QUALITY CHARACTERISTICS OF SOILS IN THE VICINITY OF AN OILFIELD WASTEWATER DISCHARGE POND

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ABSTRACT

Oilfield wastewater is the main wastewater associated with crude oil production activities and a major contributor of environmental pollution in the Niger Delta; being constituted by several organic and inorganic chemicals including heavy metals and polycyclic aromatic hydrocarbons (PAHs). The aims of this study were to characterize the physicochemical properties of an oilfield wastewater and surrounding soils in the Niger Delta. The oilfield wastewater and soil samples were collected from an onshore oil production platform fortnightly for a period of three months (January to March, 20118) and were analyzed for physicochemical parameters by standard methods. The average value of the soil around pond for temperature ranged from 29.1-29.6 °C, pH 5.94-9.015, conductivity 254-425 μS/cm, salinity 34-47 ‰, soil moisture 8.11-8.17 %, water holding capacity 14.5-15%, silt 11-21%, clay 26.5-29 %, sand 52.5-60 %, potassium 0.0225-0.043 mg/kg, nitrate 1.1965-1.76 mg/kg, phosphate 0.102-0.227mg/kg, calcium 0.0955-0.137mg/kg, magnesium 0.2515-0.5445 mg/kg, sulphate 0.105-0.179 mg/kg, total nitrogen 1.71-2.0075 mg/kg, organic carbon 0.31-0.5 %, total organic matter 5.925-6.65 %, total alkalinity 12.5-14mg/kg, total hydrocarbon content(THC) 153.77-226.81mg/kg, and polycyclic aromatic hydrocarbon (PAHs) 32.5205-137.03145mg/kg. While the average values of the soil 80 m away from the pond ranged from 28.3- 28.7 °C for temperature, 5.46- 5.845 for pH, 255-305 μS/cm for conductivity, 31-39 mg/kg for salinity, 4.16-6.63‰ for soil moisture, 11.1-14% for water holding capacity, 10.5-15.5% for silt, clay 23.5-29 %, sand 55.5-65.3 %, potassium 0.865-0.9375mg/kg, calcium 3.51-4.03 mg/kg, magnesium 1.0905-1.0935 mg/kg, sulphate 1.192-1.26 mg/kg, total nitrogen 2.7135-3.101 mg/kg, organic carbon 0.235-0.25%, total organic matter (TOM) 3.2-3.3%, alkalinity 12.5- 14mg/kg, total hydrocarbon content 36.58-47.55 mg/kg, PAHs 55.35-74.4 mg/kg, zinc 1.1125-2.0695 mg/l, iron 10.3475-11.964 mg/l, and copper 0.022-0.024 mg/l.

There was significant difference (P>0.05) between the soil around the pond and 80 m away from the pond in temperature, soil moisture, WHC, potassium, nitrate, phosphate, calcium, magnesium, sulphate, total nitrogen, organic carbon, TOM, THC, iron and zinc. There was no significant different in the average value of the physicochemical parameters of the soil 80m away from the pond in the various month of study except for the silt (15.5 %) and clay (29 %) which were higher in the month of March, sand 65.3 % in the month of January. There was accumulation or concentration of potassium, nitrate, phosphate, calcium, magnesium, sulphate, total nitrogen, and zinc in soil samples around the oilfield wastewater discharge pond in the various months of the study, while conductivity, clay, sand, PAHs, were impacted in the month of February and March, copper (January and February), and alkalinity in

March only. The results revealed that the soils of the study area were polluted with PAHs and hydrocarbon contents.

