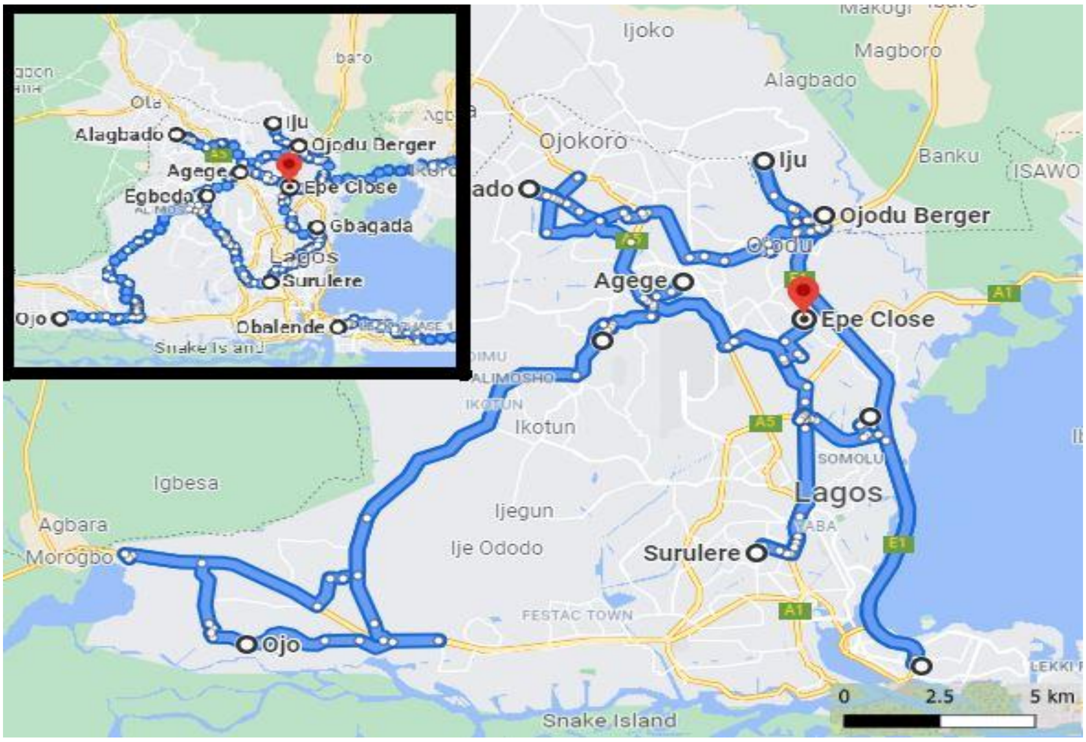

Fig. 1. Google map of Lagos showing suburban sampling locations

The suspended particulate matter (SPM) concentrations were similarly (electrochemical method) determined using CW-HAT200 particulate sampler having an accuracy limit of 0.005 mg/m^3 and detection limit of 0.001 mg/m^3. The accuracy limit for the criteria pollutants were ±0.5 mg/L, 0.02 mg/L and 0.05 mg/L for CO, NO_2 and SO_2 while the detection limits was 0.05 mg/L, 0.005 mg/L and 0.04 mg/L for CO NO_2 and SO_2. For efficiency, sampling times were 4-6 am/pm and average reported, the operating temperatures were within 27-33°C, wind speed ranged from 0.4 – 3.0 m/s, while relative humidity of 40-85 % was recorded. A total of 20 samples were obtained from each sampling site. Wind and excessive heat interrupted days were rescheduled while rainy days were was not captured due to high humidity, dampness, and dark clouds [25,26].

2.3 Determination of Heavy Metals

The determination of the metals in the particulate matter was carried out using a Whatman fiber filter paper (0,2 mm pore size) at a marked sample area of 70 x 100 cm^2 using a particulate matter counter produced by Environmental devices corporation the USA. It was programmed to collect 8 hourly samples at a constant flow rate of 1.0 m^2/min. The volume sampler was placed at 2 m above ground level, while the air volume sampler was operated at 1500 m^3 [27].

Before the analysis, the glass fiber paper was weighed and then reweighed after sampling which determined the mass of air passing through the sampler about 75-120 mg per 8 hr. We noted some days to be obstructed by interference from residents and curious local officials. All council permits were obtained and local approval was acquired and no further obstruction was recorded. An average of 10 samples was collected from each of the 10 locations [12]. Following the meteorological forecast, the rains were collected in a new sample bottle rinsed twice with distilled water. Sample bottles were labeled and covered with a black nylon bag to prevent sunlight before transportation to the laboratory for determination of anions and are presented in table 1 (dry season) and Figure 2 (wet season) and analyzed APHA [28].

After the sampling, the filter papers were sliced into pieces and introduced into a plastic bottle containing 125 mL of 20 % nitric acid solution placed inside a water bath shaker at 60°C for 300 rpm. The obtained solution was transferred into a 250 ml borosilicate glass beaker and the bottle was rinsed 3 times with the deionized water before the analysis. The borosilicate beaker was then heated at 150°C temperature to evaporate the HNO_3 solution to 20 mL. Furthermore, another 20 mL of analytical grade nitric acid was added to the beaker and boiling continued until a 10 mL volume was left. The final aliquot was filtered and the filtrate was stored in a 100 ml amber bottle in the dark until further analysis was conducted [12]. The blank values were determined by analyzing unused filter papers via the procedure described above. The samples were analyzed using Atomic Absorption Spectroscopy (Buck Model 210 VGP) equipped with a digital readout system [29]. The flow rates of air and acetylene were adjusted and the analysis was performed by a trained technologist. The concentrations of heavy metals in the samples were calculated by comparison with the standard curves of the respective metals. The detection limits of the chemical analysis for Pb, Zn, Cd, Cu, Fe, and Ni were less than 0.03 mg/L respectively and each measurement was performed thrice and the calculated difference between the three determinants was less than 5%. The calculated recovery efficiency from atomic absorption spectrometer (AAS) was 94–97% of a known amount of the metal spiked unto clean filter papers before extraction and recovery. Specific hollow cathode lamps were used for each analyte at their respective wavelengths.

