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Air Quality Survey of some locations in the Niger Delta Area

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ABSTRACT: A survey of air quality in Oyigbo (Obigbo) and environs in the Niger delta area of Nigeria revealed that air quality in the area is affected to varying degrees by industrial, human and natural activities. Results indicate that SOx values were below acceptable values for ambient conditions at most of the locations. The annual average SOx levels ranged between 92.0µg/m^3 and 430µg/m^3 against the DPR limit of 150µg/m^3. A similar trend was observed for NOx emissions whose annual averages ranged between 81.0µg/m^3 and 150µg/m^3. Levels of these atmospheric contaminants were influenced by season. The average acidity values (5.63, 5.57, 5.41 and 5.41) of rainwater collected over the monitored period show rain acidity. The low Conductivity values however indicated non-contamination of the rainwater.

Nigeria has been reported as the number one natural gas flarer on the planet both absolutely and proportionally- about 46 per cent of Africa's total and the most gas flared per tonne of oil produced (Cedigaz, 2000). The report also indicates that Nigeria accounted for 19.79 per cent of the global figure. Orubu, (2002), undertook a comparison of concentrations of ambient air pollutants in the region and Lagos State and concluded that pollutant concentrations are highest in the Niger Delta and argued that some of the green house gases (such as methane and carbon dioxide) emitted at flare sites contribute to global warming This suggested therefore that Nigeria oil fields contribute more to global warming (through flaring of associated gas) than the rest of the world. The largest proportion of these flare sites are located in the Niger Delta. Moreover, gas flare sites around the region generate tremendous heat thereby causing thermal pollution (Orubu, 2002). Ogbuigwe (1998) reported that temperatures produced at flare sites could be as high as 1,600oC. Temperature as high as 400C at an average distance of 43.8m from flare sites in Isoko, Delta State have been recorded by Alakpodia (1989, 1995) who had also shown that such flares have negative effects on vegetation growth, animal life and ecological equilibrium in the Niger Delta area.

The Intergovernmental Panel on Climate Changes (IPCC) cited in Magbagbeola, (2002) noted that as a result of global warming, an associated sea level rise (SLR) will have serious and global consequences for low lying coastal areas and island states. Awosika and Foluronsho, (2006) documented projected impacts of SLR on the Nigerian coastal area and resources and these include: large scale inundation, increased coastal erosion, salt water intrusion into coastal aquifers, habitat modification with direct effects on wild life distribution, increased frequency of high intensity rainfall events and associated increased run off, elevated erosion rates, flash floods and increased frequency of ocean storm surges. The combined effects of all these would jeopardize the survival of coastal communities. Already, annual erosion rates have been estimated at 18-24 meters at Ugborodo, 20-22meters at Forcados, 16-19meters at Brass, 15- 20 meters at Kulama, 20-24 meters at Bonny and 10-14 meters at Opobo River estuary (Ibe et al. 1984). Indeed, while Awosika et al. (1993) project a loss of up to 15,000 km2 by the year 2100 as a result of a 1m SLR, Magbagbeola, (2002) projects flooding of over 18,000km2 land area for the delta in an SLR of 1m per 100 years.

That the effects of gas flares on vegetation and microclimate, surface and ground water through acidification of rain water could be profound have been shown by Oluwole et al (1996) in a comprehensive air quality assessment of the Niger Delta. Results of the assessment show that the levels of concentration of volatile oxides of carbon, nitrogen, sulphur oxide and total particulates exceed existing Federal Environmental Protection Agency's (FEPA, 1991) standards. Olobaniyi and Efe (2007) also show elevated levels of lead (0.56 mg/l) and low pH values ranging from 5.10 – 6.35 in rain water collected in Warri and environs. Akpoborie, et al, (2000) also report low pH values from water obtained from shallow hand dug wells in Ughelli, Warri, and Okurekpo all in Delta State. They state that acidified rain water does not only corrode roofing sheets, monuments and other economic structures but it can

also damage vegetation and contaminate ponds and lakes which are the sources of livelihood to overlying indigenous rural communities in the delta.

Air quality around a location may be impacted by activities such as:
i) Burning of fossil fuel by waste gas flaring from oil production facilities.
ii) Burning of fuel in the operation of high capacity power generators for long periods.
iii) Emissions from vehicles.

