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# Soil physicochemical and hydraulic properties of petroleum-derived and vegetable oil–contaminated Haplic Lixisol and Rhodic Nitisol in southwest Nigeria

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**Abstract** Various daily human activities can result in the release of pollutants of different chemical constituents and specific gravities into natural soils. Pollution of natural soils is a recurring occurrence in the environment and it contributes greatly to the alteration of soils properties. The results of an assessment of the effects of selected petroleum-derived and vegetable oils on soil physicochemical and hydraulic properties are presented in this work. Topsoil samples at a depth of 0–20 cm of the same textural class were collected from the order Lixisols and Nitisol within Ogun State, southwest Nigeria. Surface soil samples were collected and treated with petrol, diesel and palm oil at two different volumes (50 and 100 ml). Investigated soil properties include particle size distribution, soil pH, bulk density (BD), total porosity (TP), saturated hydraulic conductivity ($K_{sat}$), available water capacity (AWC), total carbon (TC), total nitrogen (TN), organic matter (OM) content, cation exchange capacity (CEC), potassium, sodium, and soil resistivity. Analysis of variance and Pearson's correlation were used to study the variations of the relationship of analyzed soil properties under different soil types and treatments. The regression analysis shows that all the generated models for predicting $K_{sat}$ values under different soil treatments had $R^2$ values ranging from 0.999 to 1.000. Results showed that treatment with either petroleum-derived or lipids has no effects on soil pH and textural class. Results further revealed that palm oil contamination at 50 ml recorded least values of $K_{sat}$ in the two soil types. In all cases, BD and $K_{sat}$ of the contaminated soils of the two sampling locations were reduced compared with their control values. Correlation coefficient showed expected strong negative correlation between TP and BD as well as between any two of organic parameters (TC, TN, and OM) and soil resistivity, TC, and TN at 1% level in both soil types. Two-way ANOVA showed that there were significant differences at 5% level between the two locations with respects to BD, TP, and CEC while significant differences in $K_{sat}$, pH, TC, TN, and OM occur between soils from the two locations under various treatments at 5% level.

**Keywords** Pollution · Petroleum-derived · Oil · Soil type · Hydraulic · Physicochemical

## Introduction

Soil has many uses ranging from agricultural, economical, construction, mining, and other sectors of human activities. Pollution, on the other hand, can be defined as the presence of significant amount of pollutants/contaminants in a particular location which result in the changes in the natural soil properties. The incidence of soil contamination has been noted to correlate with

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the level of industrialization and level of chemical usage (Ayininuola and Kwashima 2015). The study of alteration of soil properties resulting from pollution by man-made impurities such as hydrocarbons, toxic chemicals, and heavy metals has gained prominent attention by scientists all over the world (Nazir 2011; Rosales et al. 2012; Sriraam et al. 2016). The contaminants that pollute soil and water resources may be organic or vegetable based in nature. Hydrocarbon molecules that make up petroleum products are highly toxic to many organisms and soil and are regarded as important soil organic pollutants (Villalobos et al. 2008; Stroud et al. 2007). Contamination of porous media especially top soil layer by hydrocarbon pollutants may alter the physicochemical and hydrological status of the soil and the nutrient availability to growing plants as well as groundwater quality through leaching process (Sriraam et al. 2016). Soil contamination by hydrocarbon can arise from accidental oil spillage, during transportation from the oil depot to the final end users, leakage from storage tank, servicing of automobiles by automobile technicians, and pipeline burst through the activities of oil vandals. Hydrocarbons which can be light non-aqueous phase liquid (LNAPL) and dense non-aqueous phase liquid (DNAPL) pose great environmental impacts on people, ecosystem, and available water resources (Rahman et al. 2011). Hydrocarbon can migrate vertically or horizontally through the soil layer under the influence of gravitational force and to some extent saturating the porous media in its migration path (Pamukcu and Hijazi 1992). Some hydrocarbons during the course of migrations through the soil may be trapped and clogged with ultimate decrease in hydraulic conductivity of the contaminated soils (Khamehchiyan et al. 2007). Palm oil, on the other hand, belongs to vegetable oil (lipids), made up of about 95% of acylglycerols and free fatty acids, phospholipids, and many other minor components (Pioch and Vaitilingom 2005). It is an important component of biodiesel fuel. Palm oil exhibits hydrophobic tendency towards water and thus may influence the free flow of water through the oil-contaminated soil layer (Sriraam et al. 2016). The waste generated from palm oil extraction process known as palm oil mill effluent (POME) is detrimental to the soil system (Verla et al. 2014; Nnaji et al. 2016).

Differences in soil depend on soil climate, organism, age of parent material, topography, and spatial position (McBratney et al., 2003). Different pollutants influence soil quality parameters differently; thus, the ability of soil to function optimally as a component of an ecosystem may be improved or degraded based on the changes of soil quality parameters in response to soil contamination. Soil quality indicators are measurable soil properties that reveal the soil productivity response on a short-term basis (Carter et al. 1998; Ghaemi et al. 2014). Among the soil indicators that can be used to measure changes in soil quality are BD, saturated hydraulic conductivity ($K_{\mathrm{sat}}$), porosity, available water capacity (AWC), soil organic matter (SOM), and many others (Reynolds et al. 2007; Ghaemi et al. 2014).

Hydraulic conductivity is one of the most and crucial parameters of soil and it determines the drainage functions of a soil (Yao et al. 2013; Maurya et al. 2016). The ability of soil to hold and release water for plant, stream ,and subsoil is thus one of the soil functions that may be used as a criterion for assessing the soil quality (Larson and Pierce 1991). The hydraulic conductivity of soil depends on several factors such as soil type, void ratio, pore size distribution, grain size distribution, viscosity of a fluid, and degree of saturation (Maurya et al. 2016; Sriraam and Raghunandan 2014). Soil saturated hydraulic conductivity ($K_{\mathrm{sat}}$) is a quantitative expression of soil ability to transmit water under a given hydraulic gradient (Juliá et al. 2004). Among the factors with strong influence on $K_{\mathrm{sat}}$ are topography, soil texture, vegetation type, bulk density (BD), total porosity (TP), and organic matter content (Mohanty and Moushi 2000; Cerda 1996; Aimrun et al. 2004; Yao et al. 2013). The degree of alteration of soil hydraulic properties depends not only on the nature of contaminant but also on the soil physiochemical properties (Srikanth and Harnadh 2013). There is a need to study the flow of contaminants through the subsoil as this will provide an insight into the effect of contaminant on soil system. The knowledge of the rate of migration of contaminants will also assist greatly in designing a suitable remediation program for both soil and aquifer systems (De La Vega et al. 2003).

Several scientists have studied effects of spent hydrocarbons and POME on physicochemical properties of soils (Abosede 2013; Kayode et al. 2009; Verla et al. 2014; Nwite and Alu 2015; Uzoije and Agunwamba 2011; Milala et al. 2015; Brakoreuko and Korotchenko 2016), geotechnical properties (Kermani and Ebadi 2012; Khamehchiyan et al. 2007; Alsanad and Eid 1995; Shin and Das 2000; Rehman et al. 2007; Mashalah et al. 2006; Bian et al. 2016), and soil quality assessment (Okoro et al. 2011; Nnaji et al. 2016). Most published research works were focused on the effect of spent engine oil and POME on soil physical and chemical properties as well as alteration of geotechnical properties of either spent or crude oil–contaminated soils. There seems to be little or insufficient information on the effects of non-spent hydrocarbon and edible oil on soil hydraulic and physicochemical variables. The goal of the present study is to assess the impacts of selected petroleum-derived and vegetable oils on soil hydraulic and physicochemical properties. The objectives are to evaluate if there are changes in level of analyzed properties associated with soil contamination by selected pollutants and application of multivariate statistical techniques to identify the structural relationships between soil properties based on sampling locations and treatments.