Keywords: Oilfield wastewater, soil, nitrate, heavy metal, polycyclic aromatic hydrocarbons

INTRODUCTION

Crude oil exploration and exploitation activities in Nigeria are major contributors of environmental pollution in the Niger Delta. Oilfield wastewater is the associated wastewater of crude oil production activities. Increased petroleum activities, particularly in the Niger Delta has led to pollution stress on soil and surface water, due to the discharging of large quantities of oilfield wastewater without adequate treatment techniques (Obire and Amusan, 2003; Wemedo and Obire, 2012). Oilfield wastewater containing high organic and inorganic chemicals including radioactive materials, volatile and semi-volatile organics (Warner *et al*., 2012; Kassotis *et al*., 2015) poses environmental problems. The main crucial environmental issues of the oilfield wastewater are total petroleum hydrocarbon, total solids (TS), and inorganic chemicals including heavy metals and polycyclic aromatic hydrocarbons (PAHs), biochemical and chemical oxygen demand (BOD and COD), and pathogens (Pichtel, 2016).

In Nigeria, Oil exploitation companies are known to discharge oilfield wastewater into Streams or ponds which are also a threat to the surrounding soil and groundwater (Obire and Wemedo, 1996). Accelerated soil quality change due to oilfield wastewater discharging with large quantities of nutrients and toxic substances into the environment has long become an issue problem in Niger Delta. It is estimated that over 90% of wastewater from operations of oil industries in Nigeria is still discharged to soil, rivers and streams without adequate treatment. This is largely due to the fact that most of the oil companies have no wastewater treatment plants or where they exist the facilities are inadequate (Human Rights Watch, 1998; Van Dessel, 1996).

Soil contaminated by industrial effluents has affected adversely both soil health and crop productivity. Heavy metals are one of the major pollutants of interest in the environment because of its toxicity, persistence and bioaccumulation problems (Zouboules et al., 2004). Excessive accumulation of micronutrients and other heavy metals like cadmium, lead, and nickel in the plants operates as stress factors causing physiological constraints leading to decrease vigour and plant growth (Zouboules et al., 2004) and therefore crop yield (Jaja and Obire, 2015). The effects of petroleum activities on the environment in the Niger Delta are evident through the pollution of soil and water bodies and human habitat in the major cities. The oilfield wastewater contains toxic and hazardous substances that are detrimental to human health if they enter the food chain (Rajaram and Ashutost, 2008).

The objective of this present study therefore was to investigate the characteristics of raw oilfield wastewater, wastewater in the pond, its surrounding soil and of soil some 80m distance away from the pond and the impact of the oilfield wastewater on the physicochemical constituents of the soils around the pond. This investigation was conducted for a period of three months (January–March, 2018) regarded as part of the dry season in the Niger Delta.

MATERIALS AND METHODS

Collection of Oilfield wastewater and soil samples

Oilfield wastewater was collected from Ogbogu Flow Station; an onshore oil production platform located in Ogba Egbema Ndoni local government Area (ONELGA) of Rivers State, Nigeria. The Oilfield wastewater samples were collected using 4 Litre capacity plastic bottles and stored in an ice packed cooler.

On the other hand, the soil samples were collected from around the pond and 80 meters away from the pond at a depth of 0-15cm with a sterile spatula into sterile polythene bags and stored in an ice packed cooler. The collected and appropriately labeled oilfield wastewater and soil samples were immediately transported to the laboratory for analysis within 24 hours for processing and analyses. Samples were collected twice in a month (1st and 3rd week) for a period of three months (January, 2018 to March, 2018). Soil samples for some physicochemical parameters and heavy metals were air dried in the laboratory.

Physicochemical analysis of the oilfield wastewater and soil Samples

Physicochemical analyses of the oilfield wastewater and soil samples were conducted according to standard procedures of APHA (1998) and ASTM (1999). The physicochemical parameters determined include pH, temperature, turbidity, total dissolved solids (TDS), total suspended solids (TSS), conductivity, salinity, conductivity, dissolved oxygen (DO), biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), nitrogen, phosphate, total organic carbon (TOC), total petroleum hydrocarbon, PAHs, and heavy metals such as nickel, lead, zinc, aluminum chromium, selenium, arsenic, copper, and cadmium. In addition, the soil moisture content, soil texture, water holding capacity, phosphate, nitrate, total nitrogen, potassium, calcium, sulphate, soil fertility, total organic carbon, total organic matter, alkalinity, magnesium and iron were also analyzed or determined for the soil samples.
The Impact (%) of oilfield wastewater on physicochemical constituents of soils around discharge pond during each month was calculated using the equation of Alayu and Yirgu (2018) below

$$\text{Impact (\%)} = \frac{\text{Original value (soil around pond)} - \text{Final value (soil 80 m away)}}{\text{riginal value (soil around pond)}} \times 100$$

