Bull. Chem. Soc. Ethiop. **2001**, 15(2), 109-117. ISSN 1011-3924
Printed in Ethiopia

ATMOSPHERIC POLLUTION IN NORTH-EAST NIGERIA: MEASUREMENT AND ANALYSIS OF SUSPENDED PARTICULATE MATTER

V.O. Ogugbuaja* and L.Z. Barsisa

Department of Chemistry, Faculty of Science, University of Maiduguri, P.M.B. 1069, Maiduguri, Nigeria

(Received November 15, 2000; revised July 31, 2001)

ABSTRACT. Suspended particulate matter (SPM) concentrations from Maiduguri and Yola areas of North-Eastern Nigeria were measured. Also determined were the concentrations of Cd, Cu, Fe, Mn, Pb, and Zn in the SPM. Mean SPM levels were 28.3 μg/m^3 (range, 1.3–144 μg/m^3) and 13.6 μg/m^3 (range, 1.1–52 μg/m^3) for Maiduguri and Yola areas, respectively. These were markedly below the mean value of 98 μg/m^3 reported for some selected cities in the world, and also showed pronounced differences from the annual average range of 150 μg/m^3 reported by the WHO for polluted air. Enrichments of Cd, Cu and Zn in the air relative to the soil are attributable to few industrial activities the areas; that of Pb is due to vehicular emissions. Concentration of all the metals in the SPM fell within the range reported for contaminated air in Europe and North America.

KEY WORDS: Atmospheric pollution, Suspended particulate matter (SPM), Heavy metals in SPM

INTRODUCTION

The term suspended particulate matter (SPM) incorporates different airborne particles whose size ranges from below 0.1 μm to less than 10 μm. This is contrary to what is known as total suspended particulate matter which may include the larger particles (dust falls) rapidly deposited close to their point sources [1]. Bowen [2] has generally summarized the sources of aerosol particles as soil particles with usually large amounts of Al, Si and Ti; organic particles evaporated from vegetation together with pollens and pores; soot containing much carbon and unusual levels of As, Cr, Cu, Pb, V and Zn; industrial haze particles mainly $(NH_4)_2SO_4$ and NH_4NO_3; and salt particles. It was further indicated that such aerosols have atmospheric residence time of 10 to 30 days. Primary sources of SPM therefore include dust storms, forest fires, bush and wood burning, volcanic eruptions, coal burning and traffic exhausts. Incineration of domestic and commercial wastes, and industrial activities constitute further sources of SPM.

Health problems pertaining to SPM have been considered and documented. Inhalation is recognized as the most significant pathway into the human body. About 75% of the SPM inhaled by man are retained in the body [3]. Hence chronic exposure may paralyse the cleaning functions of the cilia.

Indications are that metals account for about 0.01 to 3% of particulate air pollutants. For instance, trace elements such as Pb, Se, Sb, Cd, Ni, V, Sn and Zn are reported to be associated with particles of mass median diameters of 1.0 μm or less [4-6]. This size range is comparable to that of SPM. Of main concern therefore are the small fine size air particles (0.1–3 μm), which are normally deposited in the respiratory system upon inhalation. These exhibit 60–80% extraction efficiency into the biological system [3].

*Corresponding author. E-mail: emails@yaysib.com

Health effects as thyroid enlargement, lung cancer and pneumoconiosis (lung disease due to inhalation of hard metals from welding fumes) have long been associated with prolonged exposure to polluted air. In addition, known cancer-producing agents such as benzo-pyrene are usually present in SPM [1]. Pb and Cd mostly from vehicular emissions and industrial activities are said to cause hypersensitivity and brain damage in children [7-9]. The itai-itai syndrome is also associated with poisoning from environmental pollution with Cd [10]. Manganese poisoning on its part effects the central nervous system [11, 12]. Because of these facts SPM has been preferentially studied as compared to total suspended matter.

