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The Impact of Thermal Desorption Unit Associated with Remediation of Hydrocarbon Impacted Soils on Air Quality at Beneku, Ndokwa East, Delta State, Nigeria

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Abstract

The study is on the use of thermal desorption unit in the remediation of contaminated soils located at Beneku in Ndokwa East local government area of Delta state. This method uses heat to vaporize the contaminants, and as such only works for volatile contaminants. Air quality samples around the thermal desorption Unit (TDU), used for the treatment of hydrocarbon impacted soils were taken at six (6) different sampling points (Stations). The sampling points were 100 m apart beginning from 0 m which was the closest to the TDU. The results showed that the mean values of SO_2 were 0.01 ppm for both the dry and wet seasons and it is within the FMEnv limit of 0.01. The mean concentration of NO_2 in the dry season was 0.25 μg/m^3 and in the wet season it was 0.18 μg/m^3, which were above the FMEnv limit of 0.06 μg/m^3. It is a strong oxidizing agent that reacts with air/water to form corrosive nitric acid, as well as toxic organic nitrates. The mean concentration of CO_2 recorded in the dry season was 11.52 ppm and that for the wet season was 10.53 ppm, which were slightly above the FMEnv limit of 10.00 ppm. The levels of SPM 2.5 recorded in the study show a concentration of 132.07 μg/m^3 in the dry season and 95.93 μg/m^3 in the wet season while those for SPM 10 had 102.17 μg/m^3 in the dry season and 91.33 μg/m^3 in the wet season. The level of the VOC recorded across the study area was significantly low (0.11 μg/m^3). The mean H_2S concentration recorded across the study area was low (0.01 μg/m^3). Several health risks have been associated with SPM. Inhaling SPM affects respiratory and cardiovascular systems in both children and adults. Fine SPM (such as PM 2.5 particulate) can penetrate into the lungs and blood streams when inhaled, resulting to respiratory problems, heart attack, lung cancer and even death, while

exposure to low levels of H_2S can induce headaches as well as breathing difficulties in some asthmatic patients.

Keywords

Thermal Desorption Unit, Contaminated, Soil, Air Quality

1. Introduction

Air pollution is defined as the application of substances, particles, or biological elements into the air that causes human discomfort, disease, or death, harms other living species such as food crops, or harms the natural or built environment (Srivastava et al., 2020). It may also be described as the release of compounds into the atmosphere through natural or anthropogenic methods that have the potential to harm living organisms in the environment when they exceed the tolerance limit in the environment.

Thermal desorption is a remediation method used to clean contaminated soils. This method uses heat to vaporize the contaminants, and as such only works for volatile contaminants (Wang et al., 2016). These include mostly organic wastes composed of hydrocarbons, such as oil refining wastes, coal tar wastes, chlorinated solvents, fuels, PCBs, mixed wastes, synthetic rubber processing wastes, pesticides, and paint wastes (Swemgba et al., 2019). Thermal remediation is a category of techniques that use the application of heat to enhance the mobility of contaminants, such as steam/hot air injection to separate contaminants from soil particles (Kumar et al., 2014; Lasota & Błońska, 2018). By applying heat to the contaminated soils, the hydrocarbon contaminants with low boiling points are forced to turn into a vapor. The process is largely dependent on temperature which implies that temperature plays one of the most crucial roles in the thermal desorption process. While the pressure of the reactor is also important, only a temperature increase can volatize some of the more potent pollutants (Wang et al., 2021). Low temperature thermal desorption uses temperatures ranging from 93˚C to 316˚C, while high temperature thermal desorption ranges from 316˚C to 538˚C. Low temperature desorption preserves organic components of the soil and its physical characteristics. However, the increase in the temperature leads to emission of gases which are known as effluent gases stream generated by volatilization of the contaminants and can alter the air quality of the area, as well give rise to negative impact on the air quality in general.

Gaseous emissions have extensive impacts on our climate and our environment, air pollution not only threatens people's health, but causes decrease atmospheric visibility and degrades city scenery (Ede & Edokpa, 2015). Pollutants are categorized as primary or secondary. Examples of primary pollutants include volcanic ash, carbon monoxide (CO), or sulphur dioxide etc. Secondary contaminants are not directly emitted. Rather, they develop in the atmosphere by the reaction or interaction of primary contaminants.

