



Evaluation of Polycyclic Aromatic Hydrocarbons Levels in Mangrove Forest and Sediment around Gas Flare in Awoba Flow Station Rivers State Nigeria

¹ Simbi-Wellington W. S. and ²Ideriah T. J. K.

¹Department of Forestry and Environment, Rivers State University Nkpolu Oroworukwo, Port Harcourt

²Institute of Pollution Studies, Rivers State University Nkpolu Oroworukwo, Port Harcourt

Corresponding Author: Ideriah, T.J.K

ABSTRACT: This research was conducted to assess the impact of gas flaring on the mangrove forest ecosystem around Awoba Flow Station in Bille, Rivers State, Nigeria. Pollutant PAHs were assessed in mangrove leaves and soil in four sampling transects laid on the North, South, West and East axes of the flow station and a control location about 200km away from the flow station in the wet and dry season months. The results were analysed using the Gas Chromatography. PAH concentrations in mangrove leaves ranged from 0.0237mg/kg to 0.059mg/kg. The highest mean PAH concentration in soil was 1.1457mg/kg while the lowest was 0.0766mg/kg. Total PAH concentrations in the mangrove soil and leaves were above recommended limit; such high levels of Pollutants in the mangrove forest can pose a serious threat to the environment and health risk to humans through food chain, hence adequate public awareness should be encouraged to educate inhabitants of the area on the health implications of exposure to pollutants. Regular monitoring of these pollutants should be encouraged to ensure timely interventions.

KEYWORDS: Polycyclic Aromatic Hydrocarbons, Mangrove Forest, Sediment, Gas Flare, Awoba, Flow Station

Received 01 Mar, 2022; Revised 06 Mar, 2022; Accepted 13 Mar, 2022 © The author(s) 2022.

Published with open access at www.questjournals.org

I. INTRODUCTION

Nigeria is one of the nineteen West African countries endowed with mangrove. The Nigerian Mangrove is classified as the largest in Africa with a land area of 7368km², and the third largest in the world, it stretches across nine states within the coastal regions which includes; Abia, Akwa-Ibom, Bayelsa, Cross River, Delta, Edo, Imo, Ondo and Rivers (Aber and Ekeke, 2011). The three main mangrove families found in Nigeria are Rhizophoraceae, Avicenniaceae and Combretaceae with species such as; *Rhizophora racemosa*, *Rhizophora harrisonii*, *Rhizophora mangle*, *Avicennia germinans*, *Conocarpus erectus* and *Languncularia racemose*. Palms associated with these species are; *Nypa fruticosa*, *Prodococcus bateri* and *Ancistrophillum opacum*. Other associated plants include *Acrostichum aureum* (Obadimu et al., 2016). *Paspalum viginatum*, *Paspalum scrobiculatum* and *Mariscus alternifolius* are also associated with the Nigerian mangrove (Simbi-Wellington, 2019).

Nigeria is ranked among the top fifteen oil producing countries in the world, the first in Africa with crude oil as its major source of revenue. An estimated 70% of the crude oil exploitation and exploration activities in Nigeria is carried out in the Niger Delta mangrove causing degradation of the mangrove ecosystem (Ohimain, 2006). The Niger Delta region been the largest delta in Africa was once regarded as the most ecologically important zone in Nigeria supporting diverse species of ecological importance and accommodating the third largest mangrove in the world. However, in recent times the Niger Delta mangroves have been classified among the most fragile ecosystems in the world. The Niger Delta region which was in time past listed as one of the most productive coastal ecosystems in the world is deteriorating rapidly as a result of pollution arising from industrial and domestic sources (Ubani and Oyejekwe, 2013).

Over 22.5 billion barrels of oil reserves are stationed within an estimated 250 separate fields in the Niger Delta region. Research findings on oil and gas operation in Nigeria reveals assets of about 275 flow stations, 10 gas plants, 5,284 oil wells, 7,000km of pipelines and 10 export terminals all located within the Niger Delta region (Joab, 2004).

Large quantities of gas (90% methane) are produced in the Nigerian oil fields and burnt off (flared) at flow stations above oil wells due to liquefaction and transportation difficulties and challenges. Flaring and venting causes the emission of several air pollutants. Pollutants emitted during flaring depend on the chemistry of the gas being burnt, the disposal method (flaring or venting) and the combustion efficiency (Eniscuola Energy & Environment, 2015). Leahey *et al.*, (2001) reported that complete combustion of natural gas cannot be achieved through flaring; the incomplete combustion therefore, produces a mixture of polycyclic aromatic hydrocarbons (PAHs) and volatile organic compounds (VOCs). The most abundant hydrocarbons found around examined flare sites as reported by Strosher, (2000) are; ethynyl benzene, benzene, toluene, styrene, ethynyl-methyl benzenes, xylenes, ace naphthalene, biphenyl and fluorine.

Petroleum pollution contains complex mixtures of both the aromatic and aliphatic hydrocarbons (Olajire *et al.*, 2005; Osuji and Ozioma 2007). According to Ite and Semple, (2012) Petroleum hydrocarbons are classified into four groups which are; aromatics (naphthalene, benzene, phenanthrene, pyrene), saturates (hexadecane, pentane, octacosane, cyclohexane), asphaltenes (phenols, fatty acids, ketones, esters, and porphyrins) and resins (pyridines, quinolines, carbazoles, sulphurxides and amides). According to Ite and Ibok (2013) non-effective flare system result in incomplete combustion that releases a variety of VOCs, PAHs and inorganic contaminants. Kostiuk, *et al.*, 2004; Kindzierski, 1999 also reported that the incomplete combustion of petroleum associated gases releases a variety of VOCs and PAHs.

Several studies have revealed high levels of contaminants in vegetation, soil and air around gas flare sites and the corresponding damage on the forest ecosystems where these operating facilities are located. Early detection of pollutants is necessary for environmental safety, hence, there is need for regular assessment of forest ecosystems where oil facilities are located and gas flared. This study therefore, aims at assessing the mangrove forest ecosystem around Awoba Flow Station in order to provide information that can be used for environmental safety and a well-informed forest management decision by the host community.

II. MATERIALS AND METHODS

2.1 Study Area

The study station (Awoba flow station) is located within the Bille Territory. Bille is a low-lying coastal town in the vast mangrove forest region of the Niger Delta, Nigeria. It is a rural community in Degema Local Government Area of Rivers State. Its geographical coordinates are 4° 34' 37" North, 6° 53' 19" East. Bille is an ancient community made up of fifteen villages and forty fishing settlements with a population of thirty thousand people according to the Nigeria 1999 census. Fishing is the main occupation of the people (ERA, 1999).

The study station (Awoba flow station) lies along 4° 31' 51.486"N, 6° 49' 11.962" E while the control station (Degema Community) lies along 4° 46' 39.908" N, 6° 46' 25.980" E. Both stations are in Degema Local Government Area of Rivers State which is situated at the southern part of Rivers State having boundaries with Asari Toru Local Government Area and Port Harcourt Local Government Area at the north, Okrika Local Government Area and Bonny Local Government Area on the west, Akuku Toru Local Government Area on the east and the Atlantic Ocean on the south (Wikipedia, 2014).

