Scientific African 12 (2021) e00762

Contents lists available at ScienceDirect

Scientific African

journal homepage: www.elsevier.com/locate/sciaf

Spatial patterns of gas flaring stations and the risk to the respiratory and dermal health of residents of the Niger Delta, Nigeria

M.C. Nwosisi[a,*], O. Oguntoke[b], A.M. Taiwo[b], I.E. Agbozu[a], E.J. Noragbon[c]

[a] Department of Environmental Management and Toxicology, Federal University of Petroleum Resources, Effurun, Delta, Nigeria
[b] Department of Environmental Management and Toxicology, Federal University of Agriculture, Abeokuta, Ogun, Nigeria
[c] Department of Paediatrics, University College Hospital, Ibadan, Oyo, Nigeria

ARTICLE INFO

Article history:
Received 2 December 2020
Revised 5 April 2021
Accepted 10 April 2021

Editor: DR. B. Gyampoh

Keywords:
Environmental health
Air pollution
Gas flaring
Public health
Environmental monitoring

ABSTRACT

This study assessed the health risk for respiratory and dermal related conditions as a result of residents' exposure to air emissions from gas flaring stations (GFS). The spatial patterns of the GFS were evaluated. Air pollutants from the eight GFS were monitored and medical data were obtained from six primary health care centres that are in the proximity of the GFS. Additionally, a well-structured questionnaire was administered to 200 residents in the GFS vicinity. Nearest neighbor analysis and SPSS for Windows (version 21.0) were used to analyze the data obtained. The GFS exhibited a clustered configuration. The concentration of air pollutants varied significantly ($p = 0.001 - 0.018$) in the dry and wet seasons. NO_2 and $_{PM10}$ were higher than the WHO permissible limit. Respiratory and dermal-related ailments accounted for about 21.1 to 76.3% of the entire hospital visits; the most frequent were eye irritation and chest pain. There was a steady increase ($r^2 = 0.01–0.78$) in the reported cases of the respiratory ailment from 2013 to 2016. Strong associations ($r = -0.877–0.831$; $r^2 = 0.238 - 0.892$; $p < 0.05$) existed among air pollutants and respiratory and dermal diseases. In conclusion, the analysis shows that the residents are at high risk of respiratory and dermal issues as a result of the proximity of the gas flaring stations and their continuous exposure to gas flaring. A reduction in the volume of gas flared and the wearing of nose masks by vulnerable residents is highly recommended.

Introduction

As far as humans are concerned, air pollutants may cause or contribute to an increase in mortality or serious illness or may pose a potential hazard to human health [22]. Humans come in contact with different air pollutants primarily via inhalation and ingestion, while dermal contact represents a minor route of exposure [17]. The release of associated petroleum gases from crude oil processing facilities; which is referred to as gas flaring, remains one of the most lethal sources of air pollution in the Niger Delta [23].

* Corresponding author.
E-mail address: michaelnwosisi@gmail.com (M.C. Nwosisi).

https://doi.org/10.1016/j.sciaf.2021.e00762

Gas flaring induced pollution has a grave adverse impact on the health of residents in the Niger delta. According to IPCC [9], associated petroleum gas flared into the atmosphere contains greenhouse gases in addition to poisonous compounds such as dioxins, benzene, toluene, nitrogen, and sulphur dioxide. These poisonous gases cause severe health issues to the people living near and within the atmospheric reach of the gas flaring stations [16]. There have been several long term epidemiological studies to investigate the effects of air pollutants on human health [4]. The collective finding is that air pollutants contribute massively to increased mortality and hospitalizations. This is exacerbated by the fact that humans are exposed to a variety of air pollutants at varying doses and lengths of time [10].

The effects of air pollutants on human health range from nausea and difficulty in breathing or skin irritation, to cancer. Also, birth defects, serious developmental delays in children, and reduced activity of the immune system which leads to several diseases are traceable to air pollution [19]. Even the foetus in the womb is not immune to the effects of air pollutants. There is a risk of spontaneous abortion and reduced foetal growth [20].

Since little efforts have been made to protect the residents of the Niger Delta from the effects of gas flaring induced air pollution [23], this study is imperative to draw the attention of the government and residents to the dangers faced by continuous exposure. This study was carried out in Rivers and Bayelsa states. These states were chosen because they are the major oil-producing states in the Niger Delta. A total of eight gas flaring stations denoted A, from A1 to A8 and six primary health care centres denoted PHC, from PHC1 to PHC6 were used for this study. The gas flaring stations were used to obtain data on the air pollutants, while the primary health care centres in the same community as these stations were used to obtain data on reported cases of respiratory and dermal diseases. Previous researches have been focused mainly on the air quality status of the Niger Delta, and the contribution of gas flaring to air pollution in the Niger Delta [3,11]. This study builds on this foundation and incorporates the human and air pollution interaction interface. This study provided a unique research design to assess environmental health issues. The study used inferential statistics to provide a relationship between air pollutants from gas flaring and the deterioration of the health of residents in the communities that house these gas flaring stations. This research design can be replicated in other areas in Africa with gas flaring issues. This study aims to assess the health risk for respiratory and dermal related conditions as a result of residents' exposure to air emissions from the gas flaring stations.

Materials and methodology

Study area

Bayelsa and Rivers states have a total land area of 9059 km^2 and 21,850 km^2, respectively. They have a humid tropical climate with two seasons in a year namely, dry and wet seasons. The wet seasons starts in March and terminates in October, while the dry season is from November to February. The annual rainfall is about 2500 mm. The relative humidity is typically above 85% in the wet season and could decrease to 45.5% in the dry season [21]. South-westerly winds are prevalent in the study area in the wet season with wind speeds ranging from 0.3 to 4.5 m/s. In the dry season, wind speeds of 0.3–3.5 m/s are relatively slower [21].

Spatial analysis of sampled gas flaring stations

The geographical coordinates of the gas flaring stations and primary health care centers were taken with the aid of a Global Positioning System (Garmin® 10) and were imported into the ArcGIS 10 software for the production of the sampling map (Fig. 1). To determine the spatial pattern of all the gas flaring stations in the study area, the nearest neighbor analysis tool on ArcGIS 10 software was used. The coordinates of the sampled gas flaring stations were used to geo-reference an already existing map which shows all the gas flaring stations in the study area. Thereafter, the nearest neighbor analysis was carried out. The already existing map was produced by the National Space Research and Development Agency of Nigeria.

