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Research article

EFFECT OF GAS FLARING ON THE ENVIRONMENTAL QUALITY OF BONNY ISLAND, RIVERS STATE NIGERIA

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ABSTRACT

This study investigated the gas flare pollutant fallouts in air, soil and paw-paw (*Carica papaya*) fruit around the Bonny Oil and Gas Terminal (BOGT) flare station in Bonny Local Government Area of Rivers State, Nigeria. Ambient air quality parameters (SO_2, NO_2, CO, H_2S and SPM, and Ozone) and trace metals (As, Hg, Cd, Cu, Pb, Co, Mn, Fe, Ni and Zn) were determined in the air, soils and the fruits in five different locations in the area according to standard methods. Air quality parameters were measured with Digital Automatic Gas Monitors, while trace metal concentrations were analysed with Varian Spectra AA600 Atomic Absorption Spectrophotometer. Descriptive statistics, one-way ANOVA, principal component analysis (PCA) and variation plots were used to analyse data. Results obtained were compared with the National Environmental Standards and Regulations Enforcement Agency (NESREA) Regulatory Standards (2011). Results showed significant spatial variations in levels of trace metals in air and soils, indicating the dispersal of aerial materials from source of pollution. But there was no significant variation in the levels of trace metals in the fruits of *Carica papaya*. The mean concentrations recorded high values in the soils and fruits of the impacted area than in the control location. Trace metals As, Cd and Hg were not detected in the fruits planted in all the sampling locations. Ni concentration in air was as high as in the soil and fruits. There were significant spatial heterogeneities in mean variance of the parameters measured in ambient air [$F_{(9.20)} > F_{crit(3.90)}$] and soil [$F_{(29.89)} > F_{crit(3.94)}$] with no significant difference in fruit [$F_{(0.66)} > F_{crit(3.94)}$] at $p<0.05$. Elevated levels of some trace metals (Pb, Ni, Cu, Cd and Fe) in air, soils and fruits proximal to the station may have been contributed by gas flaring and geogenic sources.

Keywords: Ambient air quality, *Carica papaya*, gas flaring, soil, trace metals

INTRODUCTION

In the past four decades, Nigeria's economy has been depending on proceeds form oil exploitation from the Niger Delta Region of the country. As at today, there are over 600 oil fields, 5,284 on-and-off shore oil wells, 10 export terminals, 275 flow stations, 4 refineries, and a liquefied natural gas project (Lubeck *et al.*, 2007). Aside oil spillage, the most widespread effect of oil exploitation in the region is gas flaring: the burning of natural gas associated with crude oil when pumped out from the ground (Godson *et al.*, 2009). Nigeria flares about 24 million cubic meters of natural gas per year (Orji, 2012). A retinue of studies have examined the effects of gas flaring on the rural communities where the multinational oil companies (MNOCs) operate with astonishing findings: it has been linked to overheating of the atmosphere due to excess carbon emissions (Ugbomeh and Atubi, 2014), low soil pH (Isirimah, 2004), low yields and high mortality of crops around flare sites (Evoh, 2003) and loss of revenue to indigenous population (Onwubiko, 2015; NES, 2008).

Other studies associated continuous gas flaring in the region with increased poverty among rural women (Gabriel, 2004), and increased political activism (Akingbade, 2009; Peel, 2005). Health end-point studies in the region in association with gas flaring and air pollution include all-cause mortality and morbidity due to respiratory diseases in vulnerable groups such as children and the aged (Nkwocha and Pat-Mbano, 2010; Nna and Ibibia, 2011; Onuoha, 2008).

The flared gas contains major pollutants that acted as causative agents of observed corrosion of roof tops, coloration of built walls, leakage of roof tops etc, on some buildings in oil producing rural communities in Rivers State, due to their toxic properties (Nkwocha and Pat-Mbano, 2010). Another interesting study associated gas flaring in the area with *Light Pollution*: 24 hour daylight around the vicinity of the flare which effects diurnality and light-time patterns in animals and their reproduction, thus sending fish to deep sea areas (Agbebi, 2011).