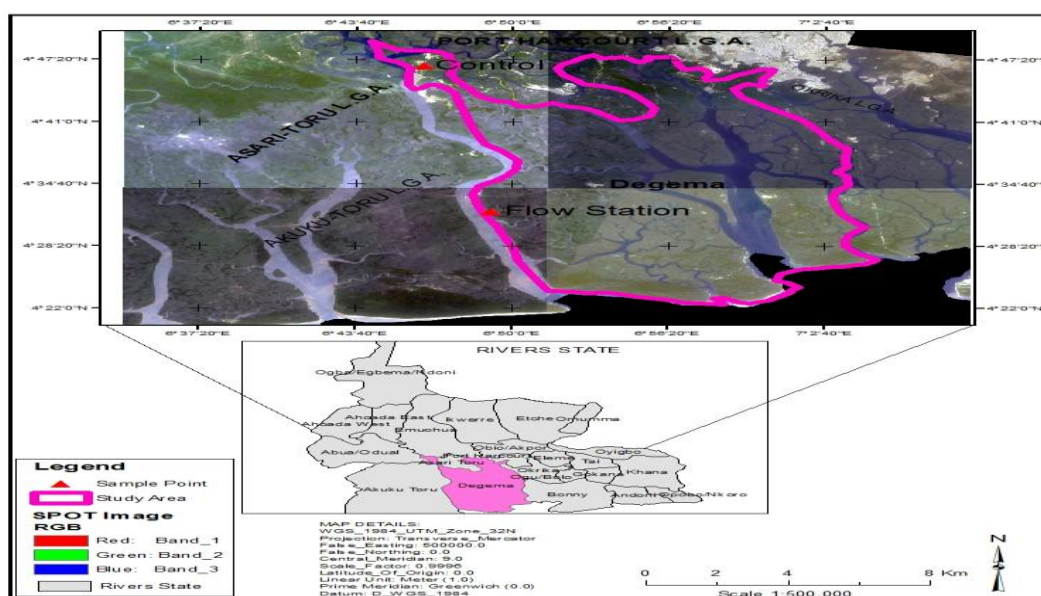


Fig 1 Map of Rivers State showing Degema Local Government area and study area

Table 1 Identification and Geographical Coordinates of Study Locations

LOCATION	N (Latitude)	E (Longitude)
CENTRAL POINT	4° 31' 52.90"	6° 49' 10.45"
WEST 1	4° 31' 52.88"	6° 49' 09.38"
WEST 2	4° 31' 52.61"	6° 49' 08.49"
WEST 3	4° 31' 52.57"	6° 49' 07.42"
SOUTH 1	4° 31' 50.90"	6° 49' 11.20"
SOUTH 2	4° 31' 48.74"	6° 49' 12.43"
SOUTH 3	4° 31' 46.97"	6° 49' 13.64"
EAST 1	4° 31' 53.59"	6° 49' 13.13"
EAST 2	4° 31' 55.54"	6° 49' 18.16"
NORTH 1	4° 32' 00.85"	6° 49' 08.79"
NORTH 2	4° 30' 00.37"	6° 49' 02.16"
NORTH3	4° 31' 56.50"	6° 49' 02.30"
CONTROL CENTRAL	4° 46' 43.91"	6° 49' 25.98"
CONTROL 1	4° 46' 44.70"	6° 49' 27.93"
CONTROL 2	4° 46' 45.50"	6° 49' 29.55"
CONTROL 3	4° 46' 42.59"	6° 49' 28.40"
CONTROL 4	4° 46' 46.27"	6° 49' 27.54"



Study location showing Flare stack and open flaring



Section of the East of the study location around Awoba Flow station



Disturbed mangrove area within the study location

2.2 Sampling Techniques and Experimental Design

The systematic sampling method was used in this research. Sampling locations were taken 20 meters away from the flow station, four transects measuring 10m x 90m were laid, each on the North (NT), South (ST), West (WT) and East (ET) of the Flow Station and were sub-divided into three sampling units measuring 10m x 30m. A total of 12 sampling units were laid for the study. Samples were randomly collected in triplicates within each sampling unit. The wind direction was noted and considered as a factor. Samples were also collected at the control (CT) station which is a mangrove forest in Degema town, over 200km away from the study station. Samples were collected in four different months; two dry season months (March 2017/March 2018) and two wet season months (June 2017/September 2017).

The experimental design used for this study is a 5 x 4 factorial in RCBD with three replications; the factors are months of data collection and location of sampling (North, South, East, West and control). Data analysis used was the multivariate analysis using General Linear Model (GLM) of SPSS statistical package (IBM SPSS, 2011). Means were considered significant at $P \leq 0.05$ and were separated using Duncan Multiple Range Test.

2.3 Determination of Polycyclic Aromatic Hydrocarbons in Plants and Soil

Ten millilitre of extraction solvent (hexane) was added to 2g of collected plant and soil samples, mixed thoroughly, allowed to settle and filtered using Buchner funnels. Extracts were concentrated to 2ml and transferred for clean-up and separation. After the clean-up and separation, concentrated aromatic fractions of soil and plant samples were transferred into glass vials with Teflon and rubber crimp caps for GC analysis. 1 μ L of the concentrated samples were injected by means of hypodermic syringe through rubber septum into columns of Gas Chromatograph (HP 5890 series 11). Separation occurred as the vapour constituent partitioned between the gas and liquid phase. The constituent aromatic compounds were automatically detected at emergence from the column by the Flame Ionization Detector (FID).

III. RESULTS

3.1 Polycyclic Aromatic Hydrocarbons in Mangrove Leaves

PAHs observed in the mangrove vegetation at the study area were; Naphthalene, 2-methyl-Naphthalene, Acenaphthene, Fluorine, Phenanthrene, Anthracene, Flouranthene, Pyrene, Benz (a) anthracene, Chrysene, Benzo (b) fluoranthene, Benzo (k) fluoranthene, Benz (a) Pyrene, Indeno (1,2,3-cd) pyrene and Dibenz (a,h)anthracene (Table 3). The mean total PAH concentrations measured ranged from 0.0237mg/kg observed in location ST to 0.059mg/kg observed in location NT. However, there were no significant differences in the mean concentrations of total PAHs observed at the different locations at $P \leq 0.05$ (Table 2).

Statistical analysis revealed a significant difference in the mean concentrations of PAHs observed in the different months of study. The mean concentration of PAHs was significantly higher in the month of September (0.0944mg/kg) and lowest in the other months (March 2017; 0.0177mg/kg, June; 0.0480 and March 2018; 0.0096mg/kg).

High concentrations of Benz (a) anthracene and Benz (a) pyrene were observed in the mangrove leaves in different months and locations of study (Table 4.2). In the month of March, 2017, high concentrations of

Benz (a) anthracene was observed in locations WT(8.331×10^{-3}) and ST (1.468×10^{-2}). High concentrations of Benz (a) pyrene was observed in locations WT (1.779×10^{-3}), ST (1.340×10^{-3}) and NT (1.389×10^{-3}).

