Soil Environ. 39(2): 173-183, 2020
DOI:10.25252/SE/2020/162338
Online ISSN: 2075-1141
Print ISSN: 2074-9546

The impact of used transformer oil on the physicochemical characteristics and persistent organic pollutant levels in soils around transformer installation areas

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[Received:** August 21, 2020 **Accepted:** October 01, 2020 **Published Online:** November 28, 2020**]

Abstract

Transformer oil spillage into the soil, if not properly handled, can lead to ground water and soil pollution, there by posing serious environmental and health threat. The transformer oil contaminated soils around transformer installation areas in Ile-Ife were collected at 0-15 cm and 15-30 cm depths. Soil physicochemical parameters (pH, available phosphorous, soil organic carbon (SOC), NO_3^-, total nitrogen, calcium, magnesium, potassium, sodium, and cation exchange capacity (CEC)) were analysed using standard analytical techniques). Persistent organic pollutants (POP) were extracted from the soil samples using soxhlet extraction technique, and n-hexane/dichloromethane (4:1, v/v) as the solvent. The extracts were analyzed using Gas Chromatography coupled with mass spectrometer (GC-MS) Detector. The results showed that the mean values of the total nitrogen, available phosphorus and organic carbon of the oil contaminated soils were higher than their critical values; while the NO_3^-, pH, and CEC values were lower than their critical values. The analysed soils contained higher percentage of sandy soil than clay and silt, which is inherent of the parent rock. The analysis of variance (ANOVA) showed that in terms of depth and sample type there was significant difference in the soil physicochemical parameters. The oil contaminated soils contained large number of alkanes and iso-alkanes, alongside non-carcinogenic. The study concludes that the presence of transformer oil in the contaminated soils altered the soil physicochemical parameters and soil quality, and also introduced a substantial quantity of polycyclic aromatic hydrocarbons (PAHs) into the soils there by exposing the residence and workers to chronic health risk.

Keywords: Gas chromatography - mass spectrometry; autoanalyzer; pahs; transformer oil; soil physicochemical parameters

Introduction

Energy plays vital roles in economic growth and development, as well as industrialization, poverty eradication, and security of any nation. It also cares for the provision of basic daily necessities such as cooking, transport, heating and running other productive activities (Oyedepo 2012). As the daily demand for energy increases in most developing countries, the installation of more high voltage transformers in urban and rural areas have been used as one of the means to sustain and extend power transmission. Transformer insulating oil (dielectric fluid) which commonly used in most high voltage transformers, serve as an insulating and cooling system for the coils in the transformer. Due to its complex chemical composition, it is physically stable to thermal and electrical stresses (Safi *et al.* 2015).

Most transformer insulating oil are products of fractional distillation of crude oil with polycyclic aromatic hydrocarbons (PAHs) as a major constituent of transformer oil used in distribution transformers (Kaplan *et al.* 2010; Liu *et al.* 2015; Pillai *et al.* 2005). Although, PAHs in the environment can be from both natural or anthropogenic sources, several PAHs have been documented to be recalcitrant, carcinogenic and mutagenic; and tend to adsorb on organic matters in soil and sediments (Adebiyi and Adeyemi 2015). The impact of their continuous low-level inputs into the soil, resulting from oil spillage is rarely noticed, and if not properly treated, it can lead to soil pollution. Indiscriminate discharge of petroleum waste on soil can also contaminate ground water (Ojekunle *et al.* 2020). This poses serious environmental and health threat due to bioaccumulation and persistence of contaminants in the environment.

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The presence of petroleum product in soil results in the reduction of soil quality and productivity, alteration of soil microbial metabolism, physical and chemical parameters such as total organic carbon, Atterberg limits, total nitrogen, moisture level, nitrate, cation exchange capacity, available phosphorous, permeability characteristics, particle size, etc (Devatha *et al*. 2019; Jabbarov *et al*. 2019). The textural composition of a soil has been reported to be highly dependent on the parent material from which the soils are formed (Oguike and Mbagwu 2009). This has been observed to influence the adsorption/desorption efficiency of the soil contaminants (Fagbemi and Sanusi 2016). Hajabbasi (2016) observed that the degradation of hydrocarbons on soil surfaces is affected by the mobility of hydrocarbon in the soil, adsorption/desorption, bulk density and soil aeration which are dependent on particle and pore size distribution.

There have been report of substantial quantities of persistent organic congeners in soils of power transmission substations in Nigeria, with transformer oils leakage from high voltage transformers (Okoh and Daniels 2016). Studies on persistent organic pollutants (POP) in Nigeria had focused on polychlorinated biphenyls (PCBs) in transformer oil and isolation and characterization of bacterial strains from transformer oil contaminated soils (Kamba *et al*. 2013; Nwinyi *et al*. 2011; Okoh and Daniels 2016). However, there is little information on the impact of transformer oil contamination on the physicochemical parameters and POP content of the contaminated soils. This study therefore, aims at assessing the impact of transformer insulating oil on the physicochemical parameters hydrocarbon and POP content in the contaminated soils.