Although the exact number of pollutants emitted from oil-related facilities in the Niger Delta differ from one area to another due to ecological differences, their potential affects on environmental quality especially in terms of food crops and fruits consumed by the local population especially in Rivers State, has not been properly investigated. Moreso, recent observations indicate premature defoliation, stunted growth, malformation of leaves and stems of major fruits such as mangoes, banana, plantain, paw-paw, coconuts and oil palm trees at proximal farming locations to flare sites (Agbebi, 2011; Efe, 2003). There are increasing concerns about long-term effects due to exposure of these fruits and crops that form part of the major staples of the autochtonous populations and their eventual consequences on environmental health. The problem of data gap on gas flaring-soil-fruits nexus has become a local and national concern. The aim of this study was to assess the effect of gas flaring on the fruits of *Carica papaya* (paw-paw) grown and widely consumed in Bonny Island, a gas flaring community near Port Harcourt in Rivers State.

MATERIALS AND METHODS

- ### Study Area

Bonny Island, the study area, houses an important oil facility; Bonny Oil and Gas Terminal (BOGT) operated by Shell Petroleum Development Company (SPDC) for the past four decades. The area lies within the provisional surface coordinates of E:525000m and N:500000m in the Eastern Niger Delta sedimentary Basin. It is situated on the East Bank of the Bonny River at Latitude 7°20′E and Longitude 4°25′N as shown in Figs. 1 and 2. The area is characterized by hot and humid weather, heavy rains lasting about 9 month in the year, with average rainfall of 3800mm and ambient temperature hovering around 33°C. With a total land area of about 642km^2, the Island supports natural vegetation of mangrove and fresh