Epidemiologic studies indicate strong links between the concentrations of PM with aerodynamic diameters of less than 10 μm and less than 2.5 μm (PM_{10} or $PM_{2.5}$, respectively) with public morbidity, respiratory-related mortality and cardiovascular diseases (Obanya et al., 2018). The concentration of Particulate Matters has become an important index of air pollution and has gained more and more attention from the administrations and organizations of environmental protection, public health and science around the world. Regulatory agencies such as Federal environmental protection agency, federal Ministry of Environment and Nigerian upstream petroleum regulatory commission (NUPRC) formerly Department of petroleum resources (DPR) have set air quality standards that dictate strict limits on particulate matters concentrations and other parameters in the ambient air.

In recent years, with the rapid development of industrialization and urbanization, PM has become the primary air pollutant in most major cities. This study examines the assessment of air quality of an area where a thermal desorption unit is used for the treatment or remediation of hydrocarbon impacted soils.

2. Materials and Methods

Air quality samples around the thermal desorption Unit (TDU), used for the treatment of hydrocarbon impacted soils were taken at six (6) different sampling points (Stations). The sampling points were 100 m apart beginning from 0 m which was the closest to the TDU.

Air Sampling for Gaseous Air Pollutants

Oxides of nitrogen (NOx), sulphur oxides (SOx) carbon monoxide (CO), hydrogen sulphide (H_2S), suspended particulate matters (SPM) and volatile organic compounds (VOCs) were measured during the study in the ambient environment of the location using the Aeroqual meter series 500 with a detection range of 0 - 500 ppm and 0.1 ppm resolution. The monitor was calibrated with Calibration and Test Certificate S/N 2424 for VOC and Calibration and Test Certificate S/N 2883 for H_2S from RAE Systems. For every field measurement, the "Auto-Zero at Start-up" calibration was carried out for the study.

Noise measurements were taken with a digital, battery-powered, sound pressure level meter (EXTECH Instruments, US Model 407730). It has 0.1 dB resolution with high- and low-metering ranges of 35 - 100 dB and 65 - 130 dB, respectively.

3. Results and Discussions

The impacts of the Thermal Desorption unit operation on the various parameters of air quality are presented below:

Sulphur Dioxide (SO_2): The values of Sulphur dioxide (SO_2) in the dry season ranged from 0.01 ppm all through the sampling points with a mean of 0.01 ppm. Same results were replicated in the wet season. The mean values for both seasons were not above the FMEnv limit of 0.01 ppm (Table 1 and Figure 1).

Table 1. Air quality results for both dry and wet seasons.

