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Chemical Characterization of Harmattan Dust across Oyo and Minna, Nigeria

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Abstract: Harmattan dust haze in Nigeria is due to annual deposition of very fine dust particles as a result of both natural and human activities. There are scanty reports on the mineralogical, elemental and heavy metal composition in the Harmattan dust blowing across the country to support the presence of minerals and elements in the Harmattan dust. The aim of this study is to assess minerals and elemental compositions of Harmattan dust variations across Oyo ($7^0$32'N, $3^0$25'E) and Minna ($9^0$35'N, $6^0$32'E), Nigeria. Harmattan dust samples were collected using clean plastic bowls of 10 cm diameter and analysis was conducted on the samples collected at the two stations using Fourier Transform Infrared Spectroscopy (FTIR), X-ray Fluoresence (XRF), Particle Induced X-ray Emission (PIXE) and Atomic Absorption Spectroscopy (AAS). It was observed that elements, such as K, Ca, Ti, Mn, Fe, Ni, Cu, Zn, Mo, As, Zr, Pb, V, Sr, Cr and Ce, were present in different concentrations in the samples collected. Minerals, such as Quartz [SiO_2], Rutile [TiO_2], Periclase [MgO], Corundum [Al_2O_3], Hematite [Fe_2O_3], Cuprite [Cu_2O], Baddeleyite [ZrO_2], Litharge [PbO], Monazite [P_2O_5], Zincite [ZnO], Montroydite [HgO] and Lime [CaO], were present in the samples collected at each station in different proportions. The soil mass concentration of the elements was calculated and observed to be 3.5179μg m^3 at Oyo and 3.4745μg m^3 at Minna. It was observed that the Harmattan dusts moving across Nigeria have almost all the elements present in Harmattan dust varying from station to station as the dust is moving towards the south of the country. The study concluded that the elemental composition of the dust samples analyzed revealed that the percentage compositions of some elements are higher than the acceptable WHO standard values, which may affect human health. It is therefore recommended that adequate precautionary measures and policies should be made to help mitigate the effects of high elemental concentrations observed.

Keywords: FTIR, PIXE, XRF, AAS, Mineralogy and element composition.

Introduction

The word Harmattan is a local term of dust storm gotten from the Twi language "haramata", which perhaps is from Arabic "haram" forbidden thing. This is a dry dusty wind that emanated from the Sahara blowing towards the West Africa coast of the world continent, which precisely started from November to March of every year. More so, the Harmattan in America is also known as a dry dusty wind that blows from the Sahara in North Africa towards the Atlantic affecting both domestic and commercial activities during its period.

Harmattan dust lifting, transportation and deposition occur naturally (Kalu [1], Falaiye et al. [2], Adimula [3], Falaiye et al. [4]). This could be a result of wind transportation that

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moves the dust from the source and deposits it along the trajectory path. The Harmattan period is usually associated with low and poor visibility of the atmosphere, which is sometimes less than 1000 m (Falaiye et al. [2], Adimula et al. [3], [4]). Falaiye et al. [5] reported that the more the Harmattan dust mass in the air, the less the visibility of both human and animal.

The wind that blows Harmattan dust across Nigeria is the north east trade wind. This wind causes different types of ailments, such as dry skin, cough, catarrh and respiratory-related diseases, which are mostly reported in hospitals during the Harmattan period (Carlson and Prospero [6], Shutz [7]). Studies have shown that the Harmattan season occurs from the month of November to the month of March of the following year in Nigeria (Falaiye [4]).

During this period, the atmosphere is laden with dust, thus reducing visibility and causing domestic as well as outdoor activities' inconvenience (Aweda et al. [8]). During the period of this study (November – March), the West African region experiences the prevailing north-easterly wind regime known as Harmattan (Adimula et al. [3]). Junge [9] reported that on the average, it takes about twenty-four hours for the Harmattan to reach the Northern part of Nigeria from its source. Bertrand et al. [10] reported that dust particles are deposited over the region where dust plumes predominantly originate from the *Bódelé* depression in the Chad Basin. This fact has been pointed out by various meteorological observers according to Samway [11].

Different authors have worked on the mechanisms of the path way of dust on the Cape Verde Islands as reported by (Glaccum and Prospero [12], Talbot et al. [13]). Since the majority of land-derived sediments in this part of the Atlantic Ocean are of Aeolian origin, often the erogenous sediment fraction was taken to be windblown (deMenocal et al. [14], Moreno et al. [15], Sarnthein [16]).

In another vein, admixtures of fluvial-transported or laterally adverted sediments were also found to play a role in Harmattan dust as well (Holz et al. [17], Koopmann [18], Ratmeyer et al. [19], Zabel et al. [20]). In Harmattan dust production, Chad Basin was estimated to be up to 6.3 × 108 and 7.1 × 108 t/yr in1981 and 1982, respectively (McTanish and Walker [21]).

Studies have been conducted on the pollutant concentrations in the ambient air (Obiajunwa et al. [22]). This is powerful and widely used for the purpose of identifying the dominant sources of dust (Owoade et al. [23], Cohen et al. [24], Mooibroek et al. [25]). The emission rate that increases the range of air pollutants associated with iron smelter process (Brook et al. [26], Pope and Dockey [27], Zhang et al. [28], Tai et al. [29]) in the part of south west contributes to the increase of iron concentration. The light-absorbing species in the atmosphere play a major role in the block carbon of the aerosol climatic forcing and visibility degradation (Malm et al. [30], Jacobson [31] and Bond et al. [32]).

