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ARTICLE

Heavy Metal Concentration in Harmattan Dust across Selected Stations in Nigeria

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Abstract: The atmospheric assessment of elements and heavy metals concentrations contained in Harmattan dust samples is addressed in this research. From November 2017 to March 2018, suspended Harmattan dust was sampled using locally constructed Australian model gauges installed at each sampling points (Iwo, Oyo, Ilorin, Minna, Abuja, Lafia, and Jos). The gauges used stood around 5.0 meters tall and were made of 10.0 mm plastic bowls installed on a plastic container that was encased in a metal shell for support and stability. The concentrations of various elements and heavy metals included in suspended Harmattan dust across selected Nigerian cities were assessed using particle-induced x-ray emission (PIXE) technology. The samples were subjected to statistical analysis using the ANOVA test in order to discover the significant differences between the positions of the elements in the sample. The suspended Harmattan dust samples revealed the presence of the following eighteen elements: Na, Mg, Al, Si, P, S, Cl, K, Ca, Ti, Cr, Mn, Fe, Cu, Zn, Rb, Sr, and Zr. Particle-induced x-ray emission (PIXE) demonstrated that these elements are present in various amounts. The samples contain both heavy metals (Ti, Cr, Mn, Fe, Cu, Zn, and Zr) and non-heavy metals (Na, Mg, Al, Si, Cl, K, Ca, Rb, and Sr). The study's results indicate that the presence of heavy metals in Harmattan dust can be attributed to various activities within the country. Consequently, it is advised that further research be conducted in order to raise public awareness about environmental issues.

Keywords: Harmattan, PIXE, Elements, Dust, Heavy metals.

Introduction

The atmosphere is the gaseous layer that surrounds the world. This layer is translucent, allowing life-sustaining solar energy to flow through and reach the surface of the earth [1]. Particulate matter and heavy metals have emerged as a result of current industrial activity, causing the current atmosphere to deviate from the natural environment [2]. Rapid industrialization and urbanization, according to Chowdhury *et al*. [3], resulted in a rise in anthropogenic emissions from both fossil fuel and biomass burning.

Particulate matter is made up of a mix of particles that are directly discharged into the air and particles that are generated in the air as a result of chemical transformations of gaseous contaminants [4]. According to Martinez-Ramirez and Thompson [5], particulate matter (PM) is divided into two categories: PM_{10} and $PM_{2.5}$. Metals present in the atmosphere originate from a combination of natural and human-made

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processes. These include natural sources such as dust re-suspension, emissions from vegetation, volcanic activity, and the release of particles from water bodies. Additionally, human activities, particularly industrial and automotive emissions, contribute to the presence of metals in the atmosphere [7], [6]. Roadside dust and soil suspension in the atmosphere are two further sources of heavy metals. Iron is a dominant metal found in significant concentrations in the atmosphere, with most of its emissions originating from air pollution particles. On the other hand, lead sources have been linked to factors such as vehicular emissions, resuspended soil, and the burning of oil, as reported by Schroeder *et al*. [8].

As stated by Schroeder *et al*. [8], atmospheric particulate matter contains heavy metals at a concentration of 30–35 μm^{-1}. Strontium, copper, zinc, cadmium, manganese, iron, nickel, potassium, chromium, nickel, potassium, calcium, vanadium, barium, arsenic, selenium, and arsenic are well-known metals that have been extensively researched in pollution sources [4]. Sivertsen [9] stated that yearly mean total suspended particles (TSP) concentrations range between 20 to 80 μm^{-3} throughout Western Europe, Northern America, and the Western Pacific, with the exception of China. PM_{10} levels are also known to range between 10 and 55 micrograms per meter squared (μm^{-3}). PM_{10}, on the other hand, has annual mean concentrations that are seen in Southern Asia at high TSP [9], with TSP ranging from 100 to 400 μm^{-3} and PM_{10} from 100 to 300 μm^{-3} [4]. In some of China's major cities, yearly TSP concentrations of 300–500 μm^{-3} have been recorded. According to Smith *et al*. [10], TSP mean annual readings in Lahore (Pakistan) are 607–678 μm^{-3}. According to Sharma *et al*., PM_{10} levels in Indian cities have been found to be in the range of 100 – 400 μm^{-3}. Dust pollution, on the other hand, is a common occurrence in Africa's Sub-Saharan region. Pollution is a widespread environmental issue throughout most of West Africa [11].