Ambient air quality sampling

Air quality samples were taken in the windward direction of the sampling locations for in-situ determination of the CO, NO_2, SO_2, and VOC parameters of the ambient air using hand-held Aeroqual Gas Monitor (500 Series) portable air quality monitoring equipment, while $_{PM10}$ was measured using Met One AEROCET 531. The Met One AEROCET 531 equipment was configured to use the stored particle count data and an algorithm to derive the mass concentration. The equipment makes use of a sensor that has a long-life laser diode, an efficient light-collecting elliptical mirror, and unique optics, to provide a high concentration limit. The isokinetic probe which functions to reduce the count errors as a result of sample flow velocity and the aerodynamics of small particles was facing upward during the sampling. The accuracy, sensitivity, flow rate, and operating temperature of the equipment were ± 10%, 0.5 µm, 0.1 cfm, and 0° to +50 °C respectively. The Aeroqual Gas Monitor (model 500 series) is a digital meter, which takes measurements at a time-weighted average. The equipment initializes for exactly 3 min before displaying the concentration of the gases. The sensor head uses Gas Sensitive Electrochemical (GSE) technology to detect gases at differing (based on the gases) resolution, operating temperatures, and accuracy. To prevent interference from fugitive dust, the measurements were taken at the chest level. The equipment was calibrated based on the manufacturer's recommendation before and after each batch of sampling.

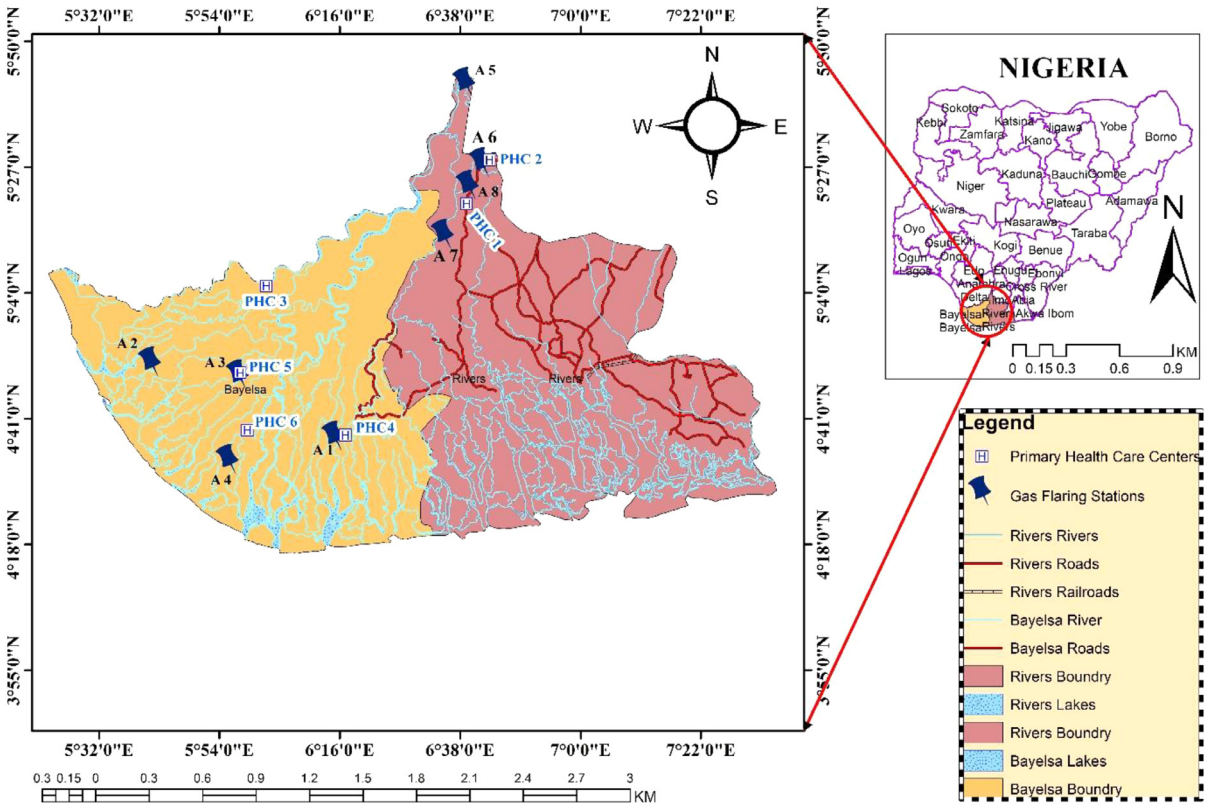

Fig. 1. Map of study area showing the sampling locations.

Health profiling of study area

In profiling the respiratory and dermal health of residents, primary data on health indices were collected through the questionnaire administration, while secondary data via clinical records from six primary health care centres in the study areas. These health care centers were in the same community as the gas flaring stations. Furthermore, the residents in the communities housing the gas flaring stations, seek medical attention in these health centers. A four year (2013–2016) clinical record was obtained. Permission of individual patients, as well as ethical approval, was not required by the health center management since aggregated data were used in this study; there were no names, photographs, or physical addresses of sampled record owners.

Questionnaire administration

Due to frequent social unrest, community agitation, and activities of security operatives in the study area, a rapid rural appraisal was adopted to elicit information on residents' perception of health risks that are associated with the gas flaring in the study area. To achieve this, a well-structured and pre-tested questionnaire adapted from Busha and Harter [5] was administered to 200 residents in the entire study area. These residents reside in the communities housing the gas flaring stations. The questionnaire involved both open and close-ended questions.

Statistical analysis

SPSS for Windows (version 21.0) was utilized for the statistical analysis. Analysis of Variance (ANOVA) was used to examine the variations in the levels of monitored parameters across locations. Duncan Multiple Range Test (DMRT) was used to ascertain the sources of variation among monitored parameters that showed variation across the locations. Responses from the structured questionnaire were subjected to both descriptive (frequency and tables) and inferential (Chi-square) statistics. Chi-square was used to determine whether the location of the gas flaring station influenced respondents' perception. Descriptive statistics such as tables, percentages, means, and frequency distribution were used to analyze and present the clinical data. Also, correlation and regression were employed to show an association between the air quality status and health of the residents.