Heavy metals, such as As, Cd and Cr, are part of the constituents of particulate matter with iron and steel production (Cohen et al. [33]) in some parts of Nigeria. Hence, this study focuses on the assessment of trace elementals and minerals in Harmattan dust in the selected locations and their effects on the human health.

Material and Methods

(A) Sample Collection

A dry standard plastic bowl of a diameter of 10 cm and a height of 40 cm was used to collect each of the Harmattan samples across the two selected stations. This plastic bowl was kept in a wire gauge of (100x100x100 cm) firmed on the top of residential buildings, so as to prevent the dust from reptiles and wind disturbance. The choice of plastic bowl was taken, because the bowl has a heavy weight that can prevent wind from blowing it away and dust can settle in it successfully. In Nigeria, plastic bowl is one of the important materials used for domestic and commercial purposes. Different precautionary measures were put in place to avoid contamination by keeping the plastic in a polythylene box (60x60x60 cm) with a hole on its sides for aeration. See Fig. 1. Distilled water was also exposed on an elevated platform and in residential buildings at the two locations: Oyo ($7^0$32'N, $3^0$25'E) and Minna ($9^0$35'N, $6^0$32'E). The maps of sampling locations are shown in Figs. 2 and 3. Some of the bowls were exposed to collect dust particles from November for a period of one week or one month, while some were exposed to collect the dust samples for a period of five months (November to March), respectively. A total of ten (10) samples were collected and stored in desiccators prior to the analysis in order to avoid contamination which could influence the results. This experiment follows the method adopted by Falaiye et al. [4] and Falaiye and Aweda [5], where Petri dishes were exposed on an elevated platform to collect Harmattan dust samples in order to conduct mineralogical and chemical analysis. During the collection process, as reported by Falaiye et al. [4], measures such as keeping the sample containers away from public roads and highways were taken into consideration in order to minimize contamination by the local dust. However, the experimental setup for this research is shown in Fig. 1 below.

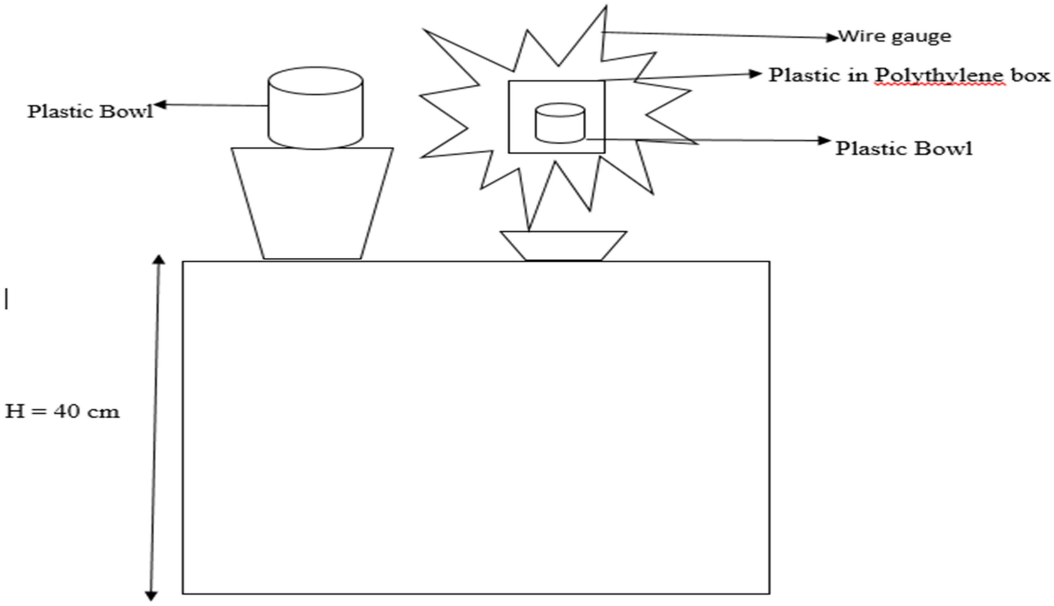

FIG. 1. Schematic diagram of the experimental setup for sample collection.