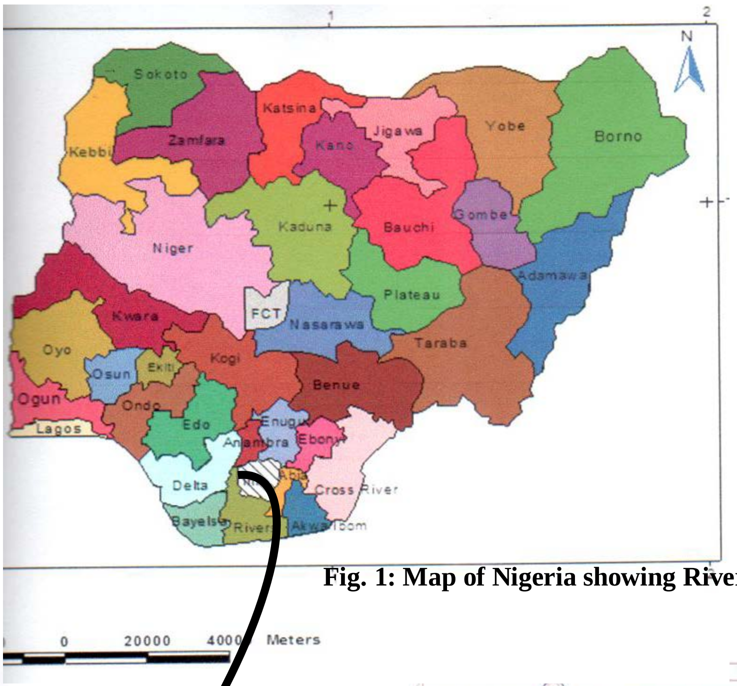

Fig. 1: Map of Nigeria showing Rivers State

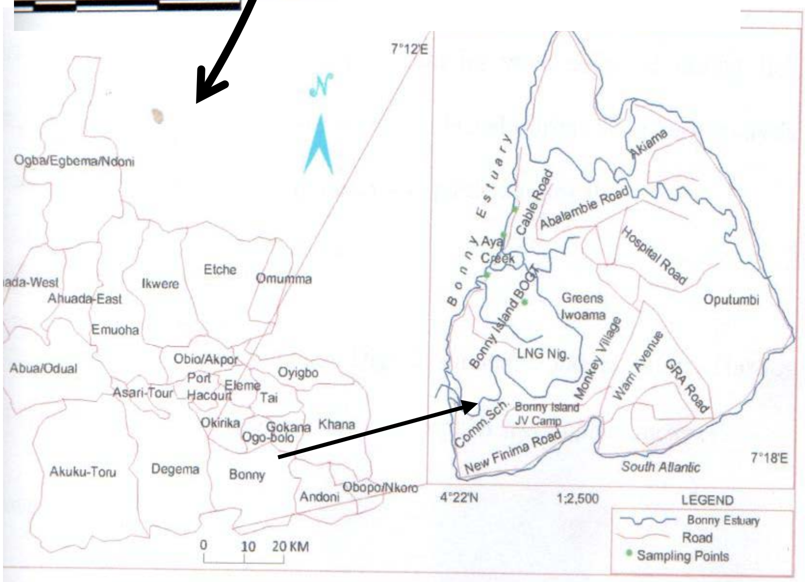

Fig. 2: Map of Rivers State showing Bonny Island

water swamp forests. Its population is estimated at 310,100 people whose main occupations are farming, fishing and trading. Farming activities still at subsistence level, take place on the dry land ridges producing food crops (cassava, yam, maize) and lots of fruits such as melon, banana, paw-paw, guava, mangoes which form part of the local staple.

- ### Sample Collection and Analysis

Five sampling locations were identified for the study within the area where associated gas is constantly flared from the Oil and Gas facilities. Location 1 was the Bonny Natural Associated Gas Unit (BNAC), Location 2, is about 10m from the Gas Turbine Unit (GTU), Location 3 is at Unit 37, a gas flare facility (GFF), Location 4 at the Thermal Desorption Unit (TDU). The GTU is located at about 4km from BNAC; GFF is almost 4km from GTU, while TDU is about 2km from GFF. Location 5 is the control area, located at Ndoni community, about 20km from BOGT.

Soil samples were collected with stainless auger at five sampling locations between June and August 2016. Replicate samples from the respective locations were composited and taken to the laboratory in labeled polythene bags. Also, samples of the fruits of paw-paw (*C.papaya*) grown in farms at five sampling locations were also carefully collected by cutting their stalks from the trees with stainless knife in replicates and taken to the laboratory. All samples were prepared and analysed using ASTM methods (D422-63) (2007). Analyses of fruit and soil samples focused on trace metals, (As, Hg, Cd, Pb, Mn, Fe, Ni, Co, Cu and Zn) as Nigerian crude oils have relatively high concentration of most of these elements (Kakulu 1985; Omgbu and Kokogho, 1993). As the study attempted to establish a relationship between pollutant pathways in air, through soil matrices into the analysed fruits in the proximal reaches of the oil and gas facilities, in-situ measurements of major air pollutants, namely CO, SO_2, NO_3, SPM, VOC, H_2S and Ozone were systematically carried out at the same sampling locations using Digital Automatic Gasman Air Monitors. Meterological data at the sampling locations, specified by longitude and latitude (to three decimal degrees) were obtained from Port Harcourt weather station for wind speed, ambient temperature, pressure, wind direction and turbulence, relative humidity and precipitation. Soil and fruit analyses were carried out at in the Department of Soil Science, Federal University of Technology, Owerri.

- ### Statistical Analyses

Descriptive statistics that further employed the use of graphical illustrations were used to present requisite data. Data analysed first examined summary statistics and scatter plots for key variables to identify outliers. The factor analysis procedure using principal component analysis (PCA) method of extraction for data reduction and further structure detection was used to remove highly correlated variables from the data. The entire data were replaced with smaller uncorrelated variables to further examine the relationships between the variables. The test of equality in mean variances of the parameters measured in air, soil and fruit was conducted using one-way analysis of variance (ANOVA). Factor rotation for the transformation of extracted factors to a new position for interpretation was achieved with the Varimax method. The SPSSv.17.0 was used for all statistical analyses as the significance was set at $p<0.05$.

RESULTS AND DISCUSSION

- ### Results

The ambient air quality parameters measured around the BOGT showed that, other than CO and SPM, the other parameters recorded slight or narrow variations at all the sampling points during the period. The mean values of the two gases mentioned above were 2.02 and 77.08ppm respectively (see Tables 1 and 2). Comparatively, wide variation was recorded for the concentration of Ni (0.38mg/kg) in the ambient air around

BOGT (see Tables 3 and 4). Other trace metals recorded narrow variations. However, Cu, Hg and Mn were not detected in the ambient air samples.