Emissions from these sources include sulphur dioxide, oxides of nitrogen, and carbon monoxide in addition to unburnt fossil fuel that may be presented as suspended particulates & soot. The largest single anthropogenic source of sulphur dioxide is the combustion of sulphur-containing fossil fuel. Sulphur Dioxide is emitted directly into the atmosphere and can remain suspended for days allowing for wide distribution of the pollutant. One effect of sulphur dioxide is the formation of acid rain. Sulphur dioxide in the air is hazardous to vegetation. High SOx emission level is due to some extent from automobile emissions.

Nitrogen oxide is formed by the combustion of nitrogen-containing compounds (including fossil fuels) and by thermal fixation of atmospheric nitrogen. Thus all high-temperature processes produce NO_3 which is then oxidized further to NO_2 in the ambient air. At ambient concentration levels, NO_2 is an irritating gas that may constrict the airways of asthmatics. High NOx level is known to be associated with combustion of fuels in stationary sources. CO is a product of the incomplete combustion of carbon-containing compounds. Most of the CO in the ambient air comes from exhaust pipes. Carbon Monoxide is readily absorbed into the body by the lungs. It decreases the capacity of the blood to transport oxygen.

*Smoke and Opacity***:** Visible smoke from a flare is often the only immediate evidence of a pollution violation that is external to a location. Smoke issuing from a flare is indicative of incomplete or poor combustion. DPR's Environmental Guidelines and Standards for the Petroleum Industry in Nigeria stipulates that *"the flare shall show complete combustion at operating gas flow rate the relative density of emitted smoke shall not exceed two Ringlemann Number which is related to 40% of smoke density and 60% of light transmission through smoke, observed over a period of one (1) hour."*

Noise is unwanted or extraneous sound. It is a form of environmental pollution because it may impair human the health of some organisms within the eco-system. Noises around location are mainly from the power generators, the gas compressor engines and the flaring of natural gas. The extent to which a given noise is unacceptable depends on the following factors, pitch, period (time) of day, irregularity, duration, rhythm, unexpectedness, or whether the noise has a meaning for the particular observer. However, there is a statutory level of sound above which harm occurs. Exposure to noise exceeding 85 - 90 dB(A) has been shown to cause hearing loss, which could be temporary and permanent. The FEPA regulation (See table 2) for location Noise Level specified that *"The noise level for unprotected ears shall be well within the threshold of pain (80-100dBA)".*

The site and extent of deposition of particulates in the respiratory tract are function of certain physical factors, the most important of which is particle size. The form and size of airborne non-gaseous pollutants are:

(a) Dust, consisting of solid particles that are **(i)** entrained by process gases **(ii)** entrained materials used in a mechanical operation, are between 0.1 micron and 10mm in diameter.
(b) Fume, that is, solid particles formed by the condensation of vapours by sublimation or chemical reactions are from 0.03 to 0.3µm in diameter.
(c) Mist, liquid particles are formed by the condensation of a vapour and sometimes by chemical reaction
(d) Smoke, which consists of solid particles formed by incomplete combustion of carbonaceous materials are between 0.05µm and approximately 1µm.
(e) Spray, which is liquid particles formed by the atomisation of a parent liquid.

For this study, the Nigerian National ambient air quality standards (Table 1) were used for comparison.

TABLE 1: Nigerian National Air Quality Guidelines for Maximum Exposure

Pollutant	1-Hour Mean ($\mu g/m^3$)	8-Hour Mean ($\mu g/m^3$)	Daily Average/ Mean ($\mu g/m^3$)	Annual ($\mu g/m^3$)
Suspended Particulate Matter (SPM): Black Smoke				40 - 60

Total SPM	150 - 230		60 - 90	
Carbon Monoxide*	30		10	
Sulphur Dioxide*	350		100 - 150	40 - 60
Nitrogen Dioxide*	400		150	-
Lead	0.5 – 1.0			

***Not to be exceeded**

Source: Table III-3, DPR (2002) Environmental Guidelines & Standards for the Petroleum Industry in Nigeria

Table 2: Noise Exposure Limits (FEPA, 1991)

Duration per Day (Hour)	Permissible Limit (dBA)
8	90
6	92
4	95
3	97
2	100
1.5	102
1	105
0.5	110
0.25 or less	115

MATERIALS AND METHODS

Sample Collection and Handling: Sample points (60m, 200m and 500m) from the major emission sources were measured with a GPS Garmin ® GPS 12. Samples were collected, handled and preserved according to the relevant test methods. The general layout of the Oyigbo (Obigbo) location and environs is presented in Fig. 1.