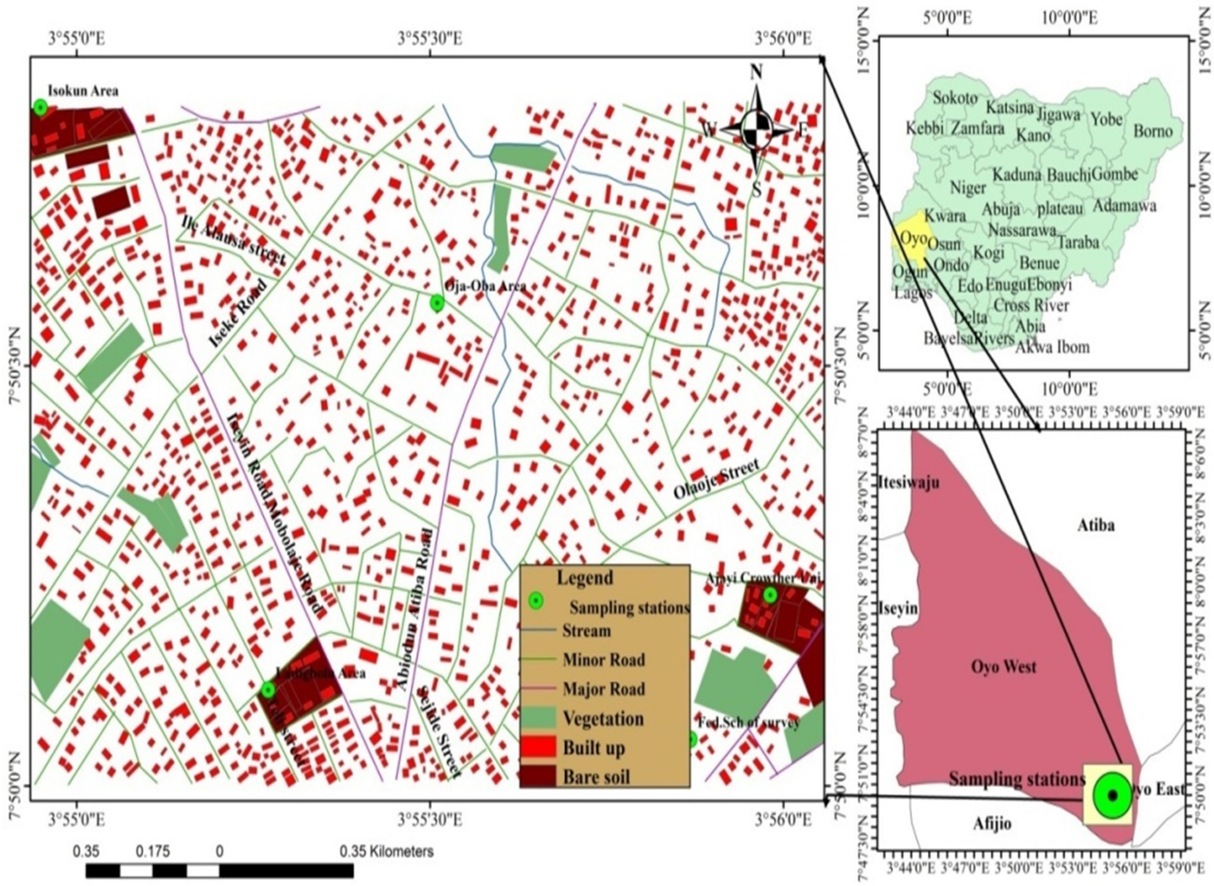

FIG. 2. Map of Oyo showing the sampling location.