Table 2. Mean Concentrations (mg/kg) of Pollutants at the study Locations

LOCATION	Leaves	Soil
	PAH	PAH
WT	0.0373 ^a	0.1999 ^c
ST	0.0237 ^a	0.1076 ^c
ET	0.0291 ^a	1.1457 ^a
NT	0.0594 ^a	0.6863 ^b
CT	0.0531 ^a	0.0766 ^c

Mean with different superscripts within columns are significantly different at $p \leq 0.05$ using DMRT

Table 3 Mean Concentrations (ppm) of Individual Polycyclic Aromatic Hydrocarbons in leaves

MARCH 2017							
S/No	PAHs	WT	ST	ET	NT	CT	USEPA 2013
1	Naphthalene	4.006×10^{-3}	2.179×10^{-3}	7.383×10^{-4}	1.199×10^{-3}	BDL	4.0×10^{-2}
2	2-methyl-Naphthalene	5.182×10^{-3}	4.492×10^{-3}	9.895×10^{-4}	3.616×10^{-3}	BDL	4.0×10^{-2}
3	Acenaphthylene	2.196×10^{-3}	2.272×10^{-3}	1.964×10^{-4}	1.303×10^{-3}	BDL	2.0×10^{-1}
4	Acenaphthene	2.492×10^{-3}	8.338×10^{-3}	1.65×10^{-3}	2.356×10^{-3}	BDL	2.0×10^{-1}
5	Fluorene	7.899×10^{-4}	3.181×10^{-3}	4.792×10^{-4}	1.003×10^{-3}	BDL	2.0×10^{-1}
6	Phenanthrene	4.422×10^{-3}	3.505×10^{-3}	3.979×10^{-4}	1.581×10^{-3}	BDL	2.0×10^{-1}
7	Anthracene	2.354×10^{-3}	8.877×10^{-4}	2.290×10^{-4}	1.106×10^{-3}	BDL	2.0×10^{-1}
8	Flouranthene	3.654×10^{-3}	3.469×10^{-3}	6.437×10^{-4}	1.192×10^{-3}	1.023×10^{-5}	2.0×10^{-1}
9	Pyrene	1.042×10^{-3}	9.614×10^{-3}	6.628×10^{-4}	4.640×10^{-4}	6.786×10^{-6}	2.0×10^{-1}
10	Benz (a) anthracene	8.331×10^{-3}	1.468×10^{-2}	3.387×10^{-5}	2.613×10^{-5}	1.229×10^{-4}	1.0×10^{-4}
11	Chrysene	1.575×10^{-3}	1.537×10^{-5}	8.752×10^{-6}	1.118×10^{-5}	1.5756×10^{-6}	2.0×10^{-1}
12	Benzo (b) fluoranthene	9.849×10^{-5}	1.561×10^{-3}	BDL	2.529×10^{-3}	9.787×10^{-7}	2.0×10^{-1}
13	Benzo (k) fluoranthene	5.369×10^{-4}	7.719×10^{-4}	2.080×10^{-5}	1.529×10^{-4}	3.476×10^{-7}	2.0×10^{-1}
14	Benz (a) Pyrene	1.779×10^{-3}	1.340×10^{-3}	2.959×10^{-5}	1.389×10^{-3}	1.382×10^{-6}	2.0×10^{-4}
15	Indeno (1,2,3-cd) pyrene	2.272×10^{-4}	7.444×10^{-5}	8.341×10^{-6}	1.556×10^{-4}	2.829×10^{-6}	4.0×10^{-1}
16	Dibenz (a,h)anthracene	3.629×10^{-4}	5.051×10^{-3}	7.979×10^{-5}	1.110×10^{-4}	1.484×10^{-3}	3.0×10^{-1}
JUNE 2017							
S/No	PAHs	WT	ST	ET	NT	CT	USEPA 2013
1	Naphthalene	3.362×10^{-4}	1.059×10^{-3}	BDL	7.933×10^{-5}	BDL	4.0×10^{-2}
2	2-methyl-Naphthalene	3.463×10^{-3}	1.036×10^{-3}	BDL	7.606×10^{-5}	BDL	4.0×10^{-2}
3	Acenaphthylene	3.349×10^{-4}	BDL	1.151×10^{-4}	1.127×10^{-4}	BDL	2.0×10^{-1}
4	Acenaphthene	4.363×10^{-2}	1.623×10^{-2}	9.280×10^{-5}	1.523×10^{-4}	BDL	2.0×10^{-1}
5	Fluorene	1.439×10^{-3}	5.537×10^{-4}	6.724×10^{-3}	3.933×10^{-3}	BDL	2.0×10^{-1}
6	Phenanthrene	6.653×10^{-5}	3.558×10^{-3}	1.831×10^{-2}	1.092×10^{-4}	1.099×10^{-4}	2.0×10^{-1}
7	Anthracene	4.239×10^{-3}	5.416×10^{-5}	3.171×10^{-3}	6.449×10^{-3}	2.492×10^{-3}	2.0×10^{-1}
8	Flouranthene	7.099×10^{-4}	2.389×10^{-4}	1.482×10^{-4}	1.662×10^{-4}	1.275×10^{-4}	2.0×10^{-1}
9	Pyrene	3.344×10^{-4}	1.839×10^{-5}	3.798×10^{-3}	1.264×10^{-4}	7.871×10^{-5}	2.0×10^{-1}
10	Benz (a) anthracene	1.159×10^{-4}	1.163×10^{-4}	2.788×10^{-5}	4.490×10^{-5}	8.987×10^{-5}	1.0×10^{-4}
11	Chrysene	1.573×10^{-4}	2.249×10^{-4}	2.671×10^{-5}	6.694×10^{-5}	1.019×10^{-5}	2.0×10^{-1}
12	Benzo (b) fluoranthene	7.279×10^{-3}	9.351×10^{-6}	5.263×10^{-3}	3.805×10^{-4}	5.996×10^{-4}	2.0×10^{-1}
13	Benzo (k) fluoranthene	5.838×10^{-4}	6.552×10^{-4}	1.493×10^{-5}	6.037×10^{-4}	7.553×10^{-6}	2.0×10^{-1}
14	Benz (a) Pyrene	8.848×10^{-4}	1.693×10^{-4}	1.569×10^{-5}	4.834×10^{-5}	2.721×10^{-5}	2.0×10^{-4}
15	Indeno (1,2,3-cd) pyrene	3.581×10^{-5}	1.399×10^{-4}	7.183×10^{-5}	2.218×10^{-5}	1.332×10^{-4}	4.0×10^{-1}
16	Dibenz (a,h)anthracene	9.423×10^{-2}	3.069×10^{-4}	3.523×10^{-2}	1.108×10^{-2}	4.650×10^{-4}	3.0×10^{-1}
SEPTEMBER 2017							
S/No	PAHs	WT	ST	ET	NT	CT	USEPA 2013
1	Naphthalene	3.168×10^{-3}	4.266×10^{-5}	NS	BDL	1.648×10^{-4}	4.0×10^{-2}
2	2-methyl-Naphthalene	BDL	BDL	NS	BDL	BDL	4.0×10^{-2}
3	Acenaphthylene	BDL	BDL	NS	BDL	BDL	2.0×10^{-1}
4	Acenaphthene	BDL	BDL	NS	BDL	BDL	2.0×10^{-1}
5	Fluorene	BDL	BDL	NS	BDL	BDL	2.0×10^{-1}
6	Phenanthrene	BDL	BDL	NS	BDL	BDL	2.0×10^{-1}
7	Anthracene	BDL	BDL	NS	BDL	BDL	2.0×10^{-1}
8	Flouranthene	BDL	1.184×10^{-3}	NS	1.245×10^{-2}	BDL	2.0×10^{-1}
9	Pyrene	BDL	7.933×10^{-3}	NS	2.178×10^{-2}	1.052×10^{-4}	2.0×10^{-1}
10	Benz (a) anthracene	7.205×10^{-4}	2.259×10^{-2}	NS	8.505×10^{-3}	1.923×10^{-3}	1.0×10^{-4}
11	Chrysene	1.258×10^{-2}	BDL	NS	1.400×10^{-3}	1.371×10^{-4}	2.0×10^{-1}
12	Benzo (b) fluoranthene	3.891×10^{-3}	5.849×10^{-3}	NS	1.653×10^{-2}	2.882×10^{-2}	2.0×10^{-1}
13	Benzo (k) fluoranthene	4.511×10^{-4}	1.485×10^{-3}	NS	2.446×10^{-3}	4.918×10^{-4}	2.0×10^{-1}
14	Benz (a) Pyrene	1.589×10^{-3}	6.909×10^{-4}	NS	2.526×10^{-2}	1.641×10^{-3}	2.0×10^{-4}
15	Indeno (1,2,3-cd) pyrene	1.866×10^{-3}	7.839×10^{-4}	NS	9.218×10^{-4}	5.419×10^{-4}	4.0×10^{-1}

