### Harmattan Particulate Concentration and Health Impacts in Sub-Saharan Africa

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Air pollution is becoming a serious problem in developed and developing countries, but there is not sufficient recognition of the problem of suspended particulate matter. Environmental pollution problems, which had been largely ignored in the past, have now become a subject of considerable national interest in Nigeria. An agency has been established to set environmental protection guidelines and enforce compliance, and the public is gradually becoming more aware of the consequences of environmental pollution. In this work, the determination of aerosol concentration and the elemental composition of air obtained during the Harmattan season at Uturu (latitude 5°29'N, longitude 7°33'E), Nigeria, were carried out using Atomic Absorption Spectroscopy (AAS) after digestion of the collected dust samples by wet ash method. The mass concentrations of aerosols in air for the two Harmattan seasons are 1.20 mg/cm<sup>2</sup> and 3.67 mg/cm<sup>2</sup>, respectively. The mean sizes of the collected Harmattan dust samples determined for the two seasons are 2.7  $\mu$  m and 4.4  $\mu$  m, respectively. The mean values of the elemental concentrations obtained for the two periods of the Harmattan seasons are 16.470 mg/kg for potassium (K), 9.098 mg/kg for magnesium, (Mg), 331.995 mg/kg for calcium (Ca), 47.673 mg/kg for Iron (Fe), 81.598 mg/kg for Zinc (Zn), 12.791 mg/kg for magnesiem (Mn), and 1.161 mg/kg for lead (Pb) for the first period of the Harmattan season. The Harmattan particulates affected negatively the health of the people causing respiratory diseases to adults and children.

### 1. Introduction

As a result of the intense heating over the Sahara Desert, sand and dust particles are uplifted into the atmosphere by convective forces to great heights estimated to reach 6.0km above the surface [1] and [2] showed that large particles, 0.1-1mm in radius, are transported over a distance of 6,000km before being deposited on the surface. The significance of the Saharan dust particles is shown by their presence in central Europe as reported by [3]) and in Miami, Florida, reported by [4]. Due to the impact of aerosols on life, research interest has been directed to analyzing aerosols from major sources, the Sahara Desert having been identified as an important source of natural aerosol pollution in the atmosphere. Consequently, [5] estimated that about 23-27 millions of dust particles are conveyed through the longitude of Barbados each year. Furthermore, [6] noted a marked increase of the Sahara dust concentration in the atmosphere over a decade in Barbados.

Bierly and Gilmand [7] observed that the rationale for measuring pollutants includes the following: (i) for developing scientific hypotheses (ii) monitoring for trends (iii) to ascertain the level of human health effects and ecosystem damage as input to environmental decision-making. On the other hand, [8] noted that mineral dust aerosols are notably drawn earth ward by gravity along their transport paths and so are deposited to lands and oceans where they provide iron and other micronutrients to terrestrial and marine ecosystem. In view of the need to understand better roles of atmospheric aerosols in climate change, air quality, acid deposition, visibility reduction, and cloud and precipitation process, an internationally coordinated program of research on atmospheric aerosol was urgently required and to this end, in 1994 the International Global Atmospheric Chemistry (IGAC) and the International Global Aerosol Program (IGAP) agreed to merge their on-going efforts and plans into a new integrated focus on Atmospheric Aerosol to be carried out under the aegis of IGAC [9]. There is currently wide spread interest in the roles of aerosols generated by human activities in the radiative forcing of climate, but the magnitude of this forcing is highly uncertain [10, 11]. An example is particulate pollution which, when accelerated by wind, causes destructive erosion of building surfaces although the magnitude is not fully quantified [12].

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Related works include that of [13], who investigated the inter-annual variability and longterm trend of UV-absorbing aerosols (mainly soil dust and smoke from biomass burning) during Harmattan seasons in the Sahel zone of Nigeria using the total ozone mapping spectrometer aerosol index (TOMS AI) and horizontal visibility data from four synoptic stations in the Northern part of the country. During two Harmattan seasons of 1999/2000 and 2000/2001, Harmattan [1] collected dust particles by suction on pre-weighted filter papers by gravitational settling on microscope slides placed 2 metres above the ground at the Northern Nigerian cities of Bauchi (10.4°N, 9.8°E), Jos (9.9°N, 8.9°E) and Makurdi (7.7°N, 8.5°E) (for related literatures, see [14], [15], [16], [17], [18], [19], [20] and [21]). Adepetu et al. [22] worked with dust from Lagos and [23] from Ile-Ife, both in the southwest of Nigeria. This work, which is the first of its kind in these locations, involves the determination of aerosol concentration, its elemental composition and health impacts on adults and children during the Harmattan season at Uturu (latitude 5°29'N, longitude 7°33'E), Nigeria, The study will help in addressing an important scientific question on the concentration of atmospheric aerosols in the environment with the attendant implications on health, economy, and air navigation among others.

