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Assessment of Air Quality in Mangrove Forest around Gas Flare in Awoba Flow Station in Rivers State Nigeria

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Abstract: *This research was conducted to assess the impact of gas flaring at Awoba Flow Station on the air quality around mangrove forest ecosystem in Bille, Rivers State. Air pollutants such as Total Particulate Matter (TPM), Volatile Organic Carbon (VOC), methane (CH_4), Hydrogen Sulphide (H_2S), Carbon monoxide (CO), Nitrogen dioxide (NO_2), Sulphur dioxide (SO_2) were assessed. The results of NO_2, VOC, CO, and CH_4 concentrations were significantly higher in the West location ranging from 0.119833ppm, 27.735833ppm, 0.7083ppm to 2.3750ppm respectively and lowest at the control location ranging from 0.008188ppm, 1.168750 ppm, 0.0000 ppm to 0.7500 ppm respectively. The air quality of the area is poor as pollutants such as NO_2, VOC, and NH_3 were above their recommended limits by WHO. The use of flaring to dispose unwanted gas should be discouraged and regular monitoring of these pollutants was recommended.*

Keywords: *Air Quality, Flow Station, Mangrove forest, Degema*

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I. Introduction

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 lying between 4° 34' 37" North and 6° 53' 19" East with a population of thirty thousand people according to the Nigeria 1999 census. Fishing is the main occupation of the people [1].

Awoba flow station lies along 4^0 31' 51.486" N, 6^0 49' 11.962" E while Degema lies along 4^0 46' 39.908" N, 6^0 46' 25.980" E. Both 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 [2].

Mangrove is ecologically and taxonomically referred to as the dominant shrubs and trees which form the plant communities in tidal saline wetlands of the sub-tropical and tropical coasts [3]. Mangrove trees and shrubs are commonly known to thrive in shallow and muddy salt water or in brackish waters, mostly along shorelines and estuaries in tropical and sub-tropical regions because they cannot withstand the freezing temperatures of the temperate and polar regions. Mangrove is distinct structurally and functionally by its morphological and eco-physiological characteristics [4].

Mangrove is commercially and traditionally used worldwide. Communities in the coastal areas depend on the mangrove wood for building houses, heating and cooking, making of huts and fences, scaffolds and matting. Wood gotten from the mangrove is widely used for charcoal production, fish cages and trap production, furniture making, bridge and boat construction, poles and many other products. While its tannin and resins are used for dying and leather making. The mangrove plants are also used for herbal medicines [5]. The mangrove provides several human utility benefits as well as ecosystem functions for communities in the coastal areas of the Niger Delta, Nigeria. The mangrove plays important role in biogeochemical cycle, nutrient export, coastal protection, sediment trapping and also provide breeding and nursery grounds for marine and estuarine organisms [6]. The Niger Delta mangroves are considered to play important roles in carbon sequestration, sink for carbon dioxide and mitigates changes caused by air pollution [7]. The halophytic nature of the mangrove and the ability to survive low oxygen in the soil aids its existence in the coastal swamps [8]. However, the breathing root system of the mangrove makes it vulnerable to oil spill attack; which leads to blockage of the root openings.

According to [9] the mangrove plays an important role in coastal ecosystem, contributing to coastal fishery, preventing erosion, serving as nurseries for prawns and fish and acts as barriers to storm and tidal surges. However, the report further stated that the mangrove forest is currently less than 50% of its initial coverage and over 50% of what is left is degraded and not adequately productive.

Gas flaring according to [10] is the combustion of the natural gas associated with crude oil during the exploration and production process and is mostly employed in areas where infrastructure is not sufficient

enough to effectively use the natural gas [11]. Gas flaring is hence a means of disposal of the unwanted natural gas. Gas flaring is carried out by means of a combustion facility called the flare stack. Flaring can be programmed to occur temporarily, periodically or continually. Another means of disposing associated gas through venting. Venting is the deliberate release of associated gas without any means of combustion [12]. Flaring and venting causes the emission of several air pollutants. The type of pollutants emitted during combustion depends on the chemistry of the gas being burnt, the disposal method (flaring or venting) and the combustion efficiency [12].