## Materials and methods

### Description of the study area

The study was carried out in Odeda and Ikenne within Ogun state, southwest Nigeria. Odeda lies between latitudes 7° 29′ 58″ and 7° 29′ 94″ N and between longitudes 3° 26′ 76″ and 3° 47′ 28″ E, while Ikenne lies between latitudes 6° 50′ 00″ and 6° 52′ 00″ N and longitudes 3° 40′ 00″ and 3° 43′ 00″ E. Based on 2006 population census, Odeda and Ikenne have a population of 109,449 and 118,735 respectively (Usikalu et al. 2015; Balogun et al. 2016). Odeda has an area of 1560 km$^2$ while Ikenne has an area of 144 km$^2$. The relative humidity in Odeda is 83% during the rainy season but drops to 53% in the dry season. The relative humidity in Ikenne during the rainy session is 87% but drops to 65% during dry season. The mean annual rainfall of Odeda is 1220 mm while the mean annual temperature is 26.7 °C (Kilanko-Oluwasanya 2009).

The mean annual rainfall in Ikenne is 1500 mm and the mean annual temperature and sunshine are about 27 °C and 2100–2350 h respectively depending on the season (Anaeto et al. 2009). The rainy session in the two study areas starts from March and ends in October; this is associated with moist maritime south-westerly wind while the dry season occurs from December to March under the influence of north-westerly wind (Kilanko-Oluwasanya 2009). The soils in Odeda belong to Haplic Lixisol/Typic Kanhapludalf while those of Ikenne belong to Rhodic Nitisol/Rhodic Kandidult (Soil survey staff 2015; FAO 2015) and classified locally as Ibadan and Alagba Series respectively (Smyth and Montgomery 1962). Odeda and Ikenne soil samples represent soils of the order HL and RN respectively. The location map of the study area is shown in Fig. 1.

### Geology of the study area

The study area falls within the southwest part of Nigeria. Odeda, a town within Abeokuta, is underlined by crystalline basement which is basically granitic. The basement complex rock comprises of folded gneiss, schist quartzite, older granite, and amphibolites/mica schist (Jones and Hockey 1964). Abeokuta is located on crystalline basement complex of igneous and metamorphic origin (Gbadebo et al. 2010). The basement rocks are of Precambrian age to early Paleozoic age and extend from the north-eastern part of Ogun state, of which Abeokuta belongs and is dipping towards the coast (Ako 1979). The basement complex rock comprises of coarse-porphyritic hornblende-biotite-granodiorite, biotite granite gneiss, pegmatite, porphyoblastic granite gneiss, quartz schist, and amphibolite/mica schist (Jones and Hockey 1964; Kehinde-Phillips 1992). The migmatite is the mostly widespread in the basement complex of south west Nigeria. Geologically, Ikenne is within the Dahomey basin with the lithostratigraphic formations from the oldest to youngest being in Abeokuta, Ewekoro, Akinbo, Oshosun, Ilaro, and Benin formations (Usikalu et al. 2015). Cretaceous Abeokuta formations were described as a group consisting of Ise, Afowo, and Araromi formations (Aizebeokhai and Oyeyemi 2014). The dominant rock types in the two sampling locations are popyritic granitic gneiss and Abeokuta formation (as shown in Fig. 2).

### Soil sample collection, experimental setup, and analytical methods

Soil samples were collected within two cities in Ogun State based on two major geological formations in Southwestern Nigeria. Twenty four (24) cluster soil samples were randomly collected at the two locations, while each cluster is a composite of 10 samples that were bulked within each location during the months of May and June, 2017. The soil samples were collected with the aid of soil auger at a depth of 0–20 cm from various sampling points.. The collected soil samples

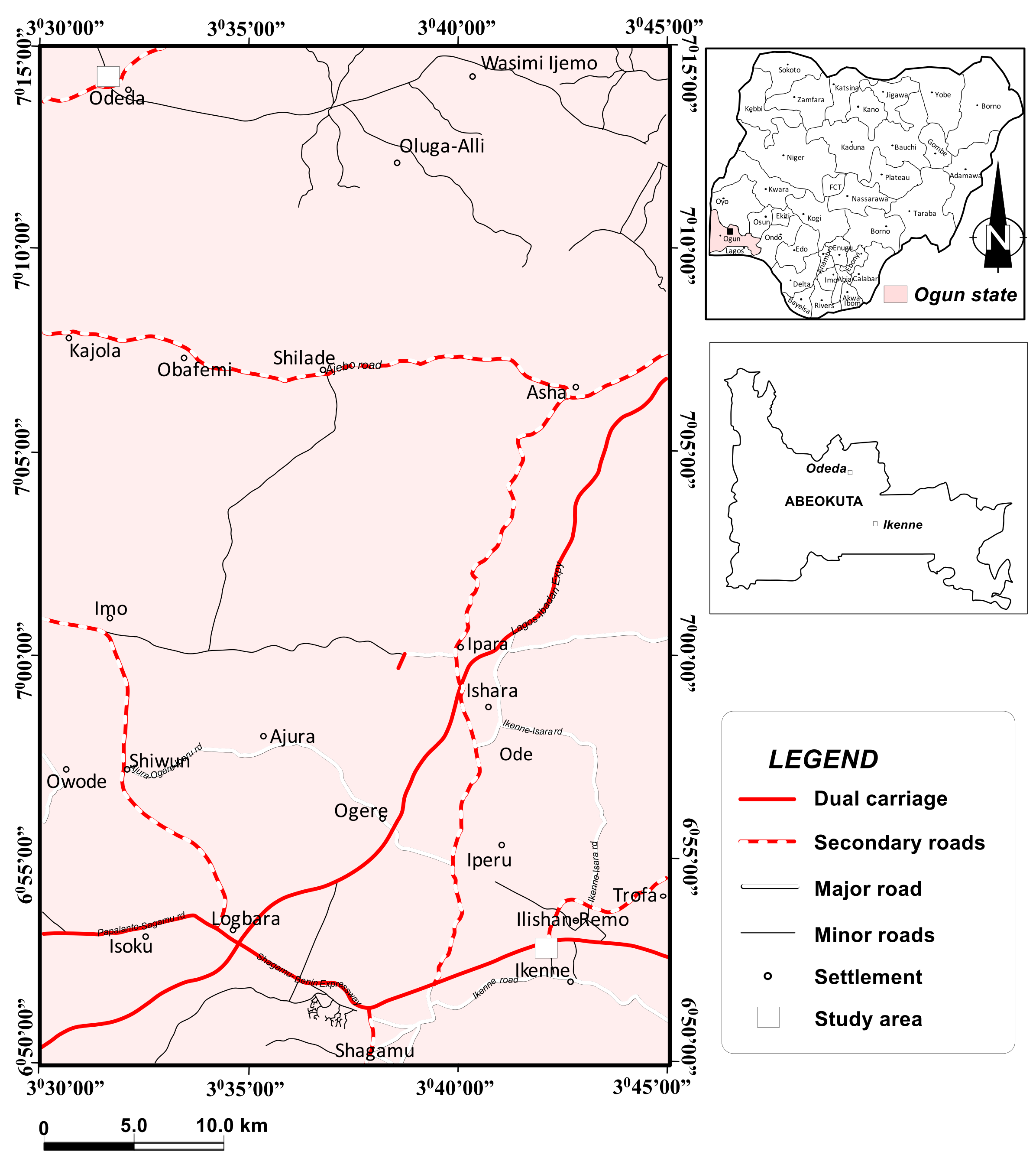

**Fig. 1** Location/accessibility map showing the access roads to the study area

from each location were air-dried and allowed to pass through a 2-mm sieve and thereafter filled into 21 (10 kg size) pots and properly labeled in accordance with the experimental setup.