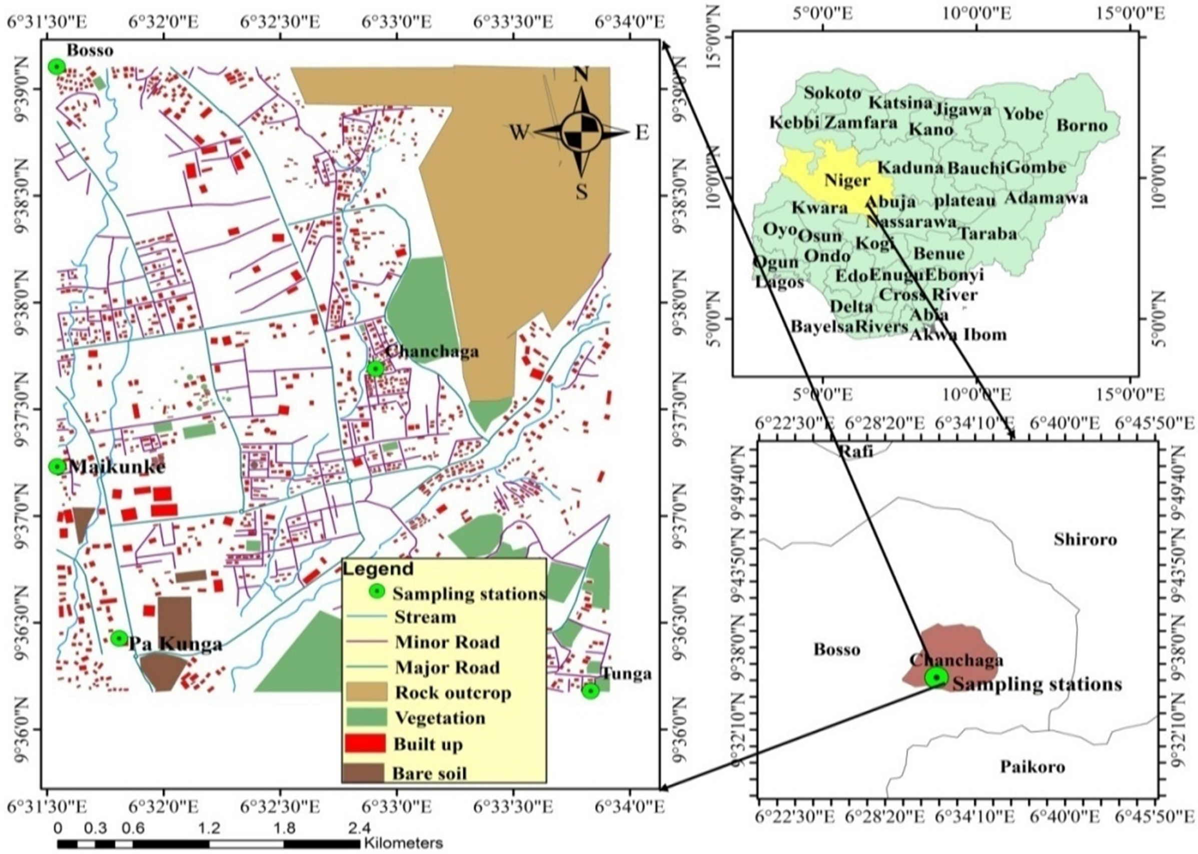

FIG. 3. Map of Minna showing the sampling location.

TABLE 1. Coordinates of different sampling locations across each station.

Location	Longitude (N)	Latitude (E)	Elevation (m)
Minna Area			
Bosso	$9^{0}39'17.13''$	$6^{0}31'39.73''$	909
Maikunkele	$9^{0}41'11.48''$	$6^{0}28'24.39''$	1026
Tunga	$9^{0}35'40.78''$	$6^{0}33'54.80''$	868
Pa Kungu	$9^{0}35.849'$	$006^{0}31.487$	597
Chanchaga	$09^{0}33'11.16''$	$06^{0}34'58.19''$	744
Oyo Area			
Federal School of Survey	$7^{0}50'31.86''$	$3^{0}56'57.98''$	1030
Ajayi Crowther University	$7^{0}50'13.49''$	$3^{0}56'06.19''$	1030
Isokun Area	$7^{0}50'49.22''$	$3^{0}54'57.58''$	937
Ladigbolu Area	$7^{0}49'11.45''$	$3^{0}55'07.68''$	973
Oja-Oba Area	$7^{0}50'58.33''$	$3^{0}55'47.79''$	951

(B) Sample Preparation and Characterization

The dry Harmattan dust samples were pelletized before being analyzed. Pelletization of the samples was done with steel mold pellets and a hydraulic press. Aluminum foil was used as the binder to hold the sample particles together after their removal from the molds. Thereafter, the samples were transferred into the accelerator for the XRF and PIXE employed in the research analysis.

Mineralogical and elemental analyses were carried out on the Harmattan dust gathered across the two stations under consideration. The analyses were carried out using the following characterization techniques: PIXE, XRF, FTIR and AAS, to determine the minerals and elements present in the samples collected across the two stations.

(C) Machines Used and Their Description

The elemental analysis of the Harmattan dust samples was carried out using the Energy Dispersive X-ray Fluorescence (EDXRF) spectrometry, Particle-Induced X-ray Emission, Fourier Transform Infrared Machine (FTIR) and Atomic Absorption Spectroscopy (AAS). The spectrometer brand name of EDXRF is ECLIPSE Ш, supplied by AMTEK INC. MA; USA. It is a self-contained miniature X-ray tube system. The detection system for all the measurements is of Model XR-100CR which is a high-performance X-ray detector with a preamplifier and a cooler system which uses a thermoelectrically cooled Si-PIN photodiode as an X-ray detector. The power to the XR-100CR is provided by a PX2CR power supply. The detector is coupled to the pocket MCA 8000A Multichannel Analyzer. The resolution of the detector for the 5.9 keV peak of 55Fe is 220 eV FWHM with 12µs shaping time constant for the standard setting and 186 eV FWHM with 20µs time constant for the optional setting. The optional setting was used for measurements with a resolution of 186 eV for the 5.9 peak of 55Fe. The Particle-Induced X-ray Emission machine with the name National Electrostatics Corporation Model 5SDH pelletron which is a 1.7MV tandem electrostatic ion acceleration was used for the analysis. This system is designed to accelerate light ions for material science research using such techniques as Rutherford backscattering, PIXE, hydrogen profiling and implantation and nuclear physics experiments. However, it is also capable of producing low current of heavy ions. This technique can be applied to different sample materials which include geological, archaeological, biological, material science and environmental pollution in which Aerosol samples are classified. The detailed setup of the proton-induced X-ray emission technique (PIXE) setup used for this work was reported by Ezeh and Obiajunwa [34] and it was briefly described by Ezeh et al. [35]. The accelerator tank is linked with the charge exchange ion (beam) source which is equipped with hydrogen and helium. The Fourier Transform Infrared Machine (FTIR) manufactured by Agilent Technologies with the model number CARY 630FTIR was used for the analysis of the liquid samples. The Atomic Absorption Spectroscopy (AAS) with model number PG990 was used for the analysis of the liquid samples.

(D) Sample Preparation Using EDXRF and PIXE

The Harmattan dust samples analyzed were dried and pelletized. The pelletization of the samples is done with steel molds, pellets and a hydraulic press, by aluminum foil as the binder, to hold the sample particles together after their removal from the molds.