[13] reported that flaring and venting of associated gas in the Niger Delta contributes to annual atmospheric concentrations of approximately 35 million metric tons of CO_2, CH_4, hydrocarbons and other green–house gases. [14] stated that gas flaring emits CO_2, CO, CH_4, H_2S, NO_2, NO, N_2O, SO_2, SO_3, soot, smoke and heat. [15] reported that pollutants such as N_2O, CO_2, CO, SO_2, PM, HC and H_2O arising from gas flaring contaminates the atmosphere. According to [16] Particulate Matter is a complex mixture of liquid and solid particles of inorganic and organic substances suspended in the air with nitrates, sulphate, ammonia, sodium chloride, black carbon, mineral dust and water as its major constituents. Particulate Matter have been reported to affect more people than any other pollutant. [17] also reported that Flaring of associated gas releases pollutants such as CO_2, CO and a variety of air pollutants, such as VOCs, NOx, SO_2, toxic heavy metals, and black carbon soot. According to [13], [18], [19], non-effective flare system result in incomplete combustion that releases a variety of VOCs, PAHs and inorganic contaminants.

Vehicular emissions also give rise to air pollutants. The burning of hydrocarbons in the engines of vehicles give rise to air pollutants such as CO_2, CO, SO_2, NO and NO_2 [20]. [21] reported that vehicular emissions accounts for 40% to 50% of the total emission of volatile hydrocarbons and other hydrocarbons, 70% emitted by incomplete combustion, 10% in the process of fuelling, 20% by storage unit evaporation.

Increase in industrialization has caused an increase in environmental pollution. Several researches have shown that the load of contaminants in vegetation, soil and air around gas flare sites are increasing yearly and negatively impacts on the forest ecosystems where the operating facilities are located. Regular assessment of the forest ecosystems where oil facilities are located and gas flared and the early detection of pollutants around such facilities is essential for economic and environmental safety.

This study aims to assess the levels of air pollutants in the area as a result of gas flaring in the mangrove forest ecosystem around Awoba Flow Station.

In Africa, Nigeria is the highest emitter of greenhouse gas, classified as the sixth producer of crude oil in the world, and is ranked as one of the top 10 countries releasing 75% of the flaring emissions in the world [22] with about 123 flaring sites and over 250 oil fields. Many flaring sites burn 24hours daily and have been flaring for over 50 years. Over the years, this practice has endangered the health of human and has adversely affected the environment, particularly coastal communities [23]. According to [24] gas flaring is a major contributor to environmental hazards such as acid rain which has impacted heavily on the Niger Delta environment causing damage to vegetation, increased mortality of aquatic lives and corrosion of roofing sheets. [25] reported that emissions from gas flaring increases atmospheric greenhouse concentration and contributes to global warming. Gas flaring emissions are the main sources of lung irritants (NOx, SOx, H_2S) and carcinogenic benzene [26]. Gas flaring also gives rise to other environmental problems such as high temperature, noise pollution and visibility reduction caused by soot arising from the flares. Reports from local communities in the Niger-Delta region of Nigeria reveals that the unpleasant odour, loud noise and high temperature caused by flaring and venting have resulted in several health issues such as cancer, skin diseases, hearing problems, respiratory and eye infections [27], [28].