Table 1: Ambient air quality around the Bonny Oil and Gas Terminal (BOGT) (11/06/2016)

Sampling Stations	CO	SO_2	NO_2	SPM	VOC	H_2S	Ozone	Smoke Density
	Parameters (ppm)							
BNAG	1.20	0.01	n.d	80.00	n.d	0.001	0.01	low
Gas Turbine	2.00	0.01	n.d	80.20	n.d	0.001	0.01	low
Unit 37	2.20	n.d	n.d	70.00	0.01	0.001	0.01	low
TDU	2.40	0.01	n.d	75.00	n.d	0.001	0.01	low
Control	0.05	0.1	n.d	40.00	n.d	n.d	0.10	n.d

SPM = Suspended particulate matter, VOC = volatile organic compound, BNAG = Bonny non-associated gas, TDU = Thermal desorption unit, N.D = not detected

Table 2: Ambient air quality around the Bonny Oil and Gas Terminal (BOGT) (20/08/2016)

Sampling Stations	CO	SO_2	NO_2	SPM	VOC	H_2S	Ozone	Smoke Density
	Parameters (ppm)							
BNAG	2.20	0.01	n.d	80.00	n.d	0.001	0.01	low
Gas Turbine	3.00	0.01	n.d	80.20	n.d	0.001	0.01	low
Unit 37	2.00	n.d	n.d	80.00	0.01	0.001	0.01	low
TDU	2.00	0.01	n.d	85.00	n.d	0.001	0.01	low
Control	0.05	0.10	n.d	40.00	n.d	n.d	0.10	n.d

SPM = Suspended particulate matter, VOC = volatile organic compound, BNAG = Bonny non-associated gas, TDU = Thermal desorption unit, N.D = not detected

There were recorded variations in the levels of meteorological parameters measured around BOGT. Other than wind speed, ambient temperature and relative humidity, other parameters recorded slight variations. Wind speed varied from 0.02 to 0.40(0.25 ±0.01) ms^{-1}, air temperature from 27.00 to 29.20 (28.16±0.13)^oC; pressure from 1000 to 1200 (1020.86±7.40) psi; and relative humidity from 70 to 90 (81±0.90)% respectively (see Tables 5 and 6). Analysis of soil parameters around BOGT facility showed wide variations in their concentrations with Pb varying from 6.30 to 25.05 (13.35±3.25)mg/kg; As from 0.00 to 8.20 (3.44±1.67) mg/kg; Cd from 2.70 to (9.46 5.68±1.09) mg/kg; and Cu from 20.38 to 60.80 (39.04 ± 6.47) mg/kg respectively. All the trace metals in the soil samples, including Pb, As, Cd, Cu, Ni, Zn, Fe and Mn exceeded those obtained at the control point with the exception of Hg and Co not detected in all the locations. Highest levels of Pb (25.05mg/kg), Cu (60.80mg/kg) and Zn (20.20mg/kg) were recorded at sample point TDU; Ni (14.60mg/kg) and Fe (24.80mg/kg) recorded highest concentrations at location near Gas Turbine, while sample location BNAC recorded highest concentrations of Mn (60.80mg/kg).

Table 3: Heavy metal Data in air around the Bonny Oil and Gas Terminal (BOGT) (11/06/2016)

Sampling Stations	As (ppm)	Pb (ppm)	Cu (ppm)	Ni (ppm)	Co (ppm)	Zn (ppm)	Hg (ppm)	Fe (ppm)	Cd (ppm)	Mn (ppm)
BNAG	1.20	0.50	n.d	0.80	0.20	0.001	n.d	0.20	0.10	n.d
Gas Turbine	2.00	0.60	n.d	0.80	0.20	0.001	n.d	0.50	0.20	n.d
Unit 37	2.00	0.01	n.d	0.70	0.40	0.001	n.d	n.d	0.30	n.d
TDU	2.30	0.80	n.d	0.75	0.20	0.001	n.d	n.d	n.d	n.d
Control	0.05	0.40	n.d	0.30	n.d	n.d	n.d	0.001	0.1	n.d

BNAG = Bonny non-associated gas, TDU= Thermal Desorption Unit, N.D = not detected

Table 4: Heavy metal Data in air around the Bonny Oil and Gas Terminal (BOGT)) (20/08/2016)

Sampling Stations	As (ppm)	Pb (ppm)	Cu (ppm)	Ni (ppm)	Co (ppm)	Zn (ppm)	Hg (ppm)	Fe (ppm)	Cd (ppm)	Mn (ppm)
BNAG	1.00	0.40	n.d	0.60	n.d	0.001	n.d	0.30	0.02	n.d
Gas Turbine	1.00	0.30	n.d	0.50	n.d	0.001	n.d	0.20	0.03	n.d
Unit 37	2.00	0.50	n.d	0.60	0.01	0.001	n.d	n.d	0.04	n.d
TDU	2.00	0.60	n.d	0.85	n.d	0.001	n.d	0.20	0.04	n.d
Control	0.05	0.40	n.d	0.30	n.d	n.d	n.d	0.001	0.10	n.d