Survey of Literature

The word "Harmattan" in the Twi language is believed to have been derived from the Arabic word "ḥaram"[12]. The Bodélé Depression (Lake Chad), which has the largest dust reservoirs, has been identified as a key source of dust by many experts [13 -17]. The Northeast trade wind flows through the Sahara Desert, following Nigeria's path to the Gulf of Guinea and beyond. The harmattan dust reaches a height of almost 300 meters above ground level, well above the stratosphere. The transportation and deposition of Sahara dust have significant effects on the Earth's radiation budget [18-20] and photolysis rates [16]. These processes occur naturally [21-24]. According to Resch *et al*. [25] and Sunnu *et al*. [26], this dust falls over exposed sun-dried agricultural products intended for human consumption. Dust accumulation in the atmosphere is influenced by various factors, including climate change and large-scale weather features such as the Intertropical Convergence Zone (ITCZ) [14], [15], [26], [27], [18], [20], [28- 38].

According to Aweda *et al*. [39, 40], FTIR screening research revealed that Harmattan dust has thirteen functional groups. Furthermore, according to Aweda *et al*. [39], the composition of minerals and elements in Harmattan dust varies depending on the concentration levels associated with the climatic conditions and geographical locations of different towns in Nigeria. The heavy metal component of Harmattan dust consists of both light and heavy elements, which may be attributed to anthropogenic activities and the local dust plume. The concentrations of heavy metals and elements in dust across selected stations in Nigeria were determined by particle-induced x-ray emission (PIXE) analysis of suspended Harmattan dust across Sub-Saharan Africa observed in the 2017/2018 season. Many researchers have worked on the elemental analysis of Harmattan dust using atomic absorption spectroscopy (AAS) and EDXRF machines. However, only a limited number of studies have employed particle-induced x-ray emission (PIXE), i.e. particle accelerator, to determine the heavy metal and elemental concentrations in Harmattan dust in Nigeria. As a result, there was a distinct need to employ PIXE to measure the heavy metal and elemental content of Harmattan dust in Nigeria, a Sub-Saharan African country.

Materials and Methods

(A) Sample Collection

From November 2017 to March 2018, suspended Harmattan dust was sampled using

locally constructed Australian model gauges installed at various sampling points (Iwo, Oyo, Ilorin, Minna, Abuja, Lafia, and Jos) located in the Northern Guinea Savana and the Derived Savana of the Nigeria climatic zone as shown in Fig. 1. The samples were collected from five separate locations in each station; hence, the average data was reported for the elemental analysis. The gauges used stood around 5.0 meters tall and were made out of 10.0 mm plastic bowls installed on a plastic container that was encased in a metal shell for support and stability. With the help of the plastic funnels, the Harmattan dust dropped freely into the container, and the samples were gathered after a month of continuous exposure (see Fig. 2). After that, the samples were taken to the particle-induced x-ray emission (PIXE) equipment for examination.