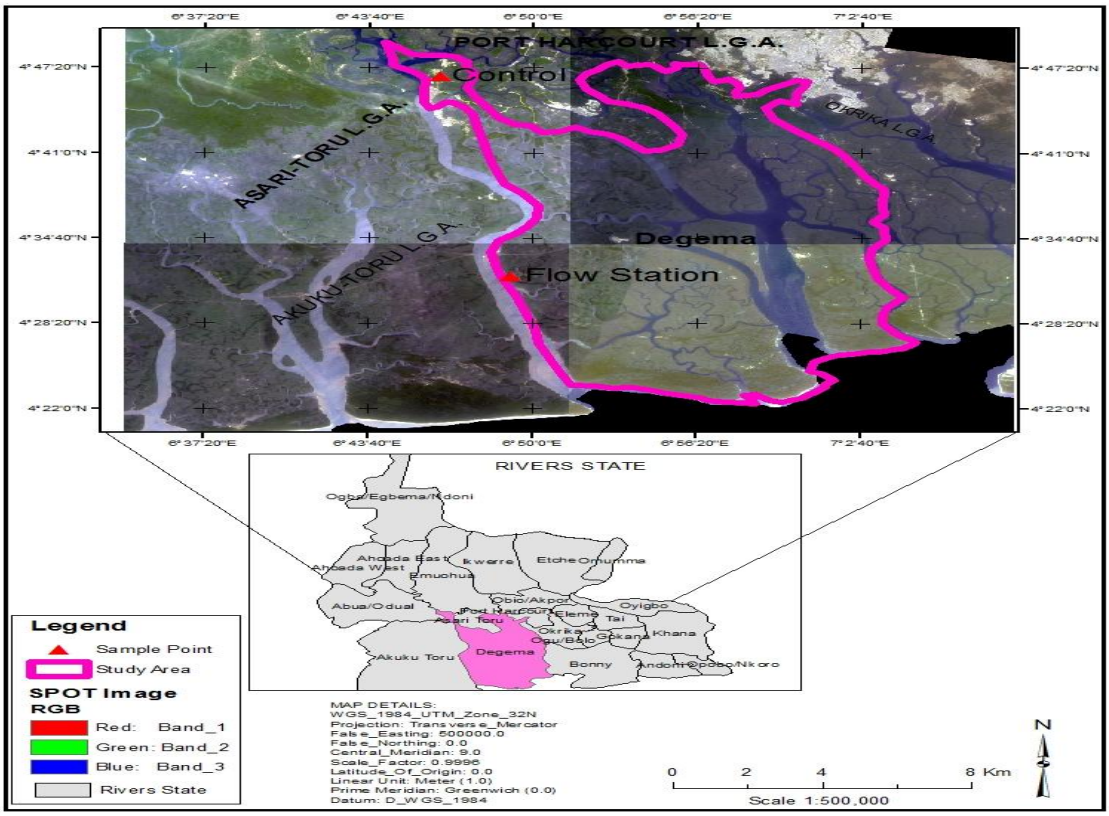


Fig. 1 Map of Rivers State showing Degema Local Government area and study area

II. Materials And Methods

Table 1. Identification and Geographical Coordinates of Study Locations

LOCATION	N (Latitude)	E (Longitude)
CENTRAL POINT	4^0 31' 52.90"	6^0 49' 10.45"
WEST 1	4^0 31' 52.88"	6^0 49' 09.38"
WEST 2	4^0 31' 52.61"	6^0 49' 08.49"
WEST 3	4^0 31' 52.57"	6^0 49' 07.42"
SOUTH 1	4^0 31' 50.90"	6^0 49' 11.20"
SOUTH 2	4^0 31' 48.74"	6^0 49' 12.43"
SOUTH 3	4^0 31' 46.97"	6^0 49' 13.64"
EAST 1	4^0 31' 53.59"	6^0 49' 13.13"
EAST 2	4^0 31' 55.54"	6^0 49' 18.16"
NORTH 1	4^0 32' 00.85"	6^0 49' 08.79"
NORTH 2	4^0 30' 00.37"	6^0 49' 02.16"
NORTH 3	4^0 31' 56.50"	6^0 49' 02.30"
CONTROL CENTRAL	4^0 46' 43.91"	6^0 49' 25.98"
CONTROL 1	4^0 46' 44.70"	6^0 49' 27.93"
CONTROL 2	4^0 46' 45.50"	6^0 49' 29.55"
CONTROL 3	4^0 46' 42.59"	6^0 49' 28.40"
CONTROL 4	4^0 46' 46.27"	6^0 49' 27.54"

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 Line Model (GLM) of SPSS statistical package [29]. Means were considered significant at $P \leq 0.05$ and were separated using Duncan Multiple Range Test.

Measurement of Air Pollutants

Digital hand held monitors were used for measurement of air pollutants. The air pollutants monitored in the study area which are; Particulate Matter [PM_1, $PM_{2.5}$, PM_7, PM_{10} and Total Suspended Particulate Matter(TSP)], Volatile Organic Compounds (VOCs), Methane (CH_4), Hydrogen Sulphide (H_2S), Carbon Monoxide (CO), Nitrogen dioxide (NO_2), Sulphur Dioxide (SO_2) and Ammonia (NH_3).

A Met One Instrument INC aerosol mass monitor was used for the detection of Particulate Matter; Multi RAE PLUS (PGM-50) programmable Multi Gas Monitor was used to determine VOC and SO_2. An industrial scientific corporation TX Multi Gas Monitor model GC 401 was used for detection of CO. ITX Multi Gas Monitor was used for the detection of NO_2 while a defender Multi Gas Detector, Model DZ-2002, manufactured by DW Technologies was used for the determination of methane gas.

Particulate Matter

A MET One Instrument INC aerosol mass monitor was used for the detection of particulate matter. The mass monitor with recorder collects and records information on air borne particulate concentration in addition to providing continuous particle monitoring. The concentration is limited to 300micrograms with a measuring sensitivity of 0.1 microgram. Particulate matter was categorized and measured according to their mean aerodynamic sizes of PM_1, $PM_{2.5}$, PM_7, and PM_{10}.

Volatile Organic Carbons (VOCs)

A Multi RAE PLUS (PGM-50) programmable Multi Gas Monitor was used to measure VOCs. It has a photo-ionization detector (PID) using 10.6 eV gas discharging lamp. It has an integrated sampling pump diaphragm providing about 250cc per minute flow at high setting. It measures VOC over two ranges; 0 – 200 ppm with a resolution of 0.1ppm and 200-2,000ppm, with a resolution of 1ppm.