There were seven (7) treatments for each location with the treatments comprised 3 contaminants (petrol, diesel, and palm oil) and a no contaminant which served as a control. Each of the contaminants was added to the

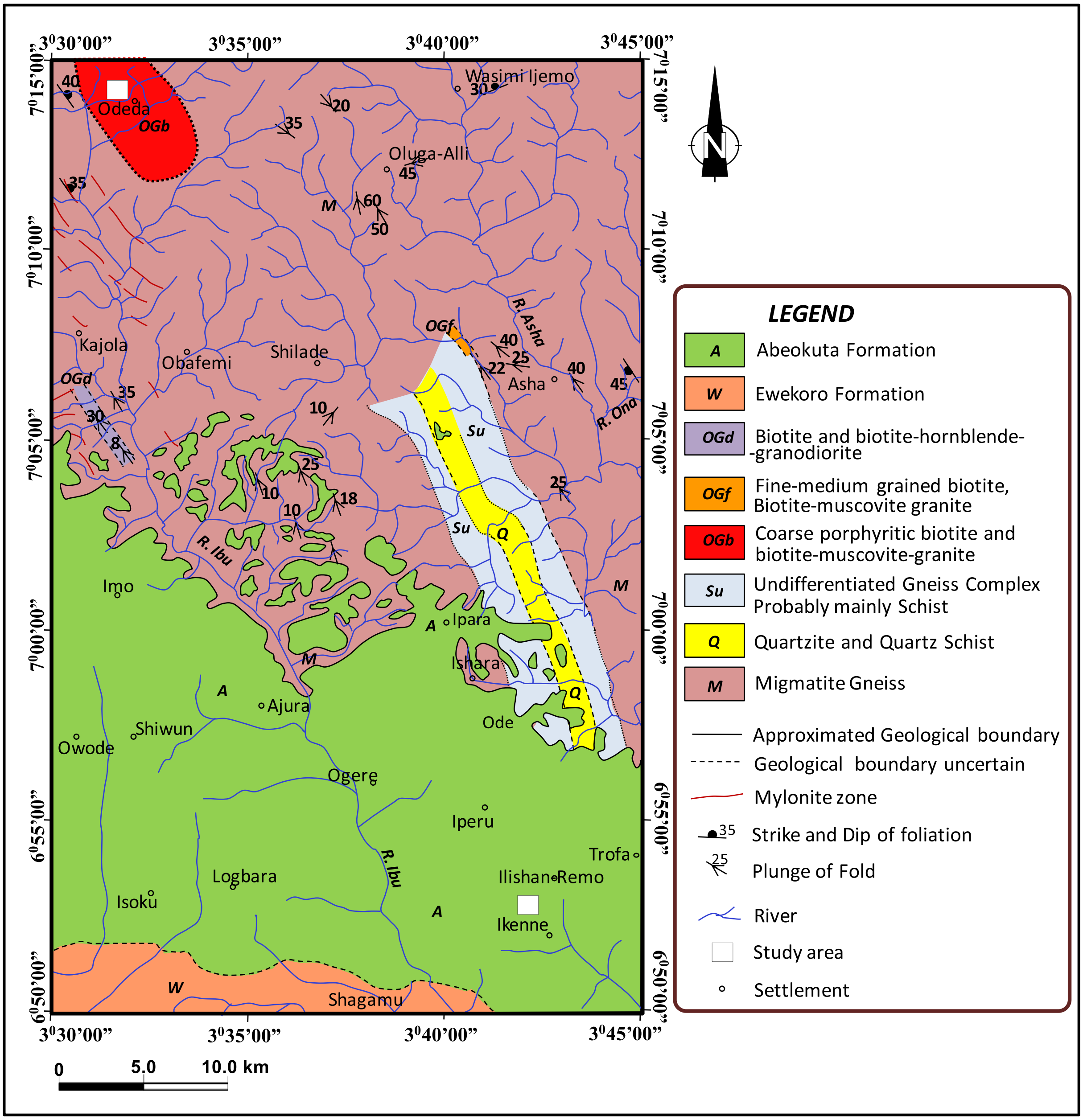

**Fig. 2** Geological map showing the rock type that underlies the study areas (adapted from Jones and Hockey 1964)

soil samples at 50 and 100 ml separately, thereby making 6 treatments and a control without contaminant served as treatment number 7 and replicated thrice (see detail in Table 1). Therefore, a total of 21 pots containing seven treatments assigned for each location were used for the study. The treatments were set up in the laboratory, watered to field capacity, and thereafter kept in airtight for 30 days to attain homogeneous mixture before carrying out physical and chemical analyses.

The parameters of taken analyses were as follows: soil pH, bulk density (BD), total porosity(TP), available water capacity (AWC), particle size distribution, saturated hydraulic conductivity ($K_{\mathrm{sat}}$), total organic carbon, total nitrogen, organic matter content, cation exchange capacity (CEC), potassium, sodium, and soil resistivity. A digital pH meter was used to determine the pH in water of each soil sample based on ASTM G51-95 (ASTM G51-95 2012) standard while a cylindrical core (5 cm in height and 5 cm in diameter) was used to sample the soil samples for soil hydraulic conductivity, and it was measured using the constant head method as described by Reynolds and Elrick (2002). The AWC expressed on a gravimetric basis was estimated as the difference between the field capacity (FC) obtained at 10 kPa (100 cm of water) and the permanent wilting point (PWP) determined at 1500 kPa (15,000 cm water) as described in the equation:

$$AWC = (\Theta FC - \Theta PWP)$$

where FC is the gravimetric moisture content (%) at field capacity and PWP is the gravimetric moisture content (%) at permanent wilting point. Particle size distribution of the soil from each pot was carried out using a modified Bouyoucos hydrometer method as described by Gee and Or (2002) with textural classification done using the USDA textural triangle (Kroetsch and Wang 2008). The soil sample collected with cylindrical core sampler for $K_{sat}$ was also used for the determination of BD following the Grossman and Reinsch (2002) method. Total porosity was extrapolated from the bulk density using the relationship described by Hillel (2004) in the equation:

$$TP = 1 - \frac{\rho_b}{\rho_s} \tag{2}$$

where TP is the soil total porosity, $\rho_b$ is the soil bulk density, and $\rho_s$ is the particle density assumed to be 2.65 Mg/m$^3$. The soil resistivity was measured using the M.C. Miller soil boxes according to the ASTM G57-05(ASTM G57-05 2005) standard while soil CEC was determined using the ammonium acetate ($NH_4OAC$) displacement method by Jackson (1958). The exchangeable sodium and potassium were determined using flame photometry method. Total nitrogen (TN) was determined using the Kjeldahl method (Bremmer 1996) while total carbon (TC) was determined using the loss on ignition method based on Cambardella et al. (2001). OM content was determined using the $K_2Cr_2O_7 \cdot H_2SO_4$ wet oxidation method of Walkley and Black (1934) as modified by Nelson and Somners (1982).

