EVALUATION OF THE EFFICACY OF SOIL FLUSHING REMEDIATION METHOD ON CRUDE OIL-SPILLED MANGROVE SEDIMENT AT BODO CREEK, GOKANA, NIGERIA

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ABSTRACT

The efficacy of soil flushing remediation method of a crude oil spilled mangrove sediment at Bodo creek, Bodo, Nigeria was evaluated. Field observation revealed that after soil flushing remediation operation of the Bodo crude oil-spilled site in 2018 by Shell Petroleum Development Company of Nigeria, no post-remediation assessment was carried out to determine the effectiveness of the technique as a remediation strategy. This study was carried out to ascertain the effectiveness of soil flushing remediation method for decontamination of hydrocarbon-spilled mangrove environment. Sediment samples were collected from 3 stations within the creek which were non-remediated crude oil-polluted station, soil flushing remediated station and non-polluted station, at depths of 0 – 15 cm and analysed for sediment temperature, pH, conductivity, Total Petroleum Hydrocarbon (TPH), Total Hydrocarbon Content (THC) and microbial properties. Results showed significant decrease in TPH and THC (1241.71 mg/kg and 1755.45 mg/kg, respectively) in the soil flushing remediated station when compared with non-remediated polluted station (1792.93 mg/kg and 28261.5 mg/kg, respectively). Despite the significant decrease in THC and TPH in the soil flushing station, the values were still above environmentally permissible limits. This implies that other remediation techniques should be adopted after the soil flushing approach.

Key words: Remediation, Pollution, Soil Flushing, Mangrove, Niger Delta, Bodo City

INTRODUCTION

The expedition for civilisation, industrialisation and urbanisation has given rise to pollution and subsequent degradation of the environment. One of such pollutions is crude oil environmental pollution. Crude oil is a source of energy for industry and daily life (Ite *et al*., 2016); as a result, it is constantly exploited.

The Niger Delta in Nigeria has suffered severe environmental degradation for over five decades now. Since crude oil was discovered in Bomu, Ogoni, Rivers State, alongside Oloibiri, Bayelsa State in 1956 and its commercialisation in 1958, crude oil environmental contamination has been a frequent experience in the area. Okparanma (2013) catalogued incidents of crude oil spill in Niger Delta and reported that from 1976 – 2005, a total of 9,107 oil spill cases were documented to occur in the area, spilling a total volume of 496,343.07 m^3 into the environment. This was corroborated by Khan *et al*. (2013) and Nwaichi *et al.* (2015) who reported high levels of petroleum hydrocarbon as pollutants in sediment and water at different locations of the Niger Delta environment.

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Ogoniland is located in the Niger Delta region at the southern region of Nigeria. It is one of the areas most severely devastated by petroleum hydrocarbon pollution due to widespread crude oil exploration and exploitation activities of the oil by multi-nationals in the area. Bodo is a village in Ogoni located by the Bonny River in the eastern part of Niger Delta and bordered at the southern part by the Atlantic Ocean (Little *et al*., 2018). Pegg and Zabbey (2013) noted that Bodo Creek occupies approximately 9,230 ha of swamp land that comprises interconnected channels of brackish water creeks at the upper reach of Andoni-Bonny Estuary system in Rivers State, Nigeria. Zabbey and Babatunde (2015) noted that Bodo Creek has four major channels: Koola Seato, Kpador, Koola Tobsoi and Dor Nwezor that conduct saltwater in and out of it. Bodo Creek is an endowed mangrove ecosystem which has been highly impacted by petroleum hydrocarbon pollution. The source of contamination in the creek resulted from two operational spills in 2008 due to corrosion on the Trans-Niger Pipeline which crossed the area (Gundlach, 2013). Before these cases of oil spill incidents in Bodo Creek, the Bodo mangrove ecosystem was dense and formed a self-sustaining coastal defense against storm from the Atlantic Ocean. It provided several habitats for brackish water flora and fauna of the area as well as other environmental services (Little *et al*., 2018; Kauffman *et al.*, 2011). Bouillon (2011) and Donato *et al.* (2011) noted that mangrove sediment can store carbon approximately five times higher than temperate boreal and other sub-tropical terrestrial forests.