(E) Sample Preparation Using AAS and FTIR

The samples collected at each location were taken to the laboratory for analysis using Atomic Absorption Spectroscopy (AAS). The samples were digested before taking them for the elemental analysis using AAS. The digestion process was done in a fume cupboard for safety purposes, by measuring 50 ml of each waste water sample (4 samples) and adding 5 ml of hydrochloric acid, followed by boiling till 20 ml. They were all filtered and the filtrates were taken for chemical analysis using PG990 model buck scientific AAS. For FTIR, the samples collected at each location were taken to the laboratory for analysis using Fourier Transform Infrared Machine (FTIR) manufactured by Agilent Technologies with the model number CARY 630FTIR. The sample liquid was shaked vigorously and then a little quantity of the sample was dropped on the sensor part of the machine where a software installed on a computer was used to determine the spectrum

Results and Discussion

A. Elemental Composition and Concentrations

Elemental concentrations of Harmattan dust collected in Oyo and Minna include: Cu, Zn, Fe, Pb, Ca, Mn, Ni, As, K, Ti, Mo, V, Sr and Zr. Table 2 reveals the elements present in Oyo. Fig. 4 shows the spectrum of the elements present in the samples as obtained from PIXE results for samples from Oyo. The order of magnitude of the concentration values is: Ca>Fe>K>Ti>Mn>Pb>Zn>V>Ni>Cu≥Sr>Mo> As.

Calcium (Ca) was discovered to be of highest concentration in the samples at Oyo and Minna. This was due to some activities taking place at Oyo during the sampling collection.

TABLE 2. Average concentrations of metals in different elemental forms as revealed by PIXE for solid sample collected across Oyo.

	A (mg/L)	B (mg/L)	C (mg/L)	D (mg/L)	E (mg/L)	Average (mg/L)
K	32506	32453	32453	32453	32400	32453
Ca	82898	82799	82799	82799	82700	82799
Mn	4080	3000	3580	3540	3500	3540
Fe	82364	82344	82358	82354	82350	82354
Ni	504	450	474	484	474	474
Cu	300	253	250	256	203	253
Mo	100	96	97	98	99	98
As	100	92	96	98	94	96
Zr	300	256	200	250	253	253
Pb	777	778	779	780	776	778
V	550	450	400	560	490	490
Sr	200	143	173	176	170	173
Cr	143	200	170	173	176	173

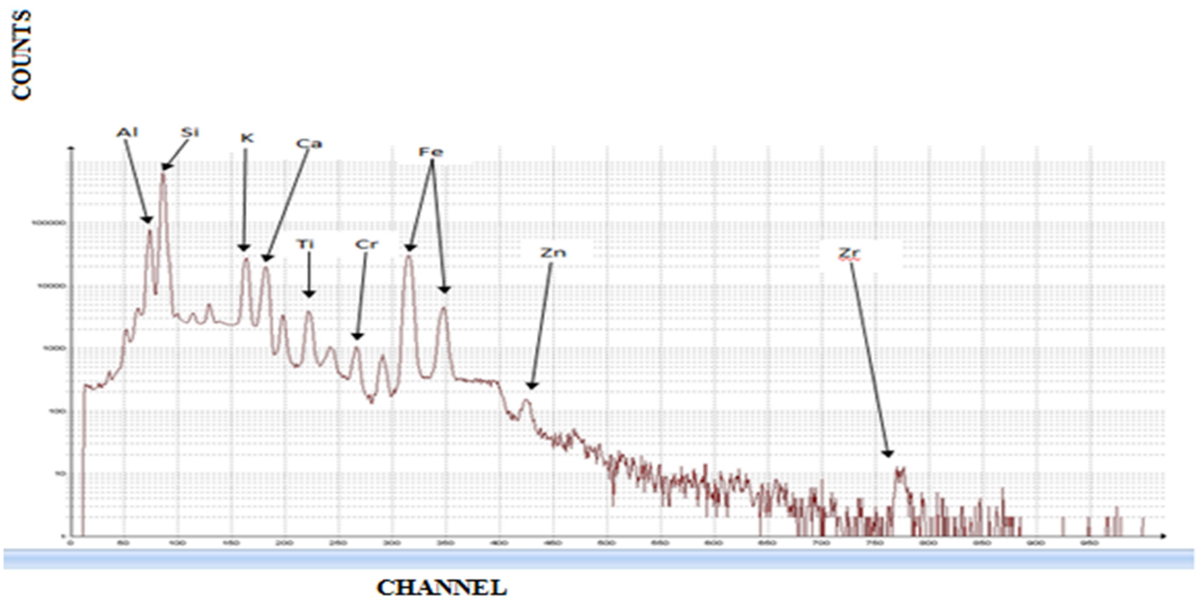

FIG. 4. PIXE spectrum of Harmattan dust sample from Oyo deposit.

The sampling locations were labelled with different letters which are: A (Federal School of Survey), B (Ajayi Crowther University), C (Isokun), D (Ladigbolu) and E (Oja-Oba). These locations are in the ancient part of Oyo town in Oyo State, Nigeria, as shown in Fig. 2. They are also represented with different coordinates, as shown in Table 1.

Table 3 reveals the elemental concentrations as observed in the Harmattan dust collected at Minna. The sampling locations were labelled with different letters which are: F (Bosso), G (Maikunkele), H (Tunga), I (Pakungu), J (Chanchaga). These locations are in Minna Township in Niger State, Nigeria as shown in Fig. 3. They are also represented with different coordinates, as shown in Table 3. These coordinates represent the point at which the samples were collected across each station during the process of the research. Fig. 5 shows the spectral result of the samples collected at Minna during the period of the study.