Materials and Methods

Description of study area, sample collection and preparation

The study area (Ile-Ife) is located in Osun state, Nigeria, and lies between Latitudes 7°26′ N and Longitudes 4°28′ E, and Latitudes 7°34′ N and Longitudes 4°34′ E (Akhigbe *et al.* 2019). Ile-Ife is a highly commercialized town with few industries and some electric power distribution station. The soils of the area is composed mainly of deep clay soils and sandy soils, and its bedrock is with metamorphic rocks (Ajala and Olayiwola 2013; Akhigbe *et al.* 2019). Surface soil (0 – 15 cm) and subsurface soil (15 -30 cm) samples were collected from soils contaminated with transformer oil around transformer installation areas, and soils of little anthropogenic activities (control soil samples) about 100 m away from the transformer installation area, using a graduated Dutch Hand Auger. The soil samples were taken immediately to the laboratory, air-dried (room temperature), crushed into 2 mm mesh size using agate mortar and pestle, and mixed thoroughly using the coning and quartering method (Akpan *et al.* 2011; Okon and Ogba 2018). Thereafter, the samples were used for various analysis.

Physicochemical parameters of the transformer oil impacted soils

The modified hydrometer method was used to determine the particle size distribution of the soil samples (Gee and Or 2002). Soil pH was determined using a standardized pH meter at 25 °C (Bailey 1986). The soil organic carbon (SOC) content of the soil samples was determined by using chromic acid digestion method (Akeredolu and Akinnibosun 2017) and colorimetric method at 550 nm wavelength using Autoanalyzer (SEAL analytical AA3) (Nelson and Sommers 1996). The cation exchangeable capacity (CEC) was determined by extracting the soil samples using 1 N ammonium acetate at pH 7 and thereafter measured with atomic absorption spectrophotometry (AAS) (ALPHA 4, Chemtech Analytical, UK) (Lee *et al.* 2013). Kjeldahl digestion method was used for the determination of total nitrogen (Bremner 1996). The available soil phosphorus was determined using the Bray-1 method (Bray and Kurtz 1945). Nitrate level was determined using the American Public Health Association (APHA), 1992) method.

POP were extracted using soxhlet extraction techniques and a mixture of n-hexane and dichloromethane (4:1, v/v) as the solvent (Pakpahan 2011). The extracts were cleaned up using capillary column chromatography and eluted with n-hexane and dichloromethane (4:1). Qualitative and quantitative determination of POP was carried out using gas chromatography coupled with mass spectrometer detector. All measurements were carried out in triplicates and expressed as mean ± standard deviation (SD). Analysis of variance (ANOVA), using (Duncan Multiple Range test, $p < 0.05$) was performed using SAS version 9.0.0 software. Coefficient of variation (CV %) was used to evaluate the degree of variability of the soils physicochemical parameters (Ojetade *et al*. 2016).

Gas chromatography-mass spectrometry (GC-MS) analysis

The GC system (Agilent 7890A model) used for the determination of POP was equipped with Mass Spectrometer Detection 5975C with electron impact ionization (70 eV), a split-split less injector (Auto) 7683 series, and fitted with HP-5 MS capillary column (length 30 m x 250 µm, film thickness 0.25 µm) coated with 5% phenyl methyl silicone, 95% dimethylpolysiloxane. The column temperature was set to rise gradually from 60 ℃ to 270 ℃ at 6 ℃ min^{-1}, and finally held at 305 ℃ for 10 min. Helium was used as the carrier gas at a flow rate of 1.0 ml min^{-1}. Samples were injected at 270 ℃ and scanned from 50 to 550 mz^{-1} at 0.8 scan sec^{-1} (Eljazi *et al.* 2018). Compound identification was carried out by matching the spectral with that in the database of the National Institute of Standards and Technology library (NIST).

Table 1: Soil particle size distribution for transformer oil impacted soils (%)

	Surface soil (0 − 15 cm)				Sub-surface soil (15 − 30 cm)			
Sampling Location	**Sand**	**Clay**	**Silt**	**Textural class**	**Sand**	**Clay**	**Silt**	**Textural class**
T 1	49	36	15	Sandy clay	46	40	14	Sandy clay
T 2	73	20	7	Sandy clay loam	72	14	14	Sandy loam
T 3	67	16	17	Sandy loam	56	24	20	Sandy clay loam
T 4	67	18	15	Sandy loam	70	16	14	Sandy loam
T 5	67	16	17	Sandy loam	36	38	26	Clay loam
T 6	77	10	13	Sandy loam	55	29	16	Sandy clay loam
T 7	69	14	17	Sandy loam	72	12	16	Sandy loam
T 8	57	24	19	Sandy clay loam	36	38	26	Clay loam
T 9	57	22	21	Sandy clay loam	43	35	22	Clay loam
T 10	53	33	14	Sandy clay loam	54	32	14	Sandy clay loam
Average	**63.6**	**20.9**	**15.5**	**Sandy clay loam**	**54**	**27.8**	**18.2**	**Sandy clay loam**

Table 2: Soil particle size distribution for control soil samples (%)