Statistical analysis was also conducted using Duncan Multiple Range test and Analysis of variance to determine whether there is significant difference between the physicochemical constituent of the soil around the pond and the soil 80 m away from the soil and between the physicochemical constituents of produced water and the recipient pond,

RESULTS

The result of the calculated average values of physicochemical constituents of oilfield raw wastewater before and after discharge into the recipient pond is as shown in Table 1 below. The average values of Temperature, pH, Total suspended solid (TSS), Dissolved oxygen (DO), Nitrogen, Phosphate, Total organic carbon (TOC), Polycyclic aromatic hydrocarbons (PAHs) were higher in the pond effluent than in the raw wastewater. While the sum average for Biological oxygen demand (BOD), Chemical oxygen demand (COD), Total dissolved solid (TDS), Salinity, Turbidity, Conductivity and Total petroleum hydrocarbon (TPH) were higher in the raw wastewater than in the pond effluent. The TSS was statistically different in the samples, however no statistical difference in other physicochemical parameters in the raw wastewater and in the pond effluent.

Table 1: Average values of physicochemical constituents of oilfield wastewater before and after discharge into pond

Parameter	January		February		March	
	Raw wastewater	Pond effluent	Raw wastewater	Pond effluent	Raw wastewater	Pond effluent
Temperature °C	27.7	28.8	28.57	30.255	31.01	30.255
pH	7.65	7.82	8.48	6.89	7.485	7.505
Salinity (Mg/l)	61.86	22.73	32.5	26.5	28.5	26.5
Turbidity (NTU)	23.8	16.3	9.15	12.95	31.9	14.55
Conductivity(μS/cm)	134.5	355.5	395	55	164	132
TDS (Mg/L)	0.605	150	197.5	47	82	44
TSS (Mg/L)	4.7	13.1715	1.167	11.9575	2.9205	11.3545
DO (Mg/L)	1.99	2.37	2.675	2.405	3.33	3.76
BOD (Mg/L	19.04	9.37	3.0975	7.13	5.9135	6.7825
COD (Mg/L)	185.26	82.03	100.8	72	36.8	86.4
Nitrogen (Mg/L)	3.376	6.185	0.9645	3.4155	1.637	2.3005
Phosphate (Mg/L)	0.546	0.813	0.1905	0.2145	0.1785	0.229
TOC (Mg/L)	135.16	225.62	133.745	228.3	132.01	231.44
TPH (Mg/L)	286.785	92.15145	213.765	83.555	142.915	83.1655
PAHs (Mg/L)	93.18	69.7005	0.455	67.727	0.058	40.52

The result of the calculated average values of heavy metal content of raw oilfield wastewater samples before and after discharge into the recipient pond is as shown in Table 2 below. The sum average in Aluminum was higher in the raw wastewater than in the pond effluent. Lead, Zinc, Nickel, Chromium, Copper were higher in the pond effluent than in the raw wastewater. Cadmium had the same value while arsenic and Selenium were below the level of detection. Statistically, there was no significant different between the raw wastewater and the pond effluent except for Aluminum. Chromium, Zinc, Lead were higher in January sampling in the raw wastewater compared to the other months.

The result of the physicochemical constituents of the soil samples around the oilfield wastewater discharged pond is as shown in Table 3 below. Statistical analysis showed that there was significant difference in the pH, silt, sand, potassium, nitrate, phosphate, calcium, sulphate, organic carbon, total organic matter (TOM), total hydrocarbon content (THC) and polycyclic aromatic hydrocarbons (PAHs) in the various months of study.