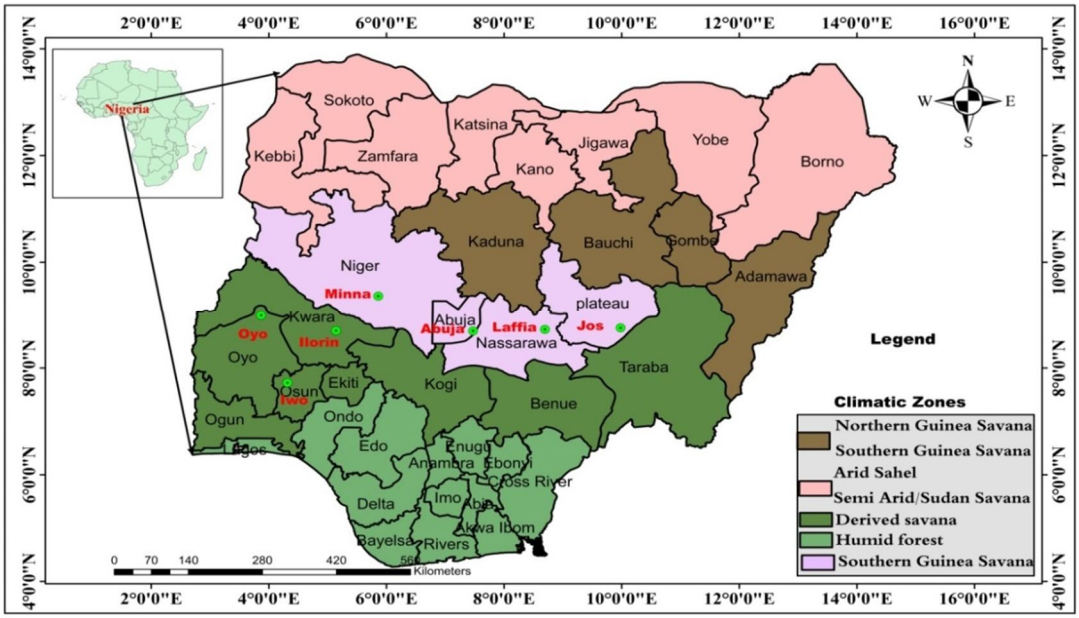

FIG. 1. Map of the Sampling location according to their climatic zones.

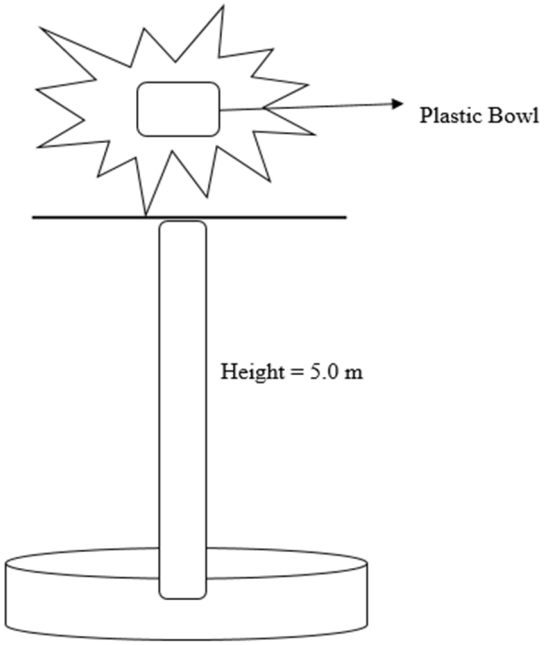

FIG. 2. Schematic diagram of the sample collection process.

(B) Sample Preparation Using PIXE

Pelletization was used to analyze the dried Harmattan dust sample. The samples were pelletized using steel molds, pellets, and a hydraulic press, with aluminum foil serving as a binder to keep the sample particles together after they were removed from the molds. After that, the sample was put into the particle accelerator (see Fig. 3 below).

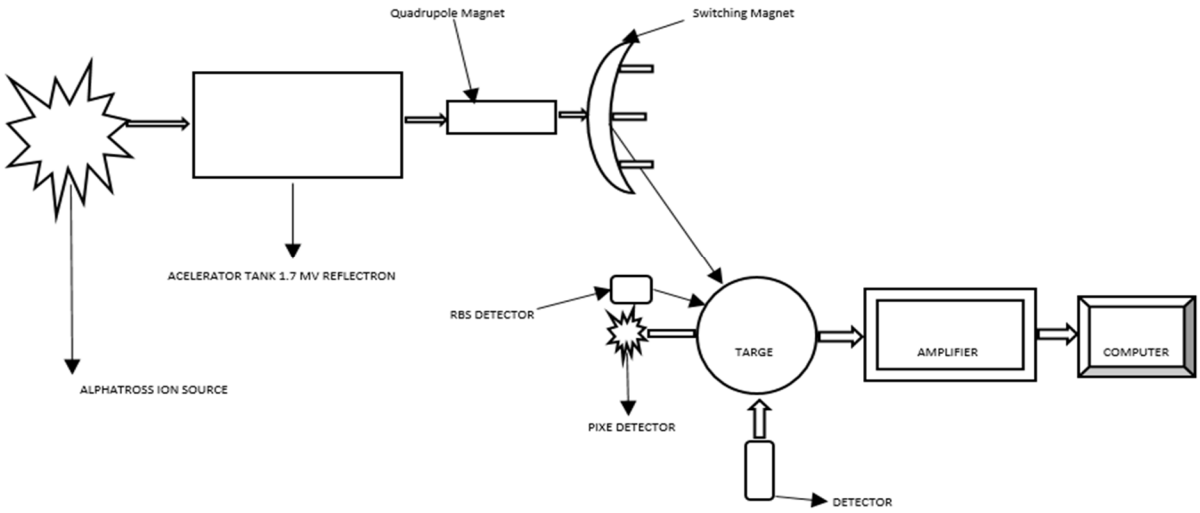

FIG. 3. The PIXE Instrument Setup at the Centre for Energy Research and Development (CERD) is depicted in this diagram.

