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SHORT COMMUNICATION

DAYTIME ATMOSPHERIC SULPHUR DIOXIDE CONCENTRATIONS IN IBADAN CITY, NIGERIA

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ABSTRACT. Atmospheric sulphur dioxide concentrations were determined at 27 locations in the city of Ibadan, Nigeria, during May-June 1997. The locations were chosen from zones of high and low traffic densities, residential areas, industrial areas, and remote (control) areas. Sulphur dioxide levels did not significantly vary with the time of day of sampling, which was between 9 a.m. and 5 p.m. Average levels were: high and medium traffic density zones, 34.8 μg/m³; low traffic density and residential zones, 20.0 μg/m³; industrial zones, 68.9 μg/m³; and control zones, 14.5 μg/m³. The average level for all the zones, 34.1 μg/m³, is within the limits of worldwide guidelines for air quality, but slightly higher than prevailing levels in some cities of the developed countries.

KEY WORDS: Atmospheric sulphur dioxide concentrations in Ibadan, Nigeria

INTRODUCTION

Atmospheric sulphur dioxide pollution is one of the most worrisome environmental problems associated with industrial development. The pollutant is derived primarily from the combustion of fossil fuels such as industrial fuel oil, diesel oil, and coal. Annual emission estimate is put at 130 million tonnes for industrialized Europe, Asia and the USA [1-3]. Sulphur dioxide pollution is implicated in many forms of damage to human health, vegetation, wildlife, aquatic resources and economic objects. In humans, incidence of respiratory, cardiac, and reproductive disorders have been related to episodes of sulphur dioxide pollution [4-9]. Sulphur dioxide pollution is known to inhibit photosynthetic activities in lower and higher plants [10-16], and is the main source of acidity in rainfall. In Europe, acid rain has damaged vast expanse of forests, acidified freshwaters, and caused significant economic damage to building materials and other objects [17].

The routine monitoring and reduction of atmospheric sulphur dioxide levels is a major preoccupation of federal and municipal governments in developed countries. In many cities, ambient levels are determined on an hourly basis, and regulations are enacted to drastically reduce industrial and traffic related emissions of the pollutant. A global air quality monitoring network was established in 1973, and is now part of the Global Environmental Monitoring Systems (GEMS), coordinated by the United Nations Environmental Programme (UNEP) and the World Health Organisation (WHO). Only a few centers in Africa are designated in the network. Air quality data for most cities of developing countries such as Nigeria are sparse or non-existent. Where urban environmental monitoring studies have been undertaken, these have mostly been restricted to soil and water pollution issues. Results of some of such studies have shown that the degrees of environmental pollution may be significant even in developing countries. Proper management of the total environment in such countries requires the acquisition of more baseline data including those of urban and rural air quality.

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This paper describes a study of the atmospheric sulphur dioxide concentrations in the city of Ibadan, the largest and second most populated city (population estimated at about 4 million) in Nigeria. The aim is to provide data for assessing the relative levels of sulphur dioxide pollution in parts of this typical urban center in Nigeria, determine the degree of compliance with worldwide guidelines on air pollutant levels, assess the prevailing exposure risk, and compare the levels with those of cities in other countries.

EXPERIMENTAL

The study was conducted during the period May-June, 1997. Sulphur dioxide monitoring was carried out by use of an air sampling train and determination by the West-Gaeke procedure [18]. A total of twenty seven sampling locations were selected across the city to reflect the following categories of interest: high traffic density zones (5 sites), medium traffic density zones (5 sites), low traffic density zones (5 sites), residential zones (5 sites), industrial zones (5 sites), and control zones (2 sites). Sites for each zone were as far as possible selected from different parts of the city. The control sites were the Botanical garden of the University of Ibadan, and another forest reserve (the Jericho Reserve), both within the city, but remote from the direct influence of traffic and industrial activities. In order to determine the degree of variation during a daytime cycle of urban activities within the city, air was sampled at each location during five defined one-hour periods of any sampling day. The sampling periods were: 9 a.m.–10 a.m.; 10.30 a.m.–11.30 a.m.; 12 noon–1 p.m.; 2 p.m.–3 p.m.; and 4 p.m.–5 p.m. for all locations.