2.4 Statistical Methods

The mean values of results from the study were obtained after sampling in triplicates Origin 9.0 was used to show significant differences in the plots and also perform multivariate statistical analysis. The Pearson correlation, Biplot, and Principal component analysis were also performed using Origin 9.0 as described in detail in a recent publication.

3. RESULTS AND DISCUSSION

3.1 Anions Concentration

The assessment of the concentrations of anions (Cl^-, SO_4^{2-}, CO_3^{2-}, NO_3^{2-}, PO_4^{3-}) in sampled rainwater was measured and determined as shown (table 1 and Figure 2). During both seasons the pH showed little or no variation within ≥ 6.8 ≤ <7.8 showing a higher tendency to acidity, while some anions significantly varied. Recall that rainwater is a major indicator of sources of atmospheric pollutants via its chemical composition, hence acidic pH is a pointer to some acids loaded in the rainwater. The high values of Cl^- during both seasons, therefore, suggest it as a major pollutant within the area. The anion concentrations of the rainwater followed the sequence Cl^- > CO_3^{2-} > SO_4^{2-} > NO_3^{2-} > PO_4^{3-} during rains while at dry season the following sequence Cl^- > CO_3^{2-} > $SO4^{2-}$ > PO_4^{3-} > NO_3^{2-} was observed. These showed that Cl^- accounts for approximately 85% of the total anion concentration ranging from 10-26 mg/L [30]. However, the ion concentration levels showed a relatively low standard deviation of less than 5% which indicated low variations of anions over the study period.

The ratio of the average concentrations of (NO_3^- + Cl^-)/SO_4^{2-} according to the study was > 1 and showed that hydrochloric acid and nitric acid mainly influence the rainwater. Furthermore, the µeq/L of (Na^+, K^+, and Ca^{2+}) water in rainwater was known by spectrophotometric method to determine the likely sources of the pollutants reported for the first time. A correlation between ions (Na^+ and SO_4^{2-}), (Ca^{2+} and NO_3^-), (K^+ and SO_4^{2-}) was observed to be 0.89, 0.88, 0.92, while (Na^+ and Cl^-), (K^+ and Cl^-), and (Ca^{2+} and Cl^-) were 0.93, 0.72 and 0.76 respectively [31]. These data strongly suggest that acidic compounds such as H_2SO_4, HCl, and HNO_3 react with the alkaline compounds, which are then blown into the atmosphere by wind. Therefore wind sources of atmospheric particulate matter (dust) play a crucial role in the water chemistry of the suburban study areas. Owing to the lack of published data on rainwater in the study locations, the results of the data are compared to [32] near the study site showing similar findings in levels of pH and Cl^- while that of anions near the study site were within [33].

3.2 Criteria Pollutants

The measurement of atmospheric criteria pollutants (SO_2, NO_2, CO) at the 10 different locations in Lagos suburban was during the wet and dry seasons. Overall, there are higher levels of SO_2 during the wet season than in the dry season. The overall average value of SO_2 at 10 sampling locations was about 12 µg/m^3 which is lower than the 20 µg/m^3 24-hr mean standard by WHO [34]. Also, the highest value was determined to be 41 µg/m^3 at Ojodu during rains which are the closest to 125 µg/m^3 24-hour average for long-term exposure by World Health Organization (WHO). However, both the average SO_2 value and the highest concentration exceeded Nigeria FMEnv of 0.01 ppm [26].

Therefore, this critical value within the Nigerian context suggests that exposure to SO_2 at these sampling locations which has never been reported may lead to mild symptoms of respiratory problems [35]. This ambient air problem according to Manisalidis et al. is mainly from household generation and heavy traffic congestions, and women are more likely to suffer more when indoor air pollution is also taken into consideration.

The total average concentration of NO_2 at 10 locations in Lagos suburban was 10 µg/m^3, which is 1/4 of 40 µg/m^3 annual mean standard of WHO. Nitrogen dioxide is a noxious gas with a high tendency of causing health-related challenges. The NO_2 enters the atmosphere via the decomposition of nitrogen-based fertilizer by microorganisms but primarily by anthropogenic sources mainly from fossil fuel cars [36]. The highest NO_2 concentrations were determined at Ojodu and Obalanele to be 27 and 33 µg/m^3 during the wet season and happen to be areas with the highest traffic. These values are below WHO 200 µg/m^3 1-hr mean standard and are not a potential (pollutant) threat level. However, according to FMEnv, the Nigerian standard is 0.06 ppm for 24-hr exposure which, therefore, negates the obvious that since all the determined NO_2 concentrations (> 6 < 33 µg/m^3) exceeded the FMEnv standard, there is according [37] the likelihood to cause health challenges to the susceptible population. A representative study on short-term exposure of NO_2 levels of 0.1-3.5 ppm according to [38] showed that for asthmatic and chronic obstructive disease patience, there is an induced lung inflammation even at 0.6 ppm levels.

Table 1. Average mean concentrations of anions in the Lagos study sites during the wet season

Location	Geolocation	pH	Cl^- (ueq/L)	SO_4^{2-}	CO_3^{2-}	NO_3^-	PO_4^{3-}
Agege	6°64'N 3°31'E	7.6	13.3	0.092	4.67	0.037	0.045
Ojo	6°46'N 3°20'E	7.6	14.4	0.091	2.50	0.090	0.037
Egbeda	6°59'N 3°30'E	7.6	24.3	0.024	3.75	0.028	0.048
Surulere	6°50'N 3°32'E	6.8	24.8	0.015	2.75	0.055	0.047
Gbagada	6°55'N 3°38'E	7.5	26.7	0.015	2.45	0.039	0.037
Obalenle	6°52'N 3°37'E	7.5	26.7	0.016	0.018	0.035	0.060
Iju	6°66'N 3°32'E	7.6	14.5	0.048	2.47	0.028	0.026
Ojodu	6°63'N 3°35'E	7.7	11.1	0.050	4.78	0.041	0.024
Alagbado	6°65'N 3°25'E	7.7	13.4	0.090	2.10	0.048	0.040
Epe	6°59'N 3°98'E	6.8	12.1	0.028	1.20	0.025	0.015