(C) Particle-Induced X-ray Emission (PIXE)

A PIXE (particle-induced x-ray emission) system was employed to assess the heavy metal and trace elements concentrations within Harmattan dust samples collected from several locations in Nigeria as part of an environmental research study. This technique is also used for identifying aerosol samples and can be applied to various types of sample materials, including those in geological, archaeology, biological, material science, and environmental pollutant research.

(D) Sample Irradiation of PIXE Machine and Description of the Accelerator

Ezeh and Obiajunwa [43] provided the comprehensive configuration of the proton-induced X-ray emission technique (PIXE) system utilized in this study. The charge exchange ion (beam) source, which is furnished with hydrogen and helium and has facilities for five beam lines maintained by quadrupole magnets, is connected to the accelerator tank [44]. The Model 5SDH Pelletron from the National Electrostatics Corporation is a 1.7MV tandem electrostatic ion accelerator. This device is designed to accelerate light ions, primarily for the purpose of advancing material science research through techniques such as Rutherford backscattering, PIXE, and hydrogen profiling, as well as for conducting experiments related to implantation and nuclear physics experiments, among other approaches. To control beam size, the end station contains a turbo pump and a variable collimator. A target scattering chamber houses the sample holder and is connected to the detectors for PIXE and Rutherford Back Scattering (RBS) investigations. For monitoring the beamlines at 0.0, PIXE detectors were set at a glancing angle of 1350^0 perpendiculars to the typical beam windows. The detector employed was a solid-state Si-Li detector that was liquid nitrogen cooled and coupled to the multi-channel analyzer (MCA).

Results and Discussion

Table 1 shows the findings of Harmattan dust samples collected over time in various places. Particle-induced x-ray emission was used to determine the elemental compositions and concentrations of Harmattan dust samples (PIXE). The study revealed the presence of eighteen (18) elements in both light and heavy forms, as determined by the mean value of elemental concentrations obtained throughout the Harmattan season. These elements include Na, Mg, Al, Si, P, S, Cl, K, Ca, Ti, Cr, Mn, Fe, Cu, Zn, Rb, Sr, and Zr. Among the elements identified, Zr. K, Ca, Ti, Mn, Fe, Cu, Zn, Zr, Sr, and Cr were found in the samples. Other elements detected in the samples, including Na, Al, Si, P, S, Cl, and Rb, are not transition metals. The particle-induced x-ray emission analysis indicated that these elements are present in varying amounts (PIXE).

Particle-induced x-ray emission (PIXE) can also be utilized to detect the concentration of transition metal elements and heavy metals in Harmattan dust, according to this research.

Ti, Cr, Mn, Fe, Cu, Zn, and Zr are heavy metals found in the samples, while Na, Mg, Al, Si, Cl, K, Ca, Rb, St, and Sr are light metals.

Si had the highest concentration of Harmattan dust in the samples collected across all of the selected stations in Nigeria, as shown in Fig. 4 (A-Iwo, B-Oyo, C-Ilorin, D-Minna, E-Abuja, F-Lafia, G-Jos). While elements like Na, Mg, P, S, Ce, Zn, and Zr have low elemental concentrations, elements like Ca and Fe have a consistent concentration throughout all of the stations studied. The average concentration of Ca and Fe in Nigeria is due to the presence of an iron smith firm, animal bones in abattoirs, and waste bin areas around the country, all of which contribute to the concentration of those elements in the samples.

TABLE 1. Elemental concentration of Harmattan dust using PIXE.