Carbon Monoxide (CO)

An Industrial Scientific Corporation TX Multi Gas Monitor Model GC 401 was used for measurement of CO. The equipment detects CO via an electrochemical sensor that generates a signal linearly proportional to the concentration of the gas. The range of detection is between 1-1999ppm, and the limit of detection is 1ppm. Measurement was done at each sampling location by holding the sensor to a height of about 2 m in the direction of the prevailing wind and readings recorded at stability.

Sulphur dioxide (SO_2) and Hydrogen Sulphide (H_2S)

A Multi RAE PLUS (PGM-50) programmable multi gas monitor with electrochemical sensor was used for the detection of SO_2 and H_2S. The range of detection was between 0-20ppm with a resolution of 0.1ppm. Measurement was done by holding the sensor to a height of 2m in the direction of the prevailing wind and readings recorded at stability.

Nitrogen dioxide (NO_2)

An ITX Multigas Monitor was used for the detection of NO_2. The range of detection was between 0-999ppm with a resolution of 0.1ppm. Measurement was done by holding the sensor to a height of 2m in the direction of the prevailing wind and readings recorded at stability.

Methane (CH_4)

A Defender Multi- Gas Detector, Model DZ-2002, manufactured by DW Technologies was used for the determination of methane gas. The equipment detects the gas via a plug-in catalytic bead and has a detection range of 0-100% LEL i.e. 0-5% CH_4. Measurement was done by holding the sensor to a height of 2m in the direction of the prevailing wind and readings recorded at stability. The limit of detection was 0.01% methane.

Measurements of Meteorological Parameters

Meteorological parameters such as temperature, relative humidity, wind speed and wind direction were measured. Extech Portable hand held weather station was used to record wind speed, temperature and relative humidity. The equipment determines the wind via wind vane which was held to a height of 2m in the prevailing wind direction. A Compass Model M-73 was used to determine the direction of wind. GPS co-ordinates of the study area and control station were recorded with digital hand held GPS recorder.

III. Results

Particulate Matter

The mean concentrations of PM_1, observed in location ET (0.001375mg/m^3) and CT (0.001375 mg/m^3) were significantly higher than the mean concentrations observed in the other locations; WT (0.00500 mg/m^3), ST (0.000083 mg/m^3) and NT (0.000417 mg/m^3) at P≤0.05 (Table 2). The highest mean concentration of $PM_{2.5}$ was observed in location ET (0.006367 mg/m^3) while the lowest was observed in location ST (0.002292 mg/m^3). Mean concentrations of PM_7, PM_{10} & TSP were significantly higher in location ET (0.016583mg/m^3, 0.021225mg/m^3 & 0.023333 mg/m^3 respectively), NT (0.014833mg/m^3, 0.017792mg/m^3 & 0.023667mg/m^3 respectively) and CT (0.014688mg/m^3, 0.019312mg/m^3 & 0.023000mg/m^3 respectively). The lowest mean concentration of PM_7 was observed in location ST (0.007417mg/m^3) while the lowest for PM_{10} and TSP were observed in location ST (0.009458mg/m^3 & 0.010958mg/m^3 respectively) and WT (0.011083mg/m^3 & 0.012917mg/m^3 respectively) as shown in Table 2.

The mean concentration of PM_1, $PM_{2.5}$, PM_7, PM_{10} & TSP recorded in the month of March 2017 (0.001656mg/m^3, 0.008375mg/m^3, 0.018250mg/m^3, 0.022000mg/m^3 & 0.027869mg/m^3 respectively) was significantly higher than the mean concentrations recorded in the other months of data collection as shown in Table 3 at P≤0.05. The lowest concentrations of $PM_{2.5}$, PM_{10} & TSP were recorded in the month of September 2017 (0.001125mg/m^3, 0.009500mg/m^3 & 0.011563mg/m^3 respectively).

Gaseous Air Pollutants

The mean concentrations of NO_2, VOC, CO, and CH_4 as shown in tab 4.6 were significantly higher in location WT (0.119833ppm, 27.735833ppm, 0.7083ppm & 2.3750ppm respectively). The lowest mean concentrations of these parameters were recorded in location CT (0.008188ppm, 1.168750 ppm, 0.0000 ppm & 0.7500 ppm respectively). The highest mean concentration of SO_2 was observed in location NT (0.072125 ppm) while the lowest was observed in location CT (0.001875 ppm). The highest mean concentration of NH_4 was observed in location ET (6.2042 ppm), the lowest was observed in location CT (0.0000 ppm) Table 4.