**Table 1** Mean values of analyzed soil hydraulic and physicochemical parameters

| Soil type and location | Impurities | Varied volume (ml) | $K_{sat}$ (cm/h) | BD (g/cm$^3$) | TP (%) | AWC | Soil pH | Na (cmol/kg) | K (cmol/kg) | TC (%) | TN (%) | OM | CEC (cmol/kg) | Soil resistivity (Ω/cm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Haplic Lixisol (HL) Odeda | Control | | 6.17 | 1.26 | 52.65 | 0.118 | 6.08 | 0.47 | 0.85 | 1.23 | 0.21 | 2.12 | 4.87 | 5.13 |
| | Petrol | 50 | 3.43 | 1.26 | 52.55 | 0.122 | 5.83 | 0.50 | 0.85 | 0.93 | 0.15 | 1.60 | 5.18 | 8.12 |
| | | 100 | 2.55 | 1.30 | 51.55 | 0.120 | 5.55 | 0.49 | 0.84 | 1.18 | 0.20 | 2.03 | 4.94 | 6.89 |
| | Diesel | 50 | 5.11 | 1.16 | 56.10 | 0.125 | 5.55 | 0.46 | 0.83 | 3.04 | 0.50 | 5.25 | 4.69 | 1.99 |
| | | 100 | 3.09 | 1.12 | 57.80 | 0.124 | 5.40 | 0.44 | 0.75 | 3.87 | 0.64 | 6.67 | 4.45 | 1.84 |
| | Palm oil | 50 | 1.32 | 1.18 | 55.50 | 0.105 | 5.98 | 0.51 | 0.89 | 5.84 | 0.97 | 10.07 | 5.24 | 1.19 |
| | | 100 | 1.85 | 1.15 | 56.60 | 0.085 | 5.93 | 0.50 | 0.85 | 8.76 | 1.45 | 15.11 | 5.11 | 0.72 |
| Rhodic Nitisol (RN) Ikenne | Control | | 8.18 | 1.63 | 38.70 | 0.124 | 5.90 | 0.38 | 0.69 | 0.24 | 0.04 | 0.42 | 3.88 | 8.75 |
| | Petrol | 50 | 5.91 | 1.39 | 47.40 | 0.109 | 5.88 | 0.37 | 0.60 | 0.98 | 0.17 | 1.70 | 3.72 | 6.26 |
| | | 100 | 1.48 | 1.52 | 42.60 | 0.113 | 5.65 | 0.39 | 0.65 | 1.05 | 0.18 | 1.81 | 3.96 | 6.11 |
| | Diesel | 50 | 3.45 | 1.60 | 39.80 | 0.106 | 5.53 | 0.36 | 0.65 | 1.11 | 0.19 | 1.91 | 3.69 | 8.05 |
| | | 100 | 2.73 | 1.57 | 40.80 | 0.066 | 5.33 | 0.33 | 0.63 | 1.82 | 0.30 | 3.13 | 3.46 | 9.49 |
| | Palm oil | 50 | 1.37 | 1.32 | 50.40 | 0.094 | 5.95 | 0.36 | 0.58 | 6.49 | 1.07 | 11.19 | 3.61 | 0.95 |
| | | 100 | 2.94 | 1.55 | 41.70 | 0.091 | 5.85 | 0.31 | 0.51 | 8.38 | 1.38 | 14.44 | 3.11 | 0.79 |

### Statistical analysis

Analysis of variance (ANOVA) was performed for the soil data to assess the significance of all the analyzed parameters based on sampling locations and treatments. All data were presented as mean ± standard deviation where the means were separated at the $p \leq 0.05$ level of significance. Pearson's correlation analysis was performed to examine the relationship between two parameters relating to soil physicochemical and hydraulic factors. The relationship between the dependent variables ($K_{sat}$) and the associated predictors based on soil treatments with diesel, petrol, and palm oil was evaluated using the multiple regression analysis.

## Results and discussions

### Physicochemical and hydraulic parameters

The average results of analyzed parameters for control and conditioned soil samples of petrol, diesel, and palm oil treatments are presented in Table 1. All the soils retain their soil textural class of sandy loam after treatment with impurities in both locations. Although there were little variations among the particle sizes following the addition of selected oil contaminants, there is no overall change in soil textual class. The textural class (sandy loam) of the analyzed soils among the treatments was not statistically different (Tables 4 and 5). This lack of change in the soil textural class agrees with Hulugalle (1994), Okonokhua et al. (2007), and Are et al. (2018) who reported that changes in soil texture due to soil treatment do not come easily and may take several years to take place irrespective of land management practice. The mean pH of the soil samples remained within the acid range (5.3–6.1) in both locations and varied from 5.6 to 6.1 and from 5.3 to 5.9 in the Haplic Lixisol (HL) and Rhodic Nitisol (RN) soils respectively. This is an indication that soil pH status after treatments with contaminants still retains acidic form when compared with control value. The mean CEC ranged from 4.45 to 5.24 and from 3.11 to 3.96 cmol/kg in Odeda and Ikenne respectively. The low values of mean CEC (< 15 cmol/kg) obtained in our study for tropical soils fall within the 15 cmol/kg limit for urban soils as obtained by Short et al. (1986) and Jim (1998). The highest mean value of CEC in HL soils occurred in palm oil–treated soil at 50 ml while the lowest mean CEC value was found in diesel-treated soil at 50 ml. However, the highest mean value of CEC was noticed in RN soils in petrol-contaminated soil at 100 ml while palm oil–treated soil at 100 ml has the least amount of mean CEC (Table 1). In HL soils, CEC values increased in petrol-treated and palm oil–treated soils (Martinsen et al. 2015) but decreased in diesel-treated soils when compared with CEC value in control soil. However, in RN soils, there is no clear trend of change in CEC value in petrol-treated soils while there are reduced CEC values in diesel-treated and palm oil–treated soils as volume of contaminant increases. The mean K and Na in centimoles per kilogram ranged from 0.75 to 0.89 and from 0.44 to 0.51in HL and RH soils respectively. The exchangeable cation values were generally low (< 1.0 cmol/kg) in the soils from the two locations resulting in corresponding low CEC values (Igwe et al., 2013). There is no clear trend of changes in Na and K on soils treated with organic hydrocarbon (petrol and diesel) and lipids (palm oil) in the two soil orders. The mean values of TC, TN, and OM ranged from 0.93 to 8.76%, from 0.15 to 1.45%, and from 1.60 to 15.11% respectively in HL soils and ranged from 0.24 to 8.38%, from 0.04 to 1.38%, and from 0.42 to 14.44% respectively in RN soils (Table 1). The highest values of mean TC, TN, and OM in HL soils were found in palm oil–treated soil at 100 ml while the least mean values of TC, TN, and OM (0.93) were recorded in petrol-treated soil at 50 ml. However, in RN soils in Ikenne, the highest mean values of TC, TN, and OM were also noticed in palm oil–treated soils at 100 ml while untreated control soils had the least amount of TC, TN, and OM. This result is in line with increased TC, TN, and OM in POME-polluted soils as reported by Piotrowska et al. (2006), Nwoko and Ogunfemi (2010), Nnaji et al. (2016), Rupani et al. (2010), and Iyakndue et al. (2017) who obtained significant increase in these parameters in soil treated with POME. The general increase in OM, TC, and TN in treated soils with all the three contaminants at varied volumes in RN soils at Ikenne agree with findings of Agbogridi et al. (2007) and Okoro et al. (2011) who reported rapid decay and mineralization of organic and mineral materials in sedimentary formation region. Compared with the control mean TC values (Table 1), increase in mean TC value of contaminated soils as volume of contaminant increases in both locations may be attributed to high content of carbon in petroleum-derived and lipid contaminants (Ellis and Adams 1961; Benka-Coker and Ekundayo

1995; Agbogridi et al. 2007; Ekundayo and Obuekwe 1997). It may also be as a result of increased contact between occluded organic carbon and soil mineralogical components (Adhikari and Bhattacharyya 2015). Similarly, increase in TN for diesel-treated soils in both locations may be due to stimulated small proliferation of organotrophic *Nitrobacter* in the presence of diesel hydrocarbon (Deni and Penninckx 2004). However, there is reduced mean TC value in petrol-treated soils at 50 and 100 ml (0.93 and 1.18) when compared with control TC value (1.23) in HL soils. Lowest mean values of TN (0.15 and 0.20) in petrol-treated soils in HL soils compared with control mean TN value (0.21) may be due to decrease in nitrification process and low proliferation of *Nitrobacter* (Paul and Clark 1996; Bona et al. 2011). Low TN values of (< 0.7%) in all contaminated soils by petroleum-derived contaminants in both locations may be due to the fact that petroleum hydrocarbon in Nigeria contains sulfur, nitrogen, and oxygen in low concentration (Davies 1991).