After the 2008 cases of oil spill incidents, other cases of spill were also reported. Consequent upon the numerous oil spill cases that happened in this area, especially after the 2008 spills, Shell Petroleum Development Company (SPDC) of Nigeria undertook pollution remediation operation on the area. The method used was Soil Flushing Technique. This remediation technique mechanically removes the pollutant (i.e. petroleum hydrocarbon) in order to facilitate recovery of polluted sites and subsequent revegetation. Soil flushing is an *in-situ* physical remediation technique aimed at extracting the pollutant from soil or sediment using soil washing solution (surfactant) by injecting a solution of water or liquid with high pressure into the zone of pollution. This operation causes the dispersal of pollutant substance out of the polluted soil and, therefore, causes recovery of clean soil or sediment from pollution.

The aim of this study was to determine the efficacy of soil flushing technique as a method of soil pollution remediation technique on crude oil impacted mangrove ecosystem. It is expected that results obtained will expand on our knowledge of crude oil pollution remediation and its suitability for application to clean up petroleum hydrocarbon impacted mangrove sediment.

MATERIALS AND METHODS

Description of Study Area

This assessment was conducted at Kpador Mangrove Swamp which is a creeklet of Bodo Creek. Bodo Creek is located at Bodo City in Gokana Local Government Area (Fig. 1) of Rivers State, Niger Delta, Nigeria.

The study site lies between latitudes 4° 58’ 52.2” E to 4° 63’ 00.5” E and longitudes 7° 24’ 38.1” N to 7° 25’ 38.9” N.

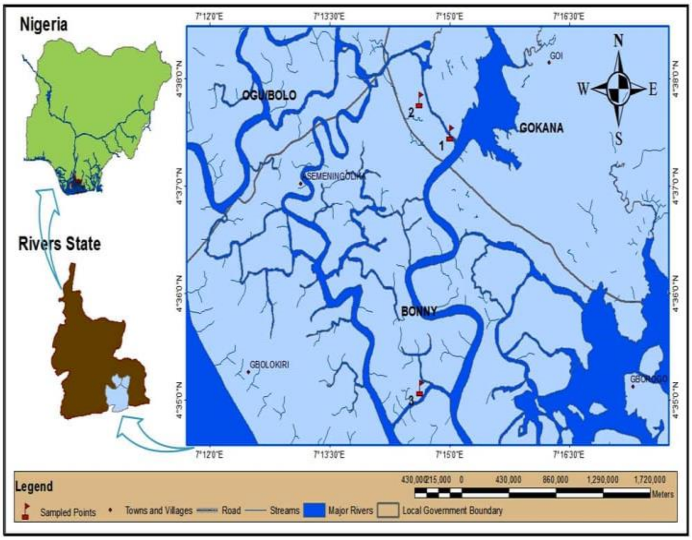

Fig. 1: Map of the study area

Sampled Stations

Three (3) sampled stations were selected on the intertidal flats on the fringes of Kpador Mangrove Swamp channel. The locations were on isolated flats, which did not require any human demarcation for identification. Each of these locations is concisely described below.

Sampled Station 1

This site was polluted by crude oil spill and was not remediated since after the last spill of 2008. This station is geographically located at latitude 4^o 62' 49.1" E and longitude 7^o 25' 02.2" N (Fig. 1). The station is without any living plant as the mangrove plants which formed a component of the ecosystem here before the crude oil spill incident were killed by the crude oil spill incident, thus, the location is bare of living plant organisms (Plate 1).