BNAG = Bonny non-associated gas, TDU= Thermal Desorption Unit, N.D = not detected

Table 5: Metrological Data around the Bonny Oil and Gas Terminal (BOGT) (11/06/2016)

Sampling Stations	Wind Speed (m/s)	Ambient Temp (°C)	Pressure (psi)	Wind Turbulence	Sun Radiation	Wind Direction	Relative Humidity	Precipitation (%)
BNAG	0.2	27.2	1090	low	sunny	NS	75	low
Gas Turbine	0.3	29.0	1060	low	sunny	NS	70	low
Unit 37	0.3	29.0	1120	low	sunny	NS	70	low
TDU	0.3	29.2	1003	low	sunny	NS	73	low
Control	0.3	27.7	1010	low	sunny	NS	80	low

BNAG = Bonny non-associated gas, TDU= Thermal Desorption Unit

Table 6: Metrological data around the Bonny Oil and Gas Terminal (BOGT) (20/08/2016)

Sampling Stations	Wind Speed (m/s)	Ambient Temp (°C)	Pressure (psi)	Wind Turbulence	Sun Radiation	Wind Direction	Relative Humidity	Precipitation (%)
BNAG	0.3	27.0	1030	low	sunny	NS	80	low
Gas Turbine	0.3	27.0	1070	low	sunny	NS	80	low
Unit 37	0.3	29.0	1100	low	sunny	NS	90	low
TDU	0.3	29.0	1006	low	sunny	NS	83	low
Control	0.3	27.7	1010	low	sunny	NS	80	low

BNAG = Bonny non-associated gas, TDU= Thermal Desorption Unit

With the exception of Hg, As and Co that were not detected, other trace metals in paw-paw tissues recorded values higher than those at the control location. Sample point TDU recorded the highest levels of Pb (3.80mg/kg), Ni (6.00mg/kg) and Mn (1.70mg/kg) while Location Unit 37 recorded the least values on the three elements. Highest value of Cd (0.66mg/kg) was detected at the location close to Gas Turbine while the least value of same metal (0.02mg/kg) was recorded at Location near TDU. Sample location BNAG recorded the highest concentration of Cu (15.65mg/kg), and the least level detected at Location near TDU (11.14mg/kg). Finally, BNAG also recorded the highest level of Fe (3.16mg/kg) and the least at Location Unit 37 with 2.300mg/kg.

Table 7: Concentration of heavy metals in soils around the Bonny Oil and Gas Terminal (BOGT) (2016)

Sampling						**(mg/kg)**				
Stations	**Pb**	**Hg**	**As**	**Cd**	**Cu**	**Ni**	**Co**	**Zn**	**Fe**	**Mn**
SSTDU	25.05	n.d	8.20	9.40	60.80	10.400	n.d	20.200	20.500*10	50.500
SSGTG	15.16	n.d	6.40	5.60	38.50	14.600	n.d	15.450	24.800*10	50.000
SSBNAG	10.24	n.d	2.60	6.10	40.10	13.420	n.d	18.520	20.800*10	60.800
SSU37	10.02	n.d	n.d	4.60	35.40	12.840	n.d	16.820	25.400*10	50.220
SSC	6.30	n.d	n.d	2.70	20.38	7.180	n.d	10.280	20.400*10	40.800

SSGTG = Soil sample at gas turbine site. SSU37 = Soil sample at Unit 37 gas flare. SSBNAG = Soil sample at Bonny non-associated gas site. SSTDU = Soil sample at thermal desorption unit. SSC = Soil sample control. N.D = not detected

Table 8: Concentration of heavy metals in paw paw tissue around Bonny Oil and Gas Terminal (BOGT) (2016)