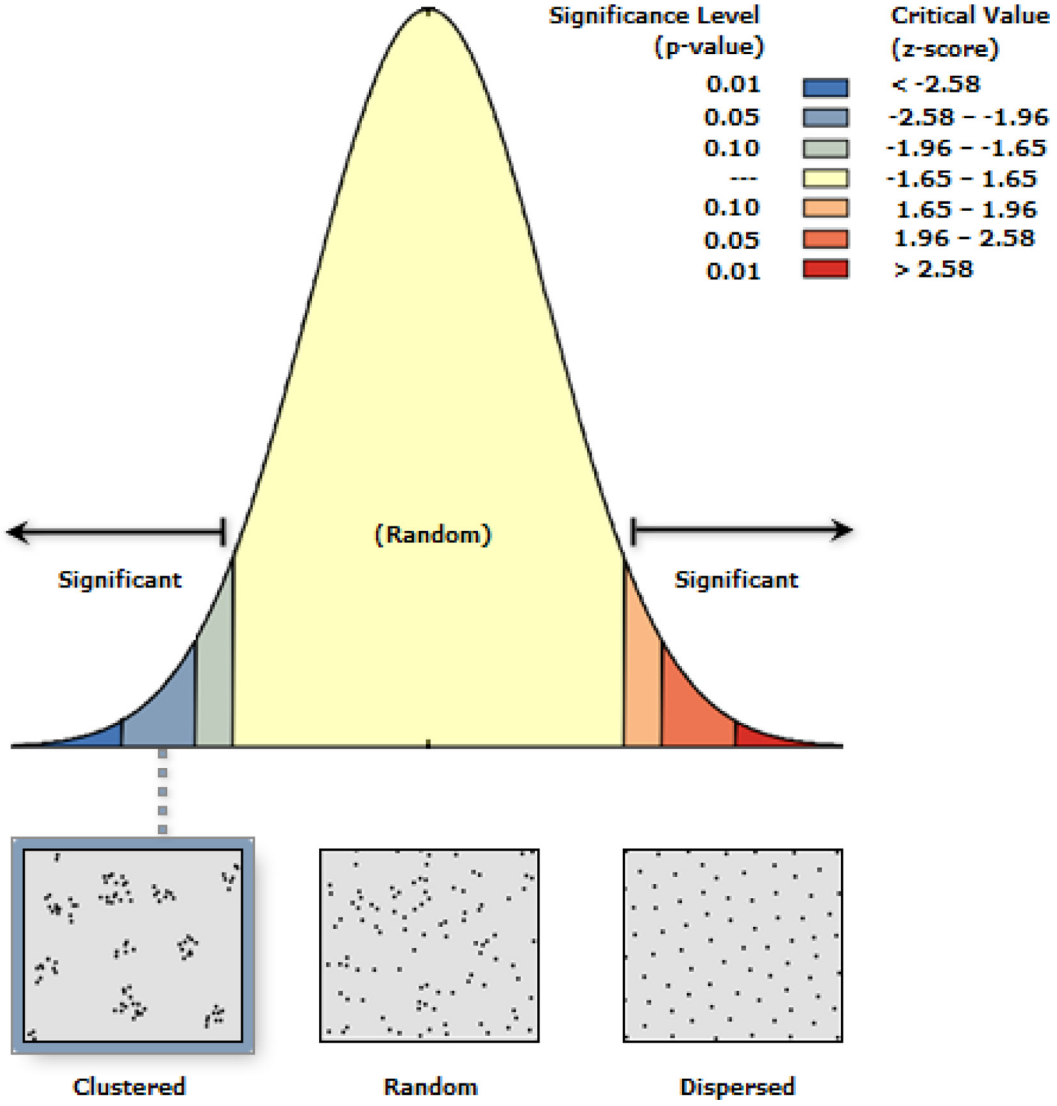

Fig. 2. Spatial pattern of gas flaring stations in the study area
given the z-score of -2.06 ($p < 0.039$), there is a less than 5% likelihood that this clustered pattern could be the result of random chance.

Results and discussion

The spatial pattern of gas flaring stations in the study area

The spatial analysis of the location of the gas flaring stations in the study area was carried out. From the nearest neighbor analysis result (Fig. 2), it was observed that the gas flaring stations were not randomly distributed within the study area, as the analysis presented a Z-score of -2.06 ($p = 0.039$). This implies that the locations of the gas flaring stations are clustered within the study area. By implication of the closeness of the gas flaring stations to one another, there would be a pooled effect of the hazards associated with the continuous flaring of gas within the study area. Thus, the residents within the sphere of influence of the gas flaring stations are more susceptible to the health risk associated with gas flaring.

Likewise, the environment of the study area is expected to be polluted and is likely to be unsafe for the residents. The result of this analysis corresponds with the findings of Anejionu et al. [3] on the detection of gas flares and estimation of flare volumes in flow stations in the Niger Delta region. They found that there was a considerable spatial and temporal variability in gas flaring across the Niger Delta, with some stations being clustered together.

Table 1
Mean concentrations of air pollutants (dry and wet seasons).