Sampled Station 2

This station is located at latitude 4^o 63' 00.5" N and longitude 7^o 24' 38.1" E (Fig. 1). This location was polluted but declared remediated by SPDC. The remediation exercise was carried out for six (6) months: from September 2017 to March 2018. Soil flushing remediation technique was used in the exercise. According to a report, after flushing, re-vegetation with mangrove species seedlings was undertaken but all the seedlings planted died. Thus, the location is a mangrove vegetation, but has remnants of dead mangrove woods which were killed due to the pollution incident (Plate 2).

Sampled Station 3

Sampled station 3 is located at latitude 4° 58’ 52.0” E and longitude 7° 24’ 38.8” N (Fig. 1). This station was not polluted i.e. not impacted by any crude oil spill. Mangrove species such as *Rhizophora racemosa* G. Mey., *Rhizophora mangle* L., *Rhizophora harrisonii* Leechman. etc are some of the species of the vegetation of this station. These species make up about 90% of the plant species found here (Plate 3).

Plate 1: Sampled station 1 (Polluted but not remediated station)

Plate 2: Sampled station 2 (Remediated station)

Plate 3: Sampled station 3 (the unpolluted station)

Sample Collection and Analysis

Sample collections were done in the month of May 2019. Samples were collected from each of the 3 stations. At each station, 3 randomly located sample plots of 5 m x 5 m were mapped out and sediment samples collected from it with soil auger at a depth of 0 – 15 cm and placed in polyethylene sampling bags. At each of the stations, samples were collected in triplicates and bulked together to form a composite sample. The composite sample was immediately shared into two portions, each portion separately labeled and placed in separate thermos cooler with ice packs to avoid any mix-up and alteration in the chemical nature of the sediment *in-situ*. One part of the sample was used for the determination of physico-chemical properties, total hydrocarbon content and total petroleum hydrocarbon content at the Anal Concept Limited laboratory, Port Harcourt, and the other part was used for microbial analyses at research laboratory in the Department of Microbiology, University of Port Harcourt, Port Harcourt, River State.

Parameters of the Study and their Determinations

Total hydrocarbon content (THC) was obtained by spectrophotometric method after oven-drying 1 g of soil sample at 70°C for 24 h. Sample THC content was first extracted using chloroform as extraction solvent and extract THC concentration measured using spectrophotometer (Genesis 10 UV). The total petroleum hydrocarbon content (TPH) was determined using Gas chromatography method (HP5890 series II). Sediment temperature was determined *in-situ* using soil thermometer. The sensitive end of the thermometer (mercury-in-glass) was inserted into sediment and allowed for 5 minutes before the instrument was removed from the sediment and the level of mercury in the instrument was quickly read and recorded.

Sediment pH and conductivity were determined in the laboratory using pH meter (Hanna Hi 8314) from 4:1(w/v) mixture of distilled water and sediment by means of pH meter electrode vertically dipped into the mixture and reading was taken. Conductivity was determined using conductivity meter (Labtech digital conductivity meter) and a similar procedure was used in the determination of pH.

Total Heterotrophic Bacteria (THB) and Total Heterotrophic Fungi (THF) were determined using the methods described by American Public Health Association (1976) while Hydrocarbon Utilising Bacteria (HUB) and Hydrocarbon Utilising Fungi (HUF) were determined using the methods described by Odokuma and Okpokwasili (1992; 1993).

Statistical Analyses and Data Presentation

Data gathered from sampling were used for statistical analyses using Minitab 17. Analysis of variance (ANOVA) was used to determine the difference between means at $p < 0.05$. Tukey grouping with superscript a, b and c were used to compare means obtained from sampled stations for significant difference.

RESULTS

The results of post-remediation assessment of Bodo mangrove ecosystem are presented below.

Total Hydrocarbon Content

The result of total hydrocarbon content (THC) as presented in Fig. 2 showed high THC in the polluted-unremediated station and low content of THC in polluted-remediated and unpolluted stations. The mean of THC of the polluted station was 28261.5 mg/kg, that of remediated station was 1755.45 mg/kg and the unpolluted station was found to be 1426.28 mg/kg. There was significant difference ($p<0.05$) between the means at all stations.