Symbol	A Conc. (mg/kg)	B Conc. (mg/kg)	C Conc. (mg/kg)	D Conc. (mg/kg)	E Conc. (mg/kg)	F Conc. (mg/kg)	G Conc. (mg/kg)
Na	3803.1	2952.9	2836.7	3072.8	1944.8	2762.1	3018.9
Mg	2836.2	2234.2	1636.4	1471.8	5230.6	2178.4	3507.6
Al	27263.4	15945.1	28021.7	24237.7	16277.8	22175.1	36656.8
Si	279170.0	232706.6	231153.9	224044.8	265783.7	209883.2	317230.3
P	631.3	629.0	499.8	343.4	567.5	296.1	646.7
S	997.8	0	0	860.8	4949.3	1218.5	2441.0
Cl	1676.0	1170.6	1138.0	492.4	622.9	388.1	902.9
K	18947.6	5101.3	12476.5	8140.0	6312.2	15540.5	14218.6
Ca	14610.9	14633.4	9025.1	30835.5	58455.5	17846.7	30191.1
Ti	2208.8	1625.3	1950.6	1666.1	2568.7	1572.9	2835.6
Cr	90.5	133.8	108.9	103.4	178.0	71.2	131.9
Mn	391.8	321.1	438.2	316.6	120.4	140.2	393.6
Fe	19940.2	24123.0	36387.0	28857.5	16694.3	10461.3	40312.8
Cu	0	182.2	233.1	109.7	139.9	100.4	293.2
Zn	747.4	494.8	554.5	215.9	296.6	239.2	471.0
Rb	0	0	0	0	0	65.4	0
Sr	0	0	0	87.0	124.8	111.0	82.1
Zr	294.4	401.0	371.9	398.1	117.1	0	487.6

A(Iwo), B(Oyo), C(Ilorin), D(Minna), E(Abuja), F(Lafia), G(Jos)

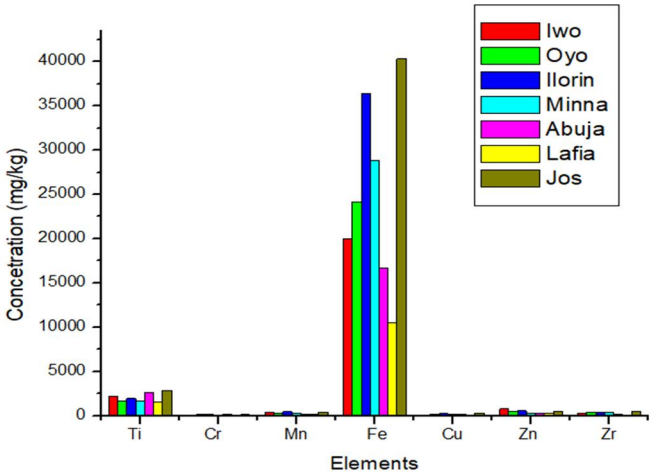

FIG. 4. Elemental concentration across each location.

The analysis of samples collected from selected sites in Nigeria revealed the presence of heavy metals, as shown in Fig. 4. These heavy metals, including Ti, Cr, Mn, Fe, Cu, Zn, and Zr, were found in varying concentrations throughout the study. This finding underscores the efficacy of the particle-induced X-ray emission (PIXE) method in detecting the elemental composition of particulate matter, a fact previously reported by Makra *et al.* [41] and Abiye *et al.* [42]. The allowable quantities of Fe, Ca, Mg, and Zn in the air are limited to 0.4 mg/m^3 for twenty-four hours to ensure air quality and safety for human health, according to the Arizona Ambient Air Quality (1999).

Meanwhile, the PIXE machine reported that the concentration of the elements in this research as follows: 19940.2 mg/kg in Iwo, 24123.0 mg/kg in Oyo, 36387.5 mg/kg in Ilorin, 28857.5 mg/kg in Minna, 1669.3 mg/kg in Abuja, 10461.3 mg/kg Lafia, and 10461.3 mg/kg in Jos (40312.8 mg/kg). During the year of examination, the significant concentration of Harmattan dust that spread across all the reviewed stations exceeded the WHO-recommended levels of iron in the human body. This could be attributed to various activities occurring in these areas, including factors like vehicular mobility and industrial operations. When compared to established standards, the percentage levels of iron (Fe) in the air at each of the stations under study were as follows: Iwo - 9%, Oyo - 9%, Ilorin - 14%, Minna - 3%, Abuja - 6%, Lafia - 2%, and Jos - 1% (3%). This indicates that the concentration of iron in Ilorin was notably higher compared to other stations. This may be linked to Ilorin's geographical location in the heartland of Nigeria. However, even though there was a slight increase in iron levels at all of these sites, it suggests that the air quality in these areas may not be considered pristine.

It's worth noting that iron is essential for the survival of plants and animals, as it plays a key role in the synthesis of chlorophyll in plants. Iron is also an important component of human and animal hemoglobin, the material that transports oxygen throughout the human body's red blood cells. However, according to the World Health Organization, too much iron in the body promotes liver and heart damage.