At each sampling site, the sampling train was mounted on a stand, 2 m high, at a distance of 5-10 m from the roadside in the traffic zones, or at a suitable open space in the residential, industrial and control zones. The sampling trains were configured with critical orifices calibrated to a flow rate of 500 cm^3 min^{-1}, and the bubblers were filled with 10 cm^3 of 0.1 M potassium tetrachloromercurate(II). Each sampling was operated for 1 h using a duplicate set of samplers. After each air intake, the bubbler was removed and the absorbent solution transferred quantitatively into a vial. This was subsequently analysed by the West-Gaeke procedure involving the addition of *p*-rosaniline, formaldehyde and hydrochloric acid, followed by absorbance measurement at 548 nm [18]. Calibration curves were prepared from standard sodium sulphite solution. Reagents used were either of analytical reagent (AnalaR) grade or were further purified by appropriate standard procedures. Distilled water was further deionised. Reagent blanks were analysed for each daily sampling and analysis. The wavelength setting of the spectrophotometer used was routinely checked by standard instrument calibrating procedures.

Traffic densities at some of the locations were estimated by visual 30 min counts of traffic flow at three different times of the day, and then averaging for hourly flow rates. Statistical analysis of the data was carried out using the Jandell SigmaStat 2.0 package.

RESULTS AND DISCUSSION

Sulphur dioxide concentrations data obtained for the locations was subjected to statistical tests to determine the significance or otherwise of the factors of sampling time and sampling zone. Using the Kruskal-Wallis Analysis of Variance on Ranks, it was determined that sampling time was not a statistically significant factor ($p = 0.155$; $H = 6.664$). Thus, a single average value with standard deviation was sufficient to describe the sulphur dioxide level for a site over the re day period. The same test however showed that the variations observed among the erent sampling zones were statistically significant ($p < 0.001$). Among the different traffic sity zones however, it was established with the Dunnett's Multiple Comparison test that ilts for the low traffic zones were significantly different from those of the high and medium fic density zones, while the results for the later two did not significantly differ from each er. Results for the low traffic density zones did not differ significantly from those of the dential zones. The prevailing wind of the study period was the South-West wind. mination of the results for various locations relative to the wind direction did not reveal any cific trend. Considering the results of these tests and observations, the summary of the results e therefore presented according to four differing zones: (i) high and medium traffic density es, (ii) low traffic density and residential zones, (iii) industrial zones, and (iv) control zones.

Table 1 gives the average of duplicate results of sulphur dioxide concentrations at each of twenty seven locations, and for all the five sampling periods. A summary of the data ording to the four distinct zones is given in Table 2. Sulphur dioxide concentrations in the h/medium traffic density zones ranged from 14.8 $\mu g/m^3$ to 51.5 $\mu g/m^3$. The average for the e was 34.8 $\mu g/m^3$. Levels in this zone were about 2–3 times higher than those obtained in the ote control zones of the city. The pollutant levels in the low traffic density and residential es were lower than obtained in the high/medium traffic density zones, but higher than in the trol zones. The values here ranged from 14.8 $\mu g/m^3$ to 29.6 $\mu g/m^3$ with an average of 20.0 m^3. The results indicate the significance of the contribution from traffic to the sulphur xide pollution in the city. Sulphur dioxide is emitted from diesel oil combustion in heavy-y diesel vehicles, and to a much lesser extent from gasoline powered vehicles. Additional tribution to the level in the residential areas was derived from the frequent use of diesel-vered electricity generators in many homes, due to the perennial power outages in the city. hest levels of sulphur dioxide were obtained around the industrial zones where levels were ut five times higher than in the control zones. The range for the industrial areas was 29.6 m^3 to 111 $\mu g/m^3$, with an average of 68.9 $\mu g/m^3$. The primary source of the pollutant in this e is from the combustion of heavy fuel oils and diesel oil in various industrial processes. The ustrial contribution is aggravated by other factors. Nigerian crude oil is known to be very in sulphur content. However, in recent years a substantial portion of domestic consumption petroleum products in Nigeria has been imported from other countries where the sulphur tents are not necessarily low. In addition, all industries operate fossil fuel-combusting power erating machines for a significant number of hours daily due to the persistent power outages. lower average level of 14.5 $\mu g/m^3$, which was obtained in the control zone, represented the kground levels for Ibadan. The overall average for the city, using all the data was estimated e 34.1 $\mu g/m^3$.

