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Original Research Article

Impacts of gas flaring on ambient air Quality of Obrikom community, Rivers state Nigeria

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ABSTRACT

This research investigated the contributions of pollutants in ambient air by the Obrikom Flow station in Ogba/Egbema/Ndoni Local Government Area of Rivers State. Four sampling points spaced 100m apart in the prevailing wind direction and a control sited 5km in the upwind direction from the gas flare stack were established. The high volume sampler and digital automatic gas monitors were used to monitor air quality parameters *in situ* in the field and the atomic absorption spectrophotometer was used to analyze heavy metals in the laboratory. The descriptive statistics, one-way ANOVA and Principal Components Analysis (PCA) were used to analyze data. CO, SOx, NOx, suspended particulate matter (SPM), volatile organic compounds (VOC), H_2S and O_3 varied as follows: 1.20-3.60 (2.43 ± 0.15), 0.00-0.04 (0.02 ± 0.003), 0.00-0.03 (0.012 ± 0.002), 70.00-95.00 (81.71 ±1.68), 0.00-0.03 (0.017 ± 0.002), 0.001-0.004 (0.002 ± 0.0002) and 0.01-0.02 (0.013 ± 0.001), while As, Pb, Cu, Ni, Co Zn, Fe, Cd and Mn varied from 1.20-2.50 (1.98 ± 0.08), 0.01-0.90 (0.44 ± 0.08), 0.00-0.03 (0.01 ± 0.002), 60.00-88.00 (73.86 ± 1.55), 0.10-0.40 (0.28 ± 0.022), 0.001-0.003 (0.002 ± 0.0002), 0.01-0.80 (0.35 ± 0.06), 0.00-0.40 (0.18 ± 0.03) and 0.00-0.02 (0.007 ± 0.0015) ppm respectively. There was significant spatial inequality in mean levels of the parameters measured at $P<0.05$ (Sig.F=0.000) and SPM contributed the difference. Four PCs which were most highly correlated with Pb (0.890), Ni (0.891), SOx (0.870) and O_3 (0.948) formed the extraction solution that explained about 85.02% variability in the original 19 variables. Though the levels of the air-borne pollutants were not significantly elevated above natural ambient levels, observed slight elevations were obviously contributed by the gas flare stack in the neighborhood of the sampling points.

Keywords

Ambient air, pollutants, Obrikom Flow station, suspended particulate matter

Introduction

Crude oil is a complex mixture of mainly hydrocarbons with varying physical,

estimated that about 40% of the worlds present energy supply comes from crude oil which is a mixture of many thousands of organic compounds of which more than three-quarters are hydrocarbon (Tokolo, 1988; Whittle *et al*., 1988). According to Don-Pedro (2009), Nigeria produces over 2.3million barrels of oil per day from its oil fields in the Niger Delta alone and most of this oil comes from deposits containing associated natural gas. About 2 billion standard cubic feet of this associated gas is produced everyday and sadly enough, most of it is flared due to inadequacy in facilities for its utilization. Worse still, successive governments and regulators have since ignored the environmental impact of gas flaring, but rather continued the prolongation of flaring phase-out dates since 2008. With increasing production of crude oil since its discovery in Oloibiri, Bayelsa State in 1956, gas flaring activities have also been on the increase.

Oghenejoboh (2005) states that gas flaring are major contributor to the emission of toxic gases and other pollutants. Like the combustion of other carbonaceous fuels, gas flaring produces oxides of carbon (CO_X), sulphur (SOx) and nitrogen (NOx), water vapour, volatile and non-volatile forms of trace metals (e.g. Pb, Hg, Cd, As, etc). Ogwejifor (2000) observes that incomplete combustion of the flared gas also produces greenhouse gases (such as methane), other gaseous pollutants (such as CO), and organic elemental participates (such as coke). Additionally, gas flaring generates heat around flare stacks, a phenomenon that could induce insomnia, especially in the night (since the area is permanently bright red like day light) (Don-Pedro, 2009). Ebuna (1987) observed that flares are also associated with high sound intensity, while Agbo (1997) observed that particulate outfalls from flares contain polynuclear aromatic hydrocarbons (PAHs), acids and trace metals, which could cause lung cancer, cardiovascular and respiratory tract diseases. According to Mbaneme (2012) BTEX is an acronym that stands for benzene, toluene, ethylene and xylene which is also interchangeably used to identify the mononuclear aromatic hydrocarbons (MAHs). These compounds are some of the volatile organic compounds found in petroleum as well as petroleum derivatives such as gasoline. BTEX compounds are emitted during various oil and gas operations, including flaring, venting, as well as dehydration of natural gas. Excessive load of oxidisable substance may occasionally consist of chemically oxidisable inorganic compound but one are more usually encountered in form of organic maters which when discharge in river undergo by chemical in the present of bacteria (Okoli, 2007).