### 2. Theoretical background

Harmattan season as applied in this paper, are those months within the calendar year, when the Intertropical Discontinuity (ITD) lies to the south of a given location and the prevailing air mass is the NE trade wind blowing from the Sahara [24, 25]. The concentration  $\sigma_i$  of an element in the particulate phase at a given point is given by mass fraction C<sub>i</sub> and is related to the source contributions M<sub>j</sub>, which is the mass of material from source j per unit volume of air at the point of measurement. According to [26], the mass fraction C<sub>i</sub> of element, i, in M<sub>i</sub> is obtained using the relation;

$$\sigma_i = \sum_i C_i M_i \tag{1}$$

such that mass fraction, C<sub>i</sub>, now becomes

$$C_i = \frac{\sigma_i}{\sum M_i}$$
(2)

The intensity of light that is scattered by a particle is directly proportional to the concentration of the particle in air. According to Rayleigh scattering, the intensity of light,  $I_{sc}$ , that is scattered by a particle is inversely proportional to the fourth power of the wavelength,  $\lambda$ . Thus

$$I_{sc} = \frac{1}{\lambda^4} \tag{3}$$

Rayleigh scattering, accounts for the blue colour of the clear sky in daylight since blue light of wavelength 4500A° is scattered more intensely than red light of wavelength 6500A° because of the inverse relationship existing between scattered intensity and wavelength. Rayleigh scattering is applicable to those particles whose sizes are small when compared with the wavelength of the incident light. The working of Atomic Absorption Spectroscopy (AAS) is based on the principle that the amount of energy absorbed by the flame is proportional to the concentration of the element in a sample since each element has its own characteristic absorption wavelength. Monochromatic radiation absorption by atmospheric aerosols can be described by the Lambert's law, which can be expressed in the form:

$$\mathbf{I} = \mathbf{I}_{o} \ \mathbf{e}^{-\mathrm{ad}} \tag{4}$$

Where, a is the absorption coefficient and d is the thickness of the sample,  $I_o$  is the first direct measured intensity of monochromatic beam of radiation (from a monochromator) when no absorber was placed between the source and detector, while I is the measured intensity of a monochromatic radiation when an absorber was placed between the source and the detector.

Spectrocopists often use Lambert's Law in the form

$$I = I_o 10^{-\mu d} \tag{5}$$

and

$$\mu = 0.434a$$

Where,  $\mu$  is the linear extinction coefficient. When dealing with substances in solution, it is found that the measured extinction coefficient is proportional to the concentration,  $\sigma$ , of the absorbing substance (Beer's Law). Thus:

$$\mu = k\sigma \tag{6}$$

with k being the extinction coefficient per unit concentration.

### 3. Materials and methods

The total suspended particulate (dust sample) matter was collected by means of a Whatman filter paper using direct deposition method [27]. The Whatman filter was used because it is easier to digest, lacks impurity, and has uniform surface area. The filter paper was placed inside a plastic jug and subsequently the jug was placed at the top base of an iron stand of height 2.47m. The mass of the membrane filter was determined before and after deposition by weighing it using an electronic digital balance. The experiment was done for October 2001 to February 2002 Harmattan season and for October 2004 to February 2005 Harmattan season. The mass concentration (loading) of the suspended particulate matter was calculated by dividing the net mass by the surface area of the filter paper and was reported as gram per square centimeter (g/cm<sup>2</sup>). Direct deposition method of dust sample collection was preferred in this work since one of the objectives is to determine the mass of the particulate matter in the atmosphere, after which the chemical analysis of the collected particulate matter was made possible. One disadvantage of particle-size analysis by deposition or impingement is that the dust may agglomerate or disintegrate as a result of monitoring and as check samples were collected during the Harmattan season and handled with care. The 200A model Buck Scientific Atomic Absorption Spectroscopy (AAS) was used in this study for the reason. As an analytical technique for trace elemental determinations, AAS has important advantages having a high sensitivity for many elements and being relatively low-cost [27].