S/No	PAHs	WT	ST	ET	NT	CT	USEPA 2013
16	Dibenz (a,h)anthracene	1.819 x 10 ⁻³	3.623 x 10 ⁻³	NS	2.376 x 10 ⁻¹	2.375 x 10 ⁻¹	3.0 x 10 ⁻¹
MARCH 2018							
1	Naphthalene	2.014 x 10 ⁻⁶	BDL	BDL	9.524 x 10 ⁻⁷	1.435 x 10 ⁻⁷	4.0 x 10 ⁻²
2	2-methyl-Naphthalene	4.898 x 10 ⁻⁵	6.187 x 10 ⁻⁵	BDL	1.331 x 10 ⁻⁶	BDL	4.0 x 10 ⁻²
3	Acenaphthylene	9.899 x 10 ⁻⁶	5.762 x 10 ⁻⁵	5.958 x 10 ⁻⁶	5.595 x 10 ⁻⁶	BDL	2.0 x 10 ⁻¹
4	Acenaphthene	3.231 x 10 ⁻⁶	1.339 x 10 ⁻⁵	7.781 x 10 ⁻⁶	3.504 x 10 ⁻⁷	BDL	2.0 x 10 ⁻¹
5	Fluorene	1.252 x 10 ⁻⁵	1.206 x 10 ⁻⁴	4.162 x 10 ⁻⁵	BDL	BDL	2.0 x 10 ⁻¹
6	Phenanthrene	7.332 x 10 ⁻⁵	1.328 x 10 ⁻⁴	3.207 x 10 ⁻⁴	BDL	BDL	2.0 x 10 ⁻¹
7	Anthracene	4.018 x 10 ⁻⁶	9.209 x 10 ⁻⁵	1.192 x 10 ⁻⁵	BDL	BDL	2.0 x 10 ⁻¹
8	Fluoranthene	3.628 x 10 ⁻⁵	2.002 x 10 ⁻⁴	4.820 x 10 ⁻⁵	4.917 x 10 ⁻⁶	1.003 x 10 ⁻⁵	2.0 x 10 ⁻¹
9	Pyrene	1.135 x 10 ⁻⁴	2.953 x 10 ⁻⁵	6.712 x 10 ⁻⁵	6.051 x 10 ⁻⁷	6.896 x 10 ⁻⁶	2.0 x 10 ⁻¹
10	Benz (a) anthracene	9.534 x 10⁻³	2.019 x 10⁻³	1.462 x 10⁻³	5.609 x 10⁻³	1.199 x 10⁻²	1.0 x 10⁻⁴
11	Chrysene	8.947 x 10 ⁻⁴	1.788 x 10 ⁻⁴	1.524 x 10 ⁻⁴	1.742 x 10 ⁻⁷	1.5733 x 10 ⁻⁶	2.0 x 10 ⁻¹
12	Benzo (b) fluoranthene	8.710 x 10 ⁻⁴	6.148 x 10 ⁻⁵	1.958 x 10 ⁻⁴	2.541 x 10 ⁻⁷	9.778 x 10 ⁻⁷	2.0 x 10 ⁻¹
13	Benzo (k) fluoranthene	5.284 x 10 ⁻⁵	7.909 x 10 ⁻⁴	1.728 x 10 ⁻³	4.967 x 10 ⁻⁷	3.476 x 10 ⁻⁷	2.0 x 10 ⁻¹
14	Benz (a) Pyrene	3.423 x 10⁻³	3.188 x 10 ⁻⁵	2.030 x 10 ⁻⁵	9.777 x 10 ⁻⁷	1.308 x 10 ⁻⁶	2.0 x 10⁻⁴
15	Indeno (1,2,3-cd) pyrene	3.739 x 10 ⁻⁴	3.079 x 10 ⁻⁵	7.005 x 10 ⁻⁵	4.688 x 10 ⁻⁷	2.817 x 10 ⁻⁶	4.0 x 10 ⁻¹
16	Dibenz (a,h)anthracene	1.365 x 10 ⁻³	1.148 x 10 ⁻⁴	8.109 x 10 ⁻⁵	6.568 x 10 ⁻⁷	1.485 x 10 ⁻³	3.0 x 10 ⁻¹

BDL: Below Detectable Limits. NS = Not Sampled

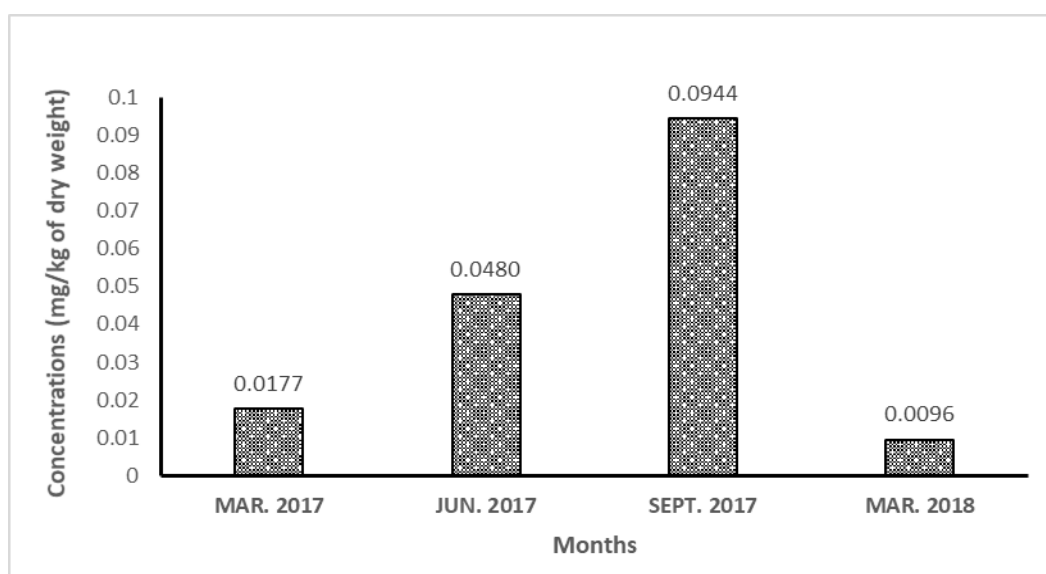


Fig 2: Effect of seasonal variation on the concentration of PAH in leaves.

3.2 Polycyclic Aromatic Hydrocarbons in Mangrove Soil

Naphthalene, 2- methyl Naphthalene, Acenaphthylene, Acenaphthene, Fluorene, Phenanthrene, Anthracene, Fluoranthene, Pyrene, Benz (a) anthracene, Chrysene, Benzo (b) fluoranthene, Benzo (k) fluoranthene, Benzo(a) pyrene, Indeno (1,2,3-cd) pyrene and Dibenz (a, h) anthracene were detected in the mangrove soil (Table 4). Table 2 shows the mean concentrations of total PAHs observed in mangrove soil at the study locations. The mean concentration observed at location ET (1.1457mg/kg) was significantly higher followed by location NT (0.6863mg/kg). The lowest PAHs concentrations in soil were observed in location CT (0.0766mg/kg), ST (0.1076mg/kg) and location WT (0.1999mg/kg) at P<0.05 using Duncan Multiple Range Test.