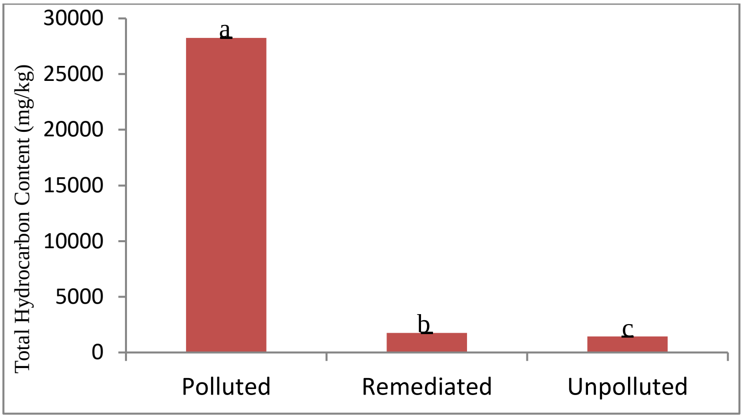

Fig. 2: Total Hydrocarbon Content for sediment at different stations

Total Petroleum Hydrocarbon Content

There was high total petroleum hydrocarbon contamination at the 3 sampled stations. The polluted station recorded 1792.93 mg/kg TPH content concentration while the remediated station and unpolluted station recorded values of 1364.16 mg/kg and 1241.71 mg/kg, respectively (Fig. 3). The result recorded at the unpolluted station suggested that it might have been contaminated by the pollutant through transport of the pollutant substance to the site. However, ANOVA of the result showed significant difference between the sampled stations at $p < 0.05$. Tukey groupings showed significant difference between sampled station means.

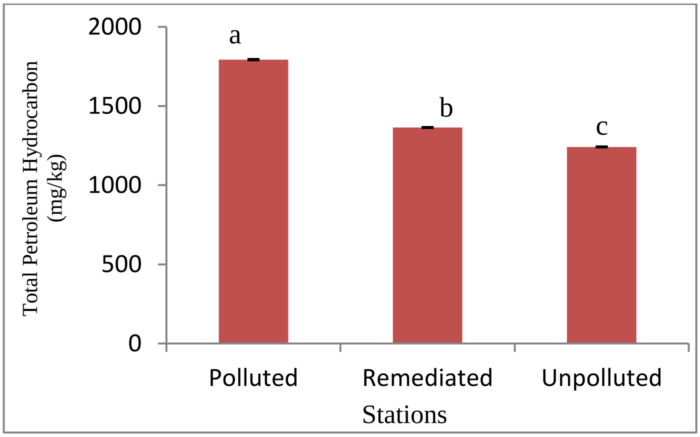

Fig. 3: Total Petroleum Hydrocarbon in sediment at different stations

Sediment Temperature

Results of sediment temperature of sampled stations showed higher temperature at the polluted site (31 ^{o}C) compared with 28 ^{o}C recorded at the remediated and unpolluted locations (Fig. 4). There was significant difference between polluted station and the unpolluted but no significant difference between the remediated and non-polluted stations at $p < 0.05$.