Gas flaring stations	NO_2 (mg/m^3)	SO_2 (mg/m^3)	CO (mg/m^3)	VOC (µg/m^3)	$_{PM10}$ (µg/m^3)
		Dry Season			
A1	0.037 ± 0.003^{ab}	<0.01 ± 0.000	0.181 ± 0.049^{ab}	5.790 ± 0.406^{bc}	34.958 ± 5.759^{a}
A2	0.039 ± 0.002^{abc}	<0.01 ± 0.000	0.291 ± 0.169^{b}	5.846 ± 0.525^{bc}	40.097 ± 3.140^{ab}
A3	0.041 ± 0.003^{abcd}	<0.01 ± 0.000	0.125 ± 0.008^{ab}	5.324 ± 0.468^{bc}	41.903 ± 5.847^{bc}
A4	0.039 ± 0.001^{abcd}	<0.01 ± 0.000	0.195 ± 0.075^{ab}	6.089 ± 1.439^{c}	39.250 ± 1.783^{ab}
A5	0.047 ± 0.004^{d}	<0.01 ± 0.000	0.274 ± 0.135^{b}	7.486 ± 1.748^{d}	46.598 ± 1.955^{cd}
A6	0.032 ± 0.005^{a}	<0.01 ± 0.000	0.094 ± 0.034^{a}	4.056 ± 0.609^{a}	50.792 ± 3.430^{d}
A7	0.045 ± 0.004^{bcd}	<0.01 ± 0.000	0.223 ± 0.129^{ab}	4.836 ± 0.341^{ab}	44.806± 3.610^{bcd}
A8	0.047 ± 0.001^{cd}	<0.01 ± 0.000	0.146 ± 0.108^{ab}	5.667 ± 0.441^{bc}	48.930 ± 9.437^{d}
		Wet Season			
A1	0.043 ± 0.002^{a}	<0.01 ± 0.000	0.243 ± 0.055^{a}	5.792 ± 0.809^{a}	26.625 ± 4.004^{a}
A2	0.041 ± 0.003^{a}	<0.01 ± 0.000	0.192 ± 0.010^{a}	6.222 ± 1.128^{ab}	29.430 ± 5.548^{a}
A3	0.041 ± 0.002^{a}	<0.01 ± 0.000	0.141 ± 0.019^{a}	5.763 ± 0.872^{a}	27.403 ± 6.314^{a}
A4	0.041 ± 0.001^{a}	<0.01 ± 0.000	0.149 ± 0.023^{a}	6.194 ± 0.356^{ab}	29.583 ± 5.959^{a}
A5	0.051 ± 0.003^{b}	<0.01 ± 0.000	0.347 ± 0.236^{a}	7.208 ± 1.599^{b}	26.139 ± 1.955^{a}
A6	0.037 ± 0.003^{a}	<0.01 ± 0.000	0.099 ± 0.037^{a}	4.828 ± 1.089^{a}	27.459 ± 2.183^{a}
A7	0.043 ± 0.003^{a}	<0.01 ± 0.000	0.580 ± 0.332^{b}	5.180 ± 1.420^{a}	26.806 ± 5.879^{a}
A8	0.043 ± 0.003^{a}	<0.01 ± 0.000	0.144 ± 0.111^{a}	5.792 ± 0.482^{a}	28.930 ± 6.060^{a}
FMEnv Limits	0.08 – 0.12	0.28	12.3	160	250
WHO (2009) Limits	0.04	0.02	30.8	NS	50

Values are means ± standard deviation.
Different superscripts in the same column indicate significant differences at $p < 0.05$ according to the Duncan Multiple Range Test (DMRT).
FMEnv represents the Federal Ministry of Environment; NS stands for Not Stated; WHO represents the World Health Organisation.

Concentrations of monitored air pollutants (2017–2018)

In the dry season (Table 1), nitrogen dioxide (NO_2) ranged between 0.032 and 0.047 mg/m^3. The concentration of NO_2 varied significantly ($p = 0.008$) across the gas flaring stations (GFS). The GFS in A6 had the least concentration while that of A5 and A8 had the highest concentrations respectively. The concentration of sulphur dioxide (SO_2), on the other hand, was below the equipment detection limit at all the gas flaring stations. The values of carbon monoxide (CO) were between 0.094 and 0.291 mg/m^3. The minimum concentration was measured at A6, while the maximum was at A2 respectively. There was no significant difference ($p = 0.111$) among the mean concentrations of CO across the gas flaring stations. The concentrations of volatile organic compounds (VOC) ranged from 4.836 to 7.486 µg/m^3 throughout the gas flaring stations. The concentration of VOC was significantly higher in A5 than at A7, which had the lowest concentration ($p = 0.001$). The range of $_{PM10}$ was between 34.958 and 50.792 µg/m^3 and the concentrations differed significantly ($p = 0.001$) across the gas flaring stations.

The mean concentrations of the air pollutants were compared with the regulatory limits for air pollutants. The permissible limits set by the Federal Ministry of Environment (FMEnv) and the World Health Organization (WHO) were used in assessing the level of compliance (Table 1). NO_2 and $_{PM10}$ were greater than the WHO limits (0.04 mg/m^3 and 50 µg/m^3, respectively) in some gas flaring stations in the dry season. Conversely, all other pollutants were below the threshold set by FMEnv.

In the wet season (Table 1), the concentration of NO_2 was between 0.031 and 0.051 mg/m^3. Similar to the dry season, A5 recorded the maximum concentration ($p = 0.015$). Akin to the dry season, the concentration of SO_2 was below the equipment detection limit. CO, on the other hand, was significantly ($p = 0.002$) higher in A7 GFS (0.580 mg/m^3) than at A6 (0.099 mg/m^3) which had the least concentration. The concentration of VOC ranged from 4.828 to 7.208 µg/m^3. The GFS at A6 and A5 had the lowest and highest ($p = 0.018$) concentrations. Generally, particulate matter pollution was low across the GFS. $_{PM10}$ ranged from 26.139 to 29.583 µg/m^3. Statistically, the amount of $_{PM10}$ did not differ from each other ($p = 0.909$). When compared with the regulatory standards, all measured pollutants were within the regulatory limits except for NO_2 which exceeded the WHO limit (0.04 mg/m^3).

The results obtained in this study were in tandem with the results of Gobo et al. [8], Gobo et al. [7], and Mbaneme et al. [11]. These authors worked on air pollution from gas flaring in the Niger Delta. While there are other sources of SO_2, the low sulphur content in Nigeria's crude oil could be a contributing factor to the SO_2 values that were below the equipment detection limit [13]. Similar works on SO_2 levels in flow stations follow the same trend [1,15]. The reduced ground concentration of $_{PM10}$ and gases could be a result of the rapid dispersion of the particles. The high wind speeds and low relative humidity conditions in the study area are responsible for the transport of the particles. This is worrisome because the gases emitted from the flare stacks could adsorb to the particles and be transported to other areas and the residents could inhale the $_{PM10}$ laden with these gases.

Table 2
Disease distribution in the sampled primary health care centers (2013 – 2016).