Mean concentrations of PAHs recorded for the months of March 2017 and June 2017 (0.6586mg/kg and 0.5441mg/kg respectively) were significantly higher than the concentrations recorded in the months of September 2017 and March 2018 (0.1962mg/kg and 0.2823mg/kg respectively) at P<0.05 using Duncan Multiple Range Test (Fig 4).

High concentration of pyrene was observed in the month of March, 2017 at location NT (2.462 x 10⁻¹). The concentrations of Benz (a) anthracene and Benz (a) pyrene in the mangrove soil were also observed to be high in the different months and locations of study (Table 3). In the month of March, 2017, high concentrations of Benz (a) anthracene were observed in all the study locations; WT (1.162 x 10⁻²), ST (3.343 x 10⁻¹), ET (2.047 x 10⁻³), NT (1.129 x 10⁻¹) and CT (1.674 x 10⁻²). High concentrations of Benz (a) pyrene were observed in locations around the flow station; WT (2.607 x 10⁻⁴), ST (13.494 x 10⁻⁴), ET (2.379 x 10⁻³) and NT (3.224 x 10⁻²).

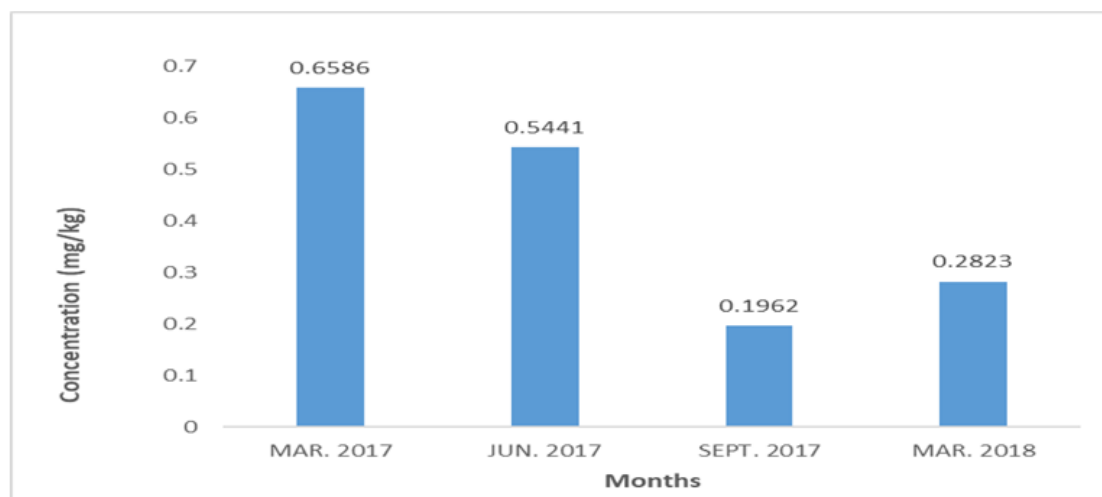


Fig 4. Effect of seasonal variation on the concentration of PAH in soil

Table 4. Mean Concentrations (ppm) of Individual Polycyclic Aromatic Hydrocarbon in the Mangrove Soil

S/No	PAHs	MARCH 2017					USEPA 2013
		WT	ST	ET	NT	CT	
1	Naphthalene	1.256×10^{-4}	5.905×10^{-5}	3.293×10^{-5}	1.242×10^{-2}	2.860×10^{-6}	4.0×10^{-2}
2	2-methyl-Naphthalene	4.613×10^{-5}	6.347×10^{-5}	1.060×10^{-5}	4.102×10^{-3}	1.215×10^{-6}	4.0×10^{-2}
3	Acenaphthylene	1.354×10^{-4}	9.622×10^{-5}	8.922×10^{-5}	BDL	5.712×10^{-6}	2.0×10^{-1}
4	Acenaphthene	2.315×10^{-5}	7.472×10^{-6}	4.614×10^{-4}	BDL	3.264×10^{-6}	2.0×10^{-1}
5	Fluorene	1.144×10^{-4}	2.088×10^{-4}	1.079×10^{-3}	BDL	2.554×10^{-5}	2.0×10^{-1}
6	Phenanthrene	1.824×10^{-4}	3.187×10^{-4}	7.577×10^{-3}	BDL	8.455×10^{-5}	2.0×10^{-1}
7	Anthracene	1.621×10^{-4}	9.435×10^{-4}	2.000×10^{-2}	BDL	2.512×10^{-5}	2.0×10^{-1}
8	Flouranthene	1.151×10^{-2}	1.393×10^{-3}	5.977×10^{-3}	1.498×10^{-1}	2.645×10^{-4}	2.0×10^{-1}
9	Pyrene	7.681×10^{-4}	1.053×10^{-3}	9.852×10^{-3}	2.462×10^{-1}	1.185×10^{-5}	2.0×10^{-1}
10	Benz (a) anthracene	1.162×10^{-2}	3.343×10^{-1}	2.047×10^{-3}	1.129×10^{-1}	1.674×10^{-2}	1.0×10^{-4}
11	Chrysene	9.976×10^{-4}	1.586×10^{-3}	4.828×10^{-3}	3.059×10^{-2}	4.139×10^{-4}	2.0×10^{-1}
12	Benzo (b) fluoranthene	1.558×10^{-3}	4.054×10^{-3}	9.382×10^{-3}	1.008×10^{-2}	6.252×10^{-7}	2.0×10^{-1}
13	Benzo (k) fluoranthene	3.599×10^{-3}	4.222×10^{-4}	6.891×10^{-3}	4.229×10^{-2}	1.088×10^{-6}	2.0×10^{-1}
14	Benz (a) Pyrene	2.607×10^{-4}	3.494×10^{-4}	2.379×10^{-3}	3.224×10^{-2}	7.393×10^{-7}	2.0×10^{-4}
15	Indeno (1,2,3-cd) pyrene	1.579×10^{-4}	5.520×10^{-4}	8.538×10^{-5}	9.945×10^{-3}	1.890×10^{-6}	4.0×10^{-1}
16	Dibenz (a,h)anthracene	7.604×10^{-3}	3.941×10^{-4}	2.648×10^{-4}	2.952×10^{-3}	2.193×10^{-6}	3.0×10^{-1}
JUNE 2017							
S/No	PAHs	WT	ST	ET	NT	CT	USEPA 2013
1	Naphthalene	3.535×10^{-5}	2.236×10^{-5}	3.654×10^{-4}	3.378×10^{-5}	3.158×10^{-6}	4.0×10^{-2}
2	2-methyl-Naphthalene	2.119×10^{-6}	4.534×10^{-6}	2.373×10^{-5}	7.458×10^{-6}	1.625×10^{-6}	4.0×10^{-2}
3	Acenaphthylene	1.834×10^{-5}	1.170×10^{-5}	8.428×10^{-5}	1.986×10^{-4}	1.015×10^{-6}	2.0×10^{-1}
4	Acenaphthene	4.414×10^{-5}	7.884×10^{-6}	BDL	4.352×10^{-5}	9.140×10^{-7}	2.0×10^{-1}
5	Fluorene	5.349×10^{-4}	2.782×10^{-4}	2.767×10^{-3}	1.754×10^{-4}	3.320×10^{-6}	2.0×10^{-1}
6	Phenanthrene	1.388×10^{-3}	3.951×10^{-4}	1.509×10^{-2}	6.792×10^{-4}	5.686×10^{-5}	2.0×10^{-1}
7	Anthracene	3.396×10^{-4}	4.847×10^{-4}	3.305×10^{-2}	1.567×10^{-3}	5.637×10^{-5}	2.0×10^{-1}
8	Flouranthene	6.127×10^{-3}	6.074×10^{-3}	3.411×10^{-2}	2.319×10^{-3}	1.044×10^{-4}	2.0×10^{-1}
9	Pyrene	7.677×10^{-4}	7.603×10^{-4}	2.962×10^{-2}	2.123×10^{-3}	8.538×10^{-5}	2.0×10^{-1}
10	Benz (a) anthracene	2.083×10^{-1}	6.129×10^{-2}	1.725×10^{-1}	5.788×10^{-1}	2.929×10^{-2}	1.0×10^{-4}
11	Chrysene	3.985×10^{-3}	6.458×10^{-3}	6.711×10^{-3}	2.338×10^{-3}	3.019×10^{-4}	2.0×10^{-1}
12	Benzo (b) fluoranthene	2.539×10^{-4}	8.165×10^{-5}	7.346×10^{-4}	6.484×10^{-3}	1.472×10^{-5}	2.0×10^{-1}
13	Benzo (k) fluoranthene	1.654×10^{-5}	1.751×10^{-4}	1.815×10^{-3}	2.226×10^{-3}	1.151×10^{-6}	2.0×10^{-1}
14	Benz (a) Pyrene	1.367×10^{-3}	1.551×10^{-3}	2.358×10^{-3}	2.614×10^{-4}	6.779×10^{-6}	2.0×10^{-4}
15	Indeno (1,2,3-cd) pyrene	3.587×10^{-4}	4.255×10^{-4}	3.118×10^{-3}	2.141×10^{-4}	2.729×10^{-6}	4.0×10^{-1}
16	Dibenz (a,h)anthracene	4.948×10^{-5}	1.101×10^{-4}	7.924×10^{-4}	6.680×10^{-6}	3.803×10^{-6}	3.0×10^{-1}
SEPTEMBER 2017							
S/No	PAHs	WT	ST	ET	NT	CT	USEPA 2013
1	Naphthalene	1.585×10^{-4}	4.984×10^{-7}	1.829×10^{-5}	4.597×10^{-7}	BDL	4.0×10^{-2}