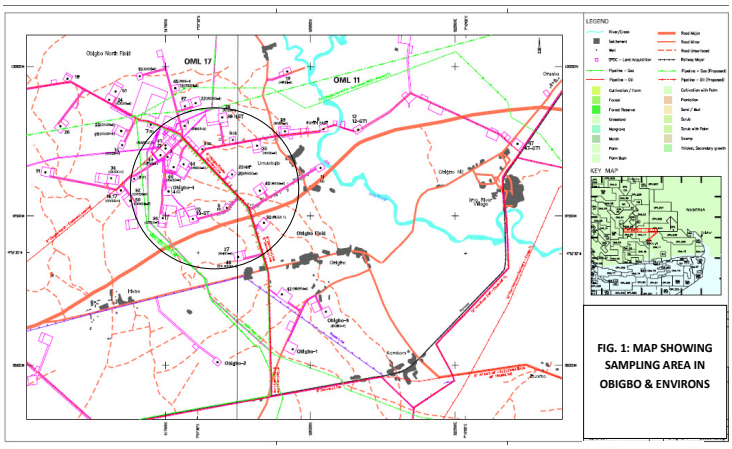

FIG. 1: MAP SHOWING SAMPLING AREA IN OBIGBO & ENVIRONS

Ambient Air Monitoring: When setting ambient air sampling units, procedures described by ASTM (2001) and Harrop (2002) were followed. Monitoring sites are classified into three types: peaks, neighbourhood or background. When selecting a monitoring site, parameters including possible chemicals or physical interference, locality, terrain, services and local activities were considered. Wind speed and wind direction were located with air monitoring instruments.

*Methods for Analysis of Ambient Air Pollutants***:** Methods approved by ASTM for specific parameters were used for each measurement.

Heat Radiation: Heat radiation was measured with a Pyranometer equipped with an automatic logging system. (Skye Data Hog 2). The sensor was focused on the major emission source for ten minutes to record radiation every ten seconds interval. The mean reading taken over the ten minutes exposure time was recorded as the heat radiation value at each station. The values were recorded in W/m^2.

Relative Smoke Density: Relative smoke density at each point was measured using the Ringlemann smoke chart approved by the British Standard Institute (BS2742:1969). This was done by visual

comparison of the density of the smoke at the tip of the flare with the chart's standard shades of grey to black on a scale of 0-4.

Wind Speed and Direction: A combined wind vane and digital Anenometer were used in determining wind direction and speed. The wind speeds were measured in m/s.

Soil Temperature: Soil temperature was determined with a digital soil thermometer (American Society of Agronomy in conjunction with ASTM, 1980).

Noise Levels: Noise levels at each point were measured with a pre-calibrated digital readout noise meter. The sensor of the noise meter was directed towards the source of noise and the average readings over a period of two minutes were taken to be the Noise-level at each point. The noise levels were measured in decibels (dB).

Air Quality: Ozone: Sampling was carried out at each sample point using an air sampler mounted on a platform at a height of 1.5 – 2.0 meters from the ground. Air was drawn at a flow rate regulated by a calibrated critical orifice into a series of glass scrubbers filled with absorbent solutions to absorb specific gases. Sampling was carried out for a period of thirty minutes at each point. The absorbent solutions were then subjected to analysis in the laboratory to determine the concentration of O_3 in air.

Hydrocarbons/Volatile Organic Compounds (CxHy/VOC), Nitrogen Oxides (NOx), Sulphur Oxides (SOx) & Carbon Monoxide (CO): A TESTO 350 flue gas analyser was used. It is instrumental equipment used to perform automatic analysis of ambient air through the use of physical properties, and giving cyclic or continuous output signal. Air is continuously extracted from the atmosphere and a portion of the sample is sent to the analyzer for the determination of the pollutant gas of interest.