Sampling						**(mg/kg)**				
Stations	**Pb**	**Hg**	**As**	**Cd**	**Cu**	**Ni**	**Co**	**Zn**	**Fe**	**Mn**
SPTDU	3.80	n.d	n.d	0.02	11.14	6.000	n.d	2.500	2.4500	1.7000
SPGTG	2.18	n.d	n.d	0.60	10.80	4.400	n.d	5.800	2.8000	1.3800
SPBNAG	1.30	n.d	n.d	0.04	15.65	3.420	n.d	5.520	3.1600	0.6000
SPU37	0.42	n.d	n.d	0.05	12.30	3.180	n.d	6.500	2.3000	1.5800
SPC	0.25	n.d	n.d	n.d	10.45	0.620	n.d	0.600	2.0000	1.2000

SPGTG = Paw paw tissue sample at gas turbine site. SPU37 = Paw paw tissue sample at Unit 37 gas flare. SPBNAG = Paw paw tissue sample at Bonny non-associated gas site. SPTDU = Paw paw tissue sample at thermal desorption unit. SPC = Paw paw tissue sample control. N.D = not detected

The outputs of the principal component analyses extraction procedures that utilized the ambient air quality parameters presented communalities that were high, indicating extracted components represented the variables well. The first 6 PCs formed the extraction solution in a total of 15 variables with a cumulative 75.15%: the first component accounted for about 22.72% of variance, second 15.82%, third 13.00%, fourth 9.08%, fifth 7.53% and sixth 6.99%.

The first PC was most highly correlated with Cu (0.851) and also high loadings for Ni (0.560), Cd (0.819) and RH (-0.594). The second PC was most highly correlated with VOCs (0.808) with high loadings for Fe (-0.643) and air pressure (0.765). The third PC correlated with ambient temperature (0.814) with high loadings for As (0.739) and Pb ions (0.664).

On the spatial variation in the levels of heavy metals in soils, the least concentration of 7.18mg/kg was recorded for Ni at the control location while the maximum level of 14.60mg/kg was detected in the soil at the Gas Turbine location. However, the least concentrations of 2.70mg/kg and 6.30mg/kg were recorded for Cd and Pb at the control location respectively as As remained undetected. The corresponding maximum values for these three elements were 9.40mg/kg, 8.20mg/kg and 26.05mg/kg all recorded at the TDU sampling location. Also, while the least concentration of Mn (40.80mg/kg), Fe(20.80mg/kg) Zn (10.38mg/kg) and Cu (20.38mg/kg) were all detected at the control location, their maximum values of 60.80mg/kg, 25.40mg/kg, 18.52mg/kg, 60.80mg/kg were detected at BNAG, Unit 37, TDU and TDU sampling locations respectively (see Appendices 1to 4).

The test of homogeneity in mean variance of the level of trace metals is soils revealed significant heterogeneity [$F_{(29.89)} > F_{crit\ (3.94)}$] across the sampling locations at $p <0.05$. At the Gas Turbine and TDU sampling locations, Cu (20.38mg/kg), Fe (20.40mg/kg) and Mn (40.80mg/kg) were most responsible for the observed heterogeneity (see Appendix 5).

Spatial variation in levels of trace metals were also recorded in the fruit samples. Minimum levels of Ni (0.62mg/kg) and Pb (0.20mg/kg) were recorded in the vicinity of the control location, while the maximum concentrations of Ni (6.00mg/kg) and Pb (3.80mg/kg) were detected at TDU sampling location. In the same vein, while minimum concentrations of Mn (1.20mg/kg), Fe (2.00mg/kg), Zn (0.60mg/kg) and Cu (10.45mg/kg) were also recorded in the fruits at the vicinity of the control location, the maximum levels of Mn (1.70mg/kg), Fe (3.16mg/kg), Zn (6.50mg/kg) and Cu (15.65mg/kg) were recorded in the fruits planted around TDU, BNAG, Unit 37 and BNAG sampling locations respectively. However, Cd Hg, Co and As were not detected in the fruits of paw-paw at all the sampling locations. The test of homogeneity in the levels of trace metals detected in the fruits in the impacted area revealed that there was no significant difference as [$F_{(0.66)} < F_{crit\ (3.94)}$] at $p < 0.05$.