Diseases	PHC1		PHC2		PHC3		PHC4		PHC5		PHC6		t value	Sig
	Freq	%	Freq	%	Freq	%	Freq	%	Freq	%	Freq	%		
Fever	2291	27.1	373	14.5	2454	17.8	2244	12.2	2976	19.0	1851	15.6	8.3	0.00
Cough	810	9.6	246	9.6	1425	10.3	258	1.4	1590	10.2	669	5.6	5.3	0.00
Loss of appetite	82	1.0	154	6.0	770	5.6	1277	6.9	352	2.2	578	4.9	4.7	0.01
Stooling/dysentery	152	1.8	39	1.5	976	7.1	1217	6.6	894	5.7	749	6.3	4.7	0.01
Catarrh/cold	566	6.7	164	6.4	787	5.7	832	4.5	1190	7.6	506	4.3	11.1	0.00
Vomiting	219	2.6	54	2.1	1055	7.6	1507	8.2	511	3.3	239	2.0	3.7	0.01
Body weakness	205	2.4	263	10.2	618	4.5	156	0.8	338	2.2	393	3.3	2.9	0.03
Boil	37	0.4	3	0.1	89	0.6	254	1.4	105	0.7	64	0.5	3.5	0.02
Breathing difficulties	126	1.5	33	1.3	66	0.5	118	0.6	60	0.4	49	0.4	3.9	0.01
Headache	219	2.6	248	9.6	1306	9.5	226	1.2	1885	12.0	1310	11.0	4.1	0.01
Eye irritation	4	0.1	58	2.3	51	0.4	667	3.6	76	0.5	83	0.7	2.2	0.07
Abdominal pain	198	2.3	74	2.9	80	0.6	1390	7.5	118	0.8	153	1.3	2.4	0.06
Skin disease/itching	85	1.0	76	3.0	388	2.8	578	3.1	647	4.1	530	4.5	6.2	0.00
Malaria	2388	28.3	398	15.5	1740	12.6	1583	8.6	2402	15.3	2113	17.8	6.0	0.00
Bleeding	66	0.8	20	0.8	22	0.2	1186	6.4	26	0.2	85	0.7	1.5	0.18
Body pain	205	2.4	119	4.6	967	7.0	761	4.1	1800	11.5	1543	13.0	4.1	0.01
Weight loss	6	0.1	0	0.0	350	2.5	654	3.5	177	1.1	296	2.5	2.8	0.04
Chest pain	78	0.9	180	7.0	69	0.5	1677	9.1	59	0.4	134	1.1	2.0	0.10
Dizziness	95	1.1	32	1.2	434	3.1	353	1.9	310	2.0	450	3.8	5.0	0.00
Pneumonia	516	6.1	26	1.0	62	0.4	857	4.6	27	0.2	2	0.0	1.9	0.11
Measles	9	0.1	0	0.0	20	0.1	528	2.9	42	0.3	30	0.3	1.3	0.24
Asthma	88	1.0	14	0.5	84	0.6	117	0.6	69	0.4	53	0.4	6.4	0.00
Total	**8445**	**100**	**2574**	**100**	**13813**	**100**	**18440**	**100**	**15654**	**100**	**11880**	**100**		

Freq: Frequency; %: Percentage; Source: Field Survey 2017.

From this study, it was observed that the concentrations of air pollutants were generally low. This could be attributed to the gas to line projects operated by the government of Nigeria, to utilize some of the associated petroleum gas generated during crude oil separation, instead of flaring all of it. Though the concentrations were low and were largely within regulatory limits, one should be aware that regulatory limits are based on effective thresholds below which significant health impacts are not likely to occur. Regardless, there might be a high risk for susceptible residents such as the children, the elderly, and persons with impaired respiratory systems

Health profile of residents in the study area

Data gleaned from the obtained medical records (Table 2) indicates that the most prevalent cases in the PHC1 community were Malaria (28.3%), Fever (27.1), Cough (9.6%), Catarrh/Cold (6.7%), and Pneumonia (6.1%). The least common cases were Measles, Weight loss, and Eye irritation with 0.1% of the reported cases each. Similarly, the most prevalent cases in the PHC2 community were Malaria (15.5%), Fever (14.5%), Body weakness (10.2%), Cough, and Headache (9.6% each), and Chest pain (7.0%). The least reported cases were Body boil, Weight loss, and Measles with 0.1% each. Correspondingly, the predominant cases in the PHC3 community were Fever, Malaria, Cough, and Headache, which accounted for more than half the number of the reported cases (50.2%). Measles, Bleeding, Eye irritation, and Pneumonia cumulatively constituted the least reported cases (1.1%).

In the PHC4 community, cases of Fever (12.2%), Chest pain (9.1%), Malaria (8.6%), and Vomiting (8.2%) were relatively higher, while the least reported cases were Body weakness (0.8%), Asthma, and Headache (0.6% each). Likewise, Fever, Malaria, Headache, Body Pain, and Cough were in the order of 19.0, 15.3, 12.0, 11.5, and 10.2%. These five conditions were recorded as the highest number of reported cases in the PHC5 community. Pneumonia, Bleeding, Measles, Asthma, and Breathing difficulties cumulatively (1.5%) made up the least reported cases. Congruently, medical records from the PHC6 community show that 50.7% of the residents suffered from Malaria, Fever, Headache, and Stooling/dysentery, while Pneumonia (0.1%), Measles (0.3%), Asthma (0.4%), and Breathing difficulties (0.4%), were the least reported cases during the period under review.

Health conditions such as asthma, cough, breathing difficulty, chest pain, eye irritation, and dizziness which are commonly associated with air pollution [17,22] occurred more frequently in the PHC2 (21.9%), PHC4 (17.2%), PHC3 (15.4%), PHC1 (14.2%), PHC5 (13.9%), and PHC6 (12.0%). The reported cases in the study area were also similar to those obtained by Gobo et al. [8] in a gas flaring community (22.4%) compared to a community with no history of gas flaring (5.9%).

Considering the total number of reported cases across the study area, the PHC4 community was the highest (18440) with the PHC2 community being the lowest (2574). The lower number of reported cases in the PHC2 community could be attributed to the politically motivated communal crisis that plagued the community during the study period [12]. On the other hand, the PHC2 community though having the lowest frequency of reported cases had the highest proportion of reported cases of air pollution-related health conditions (21.9%). The rise in air pollution-related cases in this community