TABLE 3. Average concentrations of metals in different elemental forms as revealed by PIXE for solid sample collected across Minna.

	F (mg/L)	G (mg/L)	H (mg/L)	I (mg/L)	J (mg/L)	Average (mg/L)
K	28384	28192	28192	28192	28000	28192
Ca	112054	111054	111554	111554	111554	111554
Mn	2416	1016	1716	1716	1716	1716
Fe	65000	61662	63331	63331	63331	63331
Ni	190	177	164	177	177	177
Cu	93	73	83	80	86	83
Mo	50	42	36	42	42	42
As	58	20	38	18	20	28
Zr	202	196	196	196	190	196
Cr	900	832	866	866	866	866
Ti	6387	6380	6394	6387	6387	6387
Ce	866	860	860	878	878	866
Pb	248	248	240	256	248	248
Zn	291	291	291	291	291	291

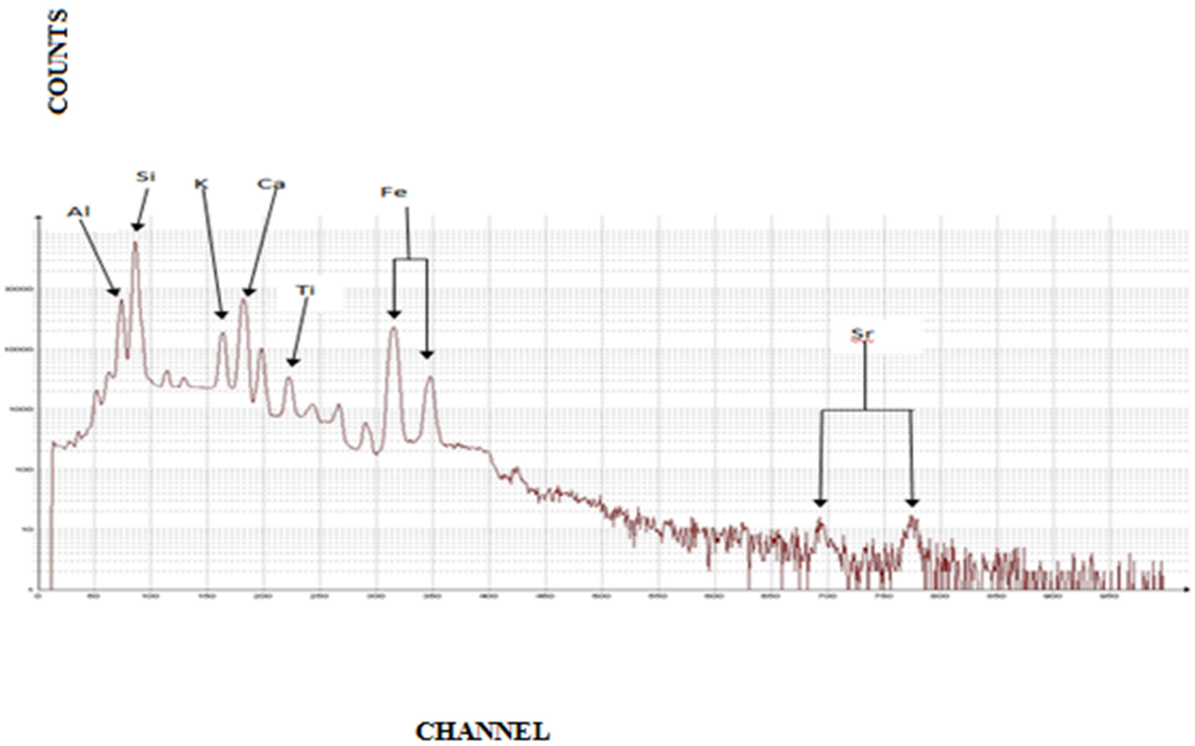

FIG. 5. PIXE spectrum of Harmattan dust sample from Minna deposit.

The soil mass concentration of the elements present in the samples collected across the two stations under consideration was also calculated. It was observed that the soil mass concentration collected in Minna was determined to be $3.4745\mu g/m^3$ while the soil mass concentration for Oyo was observed to be $3.5179\mu g/m^3$. The value for Oyo was found to be higher than the value for Minna as a result of activities taking place during the collection of the samples, such as highway vehicular activities, road side kitchens and many more.

B. Health Implications of Elemental Dust Composition

From the liquid samples, it was observed that there is a presence of lead (Pb) particulate matter in the air. This may be a result of the activities taking place in the environment of the sample collection. These activities include fossil fuel combustion (including vehicles), metal processing industries and waste incineration around the sample collection area, as reported by Isozaki et al [36]. However, research has shown that the little amount of Pb can be harmful to human beings, more especially little babies and young children, as their bodies are prone to the absorption of high elements (Chineke and Chiemeka [37]). As reported by Chineke and Chiemeka [37], if much of Pb is inhaled by a pregnant woman, it may affect the health of the unborn child. Since lead is one of the toxic elements, it will be considered that the presence of lead in Oyo may be as a result of the activities taking place in the Isokun area of Oyo town, where we have heavy vehicular movements, particularly of articulated vehicles. As reported by Chineke and Chiemeka [37], the Air Quality Archive [38] and WHO [39], the acceptable value of potassium in the air as recommended by WHO was observed to be 8.7 mg/m^3. Meanwhile, the two stations Oyo and Minna have average values of potassium to be higher than the recommended value, which could be a result of accumulation of the dust for a long period of time during the sample collection. But, the presence of the high value of the element may be a result of the accumulation of the dust in the dust collector before taking it to laboratory for analysis.