### 3.1 Method of dust sample collection

Total suspended particulate matter was collected by direct deposition method using Whatman filter paper. Four samples of mass 0.01315g, 0.02627g, 0.02457g, 0.02542g were collected over periods of 30 days (11th Nov. - 12th Dec. 2001) and 30 days (12th Dec. - 11th Jan. 2002). The samples were collected for another 30 days (11th Jan. - 10th Feb. 2002) and for a further 61 days as shown in Table 1 for the first Harmattan season from October 2001 to February 2002. For the second Harmattan season, from October 2004 to February 2005, two samples of mass 0.0771g, and 0.0448g were collected for periods of 15 days and 7 days, respectively (see Table 1). The period of collection for the last sample during the first Harmattan season lasted for 61 days instead of 30 days because of interference by rain during the period of collection. The same reason is also applicable for extending the period of collection of the first sample in 2004/2005 Harmattan season to 15 days instead of 7.

Table	1: Mass	of the	(collected)	dust	samples	and	the	calculated	mass	concentrations	for	the	two	Harmattar	n
season	s (Octob	er 2001	-February 2	2002	and Octo	ber 2	004	- February	y 2005	<b>5</b> ).					

Sample number	Period	Mass collected (g)	Mass concentration (g/cm <sup>2</sup> )
1	11th Nov. 2001-12 <sup>th</sup> Dec. 2001 (30days)	0.01315	1.92 x 10 <sup>-4</sup>
2	12th Dec11th Jan. 2002 (30days)	0.02627	1.58 x 10 <sup>-3</sup>
3	11th Jan10 <sup>th</sup> Feb. 2002 (30days)	0.02457	1.48 x 10 <sup>-3</sup>
4	11th Nov. 2001-10 <sup>th</sup> Feb. 2002 (61days)	0.02542	$1.53 \times 10^{-3}$
5	27th Jan. 2005-11 <sup>th</sup> Feb. 2005 (15days)	0.0771	4.64 x 10 <sup>-3</sup>
6	11th Feb. 2005-18 <sup>th</sup> Feb. 2005 (7days)	0.0448	2.70 x 10 <sup>-3</sup>

Table 1 shows that for the two periods of the Harmattan season in which samples were collected namely October 2001 to February 2002 and October 2004 to February 2005. The mean of the mass concentrations of the collected dust samples obtained by calculation are  $1.35 \times 10^{-3} \text{ g/cm}^2$  and  $3.67 \times 10^{-3} \text{ g/cm}^2$ , respectively. As a control, no dust sample was deposited or collected on a control filter paper, which was placed outside during the rainy seasons (July to August 2002 and 2005, respectively). This in effect confirms the fact that Harmattan dust particles are mainly air borne during its seasons. The effective date for the collection of the dust samples started in November due to lateness in the commencement of the Harmattan season and interference of late rainfall. The effective date of collection of samples for October 2004 to February 2005 season is January 2005 due to late commencement of Harmattan in that season, one of the signs of climate change that we are still trying to quantify scientifically. The Harmattan particulates were then digested to dissociate and dissolve the elemental components. The dust sample was digested by wet ash method for a period of one hour thirty minutes over low heat at 60°C using 6ml concentrated sulphuric acid, 6ml hydrochloric acid to ensure complete digestion. The digested sample, when cold, was diluted to a volume of 20cm<sup>3</sup> with de-ionized water

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and then filtered to remove silicate and other insoluble materials that could clog the atomizer.

## 3.2 Analysis of the digested dust samples using AAS

The elemental compositions and concentrations in mg/L of the collected and digested dust samples as revealed using AAS are as shown in Table 2 for samples 1 - 4 were collected from October 2001to February 2002 and samples 5-6 were collected from October 2004 to February 2005 (Table 2). The mean values of the elemental concentrations obtained for the whole period of deposition for the two Harmattan seasons as revealed by AAS starting from October 2001 to February 2002 and October, 2004 to February 2005 are shown in Table 3 and Table 4, respectively. Generally a careful look at both tables reveal that the concentration of the elements in air obtained during the first Harmattan season from October 2001 to February 2002 was higher than that obtained during the second Harmattan season by about 31% for K, Mg, Ca, Fe, Zn and Mn and 88% for Pb. Therefore, this means that the concentration of the elements in air obtained during the second Harmattan season was generally on the decrease. The concentrations of the elements K, Mg, Ca, Fe, Zn, and Mn decreased by about 31% while Pb decreased by 88%.