Suspended Particulate Matter (SPM): A mini-volume portable air sampler (Airmetric ®) with a pre-weighed membrane filter (47µm) was used to collect particulate matter. After sampling, the membrane filter was dried at 105°C, cooled in a dessicator and weighed to the nearest milligram. The mass concentration was calculated by measuring the mass of particulate matter and dividing by the volume of air.

The volume of Air was determined as follows: Volume of Air (m^3) = flow rate x time of sampling

$$V = q \times t$$

Where q = flow rate in litres per minute; t = time of sampling in minutes; 0.001(the conversion from litres to cubic meters); V (m^3) = 0.0001m^3/l x q l/min x t min

$$\text{Conc. of SPM } (\mu g/m3) = \frac{1000\mu g/mg \times Wn\ (mg)}{Vm3}$$

Where: Wn (mass change of the filter); V (m^3) (volume of air sample); 1000 (conversion from milligrams to micrograms).

Heavy Metals in Air: The samples are collected on quartz membrane filters and treated with nitric acid to destroy the organic matrix and dissolve the metal present. The analysis is subsequently made by flame atomic absorption spectrophotometry (AAS):

$$\text{Metal Concentration. } \mu g/m3 = C\left[\frac{(V1 - B)\ V}{F}\right]$$

Where: C = Concentration of Metal Solution Aspirated, µg/ml; V_1 = Final Volume to which any aliquot of sample is diluted, ml; B = Total metal in the blank, µg; F = Dilution Factor, Volume of Aliquot taken divided by Original Volume of Sample; V (m^3) = Volume of Air Samples.

Similarly, USEPA (1995a) has developed emissions factors in an attempt to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant. These factors are usually expressed as the weight of pollutant divided by a unit weight, volume, distance, or duration of the activity emitting the pollutant (e.g., kilograms of particulate emitted per megagram of coal burned). Such factors facilitate estimation of emissions from various sources of air pollution. In most cases, these factors are simply averages of all available data of acceptable quality, and are generally assumed to be representative of long-term averages for all facilities in the source category (i.e., a population average).

Absolute Pressure and Relative Humidity: A logger (Testo 450) was used for Atmospheric Pressure and Relative Humidity. The logger is equipped with an atmospheric pressure probe (barometer) and relative humidity probe (Hygrometer). The logger measures and stores the values.

RESULTS AND DISCUSSION

Results of parameters monitored are presented in Tables 3 - 15 and Figures 2 & 3**.** *Air Quality***:** SOx values were below acceptable values for ambient conditions at all the facilities except Agbada-2 location. The annual SOx average at Agbada-1 location was 106µg/m^3, 430µg/m^3 at Agbada-2 location; 122µg/m^3 at Oyigbo Location 1 and 92.0µg/m^3 at Oyigbo Location 2, against the DPR limit of 150µg/m^3 for average SOx emissions per annum.

SOx emissions did not comply at Oyigbo Location 1 and Oyigbo Location 2 (December), Agbada-1 location (September), Agbada-2 location (September, October and December) most of the non-compliance were recorded during the dry season.

A similar trend was observed for NOx emissions. The annual NOx average at Agbada-1 location was 90.0µg/m^3; 150µg/m^3 at Agbada-2 location; 81.0µg/m^3 at Oyigbo Location 1 and 83.1µg/m^3 at Oyigbo Location 2. This shows that all the facilities except Agbada-2 location had annual averages that complied with the DPR limit of 150µg/m^3. SOx and NOx had higher concentrations in the dry season compared to those in the rainy season. Concentrations in the dry season normally rose in the evening and remained at elevated concentrations until the early hours of the morning. NOx emissions at Agbada-2 location did not comply in the months of October and November 2007. Most of these non-compliances were recorded during the dry season. Ukpebor and Okolo (2002) had reported annual ranges of 4.10 - 11.48 µgm-3 NO2 and of 2.72 - 3.78µgm-3 O in a proposed Associated Gas Gathering project location. Temporal and spatial variations were observed in the obtained results.