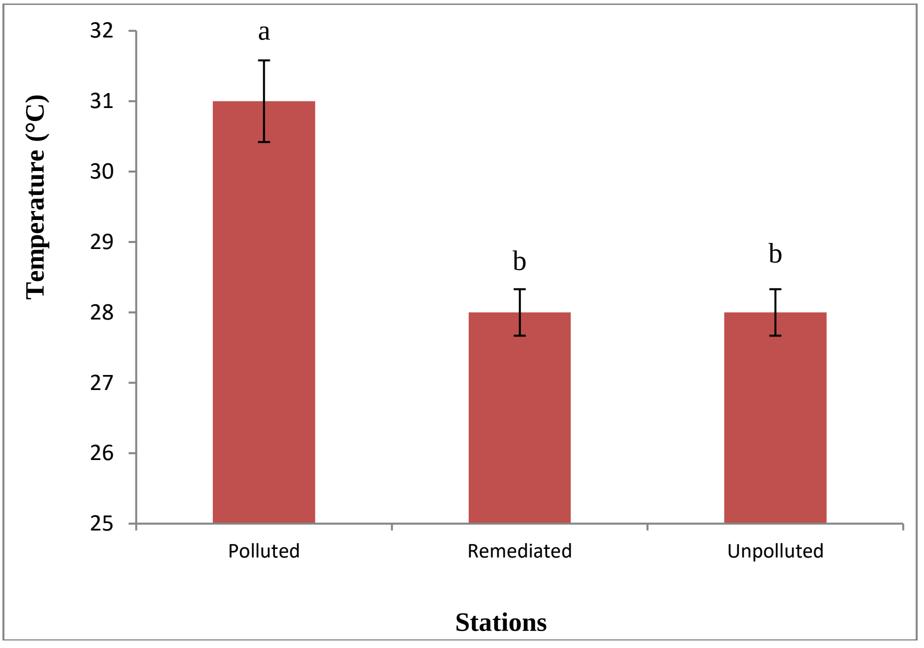

Fig. 4: Temperature in sediment at different stations

Sediment pH

The polluted station recorded mean pH of 7.0 while that of remediated and unpolluted stations were 7.3 as shown in Fig. 5. There was no significant difference between mean pH of the stations at $p<0.05$.

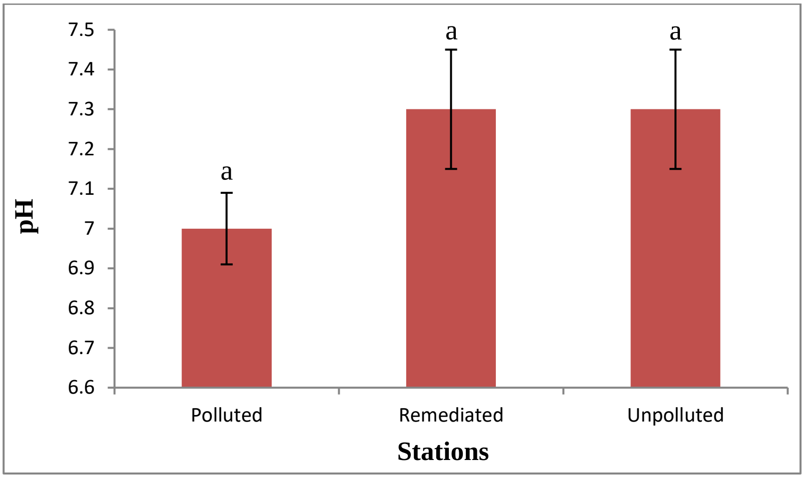

Fig. 5: pH for sediment at different stations.

Sediment Conductivity

Soil conductivity varied between remediated and the other sampled stations. Higher values were recorded at the polluted and unpolluted stations compared with the remediated station (Fig. 6). There was significant difference between the remediated station and the other stations (Fig. 6).

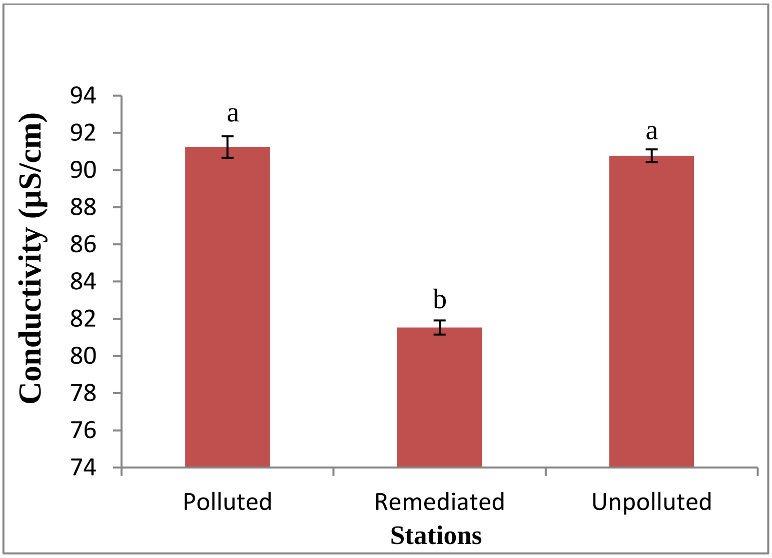

Fig. 6: Conductivity of sediment at different station

Total Heterotrophic Bacteria (THB)