Sample number	Κ	Mg	Ca	Fe	Zn	Mn	Pb
1	0.018	0.010	0.362	0.052	0.089	0.014	< 0.001
2	0.020	0.012	0.396	0.057	0.097	0.015	0.002
3	0.017	0.009	0.344	0.049	0.085	0.013	< 0.001
4	0.012	0.006	0.249	0.036	0.061	0.010	< 0.001
5	0.015	0.008	0.307	0.044	0.075	0.012	< 0.001
6	0.014	0.007	0.282	0.041	0.069	0.011	0.004

Table 2: Elemental compositions and concentrations as revealed by AAS.

 $Error = \pm 0.001 \text{ mg/L}$ 

Table 3: Mean concentration for the 1st Harmattan season in mg/L and mg/kg (October 2001-February 2002).

Element	mg/L	Mg/kg
K	$0.017 \pm 0.002$	$16.47000 \pm 0.00001$
Mg	$0.009 \pm 0.002$	$9.09800 \pm 0.00001$
Ca	$0.338 \pm 0.040$	331.99500± 0.00001
Fe	$0.049 \pm 0.005$	47.67300 ± 0.00001
Zn	$0.083 \pm 0.009$	81.59800 ± 0.00001
Mn	$0.013 \pm 0.001$	$12.79100 \pm 0.00001$
Pb	$0.001 \pm 0.000$	$1.16100 \pm 0.00001$

Element	mg/L	mg/kg	
К	$0.015 \pm 0.001$	$5.0710 \pm 0.0001$	
Mg	$0.008 \pm 0.001$	$2.6000 \pm 0.0001$	
Ca	$0.295 \pm 0.010$	$102.7650 \pm 0.0001$	
Fe	$0.065 \pm 0.002$	$14.8590 \pm 0.0001$	
Zn	$0.072 \pm 0.003$	25.1300 ± 0.0001	
Mn	$0.012 \pm 0.001$	4.0120 ± 0.0001	
Pb	$0.003 \pm 0.002$	$1.0230 \pm 0.0001$	

Table 4: Mean concentration for the 2nd Harmattan season in mg/L and mg/kg (October 2004-February 2005).

The general reduction in concentration during the second Harmattan season may be attributable to the reduction in the dust level carrying capacity, although further results will help us quantify whether climate change or tele-connections has more impact. William and Barbara [28] observed that topography, climate, and physical processes in the atmosphere play an important role in transport, concentration, dispersal, and removal of many air pollutants. Wind speed, mixing between air layers, precipitation and atmospheric chemistry determine whether pollutants will remain in the locality where they are produced or go elsewhere. The mean surface wind speed during Harmattan is 1.76 m/s for stations south of latitude 6 °N in Nigeria, which will favor a longer residence time of the fine particles since the rate of dust removal from the atmosphere by turbulent mix-out [24].

# 4. Discussion of the concentrations of the collected dust samples

This work is aimed at establishing the air aerosol elemental composition and concentrations during the Harmattan seasons. Noone et al. [29] noted that aerosols directly influence climate by scattering or absorbing incoming solar radiation, and indirectly influence climate by acting as nuclei on which clouds can form. Pb particulates in the air are a result of such activities as fossil fuel combustion (including vehicles), metal processing industries and waste incineration [30]. Even small amounts of Pb can be harmful, especially to infants and young children. In addition, Lead taken in by the mother can interfere with the health of the unborn child. Exposure has also been linked to impaired mental functions, such as visual - motor performance and neurological damage in children, as well as memory and attention span [31]. The World Health Organization (WHO) acceptable average air lead level for non-urban site is below 0.15mg/m<sup>3</sup> [32].

From our result, the level for Pb in the air is  $0.001 \text{ mg/m}^3$  and  $0.003 \text{ mg/m}^3$ , respectively. When compared with the WHO acceptable level, the percentage concentration of lead in air is 0.7% and 2.0%, respectively, and can be considered to be insignificant and hence the environment is relatively clean of Lead.