Table 3: AVERAGE VALUES OF GASEOUS EMISSIONS CHARACTERISTICS AT OYIGBO LOCATION 1

Parameter	Mean Monthly Values								ANNUAL MEAN VALUES				
									Windward Direction		Leeward	Average	DPR Limits
	May	**June**	**July**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**	**60m**	**500m**	**100m**		
Soil Temp.(°C)	30.5	27.3	26.3	27.6	27.8	29.0	28.6	27.3	28.2	27.9	28.1	28.1	-
Noise Level (dBA)	65.8	65.3	64.8	70.8	67.1	66.9	67.2	71.8	64.5	66.4	71.4	67.4	80 -100
Smoke Density (Ringlemann)	0	0	0	1	0	0	1	0	0	0	0	0	2
Heat Radiation (W/m^2)	202	195	161	148	149	151	161	166	183	154	163	167	6310
SOx, (µg/m^3)	51.1	47.1	139	107	127	126	123	256	95.4	164	107	122	100-150
NOx, (µg/m^3)	49.0	48.4	74.8	95.2	115	113	116	37.2	81.9	76.3	84.8	81.0	150
Particulate Matter, (µg/m^3)	74.0	76.1	101	99.1	103	119	111	108	106	90.1	101	98.9	150 -230
Carbon Monoxide (µg/m^3)	0.46	0.29	0.45	0.60	0.15	0.21	0.19	0.87	0.33	0.53	0.35	0.40	10

Table 4: AVERAGE VALUES OF GASEOUS EMISSIONS CHARACTERISTICS AT OYIGBO LOCATION 2

Parameter	Mean Monthly Values								ANNUAL MEAN VALUES				
									Windward Direction		Leeward	Average	DPR Limits
	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	60m	500m	100m		
Soil Temp.(°C)	30.4	27.7	27.9	28.3	27.4	28.5	27.9	27.9	No Access	28.2	28.3	28.3	-
Noise Level (dBA)	56.9	57.2	56.3	63.1	60.8	51.6	56.1	55.1		57.0	57.2	57.1	80 -100
Smoke Density (Ringlemann)	0	0	0	0	0	0	1	0		0	0	0	2
Heat Radiation (W/m^2)	131	141	134	161	129	120	130	144		139	139	139	6310
SOx, (µg/m^3)	54.2	49.1	53.4	79.9	116	103	110	166		68.5	116	92.0	100-150
NOx, (µg/m^3)	60.7	53.3	64.0	110	117	115	116	29.2		76.6	89.5	83.1	150
Particulate Matter, (µg/m^3)	132	136	95.3	106	112	109	118	112		103	127	115	150 -230
Carbon Monoxide (µg/m^3)	0.62	0.42	0.49	0.59	0.25	0.19	0.19	0.36		0.39	0.38	0.39	10

Table 5: AVERAGE VALUES OF GASEOUS EMISSIONS CHARACTERISTICS AT AGBADA LOCATION 1

Parameter	**Mean Monthly Values**								**ANNUAL MEAN VALUES**				
									Windward Direction			**Leeward**	**DPR Limits**
	May	**June**	**July**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**	**60m**	**500m**	**100m**	**Average**	
Soil Temp.(°C)	27.9	28.7	28.6	28.0	27.0	28.7	29.2	27.5	28.4	28.0	28.1	28.2	
Noise Level (dBA)	69.3	71.7	67.9	71.5	72.1	69.5	73.8	73.6	68.9	70.0	74.3	71.1	80 -100
Smoke Density (Ringlemann)	0	1	1	1	1	1	1	1	1	1	1	1	2
Heat Radiation (W/m^2)	108	179	205	216	229	212	225	231	226	193	191	203	6310
SOx, (µg/m^3)	32.9	36.1	106	215	128	111	134	43.8	100	79.9	138	106	100-150
NOx, (µg/m^3)	38.1	38.6	90.6	134	113	111	126	37.0	96.6	72.6	101	90.0	150
Particulate Matter, (µg/m^3)	102	96.0	135	139	138	142	130	128	137	124	126	129	150 -230
Carbon Monoxide (µg/m^3)	0.20	0.43	0.96	0.91	0.37	0.50	0.18	1.41	0.66	0.81	0.43	0.63	10