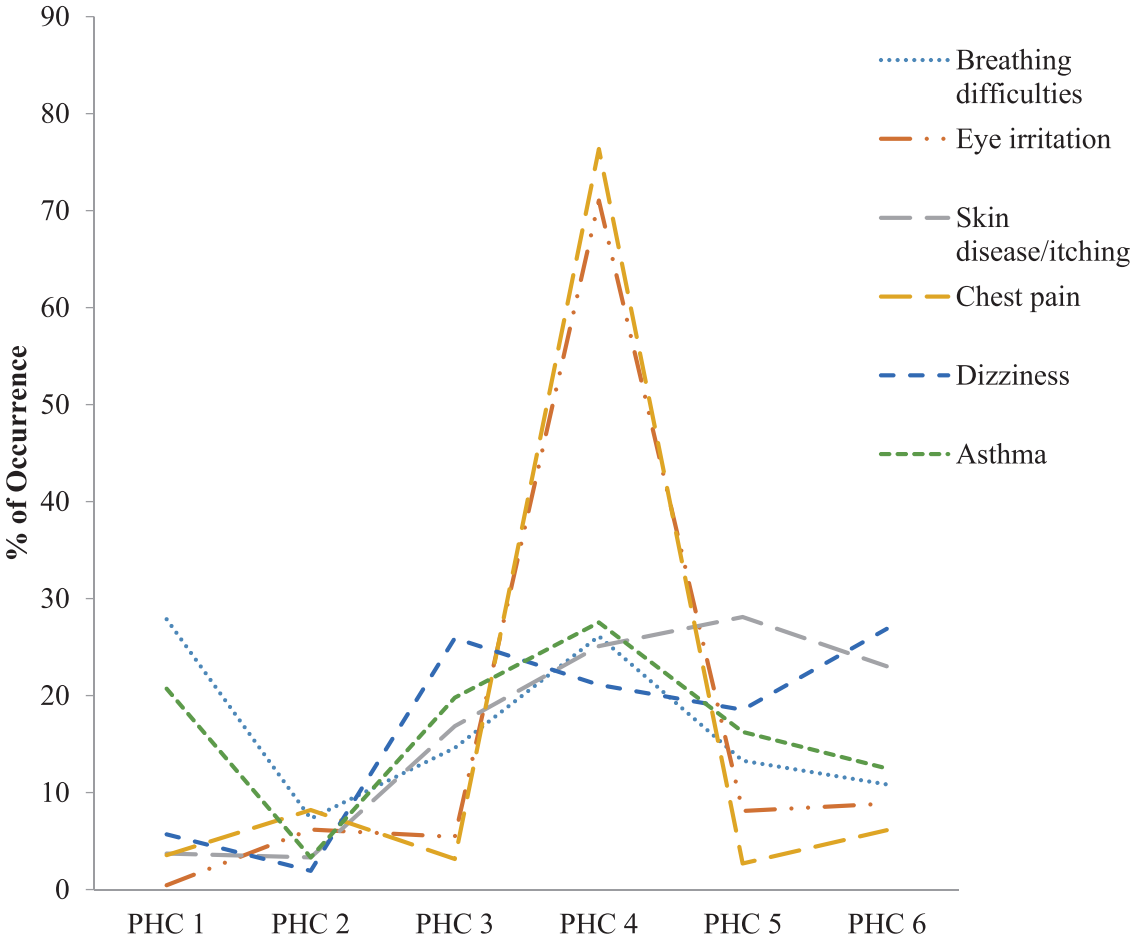

Fig. 3. Trends in the occurrence of respiratory and dermal related ailments (2013–2016).

could be attributed to two major gas flaring stations (A6 and A8) that are operational daily all through the year and are barely 1 km apart from each other [2].

Trends in respiratory and dermal ailments across the study area

The respiratory and dermal conditions suffered by the residents between 2013 and 2016 are presented in Fig. 3. It was observed that PHC1 and PHC4 (27.9% and 26.1%) had the highest occurrence of breathing difficulties across the study area. There was however a remarkable decline in the cases of breathing difficulties during the period under review, with the locations accounting for 12.6% of the occurrence of the ailment across the study area (Fig. SM 1).

The highest number of reported cases of eye irritation was observed at PHC4 (71.0%) with PHC1 having the least recorded cases (0.4%). The number of reported cases of eye irritation was shown to be on the increase, with the location contributing to 5.1% of the variation in the recorded cases of the ailment across the study area (Fig. SM2). Similarly, PHC4 had the highest recorded cases of chest pain, dizziness, and asthma (76.3, 21.1, and 27.5%), with all of these reported conditions being on the increase across the study area during the period under review. While the location accounted for 1.6% (Fig. SM3) of the cases of chest pain, it also contributed to 5.9% (Fig. SM4) and 0.1% (Fig. SM5) of dizziness and asthma respectively. The high occurrence of chest pain and eye irritation in PHC4 could be attributed to the severity of gas flaring from the several stations in the area.

Considering the dermal health of the residents, PHC5, PHC4, and PHC6 experienced more cases of skin diseases and itching ranging between 23.0 and 28.1%. Generally, there was a remarkable increase in the reported cases of skin diseases and itching, with the locations accounting for 77.9% of the variation of the ailment (Fig. SM6).

These findings agree with that of Gobo et al. [8]. They observed that the reported cases of diseases associated with air pollution in a certain community with gas flaring stations were almost quadruple of that of another community without a gas flaring station.

Table 3
Relationship between air pollutants, respiratory and dermal diseases

	Correlation			
Disease	NO_2	CO	VOC	PM_{10}
Breathing Difficulties	0.807*	0.831*	0.760	-0.329
Eye Irritation	-0.590	-0.472	-0.541	-0.901*
Skin disease/itching	-0.079	-0.125	-0.001	0.683
Chest pain	-0.229	-0.059	-0.217	-0.837*
Dizziness	0.212	0.232	0.334	-0.550
Asthma	0.701	0.715	0.721	-0.457
	Regression			
	Regression Model	*R*	R^2	Sig Level
Breathing difficulties	$Y_{Brth} = -107.975 + 10753.169X_{NOx} + 947.103_{CO} + -51.903X_{VOC} + 21615.984X_{PM10}$	0.944	0.892	0.016
Eye Irritation	$Y_{Eye} = 1356.435 + -151555.700X_{NOx} + 7117.649_{CO} + -99.706X_{VOC} + 233143.176X_{PM10}$	0.628	0.394	0.932
Skin disease/itching	$Y_{Skin} = 164.532 + -37113.777X_{NOx} + -5380.472_{CO} + 392.469X_{VOC} + - 86969.286X_{PM10}$	0.488	0.238	0.977
Chest pain	$Y_{Chest} = 164.532 + -37113.777X_{NOx} + -5380.472_{CO} + 392.469X_{VOC} + -86969.286X_{PM10}$	0.707	0.499	0.055
Dizziness	$Y_{Dizz} = 1097.219 + -150398.690X_{NOx} + -2889.011_{CO} + 545.474X_{VOC} + -95096.571X_{PM10}$	0.762	0.580	0.043
Asthma	$Y_{Asth} = -4.131 + 5204.896X_{NOx} + 513.985_{CO} + -20.375X_{VOC} + -1559.239X_{PM10}$	0.712	0.507	0.049

* Correlation is significant at the 0.05 level (2-tailed); *R* means correlation while R^2 means regression

The relationship between air pollution parameters, respiratory and dermal diseases

There was a significant correlation between air pollutants, respiratory, and dermal diseases in the communities surrounding the gas flaring stations (Table 3). Breathing difficulty was significantly ($p < 0.05$) correlated with NO_2 and CO ($r = 0.807$ and 0.831). Eye irritation exhibited a significant negative relationship with $_{PM10}$ ($r = -0.901$) and associated negatively ($r = -0.472$ to -0.590) with the gaseous pollutants. Similarly, chest pain showed a significant negative association with $_{PM10}$ ($r = -0.837$) and weak negative interconnectedness ($r = -0.059$ to -0.229) with the gaseous pollutants.