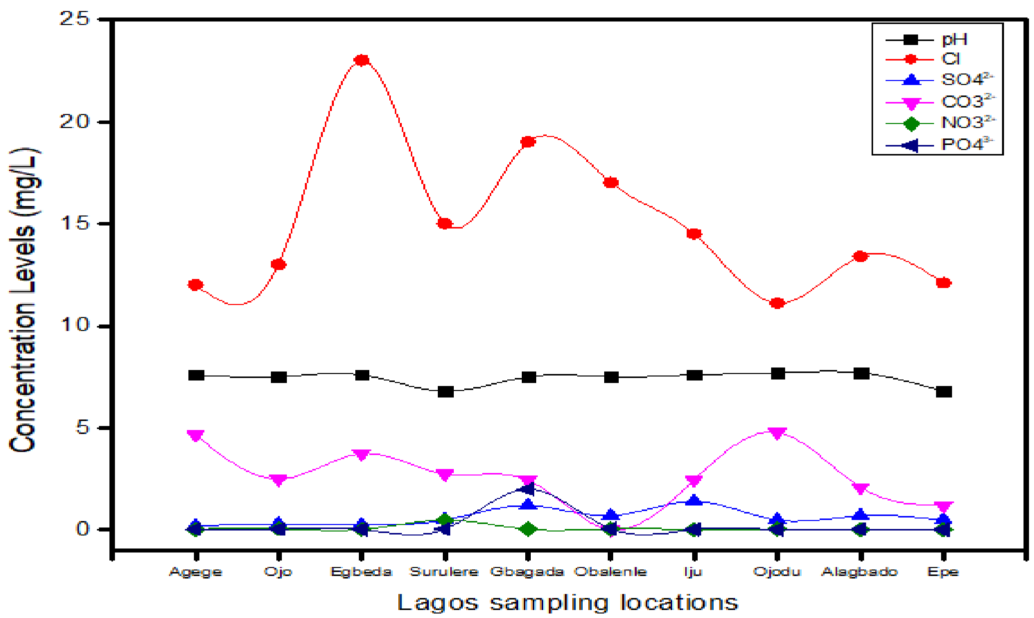

Fig. 2. Concentration levels of anions in the sampling sites the during dry season

On the other hand, the measured values of CO between the 10 sites ranged from 468-1350 μg/m^3 during the wet season and 447-1864 μg/m^3 during dry seasons. The ambient Nigerian FMEnv is 10 ppm for an 8-hr mean but was exceeded by all sampling sites. During the rains, the least polluted site was at Epe while the highest polluted site was at Obalenle. During the dry season, the least polluted site was at Ojo while the highest polluted site was also at Obalelnle. This high concentration is found to be statistically significant when compared with studies from Odekanle et al. [39] in a different location in Lagos State, Nigeria. Moreover, as Maduekwe et al. [40] noted, the major contributor of CO are the old vehicles plying the streets of Lagos in which emission reduction will be difficult.

Hence, there are possibilities of the reduced oxygen-carrying capacity of the blood among residents of the area due to high levels of CO. Additionally there is the danger of frequent headache, dizziness, body weakness, and nausea [41]. Moreover, according to [42], children are more susceptible to carbon monoxide pollution because they spend a lot of time in school and recreation centers which makes their respiratory system vulnerable to CO attack.

The suspended particulate matter consists of soluble, hygroscopic, and deliquescent particles less than 10 μm in diameter, which are suspended in the atmosphere. They often originate from boilers, combustion, incinerators, automobiles, etc, and are also a product of photochemical reactions of gaseous substances in the atmosphere [13], and the values are reported for the first time in this article.

The mean concentrations were about 80 μg/m^3 during the wet season and more than double at 195 μg/m^3 during the dry season which means those study locations mainly encounter pollutions in the dry seasons. The highest recorded SPM was in the dry season at Algbado, Obalenle, and Epe study locations (295, 258, 250 μg/m^3 respectively). In the Nigerian FMEnv standard for SPM, it is taken as 250 μg/m^3 per 24 hr mean, hence only dry season mean values exceeded this threshold. The data obtained were compared to the E.U regulation and the EPA standard on the suspended particulate matter [12]. The primary EPA standard focusing on human health protection regulates 75 μg/m^3 which is taken as an annual geometric mean. Hence, from the graph, the wet season showed little deviation from the standard, while the dry season exceeded this regulatory benchmark and should be an area of environmental concern. Additionally, the EU limit (EU Directive 80/779/EEC) values for suspended particulates matter recommends 150 μg/m^3 mean for an average of annual exposure and 120 μg/m^3 SPM for 24 hr maximum exposure [43]. Hence going to the study data these values in the dry season indicated that a large fraction of the suburban population is exposed to levels of suspended particulate matter above threshold values set for the protection of human health. Hence, this study has identified the need for investigation on PM_{10}, $PM_{5.0,}$ and $PM_{2.5}$ concentration levels in the study locations towards gaining a holistic understanding of particulate matter. There is a risk of non-cancer health-related effects causing injury to the respiratory system and bronchitis arising from SPM [9]. Also, reduced visibility is commonly observed at study sites owing to light absorption and scattering by these particles [10]. Then again soiling of painted buildings, roof discoloration, black-particulate coated windows are randomly observed at those study locations [26].

3.3 Air Quality Index (AQI)

Using the air quality index (AQI) formula described by Anyika et al., (2020), the data were computed and the results of the AQI were determined for the study period. The AQI values obtained were between 100 and 300, which is an indication of a non-hazardous environment that is moderately unhealthy and sensitive to vulnerable populations. Only EPE, Ojo, and Ojodu areas fell within the moderate AQI benchmark of ~100 for the wet and dry seasons. Hence there is a regular distribution and pattern of atmospheric pollutants around those areas. The Obalenle area had the highest AQI value of 280 for SO_2 and 257 for NO_2 pollutants and it corresponded to the study observation. The AQI values for CO are calculated to be within the unhealthy and very unhealthy AQI benchmark. Hence the CO is the principal pollutant for all sampled locations while the Obalenle study area also had NO_2 and SO_2 as contributory pollutants [44].

3.4 Heavy Metals

Hence, for the first time, the atmospheric heavy metal concentrations of the study area were determined at 10 different locations in the suburban sampling sites in the wet season: May-July and in the dry season: October-December of 2019. The measured concentrations are presented in tables 2 and 3 showing the average mean value of determined concentrations.