Total Heterotrophic Bacteria (THB) count showed increasing trend from the polluted to unpolluted sampled station with the least (30,000 cfu) recorded on the polluted station and the highest (Fig. 7) (≈ 80 000 cfu) on the unpolluted sampled station. There was 35% difference in THB count between the unpolluted and remediated station and 63% between the unpolluted and polluted stations. There was significant difference between the stations at $p < 0.05$ (Fig. 6).

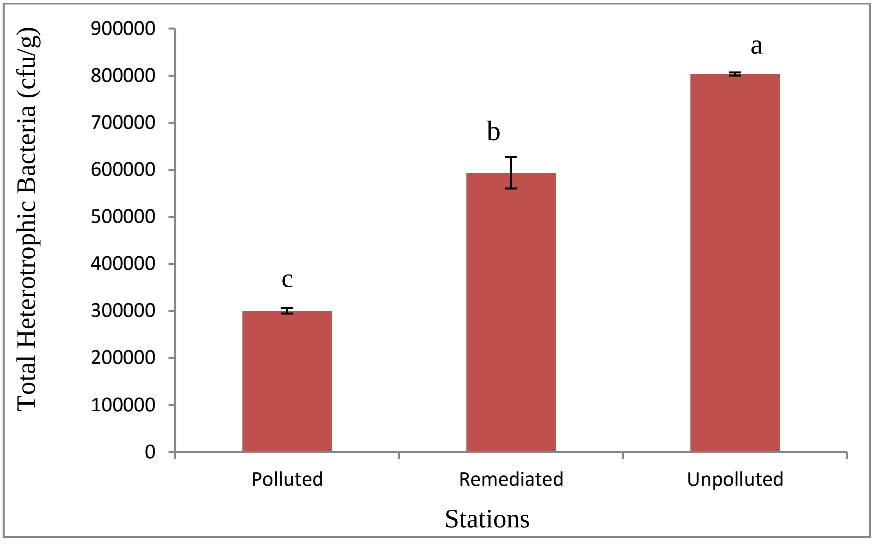

Fig. 6: Total Heterotrophic Bacteria in sediment at different stations

Hydrocarbon Utilising Bacteria (HUB)

The result for Hydrocarbon Utilising Bacteria (HUB), as presented in Fig. 7, showed significant difference ($p<0.05$) between the different sampling stations. Highest HUB was recorded in polluted station with a mean of 7076667 cfu/g. The remediated station had a mean of 700333 cfu/g while unpolluted station had the least with a mean of 666666 cfu/g. The percentage difference between the polluted station and both remediated and unpolluted stations was 90%.