	Surface soil (0 − 15 cm)				Sub-surface soil (15 − 30 cm)			
Sampling location	**Sand**	**Clay**	**Silt**	**Textural class**	**Sand**	**Clay**	**Silt**	**Textural class**
C 1	73	11	16	Sandy loam	74	8	18	Sandy loam
C 2	59	18	23	Sandy loam	60	18	22	Sandy loam
C 3	73	10	17	Sandy loam	76	6	18	Sandy loam
C 4	57	28	15	Sandy clay loam	56	26	18	Sandy clay loam
C 5	55	32	13	Sandy clay loam	55	29	16	Sandy clay loam
Average	**63.4**	**19.8**	**16.8**	**Sandy loam**	**64.2**	**17.4**	**18.4**	**Sandy Loam**

Results and Discussion

Characterization of soil physicochemical parameters

Particle size distribution of the oil impacted soils

The soil particle size distribution and a textural class of the transformer contaminated soils, and control soil samples are presented in Tables 1 and 2 respectively. The surface and sub-surface soils for all the sampling locations had a higher percentage of sand and varied in the percentage of clay and silt. The textural class of the surface soils of the transformer oil impacted soils were sandy clay, sandy clay loam, and sandy loam, while the subsurface soil texture class was sandy clay, sandy loam, sandy clay loam, and clayey loam. The texture class of the surface soils and subsurface soils of the control soils were sandy clay loam and sandy loam. It was observed that the percentage of clay in most sampling locations increased with depth. The results of other soil physicochemical parameters (pH, available phosphorous, soil organic carbon, NO_3^-, total nitrogen, Ca, Mg, K, Na, CEC) of the analysed soil samples are presented in Table 3.

Effect of transformer oil spillage on soil physicochemical parameters

It was observed that the soils of the study area contain higher percentage of sand, suggesting high porosity and aeration in the soil. Soils with higher percentage of sandy soils and low percentage silt and clay contains smaller bacterial biomass, hence lowering hydrocarbon degradation; and it can be attributed to an increase in bioavailability of contaminants, soil aeration, bulk density and porosity (Hajabbasi 2016). However, as a result of poor water retention and increase mobility of contaminants, there is higher tendency for ground water contamination in such soils (Edori and Iyama 2017).

The analysed soils were moderately acidic and their values fell within the pH range (4.0–6.9) of soils in

Table 3: Physicochemical parameters of transformer oil impacted soils (mean ± standard deviation, cv %)

Parameter	This study				Similar studies	
	Oil impacted soil		Control soil			
	Surface	Sub surface	Surface	Sub surface	Adepetu *et al.*, (2014)	Ohwoghere (2012)
pH	4.24 - 6.58 (5.22 ± 0.77, 14.75)	5.01 - 6.96 (6.02 ± 0.78, 12.96)	5.46 - 6.25 (5.94 ± 0.37, 6.23)	4.68 - 6.16 (5.33 ± 0.64, 12.01)	5.00	6.50 -7.50
Available P (mg kg^{-1})	21.50 - 30.15 (23.48 ± 2.62, 11.16)	21.52 - 25.35 (22.59 ± 1.12, 4.96)	21.26 - 23.72 (22.19 ± 0.93, 4.19)	21.20 - 23.45 (22.00 ± 0.87, 3.95)	10.00	15.00
SOC (g kg^{-1})	19.43 - 37.67 (29.31 ± 5.67, 19.35)	4.53 - 33.02 (20.01 ± 7.72, 38.58)	8.36 - 15.58 (12.18 ± 2.68, 22.00)	3.52 - 8.42 (6.39 ± 2.40, 37.56)	11.63	15.13
NO_3^- (mg kg^{-1})	0.03 - 10.18 (1.80 ± 0.25, 13.89)	0.09 - 9.94 (1.65 ± 1.09, 66.06)	0.52 - 2.25 (1.30 ± 0.70; 53.84)	0.25 – 1.22 (0.66 ± 0.40, 60.61)	3.00	NDT
Total Nitrogen (g kg^{-1})	1.09 - 4.84 (2.59 ± 1.35, 52.12)	0.10 - 1.69 (0.69 ± 0.46, 66.67)	1.48 - 1.83 (1.63 ± 0.18, 11.04)	0.07 - 0.84 (0.59 ± 0.30, 50.84)	1.10	1.50
Ca (mg kg^{-1})	1.26 - 2.70 (1.90 ± 0.44, 23.16)	0.52 - 1.51 (1.15 ± 0.31, 26.96)	0.78 - 2.31 (1.24 ± 0.63, 50.81)	0.22 – 1.69 (0.82 ± 0.55, 67.07)	NDT	2.60
Mg (mg kg^{-1})	0.05 - 0.20 (0.11 ± 0.05, 45.46)	0.04 - 0.22 (0.11 ± 0.06, 54.55)	0.05 - 0.22 (0.14 ± 0.07, 50.00)	0.01 - 0.25 (0.12 ± 0.11, 91.67)	0.28	0.40
K (mg kg^{-1})	0.01 - 0.21 (0.12 ± 0.07, 58.33)	0.03 - 0.31 (0.12 ± 0.08, 66.67)	0.03 - 0.68 (0.22 ± 0.07, 31.82)	0.06 - 0.30 (0.15 ± 0.10, 66.67)	0.20	0.20
Na (mg kg^{-1})	0.05 - 0.13 (0.08 ± 0.02, 25.00)	0.06 - 0.11 (0.08 ± 0.02, 25.00)	0.06 - 0.10 (0.08 ± 0.02, 25.00)	0.06 - 0.16 (0.08 ± 0.04. 50.00)	NDT	NDT
CEC (cmol kg^{-1})	1.56 - 3.04 (2.19 ± 0.45, 20.54)	0.75 - 1.91 (1.45 ± 0.34, 23.45)	1.02 - 2.53 (1.67 ± 0.66, 39.52)	0.62 - 2.19 (1.18 ± 0.60, 50.84)	<5.00	NDT