Table 6: AVERAGE VALUES OF GASEOUS EMISSIONS CHARACTERISTICS AT AGBADA LOCATION 2

Parameter	Mean Monthly Values								ANNUAL MEAN VALUES				DPR Limits
									Windward Direction			Leeward	
	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	60m	500m	100m	Average	
Soil Temp.(°C)	23.1	28.5	27.6	28.3	28.3	29.1	29.0	27.5	27.7	27.5	27.6	27.6	-
Noise Level (dBA)	51.7	72.3	67.5	68.2	69.5	69.1	74.0	69.4	65.5	65.9	70.5	67.3	80 -100
Smoke Density (Ringlemann)	0	1	1	0	1	1	1	0	0	0	0	0	2
Heat Radiation (W/m^2)	171	174	173	168	163	163	220	176	200	156	174	177	6310
SOx, ($\mu g/m^3$)	69.7	69.8	467	194	780	910	148	530	641	316	333	430	100-150
NOx, ($\mu g/m^3$)	54.7	52.8	94.1	187	185	347	152	79.3	214	114	135	154	150
Particulate Matter, ($\mu g/m^3$)	101	107	96.2	109	109	116	112	108	120	97.9	107	108	150 -230
Carbon Monoxide ($\mu g/m^3$)	0.64	0.29	0.90	0.68	0.23	0.25	0.16	0.69	0.54	0.64	0.32	0.50	10

Table 7: ANNUAL pH MEAN VALUES OF RAINWATER CHARACTERISTICS OF ALL THE LOCATIONS MONITORED

Facilities	Windward Direction		Leeward	Average	DPR Limit
	60m	500m	100m		
Oyigbo Location 1	5.64	5.57	5.68	5.63	5.60
Oyigbo Location 2	No Access	5.42	5.71	5.57	"
Agbada Location 1	5.41	5.35	5.47	5.41	"
Agbada Location 2	5.45	5.48	5.30	5.41	"

Table 8: ANNUAL MEAN VALUES OF HEAVY METALS IN AIR CONCENTRATIONS ($\mu g/m^3$) AT OYIGBO LOCATION 1

$\mu g/m^3$	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Average
Mn	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	**<50.0**
Cr	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	**<50.0**
Pb	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	**<10.0**
V	<10.0	<10.0	<10.0	<0.10	<0.10	<0.10	<10.0	<10.0	**<10.0**
Ni	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	**<50.0**
Zn	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	**<50.0**

Noise: All Noise Level measurements made during the year were below the DPR regulatory level of 80-100dB in all the stations monitored. The Noise Level recorded 100% compliance at all the locations.

Relative Smoke Density: The smoke density measures for the flare showed 100% compliance and were below the DPR Regulatory level of two (2) Ringlemann. However, smokeless emissions have been reported not to have any effect on sulphur dioxide emissions (Ashby and Anderson, 1981)

Heat Radiation: There was 100% compliance with the DPR limit for Heat Radiation in the past one year. The highest heat radiation levels monitored at the different locations during the period were far below the DPR limit. The annual Heat Radiation values ranged from $139W/m^2$ at Oyigbo Location 2 to $203W/m^2$ at Agbada-1 location.

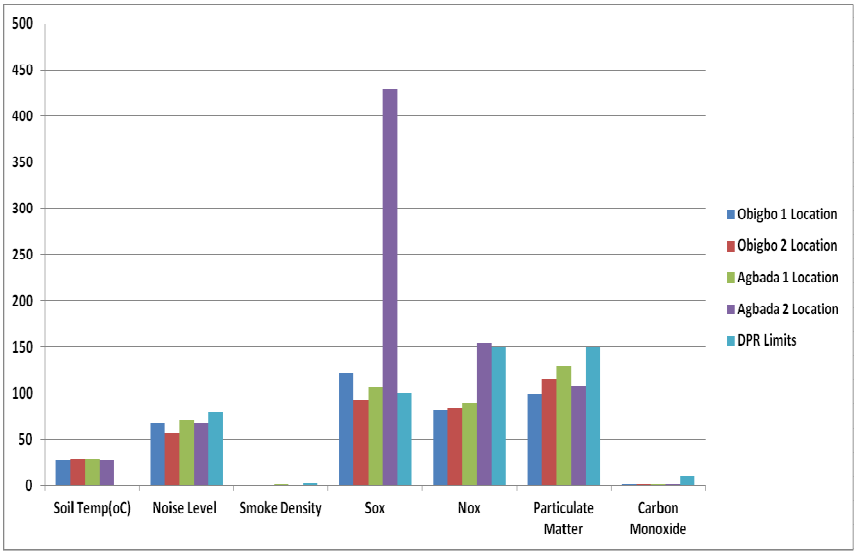

Fig. 2: annual average values of selected parameters vs dpr limits in all the monitored locations