- **Discussion**

Results obtained on SPM and Ni in ambient air indicated that these pollutants emanated from the gas flared at BOGT. Although the ambient air levels of As, Pb, and Ni at sampling points located in the impacted area were above the NESREA (2011) accepted limits in Nigeria, their concentrations were significantly low at the control point in Ndoni. The exceedances of these pollutants in the air of the impacted area could portend ecological hazards of bioaccumulation of these trace elements in plants, animals and even the local residents (Ugbomeh and Atubi, 2014), causing chronic pulmonary diseases (Ezzati and Kammen, 2002), increased risk of liver failure (Messner *et al.*, 2008) and other environmental health risks (Odedari *et al.*, 2005). The observed significant heterogeneity in mean levels of the ambient air pollutants (especially SPM) indicates unequal contribution of the pollutant by the different facility Units serving as sampling points in the study. This report supports a similar result obtained by Efe (2008) who reported that ambient particulate matter (PM_{10}) from various locations showed significant differences. The narrow variations observed in ambient air temperature, wind speed and relative humidity, reflects the general stability in the weather conditions in the Niger Delta region where Bonny Island is located. The relatively high concentrations of Pb, Cu and Mn in the soil samples than in the ambient air at different sample locations especially in the impacted area could be as a result of the repository role of soils. The recorded high level of these elements and their accumulation over a long period of time could cause decline in crop productivity and sustainability (Hart *et al.*, 2005), as well as a potential danger to local consumers and animals (Agbebi, 2011; Nkwocha *et al.*, 2011). The high pH of the soil in the study area could be attributed to high rainfall that causes leaching which corroborates results obtained by Vandana *et al* (2011) in the Niger Delta. The observed significant heterogeneity in mean levels of Cu, Mn and Fe in soil samples indicates variant contribution of these pollutants at different sampling facility units in this study. Omran and Abdel Razek (2012) attributed similar significant heterogeneity to variation of Cu and Mn in the soils of Bahr El-Baker region of Egypt.

The levels of Cu, Ni and Zn in the *C. papaya* fruits sampled from various locations in the impacted area were notably higher than those obtained by Sobukola *et al* (2010) in similar studies in Lagos and those of

Salama (2006) in Egypt. The level of Cu in the fruits was above the natural background level of NESREA (2011). Since Cu was apparently not detected in ambient air samples proximal to the flare station, its presence in fruits in the study area must have originated from geogenic sources (Ogbuagu *et al.,* 2013).

The high values obtained in Pb and Ni in the fruit samples and their bioaccumulation over time could cause strange diseases such as schizophrenia in humans (Zhao *et al.*, 2008) and adversities in plants (Okpara, 2004). The observed non-significant difference in levels of the trace elements in fruits of *C. papaya* was similar to the results obtained by Muhammad *et al.*, (2008).

CONCLUSION

This study has tried to investigate the effects of gas flaring on the environmental quality of Bonny Island, Rivers State of Nigeria. The results presented the concentration of air pollutants as well as heavy metals in the ambient air in the study area. Trace metal concentrations in soils and in *Carica papaya* fruits grown in four sampling locations in the impacted area and another in Andoni, (control area) were also presented. Results obtained showed that the flare from Bonny Oil and Gas Terminal was the major source of pollutants detected in the fruits of *Carica papaya*, with levels higher than those obtained in the control area. The wide variety of chemical pollutants found in the fruit examined will certainly impact the health of local consumers in extremely complicated and harmful ways in the years ahead. The results obtained in this study, however, should be viewed with the caveat that only one fruit (*C. papaya*) was examined with limited number of sample points, consequently, there is a higher possibility of chance findings. In follow-up research, samples of more fruits grown in different impacted areas, such as those of banana, mangoes, oranges, guava etc, should be properly investigated in order to obtain more comprehensive information on the levels of pollution in these fruits. Ultimately, a new and arduous task has to be put forward for environmental health researchers to study fruit-related disease pathogenesis. As many people are engaged in studies on the impact of gas flaring in the Niger Delta environment (MNOCs, government agencies, universities, organizations, etc.) results obtained should be made open, more transparent, and less politicized mainly for the interest of the primary stakeholders within the sub-region as this could facilitate better prevention or reduction of negative effects resulting from interactions of these pollutants.