SOC = Soil Organic Carbon; CEC = Cation exchange capacity; CV = coefficient of variance; NDT = Not determined

Southern, Nigeria (Asubiojo and Adebiyi 2011). Soil micronutrients and organic contaminants become more readily available for plants uptake at this pH, with an increase in redistribution, solubility, and mobility (Olutona *et al.* 2017). The pH of the transformer oil contaminated soils was more acidic at the surface soils than at the subsurface soils, suggesting the presence of high concentration of petroleum products at the surface soils than at the subsurface soil (Adebiyi and Afedia 2011). Enzymatic actions of microorganisms tend to be higher in moderate acidic pH, hence supporting biodegradation of hydrocarbons and persistent organic pollutants by microorganisms (Emoyan *et al.* 2020).

The mean values for available phosphorus and NO_3^- in the soils were slightly higher in the transformer oil contaminated soils than the control. This study is contrary to previous study which reported low available phosphorous value at low pH (acidic) for agricultural soils in Ile-Ife (Akinde *et al*. 2020). These soil nutrients are very essential in plant metabolism and growth, since they help in energy storage and transportation. Their deficiency in the soil lowers the productivity of the soil and alters the nitrogen metabolism of plants. The SOC was relatively higher in soils of the transformer oil contaminated soils than the control soil samples. Soil organic carbon content increases with an increase in the presence of petroleum product and degradable matters in the soils (Emmanuel *et al*. 2016; Jabbarov *et al*. 2019). The mobility and bioavailability of contaminants in the soil, decreases as they adsorb on soil organic matter (Eze *et al.* 2018). According to the FAO criteria for the classification of soil physicochemical parameters, the transformer oil contaminated soil, had medium values for available phosphorous, and high values for nitrogen and soil organic carbon (Ohwoghere, 2012).

The concentrations of total nitrogen were higher in the transformer oil contaminated soils than in the control soils, and also higher at the surface soil than at the subsurface soil, indicating anthropogenic source. The levels of nitrogen in the soils can be influenced by the amount of organic matter content in the soil, which is a source and store of nitrogen-containing compounds, soil nutrients and other organic substances (Awotoye *et al.* 2009) and also the presence of nitrogen compounds (heteroatoms) in the petroleum hydrocarbon products. Soil quality and productivity can also be improved by increasing the amount of organic matter and nitrogen in the soil (Iwara and Abalaka 2018).

In this study, it was also observed that the concentration of Ca^{2+} in the soil is relatively more abundant than those of other cations (Mg^{2+}, Na^{+}, and K^{+}), which could be as a result of their strong tendency to bind to the soil surface and exchangeable site (Adepetu *et al.* 2014). The cation exchange capacity concentration of the soils of this study were low and it decreases with an increase in sampling depth. According to Devatha *et al*. (2019), petroleum hydrocarbon spillage tends to increase carbon concentration in the soil, hence affecting the equilibrium of soil nutrient. Although soil organic matter is high, the low CEC content and pH of the soil, suggests an increased level of bioavailability of contaminates in the soil. This low exchangeable cation content is an indication of the moderate acidity of the soil, high soil organic matter and parent rock from which the soil was formed, which is a determinant of the soil parameters. The soils of the geographical region of this study area are composed of the 1:1 lattice clay minerals (kaolinites), which is an inherent property of lateritic soils (Ohwoghere 2012).

Coefficient of variation (CV%) was used to evaluate the variability pattern of the physicochemical parameters in the soils. The CV values for pH and available phosphorous (Table 3), in all the analysed soil samples were <15%, showing that they had is little variation within the samples. While the CV values for SOC, NO_3^- , Ca, Na and CEC of the surface soil of transformer oil contaminated soils were moderately variable. However, CV values for total nitrogen, K and Mg of the transformer oil contaminated soils were highly variable. The variations in the parameters could be as a result of an uneven spillage of the transformer oil into the soils, and disparity between the sampling locations (Oyekunle *et al*. 2012).