Akin to eye irritation and chest pain, dizziness exhibited both direct ($r = 0.212 – 0.334$) and inverse relationships ($r = -0.550$) with air pollutants. Likewise, asthma followed the same trend as it correlated positively with NO_2 ($r = 0.701$), CO ($r = 0.715$) and VOC ($r = 0.721$) and negatively with $_{PM10}$ ($r = -0.457$). On the contrary, skin disease/itching had an all negative relationship with the gaseous pollutants ($r = -0.001$ to -0.160) but had a positive correlation with $_{PM10}$ ($r = 0.683$). Ordinioha and Brisibe [18] and Nriagu et al. [14], in their study on human health implications of crude oil spills and health risks associated with oil pollution in the Niger Delta, held similar views with these findings.

The regression of the concentration of air pollutants and the occurrence of respiratory and dermal diseases revealed that air pollutants accounted for 23.8–89.2% of the occurrence of respiratory and dermal ailments in communities around the gas flaring stations (Table 3). The prevalence of breathing difficulties was attributed largely to the dispersion of air pollutants (89.2%) from the gas flaring stations. In the same manner, it explained 39.4% of the frequency of eye irritation in the study area. Air pollutants were also implicated in the incidence of chest pain, dizziness, and asthma. It accounted for 49.9, 58.0, and 50.7% of the reported cases of these conditions.

On the other hand, air pollutants explained the variation (23.8%) in the number of cases of skin disease/itching through the environs of the gas flaring stations. Although air pollutants did not account for a 100% explanation of the occurrence of respiratory and dermal diseases in the residents within the vicinity of gas flaring stations, they had a very significant impact. Ordinioha and Brisibe [18] and Nriagu et al. [14] corroborate this assertion.

Respondents' demographics and perception of the health effects of residing near gas flaring stations

The socio-demographics indicate that the study area has a largely educated youthful population comprising mostly of males, with more married individuals (Table SM1). They are mostly self-employed and engaged in activities such as farming, fishing, and trading. Despite their educational attainment, only a handful of them is employed by oil companies that own gas flaring stations that operate in the study area. This may likely explain the incessant rate of youth restiveness in the study area. Most of the residents have lived for more than 5 years in the vicinity of the gas flaring stations (Fig. SM7) and have witnessed the duration of gas flaring from these stations (Fig. SM8). About 81% of the respondents affirm that there is an effect on their health as a result of gas flaring (Fig. SM9). However, there is no significant difference between those who claimed it affects and those who declined ($\chi^2 = 9.122$, $p < 0.244$). This diverse opinion is not farfetched since several other factors than gas flaring can impact the health of individuals. Nearly 68.3% of the respondents think that children are more vulnerable to the effects of air pollution than adults (Fig. SM10). However, there was no significant variation in the opinion on the variation ($\chi^2 = 10.421$, $p < 0.167$) between children and adults' vulnerability to air pollution. This infers that both children and adults are equally vulnerable to air pollution. Children face special risks from air pollution because their lungs are growing [6] and they are more likely to inhale more polluted outdoor air than adults typically do [24].

About 17% and 52% of the respondents have always and occasionally experienced eye irritation in the study area, while 24.1% have rarely experienced eye irritation (Fig. SM11). Similarly, 12.6 and 54% of the respondents have always and occasionally experienced nose irritation across the study area, while 23% have rarely experienced this condition. About 89% of the respondents have at some point experienced difficulties in breathing, as well as 61.5 and 90.2% have suffered from asthma and chest pain respectively. Around 94% of the respondents have experienced fatigue, with 87.4% of them nauseating and 89.1% of them vomiting. Only as little as 7.5% of the respondents have never encountered skin reactions. Almost 97, 94, and 93% of the respondents have come down with catarrh/cough, headache, and sore throat in that order. According to the World Health Organization [25], the symptoms of individuals suffering from the health effects of air pollution includes; tiredness, headache or dizziness, coughing and sneezing, wheezing or difficulty breathing, more mucous in the nose or throat and dry or irritated eyes, nose, throat, and skin.

Conclusion and recommendations

The health risk for respiratory and dermal conditions associated with the exposure of residents to the gas flares from gas flaring stations was studied. The nearest neighbor analysis revealed that the gas flaring stations are clustered within the study area. The mean concentrations of gases and particulate matter in the atmosphere of the study area were generally low and within regulatory limits for both dry and wet seasons, except for NO_2 and $_{PM10}$ which were slightly higher than the WHO limit in some locations. However, the concentration and duration of exposure to these pollutants pose a potential health risk to the residents within the study area. From reported cases of ailments in primary health care centers in the study area, fever, malaria, headache, body pain and cough had the highest number of reported cases while pneumonia, bleeding, measles, asthma, and breathing difficulties made up the least reported cases of ailments between 2013 and 2016. Within the period under review, there was also a remarkable rise in the reported cases of respiratory and dermal related ailments such as eye irritation, chest pain, dizziness, asthma, skin diseases, and itching. There would likely be a further increase if gas flaring is unabated. Air pollutants, respiratory and dermal diseases exhibited both positive and negative interconnectedness. The correlation and regression analysis showed that air pollutants from the gas flaring stations are responsible for the occurrence of respiratory and dermal ailments in the study area. These findings are germane to the oil and gas sector in Africa as a whole. For every researcher passionate about the health and wellbeing of residents in oil producing areas in Africa, this study is an effective catalyst to prompt them to carry similar studies in other areas.