No significant differences were observed in the mean concentrations of NO_2 and NH_4 recorded in all the months of data collection as shown on Table 5. The mean concentration of SO_2 was highest in the month of March 2018 (0.086250 ppm) and lowest in the months of September 2017 (0.004375 ppm) and March 2017 (0.023750 ppm). The mean concentrations of VOC and CH_4 were highest in the month of March 2018 (24.637500 ppm & 2.26250 ppm respectively) and lowest in the month of September 2017 (0.138125 ppm & 0.3125 ppm respectively). The highest mean concentration of CO was observed in the months of March 2017 (0.3750 ppm) and March 2018 (0.3125 ppm) and lowest in the month of September 2017 (0.0625 ppm).

Table 2. Mean Concentrations of Particulate Matter at the Study Locations

Location	Mean Concentrations (mg/m^3) of Particulate Matter				
	PM_1	**$PM_{2.5}$**	**PM_7**	**PM_{10}**	**TPM**
WT	0.000500^{b}	$0.003708^{c,d}$	0.009583^{b}	0.011083^{b}	0.012917^{b}
ST	0.000083^{b}	0.002292^{d}	0.007417^{c}	0.009458^{b}	0.010958^{b}
ET	0.001375^{a}	0.006367^{a}	0.016583^{a}	0.021225^{a}	0.023333^{a}
NT	0.000417^{b}	$0.004292^{b,c}$	0.014833^{a}	0.017792^{a}	0.023667^{a}
CT	0.001375^{a}	$0.005500^{a,b}$	0.014688^{a}	0.019312^{a}	0.023000^{a}

Mean with different superscripts within columns are significantly different at p≤0.05 using DMRT

Table 3. Effect of Seasonal Variation on the Mean Concentrations of Particulate Matter

MONTHS	Mean Concentrations (mg/m^3) of Particulate Matter				
	PM_1	**$PM_{2.5}$**	**PM_7**	**PM_{10}**	**TPM**
MAR. 2017	0.001656^{a}	0.008375^{a}	0.018250^{a}	0.022000^{a}	0.027869^{a}
JUN. 2017	0.000688^{b}	0.003431^{c}	0.009312^{c}	0.014794^{b}	0.016600^{b}
SEPT. 2017	0.000437^{b}	0.001125^{d}	0.008187^{c}	0.009500^{c}	0.011563^{c}
MAR. 2018	0.000250^{b}	0.005063^{b}	0.015250^{b}	0.017688^{b}	0.020125^{b}

Mean with different superscripts within columns are significantly different at p≤0.05 using DMRT

Table 4. Mean Concentrations of Gaseous Air Pollutants at the Study Locations

Location	Mean Concentrations (ppm) of Gaseous Air Pollutants					
	NO_2	**SO_2**	**VOC**	**CO**	**NH_3**	**CH_4**
WT	0.119833^{a}	$0.049583^{a,b}$	27.735833^{a}	0.7083^{a}	$0.6667^{a,b}$	2.3750^{a}

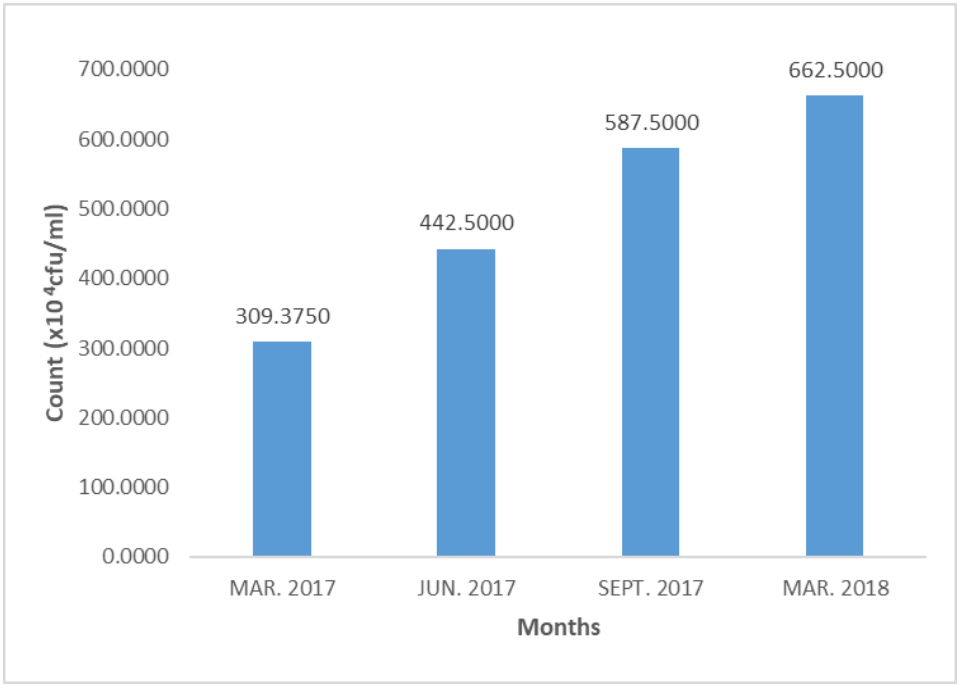
ST	0.057792^{b}	0.060417^{a,b}	9.800000^{c}	0.0833^{c}	0.4167^{a,b}	1.1667^{b,c}
ET	0.063917^{b}	0.043750^{b}	10.562500^{b,c}	0.4167^{b}	6.2042^{a}	1.2500^{b,c}
NT	0.078375^{a,b}	0.072125^{a}	15.700833^{b}	0.0000	1.5000^{a,b}	1.6667^{b}
CT	0.008188^{c}	0.001875^{c}	1.168750^{d}	0.0000	0.0000	0.7500^{c}