North-Eastern Nigeria is close to the Sahara desert and lies within the semi-arid climatic region. It has two distinct climatic seasons; the hot dry season with relatively high temperatures, and rainy season. The latter is usually preceded by dusty, harmattan winds. Interposed between these is a cold period (December to early February) when the temperature may fall to about 15 ^{0}C. SPM is mostly associated with sand storms and harmattan winds that blow across the desert, just before the commencement of rainy season here. These sandstorms are able to penetrate deep into this region due to the open and flat topography of Borno and Yobe States. However, no data on air particulate matter is available in this part of Nigeria. This study is, therefore, undertaken to meet that need. It also helps to accentuate the national concern about the state of our environment. Concentrations of SPM and some elemental contents of particulate matter in this area were studied to meet the stated objective. Comparisons are also made between the data obtained and some reported values.

EXPERIMENTAL

Sampling

Suspended particulate matter (SPM) was obtained from two locations each in Maiduguri and Yola area. Maiduguri and Yola are two large cities in North-Eastern Nigeria with fairly high human and industrial activities, hence the choice.

SPM samples were collected using the apparatus previously used and reported [13] (Figure 1). Air was drawn for 24 h by means of a vacuum pump (Edwards High Vacuum Pump ED 50, UK) through a pre-weighed 12.5 cm Whatman No. 1 filter paper attached to a funnel. The filter paper with the funnel was positioned outside the building (sampling station). Flask A (Figure 1) served as a bubbler in case of SPM collection, (but as a sample collector for SO_2 (g) collection). Flask B contained CaO, which acted as a moisture trap to protect water molecules from getting to the pump. After sampling the filter paper was detached and reweighed. The difference in weights provided the amount of SPM in the air during the 24 h sampling period. SPM concentrations ($\mu g/m^3$) were obtained by dividing the weight differences by the volume of air (m^3) sample. Volume of air sampled was determined using the apparatus shown in Figure 2. Volume of water displaced from a water container by air sucked in per time was measured. Assumption here is that at a given temperature and pressure air displaces its own volume of water. The volume per time (m^3/time; 90 m^3/h) multiplied by the sampling period (24 h) provided the volume of air sampled (m^3) [13]. Three samples per month were collected. Forty two (24 h) samples were obtained. The apparatus (Figure 1) conforms to the standard sampling devices for gaseous and particulate matter collection [14].

Particulate matter samples analysed for trace metal contents were collected using trace element free easily ashed Whatman No. 1 filter papers [15]. The filter papers were secured on watch glasses and positioned in open spaces away from any buildings and trees. Collection at

ground level was by dry deposition from direct gravitational settling and impaction on the filter papers exposed to turbulent atmospheric flow. The efficiency of impaction has been defined as the ratio of the number of particles deposited on a surface to those originally contained in the volume of air diverted. Laws governing the impaction process have been discussed [15].

Figure 1. Apparatus for the determination of SPM and SO_2.

Figure 2. Apparatus for the determination of volume of air.

Analysis of particulate matter for trace elements

Sample preparation. Two grams of the particulate matter sample were digested with the filter papers at a temperature of 110 ^{0}C for 2 h, in a solution containing 50 cm^3 aqua regia, 5 cm^3 water and 20 cm^3 aqueous HF (hydrofluoric acid). After digestion, the mixture was centrifuged and the supernatant liquid was placed in 100 cm^3 volumetric flask. The volume was made up to the mark with distilled water. Blank samples of the reagents, filter paper only, water without any samples were also prepared. Prepared samples were stored in refrigeration prior to analysis.

Determination of trace elements. The prepared samples were analysed for Cd, Cu, Pb, Zn, Mn and Fe using atomic absorption spectroscopy (AAS). A Pye Unicam SP 9 AAS instrument was

utilized for the elemental determinations using air/acetylene flame source. Standard calibration method was used for metal content determination.

Calculation of metal enrichment factors (EF) for SPM. The metal enrichment factor (EF) was calculated by equation 1:

$$EF = \frac{(M)_{SPM}\,(Mn)_{soil}}{(M)_{soil}\,(Mn)_{SPM}} \quad (1)$$

where (M) and (Mn) represent the respective concentrations of each metal (M) and manganese (Mn) in the soil and SPM. Mean soil data values used were obtained from those reported in [2]. The normalization equation follows similar ones reported [2] in which scandium (Sc) and titanium (Ti) were, respectively, used as normalizing elements instead of Mn.