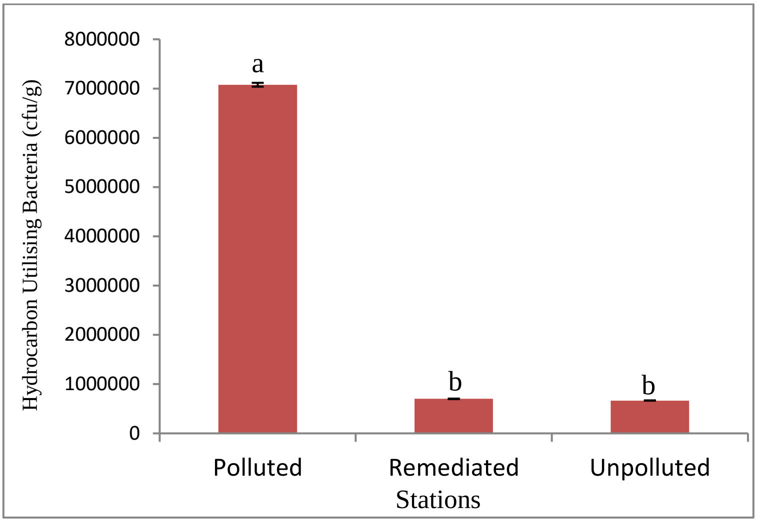

Fig. 7: Hydrocarbon Utilising Bacteria in sediment at different stations

Total Heterotrophic Fungi (THF)

Total Heterotrophic Fungi (THF) were not detected in all stations (Fig. 8).

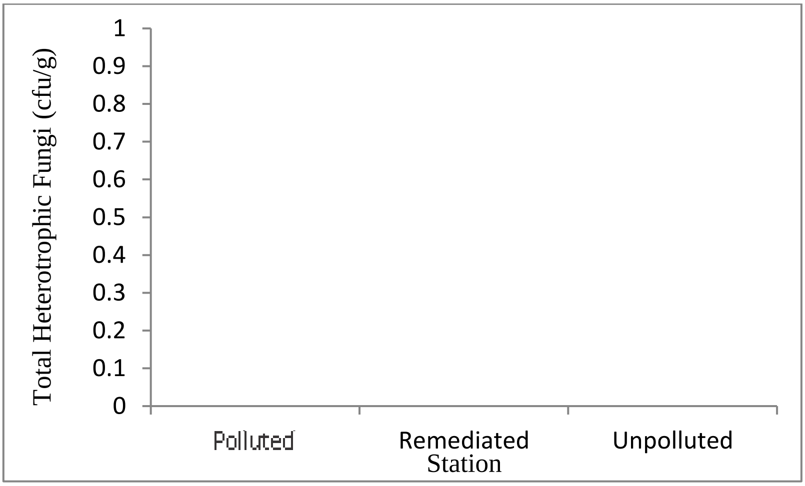

Fig. 8: Total Heterotrophic Fungi in sediment at different stations

Hydrocarbon Utilising Fungi (HUF)

Hydrocarbon utilising Fungi (THF) were not detected in all the stations as shown in Fig. 9.

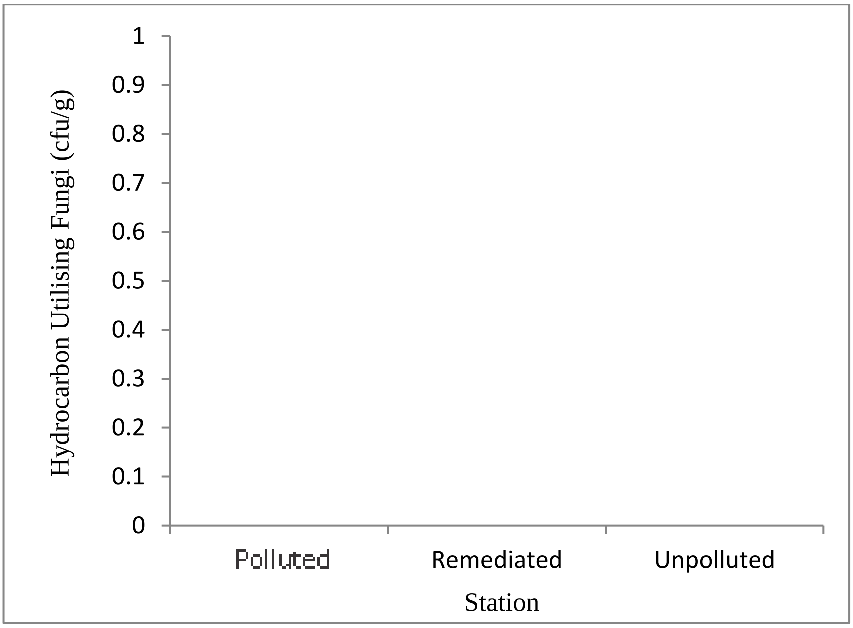

Fig. 9: Hydrocarbon Utilising Fungi in sediment at different stations

DISCUSSION

Some impacts of crude oil pollution on the physical, chemical and biological characteristics of environment have been reported by Tanee and Kinako (2008). An effective remediation restores polluted environment to almost its physical and chemical condition and facilitates biological recovery of the environment.