Mean with different superscripts within columns are significantly different at p≤0.05 using DMRT

Table 5. Effect of Seasonal Variation on the Mean Concentrations of Gaseous Air Pollutants

MONTHS	**Mean Concentrations (ppm) of Gaseous Air Pollutants**					
	NO_2	**SO_2**	**VOC**	**CO**	**NH_3**	**CH_4**
MAR. 2017	0.068156^{a}	0.023750^{c}	16.633125^{b}	0.3750^{a}	3.5031^{a}	1.1563^{b}
JUN. 2017	0.052719^{a}	0.056906^{b}	7.609375^{c}	0.1563^{a,b}	0.3750^{a}	1.5000^{b}
SEPT. 2017	0.052188^{a}	0.004375^{c}	0.138125^{d}	0.0625^{b}	1.1500^{a}	0.3125^{c}
MAR. 2018	0.075063^{a}	0.086250^{a}	24.637500^{a}	0.3125^{a}	1.5625^{a}	2.6250^{a}

Mean with different superscripts within columns are significantly different at p≤0.05 using DMRT



IV. Discussion

Particulate Matter

The mean concentrations of PM_1, observed in location ET (0.001375mg/m^3) and CT (0.001375 mg/m^3) were significantly higher than the mean concentrations observed in the other locations; WT (0.00500 mg/m^3), ST (0.000083 mg/m^3) and NT (0.000417 mg/m^3). The highest mean concentration of $PM_{2.5}$ was observed in location ET (0.006367 mg/m^3) while the lowest was observed in location ST (0.002292 mg/m^3). Mean concentrations of PM_7, PM_{10} & TPM were significantly higher in location ET (0.016583mg/m^3, 0.021225mg/m^3 & 0.023333 mg/m^3 respectively), NT (0.014833mg/m^3, 0.017792mg/m^3 & 0.023667mg/m^3 respectively) and CT (0.014688mg/m^3, 0.019312mg/m^3 & 0.023000mg/m^3 respectively). The lowest mean concentration of PM_7 was observed in location ST (0.007417mg/m^3) while the lowest for PM_{10} and TPM were observed in location ST (0.009458mg/m^3 & 0.010958mg/m^3 respectively) and WT (0.011083mg/m^3 & 0.012917mg/m^3 respectively). The concentrations of particulate matter observed at the study stations were below permissible limits recommended and therefore pose no significant threat to the surrounding environment. $PM_{2.5}$ PM_{10} and TPM were all below the 24hour limits (10µg/m^3, 50µg/m^3 and 100µg/m^3 respectively) recommended by [16]. The low concentrations of particulate matter observed at the study locations could be as a result of high wind speed arising from the seas (Bille creek and Sombriero River), which could lead to the dispersal of these particulates.

It was generally, observed that the concentrations of PM_1, $PM_{2.5,}$ PM_7, PM_{10} and TSP were higher in location ET, this could be attributed to the dust and smoke particles generated from fish drying and smoking activities at a fishing settlement in close proximity to the location. [30] reported that the high concentrations of particulate matter at two locations in the Port Harcourt metropolis were as a result of abattoir activities which included the burning of animal skin. The high concentrations of PM observed at the control location could be attributed to vehicular emissions from the adjacent road. The control station is located close to a major road linking Degema and Akuku-Toru local Government Areas of the state. Other small-scale commercial activities (Roasting of plantain and fish with charcoal) were also observed around the location and could have greatly affected the concentration of PM at that location. [31] reported that road traffic is a major source of anthropogenic distribution of particulate matter. [30] reported that high traffic densities as well as other industrial and commercial activities are major contributors of particulate matter in the Port Harcourt metropolis.