Parameters	Distance from Facility (m)						Average	FMEnvStandard 1991
	Stn 1 (0 m)	Stn 2 (100 m)	Stn 3 (200 m)	Stn 4 (300 m)	Stn 5 (400 m)	Stn 6 (500 m)		
SO_x, (ppm) (Dry Season)	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	0.01
SO_x, (ppm) (Wet Season)	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	0.01
NO_x, (ppm) (Dry Season)	0.33 ± 0.01	0.33 ± 0.01	0.29 ± 0.01	0.21 ± 0.01	0.17 ± 0.01	0.17 ± 0.01	0.25 ± 0.01	0.06
NO_x, (ppm) (Wet Season)	0.32 ± 0.01	0.32 ± 0.01	0.26 ± 0.01	0.18 ± 0.01	0.01 ± 0.00	0.01 ± 0.00	0.18 ± 0.01	0.06
CO_x, (ppm) (Dry Season)	15.08 ± 0.66	14.33 ± 0.57	11.17 ± 0.24	10.00 ± 0.00	10.00 ± 0.00	8.58 ± 0.15	11.53 ± 0.27	10
CO_x, (ppm) (Wet Season)	13.06 ± 0.32	12.08 ± 0.28	10.15 ± 0.17	10.00 ± 0.00	10.00 ± 0.00	7.69 ± 0.05	10.50 ± 0.14	10
SPM 2.5, ($\mu g/m^3$) (Dry Season)	448.98 ± 6.54	447.97 ± 6.99	438.28 ± 5.14	430.33 ± 5.46	425.30 ± 5.59	401.58 ± 7.37	432.07 ± 6.18	250
SPM 2.5, ($\mu g/m^3$) (Wet Season)	301.76 ± 7.37	300.48 ± 4.26	298.27 ± 4.28	299.45 ± 4.28	295.18 ± 4.14	280.46 ± 3.87	295.934.70	250
SPM 10, ($\mu g/m^3$) (Dry Season)	299.33 ± 1.66	257.63 ± 57.52	297.38 ± 0.62	289.23 ± 2.29	284.92 ± 4.38	284.50 ± 4.66	285.50 ± 11.86	250
SPM 10, ($\mu g/m^3$) (Wet Season)	180.23 ± 4.38	210.32 ± 69.42	170.46 ± 0.49	166.27 ± 0.26	160.34 ± 0.19	160.34 ± 0.19	174.61 ± 12.49	250
VOC, ($\mu g/m^3$) (Dry Season)	0.16 ± 0.00	0.15 ± 0.00	0.13 ± 0.00	0.11 ± 0.00	0.11 ± 0.00	0.01 ± 0.00	0.11 ± 0.00	0.05
VOC, ($\mu g/m^3$) (Wet Season)	0.15 ± 0.00	0.14 ± 0.00	0.13 ± 0.00	0.1 ± 0.00	0.1 ± 0.00	0.02 ± 0.00	0.11 ± 0.00	0.05
Smoke density (Dry Season)	3.00 ± 0.00	2.00 ± 0.00	1.00 ± 0.00	1.00 ± 0.00	1.00 ± 0.00	1.00 ± 0.00	1.5 ± 0.00	2
Smoke density (Wet Season)	3.00 ± 0.00	2.00 ± 0.00	1.00 ± 0.00	1.00 ± 0.00	1.00 ± 0.00	1.00 ± 0.00	1.5 ± 0.00	2

Continued

H_2S, (ppm) (Dry Season)	0.02 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	0.01
H_2S, (ppm) (Wet Season)	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	0.01
Noise level dB (A) (Dry Season)	74.92 ± 0.04	64.80 ± 0.28	70.13 ± 0.20	66.23 ± 0.14	56.73 ± 0.31	55.89 ± 0.39	64.78 ± 0.23	90
Noise level dB (A) (Wet Season)	74.02 ± 0.04	60.20 ± 0.24	70.10 ± 0.20	65.21 ± 0.14	55.64 ± 0.31	54.76 ± 0.39	63.32 ± 0.22	90

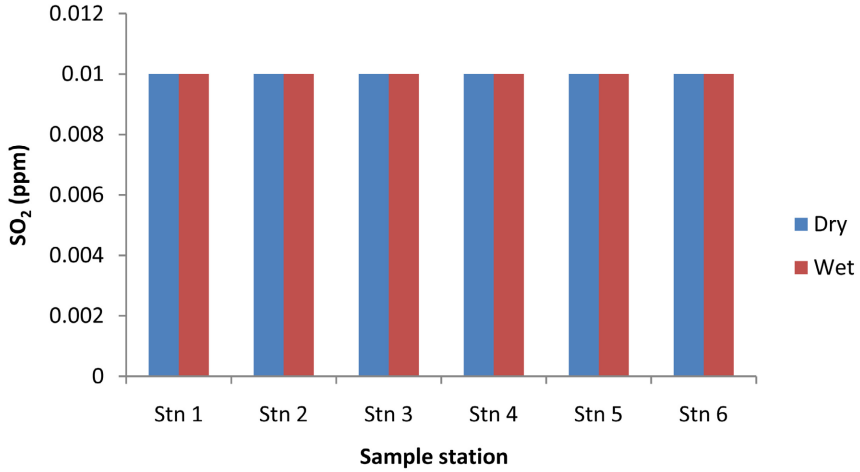

Figure 1. Concentration of Sulphur dioxide for the wet and dry seasons.

Nitrogen oxides (NO_2): The values of Nitrogen dioxide (NO_2) in the dry season ranged from 0.17 ppm to 0.33 ppm with a mean of 0.25 ppm. While in the wet season, the values ranged from 0.01 ppm to 0.32 ppm with a mean of 0.18 ppm. The mean values for both seasons were above the FMEnv limit of 0.06 ppm (Table 1 and Figure 2).