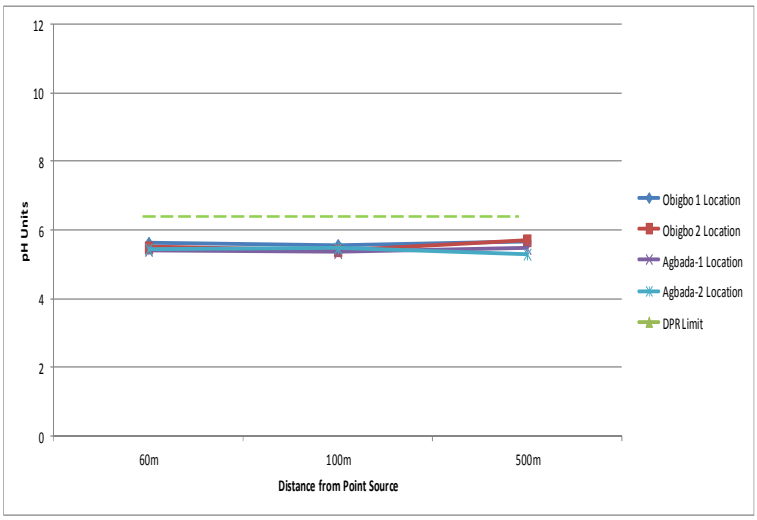

Fig. 3: Annual average pH values of Rainwater collected during the period of monitoring

Table 9: ANNUAL MEAN VALUES OF HEAVY METALS IN AIR CONCENTRATIONS (µg/m^3) AT OYIGBO LOCATION 2

µg/m^3	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Averages
Mn	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0
Cr	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0
Pb	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0
V	<10.0	<10.0	<10.0	<0.10	<0.10	<0.10	<10.0	<10.0	<10.0
Ni	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0
Zn	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0

Table 10: ANNUAL MEAN VALUES OF HEAVY METALS IN AIR CONCENTRATIONS (µg/m^3) AT AGBADA LOCATION 1

µg/m^3	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Averages
Mn	<50.0	<50.0	<50.0	<50.0	<50.0	51.0	<50.0	<50.0	51.0
Cr	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0
Pb	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	10.0	10.0
V	<10.0	<10.0	<10.0	<0.10	<0.10	<0.10	<10.0	<10.0	<10.0
Ni	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0
Zn	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0

Table 11: ANNUAL MEAN VALUES OF HEAVY METALS IN AIR CONCENTRATIONS (µg/m^3) AT AGBADA LOCATION 2

µg/m^3	May	June	July	August	Sept.	Oct.	Nov.	Dec.	Averages
Mn	<50.0	<50.0	<50.0	<50.0	51.0	51.0	<50.0	<50.0	51.0
Cr	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0
Pb	<10.0	<10.0	<10.0	<10.0	10.9	10.0	<10.0	11.0	10.0
V	<10.0	<10.0	<10.0	<0.10	<0.10	<0.10	<10.0	<10.0	<10.0
Ni	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0
Zn	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0

Soil Temperature: The effect of the flare on Soil Temperature is limited to a radius of 60m from the flare, which is usually within the bund wall. Beyond this point, the Soil Temperature is similar to ambient conditions. The annual Soil Temperature mean values range from 27.6^{o}C in Agbada-2 location to 28.3^{o}C in Oyigbo Location 2.

Suspended Particulate Matter: All facilities recorded annual values within the DPR limit of 230µg/m^3. The highest annual average SPM value of 129µg/m^3 was recorded at Agbada-1 location. The trend for Suspended Particulate Matter varies with the season. Slinn (1992) had reported on estimates for the Long Range Transport of Air Pollutants.

Rain Acidity: The average values of rainwater collected over the monitored period show rain acidity. The low Conductivity values show non-contamination of the rainwater. The average annual

Rainwater values were 5.63, 5.57, 5.41 and 5.41 at Oyigbo Location 1, Oyigbo Location 2, Agbada-1 and Agbada-2 locations respectively. Values below 5.60 indicate Rainwater acidity. Bormann & Likens, (1974) and Umukoro (1996) had previously reported acid rain as a serious regional environmental problem.