Materials and Method

Obrikom is located at the south-eastern, tropical sub region of River State Nigeria (Fig. 1), between latitudes 4° and 8° N and longitudes 6°and 9° E (Fig. 2). The area lies within the tropical rainforest belt of Nigeria, with abundant rainfall, varying landform, thick natural vegetation and abundant mineral resources. The thick natural vegetation has been depleted as a result of population growth, persistent farming and rapid social economic development including mineral exploitation and this has predisposed the area to high level of natural and man-made environmental hazards such as soil erosion, flooding and oil pollution (Odu, 2002).

The climate of the area is typical of rainforest zone of the tropics and average rainfall is about 200mm. Mean ambient temperature is 28^0C while relative humidity is about 88% (SPDC, 2002). Wet season usually lasts between March and November while the dry season lasts for remaining four months (December-February). The soil is characterized by sandy-loam (SPDC, 2002).

Figure.1 Map of Nigeria showing Rivers State

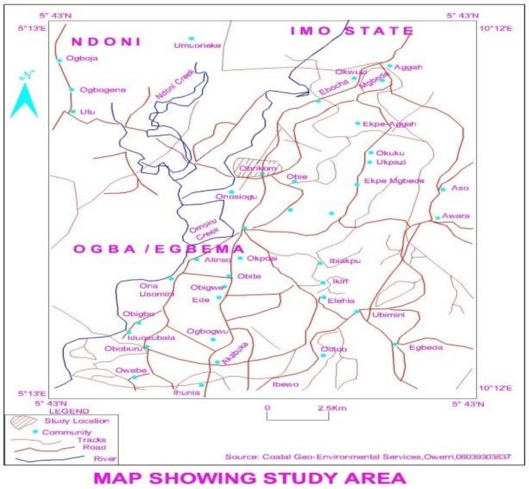

Fig.2 Map of Ogba/Egbema/Ndoni Local Government Area showing Obrikom, the study area

The study area houses an oil flow/gas station operated by the Nigerian Agip Oil Company Limited (NAOC). The flow station has gas flare stacks (Plate 1) whose outfalls diffuse across the vast farmlands within and outside its vicinity. Residents of the area are predominantly agrarian and grow crops like yam, cassava, cereals and vegetables. Comparatively minor fraction of the inhabitants is artisans, while few others are civil servants. Four sampling locations sited at 100m intervals in the prevailing wind direction and a control location sited about 5km in the upwind direction from the gas plant were established (Fig. 2). The two sampling equipment used are the High Volume Sampler (HVS) The modified EPA gravimetric high volume method was applied; involving the drawing of a known volume of air through a pre-weighted glass fibre filter (20 X 25cm) by means of heavy duty turbine blower at flow rate of 1.3 m^3/min (Lahmann, 1992). This collected suspended particulate matter (including suspended heavy metals) within the size range of 100-0.1µm diameters. Sampling was made at the five sampling locations for four months (August, October and December, 2012 and February, 2013). And Digital Automatic Gas Monitors (DAGMs). The Crowcon Gasman Air Monitor that had been pre-calibrated using air cylinder standard (SPDC, 2002) was used in the direct detection of CO, SOx, NOx, VOC, H_2S and O_3 while the Haze dust 10 µm Particulate Monitor was used for the detection of particulate matter (SPM_{10}).

Heavy metal particles collected with glass fibre filters of the HVS were extracted with concentrated H_2SO_4. The concentrations of As, Pb, Cu, Ni, Co, Zn, Hg, Fe, Cd and Mn in air samples were determined with the Varian Spectra AA 600 model atomic absorption spectrophotometer.

Plate.1 Two gas flare stacks in the Obrikom gas plant

Hand-held Testrel 4500 weather Tracker, a high precision in-situ weather monitoring equipment was used in the determination of the following meteorological data: wind speed, ambient temperature, pressure, sun radiation, wind direction, relative humidity and precipitation. The experiment was carried out at the five sampling points and the readings were read off the Liquid Crystal Display (LCD) screen of the equipment at each given time.

Univariate and multivariate analyses as provided by the SPSS© and MS Excel 2007 statistical software were used to analyze data. Descriptive statistics and graphical illustrations were used to present data. The test of homogeneity in mean variance of ambient air quality parameters was conducted with the one-way analysis of variance (ANOVA). The Principal Components Analysis (PCA) method of extraction for data reduction was used to remove highly correlated or redundant variables from the data file and replacing the entire data file with a smaller number of uncorrelated variables called factors. Factor rotation for the transformation of extracted factors to a new position for interpretation was achieved with the varimax method and the magnitude of the eigenvalues and 75% (0.75) rule for variance contribution were used for factor selection (Manly, 1986).

Discussion of the Results

The levels of the ambient air quality parameters, including heavy metals and meteorological variables measured around the Obrikom gas plant are shown in Appendixes 1, 2 and 3 respectively. Comparatively wide variations were observed in the levels of suspended particulate matter (SPM) (range=25.00ppm), Ni ions (range=28.00ppm), air pressure (range=300.00psi) and relative humidity (RH) (range=20.00%).