Relative SPM range. Overall relative range (RR) for SPM values for both sites was calculated using equation 2:

$$RR = \frac{\text{Overall range for both sites}}{\text{Overall mean value for both sites}} \quad (2)$$

RESULTS AND DISCUSSION

Monthly mean suspended particulate matter (SPM) concentrations for the months of March to September are presented in Figures 3a and 3b. High SPM values was obtained at both sites in March. This is generally the most dusty month of any year in this region. Maiduguri area generally exhibited a higher SPM level as compared to Yola area. This may be attributed to the close proximity of Borno State to the Sahara desert. The open and flat topography of Borno State somehow allows an unobstructed incursion of the harmattan sandstorms from the Sahara desert into the State. In the rainy season the values for both locations levelled off to similarly low amounts as indicated from June to September (Figures 3a and 3b).

It has been noted [16] that precipitation occurring below the rain-forming level washes out dust by falling raindrops (washout). At higher altitudes, dust particles however may constitute nuclei for condensing raindrops (rainout). The latter is mainly responsible for removal of most sub-microscopic particles from the atmosphere.

It has been shown that relatively high SO_2 range of values also related to high SPM values at Maiduguri (March–May) and Yola (April and May) [13]. The reverse is true in the rainy season when SO_2 was virtually undetected. The comparison is based on the report by WHO [1] that SO_2 and SPM are emitted simultaneously into the air especially during fossil fuel combustion.

Median SPM values for Calcutta, Delhi, Teheran, Copenhagen and Melbourne between 1973 and 1980 have been jointly reported by United Nations Environment Programme/World Health Organization [17]. A mean of 98 μg/m^3 was found for Maiduguri and Yola as compared to 1.1–144 μg/m^3 for Calcutta, Delhi, Teheran, Copenhagen and Melbourne. A range of 90% of the values was put at 49 to 413 μg/m^3 (100% of the values) obtained for NE Nigeria. Twenty four-hour mean values of 28 (range, 1.3 to 144), and 13.6 (range, 1.1 to 52) μg/m^3 for Maiduguri and Yola, respectively, were markedly lower than the standards stipulated by the National Ambient Air Quality Standards (NAAQS), United States of America. The body put forward two air standards; the National primary ambient air quality standard set the 24 h mean at 260 μg/m^3;

to provide the requisite for protection of public health; the national secondary ambient air quality standard set the 24 h mean at 150 μg/m^3; this is to afford the requisite to protect public welfare from any unknown or anticipated adverse effects [18, 19].