*Corresponding Author: Ideriah, T.J.K

2	2-methyl-Naphthalene	1.671 x 10 ⁻⁵	2.132 x 10 ⁻⁸	7.221 x 10 ⁻⁶	7.941 x 10 ⁻⁶	BDL	4.0 x10 ⁻²
3	Acenaphthylene	3.985 x 10 ⁻⁵	1.842 x 10 ⁻⁶	8.208 x 10 ⁻⁵	2.742 x 10 ⁻⁴	BDL	2.0 x10 ⁻¹
4	Acenaphthene	1.327 x 10 ⁻⁵	1.302 x 10 ⁻⁶	4.331 x 10 ⁻⁵	3.021 x 10 ⁻⁴	BDL	2.0 x10 ⁻¹
5	Fluorene	5.549 x 10 ⁻⁵	1.579 x 10 ⁻⁶	3.288 x 10 ⁻⁴	3.935 x 10 ⁻⁴	4.787 x 10 ⁻⁷	2.0 x10 ⁻¹
6	Phenanthrene	9.243 x 10 ⁻⁵	4.449 x 10 ⁻⁵	4.010 x 10 ⁻³	2.125 x 10 ⁻³	1.331 x 10 ⁻⁴	2.0 x10 ⁻¹
7	Anthracene	1.687 x 10 ⁻⁵	2.502 x 10 ⁻⁵	5.916 x 10 ⁻³	1.227 x 10 ⁻³	9.272 x 10 ⁻⁵	2.0 x10 ⁻¹
8	Flouranthene	1.343 x 10 ⁻³	3.264 x 10 ⁻⁴	3.847 x 10 ⁻³	2.285 x 10 ⁻³	9.155 x 10 ⁻⁴	2.0 x10 ⁻¹
9	Pyrene	2.013 x 10 ⁻⁵	6.341 x 10 ⁻⁵	1.057 x 10 ⁻³	1.484 x 10 ⁻³	1.952 x 10 ⁻⁴	2.0 x10 ⁻¹
10	Benz (a) anthracene	5.168 x 10⁻²	1.514 x 10⁻²	5.012 x 10⁻¹	4.669 x 10⁻¹	8.914 x 10⁻²	1.0 x10⁻⁴
11	Chrysene	3.776 x 10 ⁻⁵	1.083 x 10 ⁻⁴	2.206 x 10 ⁻³	1.725 x 10 ⁻³	7.528 x 10 ⁻⁵	2.0 x10 ⁻¹
12	Benzo (b) fluoranthene	1.004 x 10 ⁻³	3.005 x 10 ⁻⁶	7.119 x 10 ⁻³	7.751 x 10 ⁻³	2.154 x 10 ⁻⁵	2.0 x10 ⁻¹
13	Benzo (k) fluoranthene	2.984 x 10 ⁻⁴	1.532 x 10 ⁻⁵	2.492 x 10 ²	7.557 x 10 ⁻³	1.049 x 10 ⁻⁵	2.0 x10 ⁻¹
14	Benz (a) Pyrene	8.706 x 10⁻⁴	2.934 x 10 ⁻⁶	8.018 x 10 ⁻⁵	2.468 x 10 ⁻⁵	5.175 x 10 ⁻⁶	2.0 x10⁻⁴
15	Indeno (1,2,3-cd) pyrene	5.901 x 10 ⁻⁴	3.228 x 10 ⁻⁶	3.910 x 10 ⁻⁵	1.106 x 10 ⁻⁴	6.396 x 10 ⁻⁶	4.0 x10 ⁻¹
16	Dibenz (a,h)anthracene	6.717 x 10 ⁻⁵	8.949 x 10 ⁻⁶	6.396 x 10 ⁻⁵	3.853 x 10 ⁻⁵	5.147 x 10 ⁻⁵	3.0 x10 ⁻¹