Comparison of soil physicochemical parameters with critical values

The impact of the petroleum hydrocarbon products on the soils was examined by comparing the result of this study with the critical values in other studies (Table 3). The result of this study revealed that the mean values of the total nitrogen, available phosphorus, and soil organic carbon were higher than the critical values reported in the studies of Adepetu *et al.* (2014) and Ohwoghere (2012); while the NO_3^-, pH, and cation exchange capacity values were lower than the critical values. At levels higher than the critical values, phosphorous and nitrogen becomes available for plant uptake. However, soils with low pH and cation exchange capacity the values, are likely to be deficient in some micronutrients needed for soil productivity and plant

Table 4: Analysis of Variance (ANOVA) of the Physicochemical Parameters in terms of Depth and Soil Sample

Parameters	Depth		Soil Samples	
	(0 -15 cm)	(15 – 30 cm)	TOC	CO
pH	5.44b	5.89a	5.62a	5.63a
Available Phosphorous (mg kg^{-1})	23.10a	22.86a	23.04a	22.09b
SOC (g kg^{-1})	26.24a	15.54b	24.66a	9.29b
NO_3^- (mg kg^{-1})	1.35a	1.89a	1.72a	1.91a
Total Nitrogen (g kg^{-1})	2.44a	0.73b	1.64a	1.11b
Ca (mg kg^{-1})	1.36a	1.12b	1.52a	1.03b
Mg (mg kg^{-1})	0.17a	0.12a	0.10b	0.13b
K (mg kg^{-1})	0.28a	0.19b	0.12b	0.19b
Na (mg kg^{-1})	0.11a	0.11a	0.08b	0.08b

TOC = Transformer oil-contaminated soil samples, CO = Control soil samples. Means with the same alphabet in each row of either soil depth or soil sample type are not significantly different at 5% probability according to Duncan's Multiple Range Test.

growth (Lelago and Buraka 2019). This suggests that the soil physicochemical parameters were significantly affected by the impact of petroleum products spillage on the contaminated soil, resulting in nutrient imbalance and retardation of soil microbes' growth (Akpoveta *et al*. 2011; Jabbarov *et al*. 2019).

The analysis of variance (ANOVA) of the physicochemical parameters in terms of depth and soil sample

As shown in Table 4, the analysed physicochemical parameters from the different transformer oil soil samples varied significantly (Duncan Multiple Range test, $p < 0.05$). The result of the analysis of variance showed that using soil depth as the dependent variable, the physicochemical parameters of the soil samples were significantly different for pH, total nitrogen, and SOC, but available phosphorous and nitrate showed no significant difference with soil depth. Using soil sample type as the dependent variable, the physicochemical parameters of the soil samples were significantly different in the pH and nitrate for all the soil sample types. There was a significant difference for available phosphorus, SOC and total nitrogen between transformer oil-contaminated soil and control soil samples.

The analysis of variance for exchangeable cations using soil depth as the dependent variable showed that there was no significant difference in Mg and Na, while for K and Ca, there was a significant difference. Using soil sample types as the dependent variables, the exchangeable cations of the soil samples showed a significant difference in the pH and nitrate for all the soil sample types. For available phosphorus, SOC, total nitrogen, there was a significant difference between transformer oil-contaminated soil and control soil samples. The analysis of variance for exchangeable cations using soil depth as the dependent variable showed that there was no significant difference between transformer oil-contaminated soil and control soil samples in Mg, K, and Na.