Generally, the mean soil resistivity values in soils at both locations lie below 10 Ω/cm (Table 1). The mean soil resistivity values in HL and RN soils ranged from 0.72 to 8.12 Ω/cm and from 0.79 to 9.49 Ω/cm respectively. The highest mean value of soil resistivity (8.12) in HL soils was observed in petrol-contaminated soil at 50 ml while the least mean soil resistivity value (0.72) was noticed in palm oil–treated soil at 100 ml. However, in RN soils, diesel-treated soils at 100 ml had the highest mean value of soil resistivity (9.44) while the least mean soil resistivity value (0.79) was observed in palm oil–treated soil at 100 ml. Compared with control soil resistivity value in each sampling location, there is increase in soil resistivity value in petrol-contaminated soils while it reduces in diesel-treated and palm oil–treated soils in HL location. The result indicated that increase in soil resistivity occurred only in diesel-contaminated soil at 100 ml in Ikenne RN soils. The mean BD and TP ranged from 1.12 to 1.30 g/cm$^3$ and from 51.2 to 57.8% and from 1.32 to 1.63 g/cm$^3$ and from 38.7 to 50.4% in HL and NR soils respectively. The highest mean BD value (1.30) in HL soils was found in petrol-treated soil at 100 ml while diesel-contaminated soil at 100 ml had the least mean BD value of 1.12 g/cm$^3$. For RN soils, the highest mean BD (1.63) was found in control soil while the lowest BD value (1.32) was noticed in palm oil–treated soil at 50 ml concentration. The highest mean BD value (1.30) in HL soils was found in petrol-treated soil at 100 ml while diesel-contaminated soil at 100 ml had the least mean BD value of 1.12 g/cm$^3$. For RN soils, the highest mean BD (1.63) was found in control soil while the least BD value (1.32) was noticed in palm oil–treated soil at 50 ml concentration. The reverse is the case for TP values in the two locations. For instance, the highest mean BD at 100 ml of petrol-contaminated soil in Odeda HL soil corresponds to the least porosity value (51.15). This result shows an inverse relationship between the BD and TP of the experimental soil samples at the two locations (Klamerus-Iwan et al. 2015; Vogelmann et al. 2010). There is overall decrease in BD as contaminant is added to soil in both sampling locations with an exception of increase in BD at 100 ml of petrol in HL soils. The reduction in BD as a result of hydrocarbon contamination obtained in our study is in contrast with results of Abosede (2013) and Uzoije and Agunwamba (2011) who reported increased BD on crude oil–contaminated soils. However, decrease in BD value as volume increases in diesel-treated soils in both locations is in line with the result of Kayode et al. (2009) who reported decrease in BD value in sandy loam soil contaminated with spent lubricant oil. The decrease in BD of soils treated with impurities in RN soils may be due to lower quality of clay (< 20%) in soils at Ikenne which have high tendency to attract any positively charged component of hydrocarbon (Onweremadu 2008). Compared with the initial TP value (52.65) in Odeda, the value of mean TP increases with volume in diesel-treated and palm oil–treated soils but decreases in petrol-amended soil. The reduced TP in petrol-treated soil in Odeda may be due to the lowest values of OM (1.60 and 2.03) recorded in petrol-treated soil. However, in Ikenne, there is increase in TP values for all treated soils compared with control mean TP value (38.70). The mean AWC values in HL and RN soils ranged from 0.085 to 0.122 and from 0.066 to 0.124 respectively. The highest mean value of AWC (0.1222) in HL soils was observed in petrol-contaminated soil at 50 ml while the least mean AWC value (0.085) was noticed in palm oil-treated soil at 100 ml. However, in RN soils, untreated control soil had the highest mean AWC value (0.124) while the least mean AWC value (0.066) was observed in diesel-treated soil at 100 ml. Compared with control AWC value in each sampling location, there is reduction in soil AWC in RN soils while it increased in petroleum-derived treated soils in HL location. The range of mean $K_{sat}$ is from 1.32 to 6.17 cm/h in HL soils and from 1.37 to 8.18 cm/h in RN soils. The highest mean $K_{sat}$ value in HL soils was observed in untreated control soil while the least mean $K_{sat}$ value (1.32) was noticed in palm oil–treated soil at 50 ml concentration. The same holds in RN soils. Compared with control $K_{sat}$ values in both locations, there is reduction in mean $K_{sat}$ value as volume of hydrocarbon contaminants increases (Lee and Cody 2001; Daka 2015; Ayininuola and Kwashima 2015). The least reduction in $K_{sat}$ occurs in palm oil–treated soils at 50 ml in both locations (Khamehchiyan et al. 2007). In this study, we found that in palm oil–treated soils, there is reduction in $K_{sat}$ at 50 ml and then slight increase in $K_{sat}$ at 100 ml. This trend of change in $K_{sat}$ in palm oil–treated soil is in line with earlier similar results obtained by Chew and Lee (2006), Nik David et al. (2016), Maurya et al. (2016), and Eberemu (2013).

## Result of statistical analysis

The significance of the observed correlation coefficient results for each location is presented in Tables 2 and 3 while Tables 4 and 5 show the ANOVA based on sampling locations and treatments respectively. From Tables 2 and 3, out of the 105 correlations found between two analyzed parameters, 18 were found to be significant at 1% level ($p < 0.01$) while 4 were found to be significant at 5% level ($p < 0.05$) for Odeda location. For Ikenne location, 15 were found to be significant at 1% level while 9 were found to be significant at 5% level.

For Odeda (HL) sampling location, negative correlation exists between % sand and % silt (− 0.828**) and between % silt and % clay (− 0.712**). The correlation between % sand and % silt agrees with the results of Ayoubi et al. (2011) and Shukla et al. (2006). Negative correlation between % silt and % clay agrees with the result of Tsozue et al. (2016). There is negative correlation between % clay and TC (− 0.546*) as well as % clay and OM (− 0.546*). Pilania and Panchal (2016) also reported similar relationship between % clay and TC. No relationship exists between % clay and CEC. This is an indication that the two parameters acted independently as soil fertility factors (Pilania and Panchal 2016). There is also negative correlation at 5% level between % clay and soil resistivity (− 0.547*). This may be due to the fact that nitrogen mineralization reduces with increase in clay content (Cote et al. 2000; McLauchlan et al. 2006; Vejre et al. 2003). A very strong negative relationship exists between BD and TP at 1% level which buttressed the fact that there is inverse relationship between the two parameters. A significant negative correlation exists between BD and Na (− 0.788*), between BD and K (− 0.833**), and between BD and CEC (− 0.801**). Negative correlation between BD and CEC is a typical manifestation of urban soils where extensive soil compaction resulted in low value of CEC and reduced amount of Na and K (Landon 1991; Jim 1998). Positive correlation between BD and soil resistivity (0.693**) at 1% level buttressed the increase in soil resistivity value as a result of higher BD due to compaction (Mostafa et al. 2017; Grandjean et al. 2009). Positive correlations also exist between porosity and Na (0.789**), between porosity and K (0.834**), and between porosity and CEC (0.802**) while negative correlation exists between porosity and soil resistivity (− 0.691**). Positive correlation exists between TP and K. This may be due to the fact that increased BD (low TP) was attributed to increase in diffusion coefficient of potassium in soils. Positive correlation between Na and TP (0.789**) buttressed the fact that increase in BD facilitated the ease of replacement of Na from exchange site (Chatterjee and Ghosh 2014). Positive correlation between Na and K (0.973**) is expected because K can be considered equivalent of Na in soil structural stability function (Geeves et al. 1995; Rengasamy and Sumner 1998; Smiles 2006). Positive correlation exists between CEC and K (0.981**) as well as between CEC and Na (0.999**) at 1% level. Positive correlation between CEC and K confirms the fact that the higher the CEC content, the higher the rate of K absorption by the soil (Sparks and Huang 1985; Wang and Huang 2001). A significant positive correlation exists between TC and OM (1.000**) and between TC and TN (1.000**). The strong positive correlation between TC and TN confirms their main determinant roles for soil fertility and soil quality (Avramids et al. 2015; Chen et al. 2015; Jim 1998; Sakin 2012 and Tsozue et al. 2016). The correlation between TC and OM (1.000**) is an indication that the higher the TC content, the higher the increase in the OM (Kiser et al. 2009). Positive correlation also exists between TN and OM (1.000**). The significant correlation between TN and OM (1.000**) was expected because organic material supplies nitrogen in different forms (Friedel et al. 2000; Are et al. 2018). At 1% level, strong negative correlation exists between soil resistivity and TC (− 0.705**), between soil resistivity and OM (− 0.705**), and between soil resistivity and TN (− 0.705**). Negative correlation between soil resistivity and TN is in agreement with earlier work by Zhang and