The levels of CO, SOx, NOx and SPM varied from 1.20-3.60 (2.43 ± 0.15), 0.00-0.04 (0.02 ± 0.003), 0.00-0.03 (0.012 ± 0.002) and 70.00-95.00 (81.71 ±1.68) ppm respectively (Table 1). Volatile organic compounds (VOC), H_2S andO_3 varied as follows: 0.00-0.03 (0.017 ± 0.002), 0.001-0.004 (0.002 ± 0.0002) and 0.01-0.02 (0.013 ± 0.001) ppm respectively. As, Pb, Cu, Ni and Covaried from 1.20-2.50 (1.98 ± 0.08), 0.01-0.90 (0.44 ± 0.08), 0.00-0.03 (0.01 ± 0.002), 60.00-88.00 (73.86 ± 1.55) and 0.10-0.40 (0.28 ± 0.022)ppm respectively. The levels of Zn, Fe, Cd and Mn varied as follows0.001-0.003 (0.002 ± 0.0002), 0.01-0.80 (0.35 ± 0.06), 0.00-0.40 (0.18 ± 0.03) and 0.00-0.02 (0.007 ± 0.0015) ppm respectively. However, the levels of the quality parameters were below the DPR listed maximum limits for safe environment. Hg was undetected at the sampling points during the study period. Spatial variations were observed in the levels of the ambient air quality parameters measured around the Obrikom oil flow station. Mean minimum levels of SOx (0.01ppm), NOx (0.00ppm), VOC (0.00ppm) and ozone (0.01ppm) were recorded in sampling points (SP) 4 & Control, SPs2 & Control, SPs 4 & Control and SPs 3 & Control respectively (Fig. 2). And, their respective mean maximum levels (0.03, 0.01, 0.03 and 0.02ppm) were recorded in SP 1, SPs 1, 3 & 4, SP 1 and SPs 1, 2 & 4. Mean minimum level of CO (1.50ppm), SPM (70.00ppm) and H_2S (0.001ppm) were recorded in SP Control, SP Control and SPs 3 & Control, while their maximum levels of 3.00, 85.00 and 0.003ppm were all recorded in SP 1 Mean levels of the heavy metals- Fe, Co, Pb and As (0.01, 0.20, 0.02 and 1.30ppm) were recorded in SP Control, SPs 4 & Control, SPs 4 & Control and SP Control respectively. However, their mean maximum levels (0.70, 0.40, 0.80 and 2.20ppm) were recorded in SP 2, SP 3, SP 3 and SP 1 respectively (Fig. 3). Mean minimum levels of Zn (0.001ppm), Mn (0.00ppm), Cd (0.00ppm) and Cu (0.00ppm) were recorded in SPs 2, 4 & Control, SPs 1, 3 & Control, SP Control and SPs 2 & Control, while their maximum levels (0.003, 0.01, 0.30 and 0.01ppm) were recorded in SP 1, SPs 2 & 4, SP 1 and SPs 1, 3 & 4 respectively (Fig. 4). However, mean minimum and maximum levels of Ni (65.00 and 80.00ppm) were recorded in SP Control and SP 4 respectively.

The least mean wind speed (0.2m/s), ambient temperature (27.5°C), air pressure (1002psi) and relative humidity (70%) were recorded in SPs 3 & 4, SP Control, SP Control and SPs 3 & Control, while their maximum levels (0.3m/s, 29.1°C, 1130psi and 74% were recorded in SPs 1, 2 & Control, SPs 1 & 2, SP 3 and SP 1 respectively.

The one way analysis of variance (ANOVA) test of homogeneity in mean levels of the ambient air quality parameters across the sampling points revealed significant heterogeneity (Sig. F=0.000) at P<0.05 (Appendixes 4). The post-hoc structure of group means that utilized SP Control as predictor variable revealed that at all the sampling points; suspended particulate matter (SPM) contributed the observed difference (Figs. 5-.7).

The ambient air quality parameters which were subjected to the PCA procedure revealed communalities that were all high; indicating that the extracted components represented the variables well (Appendix 5). The first 4 PCs formed the extraction solution; with a cumulative percent variability of about 85.02% in the original 19 variables (Table 2).This reduces the complexity of the data set by using these components, with only about 14.98% loss of information.

The rotation maintained the cumulative percentage of variation explained by the extracted components (Table 3). The scree plot (Fig.8) represents the eigenvalue of each component in the initial solution. The extracted components are on the steep slope, while the components on the shallow slope contributed little (14.98%) to the solution. The last big drop occurred between the 4th and 5th components.

The first component was most highly correlated with Pb contents (0.890) and also had high loadings for SPM (0.604), VOC (0.605), As (0.555), Co (0.869), Zn (0.640), Cd (0.824), ambient temperature (0.745) and air pressure (0.726) (Appendix 5). The 2nd PC was most highly correlated with Ni ions (0.891) and also had high loadings for CO (0.759), NOx (0.615), H_2S (0.791), As (0.664), Cu (0.870) and Mn (0.836), the 3rd PC which was most highly correlated with SOx (0.870) also had high loadings for Zn (0.582), Fe (0.578), wind speed (0.817) and negative loading for air pressure (-0.521). However, the 4th PC had high loadings for ozone (0.948) (Appendix 5).