Table 4 shows the elemental concentrations as revealed by AAS machine using the liquid sample collected across each location. However, other elements, such as Zn, Fe, Mn, Ni, As, K, Mo, V, Sr and Zn, present in the dust samples collected at the two stations, revealed that dusts that blow across the country (Nigeria) have some of the toxic elements which may be harmful to human health. As reported by Chineke and Chiemeka [37], the presence of Zinc (Zn) in the air is essential in the elemental composition of Harmattan dust, because Zn is indispensable for human health and for all living organisms. However, research has shown that Zn, though useful and needed for good health, can be toxic to human health if the concentration is far higher than the WHO recommendations over an extended period of time (Chineke and Chiemeka [37], the Air Quality Archive [24], WHO [25]). However, for this study, it can be observed that the acceptable levels of Zn and iron in the air are the same. This is also reported by Chineke and Chiemeka [37]. This indicates that the level of Zn in Oyo and Minna shows a high value as compared with the WHO standard. This may be due to some activities taking place at the two stations, such as road construction, metal work (which makes use of zinc-based materials) and vehicular movement around the station.

TABLE 4. Mean concentrations of metals in different elemental forms as revealed by AAS.

Elements	Na	K	Ca	Mg	Fe	Cd	Zn	Mn	Cu	Cr	Pb
Oyo (ppm)	6.27	4.37	1.883	2.67	8.366	0.157	0.18	-0.054	-0.043	1.931	0.22
Minna (ppm)	19.7	44.94	23.149	9.967	2.376	0.157	7.587	0.631	-0.043	-0.205	0.25
WHO (ppm)	0.005	8.7	0.4	0.4	0.4	5.0	0.4	0.01	0.03	0.5	0.15

This shows that the Harmattan dusts that blow across the two stations under consideration are far above the WHO recommended dosage of iron in the human body. This could be a result of the activities going on in all the environments such as vehicular movement and industrial activities that may be taking place in the area. The human health risk was assessed on the basis of observed mean concentration of the particulate matter of the trace elements and its location, based on the exposure. Human health is assumed to be exposed to significant amounts of the trace elements in the samples collected across the two stations considered. Naturally, inhalation is one of the primary sources of direct exposure to dust particles in every part of the country. More so, the non-carcinogenic risks of some of the trace metals (Cu, Zn, Fe, Pb, Mn, Ni, As, K, Mo, V, Sr and Zn) for children and adults were estimated for road site and urban background elevated from the site.

C. Mineralogical Composition

Mineralogical study of Harmattan dust samples collected at Oyo and Minna, carried out using PIXE analyzer, shows minerals such as Quartz [SiO_2] (82.4%) with a specific gravity of 2.65, which predominantly dominates the samples. Other minerals present in the samples are in lower quantity, (Check Table 5 for details). Studies have shown that the Harmattan dust mineralogies have major components, such as; quartz, haematite, illite, micas, feldspars, kaolinite, chlorite and other accessory minerals, as reported by Adedokun et al. [40], Jimoh [42] and Falaiye et al. [4]. Adedokun et al. [40] at Ile-Ife and Falaiye et al. [4] at Ilorin reported higher mineral contents in Harmattan dust than for the present study. This discrepancy could be a result of different instruments used for analysis: Adedokun et al. [40] and Falaiye et al. [4] used X-ray Diffraction (XRD) machine while in the present study PIXE machine was used.

TABLE 5. Percentage proportions of minerals present in Harmattan dust at Oyo and Minna compared to those of Ile-Ife (Adedokun et al. [40]) and Ilorin (Falaiye, et al. [4]) using XRD machine.

Mineral	Specific Gravity	Ilorin (%)	Ile-Ife (%)	Oyo (%)	Minna (%)
Quartz [SiO_2]	2.65	76.47	74.78	82.4	75.6
Gibbsite [$Al(OH)_3$]	2.35	7.09	-	-	-
Rutile [TiO_2]	4.2	5.78	-	0.45	0.44
Goethite [$Fe_2O_3.H_2O$]	4-4.2	4.59	-	-	-
Halloysite [$Al_4Si_4O_{10}(OH)_8 \cdot 8H\ O$]	2.6	3.93	1.45	-	-
Kaolinite [$Al_4\ Si_4\ O_{10}\ (OH)_8$]	2.6	2.09	10.29	-	-
Microcline [$KAlSi_3\ O_8$]	2.56	-	17.63	-	-
Mica [$Si_4\ O_{10}$ Sheet Structure]	2.7-3.1	-	2.54	-	-
Periclase [MgO]	3.56	-	-	0.61	0.39
Corundum [Al_2O_3]	4.0-4.2	-	-	5.00	7.23
Zincite [ZnO]	5.66	-	-	5.66	0.06
Hematite [Fe_2O_3]	5.26	-	-	5.71	6.51
Cuprite [Cu_2O]	6.13-6.15	-	-	0.03	0.02
Baddeleyite [ZrO_2]	5.4-6.02	-	-	0.09	0.08
Litharge [PbO]	9.14	-	-	-	-
Monazite [P_2O_5]	4.6-5.4	-	-	0.24	0.12
Montroydite [HgO]	11.23	-	-	0.001	-
Lime [CaO]	1.97	-	-	-	6.81

(Source of Specific Gravity: Read [41]).