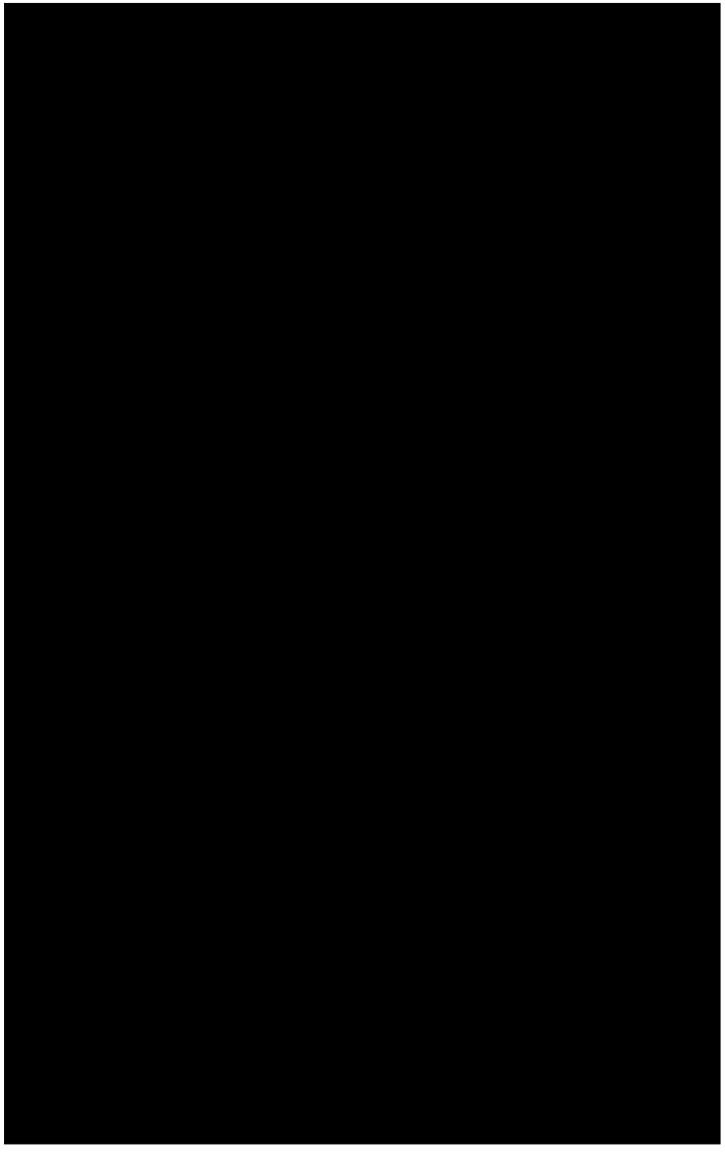

Figure 3a. Monthly mean SPM levels in Maiduguri, Nigeria.

As mentioned earlier, if SO_2 and SPM are both present in air they act synergistically exhibiting potential effects on biological systems. World Health Organization (WHO) further reported that the determination of SPM and SO_2 in air has become relevant judging from studies of long-term effects of exposure of these parameters in adults [1]. Results of such studies

indicate that people living in areas with high concentrations of SO_2 (yearly mean, 125 to 200 μg/m^3) and SPM (yearly mean, 150 to 225 μg/m^3) showed a higher incidence of respiratory symptoms than those in areas exposed to low levels of SO_2 (yearly mean, 45 to 60 μg/m^3) and SPM (100 μg/m^3) [1]. It is, therefore expedient to measure levels of both SO_2 and SPM in any air pollution study.

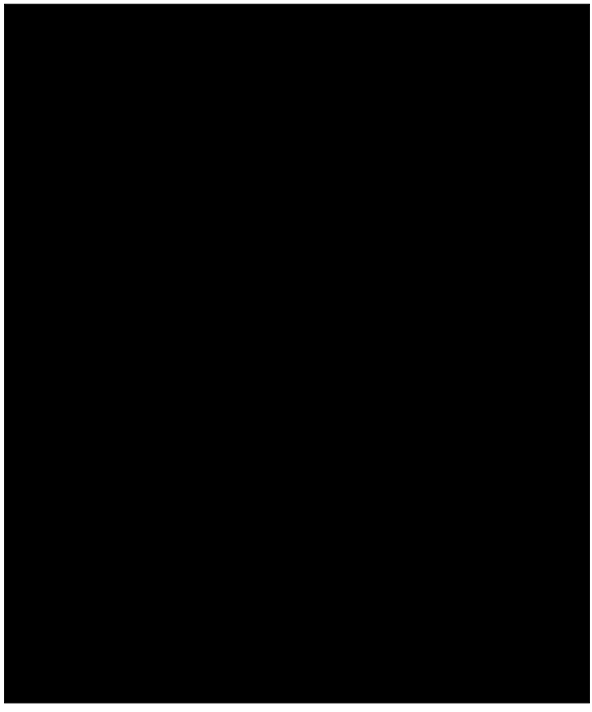

Figure 3b. Monthly mean SPM levels in Yola, Nigeria.

Table 1 shows the mean concentrations of the elements determined and their respective confidence limits. Appreciably high values were obtained for these elements. Of particular interest are the high Cd and Pb levels, in the air in this region. This is mostly from vehicular emissions [19]. Typically, Maiduguri showed Cd and Pb values of 2.0 to 8.0 ppm, and 83.1 to 111 ppm, while those of Yola were 5.3 to 5.9 ppm, and 68.6 to 95.0 ppm, respectively. Both of these metals have been definitively implicated as potential toxic elements and high levels of both metals in the air are of health concern. With the exception of Cd all other metals exhibited some significant differences ($p<0.05$) with Yola having higher mean values for Cu, Fe and Mn. Yola is situated in a valley which permits a delayed dispersion of air particulates due to slow movement of air here. Valley walls are said to channel winds, which slows dispersion of particulates. Occasionally also inversion along with terrain features results in metrological isolation of an area [20, 21]; hence the stated slow dispersion of air in Yola which lies in a valley. Elevated air elemental concentrations result as the SPM is retained in the atmosphere for a longer period of time, before gravitational impaction or wash out by rain. Enrichment factors (EF) of the metals for the SPM were obtained and are reported in Table 1. EF was employed here to compare the ratio of the metal contents in the air with the relative abundance in the soil. This approach may provide information about the sources of the pertinent metals [2, 22]. EF