The result of the physicochemical constituents of the soil samples 80m away from the oilfield wastewater discharged pond is as shown in Table 4 below. Statistical analysis showed that except for the soil texture (silt, clay and sand) which were significantly different in various months, there was no significant difference in the average value of the physicochemical constituents of soils 80m away from the discharge pond.

Table 2: Average values of Heavy metals of oilfield wastewater before and after discharge into pond

Heavy metal	January		February		March	
	Raw wastewater	Pond effluent	Raw wastewater	Pond effluent	Raw wastewater	Pond effluent
Lead (Mg/L)	0.2135	0.105	0.001	0.1035	0.001	0.1055
Zinc (Mg/L)	2.110	1.513	0.012	1.431	0.06	1.513
Nickel (Mg/L)	0.084	0.022	0.001	0.0515	0.001	0.084
Aluminum (Mg/L)	0.135	0.087	0.112	0.0815	0.179	0.0805
Chromium (Mg/L)	1.154	0.8155	0.001	0.249	0.001	0.4515
Selenium (Mg/L)	0.001	0.001	0.001	0.001	0.001	0.001
Arsenic (Mg/L	0.001	0.001	0.001	0.001	0.001	0.001
Copper (Mg/L)	0.042	0.053	0.001	0.013	0.009	0.013
Cadmium (Mg/L)	0.106	0.073	0.001	0.018	0.001	0.0425

Table 3: Average values of physicochemical constituents of soil around oilfield wastewater discharge pond in three months

Parameter	Month		
	January	February	March
Temperature °C	29.6	29.1	29.25
pH unit	6.65	5.94	9.015
Conductivity (μS/cm)	425	267	254
Salinity (‰)	47	36.5	34
Soil moisture content (%)	8.13	8.11	8.17
Water holding capacity (%)	15	15	14.5
Potassium (Mg/Kg)	0.0225	0.043	0.0285
Nitrate (Mg/Kg)	1.76	1.307	1.1965
Phosphate (Mg/Kg)	0.227	0.2065	0.102
Calcium (Mg/kg)	0.137	0.1245	0.0955
Magnesium (Mg/Kg)	0.5445	0.32	0.2515
Sulphate (Mg/Kg)	0.179	0.133	0.105
Total nitrogen (Mg/Kg)	2.0075	1.71	1.769
Organic carbon (%)	0.31	0.425	0.5
TOM (%)	5.925	6.65	6.61
Alkalinity (Mg/Kg)	14	13	12.5
THC (Mg/Kg)	226.81	153.77	158.975
PAH (Mg/Kg)	137.03145	37.52	32.5205
Zinc (Mg/L)	0.116	0.155	0.179
Iron (Mg/L)	12.607	13.338	14.137
Copper (Mg/L)	0.0185	0.0185	0.0355
Silt (%)	11	21	18.5
Clay (%)	29	26.5	28
Sand (%)	60	52.5	53.5
Soil texture	Sandy loam	Sandy loam	Sandy loam

Table 4: Average values of physicochemical constituents of soils 80m away from oilfield wastewater discharge pond

Parameters	Month		
	January	**February**	**March**
Temperature °C	28.7	28.3	28.45
pH	5.46	5.565	5.845
Conductivity (µS/cm)	255	305	275
Salinity (‰)	31	33	39
Soil moisture content (%)	4.16	6.63	6.16
Water holding capacity (%)	11.1	12.5	14
Potassium (Mg/Kg)	0.9375	0.915	0.865
Nitrate (Mg/Kg)	2.5795	2.611	2.4305
Phosphate (Mg/Kg)	0.836	0.8565	0.8175
Calcium (Mg/kg)	3.71	3.51	4.03
Magnesium (Mg/Kg)	1.0905	1.077	1.0935
Sulphate (Mg/Kg)	1.192	1.215	1.26
Total nitrogen (Mg/Kg)	3.101	2.7135	3.1005
Organic carbon (%)	0.235	0.235	0.25
TOM (%)	3.2	3.3	3.26
Alkalinity (Mg/Kg)	12.5	12.5	14
THC (Mg/Kg)	47.55	36.58	38.86
PAH (Mg/Kg)	74.4	55.35	59.505
Zinc (Mg/L)	1.1125	1.113	2.0695
Iron (Mg/L)	11.617	11.964	10.3475
Copper (Mg/L)	0.024	0.022	0.024
Silt (%)	10.5	14	15.5
Clay (%)	23.5	28.5	29
Sand (%)	65.3	57.5	55.5
Soil texture	Sandy loam	Sandy loam	Sandy loam