Table 12: MONTHLY AVERAGE VALUES OF HEAVY METALS IN AIR CONCENTRATIONS (µg/m^3) AT OYIGBO LOCATION 1

	May			June			July			August		
µg/m^3	WW Direction		Leeward	WW Direction		Leeward	WW Direction		Leeward	WW Direction		Leeward
	60m	500m	100m	60m	500m	100m	60m	500m	100m	60m	500m	100m
Mn	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0
Cr	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0
Pb	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0
V	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Ni	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0
Zinc (Zn)	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0

	September			October			November			December		
(µg/m^3)	WW Direction		Leeward	WW Direction		Leeward	WW Direction		Leeward	WW Direction		Leeward
	60m	500m	100m	60m	500m	100m	60m	500m	100m	60m	500m	100m
Mn	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0
Cr	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0
Pb	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0
V	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Ni	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0
Zn	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0

Table 13: MONTHLY AVERAGE VALUES OF HEAVY METALS IN AIR CONCENTRATIONS (µg/m^3) AT OYIGBO LOCATION 2

	May			June			July			August		
µg/m^3	WW Direction		Leeward	WW Direction		Leeward	WW Direction		Leeward	WW Direction		Leeward
	60m	500m	100m	60m	500m	100m	60m	500m	100m	60m	500m	100m
Mn	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0
Cr	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0
Pb	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0
V	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Ni	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0
Zn	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0

	September			October			November			December		
µg/m^3	WW Direction		Leeward	WW Direction		Leeward	WW Direction		Leeward	WW Direction		Leeward
	60m	500m	100m	60m	500m	100m	60m	500m	100m	60m	500m	100m
Mn	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0
Cr	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0
Pb	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0
V	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Ni	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0
Zn	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0

Table 14: MONTHLY AVERAGE VALUES OF HEAVY METALS IN AIR CONCENTRATIONS (µg/m^3) AT AGBADA LOCATION 1

	May			June			July			August		
µg/m^3	WW Direction		Leeward	WW Direction		Leeward	WW Direction		Leeward	WW Direction		Leeward
	60m	500m	100m	60m	500m	100m	60m	500m	100m	60m	500m	100m
Mn	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0
Cr	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0
Pb	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0
V	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Ni	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0
Zn	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0

	September			October			November			December		
(µg/m^3)	WW Direction		Leeward	WW Direction		Leeward	WW Direction		Leeward	WW Direction		Leeward
	60m	500m	100m	60m	500m	100m	60m	500m	100m	60m	500m	100m
Mn	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0
Cr	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0
Pb	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	11.0	<10.0	<10.0
V	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Ni	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0

Zn	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0

Table 15: MONTHLY AVERAGE VALUES OF HEAVY METALS IN AIR CONCENTRATIONS (µg/m^3) AT AGBADA LOCATION 2

	May			June			July			August		
µg/m^3	WW Direction		Leeward	WW Direction		Leeward	WW Direction		Leeward	WW Direction		Leeward
	60m	500m	100m	60m	500m	100m	60m	500m	100m	60m	500m	100m
Mn	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0
Cr	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0
Pb	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0
V	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Ni	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0
Zn	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0

	September			October			November			December		
µg/m^3	WW Direction		Leeward	WW Direction		Leeward	WW Direction		Leeward	WW Direction		Leeward
	60m	500m	100m	60m	500m	100m	60m	500m	100m	60m	500m	100m
Mn	<50.0	<50.0	<50.0	51.0	<50.0	<50.0	<50.0	<50.0	<50.0	51.0	<50.0	<50.0
Cr	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0
Pb	<10.0	<10.0	<10.0	10.0	<10.0	<10.0	<10.0	<10.0	<10.0	11.0	<10.0	<10.0
V	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Ni	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0
Zn	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0

Heavy Metals in Air: Agbada-2 location had lead concentrations within the facilities with an average value of 10.0µg/m^3. This did not exceed the DPR limit of 10.0µg/m^3.

Substantial color changes have been recorded for several compounds exposed to photochemical oxidants (O_3, NO_2, PAN) both singly and as a mixture. Increasing the humidity from 46 to 83% resulted in a large increase in color change for several colorants exposed to the mixture of oxidants (Grosjean et al, 1994). Plants have also been reported to be affected by air pollutants (Thomas, 1961).

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