**Table 2** Correlation coefficient of analyzed parameters in Odeda (Haplic Lixisol)

| | Sand | Clay | Silt | Hydr. Cond | Bulk density | Total porosity | AWC | pH | K | Na | TC | Organic matter | TN | CEC | Soil resistivity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sand | 1 | | | | | | | | | | | | | | |
| Clay | .196 | 1 | | | | | | | | | | | | | |
| Silt | − 0.828** | − 0.712** | 1 | | | | | | | | | | | | |
| Hydr. Cond | − 0.088 | − 0.063 | 0.099 | 1 | | | | | | | | | | | |
| Bulk density | 0.186 | 0.464 | − 0.399 | − 0.179 | 1 | | | | | | | | | | |
| Total porosity | − 0.187 | − 0.456 | 0.395 | 0.179 | − 1.000** | 1 | | | | | | | | | |
| AWC | − 0.001 | 0.028 | − 0.015 | 0.480 | − 0.471 | 0.474 | 1 | | | | | | | | |
| pH | − 0.257 | 0.268 | 0.030 | − 0.005 | − 0.039 | 0.042 | − 0.082 | 1 | | | | | | | |
| K | − 0.440 | − 0.175 | 0.415 | 0.144 | − 0.833** | 0.834** | 0.402 | 0.341 | 1 | | | | | | |
| Na | − 0.387 | − 0.142 | 0.359 | 0.048 | − 0.788** | 0.789** | 0.285 | 0.310 | 0.973** | 1 | | | | | |
| TC | − 0.008 | − 0.546* | 0.318 | − 0.202 | − 0.484 | 0.478 | − 0.322 | 0.142 | 0.327 | 0.407 | 1 | | | | |
| Organic matter | − 0.008 | − 0.546* | 0.318 | − 0.202 | − 0.483 | 0.478 | − 0.323 | 0.142 | 0.327 | 0.407 | 1.000** | 1 | | | |
| TN | − 0.010 | − 0.547* | 0.320 | − 0.204 | − 0.483 | 0.477 | − 0.322 | 0.143 | 0.326 | 0.407 | 1.000** | 1.000** | 1 | | |
| CEC | − 0.398 | − 0.158 | 0.375 | 0.068 | − 0.801** | 0.802** | 0.307 | 0.325 | 0.981** | 0.999** | 0.398 | 0.397 | 0.397 | 1 | |
| Soil resistivity | 0.085 | 0.551* | − 0.376 | − 0.089 | 0.693** | − 0.691** | − 0.202 | − 0.118 | − 0.386 | − 0.318 | − 0.705** | − 0.705** | − 0.705** | − 0.333 | 1 |

**Correlation is significant at the 0.01 level (2-tailed)

*Correlation is significant at the 0.05 level (2-tailed)

Location = Odeda

**Table 3** Correlation coefficient of analyzed parameters in Ikenne (Rhodic Nitisol)

| | Sand | Clay | Silt | Hydr. Cond | Bulk density | Total porosity | AWC | pH | K | Na | TC | Organic matter | TN | CEC | Soil resistivity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sand | 1 | | | | | | | | | | | | | | |
| Clay | − 0.208 | 1 | | | | | | | | | | | | | |
| Silt | − 0.640* | − 0.618* | 1 | | | | | | | | | | | | |
| Hydr. Cond | 0.136 | − 0.042 | − 0.076 | 1 | | | | | | | | | | | |
| Bulk density | 0.167 | 0.021 | − 0.151 | 0.322 | 1 | | | | | | | | | | |
| Total porosity | − 0.161 | − 0.029 | 0.152 | − 0.328 | − 1.000** | 1 | | | | | | | | | |
| AWC | 0.114 | 0.359 | − 0.374 | 0.403 | 0.122 | − 0.134 | 1 | | | | | | | | |
| pH | 0.345 | − 0.260 | − 0.073 | 0.270 | − 0.395 | 0.399 | 0.258 | 1 | | | | | | | |
| K | − 0.577* | − 0.042 | 0.496 | 0.301 | 0.044 | − 0.053 | 0.247 | − 0.230 | 1 | | | | | | |
| Na | − 0.604* | 0.274 | 0.270 | 0.236 | − 0.234 | 0.222 | 0.573* | 0.046 | 0.776** | 1 | | | | | |
| TC | 0.238 | − 0.281 | 0.030 | − 0.450 | − 0.323 | 0.332 | − 0.394 | 0.356 | − 0.714** | − 0.592* | 1 | | | | |
| Organic matter | 0.238 | − 0.280 | 0.029 | − 0.449 | − 0.323 | 0.332 | − 0.393 | 0.356 | − 0.714** | − 0.592* | 1.000** | 1 | | | |
| TN | 0.240 | − 0.280 | 0.027 | − 0.451 | − 0.324 | 0.332 | − 0.393 | 0.356 | − 0.715** | − 0.594* | 1.000** | 1.000** | 1 | | |
| CEC | − 0.619* | 0.213 | 0.330 | 0.256 | − 0.156 | 0.144 | 0.521 | − 0.054 | 0.873** | 0.984** | − 0.674** | − 0.674** | − 0.676** | 1 | |
| Soil resistivity | − 0.119 | 0.047 | 0.059 | 0.255 | 0.277 | − 0.278 | 0.024 | − 0.262 | 0.700** | 0.300 | − 0.729** | − 0.729** | − 0.729** | 0.431 | 1 |

*Correlation is significant at the 0.05 level (2-tailed)

**Correlation is significant at the 0.01 level (2-tailed)

Location = Ikenne

Wienhold (2002) who reported linear relationship between $NO_3$-N concentration and soil electrical conductivity (EC). The negative correlation between soil resistivity and TC, TN, and OM means that soil resistivity displayed a negative correlation with soil organic constituents.

In Ikenne sampling location, negative correlation exists between % sand and % silt (− 0.640*) and between % silt and % clay (− 0.618*) at 5% level. There is expected strong negative correlation between TP and BD at 1% level. At 5% level, negative correlation exists between K and % sand (− 0.577*) and between Na and % sand (− 0.604*). Negative correlation between K and % sand agrees with the results of Ghiri et al. (2012) and Adam et al. (2015) who reported that sand fraction released the lowest amount of K in soil. Negative correlation between CEC and % sand (− 0.619*) confirms the fact that sand generally has low CEC value compared with other soil particles (Ifeanyi and Agwu 2014). It may also be due to the coarse-textured soil being commonly lower in both clay and humus content. Na exhibits positive correlation with AWC (0.573*) at 5% level and expected positive correlation with K (0.776*). Both K and Na displayed negative correlation with TC, TN, and OM at 1% level ($p < 0.01$). The negative correlation between exchangeable cations and TC, TN, and OM is in agreement with similar result observed by Tsozue et al. (2016) and Sparks and Huang (1985). However, positive correlations at 1% level exist between K and CEC (0.873**), between Na and CEC (0.984**), and between K and soil resistivity (0.7000**). A very strong positive correlation also exists at 1% level between TC and OM (1.000**), between TC and TN (1.000**), and between TN and OM (1.000**). However, a strong negative correlation at 1% level was observed to exist between CEC and TC (− 0.676**). Negative correlation between CEC and TC (− 0.674**) might be a result of the fact that total extractable organic carbon (TEOC) has an inverse relationship with the degree of base saturation and clay content of soils (Gallardo 1999) in soils within the Mediterranean region. The same strong negative correlation also exists between soil resistivity and organic matter constituents (TN, TC, and OM) with the same $R^2 = -0.729^{**}$ in Ikenne sampling location.