Carbon Monoxide (CO_2): The concentrations of Carbon monoxide (CO_2) in the dry season ranged between 8.58 pm and 15.08 ppm with a mean of 11.53 ppm. The values in the wet season ranged from 7.69 ppm to 13.06 ppm with a mean of 10.50 ppm (Table 1 and Figure 3). The mean values for both seasons were above the FMEnv limit of 10.0 ppm.

Suspended Particulate Matter (SPM 2.5): The values of Suspended Particulate matters (SPM 2.5) in the dry season ranged from 101.58 μg/m^3 to 124.98 μg/m^3 with a mean of 132.07 μg/m^3. While in the wet season, the values in the wet season ranged from 80.46 μg/m^3 to 101.76 μg/m^3 with a mean value of 95.93 μg/m^3. The mean values for both seasons were above the FMEnv limit of 25 μg/m^3 (Table 1 and Figure 4).

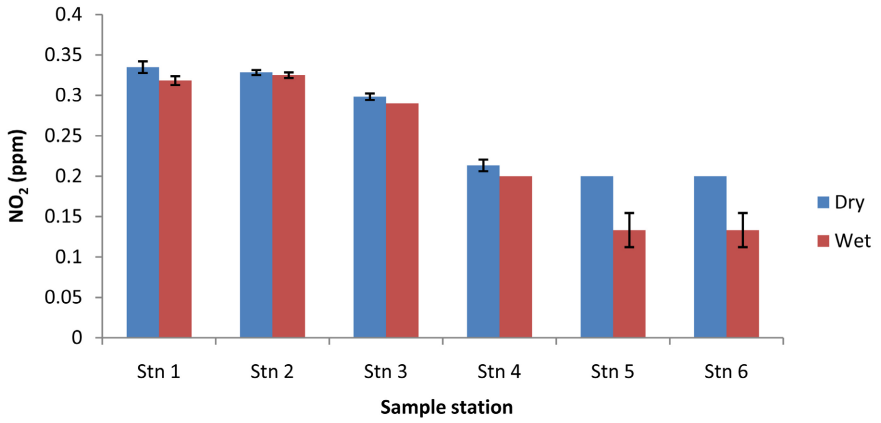

Figure 2. Concentration of nitrogen oxides for the wet and dry seasons.

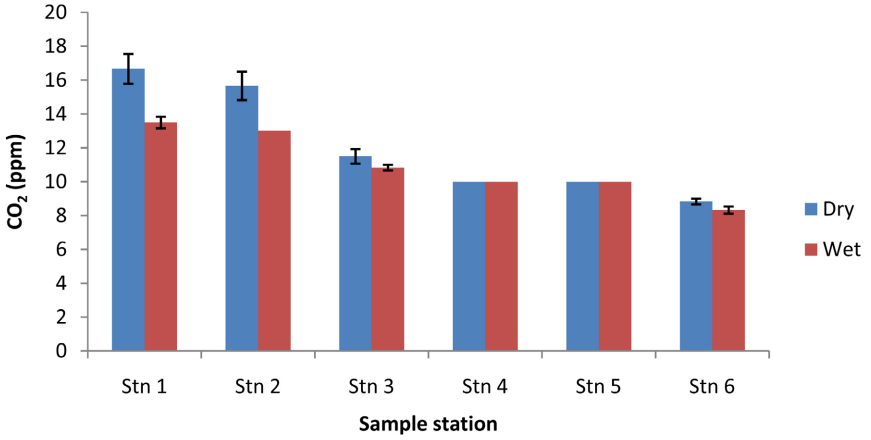

Figure 3. Concentration of carbon monoxide for the wet and dry seasons.