The main use of iron ores in Nigeria is for steel production. Iron is also used in the production of paint pigments, polishing agents and electrical materials. The Arizona Ambient Air Quality [33] acceptable level for Fe, Ca, Mg and Zn in the air is  $0.4 \text{ mg/m}^3$  for twenty four hours. The concentration of iron in the air from our result is  $0.049 \text{ mg/m}^3$  and 0.065 mg/m<sup>3</sup>, respectively, for the two Harmattan seasons. A comparison of these levels with the standard showed that the concentrations of iron in the air for the two seasons are 12 % and 16 %, respectively, which is quite insignificant and hence the air within Uturu is relatively clean in terms of iron. Iron helps to keep plants and animals alive and plays a role in the creation of chlorophyll in plants. It is also an essential part of haemoglobin, the substance that carries oxygen within the red blood cells. Iron sulphate is used to treat anemia, a blood disease. Excess of iron causes liver and heart disease. From our result, the levels of magnesium in air for the two seasons under study are 0.009  $mg/m^3$  and 0.008  $mg/m^3$ , respectively. The percentage concentrations in the air are 2.3 % and 2.0 % of the standard which is quite insignificant and below the deleterious level. Hence we conclude that the air at Uturu is relatively clean in terms of magnesium.

The acceptable level of calcium in the air is the same as that of iron. Beyond this level, the air can cause air related diseases like catarrh and cough. From our result, the levels of calcium in air for the two seasons are 0.338 mg/m<sup>3</sup> and 0.295 mg/m<sup>3</sup> respectively. This shows that the level is quite

significant, but below the deleterious level. Calcium was found to be in highest quantity in the air. A comparison of our results with the standard gave concentrations of 84.5 % and 73.8 %, respectively, thereby confirming the fact that the concentration level in the air is below the deleterious level and hence the area is clean with respect to calcium. Manganese is used in the manufacture of cell batteries and as an oxidizing agent in chemical industry. The Nigerian tolerable limit for manganese in air is 0.01 mg/m<sup>3</sup>. From our result, the levels for manganese in air for the two seasons are 0.013 x  $10^{-3}$  mg/m<sup>3</sup> and 0.012 x  $10^{-3}$  $mg/m^{3}$ The percentage concentrations of manganese in air when compared with the standard for the two seasons are 0.13% and 0.12% respectively. This showed that the level is quite below the deleterious level and relatively clean with respect to manganese.

Zinc is also an essential element indispensable for human health and for all living organisms. Zinc can be toxic to organisms when concentrations are too high and can lead to gastro-intestinal disorders. The acceptable level for zinc in the air is same as that of iron. Our results show the levels of zinc in air for the two seasons are  $0.083 \times 10^{-2} \text{ mg/m}^3$  and  $0.072 \times 10^{-2} \text{ mg/m}^3$ , respectively. A comparison with the standard showed that the percentage concentrations of zinc in the air for the two seasons are 0.2% and 0.18%, respectively. This shows that this is quite insignificant and below the deleterious level. Potassium pentaborate is white, odorless powder substance that is not flammable, combustible, or explosive and has low acute oral and dermal toxicity. Inhalation is the most significant form of exposure in occupational settings. Occupational mild irritation effects to the nose and throat may occur from inhalation of potassium tetraborate dust at high levels. The element can be used in fertilizer, fireworks, alloys, solders, and biocides. The acceptable standard level for potassium is 8.7 mg/m<sup>3</sup>. For the two seasons under study, the concentrations of potassium in air from our result are 0.017 mg/m<sup>3</sup> and 0.015 mg/m<sup>3</sup>, respectively. A comparison of these concentrations with the standard showed that the concentration of potassium in the air for the period of study was 0.19% and 0.17%, respectively, which is quite insignificant and below the hazardous level. Therefore, we conclude that the study area is relatively clean in terms of potassium.

In Fig. 1, we see the mass concentration for the two Harmattan seasons (October 2001 – February 2002 and October 2004 – February 2005) with the actual dates of harmattan dust sample collection

indicated. We had a higher amount of mass concentration  $(g/cm^2)$  for sample 5 due to the fact that 27 Jan. 2005-11 Feb. 2005 period recorded a high level of Harmattan dust than other years for reasons that are still unclear and which we won't simply attribute to anthropogenic contribution like biomass burning or climate change. The climate system is dynamic and conclusions can only be made when the complete system is considered. The solid concentration (mg/Kg) and mass fraction (C<sub>i</sub>) for the elemental composition of all the samples are shown in Fig 2 and Fig. 3. The levels for Lead (Pb) are low, which is very interesting regarding air quality although some respiratory diseases have been listed to be prevalent during the Harmattan period [34]. Uturu, where Abia State University is located, is a typically rural setting with no industries. The levels of Calicum and Zinc seem to be higher than those of other elements (Figs. 2-3). Similar results were reported for Ile-Ife and Lagos, both semi-urban and metropolitan cities respectively, in the southwest of Nigeria [22, 23]. The summary of the number of reported cases for asthma attacks and hospital admissions at the University's medical centre during the two Harmattan seasons are shown in [34], which show that there were increased cases of Harmattanparticulate related hospital admissions for both adults and children.