Total Hydrocarbon (THC) of the polluted station was higher than that of the remediated station. The high THC of the polluted station could have resulted from petroleum hydrocarbon spill incidents and the fact that no remediation action was taken at the station. The lower THC of the remediated station could have resulted from the remediation i.e. soil flushing. The lower THC content of the remediated station corroborated the findings of Adesuyi *et al*. (2016) and Wokoma (2014) in similar studies carried out on other creeks in the Niger Delta.

The TPH content of the polluted sediment was higher than that of the remediated station. The high TPH of the polluted station is capable of causing ecological damages in both soil and water as it is toxic, mutagenic and carcinogenic (Wang *et al.*, 2011; Liu *et al.*, 2012; Khan *et al*., 2013; Nwaichi *et al.*, 2015). This is evidenced in bare physical condition of the polluted station as no plant regeneration and presence of animals were observed, perhaps, due to the high TPH content. Such high TPH is hardly degraded by microbes and, therefore, persistent in soil or sediment and water for a long time. According to Chorom and Hosseini (2011) as well as Das and Chandran (2011), the long duration of persistence of the hydrocarbon is because it is predominantly composed of $C_{5–35}$ chains with numerous structural carbon atom configurations. Similar to THC, TPH had a significant reduction in the remediated station which was due to the remediation carried out there. However, the TPH content was above

50 mg/kg and 1,000 mg/kg stipulated by EGASPIN (2002) as environmentally acceptable toxic limits to man, respectively. Osuji *et al*. (2004) stated that such high hydrocarbon levels affect both above-ground and subterranean flora and fauna, which play essential roles in the biogeochemical cycle and ecosystem sustenance.

Sediment conductivity was lower in the remediated station when compared with the polluted and unpolluted stations. This is an indication that soil flushing technique is capable of reducing electrical conductivity of polluted sediment. This contradicts the report of Tanee and Albert (2011) who observed lower soil conductivity in polluted soil when compared with remediated soil.

The THB in the polluted station were observed to be low compared with the remediated station. Low THB could have resulted from suffocation and death of sediment microbial flora populations as crude oil soil-pollution negatively affects soil aeration. This is an indication of crude oil toxicity to THB which could result in low degradation of the pollutant. Eni and Okpiliya (2011) reported a similar finding on evaluation of on-shore oil spill remediation operations in Port Harcourt, Nigeria.

Hydrocarbon utilising bacteria (HUB) in the polluted station were very high compared with those of the remediated station. This means that the remediation approach reduced HUB in the remediated station. However, Eni and Okpiliya (2011) noted that to be certain that the level of clean-up is high, the HUB should not be more than 1.0%. This implies that the remediated station still has significant amount of hydrocarbon pollution.

Total heterotrophic fungi and hydrocarbon-utilising fungi were not detected across the stations. This could be as a result of the presence of quaternary ammonium compounds which are known to be very active antifungal (Abedon, 2008).

CONCLUSION

The results obtained in this study indicate significant reduction in THC and TPH in the remediated station when compared with the un-remediated station. Specifically, 94% reduction was observed on THC and 31% on TPH. Despite the reduction, the THC and TPH were still at toxic levels as shown by the low microbial populations in the impacted station. This is an indication of the ineffectiveness of the soil flushing technique as a mono-remediation approach. Therefore, there is the need for a secondary remediation treatment after soil flushing technique for effective remediation and ecosystem restoration through post-remediation re-vegetation.

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