The scatter plot matrix revealed that the extracted components had skewed distribution between the Factors (Fig. 9); a distribution pattern that is confirmed by the component plot in rotated space of the parameters (Fig. 10). The component plot revealed that Ni, Cu, As, Fe, SPM, Cd, ambient temperature, air pressure, VOC, Pb, Co, Zn and O_3 were more closely associated on one side, and H_2S, SOx and wind speed on the other side.

Conclusion and recommendations

The levels of the pollutant gases and airborne trace metals were not significantly elevated above natural ambient levels. This slight elevation was contributed by the gas flare stack in the neighborhood of the sampling points.

There was observed significant spatial variation in levels of the suspended particulate matter in ambient air due to dispersal of aerial materials from point sources of pollution. Sampling points 1 and 2, the closest to the oil and gas flow station had the highest concentrations of the pollutants, while the control location in the upwind direction had the least concentrations of the pollutants.

Four PCs were extracted and accounted for 85.02% variability in the 19 parameters measured. They were most highly correlated with the levels of the heavy metals (Pb and Ni) and SOx and ozone. The extracted components had skewed distribution pattern in space due mainly to seasonal variations in the study area.

Table.1 Descriptive statistics of ambient air quality parameters around the Obrikom Oil Flow Station

Parameters	Minimum	Maximum	Range	Mean	SE	DPR
CO (ppm)	**1.20**	**3.60**	**2.40**	**2.43**	**0.15**	**10.00**
SOx (ppm)	**0.00**	**0.04**	**0.04**	**0.018**	**0.003**	**0.1**
NO_x(ppm)	**0.000**	**0.03**	**0.03**	**0.012**	**0.002**	**0.06**
SPM (ppm)	**70.00**	**95.00**	**25.00**	**81.71**	**1.68**	**250**
VOC (ppm)	**0.00**	**0.03**	**0.03**	**0.02**	**0.002**	**NA**
H_2S (ppm)	**0.001**	**0.004**	**0.003**	**0.002**	**0.0002**	**0.008**
O_3(ppm)	**0.01**	**0.02**	**0.01**	**0.013**	**0.001**	**0.1**
As (ppm)	**1.20**	**2.50**	**1.30**	**1.98**	**0.08**	**-**
Pb (ppm)	**0.01**	**0.90**	**0.89**	**0.44**	**0.08**	**-**
Cu (ppm)	**0.00**	**0.03**	**0.03**	**0.01**	**0.002**	**-**
Ni (ppm)	**60.00**	**88.00**	**28.00**	**73.86**	**1.55**	**-**
Co (ppm)	**0.10**	**0.40**	**0.30**	**0.28**	**0.023**	**-**
Zn (ppm)	**0.001**	**0.003**	**0.002**	**0.002**	**0.0002**	**-**
Fe (ppm)	**0.01**	**0.80**	**0.79**	**0.35**	**0.055**	**-**
Cd (ppm)	**0.00**	**0.40**	**0.40**	**0.18**	**0.03**	**-**
Mn (ppm)	**0.00**	**0.02**	**0.02**	**0.007**	**0.002**	**-**
Wind speed (m/s)	**0.10**	**0.40**	**0.30**	**0.25**	**0.02**	**-**
Temperature (°C)	**27.00**	**29.10**	**2.10**	**28.24**	**0.15**	**-**
Pressure (psi)	**1000.00**	**1300.00**	**300.00**	**1075.70**	**18.53**	**-**
RH (%)	**70.00**	**90.00**	**20.00**	**77.85**	**1.45**	**-**

SE = standard error of means, SPM = suspended particulate matter, NS = not specified

Table.2 Extraction Sums of Squared Loadings of ambient air quality parameters

Components	Total	% of Variance	Cumulative %
1	**9.922**	**52.220**	**52.220**
2	**3.008**	**15.830**	**68.049**
3	**1.817**	**9.564**	**77.613**
4	**1.407**	**7.404**	**85.017**

Table.3 Rotation Sums of Squared Loadings of ambient air quality parameters

Components	Total	% of Variance	Cumulative %
1	**5.476**	**28.822**	**28.822**
2	**5.452**	**28.697**	**57.519**
3	**3.407**	**17.930**	**75.449**
4	**1.818**	**9.567**	**85.017**

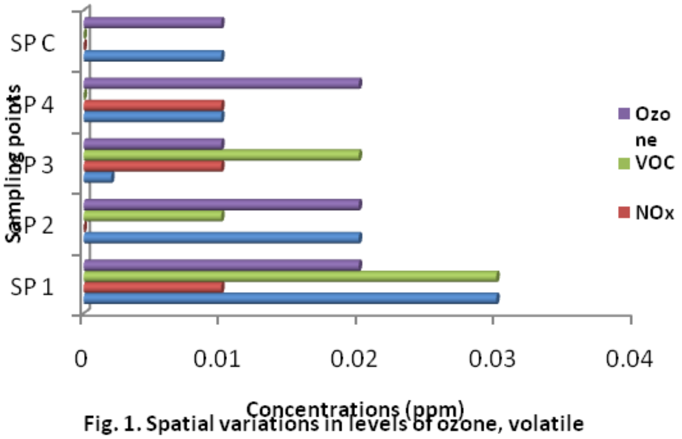

Fig. 1. Spatial variations in levels of ozone, volatile organic compounds and oxides of nitrogen and sulphur in ambient air around the Obrikom gas station