The mean concentration of PM_1, $PM_{2.5}$, PM_7, PM_{10} & TSP recorded in the month of March 2017 (0.001656mg/m^3, 0.008375mg/m^3, 0.018250mg/m^3, 0.022000mg/m^3 & 0.027869mg/m^3 respectively) were significantly higher than the mean concentrations recorded in the other months of data collection. lowest concentrations of $PM_{2.5}$, PM_{10} & TSP were recorded in the month of September 2017 (0.001125mg/m^3, 0.009500mg/m^3 & 0.011563mg/m^3 respectively). This result is in agreement with the report by [32], which stated that the concentration of PM in the wet season months were lower than concentrations recorded in the dry season months. The report stated that the high concentrations of PM observed during the dry season months can be attributed to high content of dust particles arising from the North-East Trade Wind. [33], [30] also observed the same pattern of PM distribution in the dry and wet season months.

Gaseous Air Pollutants

Mean concentrations of NO_2, VOC, CO, and CH_4 as were significantly higher at location WT (0.119833ppm, 27.735833ppm, 0.7083ppm & 2.3750ppm respectively). The lowest mean concentrations of these parameters were recorded in location CT (0.008188ppm, 1.168750 ppm, 0.0000 ppm & 0.7500 ppm respectively). This observation implicates gas flaring as the major source of these pollutants around the mangrove in the study area, and is in consonance with the report by [17] which stated that Flaring of associated gas mainly emits carbon dioxide (CO_2), carbon monoxide (CO) and a variety of air pollutants, such as VOCs, nitrogen oxides (NO_x) and sulphur dioxide (SO_2). The concentrations of the pollutants observed in location WT can be attributed to the effect of wind, since the observed wind direction was South-West. [34] reported that wind speed and direction determine the dispersal of air pollutants from the oil and gas facilities. The concentrations of NO_2, and VOC recorded at location WT exceeded their permissible limits of 0.004ppm and 0.05ppm respectively, recommended by [35]. The concentrations of NH_3 observed around the flare locations were above the tolerant limit (0.15ppm) by [36]. This is an indication of low air quality index around the study location and poses high risk to the environment. The highest mean concentration of SO_2 was observed at location NT (0.072125 ppm) while the highest mean concentration of NH_3 was observed at location ET (6.2042 ppm); the lowest concentrations of both pollutants were observed at location CT (0.001875 ppm and 0.0000 ppm respectively) which is in agreement with the report by [37] which stated that concentrations of air quality parameters such as SO_2, NO_2, H_2S, CO, VOC and PM were observed to be higher at test distances near flare point and lower values at distances farther away from flare point. SO_2 concentrations were observed to be lower than the permissible limit of 20µg/m^3 (24 hours mean) recommended by [16]. [38] reported that the Nigerian natural gas is classified as sweet, having a low sulphur contents, however, results from studies on flaring operation in the Niger Delta region revealed that SO_2 is one of the products of natural gas flare in Nigeria.

No significant differences were observed in the mean concentrations of NO_2 and NH_4 recorded in all the months of data collection. Mean concentration of SO_2 was highest in the month of March 2018 (0.086250 ppm) and lowest in the months of September 2017 (0.004375 ppm) and March 2017 (0.023750 ppm). The mean concentrations of VOC and CH_4 were highest in the month of March 2018 (24.637500 ppm & 2.26250 ppm respectively) and lowest in the month of September 2017 (0.138125 ppm & 0.3125 ppm respectively). The highest mean concentration of CO was observed in the months of March 2017 (0.3750 ppm) and March 2018 (0.3125 ppm) and lowest in the month of September 2017 (0.0625 ppm). This result agrees with the reports of [31], [30] that the concentrations of pollutants in the wet season months are generally lower than the concentrations in the dry season months.

Conclusion

This research has provided evidence on the distribution of air pollutants in the mangrove forest around Awoba flow station.

The quality of air in the area is poor as pollutants such as NO_2, VOC, and NH_3 were above the recommended limits by the World Health Organization and therefore pose potential danger in the area.

Based on the findings of this study it is recommended that the use of flaring to dispose unwanted gas should be discouraged and regular monitoring of pollutants arising from gas flaring should be encouraged, particularly around major sources of livelihood.