The average Cd concentration ranged from 0.35 -0.92 ng/m^3. The lowest occurrence of Cd was detected during the dry season at Iju and Epe, while the highest occurrences were at Ojodu and Surulere and are the Cd catchment areas. Heavy traffic congestion is the major source of Cd concentration accompanied by secondary aerosol produced from local origin. Correspondingly the EU regulation and WHO regulation for Cd suspended atmospheric matter is 5 ng/m^3 and therefore, the study area is not yet an area of concern. However regular monitoring by local authorities may be introduced.

The average Cu concentration during the rains was 0.37 ng/m^3, while the average Cu concentration during the dry season is 0.50 ng/m^3. This depicts that higher levels of suspended Cu particulates are been transported and dispersed in the dry season than in the wet season. In addition, the lowest Cu occurrence was at Ojo while the highest is at Alagbado. The major sources in the study locations are automobiles while the evaporation of spray and crushing activities of automobile technicians are also secondary contributors. There is yet no Nigerian FMEv regulation on Cu suspended particulate matter likewise the absence of Cu regulation in the EU and WHO standards.

The Zinc concentrations varied greatly within the studied site among between the seasons. The wet season showed lower levels of Zn concentration having an average concentration level of 0.043 µg/m^3, while the dry season recorded 0.57 µg/m^3 as the average concentration. Zinc metal is not listed as an occupational hazard nor is it known to be carcinogenic by the FMEnv, EU, or WHO unless there is a reported direct inhalation of zinc fumes at long durations. Moreover, the average person breathes about 15 m^3 of air daily including millions of PM pollutants which causes allergies, adverse conditions.

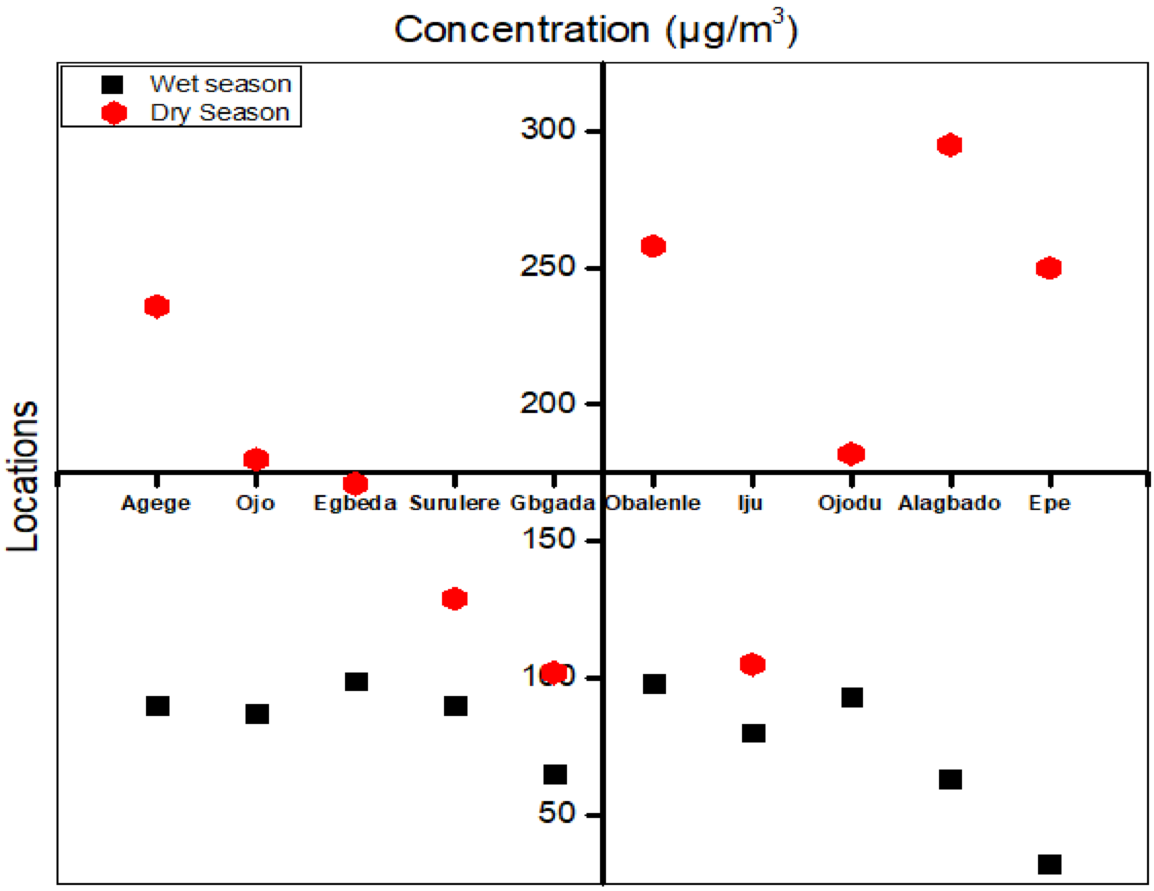

Fig. 3. Total particulate matter concentrations at ten different study locations in Lagos

Table 2. Wet season determined concentrations of trace atmospheric metals

S/N	Location	Cd (ng/m^3)	Cu (ng/m^3)	Zn (µg/m^3)	Fe (ng/m^3)	Pd (µg/m^3)	Ni (ng/m^3)
1	Agege	0.41	0.50	0.01	0.16	0.31	0.44
2	Ojo	0.41	0.40	0.02	0.06	0.16	0.45
3	Egbeda	0.39	0.46	0.01	0.26	0.13	0.35
4	Surulere	0.36	0.41	0.03	0.06	0.12	0.33
5	Gbagada	0.37	0.32	0.01	0.06	0.29	0.34
6	Obalenle	0.37	0.29	0.01	0.07	0.14	0.35
7	Iju	0.35	0.25	0.13	0.02	0.12	0.35
8	Ojodu	0.40	0.46	0.04	0.06	0.22	0.46
9	Alagbado	0.36	0.28	0.01	0.25	0.17	0.34
10	Epe	0.35	0.32	0.15	0.06	0.19	0.32