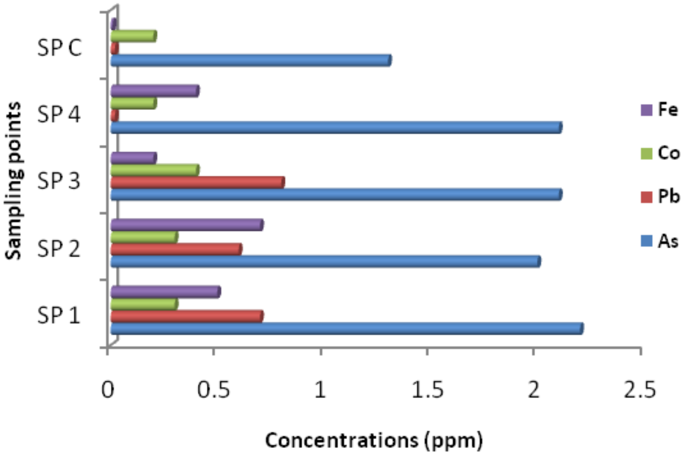

Fig. 2. Spatial variations in mean levels of Fe, Co, Pb and As in ambient air around the Obrikom gas station

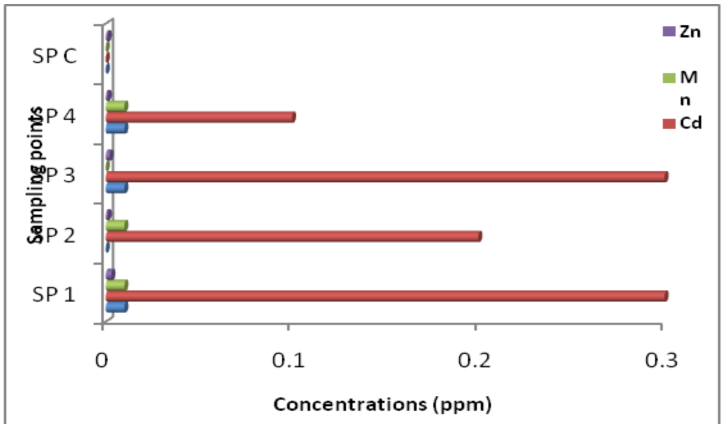

Fig. 3. Spatial variations in mean levels of Zn, Mn, Cd and Cu in ambient air around the Obrikom gas station

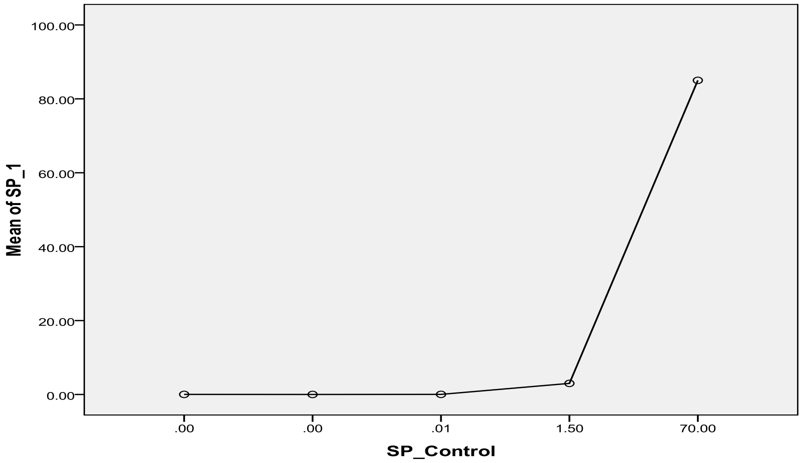

Fig.4 Means plot in ambient air quality parameters between the control and sampling point 1

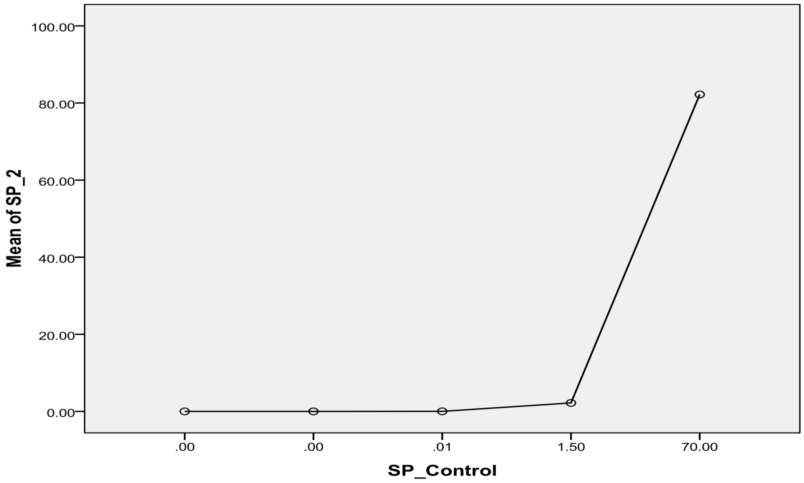

Fig.5 Means plot in ambient air quality parameters between the control and sampling point 2