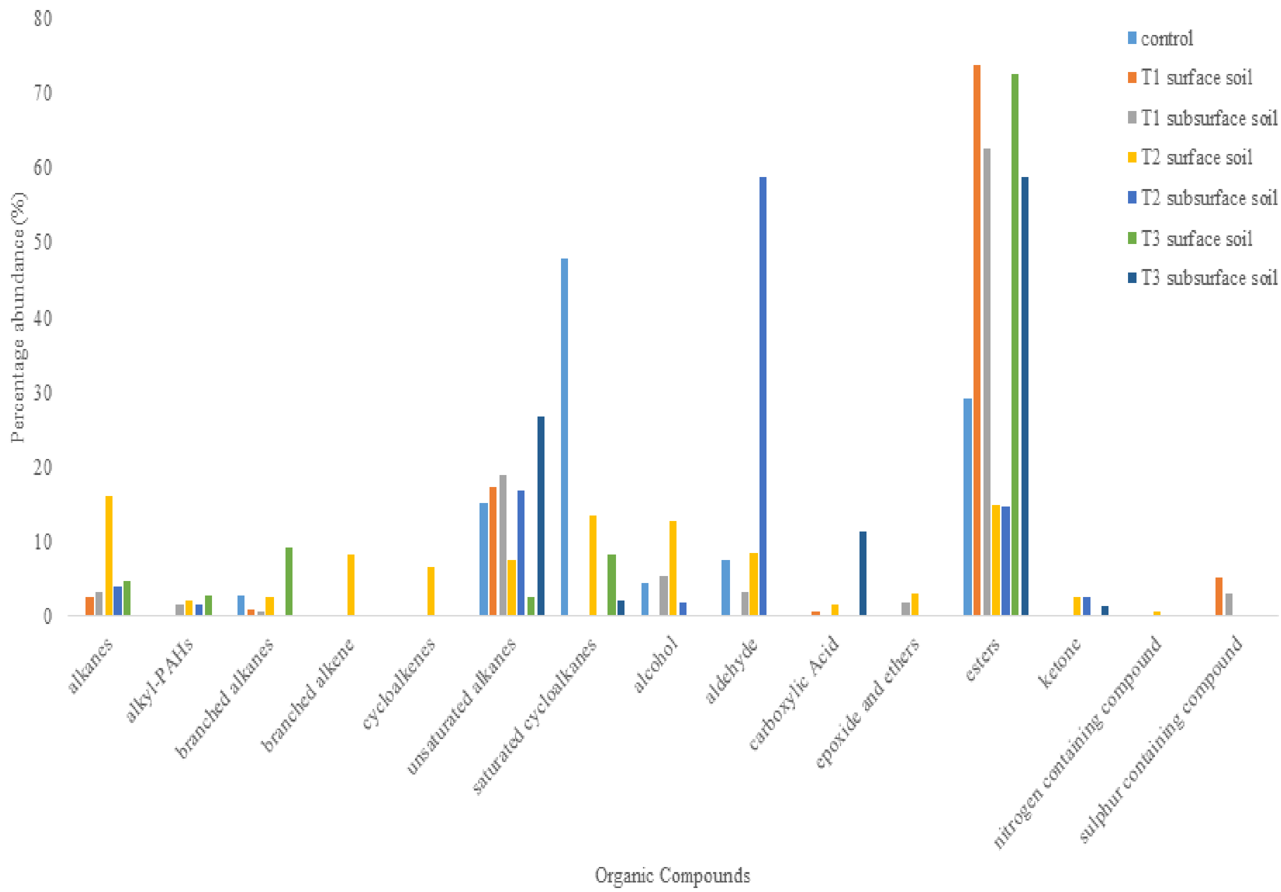

Figure 1: Frequency distribution of percentage organics in transformer oil impacted soils and control soil sample

Qualitative and quantitative analysis of the organic compounds

The graphical representation of the summary of the percentage composition of organic compounds present in the soils impacted transformer oils as elucidated by GC-MS is shown in Figure 1, while the GC-MS chromatograph of the analyzed samples are shown in Figure 2-5. The chemical composition of the organics present in the soil and in the transformer oil were categories in order of their functional groups, i.e. alcohol, aldehyde, alkanes, alkenes, alkyl-PAH, branched alkanes, branched alkanes, carboxylic acid, cycloalkenes, esters, halogenated alkane, ketone, nitrogen-containing compounds, epoxide and ethers, PAH, saturated cycloalkane, and sulfur-containing compounds. The percentage abundance of the detected PAHs in the contaminated soils were within the range of 1.96 % - 2.80 % (surface soil) and 1.53 % - 1.66 % (subsurface soil). The GC-MS results revealed the presence of C16-28 organic

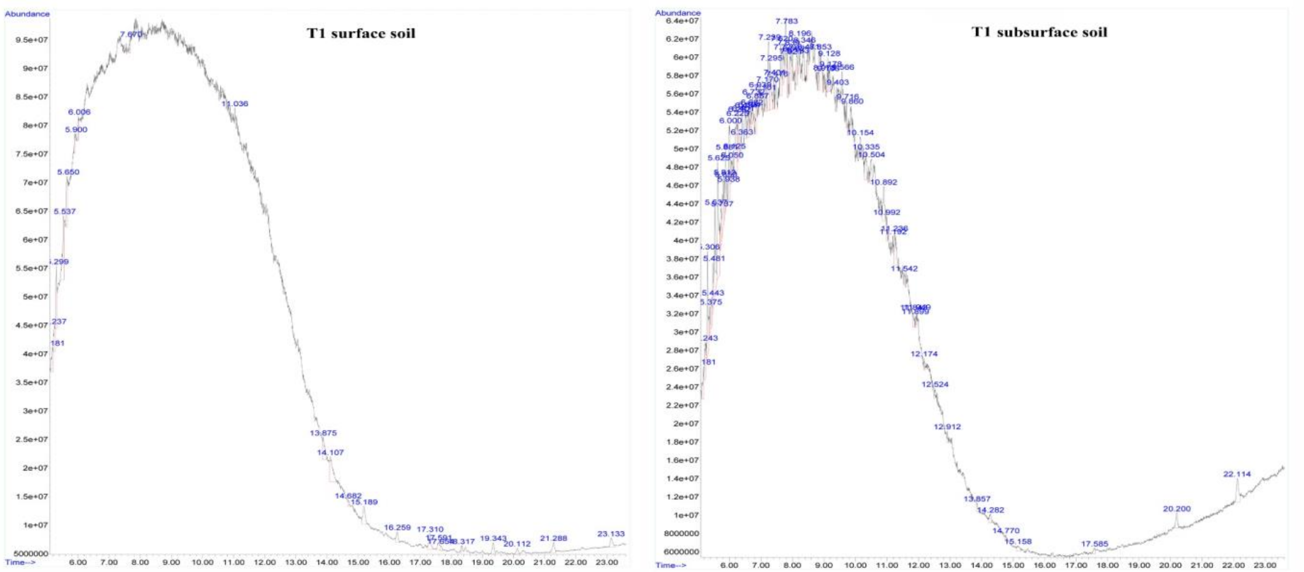

Figure 2: Chromatograph of transformer oil impacted surface and subsurface soils (T1)