The impact (%) of oilfield wastewater on physicochemical constituents of soils around discharge pond in three months is shown in Table 5 below.

Negative values show accumulation of the oilfield wastewater on the physicochemical constituents of soil around discharge pond. From the result below the following parameters; salinity, soil moisture content, water holding capacity, silt, organic carbon, total organic matter (TOM) and iron were not impacted. Other parameters such as conductivity, clay, sand, potassium, nitrate, phosphate, calcium, magnesium, sulphate, total nitrogen, alkalinity, PAH, zinc, and copper where accumulated by the oilfield wastewater in one month or the other.

DISCUSSION

The TSS in the pond effluent showed higher average value which suggests that wastes are being added to the pond effluents from other sources apart from the produced water that is being discharged into it, such as rainstorm deposition or runoffs from the surrounding as observed also by the findings of Eunice *et al*., 2017. There was no significant difference in the physicochemical parameters of the raw waste water and pond effluent except for the TSS. Total organic carbon (TOC) and polycyclic aromatic hydrocarbon (PAHs) were also observed to be high in the pond effluent than in the raw wastewater. This could be as a result of continuous discharge and accumulation over time. Total petroleum hydrocarbon and PAHs observed in the study are known to be toxic to aquatic life.

Table 5: Impact (%) of oilfield wastewater on physicochemical constituents of soils around discharge pond

Parameter	Month		
	January	February	March
Conductivity(µS/cm)	40	-14.2	-8.3
Salinity (Mg/Kg)	34.0	9.6	14.7
Soil moisture content (%)	48.8	18.2	24.6
Water holding capacity (%)	26	16.7	3.4
Soil texture			
Silt (%)	4.5	33.3	16.2
Clay (%)	18.9	-7.5	-3.8
Sand (%)	8.8	-9.5	-3.7
Potassium (Mg/Kg)	-4066.6	-2027.9	-2935.1
Nitrate (Mg/Kg)	-46.5	-99.7	-103.1
Phosphate (Mg/Kg)	-268.2	-314.7	-701.4
Calcium (Mg/kg)	-2608.0	-2719.2	-4119.8
Magnesium (Mg/Kg)	-100.2	-236.5	-334.7
Sulphate (Mg/Kg)	-565.9	-813.5	-1100
Total nitrogen (Mg/Kg)	-54.5	-58.7	-75.3
Organic carbon (%)	24.2	44.7	50
TOM (%)	45.9	50.4	50.7
Alkalinity (Mg/Kg)	10.7	3.8	-12
THC (Mg/Kg)	79.0	76.2	75.6
PAH (Mg/Kg)	45.7	-47.5	-82.9
Zinc (Mg/L)	-859.1	-618.1	-1056.1
Iron (Mg/L)	7.9	10.3	26.8
Copper (Mg/L)	-29.7	-18.9	32.4

The concentration of PAHs was higher in this study compared to the range of 0.040 to about 3 mg/l reported by Neff *et al.*, 2011. The COD, BOD, and Turbidity of the raw wastewater discharged into the pond effluent did not meet the effluent limitation standard set by DPR and FMEnv for refinery effluent in Nigeria. Uzoekwe and Oghosanine (2011) also recorded high COD and BOD values in samples collected from discharge point than water receiving body. There is no significant different between the heavy metals in the raw wastewater and the pond effluent except for Aluminum which was higher in the raw wastewater than in the pond effluent. The value of the Aluminum in raw wastewater reported by Neff *et al* (2011) was higher 1.03 mg/l than the value in this study 0.112-0.179 mg/l.