### 5. Conclusions

The extent to which atmospheric elements such as K, Mg, Ca, Fe, Zn, Mn, and Pb, can be a health hazard depends on the ability of these elements to penetrate the respiratory system. These elements can affect light as it passes through the atmosphere by scattering and absorption. The most obvious radiative consequence of airborne particles is the appearance of haze and a decrease in visibility. Less obvious, but more important, are the possible effects of these elements on the heat balance of the earth. These elements can cause a decrease in the amount of radiation reaching the ground, can increase or decrease the albedo, and if the elements absorb radiation, can cause atmospheric heating. In order to understand these optical effects, it is necessary to know the composition of the aerosols and their sizes, as these characteristics determine the scattering and absorption properties. In addition, this information is useful for estimating the residence times of these elements and for assessing which areas of the earth's surface might be most affected by a given element. The primary route of exposure to aerosols is through the human respiratory tract because of the sensitivity and reaction of the body to this route of entry. Particles deposited on the skin or eyes in sufficient quantity can produce toxic effects. Individual particles can have a wide range of physical, chemical, radiological, and biological properties that affect their toxicity.

It is supposed that the source of these elements in the atmosphere is a result of physical and chemical weathering of the igneous rocks in this environment, contributions from the Saharan dust that are transported to Uturu by the North-east trade wind, as well as natural and man-made particulate pollutant emissions in Uturu, located in the vicinity of hills. In the work by [24], where the distributions of frequency of occurrence (FOO) of 'thick dust haze' (TDH) and of 'light dust haze' (LDH) with respect to latitude, longitude, elevation and distance from source during Harmattan season (from November to February) was investigated. The aerosol elemental concentrations were not indicated and previous workers who reported elemental Harmattan particulate concentrations worked at only a few South-west sites about 600 kilometers away from the South-east geopolitical zone of Nigeria. At present, we do not have a good understanding of the regional cycles of most elements in Nigeria because of the scarcity of data on large-scale distribution of these species and their temporal variability. Data is scarce for most remote and urban region in this country. Hence, this work is a contribution in that regard and will serve as a boost for further research. The determination of the aerosol optical depth, refractive index, scattering and absorption coefficient in this part of sub-Saharan Africa is being investigated [21]. The discipline of toxicology has not advanced well enough in Nigeria to enable us to evaluate the specific effects of exposure to low levels of elements like Managanese, Potassium, etc. to the human health. We are currently using the Air quality impact assessment tool version 2.2 developed by the World Health Organization (WHO), European Centre for Environment and Health. The Air Quality Impact Assessment Tool is a specialized software that enables the user to assess the potential impact on human health of exposure to a given air pollutant in a defined urban area during a certain time period.

This work is still ongoing since we are gathering more information from other health institutions in the Southeast zone of Nigeria where Uturu is located. Another approach will include the proper quantification of the Harmattan dust emission processes, which is a key element in the aerosol schemes of climate models and depends on wind conditions, soil characteristics and particle size [35, 36]. This is a part of the research focus of our Atmospheric Physics Group, where we are using the third generation Regional Climate Model (RegCM3) of the Physics of Weather and Climate Group, Abdus Salam International Centre for Theoretical Physics (ICTP), Trieste, Italy to downscale climate model outputs for our regional climate model studies and predictability over Nigeria. Our major interest being the South-east and South-south zones or the oil-rich Niger Delta area of the country, where oil exploitation and exploration activities have caused environmental degradation, pollution and gas flaring 24 hours a day throughout the year with biomass burning! It is also in the vicinity of the volcanic-prone Lake Nyos in Cameroon [37]. The gas in Lake Nyos already has built up to a density many times greater than that in a champagne bottle, according to Klaus Tietze, a senior research scientist with the Federal Institute for Geosciences and Natural Resources in Hannover, Germany.

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Fig.1: Mass concentration (mg/cm<sup>3</sup>) for the six samples.



Fig.2: Solid concentration (mg/Kg) of the various elements in the harmattan dust.



Fig.3: Mass fraction ( $C_i$ ) of the various elements in the harmattan dust.

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