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Emission inventory of TSP, SOx, NOx and CO_2 in an industrial area of Niger-Delta, Nigeria

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Abstract
The developments of reliable anthropogenic emission inventories are essential for the understanding of air pollution sources and designing effective air pollution control measures in rural and urban areas. In this study, emission inventory of total suspended particulate (TSP), SO_x, NO_x and CO_2 were investigated within the neighborhoods of an industrial area in Niger-Delta region of Nigeria with the aim of determining the source strengths. The activity data were sourced from the data bases of the major sources (industrial, residential, road transport and electricity generators) as well as from structured questionnaire to reduce uncertainties related to activity data and technology mix. Results revealed that the total emissions in the transport were 2597512 (CO_2), 36225 (SO_x), 25071 (NO_x) and 6551 kg/day (TSP) while industrial sector contributed 217698 (CO_2), 30856 (NO_x), 8727 (SO_x) and 5549 (TSP) kg/day. The residential sector stood at 9617 (CO_2), 8975 (NO_x), 1202 (TSP) and 16 kg/day while total emissions from electricity generators had 9617 (CO_2), 8976 (NO_x), 16 (SO_x) and 1202 kg/day (TSP). Overall, road transport was the largest contributor of emissions of TSP (44 %), SO_x (78 %) and CO_2 (90 %) while industrial emissions are the largest contributor of NO_x (43 %). Based on the land area of the study site, the total emission rate estimates were: 0.57, 1.80, 2.76, and 110.30 tons/km^2, for total suspended particulate, SOx, NOx and CO_2 respectively. Results could provide an input to the national emissions data system being proposed as cost-effectiveness analysis tool for the control of these toxic gaseous air pollutants.

Keywords
anthropogenic, emission, inventory, industrial, pollution, toxic

Introduction

The economies of low and middle income countries (LMICs) today are faced with numerous environmental challenges such as air, noise, water and soil pollution as well as climate change. Climate change has been described as the resultant effects of greenhouse gases (GHG) emissions due to increasing anthropogenic activities particularly in the LMICs where rural and urban infrastructures are grossly lacking (Obioh et al, 1994). Scientific evidence has shown that the accumulation of these gases in the atmosphere are manifested in the form of global warming which has attendants implications on food production and air quality, indicating that earth's sustainability may likely be threatened by human activities. In spite of such grim prospects, there are great uncertainties about the future extent of the effects as well as the micro and macro-economic costs. In the coming decades, developing countries are expected to contribute the bulk of GHG emissions, in view of their increasing population, high economic growth and corresponding rise in activities of GHG sources. Nigeria with an estimated population of about 180 million, abundant fossil fuels and mineral resources presents an interesting case study.

Currently, information regarding air quality guidelines and threshold limits is grossly dearth in most LMICs such as Nigeria. Thus, researchers rely on international

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references which in most cases do not reflect the ideal data of local air quality values. However, a clear understanding of the baseline conditions in different localities and at different times is essential in setting guidelines for air quality indices, as pollutant limits cannot be set lower than natural concentrations of human exposures. Emission inventories are necessary sources of such information and will assist in the development of abatement options for air pollutants with unusually increased source strengths. For the first time in Nigeria, this paper presents baseline information on emission inventory of TSP, SO_x, NO_x and CO_2 which was carried out in an industrial area of Niger Delta Nigeria being part of the on-going municipal emission inventory study.

Materials and Methods

Study area, monitoring survey and sampling

The study site is Akankpa Local Government Council (5.1079° N; 8.1789° 137 E) which is situated in the central part of Cross River State, Niger-Delta 138 region of Nigeria (Figure 1). It has a land area of about 314 km^2.