The finding also demonstrates that the magnesium (Mn) concentration is the same across all of the stations studied: 391.8 mg/kg in Iwo, 321.1 mg/kg in Oyo, 38.2 mg/kg in Ilorin, 316.6 mg/kg in Minna, 120.4 mg/kg in Abuja, 140.6 mg/kg in Lafia, and 140.6 mg/kg in Jos (393.6 mg/kg).

Because of its proximity to the source of the dust, the concentration in Jos is higher than in other localities. This also demonstrates that the magnesium level in the air at all of these sites is higher than the World Health Organization's suggested standard value. Manganese acceptable value in Nigeria was found to be 0.01 mg/m3, as indicated. Manganese is utilized in the production of cell batteries as well as in the chemical industry as an oxidizing agent. The permissible level of titanium (Ti) in the air is found to be the same as that of iron. However, it was discovered in this investigation that the Ti level in the air is significantly beyond the World Health Organization's suggested standard threshold.

Zinc (Zn) is an essential element in the composition of Harmattan dust, as it is crucial for human health and the well-being of all living organisms. However, research indicates that an excessive quantity of Zn in the air can be detrimental to human health, surpassing WHO-established limits. The permissible level of Zn in the air is similar to that of iron, as observed. Nevertheless, this study revealed that the Zn levels in Iwo and Minna significantly exceed the WHO threshold. This occurrence may be attributed to specific activities taking place in both of these locations.

As for the copper (Cu) in the collected samples, Jos had the highest value of 293 mg/kg, followed by Ilorin and Oyo with values of 233.1 mg/kg and 182.2 mg/kg, respectively. Abuja was next, with a value of 139.9 mg/kg, while other stations had values below 110 mg/kg. The WHO-recommended tolerable potassium level in the air is 8.7 mg/m3. Meanwhile, stations in Oyo, Ilorin, Abuja, Lafia, and Jos had higher potassium concentrations, as shown by the PIXE analysis. According to Chineke and Chiemeka [41], potassium pentaborate is a colorless, odorless, powerful substance that is flammable, combustible, or explosive. Additionally, it contains elements with dermal toxicity. However, for this study, PIXE analysis was performed on samples obtained from all the sites studied. Figure 4 shows that the samples had a high content of iron (Fe), with Jos having the highest value, followed by Ilorin and Minna. The elevated concentration of iron in these locations is attributed to the presence of iron manufacturing facilities in these areas.

Statistical Analysis

Results in Table 2 reveal that there is no significant difference in Na between the six locations ($p>.05$) while other element metals were significantly different between locations ($p<.05$). The levels of Mg, Al, P, S, Ti, Fe, and Zr in Jos were significantly higher than that obtained in Ilorin, Minna, and Lafia while between Oyo and Jos ($p<.05$), there was no significant difference in P, K, and Zr ($p>.05$).

Results also reveal that Fe and Al were significantly higher in Jos than in other locations, while there was no significant difference in Rb and Se between Oyo and Ilorin. Abuja reported a significantly higher level of Mg compared with other locations (Table 2).

The dendrogram in Fig. 5 reveals that the spatial distribution of the element metals in Oyo and Lafia is similar (cluster 1), Ilorin and Minna form another cluster (cluster 2), Abuja represents its own cluster (cluster 3), and Jos forms a distinct cluster (cluster 4).

TABLE 2. Comparison of element metals in the different locations in the study area.