Table 6. Meteorological Parameters Measured in March 2017

LOCATION	TIME	RH (%)	TEMP ^{0}C	WIND SPEED m/s	WIND DIRECTION
WEST 1	12.00	78.6	31.8	2.6	S/W
WEST 2	12.20	70.4	33.5	1.6	S/W
WEST 3	12:40	66.3	34.1	2.7	S/W
SOUTH 1	1.10	63.1	34.8	2.6	S/W
SOUTH 2	1.25	62.1	35.7	1.4	S/W
SOUTH 3	1.46	61.1	35.9	1.6	S/W
EAST 1	2.00	55.6	35.7	3.6	S/W
EAST 2	2.21	54.6	35.8	3.7	S/W
EAST 3	2.27	54.2	35.9	3.9	S/W
NORTH 1	2.30	53.1	33.4	3.8	S/W
NORTH 2	2.40	61.1	33.3	4.3	S/W
NORTH 3	2.59	60.3	31.4	2.6	S/W

S/W = South Westerly

Table 7. Meteorological Parameters Measured in September 2017

LOCATION	TIME	RH (%)	TEMP ^{0}C	WIND SPEED m/s	WIND DIRECTION
WEST 1	12:00	71.1	32.1	2.0	S
WEST 2	12:20	70.2	32.3	1.0	S
WEST 3	1:00	69.1	32.4	1.0	W
SOUTH 1	1:16	68.1	33.4	2.1	S
SOUTH 2	1:25	67.1	33.5	1.3	S
SOUTH 3	1:36	68.3	33.6	1.4	S
EAST 1	1:48	68.4	33.7	1.5	S
EAST 2	1:59	67.9	33.6	1.2	W
EAST 3	2:10	67.9	33.4	1.1	W
NORTH 1	2:46	66.1	32.1	1.0	S
NORTH 2	2:57	66.1	32.2	1.2	W
NORTH 3	3:10	6.3	32.3	1.6	S
CONTROL 1	4:15	64.1	32.1	4.1	S
CONTROL 2	4:35	64.2	32.3	4.6	S
CONTROL 3	4:54	63.1	32.2	4.2	S
CONTROL 4	5:00	63.0	32.1	4.1	S

S = Southerly W = Westerly

Table 8. Meteorological Parameters Measured in March 2018

LOCATION	TIME	RH (%)	TEMP ^{0}C	WIND SPEED m/s	WIND DIRECTION
WEST 1	11.00	72.2	32.3	4.1	S/W
WEST 2	11.18	71.2	32.4	4.5	S/W
WEST 3	11.30	72.1	32.6	4.6	S/W
SOUTH 1	11:43	70.1	33.2	4.3	S/W
SOUTH 2	12:12	71.1	33.3	4.6	S/W
SOUTH 3	12.15	72.4	33.5	4.4	S/W
EAST 1	12:30	69.9	34.5	3.7	S/W
EAST 2	12:41	68.9	34.6	3.8	S/W
EAST 3	1:07	68.6	35.2	4.2	S/W
NORTH 1	1:20	66.7	34.7	4.2	S/W
NORTH 2	1:30	66.8	34.7	4.1	S/W
NORTH 3	1:40	67.5	34.7	4.2	S/W
CONTROL 1	2:30	62.1	33.1	1.6	S/W
CONTROL 2	2:40	62.3	33.1	1.6	S/W
CONTROL 3	3:00	62.4	33.1	1.7	S/W
CONTROL 4	3:23	61.1	33.0	1.3	S/W

S/W = South Westerly

Table 9. Meteorological Parameters Measured in June 2019

LOCATION	TIME	RH (%)	TEMP ^{0}C	WIND SPEED m/s	WIND DIRECTION
WEST 1	2.47	93.1	25.1	2.1	S/W
WEST 2	2.47	93.1	26.1	2.2	S/W
WEST 3	2.47	94.1	24.1	0.1	S/W
SOUTH 1	3.00	93.1	24.1	0.7	S/W
SOUTH 2	3.10	93.1	24.3	0.6	S/W
SOUTH 3	3.20	95.1	24.1	1.7	S/W
EAST 1	3.33	94.1	24.3	2.1	S/W
EAST 2	3.42	95.1	24.3	2.6	S/W
EAST 3	3.50	94.1	24.4	2.3	S/W
NORTH 1	3.59	95.6	24.3	1.1	S/W
NORTH 2	4.10	95.7	24.5	1.1	S/W
NORTH 3	9.15	95.7	24.5	1.1	S/W
CONTROL 1	9.30	89.9	27.6	0.1	S/W
CONTROL 2	9.50	88.9	27.7	0.2	S/W
CONTROL 3	10.20	87.8	27.6	1.6	S/W
CONTROL 4	10.45	89.7	26.6	1.4	S/W

S/W = South Westerly

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