(I) Mineralogical Composition of Harmattan Dust Using FTIR Spectrum

Fig. 6 (A and B) shows the quantitative analysis carried out on the liquid samples collected at the stations considered for this research. Prominent FTIR absorption peaks were studied to determine functional groups present which correspond to the minerals present in the dust samples. These minerals were identified with the available instruments to determine the quantities present in the samples collected.

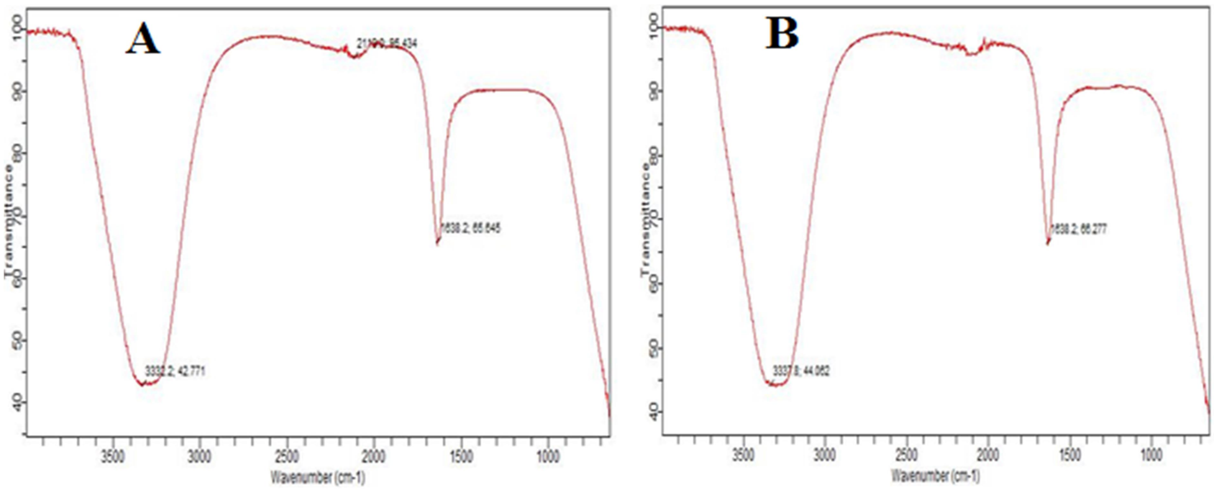

FIG. 6. A typical FTIR spectrum for Oyo (A) and Minna (B).

(II) Composition of Quartz Mineral

From the FTIR spectrum in Fig. 6, the absorption band appearing at 1638.2 cm^{-1} and 1015.7cm^{-1} suggests the presence of quartz in the samples. The bending vibration at 1971.9 cm^{-1} and symmetrical stretching vibration at 1992.3 cm^{-1} are assigned. The pattern of absorption in quartz can be explained by ascribing the 1971.9 cm^{-1} band region (Si-O asymmetrical bending vibration), the band region 1994.1 cm^{-1} (Si-O symmetrical bending vibrations) and the bands in the region 1966.2 cm^{-1} (Si-O symmetrical stretching vibrations). It was observed that there are about four to six peaks in the samples collected across each location.

(III) Composition of Clay Minerals

The presence of kaolinite, illite and montmorlinte indicated clay minerals in the samples collected across all these locations. Kaolinite is said to be a clay mineral in crystallization which occurs in the monoclinic system and forms the major constituent of Nigeria clay. It is also shown that Harmattan dust in the air reduces the visibility of air craft that may lead to air crash in some periods because of the dusts that are lifted high as far as the stratospheric region of the atmosphere before dropping into the lower atmosphere after travelling to a very long distance (Falaiye and Aweda [5], Aweda et al. [8], Falaiye and Aweda [43]). It can be observed from Fig. 6 (A and B) that the FTIR absorption peaks appearing at 1015.7cm^{-1} in the sample indicate kaolinite.

Conclusion

This research concluded that quartz percentage of Oyo is higher than those observed at Minna, Ilorin and Ile-Ife as a result of some activities taking place in the city during sampling collection. In another vein, the presence of elements in the samples gathered across Oyo and Minna shows that the dusts in Nigeria may have almost all the elements present in Harmattan. Some of the elements are in lower quantity and some are in high quantity. However, these elements can affect light as they pass through the atmosphere by scattering and absorption. More so, the study revealed that the elemental composition of the dust samples analyzed has higher percentages compared with the acceptable standard values (as recommended by WHO) for human health. It is therefore recommended that adequate precautionary measures and policies should be made to help mitigate the effects of high elemental concentrations observed. For proper verification of Harmattan dust effect on human health, daily collection of the dust is recommended.

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