Table 3. The dry season determined concentrations of trace atmospheric metals

S/N	Locations	Cd (ng/m^3)	Cu (ng/m^3)	Zn (µg/m^3)	Fe (ng/m^3)	Pb (µg/m^3)	Ni
1	Agege	0.47	0.25	0.21	0.45	0.25	0.54
2	Ojo	0.52	0.23	0.41	0.25	0.30	0.57
3	Egbeda	0.78	0.46	0.52	0.55	0.33	0.76
4	Surulere	0.89	0.49	0.31	0.25	0.50	0.39
5	Gbagada	0.66	0.67	0.43	0.27	0.31	0.54
6	Obalenle	0.55	0.49	0.71	0.37	0.34	0.83
7	Iju	0.67	0.55	0.83	0.21	0.42	0.92
8	Ojodu	0.92	0.50	0.95	0.35	0.32	0.55
9	Alagbado	0.49	0.88	0.71	0.25	0.55	0.68
10	Epe	0.53	0.39	0.61	0.36	0.29	0.39

However, environmental and human health risk regulations associated with Zn particulate matter at any risk classification are unnecessary but regular monitoring and measurement of exposure levels are required.

The presence of iron (Fe) in the suspended particulate matter can be of importance particularly when unusually high levels are detected during measurement. The study revealed that the levels of iron in the atmosphere is negligible and not an environmental concern according to table 1 and 2. Although higher occurrences of Fe are determined during the dry season, however, the average value for the same season is 0.29 ng/m^3 which is not up to ½ of 1 ng/m^3 and best described as negligible and insignificant. The major source of the traces of iron is the exhaust fume from the motorist, while secondary contributors are iron crushing, smelting, and welding activities by artisans within the area. Similarly, Zn, Cu, and Fe in the suspended particulate matter have no regulatory benchmark.

Lead (Pb) is a notorious contributor to atmospheric pollution on a global scale; hence, its regular monitoring and measurement are highly desirable. The higher Pb occurrences were seen in the dry seasons and ranged from 0.25 to 0.55 µg/m^3 while during the rains it varied lower from 0.12 to 0.31 µg/m^3. The EU and WHO regulation for Pb is 0.5 µg/m^3 for the annual averaging period. Hence, only Alagbado and Surulere are the main Pb hotspots during this study. The primary source of Pb within the area is the exhaust smoke from vehicles while other contributors of Pb are entrainment of road dust into air, construction and demolition activities; hence Pb is crustal in origin.

Nickel (Ni) is fast becoming an element of interest during suspended atmospheric particulate matter studies. The lowest Ni concentration was at EPe (0.32 ng/m^3), while the highest Ni concentration was determined to be 0.92 ng/m^3. The wet season varied from 0.32 to 0.46 ng/m^3, while the dry season varied from 0.39 to 0.92 ng/m^3 which showed that residents of the area are exposed to levels of suspended particulate matter in higher thresholds during the dry season than in the wet season. The given annual exposure mean set by the EU and WHO standard is 20 ng/m^3 and 25 ng/m^3 respectively, hence the Ni trace metal levels in atmospheric suspended particulate matter is below the threshold value and does not pose any foreseeable health challenges. The major source is the combustion of diesel oil and fuel oil, while incineration of waste and sewage are the secondary contributors.

3.5 Multivariate Analyses

Several modeling equations are often applied when atmospheric pollutants are studied to predict the source and dispersion of atmospheric particulate matter. For instance, the enrichment factor analysis is often applied when the atmospheric pollutants concentrations are higher than expected in their natural environment, which is not the case in the study. Furthermore, chemical mass balance modeling extracts information from a large number of samples and data, which limited our study. Hence according to [12], the multivariate analysis is applied when grouping and relationship variations need to be statistically expressed. The Pearson's correlation describes the total variance in the study by a linear model that ranges from -1 to 1. The principal component analysis reduces the dimensions of the data, while cluster analysis finds patterns and groupings within a given data set. The three multivariate plots in this study were extracted from tables 2 and 3 and further readings can be obtained found from [12]. Thus reported for the first time in literature in table 4, figure 4, and 5 are multivariate data interpretation of study locations using Pearson's correlation, principal component analysis, and hierarchical cluster analysis.

The results from Pearson's correlation are shown in table 4. Only the p-value of Zn/Zn and Fe/Fe of both seasons was greater than 0.05 which depicts that the correlation is insignificant and the data is also inconsistent with pearson's hypothesis. Furthermore, there are instances where the Pearson's correlation fails to determine the correlations; hence, Cd/Cd, Cu/Cu, Pb/Pb, and Ni/Ni for two seasons respectively are unable to follow pearsons dependency. The Pearson's correlation for all metals within the seasons showed negative values except Zn/Zn and Fe/Fe. This means that the levels of heavy metals differ from each other during each season while Zn/Zn and Fe/Fe a strong link exists between the metal concentrations and the seasons.

Fig. 4 shows a biplot of the principal component; the wet season eigenvalues and extracted values revealed that 54% is covered by Cd followed by Cu at 21 %. But in the dry season, only 40% is covered by Cd followed by Cu at 21 %. Hence these two atmospheric suspended particulate matter accounts for most of the variance in the observed variable. the wet season biplot showed that only Fe occupied principal component 1 which means that Fe was the major atmospheric particulate in Aglagbado, Egbeda, surulere, and Obalenle. Epe and Iju were mostly affected by Zn while the Ojodu, Ojo, Gbagada ad Agege had a fair share in the distribution of Pb, Ni, Cu, Cd suspended particulate metals. the dry season biplot revealed that primary pollutants cannot be established for Surulere, Gbagada, Epe, Ojo, and Agege among the studied atmospheric particulate matter. Furthermore, only Obalanle, Iju, and Ojodu had Ni and Zn as the principal atmospheric pollutants while Fe is observed within Egbeda and Agege.

Finally, the numbers for the cluster analysis (fig 5) corresponds to the sampling sites in tables 2 and 3. The dendrogram is showing smaller clusters built into bigger clusters. In the wet season, observations 1, 2, and 8 are similar to observations from 4 through 7 and 10, and they occupied the same distance. It means that there is a similarity of measurement and relationship in terms of concentration for the wet season. The dry season clusters had 1, 2, 10, 4, and 5 (Agege, Ojo, Epe, Surulere, Gbagada: Group 1) built into one cluster while 3, 6 through 9 (Egbeda, Obalenle, Iju, Ojodu, Alagbado: Group 2) formed another cluster at the nearly same distance. It depicts that members/locations of group 1 are closely related in terms of concentration, while members of group 2 are similarly related in terms of concentration.