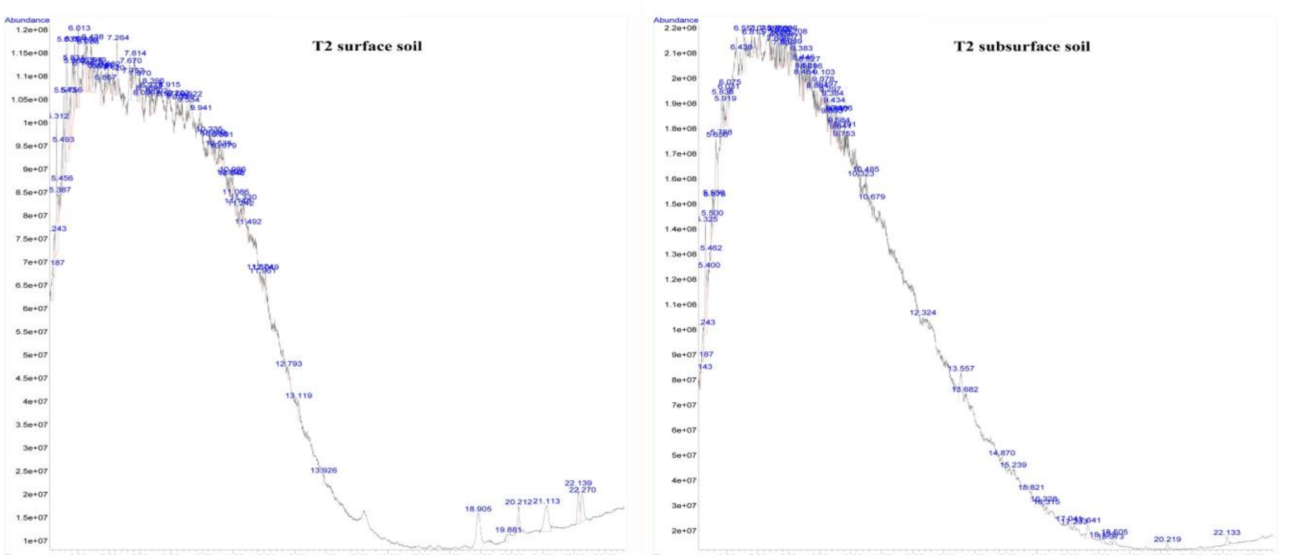

Figure 3: Chromatograph of transformer oil impacted surface and subsurface soils (T2)

compounds in the transformer oil impacted soil samples. Transformer oil is a petroleum product containing more of the lower molecular weight n-alkanes and PAHs than the heavier molecular compounds (Garba *et al.* 2013), hence, their presence in the contaminated soil samples. Also, the presence of larger amount of hydrocarbon in the surface soils than in the subsurface soils, could probably as a result of the complex structure, high hydrophobicity and low mobility factor of petroleum products (Akpoveta and Osakwe 2014; Fashina *et al.* 2016). The lower molecular weight PAHs and n-alkanes leaches through the soil faster than the higher molecular weight and their mobility decreased with soil depth (Adebiyi and Adeyemi, 2015).

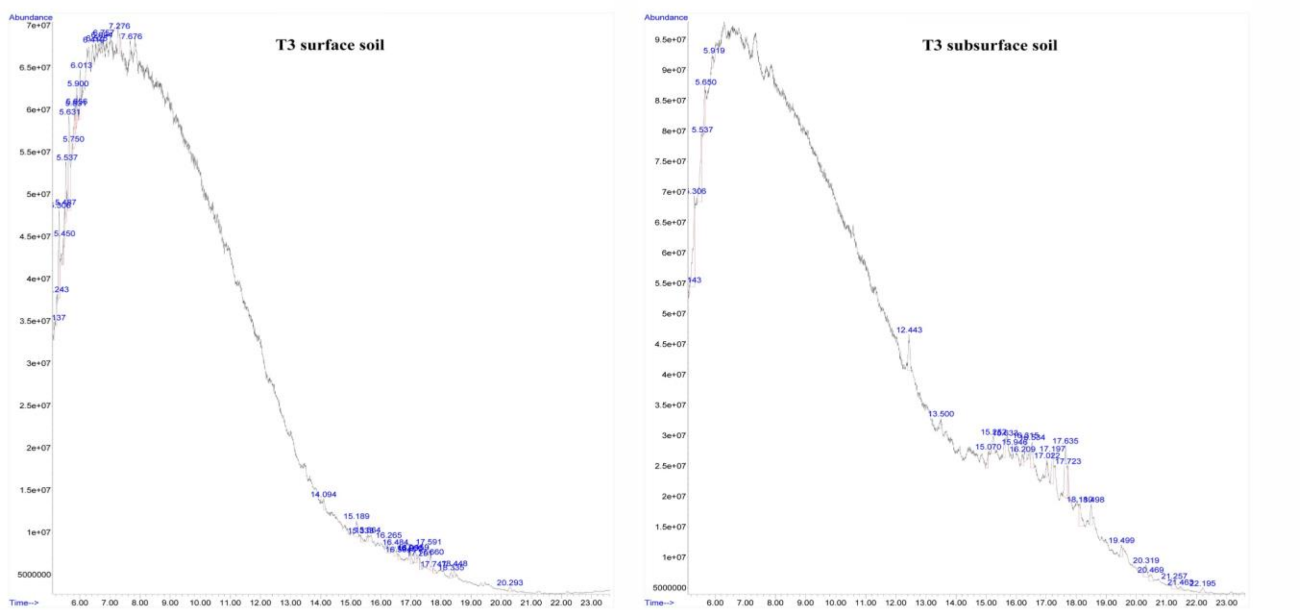

Figure 4: Chromatograph of transformer oil impacted surface and subsurface soils (T3)