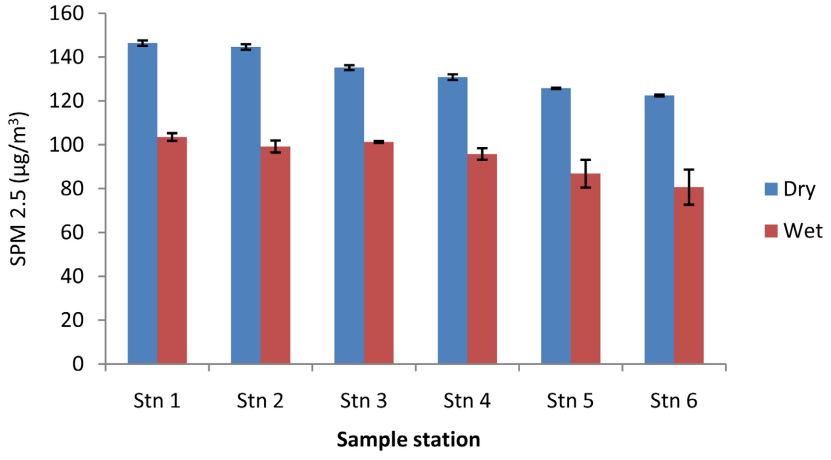

Figure 4. Concentration of Suspended Particulate Matter (SPM 2.5) for the wet and dry seasons.

Suspended Particulate Matter (SPM 10): The values of Suspended Particulate matters (SPM 10) in the dry season ranged from 84.50 µg/m³ to 157.63 µg/m³ with a mean of 102.17 µg/m³. While in the wet season, the values ranged

from 60.34 μg/m³ to 210.32 μg/m³ with a mean value of 91.33 μg/m³. The mean values for both seasons were above the FMEnv limit of 50 μg/m³ (Table 1 and Figure 5). The highest value of SPM 10 recorded in the wet season at station 2 could be attributed to the high surface area and reactivity of suspended particulate matter and the presence of the dissolved heavy metals present.

Volatile Organic Compounds (VOCs): These include methane (CH_4), ethane (C_2H_6), propane (C_3H_8) and other derivatives of aliphatic and aromatic organic compounds and are emitted from both manmade and natural sources. The values of VOCs in the dry season ranged from 0.01 μg/m³ to 0.16 μg/m³ with a mean of 0.11 μg/m³. In the wet season, the values ranged from 0.01 μg/m³ to 0.15 μg/m³ with a mean of 0.11 μg/m³. The mean values for both seasons were above FMEnv maximum permissible limit of 0.05 μg/m³ (Table 1 and Figure 6).

Smoke Density: The values of smoke density in the dry season ranged from 1.00 to 3.00 with a mean of 1.5 and in the wet season same values for the dry season were replicated (Table 1).

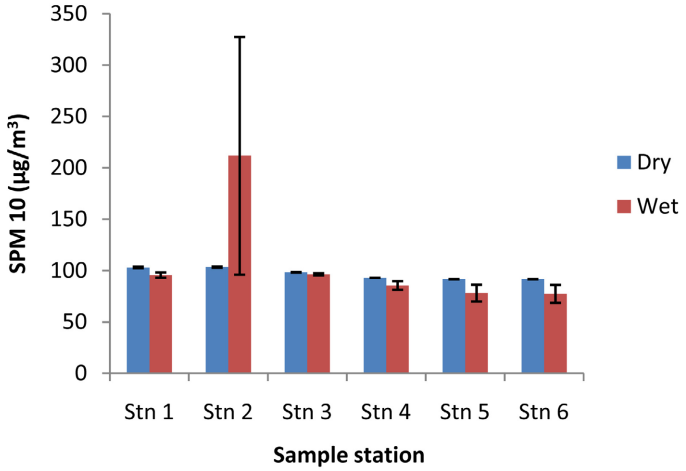

Figure 5. Concentration of Suspended Particulate Matter (SPM 10) for the wet and dry seasons.