	Locations					
Elements	Oyo	Ilorin	Minna	Abuja	Lafia	Jos
Na	2897.30±90.43^{a}	8015.56±11383.07^{a}	3077.40±7.58^{a}	1946.80±10.17^{a}	2761.50±14.23^{a}	3021.50±3.65^{a}
Mg	2248.62±11.95^{d}	1688.28±58.74^{b}	1476.40±6.46^{a}	5232.60±15.45^{f}	2177.80±11.33^{c}	3510.20±3.65^{e}
Al	15874.12±81.01^{a}	28228.02±443.70^{e}	24242.30±3.25^{d}	16279.80±12.27^{b}	22174.50±19.57^{c}	36659.4±3.65^{f}
Si	232684.12±145.67^{c}	231593.58±12027.66^{c}	224049.40±8.40^{b}	265785.70±18.41^{d}	209882.60±21.48^{a}	317232.90±3.65^{e}
P	650.20±42.93^{e}	496.78±2.75^{c}	348.00±11.49^{b}	569.50±19.22^{d}	295.50±12.39^{a}	649.30±3.65^{e}
S	0.00±0.00^{a}	0.00±0.00^{a}	865.40±8.72^{b}	4951.30±11.25^{e}	1217.90±19.25^{c}	2443.60±3.65^{d}
Cl	1161.84±20.88^{f}	1115.80±50.01^{e}	497.00±9.32^{b}	624.90±18.47^{c}	387.50±113.20^{a}	905.50±3.65^{d}
K	5203.44±120.76^{a}	12638.50±364.53^{d}	8144.60±13.44^{c}	6314.20±12.33^{b}	15539.90±16.24^{f}	14221.20±3.65^{e}
Ca	14675.70±63.96^{b}	9045.90±17.14^{a}	30840.10±2.56^{e}	58457.50±13.51^{f}	17846.10±17.26^{c}	30193.70±3.65^{d}
Ti	1661.08±28.32^{b}	1963.50±19.75^{c}	1670.70±1.64^{b}	2570.70±15.27^{d}	1572.30±23.11^{a}	2838.20±3.65^{e}
Cr	127.32±12.21^{c}	108.10±1.61^{b}	108.00±6.22^{b}	180.00±21.25^{d}	70.60±33.13^{a}	134.50±3.65^{c}
Mn	323.00±19.12^{c}	443.78±9.85^{e}	321.20±9.45^{c}	122.40±13.29^{a}	139.60±15.66^{b}	396.20±3.65^{d}
Fe	23527.60±895.79^{c}	37010.00±878.28^{e}	28862.10±5.35^{d}	16696.30±25.21^{b}	10460.70±18.89^{a}	40315.40±3.65^{f}
Cu	186.14±7.78^{c}	263.34±43.06^{d}	114.30±15.21^{a}	141.90±19.23^{b}	99.80±21.54^{a}	295.80±3.65^{e}
Zn	476.50±41.78^{c}	557.10±5.75^{d}	220.50±5.38^{a}	298.60±23.33^{b}	238.60±19.11^{a}	473.60±3.65^{c}
Rb	0.00±0.00^{a}	0.00±0.00^{a}	0.00±0.00^{a}	0.00±0.00^{a}	64.80±41.16^{b}	0.00±0.00^{a}
Sr	0.00±0.00^{a}	0.00±0.00^{a}	91.60±17.14^{b}	126.80±34.45^{d}	110.40±17.67^{c}	84.70±3.64^{b}
Zr	490.20±3.65^{e}	375.52±5.06^{c}	402.70±19.57^{d}	119.10±17.21^{b}	0.00±0.00^{a}	490.20±3.64^{e}

A similar superscript letter means not significantly different ($p>0.05$), and a different superscript letter means significantly different ($p<0.05$).

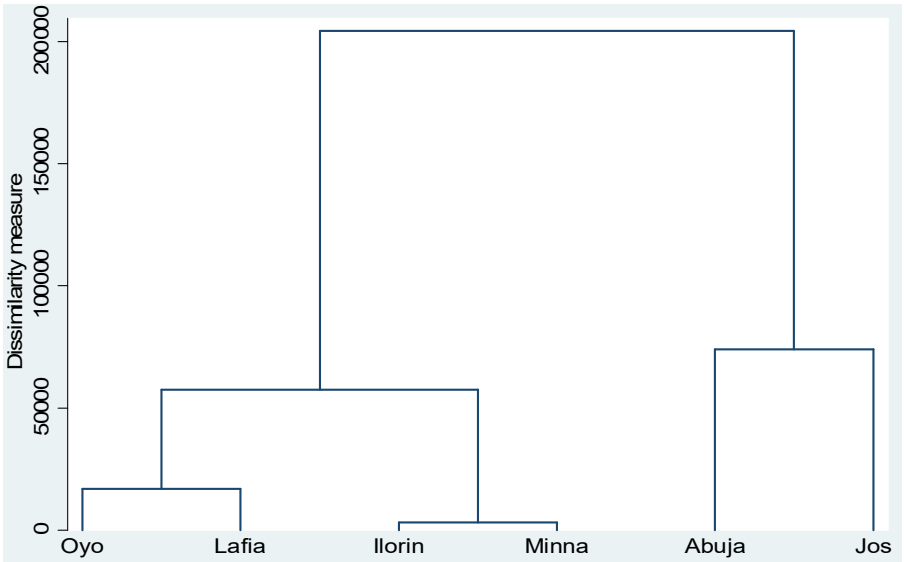

FIG. 5. Spatial distribution of the element metals in the different locations.