Using the United States Environmental Protection Agency (USEPA) guideline [19] for mating pollutant and air quality indices, the average sulphur dioxide level for each zone of city was used to calculate a sulphur dioxide quality index for the zone. The index values ained (Table 2) ranged from 8 for the control zones to 39 for the industrial zones, the overall ue for the city being 19. The total air quality index cannot be stated from these index values his requires additional index values for carbon monoxide, particulate matter, lead, nitrogen xide, and ozone, which are not available. However, on the pollutant category classification], which is based on the index values, the quality index values from this study all rank in the od' category (for QI values 0-50). This defines the condition for which no sulphur dioxide cific cautionary statements need be made, as no significant danger to health is implied from prevailing levels.

Table 1. Concentrations of sulphur dioxide (μg/m^3) at the different study sites in Ibadan, Nigeria.

Location	Category*	9-10 a.m	10.30-11.30 a.m.	12-1 p.m	2-3 p.m.	4-5 p.m.	Mean±S.D.
Ojoo	HTD (1160)	36.7	36.5	21.9	36.8	36.7	36.9±6.6
Dugbe	HTD (1110)	51.5	44.4	36.7	22.5	29.6	34±12
Apata	HTD (1039)	44.4	51.5	44.4	29.6	29.6	39.9±9.8
Agodi-Gate	HTD (932)	44.1	36.7	44.4	29.6	29.6	36.9±7.3
Molete	HTD (921)	29.6	29.6	14.8	14.8	25.5	22.9±7.5
Oke-Ado	MTD (647)	44.4	44.8	29.6	44.1	37.1	40.0±6.6
Bodija	MTD (542)	44.6	44.4	29.6	29.6	44.4	38.5±8.1
Eleyele	MTD (497)	44.4	36.7	29.6	29.6	29.6	34.0±6.6
Unibadan	MTD (361)	29.6	29.6	21.1	21.9	22.5	24.9±4.3
Basorun	MTD (343)	44.4	44.4	36.7	29.6	44.4	39.9±6.7
Mokola-Barrack	LTD (89)	29.6	29.6	21.9	21.9	22.5	25.1±4.1
Apata-Queens School	LTD (84)	29.4	29.6	22.5	14.8	14.8	22.2±7.4
Mokola-Alafia	LTD (70)	14.8	21.9	21.9	14.8	14.8	17.6±3.9
Agodi-Idi Ape	LTD (58)	14.4	14.8	21.6	14.8	14.8	16.1±3.1
Molete-Sanda	LTD (14)	14.8	14.8	14.8	14.4	14.4	14.6±0.2
Beere	Residential	14.8	14.8	21.9	14.8	14.8	16.2±3.2
Molete	Residential	29.6	21.9	21.2	21.9	14.8	21.9±5.3
Mokola	Residential	29.6	21.9	21.9	21.5	14.8	21.9±5.3
Apata	Residential	29.6	21.6	14.8	14.8	14.8	19.1±6.6
Agbowo	Residential	29.6	29.2	29.6	14.8	21.9	25.0±6.6
Oluyole IA	Industrial	104	111	104	95.8	95.8	102±6
Wofun Area	Industrial	74.0	81.0	81.0	59.2	59.2	71±11
New Ife Road	Industrial	74.0	74.0	59.2	59.6	59.6	65.3±8.0
Apata IA	Industrial	44.4	44.4	37.3	29.6	29.6	37.1±7.4
Podo	Industrial	81.0	73.3	73.3	59.2	59.2	69.2±9.7
Bot. Garden, UI	Control	14.8	14.8	14.2	14.2	14.2	14.4±0.3
Jericho Reserve	Control	14.2	14.8	14.8	14.4	14.8	14.6±0.3

*HTD: high traffic density, MTD: medium traffic density, LTD: low traffic density, figures in brackets are estimated hourly traffic volumes at sampling locations.