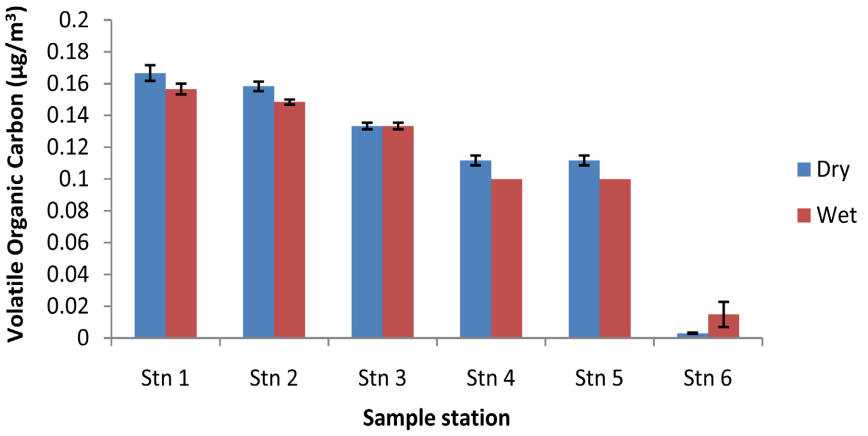

Figure 6. Concentration of volatile organic carbon for the wet and dry seasons.

Hydrogen Sulphide (H_2S): The values of Hydrogen sulphide (H_2S) in the dry season ranged from 0.01 ppm to 0.02 ppm with a mean of 0.01 ppm and in the wet season, the values ranged from 0.01 ppm to 0.01 ppm with a mean of 0.01 ppm. The mean values for both seasons were not above the FMEnv limit of 0.01 ppm (Table 1 and Figure 7).

Noise: The values of noise level obtained in the study area ranged from 55.89 dB (A) to 74.92 dB (A) with a mean value of 64.78 dB (A) and in the wet season, ranged from 54.76 dB (A) to 74.02 dB (A) with a mean of 63.32 dB (A). The mean values for both seasons were below the FMEnv limit of 90 dB (A) (Table 1 and Figure 8).

4. Discussion of Results

Gaseous emission from the operation of the thermal desorption unit can have impacts on the environment and health of people in the neighbouring environment. SO_2 is colorless and malodorous gases (Feuyit et al., 2019). The mean values of SO_2 were 0.01 ppm for both the dry and wet seasons and it is within the

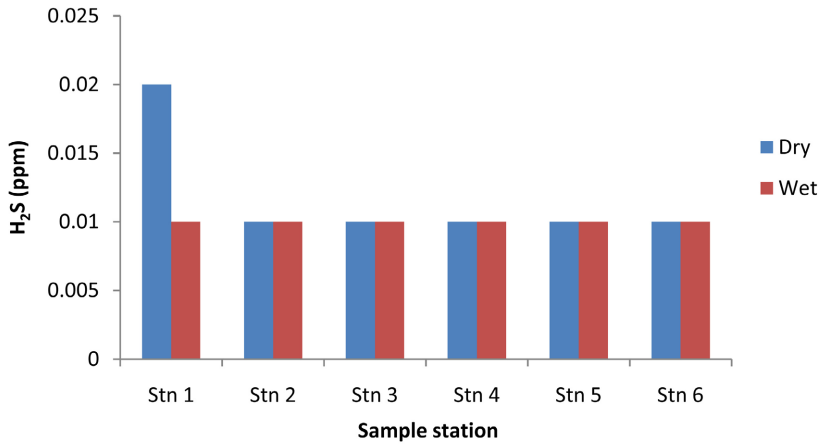

Figure 7. Concentration of hydrogen sulphide for the wet and dry seasons.

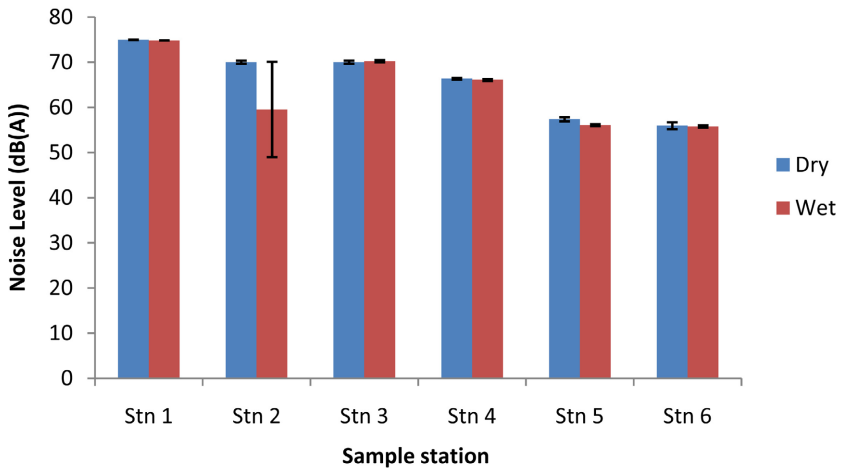

Figure 8. Concentration of noise for the wet and dry seasons.