Based on the established link between air pollutants, respiratory and dermal diseases, it is recommended that nose masks should be introduced for the most vulnerable individuals (children, women, and elderly) around these gas flaring stations. Since the majority of the pollutants measured were below the FMEnv limit and they still had an effect on the health of the residents, there is the need for an immediate review of the existing FMEnv limits. It is also advised that periodic medical examination is advised for residents (especially women, elderly, and children) in the study area. This would help in identifying latent respiratory and dermal ailments and would allow for prompt treatment. Mapping of the gas flaring station in order to ascertain their location relative to one another, is imperative. This would assist in identifying the ones that should be relocated to other areas, to avoid them being clustered. Since there are over 123 gas flaring sites in Nigeria, further research on the impact of these sites on the respiratory and dermal health of the residents in these areas is highly recommended. The limitation of this study includes the security situation in the communities where the gas flaring stations are housed and the inability of some of the primary health care centers to have a robust data recording system.

Funding

The authors did not receive any funding for this work.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.sciaf.2021.e00762.

References

[1] A. Adoki, Air quality survey of some locations in the Niger Delta Area, J. Appl. Sci. Environ. Manag. 16 (1) (2012) 125–134.
[2] A.A. Alao, G.O. Avwiri, Noise levels associated with selected oil and gas installations in Ogba/Egbema/Ndoni local government area of Rivers State, Nigeria, J. Environ. Issues Agric. Dev. Ctries. 2 (2010) 2–3.
[3] C.D. Anejionu, G.A. Blackburn, J.D. Whyatt, Detecting gas flares and estimating flaring volumes at individual flow stations using MODIS data, Remote Sens. Environ. 158 (2015) 81–94.
[4] B. Brunekreef, S.T. Holgate, Air pollution and health, Lancet 1233 (9341) (2002) 1233–1242 360PMID: 12401268, doi:10.1016/S0140-6736(02)11274-8.
[5] C.H. Busha, S.P. Harter, in: Research Methods in Librarianship: Techniques and Interpretation, Academic Press, London, 1980, p. 417.

[6] R.R. Dietert, R.A. Etzel, D Chen, Workshop to identify critical windows of exposure for children's health: immune and respiratory systems workgroup summary, Environ. Health Perspect. 108 (3) (2000) 483–490.
[7] A.E. Gobo, J.K. Ideriah, T.E. Francis, H.O. Stanley, Assessment of air quality and noise around Okrika Communities, Rivers State, Nigeria, J. Appl. Sci. Environ. Manag. 16 (1) (2012) 75–83.
[8] A.E. Gobo, G. Richard, I.U. Ubong, Health impact of gas flares on Igwuruta/Umuechem Communities in Rivers State, J. Appl. Sci. Environ. Manag. 13 (3) (2009) 27–33.
[9] Intergovernmental Panel on Climate Change (IPCC)Impacts, Adaptations, and Vulnerability - Introduction Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, UK, 2007.
[10] M. Jaishankar, T. Tseten, N. Anbalagan, B.B. Mathew, K.N. Beeregowda, Toxicity, mechanism and health effects of some heavy metals, Interdiscip. Toxicol. 7 (2) (2014) 60–72.
[11] F.N. Mbaneme, E.O. Mbaneme, O.G. Briggs, Impacts of gas flaring on ambient air quality of Obrikom Community, Rivers State Nigeria, Int. J. Curr. Microbiol. Appl. Sci. 3 (11) (2014) 926–940.
[12] Nigeria Stability and Reconciliation Programme (NSRP) 2016. Conflict Briefing No 40 (Online).
[13] NNPC - Nigerian National Petroleum Corporation 2014. Annual Statistical Bulletin (Online). http://www.nnpcgroup.com/portals/0/monthly%20performance/2014%20asb%201st%20edition%20(2) (15/09/2017).
[14] J. Nriagu, A. Emilia, I.E. Udofia, E. Godwin, Health risks associated with oil pollution in the Niger Delta, Nigeria, Int. J. Environ. Res. Public Health 13 (2016) 346.
[15] E.O. Nwaichi, M.A. Uzazobona, Estimation of the CO_2 Level due to gas flaring in the Niger Delta, Res. J. Environ. Sci. 5 (6) (2011) 565–572.
[16] M.C. Nwosisi, O. Oguntoke, A.M. Taiwo, Dispersion and emission patterns of NO_2 from gas flaring stations in the Niger Delta, Nigeria, Model. Earth Syst. Environ. 6 (1) (2019) 73–84, doi:10.1007/s40808-019-00658-z.
[17] O. Oguntoke, B.O. Opeolu, N. Babatunde, Indoor air pollution and health risks among rural dwellers in Odeda area, South-Western Nigeria, Ethiop. J. Environ. Stud. Manag. 3 (2) (2010) 39–46.
[18] B. Ordinioha, S. Brisibe, The human health implications of crude oil spills in the Niger Delta, Nigeria: an interpretation of published studies, Niger. Med. J. 54 (2013) 10–16.
[19] S.I. Ovuakporaye, C.P. Aloamaka, A.E. Ojieh, D.E. Ejebe, J.C. Mordi, Effects of gas flaring on lung function among residents of IB gas flaring community in Delta State, Nigeria, Res. J. Environ. Earth Sci. 4 (5) (2012) 525–528.
[20] L.M. Schell, M.V. Gallo, M. Denham, J. Ravenscroft, Effects of pollution on human growth and development: an introduction, J. Physiol. Anthropol. 25 (2006) 103.
[21] Shell Petroleum Development Company (SPDC) 2006. Environmental Impact Assessment (EIA) of Rumuekpe (OML 22) and Etelebou (OML 28) 3D Seismic Survey.
[22] A.M. Taiwo, T.A. Arowolo, K.L. Abdullahi, O.T. Taiwo, Particulate matter pollution in Nigeria: a review, in: Proceedings of the 14th International Conference on Environmental Science and Technology, Rhodes, Greece, 2015 3-5 September 2015.
[23] Uyigue, E. and Agho, M. 2007. Coping with climate change and environmental degradation in the Niger Delta of Southern Nigeria. Community Research and Development Centre Nigeria (CREDC). 30pp.
[24] World Health Organisation (WHO) 2005. The effects of air pollution on children's health and development: a review of the evidence (Online). http://www.euro.who.int/document/E86575.pdf (20/12/17).
[25] World Health Organisation (WHO)Guidelines for Indoor Air Quality: Selected Pollutants, World Health Organization (WHO), 2009 (Online) www.euro.who.int/__data/assets/pdf_file/0009/128169/e94535.pdf (20/10/17).