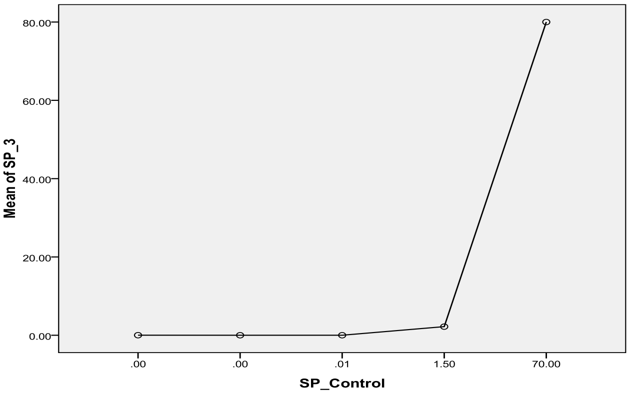

Fig.6 Means plot in ambient air quality parameters between the control and sampling point 3

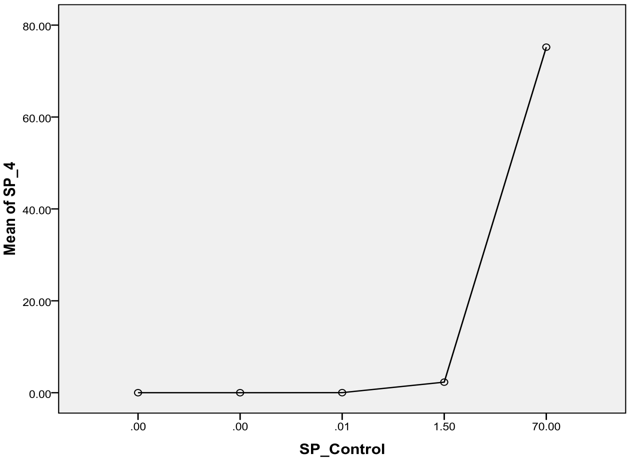

Fig.7 Means plot in ambient air quality parameters between the control and sampling point 4

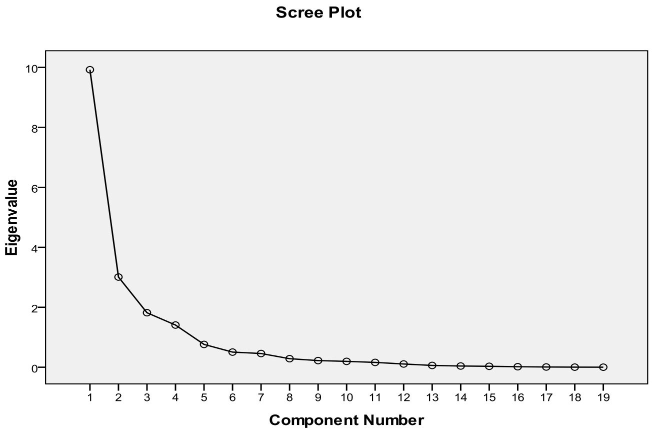

Fig.8 Screen plot of the eigen values of components in the initial solution

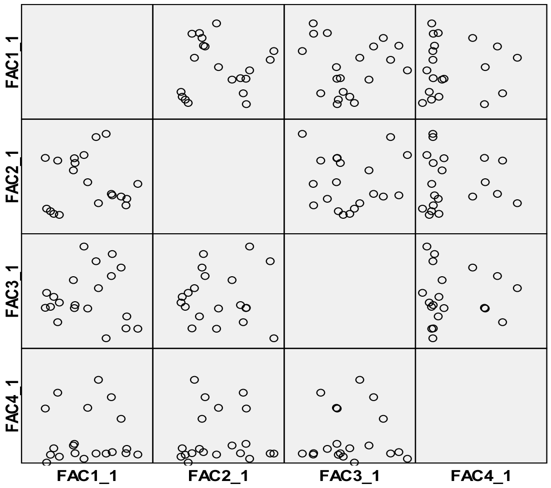

Fig.9 Scatterplot matrix of the extracted components

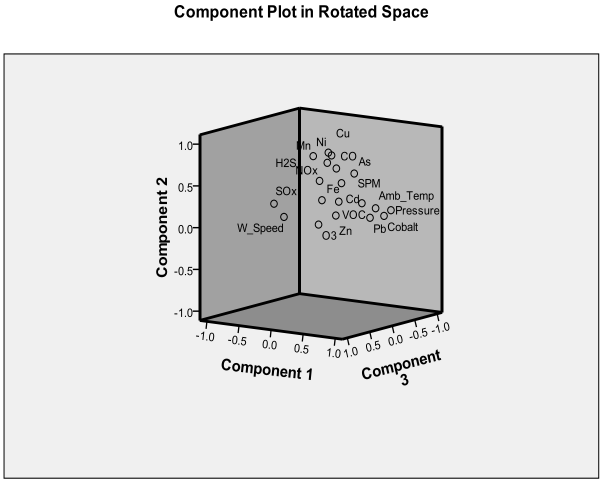

Fig.10 Component plot in rotated space of the variables

Appendix.1 Ambient air quality parameters around the Obirikom Gas Flare Station (August, 2012)