The results of soils around the pond showed temperature range of 29.1-29.6 °C and was higher than soil 80 m away 28.3-28.45 °C. Temperature of a given soil is determined by absorptive properties of that soil and ratio of the energy absorbed by the soil to the energy given out by the soil. Soil moisture was also higher in the soil around pond. According to Edori and iyama (2017) any soil with high concentration of organic matters such as observed in this study has the capacity to retain water for long time and drying of such samples may take longer than expected. The organic matter in soil around pond 5.925-6.65% in this study was higher compared to that observed by Amos-Tautua et al (2014) which ranged from 1.03 to 4.71% and that of Oyedele et al (2008). The presence of organic carbon in soil increases the exchange capacity which retains nutrients assimilated by plants. The total organic carbon in the soil around pond was higher than that in soil 80 m away from pond, though both were low to moderate. This may suggest that the soil around pond will be more suggestive of degradation. Low to moderate in total organic carbon was observed by Amos-Tautua et al (2014) in soil of study. Total hydrocarbon content was higher in the soil around pond compare to soil 80 m away from soil, suggesting that the oilfield wastewater discharged into the pond have impact on the soil around pond and its texture (clay, and sand). The total amount of hydrocarbons content found in the soil samples is useful as a general indicator of petroleum contamination at any particular sites (ATSDR, 1999). Statistically there was significant difference ($P>0.05$) between the soil around pond and soil 80m away from the pond in temperature, soil moisture, water holding capacity, potassium, nitrate, phosphate, calcium, magnesium, sulphate, total nitrogen, organic carbon, total organic matter, and total hydrocarbon content, iron and zinc.

The values of potassium, nitrate, phosphate, calcium, magnesium, sulphate were all higher in the soil 80 m away from the pond than the soil around the pond. The lower values noticed in the soil around the pond may be attributed to the activities of the biodegraders using up available nutrients. Plants growth and development largely depends on the combination and concentration of mineral nutrients available in the soil, a deficiency of any one of them may result in decreased plant productivity and or fertility. There was no significant different between the PAHs, copper, pH, conductivity, salinity, silt, clay, sand and alkalinity of the soil around the pond and 80 m away.

Soil physicochemical constituents around the pond mostly impacted by the oil field wastewater were clay, conductivity, sand, potassium, nitrate, phosphate, calcium, magnesium, sulphate, total nitrogen, alkalinity, PAH, and copper. The results in Tables 5, showed higher accumulation of potassium -4066.6 mg/kg in January; calcium -4119.8 mg/kg in March; sulphate -1100 mg/kg in March and Zn -1056.1 mg/kg in March. The above results have confirmed the observations of Dejong (1980) that oil pollution alters both chemical and physical properties of soil and degrades soil fertility. Oil is known to exert adverse effects on soil properties and plant community. Barker (1970), Amadi et al (1993) and Osuji et al (2005), observed that beyond three percent concentration oil has been reported to be increasingly deleterious to biota and crop growth.

CONCLUSION AND RECOMMENDATION

The high level of total hydrocarbon content , PAH, and some heavy metals both in the soil around the pond and 80 m away from the soil as observed in the study was as a result of the impact of the oilfield wastewater being discharged continuously to the pond. The oilfield wastewater enters the pond and during heavy rains and storms the pond overflows its banks thus depositing these pollutants in the soils of lands adjoining the pond. Storm water run offs carries these further inland. The accumulation of these through this mode of deposition with time must have resulted in the high levels of pollutants observed. Waste water management is a big challenge in today's world. Regulatory bodies should ensure that petroleum industries comply with guidelines for disposal of effluents.

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