Table 4. Pearson's correlations showing the suspended metal particulate matter

	Cd/Cd	Cu/Cu	Zn/Zn	Fe/Fe	Pb/Pb	Ni/Ni
Coefficient (r)	-0.01	-0.58	0.373	0.551	-0.542	-0.087
P value	Null	Null	0.288	0.099	Null	Null
N	10	10	10	10	10	10
T statistics	-0.029	-2.015	1.136	1.863	-1.825	-0.247
DF	8	8	8	8	8	8

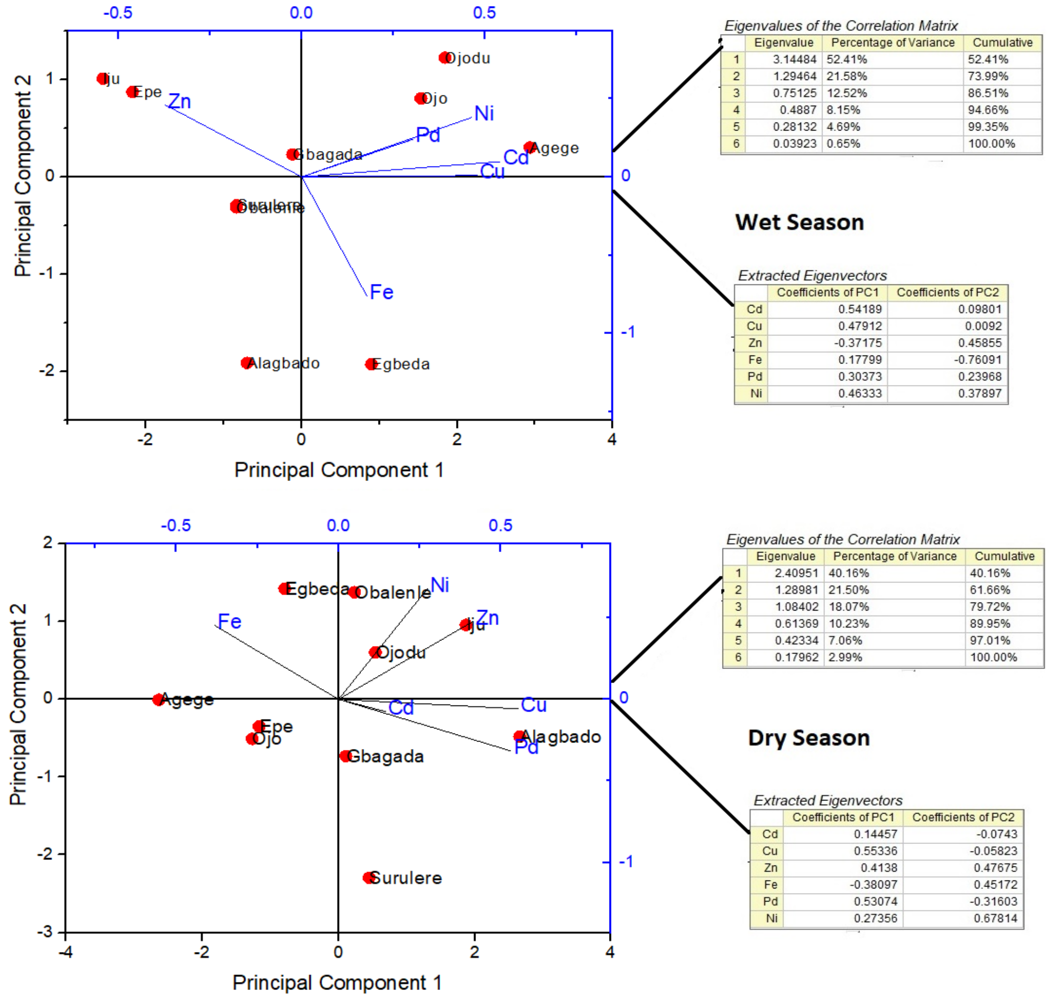

Fig. 4. The biplot of seasons variation showing the principal components and data subsets