Sampling Points	**Parameters (ppm)**						
	CO	**SOx**	**NOx**	**SPM**	**VOC**	**H_2S**	**O_3**
SP 1	**3.00**	**0.03**	**0.01**	**85.00**	**0.03**	**0.003**	**0.02**
SP 2	**2.20**	**0.02**	**0.00**	**82.20**	**0.01**	**0.001**	**0.02**
SP 3	**2.20**	**0.002**	**0.01**	**80.00**	**0.02**	**0.002**	**0.01**
SP 4	**2.30**	**0.01**	**0.01**	**75.20**	**0.00**	**0.002**	**0.02**
SP Control	**1.50**	**0.01**	**0.00**	**70.00**	**0.00**	**0.001**	**0.01**
DPR Limit	**10**	**0.1**	**0.06**	**250**	**NA**	**0.008**	**0.1**

October 2012

Sampling Points	Parameters (ppm)						
	CO	SOx	NOx	SPM	VOC	H_2S	O_3
SP 1	2.80	0.03	0.01	90.00	0.02	0.002	0.01
SP 2	2.00	0.01	0.01	85.20	0.01	0.002	0.02
SP 3	2.00	0.003	0.01	80.00	0.02	0.001	0.01
SP 4	2.50	0.02	0.01	78.20	0.01	0.002	0.02
SP Control	1.20	0.01	0.00	70.00	0.00	0.001	0.01
DPR Limit	10	0.1	0.06	250	NA	0.008	0.1

December, 2012

Sampling Points	Parameters (ppm)						
	CO	SOx	NOx	SPM	VOC	H_2S	O_3
SP 1	3.60	0.04	0.03	90.00	0.03	0.004	0.01
SP 2	2.80	0.02	0.01	88.00	0.02	0.001	0.02
SP 3	3.00	0.003	0.01	85.00	0.02	0.003	0.01
SP 4	2.50	0.02	0.01	80.20	0.02	0.003	0.01
SP Control	1.60	0.01	0.00	72.00	0.01	0.001	0.01
DPR Limit	10	0.1	0.06	250	NA	0.008	0.1

February, 2013

Sampling Points	Parameters (ppm)						
	CO	SOx	NOx	SPM	VOC	H_2S	O_3
SP 1	3.60	0.04	0.03	95.00	0.03	0.004	0.01
SP 2	2.50	0.03	0.03	88.00	0.03	0.002	0.01
SP 3	3.30	0.003	0.02	90.00	0.02	0.003	0.01
SP 4	2.50	0.03	0.01	80.20	0.03	0.003	0.01
SP Control	1.50	0.02	0.01	70.00	0.01	0.001	0.01
DPR Limit	10	0.1	0.06	250	NA	0.008	0.1

Appendix.2 Levels of Heavy Metals around the Obirikom Gas Flare Station
(August, 2012)

Sampling Points	Heavy metals (ppm)									
	As	Pb	Cu	Ni	Co	Zn	Hg	Fe	Cd	Mn
SP 1	2.20	0.70	0.01	75.00	0.30	0.003	0.00	0.50	0.30	0.00
SP 2	2.00	0.60	0.00	70.20	0.30	0.001	0.00	0.70	0.20	0.01
SP 3	2.10	0.80	0.01	72.00	0.40	0.002	0.00	0.20	0.30	0.00
SP 4	2.10	0.02	0.01	80.00	0.20	0.001	0.00	0.40	0.10	0.01
SP Control	1.30	0.02	0.00	65.00	0.20	0.001	0.00	0.01	0.00	0.00

October, 2012

Sampling Points	Heavy metals (ppm)									
	As	Pb	Cu	Ni	Co	Zn	Hg	Fe	Cd	Mn
SP 1	2.10	0.50	0.01	80.00	0.20	0.002	0.00	0.30	0.10	0.01
SP 2	2.00	0.60	0.01	70.00	0.30	0.001	0.00	0.50	0.20	0.01
SP 3	2.10	0.70	0.00	72.00	0.40	0.002	0.00	0.20	0.20	0.00
SP 4	2.10	0.02	0.01	80.00	0.10	0.001	0.00	0.30	0.10	0.01
SP Control	1.30	0.02	0.00	65.00	0.20	0.001	0.00	0.01	0.00	0.00