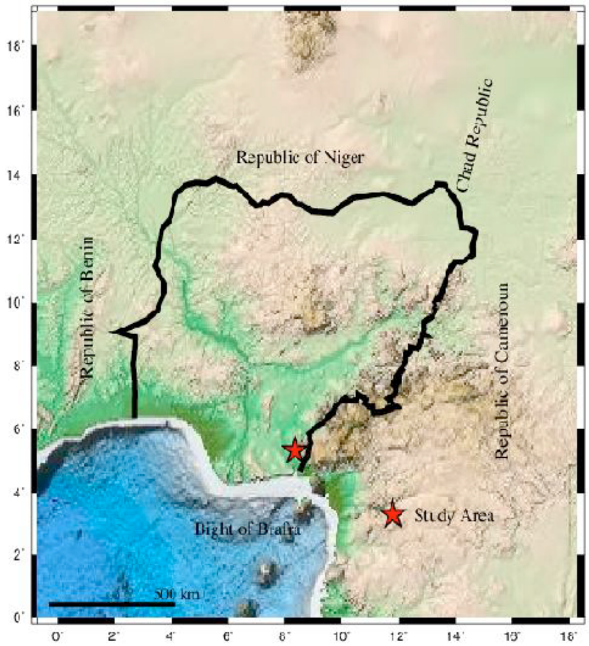

Figure 1. Map of Nigeria showing the study sites

The area is characterized with industries such as cement and iron ore mining, oil palm and food processing industries which are all situated within 10 km radius apart as well as influx of vehicular traffics. Based on the emission sources identified which includes TSP, CO_2, SO_x and NO_x, a spread sheet was developed, configured or modelled to accommodate emissions from specified sources. The activity data were sourced from the major emission sources as well as from structured questionnaire. Most of the considered emission relevant processes had incomplete, not kept in the format required for input into the spread sheet or completely non-existent data. Therefore, an estimate of some activity data was achieved using known specific descriptions or similar peculiarities.

Emission estimates by sectors

Road transport. Road transport emissions was estimated based on combustion emissions and calculated on fuel basis, vehicles types and activity data. As a consequence, traffic counts of spatial distribution of vehicles in the axis of 10 km within the industrial area were done from 7:00 to 18:00 for three days. Traffic count on Monday and Friday morning (7:00 – 10:00) was intentionally avoided so as to eliminate exceptionally high volumes of traffic data.

Vehicles were classified into six categories; Car, Truck, SUV/Hilux, Bus, Taxi and Motorcycles. Emission factors used for the estimation of total emission from different vehicle types were sourced from US EPA (2000) while total emission was computed as:

$$E = VKT \times E \times N/day \qquad [1]$$

where, VKT = vehicle travel (km) per day, E (g/km) = emission factor, N = number of vehicles

Industry. Emission in the industrial sector arises from the chemical or physical conversion of materials from one form to another. The identified industries at the study areas are cement plant, oil palm processing and iron ore mining. Activity data for estimating the emissions from the industries based on type of activity were sourced through structured technical questionnaire while aggregate emissions from all sources were modeled based on US EPA (2000) emission factors and calculated as:

$$Emission = \sum EF_{ab} \times Activity_{ab} \qquad [2]$$

where: EF = emission factor, N (kg/day) = number of activity, a = fuel type and b = sector activity

Cement production. The major emissions from cement production are particulate matter (PM) and CO_2. The emissions of CO_2 from cement production can be estimated from the stoichiometry of the production from the equation:

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$$CaCO_3 \rightarrow CaO + CO_2 \qquad [3]$$

Lime in combination with silica (SiO_2), alumina (Al_2O_3), and ferric oxide (FeO) is burned to a temperature of partial fusion to form clinker which is pulverized with hydrated $Ca(SO_4)_2$ (~ 3 to 5 %) to form cement. An estimate of the emission was obtained from the product of the fraction of lime in cement which is ~ 62 % (Obioh et al., 1994).

Oil palm processing and iron ore mining. The GHG emissions from palm oil production could emanate from operational procedures such as use of fossil fuels, fertilizers, mill effluents and changes in carbon stocks during development of new plantations (Roihatai et al. 2012). While main activities at the ore mining site include extracting, transport and coal dumping, breaking, sizing of mineral ore, drilling as well as blasting operations.