FMEnv limit of 0.01. The mean of SO_2 recorded in the study were significantly lower than the mean of 8.91 ppm recorded at the vicinity of On-Nooch dumpsite in Bangkok (Muttamara & Leong, 1999; Ezekwe et al., 2016), while Sonibare et al. (2020) recorded a zero level of SO_2 at Eneka landfill in River State and Olushosun and Abule Egba dumpsites in Lagos State respectively. High levels of SO_2 can reduce lung function and also provoke the irritation of the throat as well as the nose (ATSDR, 1998).

Nitrogen dioxide (NO_2) is a suffocating brownish gas that belongs to a family of highly reactive gases called nitrogen oxides. Nitrogen dioxide (NO_2) is formed from the oxidation of atmospheric nitrogen during combustion and from the oxidation of nitrogen-containing organic fuels. It results when fuel is combusted at high temperatures and occurs mainly from motor exhaust and stationary sources such as electric utilities and industrial boilers. The mean concentration of NO_2 in the dry season was 0.25 μg/m^3 and in the wet season it was 0.18 μg/m^3, which were above the FMEnv limit of 0.06 μg/m^3. It is a strong oxidizing agent that reacts with air/water to form corrosive nitric acid, as well as toxic organic nitrates. It plays a major role in the atmospheric reactions that produce ground level ozone or smog (USEPA, 2010). Exposure to NO_2 concentrations higher than the FMEnv regulatory limits of 0.06 μg/m^3 could alter pulmonary immunologic responses and may increase susceptibility to bacterial infection such as influenza.

CO_2 is a toxic gas produce from incomplete combustion (Radojevic & Bashkin, 1999). The mean concentration of CO_2. Recorded in the dry season was 11.52 ppm and that for the wet season was 10.53 ppm, which were slightly above the FMEnv limit of 10.00 ppm. In the study conducted by Ezekwe et al. (2016), CO_2 was not detected at Eneka landfill in River State. The mean values of CO_2 obtained in this study were lower than the values obtained in similar study in Cameroon by Feuyit et al. (2019).

The levels of SPM 2.5 recorded in the study shows a concentration of 132.07 μg/m^3 in the dry season and 95.93 μg/m^3 in the wet season while those for SPM 10 had 102.17 μg/m^3 in the dry season and 91.33 μg/m^3 in the wet season. The values recorded in the study were below those reported by Swemgba et al. (2019) in some locations at Port Harcourt but during the dry season. Several health risks have been associated with SPM. Inhaling SPM affects respiratory and cardiovascular systems in both children and adults. Fine SPM (such as PM 2.5 particulate) can penetrate into the lungs and blood streams when inhaled resulting to respiratory problems, heart attack, lung cancer and even death (Osimobi et al., 2019).

The level of the VOC recorded across the study area was significantly low (0.11 μg/m^3). The levels of VOC recorded in this study were significantly lower than the mean value of 700 μg/m^3 reported by Ezekwe et al. (2016) at Eneka landfill.

The mean H_2S concentration recorded across the study area was low (0.01 μg/m^3). Exposure to low levels of H_2S can induce headaches as well as breathing

difficulties in some asthmatic patients (ATSDR, 2014).

5. Conclusion

Thermal desorption proved to be a very successful and viable option for remediating impacted soils, gaseous emissions and the air quality around a thermal desorption unit used for the thermal remediation of hydrocarbon impacted soils. The air quality indices studied deviated from the permissible limit as stipulated by the federal ministry of environment. Such parameters that were elevated than federal ministry of environment limits include; NO_x, VOCs, SPM and Cox. This deviation is a clear indication that using thermal desorption unit for the treatment of hydrocarbon impacted soil possess some environmental threats to the air quality of the area. The concentrations of these parameters in excess lead to health impairment.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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