December, 2012

Sampling Points	Heavy metals (ppm)									
	As	Pb	Cu	Ni	Co	Zn	Hg	Fe	Cd	Mn
SP 1	2.50	0.70	0.02	80.00	0.20	0.003	0.00	0.60	0.20	0.01
SP 2	2.10	0.70	0.01	75.00	0.40	0.002	0.00	0.70	0.30	0.01
SP 3	2.20	0.90	0.01	75.00	0.40	0.002	0.00	0.30	0.30	0.00
SP 4	2.30	0.03	0.01	80.00	0.30	0.001	0.00	0.40	0.20	0.01
SP Control	1.40	0.01	0.00	60.00	0.20	0.001	0.00	0.01	0.00	0.00

February, 2013

Sampling Points	**Heavy metals (ppm)**									
	As	**Pb**	**Cu**	**Ni**	**Co**	**Zn**	**Hg**	**Fe**	**Cd**	**Mn**
SP 1	**2.00**	**0.80**	**0.03**	**88.00**	**0.40**	**0.003**	**0.00**	**0.80**	**0.40**	**0.02**
SP 2	**2.00**	**0.75**	**0.01**	**70.00**	**0.30**	**0.003**	**0.00**	**0.60**	**0.30**	**0.01**
SP 3	**2.30**	**0.90**	**0.03**	**80.00**	**0.40**	**0.002**	**0.00**	**0.20**	**0.20**	**0.02**
SP 4	**2.20**	**0.04**	**0.01**	**75.00**	**0.30**	**0.001**	**0.00**	**0.30**	**0.20**	**0.01**
SP Control	**1.20**	**0.02**	**0.00**	**65.00**	**0.10**	**0.001**	**0.00**	**0.01**	**0.00**	**0.00**

Appendix.3 Meteorological variables of the study area
(August)

Sampling Points	**Wind speed (m/s)**	**Ambient Temp (^{o}C)**	**Pressure (PSI)**	**Relative Humidity (%)**
SP 1	**0.3**	**29.1**	**1095**	**74**
SP 2	**0.3**	**29.1**	**1065**	**73**
SP 3	**0.2**	**29.0**	**1130**	**70**
SP 4	**0.2**	**29.0**	**1006**	**71**
SP Control	**0.3**	**27.5**	**1002**	**70**

(October, 2012)

Sampling Points	**Wind speed (m/s)**	**Ambient Temp (^{o}C)**	**Pressure (PSI)**	**Relative Humidity (%)**
SP 1	**0.3**	**28.0**	**1040**	**75**
SP 2	**0.2**	**28.0**	**1075**	**80**
SP 3	**0.1**	**28.5**	**1200**	**90**
SP 4	**0.2**	**28.0**	**1004**	**80**
SP Control	**0.2**	**27.0**	**1000**	**70**

(December, 2012)

Sampling Points	**Wind speed (m/s)**	**Ambient Temp (^{o}C)**	**Pressure (PSI)**	**Relative Humidity (%)**
SP 1	**0.4**	**28.0**	**1030**	**80**
SP 2	**0.3**	**28.5**	**1040**	**85**
SP 3	**0.2**	**29.0**	**1300**	**81**
SP 4	**0.3**	**28.0**	**1150**	**82**
SP Control	**0.2**	**27.3**	**1003**	**70**

(February, 2013)

Sampling Points	**Wind speed m/s)**	**Ambient Temp (^{o}C)**	**Pressure (PSI)**	**Relative Humidity (%)**
SP 1	0.3	28.0	1025	85
SP 2	0.3	28.5	1045	80
SP 3	0.2	29.0	1200	88
SP 4	0.2	28.0	1100	82
SP Control	0.2	27.2	1004	71

Appendix.4 Test of homogeneity in mean variances of ambient air parameters (P<0.05) ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
SP_1	Between Groups	6125.377	4	1531.344	1.225E7	.000
	Within Groups	.000	2	.000		
	Total	6125.377	6			
SP_2	Between Groups	5742.828	4	1435.707	5.743E7	.000
	Within Groups	.000	2	.000		
	Total	5742.828	6			
SP_3	Between Groups	5438.544	4	1359.636	3.316E7	.000
	Within Groups	.000	2	.000		
	Total	5438.544	6			
SP_4	Between Groups	4801.365	4	1200.341	2.401E7	.000
	Within Groups	.000	2	.000		
	Total	4801.365	6			

Appendix.5 Principal Components Analysis (PCA)of ambient air quality parameters

Communalities

	Initial	Extraction
CO	1.000	.927
SOx	1.000	.897
NOx	1.000	.800
SPM	1.000	.897
VOC	1.000	.830
H2S	1.000	.817
O3	1.000	.901
As	1.000	.798
Pb	1.000	.859
Cu	1.000	.881
Ni	1.000	.874
Cobalt	1.000	.807
Zn	1.000	.871
Fe	1.000	.912
Cd	1.000	.895
Mn	1.000	.778
W_Speed	1.000	.715
Amb_Temp	1.000	.829
Pressure	1.000	.866

Extraction Method: Principal Component Analysis.

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