Domestic/area and electric generator sources. Total emission from the domestic/area sources (such as cooking, open burning, waste handling and electric generator sets) were investigated using enumeration method viz-á-viz the questionnaire (Saidur et al. 2007). A total of 893 households were enumerated during the survey and total emissions were computed based on Equation [2].

Results and discussions

Road Transport

Road transport is a major contributor to the total emissions of air pollutants in Nigeria, and has been widely reported in many emission inventories (Obioh et al 1994). Figure 2 depicts the vehicle counting data which were summarized in the following order; 186 (private car) < 195 (SUV/hilux) < 253 (trucks) < 268 (buses) < 288 (taxi) < 1074 (motorcycle) per day. Such variations are common as most industrial workers commute to work with motorcycle than other vehicle types.

Table 1 displays the aggregate contributions of PM, SO_x, NO_x and CO_2 emissions based on vehicles types. PM emissions summed up to 6550 kg/day in which trucks, SUVs, bus, motorcycle, taxi and car accounted for 45, 18, 12, 10, 9 and 6 % respectively. The numbers of trucks were barely over 200; however, its contribution to PM emission was most prominent probably due to their high emission factor.

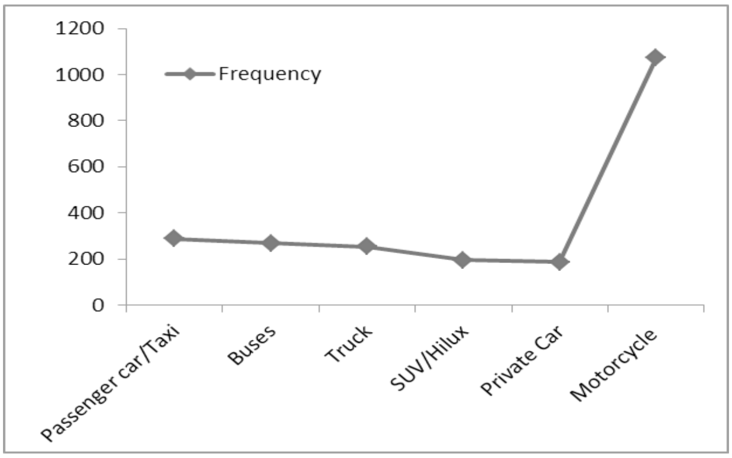

Figure 2. Frequency of vehicles per day

Vehicle Type	Total Emissions (kg/day)			
	PM	SO_x	NO_x	CO_2
Car	371.33	1856.67	2228.00	308021.00
Truck	2985.40	11385.00	10120.00	197846.00
SUV/Hilux	1168.00	2920.00	778.67	643860.00
Bus	805.00	6440.00	966.00	615020.00
Passenger car/Taxi	576.67	2883.33	3460.00	478345.00
Motorcycle	644.40	10740.00	7518.00	354420.00

Table 1. Total emission per day in the transport sector

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Again, out of the total SO_x emissions (36225 kg/day), trucks were the highest contributor (31 %) while cars with 5 % had the least. Similarly, trucks got the highest (40 %) source of NO_x emissions and closely followed by motorcycle with 30 %. High contribution of motorcycle could be connected to in-complete combustion of gasoline oil which is often associated with two-stroke engines (Ålander et al., 2005) and it is the major affordable transport mode in Nigeria. For CO_2, SUVs and bus contributed 25 % and 24 % of the total emission during the study period and closely followed by taxi whose contribution stood at 18 %. Conversely, trucks had the least contribution (7 %) to CO_2 emissions unlike in other parameters where it was dominant. Overall, road transport is the largest contributor of emissions of PM (44 %), SO_x (78 %) and CO_2 (90 %) as reported in Figure 3.