It was observed that the carcinogenic PAHs in the transformer oil contaminated soils were absent or probably below detection. The transformer oil contaminated soils contained non-carcinogenic PAHs include naphthalene, decahydro-1, 4a-dimethyl-7- (1-methylethyl), [1S(1.alpha., 4a.alpha.,7.alpha.,8a.beta.)];2(1H)-naphthalenone, octahydro-4a,7,7-trimethyl-,trans;decahydro-8a-ethyl-1,1,4a,6-tetramethylnaphthalene and 3(4H)-phenanthrenone, 4a,4b,5,6,7,8,8a,9,10,10a-decahydro-4b,8,8-trimethyl-,[4aS-(4a.alpha.,4b.beta.,8a.alpha.,10a.beta.)].

Implication of the PAHs concentrations in this study

The detected PAHs were low molecular weight PAHs (2 - 3 rings), which are less carcinogenic and easier to degrade (Emoyan *et al.* 2020). The source of PAHs in the environment is said to be pyrogenic (that is from incomplete

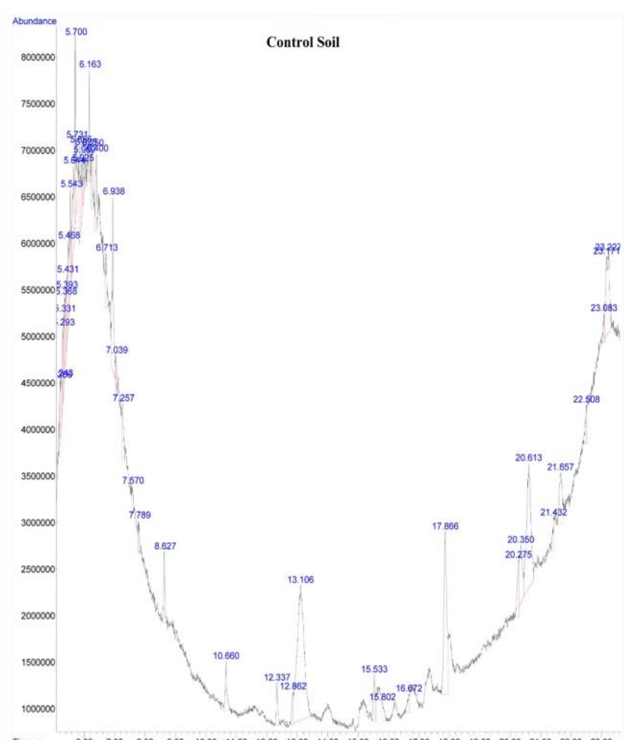

Figure 5: Chromatograph of control soil sample

combustion of fossil fuel and/or organic matter), if the ratio of low molecular weight PAHs to high molecular weight PAHs is < 1; and natural origin (petrogenic and biogenic origin), if the ratio of low molecular weight PAHs to high molecular weight PAHs is > 1 (Olayinka *et al.* 2018). In this study, it was observed that the low molecular weight PAHs were more in abundance than the high molecular weight PAHs, suggesting that the PAHs in the oil contaminated soils were generally of petrogenic origin (spillage of petroleum product or natural seepage of oil) (Olayinka *et al.* 2018; Wang *et al.* 2018). PAHs have been a major component in transformer oil as it serve as oxidation inhibitor preventing oil degradation and help in gas absorption during transformer operation, (Kaplan *et al.* 2010; Pillai *et al.* 2005). Although, these PAHs might be less carcinogenic, they are persistent in the environment and can cause potential environmental risk as they leach from the contaminated soils into the ground and surface waters, and then to microflora and fauna (Fagbote and Olanipekun, 2010). This can cause ill-health such as cancer to the inhabitants of the study areas. The chemical composition, constituent and additives of petroleum products determines its toxicity (Ujowundu *et al.* 2011). The results also revealed significant levels of esters in the transformer oil contaminated soils.

Conclusions

The study revealed that the physicochemical parameters of the soils around the transformer installation sites were altered as a result of contamination by the transformer oils. In the oil contaminated soils, it was observed that there was an increase in the SOC content as well as an imbalance in soil nutrient. The analysis of variance showed that the soil physicochemical parameters varied significantly with the soil depth and soil type, suggesting difference in the impact of oil spillage on the soil physiochemical parameters. The soil depth and type were observed to impact significantly on soil physicochemical parameters. The presence of transformer oil in the contaminated soil could pose health risk on chronic exposure; since it resulted to an increase in the quantity of alkanes, iso-alkanes and alkyl-PAHs in the soil. The detected PAHs in the contaminated soils contained higher amount of low molecular weight PAHs than the high molecular weight PAHs, suggesting petrogenic source. The study suggests prompt treatment and remediation of transformer oil contaminated soils on site. Also, to prevent contamination of ground water, leakages from transformers can be trapped by building a drainage pit under transformers.

Acknowledgement

We appreciate the support of Prof. D.J. Oyedele, of Department of Soil Science, Obafemi Awolowo University, Ile-Ife, Nigeria, towards the success of this study and for making his laboratory available for analysis.

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