MARCH 2018

S/No	PAHs	WT	ST	ET	NT	CT	USEPA 2013
1	Naphthalene	1.408 x 10 ⁻⁶	1.844 x 10 ⁻⁵	1.341 x 10 ⁻⁷	4.439 x 10 ⁻⁵	2.867 x 10 ⁻⁷	4.0 x10 ⁻²
2	2-methyl-Naphthalene	1.653 x 10 ⁻⁶	1.421 x 10 ⁻⁵	3.468 x 10 ⁻⁷	2.664 x 10 ⁻⁵	1.216 x 10 ⁻⁶	4.0 x10 ⁻²
3	Acenaphthylene	3.279 x 10 ⁻⁵	1.201 x 10 ⁻⁵	1.201 x 10 ⁻⁶	1.191 x 10 ⁻⁵	5.812 x 10 ⁻⁶	2.0 x10 ⁻¹
4	Acenaphthene	4.497 x 10 ⁻⁷	2.996 x 10 ⁻⁵	8.726 x 10 ⁻⁷	1.660 x 10 ⁻⁵	3.364 x 10 ⁻⁶	2.0 x10 ⁻¹
5	Fluorene	1.227 x 10 ⁻⁴	2.889 x 10 ⁻⁵	2.511 x 10 ⁻⁵	8.495 x 10 ⁻⁶	2.854 x 10 ⁻⁵	2.0 x10 ⁻¹
6	Phenanthrene	5.909 x 10 ⁻⁴	9.286 x 10 ⁻⁵	1.636 x 10 ⁻⁴	1.246 x 10 ⁻⁴	8.855 x 10 ⁻⁵	2.0 x10 ⁻¹
7	Anthracene	2.873 x 10 ⁻⁴	8.719 x 10 ⁻⁵	8.402 x 10 ⁻⁵	5.739 x 10 ⁻⁵	2.612 x 10 ⁻⁵	2.0 x10 ⁻¹
8	Flouranthene	3.796 x 10 ⁻³	2.611 x 10 ⁻³	9.845 x 10 ⁻⁴	2.509 x 10 ⁻³	2.625 x 10 ⁻⁴	2.0 x10 ⁻¹
9	Pyrene	4.523 x 10 ⁻⁴	2.698 x 10 ⁻⁴	2.441 x 10 ⁻⁴	4.156 x 10 ⁻⁴	1.135 x 10 ⁻⁵	2.0 x10 ⁻¹
10	Benz (a) anthracene	2.165 x 10⁻¹	6.547 x 10⁻²	5.253 x 10⁻²	1.450 x 10⁻¹	1.644 x 10⁻²	1.0 x10⁻⁴
11	Chrysene	5.510 x 10 ⁻³	1.409 x 10 ⁻³	2.129 x 10 ⁻⁴	6.933 x 10 ⁻⁴	4.119 x 10 ⁻⁴	2.0 x10 ⁻¹
12	Benzo (b) fluoranthene	1.807 x 10 ⁻⁵	3.336 x 10 ⁻⁴	2.333 x 10 ⁻⁴	2.278 x 10 ⁻³	6.202 x 10 ⁻⁷	2.0 x10 ⁻¹
13	Benzo (k) fluoranthene	1.092 x 10 ⁻⁵	7.409 x 10 ⁻⁴	7.239 x 10 ⁻⁴	1.109 x 10 ⁻³	1.048 x 10 ⁻⁶	2.0 x10 ⁻¹
14	Benzo (a) Pyrene	7.523 x 10 ⁻⁵	1.509 x 10⁻³	7.495 x 10 ⁻⁷	6.872 x 10 ⁻⁵	7.333 x 10 ⁻⁷	2.0 x10⁻⁴
15	Indeno (1,2,3-cd) pyrene	6.246 x 10 ⁻⁶	3.943 x 10 ⁻⁴	2.915 x 10 ⁻⁶	3.313 x 10 ⁻⁴	1.899 x 10 ⁻⁶	4.0 x10 ⁻¹
16	Dibenz (a,h)anthracene	3.277 x 10 ⁻⁵	7.293 x 10 ⁻⁴	1.357 x 10 ⁻⁵	3.742 x 10 ⁻³	2.191 x 10 ⁻⁶	3.0 x10 ⁻¹

BDL: Below Detectable Limit

IV. DISCUSSION

4.1 Pollutants in the Mangrove Vegetation

4.1.1 Polycyclic Aromatic Hydrocarbons (PAHs) in Vegetation

Sixteen PAHs were observed in mangrove leaves around Awoba Flow Station. The detected PAHs include; Naphthalene, 2-methyl-Naphthalene, Acenaphthylene, Acenaphthene, Fluorine, Phenanthrene, Anthracene, Flouranthene, Pyrene, Benz (a) anthracene, Chrysene,

Benzo (b) fluoranthene, Benzo (k) fluoranthene, Benz (a) Pyrene, Indeno (1,2,3-cd) pyrene and Dibenz(a,h)anthracene. At the control station seven PAHs (Naphthalene, 2-methyl-Naphthalene, Acenaphthylene, Acenaphthene, Fluorine, Phenanthrene, Anthracene) were below detectable limits. Though no significant differences were observed in the total PAH concentration of mangrove leaves, the observed concentrations in location WT (0.04mg/kg), ET (0.03mg/kg), NT (0.06mg/kg) and CT (0.05mg/kg) were above the Canadian maximum recommended limit of 0.02mg/kg and therefore poses serious threat to human and other life forms within and around the Awoba Flow Station. Acenaphthene, acenaphthylene, fluorene, phenanthrene, anthracene, pyrene, benz[a]anthracene, benzo[k]fluoranthene, benzo[a]pyrene, indeno[1,2,3-c,d]pyrene, dibenz[a,h]anthracene, benzo[b]fluoranthene, fluoranthene and chrysene found in the mangrove leaves are listed as carcinogenic and mutagenic by United States Environmental Protection Agency (USEPA, 2013), however, Benz (a) anthracene and Benz (a) pyrene were the only PAHs in the mangrove leaves observed to be higher than the recommended limits of 1.0 x 10⁻⁴ and 2.0 x 10⁻⁴ ppm respectively.

The flared gas is likely the major source of PAH in leaves around the flow station, while PAHs in leaves around the control can be attributed to vehicular activities and sawmill activities around the control location. WHO (2000) reported that PAHs are formed mainly from anthropogenic activities such as incomplete combustion of organic materials, processes of coal and crude oil, combustion of natural gas, combustion of refuse, vehicle traffic, cooking and tobacco smoking, as well as in natural processes such as carbonization. Simonich and Hites (1995) stated that PAHs in plants may be due to uptake of volatilized PAHs from ambient air which is a major pathway into plant foliage.

The detection of Naphthalene in mangrove species around the flow station could be an indicator that the gas flaring is the major source of PAH in the vegetation as reported by Sporstol *et al.* (1983) which stated that Naphthalene is a major constituent of crude oils and petroleum products and can be used as an indicator of petroleum source of PAH contamination.

5.1.2 Polycyclic Aromatic Hydrocarbons (PAHs) in Mangrove Soil

Sixteen Polycyclic aromatic hydrocarbons (PAHs) were detected in the mangrove soil. Detected PAHs include; Naphthalene, 2- methyl Naphthalene, Acenaphthylene, Acenaphthene, Fluorene, Phenanthrene, Anthracene, Fluoranthene, Pyrene, Benz (a) anthracene, Chrysene, Benzo (b) fluoranthene, Benzo (k) fluoranthene, Benzo(a) pyrene, Indeno (1,2,3-cd) pyrene and Dibenz (a, h) anthracene. The identified PAHs in soil are in consonance with PAH in soil reported by Tuteja et al. (2011). Fourteen out of the sixteen PAHs identified are listed as carcinogenic and mutagenic by the United States Environmental Protection Agency (USEPA). Total PAHs concentration of soil recorded in all the locations were above the Canadian maximum recommended limit of 0.02mg/kg and therefore poses serious threat to human and other life forms in the mangrove forest ecosystem around the Awoba Flow Station. Carcinogenic and mutagenic PAHs such as pyrene, Benz (a) anthracene and Benz (a) pyrene were observed to have concentrations higher than USEPA, 2013 recommended limits (2.0×10^{-1} , 1.0×10^{-4} and 2.0×10^{-4} respectively) in the mangrove soil.