Industry

Industry is the largest major contributor of NO_x (43 %) emissions and second major contributor of PM (19 %), SO_x (19 %) and CO_2 (8 %) as shown in Figure 3. These pollutants are emitted both from stationary industrial factories and by industrial processes.

For instance, emission from cement plants, iron ore mining site and industrial boilers have been identified as major contributors of NO_x (Obioh et al, 1993). The generation of NO_x is usually influenced by industrial temperature and oxygen availability. As awareness of the increasing NO_x emissions in cement plants is on-going worldwide, De-NO_x systems are installed in pre-calcination kilns and their penetration rate is nearly 92 % in China (Zhang et al. 2007). Apart from cement industry, PM is emitted from several other emission sources; iron ore quarrying and production of palm oil industries. These rapid growth has not been matched with the required strict regulations for environmental and personnel protection in Nigeria. Most of these industries are yet to invest in facilities necessary for improving the emissions emanating from production processes (Owoade et al., 2015).

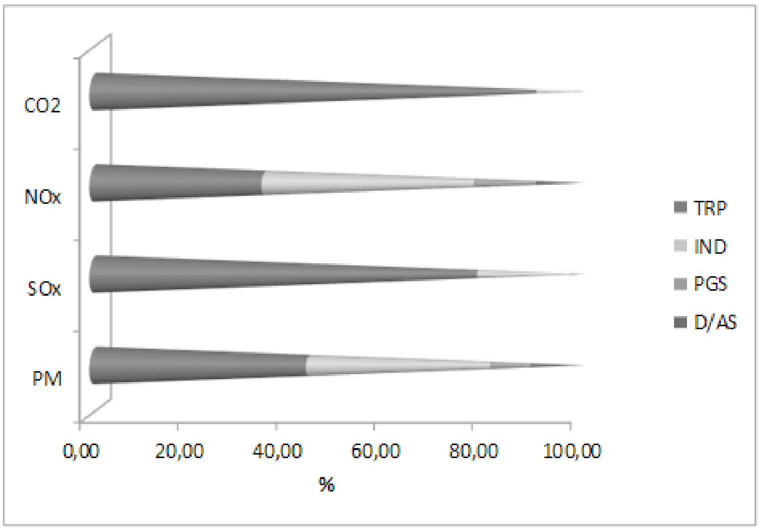

Figure 3. Overall percentages of PM, SO_x, NO_x and CO_2 emissions. (Where, TRP, IND, PGS and D/AS represent transport, Industry,Power Generating Sets and Domestic/Area sources respectively).

Residential (domestic / area sources and electric power generators)

Consumption of fossil fuels (oil and gas) for cooking and heating is associated with large emissions of air pollutants in most Nigeria cities. This could be due to its relatively low combustion efficiency and lack of controls. However, due to lack of reliable data and locally measured emission factors, the actual estimate of emissions of anthropogenic pollutants in this sector is often shredded with huge uncertainty. Energy consumption in the residential sector is highly uncertain compared to that in other sectors.

The survey revealed that kerosene, biomass and natural gas were the major sources of energy used for cooking purposes; with an average cooking rate of 3 hours per day for each household. A total of 362 (~ 40 % of the total households) use both kerosene and biomass for cooking purposes while over 47 % depend on biomass only. In addition, 2 and 9 % of the total households use natural gas and kerosene respectively. For the

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refuse management, analyses revealed that only 47 % (421 households) practice open burning of refuse for at least once per week. Further analysis indicates that burning of biodegradable, non-biodegradable and agricultural wastes were only practiced in 194, 117 and 110 households respectively. The statistics for the power generating sets reflected the economic powers of the inhabitants. The total emission emanating from the households per day due to cooking/heating purposes are presented in Table 2.