## Results of ANOVA

From Table 4, the differences in % sand, % clay, and % slit were not significant between two locations at 5% level ($p < 0.05$) while there are significant

**Table 4** ANOVA result for analyzed parameters based on sampling location

| | Odeda | Ikenne |
|---|---|---|
| Sand | 71.734 ± 3.786$^{a}$ | 71.020 ± 3.252$^{a}$ |
| Clay | 13.846 ± 3.024$^{a}$ | 14.131 ± 3.180$^{a}$ |
| Silt | 14.420 ± 5.288$^{a}$ | 14.849 ± 4.047$^{a}$ |
| Hydr. Cond | 3.358 ± 2.779$^{a}$ | 3.721 ± 2.535$^{a}$ |
| Bulk density | 1.203 ± 0.191$^{a}$ | 1.509 ± 0.126$^{b}$ |
| Total porosity | 54.614 ± 7.241$^{a}$ | 43.029 ± 4.708$^{b}$ |
| AWC | 0.114 ± 0.027$^{a}$ | 0.100 ± 0.023$^{a}$ |
| pH | 5.757 ± 0.263$^{a}$ | 5.725 ± 0.242$^{a}$ |
| K | 0.835 ± 0.128$^{a}$ | 0.614 ± 0.086$^{b}$ |
| Na | 0.479 ± .068$^{a}$ | 0.356 ± 0.038$^{b}$ |
| TC | 3.548 ± 3.081$^{a}$ | 2.866 ± 3.301$^{a}$ |
| Organic matter | 6.118 ± 5.314$^{a}$ | 4.941 ± 5.691$^{a}$ |
| TN | 0.586 ± 0.508$^{a}$ | 0.474 ± 0.543$^{a}$ |
| CEC | 4.915 ± 0.709$^{a}$ | 3.631 ± 0.396$^{b}$ |
| Soil resistivity | 3.693 ± 3.525$^{a}$ | 5.768 ± 4.968$^{a}$ |

Values show mean ± standard deviation. Values along the same row with different superscripts are significantly different at 5% ($p < 0.05$) level

differences in both mean BD and TP between the two locations at 5% level (as shown in Table 4). This result agrees with earlier works by Pouyat et al. (2007) and Yao et al. (2013) who also reported significant differences in BD and TP of soils based on land use patterns. This is an indication that BD and TP are potentially related to land use practices (Pouyat et al. 2007). Table 4 further shows that AWC, TC, TN, OM, soil resistivity, and soil pH did not differ significantly between the two locations at 5% ($p < 0.05$) level. However, K, Na, and CEC showed significant differences in their mean value for the two locations at 5% level.

For the ANOVA table based on treatment (Table 5), the differences in % sand, % clay, % silt, BD, TP, AWC, K, Na, CEC, and soil resistivity of all the analyzed soil samples were not significant among the treatments at 5% level while there are significant differences in values of $K_{sat}$, pH, TC, TN, and OM at 5% level ($p < 0.05$) among the seven treatments. It should be noted that recorded mean values for TC, TN, and OM were significantly higher than those obtained for the other 5 treatments at 5% level during palm oil treatment at 50 and 100 ml (as shown in Table 5).

**Table 5** ANOVA result for analyzed parameters based on treatment

| | Control | Diesel 50 ml | Palm oil 50 ml | Petrol 50 ml | Diesel 100 ml | Palm oil 100 ml | Petrol 100 ml |
|---|---|---|---|---|---|---|---|
| Sand | 70.020 ± 5.000$^{a}$ | 70.520 ± 3.830$^{a}$ | 69.520 ± 1.414$^{a}$ | 73.770 ± 2.630$^{a}$ | 71.770 ± 3.862$^{a}$ | 73.520 ± 4.618$^{a}$ | 70.520 ± 1.155$^{a}$ |
| Clay | 12.560 ± 2.582$^{a}$ | 13.560 ± 3.651$^{a}$ | 13.060 ± 1.915$^{a}$ | 17.060 ± 1.915$^{a}$ | 12.560 ± 1.155$^{a}$ | 13.060 ± 4.123$^{a}$ | 16.060 ± 3.416$^{a}$ |
| Silt | 17.420 ± 5.000$^{a}$ | 15.920 ± 5.292$^{a}$ | 17.420 ± 2.646$^{a}$ | 9.170 ± 3.096$^{a}$ | 15.670 ± 3.202$^{a}$ | 13.420 ± 5.745$^{a}$ | 13.420 ± 3.416$^{a}$ |
| Hydr. Cond | 7.172 ± 2.483$^{a}$ | 4.278 ± 2.811$^{ab}$ | 1.343 ± 1.315$^{b}$ | 4.668 ± 2.533$^{ab}$ | 2.908 ± 0.705$^{b}$ | 2.395 ± 1.877$^{b}$ | 2.012 ± 1.886$^{b}$ |
| Bulk density | 1.440 ± 0.282$^{a}$ | 1.378 ± 0.256$^{a}$ | 1.247 ± 0.162$^{a}$ | 1.325 ± 0.191$^{a}$ | 1.345 ± 0.266$^{a}$ | 1.347 ± 0.272$^{a}$ | 1.407 ± 0.247$^{a}$ |
| Total porosity | 45.650 ± 10.645$^{a}$ | 47.925 ± 9.632$^{a}$ | 52.925 ± 6.015$^{a}$ | 49.975 ± 7.338$^{a}$ | 49.300 ± 10.045$^{a}$ | 49.100 ± 10.299$^{a}$ | 46.875 ± 9.447$^{a}$ |
| AWC | 0.121 ± 0.009$^{a}$ | 0.115 ± 0.022$^{a}$ | 0.099 ± 0.019$^{a}$ | 0.116 ± 0.040$^{a}$ | 0.095 ± 0.035$^{a}$ | 0.088 ± 0.019$^{a}$ | 0.116 ± 0.023$^{a}$ |
| pH | 5.988 ± 0.111$^{a}$ | 5.538 ± 0.165$^{bc}$ | 5.962 ± 0.085$^{a}$ | 5.850 ± 0.071$^{a}$ | 5.362 ± 0.048$^{c}$ | 5.888 ± 0.138$^{a}$ | 5.600 ± 0.135$^{b}$ |
| K | 0.770 ± 0.167$^{a}$ | 0.740 ± 0.123$^{a}$ | 0.730 ± 0.208$^{a}$ | 0.723 ± 0.181$^{a}$ | 0.688 ± 0.108$^{a}$ | 0.678 ± 0.228$^{a}$ | 0.743 ± 0.162$^{a}$ |
| Na | 0.423 ± 0.082$^{a}$ | 0.405 ± 0.064$^{a}$ | 0.435 ± 0.104$^{a}$ | 0.435 ± 0.090$^{a}$ | 0.383 ± 0.068$^{a}$ | 0.405 ± 0.131$^{a}$ | 0.437 ± 0.080$^{a}$ |
| TC | 0.735 ± 0.624$^{a}$ | 2.073 ± 1.259$^{a}$ | 6.165 ± 1.946$^{b}$ | 0.953 ± 0.361$^{a}$ | 2.845 ± 2.088$^{a}$ | 8.565 ± 2.507$^{b}$ | 1.112 ± 0.535$^{a}$ |
| Organic matter | 1.268 ± 1.073$^{a}$ | 3.577 ± 2.169$^{a}$ | 10.630 ± 3.351$^{b}$ | 1.645 ± 0.625$^{a}$ | 4.898 ± 3.600$^{a}$ | 14.772 ± 4.323$^{b}$ | 1.915 ± 0.921$^{a}$ |
| TN | 0.123 ± 0.103$^{a}$ | 0.343 ± 0.205$^{a}$ | 1.017 ± 0.320$^{b}$ | 0.157 ± 0.061$^{a}$ | 0.470 ± 0.344$^{a}$ | 1.413 ± 0.412$^{b}$ | 0.185 ± 0.086$^{a}$ |
| CEC | 4.370 ± 0.869$^{a}$ | 4.188 ± 0.660$^{a}$ | 4.425 ± 1.123$^{a}$ | 4.415 ± 0.962$^{a}$ | 3.953 ± 0.673$^{a}$ | 4.110 ± 1.373$^{a}$ | 4.450 ± 0.836$^{a}$ |
| Soil resistivity | 6.938 ± 2.433$^{a}$ | 5.018 ± 5.131$^{a}$ | 1.065 ± 0.397$^{a}$ | 7.187 ± 3.261$^{a}$ | 5.660 ± 7.676$^{a}$ | 0.750 ± 0.226$^{a}$ | 6.495 ± 3.135$^{a}$ |