Results of the correlation between the metals as presented in Table 3 show that Na has a significant positive correlation with Cu ($r = 0.404$, $p < 0.05$). Mg demonstrates significant positive correlations with Si ($r = 0.624$, $p < 0.01$), P ($r = 0.485$, $p < 0.01$), S ($r = 0.944$, $p < 0.01$), Ca ($r = 0.843$, $p < 0.01$), Ti ($r = 0.775$, $p < 0.01$), and Sr ($r = 0.531$, $p < 0.01$). However, Mg exhibits a significant negative correlation with manganese Mn ($r = -0.496$, $p < 0.01$). Al shows significant positive correlations with Si, K, Ti, Mn, Fe, Cu, and Zr. Si exhibits significant positive correlations with P, S, Ca, Ti, Fe, Cu, and Zr. However, it has a significant inverse relationship with Rb ($p < 0.05$). Additional results for correlations between other metal elements are available in Table 3.

TABLE 3. Correlation among the elements.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Na	1																	
Mg	-.222	1																
Al	.178	-.166	1															
Si	-.186	.624**	.553**	1														
P	-.024	.485**	.076	.692**	1													
S	-.237	.944**	-.114	.541**	.218	1												
Cl	.172	-.108	.135	.260	.754**	-.391*	1											
K	.124	-.229	.712**	.108	-.364*	-.147	-.209	1										
Ca	-.265	.843**	-.231	.435*	.160	.941**	-.438*	-.384*	1									
Ti	-.063	.775**	.456*	.937**	.617**	.722**	.156	.096	.595**	1								
Cr	-.117	.799**	-.205	.586**	.685**	.703**	.232	-.589**	.740**	.692**	1							
Mn	.278	-.496**	.633**	.243	.344	-.587**	.709**	.146	-.560**	.088	-.105	1						
Fe	.260	-.212	.770**	.528**	.434*	-.265	.595**	.174	-.254	.414*	.104	.924**	1					
Cu	.404*	.054	.680**	.624**	.659**	-.120	.733**	.269	-.260	.567**	.226	.760**	.833**	1				
Zn	.287	-.082	.355	.347	.684**	-.340	.942**	.070	-.467**	.277	.164	.736**	.667**	.868**	1			
Rb	-.081	-.181	-.105	-.447*	-.632**	-.091	-.569**	.568**	-.241	-.419*	-.603**	-.530**	-.645**	-.462*	-.449*	1		
Sr	-.288	.531**	-.022	.198	-.359	.750**	-.860**	.156	.738**	.316	.195	-.700**	-.457*	-.474**	-.776**	.380*	1	
Zr	.107	-.300	.392*	.369*	.575**	-.429*	.711**	-.251	-.309	.146	.156	.856**	.818**	.628**	.614**	-.726**	-.622**	1

*Correlation is significant at 5% ($p<0.05$), **Correlation is significant at 1% ($p<0.01$).

Conclusion and Recommendations

This study looked at the amounts, chemical compositions, and presence of heavy metals in suspended Harmattan dust in Nigeria. The PIXE technique was utilized to collect the data for the analysis. The average suspended dust particle concentration differed per station, with the highest concentrations seen in Abuja and Jos. Fe and Ca concentrations were the most prominent among the 18 elements analyzed (Na, Mg, Al, Si, P, S, Cl, K, Ca, Ti, Cr, Mn, Fe, Cu, Zn, Rb, Sr, and Zr). The levels of Mg, Al, P, S, Ti, Fe, and Zr in Jos were considerably greater than those found in Ilorin, Minna, and Lafia, whereas there was no significant difference in P, K, or Zr between Oyo and Jos.

Furthermore, Jos exhibited much greater Fe and Al levels than other sites, although there were no significant differences in Rb and Se between Oyo and Ilorin. Additionally, Abuja had significantly higher Mg levels than other locations. In order to decrease pollution dispersion, it is necessary to recommend the use of dust precipitators in all cities. Other methods of pollution reduction should be devised and adopted. Risk and exposure studies should also be undertaken in study sites so that direct health impact information on humans may be obtained. Regulatory entities should build and encourage the establishment of a nationwide air quality monitoring network to track daily or weekly variations in suspended dust concentrations in all Nigerian cities. An annual suspended Harmattan dust monitoring program is also required, particularly in and around Nigeria's major cities, in order to identify pollution sources accurately. The government and other relevant organizations should implement public awareness campaigns and media initiatives about the possible dangers of inhaled suspended particles.

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