The aggregate total emission of SO_x per a day stood at 1451 kg/day out of which cooking with kerosene accounted for nearly 95 %. The major source of NO_x in this sector was kerosene consumption, representing approximately 80 % of the total NO_x emission (5827 kg/day) while natural gas had an insignificant percentage (0.20) contribution. Equally, biomass burning was the major contributor of CO_2 and PM as it contributed 97 % and 74 % of their total emissions respectively. Out of 893 households, only 448 (50 %) have electric power generating sets which ranged from 1000 VA to 3000 VA. Estimate of the three total emissions per day for each air pollutant emitted from the household sector are displayed in Table 3. Emissions in the residential sector stood at 9617, 8975, 1202 and 16 kg/day for CO_2, NO_x, PM and SO_x respectively probably due to increase use of electric generators unlike in China where CO_2 and NO_x contributions were insignificant (Zhang et al., 2007).

	Cooking			Total Emission
	Kerosene	**Biomass**	**(Gas)**	
SO_x	1372.68	78.42	0.10	1451.20
NO_x	5826.87	1537.05	14.88	7378.80
CO_2	1624.80	62485.85	3.63	64114.28
PM	448.22	1254.74	0.58	1703.54

Table 2. *Total household emissions (kg/day) for residential/area sector*

Source	PM	SOx	NOx	CO2
	kg/day			
Transport	6550.80	36225.00	25070.67	2597512.00
Industry	5549.40	8726.71	30855.69	217697.86
Power Generating Set	1202.13	16.03	8975.87	9617.00
Domestic/Area Sources	1703.54	1451.20	7378.80	64114.28

Table 3. *Total emission day,*

Based on the size of our study site, total emission per land mass (Table 4) were calculated and compared with Nigeria National Data (Obioh et al 1994). Interestingly, values recorded for SO_x, NO_x and CO_2 were approximately 2000, 1000 and 140 % higher than national data while PM emission rate were far below national data approximately in the ratio of 1:20.

In general, the emission of toxic pollutants in most Nigerian cities was generally low based on low per capita energy and other resources consumption in the country. These are expected to rise in future as a result of high population growth rate, and corresponding increase in per capita energy, industrial revolution and other resource consumption.

Source	PM	SOx	NOx	CO2
	kg/day			
Transport	0.25	1.38	0.96	99.18
Industry	0.21	0.33	1.18	8.31
Power Generating Set	0.05	0.03	0.34	0.37
Domestic/Area Sources	0.07	0.06	0.28	2.45
Total Emission	0.57	1.80	2.76	110.30
Nigeria National Data (1988)	23.05	0.094	0.28	79.36
Land Area for Nigeria =923, 768 km^2; for the study area =314.16 km^2				

Table 4. *Total emissions (ton/km^2) per land area.*

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The assessment of options to reduce future toxic pollutants is considered an important contribution to the sustainable development of Nigeria and could be undertaken in respect to energy, transportation and industrial sectors, which are the main contributors to carbon emissions.

Conclusion

This work serves as a first phase of a multi-phased approach to the computation of emission inventory of toxic gaseous pollutants in a typical industrial environment in Nigeria. Hence, further works on inventory of other toxic gaseous pollutants are imperative and should extend to other urban and rural municipalities, opportunities for national coverage are recommended in future.

Disclosure statement

No potential conflict of interest was reported by the authors

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INVENTAIRE DES EMISSIONS DE TSP, SO_x, NO_x ET CO_2 DANS UNE ZONE INDUSTRIELLE DU DELTA DU NIGER AU NIGERIA