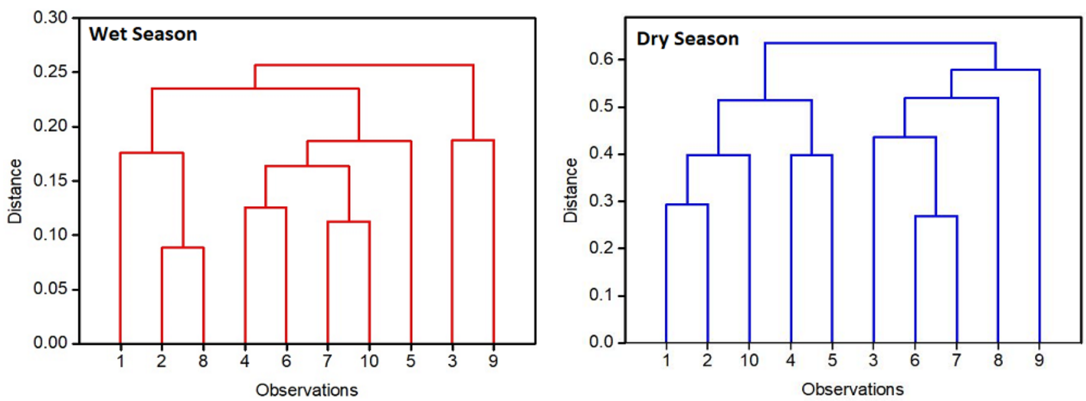

Fig. 5. Dendrogram of the seasonal concentrations at the different sampling site

4. CONCLUSION

The concentrations of atmospheric suspended particulate matter for Cd, Cu, Zn, Fe, Pd, and Ni were investigated at 10 sampling sites in Lagos suburban during the wet and dry seasons. The anions showed that Cl^- recorded high values and an indicator of a major pollutant and the other anions indicated low variation during the study period. The acidic compounds of H_2SO_4, HCl, and HNO_3 played a crucial role in atmospheric water chemistry. The SO_2 concentration exceeded Nigeria FMEnv of 0.01 ppm and suggests that exposure to SO_2 at these sampling locations may lead to mild symptoms of respiratory problems. The major contributor to CO was the old vehicles in which emission reduction will be difficult. From the AQI values, the CO is the principal pollutant for all sampled locations and the Obalenle had NO_2 and SO_2 as contributory pollutants. Suspended particulate metals did not exceed the regulatory standards and do not pose foreseeable health challenges. The Pearson's correlation for all metals within the seasons showed negative values except Zn/Zn and Fe/Fe, while the principal component analysis revealed that Fe is the principal pollutant in Egbeda and Agege. The cluster analysis showed that locations are not related by proximity but via measurement and concentration. Hence, this study provides sufficient data that relates to environmental pollution and atmospheric particulate contamination at the study locations.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Manisalidis I, Stavropoulou E, Stavropoulos A, Bezirtzoglou E. Environmental and Health Impacts of Air Pollution: A Review. Frontiers in Public Health. 2020;8:14.
2. Guan X, Wei H, Lu S, Dai Q, Su H. Assessment on the urbanization strategy in China: Achievements, challenges, and reflections. Habitat International. 2018;71:97–109.
   Available:https://doi.org/10.1016/j.habitatint.2017.11.009
3. Chao Q, Feng A. Scientific basis of climate change and its response. Global Energy Interconnection. 2018;1:420–7.
   Available:https://doi.org/10.14171/j.2096-5117.gei.2018.04.002
4. Babatola SS. Global burden of diseases attributable to air pollution. Journal of Public Health in Africa. 2018;9:813.
   Available:https://doi.org/10.4081/jphia.2018.813
5. Jiang X-Q, Mei X-D, Feng D. Air pollution, and chronic airway diseases: what should people know and do? Journal of Thoracic Disease. 2016;8:E31–40.
   Available:https://doi.org/10.3978/j.issn.2072-1439.2015.11.50
6. Sudalma S, Purwanto P, Santoso LW. The Effect of SO2 and NO2 from Transportation and Stationary Emissions Sources to SO42− and NO3− in Rain Water in Semarang. Procedia Environmental Sciences. 2015;23:247–52.
   Available:https://doi.org/10.1016/j.proenv.2015.01.037
7. Sorensen C, Murray V, Lemery J, Balbus J. Climate change and women's health: Impacts and policy directions. PLOS Medicine. 2018;15:e1002603.
8. Paralovo SL, Barbosa CGG, Carneiro IPS, Kurzlop P, Borillo GC, Schiochet MFC, et al. Observations of particulate matter, NO2, SO2, O3, H2S and selected VOCs at a semi-urban environment in the Amazon region. Science of The Total Environment. 2019;650:996–1006.
   Available:https://doi.org/10.1016/j.scitotenv.2018.09.073
9. Puławska A, Manecki M, Flasza M, Styszko K. Origin, distribution, and perspective health benefits of particulate matter in the air of underground salt mine: a case study from Bochnia, Poland. Environmental Geochemistry and Health. 2021;43:3533–56.
   Available:https://doi.org/10.1007/s10653-021-00832-2
10. Zeka A, Zanobetti A, Schwartz J. Short term effects of particulate matter on cause-specific mortality: effects of lags and modification by city characteristics. Occupational and Environmental Medicine. 2005;62:718 LP – 725.
    Available:https://doi.org/10.1136/oem.2004.017012.
11. Xu X, Nie S, Ding H, Hou FF. Environmental pollution and kidney diseases. Nature Reviews Nephrology. 2018;14:313–24.
    Available:https://doi.org/10.1038/nrneph.2018.11
12. Ichu BC, Opara AI, Ejike EN, Nkwoada AU, Ibe FC, Dioha EC. Multivariate analysis and spatial distribution of suspended particulate metals of Abakaliki and Enugu in Southeastern Nigeria. Bulletin of the National Research Centre. 2021;45:159.

Available:https://doi.org/10.1186/s42269-021-00618-7

13. Madia F, Worth A, Whelan M, Corvi R. Carcinogenicity assessment: Addressing the challenges of cancer and chemicals in the environment. Environment International 2019;128:417–29.
 Available:https://doi.org/10.1016/j.envint.2019.04.067
14. Emamverdian A, Ding Y, Mokhberdoran F, Xie Y. Heavy Metal Stress and Some Mechanisms of Plant Defense Response. The Scientific World Journal. 2015;2015: 756120.
 Available:https://doi.org/10.1155/2015/756120
15. Jaishankar M, Tseten T, Anbalagan N, Mathew BB, Beeregowda KN. Toxicity, mechanism, and health effects of some heavy metals. Interdisciplinary Toxicology. 2014;7:60–72.
 Available:https://doi.org/10.2478/intox-2014-0009
16. Briffa J, Sinagra E, Blundell R. Heavy metal pollution in the environment and their Toxicological Effects on Humans. Heliyon 2020;6:e04691.
 Available:https://doi.org/10.1016/j.heliyon.2020.e0469
17. Rafati Rahimzadeh M, Rafati Rahimzadeh M, Kazemi S, Moghadamnia A-A. Cadmium toxicity and treatment: An update. Caspian Journal of Internal Medicine. 2017;8:135–45.
 Available:https://doi.org/10.22088/cjim.8.3.135
18. Genchi G, Sinicropi MS, Lauria G, Carocci A, Catalano A. The Effects of Cadmium Toxicity. International Journal of Environmental Research and Public Health. 2020;17:3782.
 Available:https://doi.org/10.3390/ijerph17113782
19. Wani AL, Ara A, Usmani JA. Lead toxicity: a review. Interdisciplinary Toxicology. 2015;8:55–64.
 Available:https://doi.org/10.1515/intox-2015-0009
20. Badiye A, Kapoor N, Khajuria H. Copper Toxicity: A Comprehensive Study. Research Journal of Recent Sciences. 2013;2:58–67.
21. Genchi G, Carocci A, Lauria G, Sinicropi MS, Catalano A. Nickel: Human Health and Environmental Toxicology. International Journal of Environmental Research and Public Health. 2020;17:679.
 Available:https://doi.org/10.3390/ijerph17030679
22. Sane MR, Malukani K, Kulkarni R, Varun A. Fatal Iron Toxicity in an Adult: Clinical Profile and Review. Indian Journal of Critical Care Medicine : Peer-Reviewed, Official Publication of Indian Society of Critical Care Medicine. 2018;22:801–3.
 Available:https://doi.org/10.4103/ijccm.IJCCM_188_18
23. Olaniyonu S, Gbenu J, Lawal R. Demographic Parameters and Distribution of Educational Institutions among the Three Senatorial Districts in Lagos State. International Journal of Humanities Social Sciences and Education. 2016;3:11–8.
 Available:https://doi.org/10.20431/2349-0381.0304002
24. Ogungbe A., Iginla S., Alabi A., Onori E. Impact of vehicular emission on air pollution in ojo local government area of Lagos State, Nigeria. British Journal of Environmental Sciences. 2019;7:1–19.
25. Alani R, Zhao S, Liu X, Akinrinade O, Agunbiade F, Ayejuyo O, et al. Concentrations, profiles and exposure risks of polycyclic aromatic hydrocarbons (PAHs) in passive air samples from Lagos, Nigeria. Atmospheric Pollution Research. 2021;12:101162.
 Available:https://doi.org/10.1016/j.apr.2021.101162
26. Ugbebor J, Yorkor B, Amadi G. Assessment of air quality and its health implications on Abuja campus residence, University of Port Harcourt, Nigeria. Journal of Science and Technology and Environmental Informatics. ;7:500–9.
 Available:https://doi.org/10.18801/jstei.070119.52
27. WHO. WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide, and sulfur dioxide. Global Update: Summary of Risk Assessment. 2006:1–22.
 Available: http ://apps.who.int/iris/bitstream /handle/10665/ 69477/ WHO_SDE_PHE_OEH_06.02_eng. pdf? sequence =1
28. APHA. Standard methods for the examination of water and wastewater (APHA). 19th ed. New York: New York: APHA/ AWWA/WPCF.; 1995.