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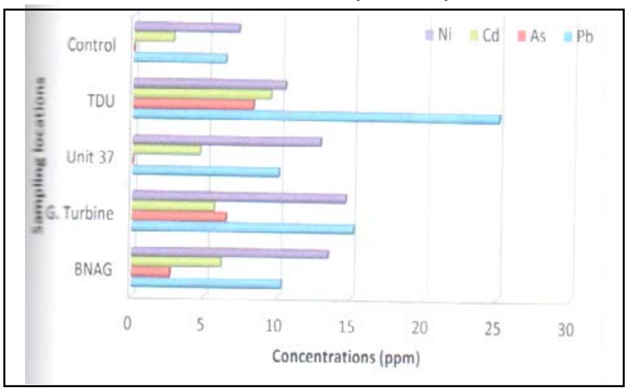
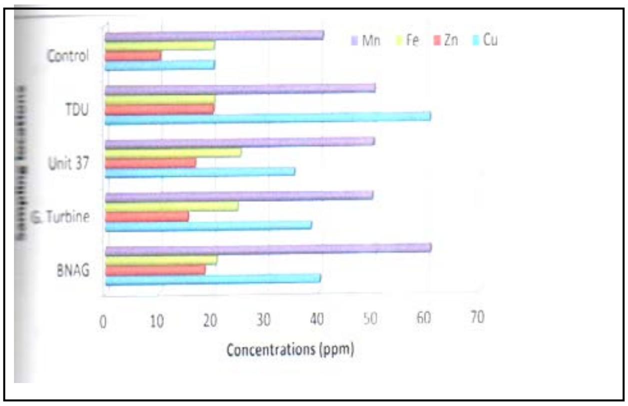
Appendix 1

Spatial variations in levels of nickel, cadmium, arsenic and lead in soils around the BOGT facility in Bonny Island



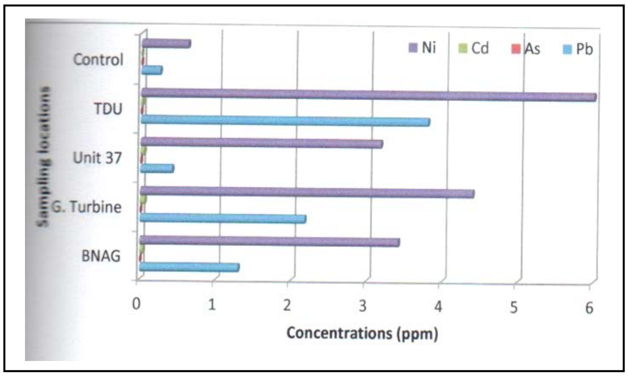
Appendix 2

Spatial variations in levels of manganese, iron, zinc and copper soils around the BOGT facility in Bonny Island



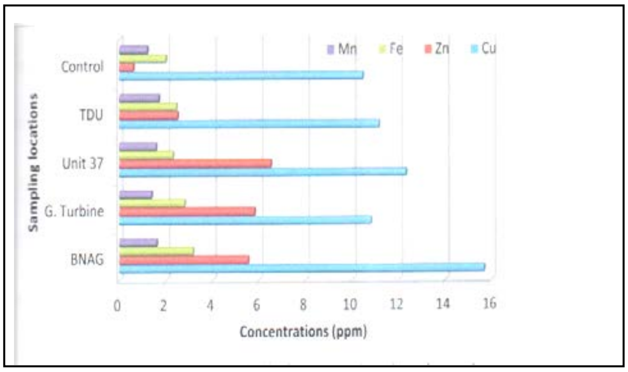
Appendix 3

Spatial variations in levels of nickel, cadmium, arsenic and lead in paw paw fruits around the BOGT facility in Bonny Island



Appendix 4

Spatial variations in levels of manganese, iron, zinc and copper soils around the BOGT facility in Bonny Island



Appendix 5: Test of homogeneity in mean variance of heavy metal in soil

Anova: Single Factor

SUMMARY

Groups	Count	Sum	*Average*	*Variance*
Column 1	50	811.4	16.2296	290.7553
Column 2	50	150	3	2.040816

ANOVA

Source Variation	S5	*df*	MS	*F*		Fcrit
Between Groups	4375.5	i	4375.558	29.88808	07	3.93811
Within	14347.0	98	146.3981			
Total	18722.5	99				

Appendix 6: Test of homogeneity in spatial variance of heavy metal in *C.papaya*.

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column	5	127.17	2.5434	
1	0	150	13.8525 3	

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*Peril*
Between	5.212089	1	5.212089	0.655885	0.419979	3.938111
Groups Within	778.7723	98	7.946656			
Groups	783.9844	99				