Résumé

La mise au point d'inventaires fiables des émissions anthropiques est essentielle pour comprendre les sources de pollution atmosphérique et concevoir des mesures efficaces de contrôle de la pollution atmosphérique en milieu rural et urbain. Dans cette étude, l'inventaire des émissions de particules en suspension totales, de SO_x, de NO_x et de CO_2 a été étudié dans les environs d'une zone industrielle de la région du Niger-Delta, dans le but de déterminer les forces à la source. Les données sur les activités ont été extraites des bases de données des principales sources (industriels, résidentiel, transport routier et producteurs d'électricité), ainsi que de questionnaires structurés visant à réduire les incertitudes liées aux données sur les activités et à la combinaison de technologies. Les résultats ont révélé que les émissions totales dans les transports étaient de 2597512 (CO_2), 36225 (SO_x), 25071 (NO_x) et 6551 kg / jour (TSP), le secteur industriel contribuant 217698 (CO_2), 30856 (NO_x), 8727 (SO_x) et 5549 (TSP) kg / jour. Le secteur résidentiel s'est établi à 9617 (CO_2), 8975 (NO_x), 1202 (TSP) et 16 kg / jour, tandis que les émissions totales des producteurs d'électricité ont été de 9617 (CO2), 8976 (NO_x), 16 (SO_x) et 1202 kg / jour. (TSP). Globalement, le transport routier est le principal contributeur d'émissions de PST (44 %), de SO_x (78 %) et de CO_2 (90 %), tandis que les émissions industrielles sont le principal contributeur de NOx (43 %). Sur la base de la superficie du site d'étude, les estimations du taux d'émission total sont les suivantes: 0.57, 1.80, 2.76 et 110.30 tonnes / km^2, pour les particules en suspension totales, les émissions de SO_x, de NO_x et de CO_2, respectivement. Les résultats pourraient apporter une contribution au système national de données sur les émissions proposé en tant qu'outil d'analyse coût-efficacité pour la maîtrise de ces polluants atmosphériques gazeux toxiques.

Mots-clés: *anthropique; émission; inventaire; industriel; la pollution; toxique*

INVENTARIO DELLE EMISSIONI DI TSP, SO_x, NO_x E CO_2 IN UN'AREA INDUSTR IALE DEL NIGER-DELTA, NIGERIA

Riassunto

Gli sviluppi di inventari affidabili di emissioni antropogeniche sono essenziali per la comprensione delle fonti di inquinamento atmosferico e per la definizione di misure efficaci di controllo dell'inquinamento atmosferico nelle aree rurali e urbane. In questo studio, l'inventario delle emissioni di particolato sospeso totale (TSP), SO_x, NO_x e CO_2 sono stati studiati nei quartieri di un'area industriale nella regione del Niger-Delta della Nigeria con l'obiettivo di determinare i punti di forza della fonte. I dati relativi all'attività sono stati ricavati dalle basi di dati delle principali fonti (industriali, residenziali, del trasporto su strada e generatori di elettricità) e dal questionario strutturato per ridurre le incertezze relative ai dati di attività e al mix tecnologico. I risultati hanno rivelato che le emissioni totali nel trasporto erano 2597512 (CO_2), 36225 (SO_x), 25071 (NO_x) e 6551 kg / giorno (TSP) mentre il settore industriale ha contribuito con 217698 (CO_2), 30856 (NO_x), 8727 (SO_x) e 5549 (TSP) kg / giorno. Il settore residenziale si attestava a 9617 (CO_2), 8975 (NO_x), 1202 (TSP) e 16 kg / giorno mentre le emissioni totali dei generatori di elettricità erano 9617 (CO_2), 8976 (NO_x), 16 (SO_x) e 1202 kg / giorno (TSP). Complessivamente, il trasporto su strada è il più grande contributore di emissioni di TSP (44 %), SO_x (78 %) e CO_2 (90 %) mentre le emissioni industriali sono il maggiore contributore di NO_x (43 %). In base all'area territoriale del sito di studio, le stime del tasso di emissione totale erano: 0.57, 1.80, 2.76 e 110.30 tonnellate / km^2, rispettivamente per il particolato sospeso totale, l'SO_x, l'NO_x e la CO_2. I risultati potrebbero fornire un input al sistema nazionale di dati sulle emissioni proposto come strumento di analisi costo-efficacia per il controllo di questi inquinanti atmosferici gassosi.

Parole chiave: *antropogenico; emissione; inventario; industriale; inquinamento; tossico*