The detection of PAHs in mangrove soil agrees with the report by Ite and Semple (2012) that soil and sediments are the ultimate sink for most petroleum contaminants, such as benzene, toluene, ethyl benzene, and xylenes (BTEX), aliphatic and polycyclic aromatic hydrocarbons (PAHs). Concentration of PAH observed in mangrove soil are significantly higher in location ET (1.1457mg/kg). PAH concentration in location CT (0.0766mg/kg), ST (0.1076mg/kg) and location WT (0.1999mg/kg) were not significantly different, however the mean value recorded for the control (CT) was observed to be lower, an indication that pollutants concentration decreases with increasing distance from flare locations as reported by Ezeigbo, *et al.*, 2013. Sojину *et al.* (2010) suggested that predominant presence of PAHs of pyrogenic sources in surface soils is an indication that either oil leakage, gas flaring or both contributes to soil contamination.

Mean soil concentration of PAHs in the months of March 2017 and June 2017 (0.6586mg/kg and 0.5441mg/kg respectively) were significantly higher than the concentration recorded for the months of September 2017 and March 2018 (0.1962mg/kg and 0.2823mg/kg respectively). The low concentration of PAH in the month of September can be attributed to seasonal effect on pollutant concentration as reported by Ideriah (2011).

V. Conclusion

This research has provided evidence on the distribution of PAHs in vegetation and soil of the mangrove forest around Awoba flow station. Carcinogen and mutagenic polycyclic aromatic hydrocarbons such as Benz(a)anthracene and Benz (a) pyrene had concentrations higher than the recommended standard limit by USEPA (2013) both in the mangrove soil and leaves around Awoba flow station. The total PAH concentrations in mangrove soil and leaves were also above the Canadian maximum recommended limit of 0.02 mg/kg in all the study locations.

References

- [1]. Abdulkadir, M.; Isah, A. G. & Sani Y. (2013) The Effect of Gas Flaring on the Environment and its Utilization (Case Study of Selected Villages in Niger Delta Area of Nigeria). *Journal of Basic and Applied Scientific Research*. 3(4).
- [2]. Abere, S.A & Ekeke, B.A (2011). The Nigerian Mangrove and Wildlife Development. Proceedings of the 1st International Technology, Education and Environment Conference (c) African Society for Scientific Research (ASSR).
- [3]. Ite, A.E. & Ibok U. J. (2013). "Gas Flaring and Venting Associated with Petroleum Exploration and Production in the Nigeria's Niger Delta. *American Journal of Environmental Protection*, 1(4) 70-77
- [4]. Eniscuola Energy & Environment (2015). Gas Flaring and Gas Venting. Accessed at www.eniscuola.net/argomento/natural-gas1/environment-and-territory1/gas-flaring-and-gas-venting
- [5]. ERA (Environmental Right Action) (1999). Shell Oil Spill in Bille in Niger Delta's Rivers State. Urhobo History Society.
- [6]. Ezeigbo O.R., Okike-Osisiogu, F.U., Ihemanma C.N. & Agomoh, N.G. (2013) Microbial Effects of Gas Flaring on Agricultural Soil at Izombe Flow Station, Imo State Nigeria. *Journal of Biology, Agriculture and Healthcare*. 2(15).
- [7]. Ite, A. E. & Semple, K. T. (2012) "Biodegradation of petroleum hydrocarbons in contaminated soils," *Microbial Biotechnology: Energy and Environment*, R. Arora, ed., 250-278, Wallingford, Oxfordshire: CAB International.
- [8]. Ideriah, T.J.K., Emerhi E.A., Abere, S.A. & Trinya W. (2011) Levels of Total Hydrocarbon Contents in Plants Along Selected Roadsides in Port Harcourt Metropolis, Nigeria. *Journal of Agriculture and Biological Sciences* vol 2(3).
- [9]. Ideriah, T.J.K., Abere, S.A. & Trinya, W. (2012). Correlation between selected ambient air pollutants and total hydrocarbon content in plant leaves along roadsides in an industrialized city in Niger Delta, Nigeria. *Journal of environmental Sciences, Computer Science and Engineering & Technology* vol 1(2).
- [10]. Kindziarski, W. B. (1999). "Importance of human environmental exposure to hazardous air pollutants from gas flares," *Environmental Reviews*, 8 (1). 41-62.
- [11]. Kostiuk, L., Johnson, M. & Thomas, G. (2004). "University of Alberta Flare Research Project Final Report November 1996–September 2004," University of Alberta, Department of Mechanical Engineering.
- [12]. Leahey, D.M., Preston, K. & Strosher, M. J. (2001) Air Waste Management. Association 51, 1610-1616. [27
- [13]. Obadimu, O.O., Owese, T., Bolaji-Olutunji, K.A., and Abi, E.A. (2016) Mangrove Forest in Nigeria: A Panoramic View. *Nigerian Journal of Forestry*; Article 2: 38th Annual Conference of the Forestry association of Nigeria
- [14]. Ohimain, E.I. (2006). Personal communication via email: West African Mangrove Report. 28th July 2006.
- [15]. Olajire, A. A., Altenburger, R. Küster, E. & Brack, W. (2005) "Chemical and ecotoxicological assessment of polycyclic aromatic hydrocarbon - contaminated sediments of the Niger Delta, Southern Nigeria." *Science of the Total Environment*, 340 (1-3). 123

- [16]. Osuji, L. C. & Ozioma, A. (2007) "Environmental Degradation of Polluting Aromatic and Aliphatic Hydrocarbons: A Case Study." *Chemistry & Biodiversity*, 4 (3). 424-430.
- [17]. Simbi-Wellington, W.S. (2019) Assessment of Impact of Gas Flaring on The Mangrove Forest Ecosystem at Awoba Flow Station Bille Rivers State. PhD Thesis submitted to Post Graduate School, Rivers State University.
- [18]. Simonich, S.L. & R.A. Hites, 1995. Organic pollutant accumulation in vegetation. *Environ. Sci. Technol.*, 29: 2905-2914.
- [19]. Sojini, O. S. S., Wang, J.Z. Sonibare, O. O. & Zeng, E. Y. (2010). "Polycyclic aromatic hydrocarbons in sediments and soils from oil exploration areas of the Niger Delta, Nigeria." *Journal of Hazardous Materials*, 174 (1-3). 641-647.
- [20]. Sporstol, S., Gjos, N., Lichtenthaler, R.G., Gustavsen, K.O., Urdal, K., Oreld, F., & Skei, J. (1983). Source identification of aromatic hydrocarbons in sediment using GC/MS. *Environmental Science and Technology* 17, 282-286.
- [21]. Strosher, M. T., (2000) "Characterization of emissions from diffusion flare systems," *Journal of the Air & Waste Management Association*, 50 (10). 1723-1733.
- [22]. Tuteja, G. Rout, C. & Bishmoi N.R (2011) Quantification of Polycyclic Aromatic Hydrocarbon in Leafy and Underground Vegetables: A case study around Panipat City, Haryana, India. *Journal of Environmental Science and Technology* 4(6).
- [23]. Ubani, E. C. & Onyejekwe, I. M. (2013). Environmental impact analyses of gas flaring in the Niger-Delta region of Nigeria. *American Journal of Scientific and Industrial Research*. 4(2),
- [24]. Ugbebor, J.N. & Yorkor, B. (2018). Assessment of Ambient Air Quality of Noise Level around Selected Oil and Gas Facilities in Nigeria. *Journal of Scientific Research and Report*. 18(6).
- [25]. Wikipedia 2014. The Bille Tribe. Accessed at www.cyclopaedia.infor/wiki/Bille-tribe