greater than one implies that other sources besides input from the soil is indicated. Manganese (Mn) was used to normalize the data as Mn contents is assumed not to have been seriously affected by human activities in the study area, as NE Nigeria is mostly an agricultural area. Such metals as ferrous (Fe) and Mn in the air are derived mostly from the soil particles, as the primary industrial sources (steel plants) are absent. Cadmium showed the highest EF values of 55.4 (Maiduguri) and 56.3 (Yola). Zinc and lead were more enriched in Maiduguri SPM, while Cu was more enriched in Yola SPM. These are shown in Table 1. Iron with an EF of 1.3 fell within the range (1 to 5) reported for British aerosol [2]. Most dust particles in Nigeria are soil-derived [2]. The indicated enrichments for Cd, Zn and Cu for NE Nigeria SPM may be due to agricultural activities and operations of such few industries as mat dying, leather processing and numerous automobile mechanic workshops situated all over the region. The latter indiscriminately dispose their waste engine oil and metal scraps. Use of leaded gasoline by automobiles and power generating plants is responsible for Pb enrichment.

Table 1. Contents of particulate matter in NE Nigeria and metal enrichment factor (EF).

Element	Maiduguri area		Yola area	
	Concentration (ppm)	*EF	Concentration (ppm)	*EF
Cd	5.0±1.2[a]	55.4	5.6±1.3[a]	56.3
Cu	25.9±10.1[a]	3.3	122.0±48.0[b]	14.3
Fe	13813.0±69.0[a]	1.3	14246.0±69.0[b]	1.3
Mn	258.0±5.0[a]	1.0	284.0±0.51[b]	1.0
Pb	97.5±58[a]	10.8	81.8 ±5.3[a]	8.2
Zn	318.0±38.0[a]	11.1	139.0±53.0[b]	5.4

[ab]Each metal content for the two areas studied with different superscripts are significantly different ($p<0.05$). *EF = enrichment factor assuming EF (Mn) = 1; that is normalized to Mn concentration.

Table 2 presents aerosol metal contents in clean air areas (North-West Canada and South Pole) and contaminated air (some European and North American cities), adapted from Bowen [2]. Included in the table also are values obtained for NE Nigeria. The comparison was done to highlight the level of elemental concentrations in SPM in NE Nigeria. As observed, the concentration of each metal fell within the contaminated air range and markedly below the stipulated clean air values. It is inferred, therefore, that air in NE Nigeria was contaminated by a variety of metals during the period of study.

Table 2. Element contents of air from various sources and those of NE Nigeria (in ng/m^3 air)[a].

Metal	Clean air		Contaminated air		
	North-West (NW) Canada (1971)	South Pole (1977)	Europe median (range)	North America median (range)	North-East (NE) Nigeria (mean)
Cd	NA	0.015	0.5-620	1-41	15.2 ± 3.4
Cu	0.9	0.038	340 (8-4900)	280 (5-1100)	211.4±140.3
Fe	71	0.84	1.40K[b](130-5.9K[b])	3.6K[b](260-14K[b])	40K[b]±279
Mn	1.5	0.01	43 (9-210)	150 (6-900)	774.2±14.3
Pb	9.14	0.63	120 (55-340)	2.7K[b] (45-13K[b])	256.3±22.6
Zn	4	0.03	1.2K[b] (13-16K[b])	500 (10-1.7K[b])	229±65

[a]1 ppm = 2.86 ng/m^3 [1, 19]; NA = not available; [b]K, x 1000 (adapted from Bowen [2]).