Table 2. Summary of zonal sulphur dioxide concentrations and quality indices

Zone	Mean (μg/m^3)	Median (μg/m^3)	Sulphur dioxide quality index	Quality index category
Industrial	68.9	73.3	39	Good
High/medium traffic density	34.8	36.6	19	Good
Low traffic density and residential	20.0	21.4	11	Good
Control	14.5	14.6	8	Good
Ibadan average	34.1	29.6	19	Good

Table 3 compares the sulphur dioxide levels obtained for Ibadan city with the specific air quality guidelines for Nigeria [20] and some other countries. The Nigerian guidelines were hurriedly introduced in 1991 following the inception of Nigeria's Federal Environmental Protection Agency (FEPA), and appear to be arbitrary, differ significantly from the current guidelines for other countries, and need to be revised. Each single hour measurement of this study falls within the 260 μg/m^3 hourly guide value for Nigeria. However, the present 24 h average guide value of 26 μg/m^3 appears unrealistic and is not attainable under prevailing circumstances. The Ibadan levels are however well within the more realistic 24 h guide values of the World Health Organisation (WHO) and other guidelines.

Table 3. Ibadan city sulphur dioxide levels compared to some national air quality guidelines.

Country/organisation/city	Guideline value (μg/m^3)	Averaging time
WHO [23]	125 50	24 h 1 y
European Union (EU)	100-150 40-60	24 h 1 y
USA	364 78	24 h 1 y
Nigeria	260 26	1 h 24 h
Japan	104	24 h
UK	266	15 min
Ibadan (this study)	34.1 (mean) 29.6 (median)	Hourly values, 2 months study

Table 4 compares the Ibadan city sulphur dioxide level with those which have been obtained for several other major cities of the world. The 1997 average level for Ibadan is slightly higher than more recently measured levels for most cities in the USA, UK, Germany, Croatia, Australia, and Belgium, where levels range between 10 μg/m^3 and 25 μg/m^3. The Ibadan levels however compares well with, or are even lower than, current levels in parts of New York (36–70 μg/m^3). Table 4 also shows that sulphur dioxide levels in many world city which were at about 30 - >100 μg/m^3 between 1976 and 1980 [21], have recently declined to average values of <20 μg/m^3. This trend is the result of concerted efforts in the developed countries towards the reduction of emissions of various pollutants.

Overall, the results of this study indicate that sulphur dioxide pollution in Ibadan city is not yet at worrisome levels. However, the current level needs actions to bring it down to that which prevails in the developed world.

Table 4. Ibadan city sulphur dioxide level compared with levels in other world cities.

City/country	Concentration ($\mu g/m^3$)	Date measured	Reference
Ibadan, Nigeria	34	1997	This study
USA (trends, average)	26 reduced to 13	1980 to 1999	[24]
UK cities (averages, 58 centres)	10 (average) 0–42 (range)	November, 2000	[http://www.aeat.co.uk/netcen/airqual/bulletins/latest/so2.html]
London (central), UK	26	1990 summer	[http://www.aeat.co.uk/netcen/report96/1990/so2/cll.htm]
Berlin, Germany	22	1995	http://www.sensut.berlin.de/SenSUT/umwelt/uisonline/dua96/html/eda30105.htm
Melbourne, Australia	20.8 – average	1988–2000	[http://www.epa.vic.gov.au/aq/info/aqa.htm]
Zagreb, Croatia	31 (city centre) 9 (residential)	Apr. 1994 – Mar. 1995	[http://mimi.imi.hr/~ksega/dorso2.html]
Fukui, Japan	42	Nov., 2000	[http://www.erc.pref.fukui.jp/Etm.asp]
Brussels, Belgium	5 – 9	Nov., 2000	[http://www.irceline,be/~celinair/airact_table.html]
New York, USA	34	1999 average	[http://www.epa.gov/oar/aqtrnd99/factbook.pdf]
Washington, USA	23	1999 average	[http://www.epa.gov/oar/aqtrnd99/factbook.pdf]
Los Angeles, USA	13	1999 average	[http://www.epa.gov/oar/aqtrnd99/factbook.pdf]
Milan, Italy	187	1976–1980	[21, 22]
Sao Paulo, Brazil	96	1976–1980	[21, 22]
Zagreb, Croatia	73	1976–1980	[21, 22]
Brussels, Belgium	70	1976–1980	[21, 22]
Glasgow, UK	68	1976–1980	[21, 22]
Manila, Philippines	55	1976–1980	[21, 22]
Tokyo, Japan	49	1976–1980	[21, 22]
Montreal, Canada	36	1976–1980	[21, 22]
Sydney, Australia	34	1976–1980	[21, 22]
Calcutta, India	31	1976–1980	[21, 22]
Amsterdam, Netherlands	29	1976–1980	[21, 22]
Auckland, New Zealand	16	1976–1980	[21, 22]

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