29. U.S EPA. Air quality criteria for particulate matter. Integrated Sampling of Suspended Particulate Matter (SPM) in Ambient Air 1999:1–13.
Available:https://www.epa.gov/sites/default
https://www.epa.gov/sites/default/files/2019-11/documents/overvw2.pdf
(accessed February 11, 2021).
30. Salve PR, Maurya A, Wate SR, Devotta S. Chemical composition of major ions in rainwater. Bulletin of Environmental Contamination and Toxicology. 2008;80: 242–6.
Available:https://doi.org/10.1007/s00128-007-9353-x
31. Wu Q, Han G, Tao F, Tang Y. Chemical composition of rainwater in a karstic agricultural area, Southwest China: The impact of urbanization. Atmospheric Research. 2012;111:71–8.
Available:https://doi.org/10.1016/j.atmosres.2012.03.002
32. Dinrifo R, Babatunde S, Bankole Y, Demu Q. Physico-chemical properties of Rain Water Collected from Some Industrial Area of Lagos. European Journal of Scientific Research State, Nigeria. 2010;41:383–90.
33. Awoyemi OM, Achudume AC, Okoya AA. The Physicochemical Quality of Groundwater in Relation to Surface Water Pollution in Majidun Area of Ikorodu, Lagos State, Nigeria. American Journal of Water Resources. 2014;2:126–33.
Available:https://doi.org/10.12691/ajwr-2-5-4
34. WHO. Global Update 2005:WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide, and sulfur dioxide; 2005.
Available:https://doi.org/WHO/SDE/PHE/OEH/06.02
35. Chen T-M, Gokhale J, Shofer S, Kuschner WG. Outdoor air pollution: Nitrogen dioxide, sulfur dioxide, and carbon monoxide health effects. The American Journal of the Medical Sciences 2007;333:249–56.
Available:https://doi.org/10.1097/MAJ.0b013e31803b900f
36. Njoku K, Rumide T, Akinola M, Adeola A, Jolaoso A. Ambient Air Quality Monitoring in Metropolitan City of Lagos, Nigeria. Journal of Applied Science and Environmental Management 2016;20:178–85.
Available:https://doi.org/10.4314/jasem.v20i1.21
37. Jo S, Kim Y-J, Park KW, Hwang YS, Lee SH, Kim BJ, et al. Association of NO2 and Other Air Pollution Exposures With the Risk of Parkinson Disease. JAMA Neurology 2021;78:800–8.
Available:https://doi.org/10.1001/jamaneurol.2021.1335
38. Hesterberg TW, Bunn WB, McClellan RO, Hamade AK, Long CM, Valberg PA. Critical review of the human data on short-term nitrogen dioxide (NO2) exposures: evidence for NO2 no-effect levels. Critical Reviews in Toxicology. 2009;39:743–81.
Available:https://doi.org/10.3109/10408440903294945
39. Odekanle EL, Fakinle BS, Jimoda LA, Okedere OB, Akeredolu FA, Sonibare JA. In-vehicle and pedestrian exposure to carbon monoxide and volatile organic compounds in a megacity. Urban Climate. 2017;21:173–82.
Available:https://doi.org/10.1016/j.uclim.2017.06.004
40. Maduekwe M, Akpan U, Isihak S. Road transport energy consumption and vehicular emissions in Lagos, Nigeria: An application of the LEAP model. Transportation Research Interdisciplinary Perspectives 2020;6:100172.
Available:https://doi.org/10.1016/j.trip.2020.100172
41. Yadava RN, Bhatt V. Chapter 8 - Carbon monoxide: Risk assessment, environmental, and health hazard. In: Singh J, Kaushik RD, Chawla MBT-HG, editors., Academic Press; 2021, p. 83–96.
Available:https://doi.org/10.1016/B978-0-323-89857-7.00030-X
42. Payus CM, Vasu Thevan AT, Sentian J. Impact of school traffic on outdoor carbon monoxide levels. City and Environment Interactions 2019;4:100032.
Available:https://doi.org/10.1016/j.cacint.2020.100032
43. Rykowski R, Brochu A, 1989/. Diesel Particulate Emissions: The Unites States, Europe, and Japan; 1989.
44. Anyika L, Alisa C, AU N, AI O, Ejike E, GN O. Spatio-Temporal Study of Criteria

Pollutants in Nigerian City. Asian Journal of Applied Chemistry Research 2020;6:1–13. Available:https://doi.org/10.9734/AJACR/2020/v6i330160 .

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