Calcutt and Boddy [23] showed that the number of samples (N) required to estimate bias could be obtained from the equation:

$$N = (ts/L)^2 \quad (3)$$

t = statistical factor at 95% probability at a defined degree of freedom (df); s = overall sample standard deviation; L = limit of error. Let L be equal to overall relative range (equation 2) obtained as 4.14, s = 34.53, and df = 3; hence t = 2.01. Then N = 280 samples. Out of this total, 42 samples only were collected. This represents only 15% of the calculated total. An improvement upon this is necessary. The study has however shown some evidence of air pollution by indicated metallic elements in the suspended particulate matter (SPM) from North-Eastern Nigeria. Their fairly long residence times in the atmosphere, unless washed out by the rains, may increase the possibilities of health problems that may result from the chronic exposures. The study needs to be expanded by determining more elements of interest in health terms. There is also a need to collect more representative air samples in order to obtain comparative data.

ACKNOWLEDGEMENTS

The authors thank the Committee on Research, University of Maiduguri for financial support. LZB also thanks Adamawa State Polytechnic for their sponsorship.

REFERENCES

1. World Health Organisation *Environmental Health Criteria*, Geneva **1979**; pp 1-108.
2. Bowen, L.E. *Environmental Chemistry of Elements*, Academic Press: New York; **1979**; pp 41-42.
3. Schroeder, H.A. *Einvironment* **1971**, 13, 18.
4. Gladney, E.S.; Zoller, W.H.; Jones, A.G.; Gordon, G.E. *Environ. Sci. Technol.* **1974**, 8, 551.
5. Lee, R.E.; Goransen, S.S.; Enrione, R.E.; Morgan, G.B. *Environ. Sci. Technol.* **1972**, 6, 1025.
6. Rahn, K.A.; Dams, R.; Robbins, J.A.; Winchester, J.W. *Atmos. Environ.* **1971**, 5, 413.
7. Wender, P.M. *Minimal Brain Dysfunction in Children*, John Willey: New York; **1971**.
8. Carrol, R.E. *J. Am. Med. Assoc.* **1996**, 198**,** 267.
9. Waldbott, G.L. *Health Effects of Environmental Pollutions*, Mosby, St. Louis: Missouri; **1973**.
10. Friberg, L.; Piscator, M.; Norberg, G. *Cadmium in the Environment*, Chemical Rubber Publishing Co.: Cleveland, Ohio; **1971**.
11. Rosenstock, H.A.; Simons, D.G.; Meyer, J.S. *J. Am. Med. Assoc.* **1971**, 217, 1354.
12. Stockinger, H.E. *Manganese in Industrial Hygiene and Toxicology*, Vol. 2, 2nd ed., Party F.A. (Ed.), Wiley Interscience: New York; **1963**.
13. Ogugbuaja, V.O.; Barsisa, Z. *Annals of Borno* **1992**, 10, 118.
14. Meetham, A.R.; Bottom, D.W.; Cayton, S. *Atmospheric Pollution*, 3rd ed., Macmillan: New York; **1984**.
15. Drinker, P.; Hatch, T. *Industrial Dust*, 2nd ed., McGraw Hill: New York; **1954**.
16. Eisenbud, M. *Environmental Radioactivity*, 3rd ed., Academic Press: New York; **1987**.

17. UNEP/WHO *Urban Air Pollution, 1973–1980*, World Health Organization: Geneva; **1988**.
18. Heinsohn, R.J.; Kabel, R.L. *Sources and Control of Air Pollution*, Prentice Hill: New Jersey; **1999**.
19. Stern, A.C.; Wohlers, H.C.; Boubel, R.W.; Lowery, W.P. *Fundamentals of Air Pollution*, Academic Press: New York; **1973**.
20. US Weather Bureau *Meteorology and Atomic Energy*, USGPO: Washinton D.C.; **1955**.
21. Dickenson, M.H.; Foster, T.; Gudiksen, P.H. *Boundary Layer Meteorol.* **1984**, 30, 333.
22. Heit, M.; Klusek, C.S.; Volchok, H.L. *Environ. Int.* **1980**, 4, 229.
23. Calcutt, R.; Boddy, R. *Statistics for Chemists*, Champman and Hall: London; **1983**.