Values show mean ± standard deviation. Values along the same row with different superscripts are significantly different at 5% ($p < 0.05$) level

## Interpretation of regression analysis result

Tables 6, 7, and 8 show the results of the regression analysis to formulate model equations for the relationship between the dependent variable ($K_{sat}$) and the predictors. Three (3) different regression models were obtained for the considered impurities: diesel, petrol, and palm oil. In the linear model generated for diesel, CEC, soil resistivity, % sand, BD, TP, and AWC were included as contributing factors to the variation in $K_{sat.}$ The linear model for diesel impurity shows that the predictor variables account for 100.0% of the total variation in the value of $K_{sat}$ with the *p* value 0.0137 implies the feasibility of the model. In the model for petrol, TC, OM, TN, soil resistivity, BD, and pH were included as explanatory variables to the variation in $K_{sat}$. The model for petrol impurity revealed that the predictor variables account for 100.0% of the total variation in the $K_{sat}$ with the *p* value 0.0115 implies the feasibility of the model. For linear model with palm oil impurity, TC, OM, soil resistivity, % clay, % silt, and pH were included as contributing factors to the variation in the $K_{sat}$. The model for palm oil impurity revealed that the predictor variables account for 100.0% of the total variation in the dependent variable $K_{sat}$. The *p* value of 0.00455 implies the feasibility of the generated model. The equations modeling the existing relationship between the $K_{sat}$ and the predictors as extracted from the regression tables for diesel, petrol and palm oil respectively are:

**Table 6** Regression table for analyzed parameters in diesel-treated soils

| Variables | Coefficient | Standard error | *F* value | *p* value |
|---|---|---|---|---|
| Intercept | − 474.20043 | 25.49830 | 345.86 | 0.0342 |
| Cation exchange capacity | 23.90771 | 0.26659 | 8042.64 | 0.0071 |
| Soil resistivity | − 0.36411 | 0.00458 | 6331.03 | 0.0080 |
| % Sand | 2.19123 | 0.02029 | 11664.2 | 0.0059 |
| Bulk density | 120.70163 | 9.26917 | 169.57 | 0.0488 |
| Total porosity | 1.63594 | 0.23378 | 48.97 | 0.0904 |
| Available water capacity | − 164.91182 | 1.72558 | 9133.46 | 0.0067 |
| *R*-square | 0.9999 | | | |
| ANOVA *p* value | 0.0137 | | | |

Dependent Variable: $K_{sat}$

**Table 7** Regression Table for analyzed parameters in petrol-treated soils

| Variables | Coefficient | Standard error | *F* value | *p* value |
|---|---|---|---|---|
| Intercept | − 51.35546 | 1.28698 | 1592.31 | 0.0160 |
| Total carbon | − 218.76950 | 5.16962 | 1790.84 | 0.0150 |
| Organic matter | 84.14402 | 3.09430 | 739.47 | 0.0234 |
| Total nitrogen | 465.85182 | 8.46109 | 3031.40 | 0.0116 |
| Soil resistivity | 0.35761 | 0.02713 | 173.77 | 0.0482 |
| Bulk density | − 5.76332 | 0.13346 | 864.98 | 0.0147 |
| pH | 9.86011 | 0.16073 | 3763.38 | 0.0104 |
| *R*-square | 1.0000 | | | |
| ANOVA *p* value | 0.0115 | | | |

Dependent variable: $K_{sat}$

$$K_{sat} = -474.20 + 23.91\ \mathrm{CEC} - 0.36\ \mathrm{SR} + 2.19\%\mathrm{sand} + 120.70\ \mathrm{BD} + 1.64\ \mathrm{TP} - 164.91\ \mathrm{AWC} \tag{3}$$

$$K_{sat} = -51.36 - 218.77\ \mathrm{TC} + 84.14\ \mathrm{OM} + 465.85\ \mathrm{TN} + 0.36\ \mathrm{SR} - 5.76\ \mathrm{BD} + 9.86\ \mathrm{pH} \tag{4}$$

$$K_{sat} = -41.07 + 141.32\ \mathrm{TC} - 81.02\ \mathrm{OM} + 2.54\ \mathrm{SR} + 1.23\%\mathrm{clay} + 0.41\%\mathrm{silt} + 1.10\ \mathrm{pH} \tag{5}$$

**Table 8** Regression table for analyzed parameters in palm oil–treated soils

| Variables | Coefficient | Standard error | *F* value | *p* value |
|---|---|---|---|---|
| Intercept | − 41.06856 | 0.40140 | 10468.1 | 0.0062 |
| Total carbon | 141.32016 | 1.42271 | 9866.76 | 0.0064 |
| Organic matter | − 81.01663 | 0.82256 | 9700.82 | 0.0065 |
| Soil resistivity | 2.54226 | 0.03931 | 4182.15 | 0.0098 |
| % Clay | 1.22966 | 0.00423 | 84487.1 | 0.0022 |
| % Silt | 0.40530 | 0.00173 | 54973.7 | 0.0027 |
| pH | 1.09884 | 0.04944 | 494.00 | 0.0286 |
| *R*-square | 1.0000 | | | |
| ANOVA *p* value | 0.0045 | | | |

Dependent variable: $K_{sat}$

where SR is the soil resistivity, TC is the total carbon, TN is the total nitrogen, OM is the organic matter, BD is the bulk density, TP is the total porosity, and AWC is the available water capacity for the linear models.

The regression analysis result reveals that significant relationship exists at 5% level between the dependent variable ($K_{sat}$ )and the predictor variables for petrol and palm oil impurities. However, the regression analysis result for diesel impurity reveals that significant relationship exists at 5% level between the $K_{sat}$ and all the predictor variables except TP which is not significant at 5% level.

## Conclusions

The study assesses the effects of selected petroleum-derived (petrol and diesel) and vegetable oil (palm oil) on both physicochemical and hydraulic properties of two soil types located on two geological formations in southwest Nigeria. The results of the present study indicated that the selected contaminants have effects on analyzed soil parameters on soils of different soil types and can be said to be site specific in some instances. The application of palm oil treatment at 50 ml resulted in least $K_{sat}$ value less than control $K_{sat}$ value in each location. In terms of BD and TP, our results showed that the highest mean BD (least TP) and least mean BD (highest TP) were found in petrol and diesel contaminants at 100 ml in Odeda HL soils. However, the highest mean BD and least mean BD in RN soils were found in untreated control and palm oil–treated soil at 50 ml respectively. This corroborates the significant differences in both mean BD and TP in the two sampling locations. Decrease in AWC was recorded in soils treated with all impurities in RN soils in Ikenne while there is increased AWC in petrol- and diesel-treated soils in Odeda location. Soil treated with palm oil at 100 ml in both locations had highest mean values of organic parameters (TC, TN, and OM). However, least values of abovementioned organic parameters were found in petrol-treated soil at 50 ml in HL soils but noticed in untreated control soil in RN soils. Compared with control values, TC, TN, and OM increased with volume of contaminants in RN soils but only in diesel and palm oil in Odeda HL soils. It was evident in this study that low TN values (< 0.7%) were noticed in petroleum hydrocarbon–contaminated soils in both locations. Our results also revealed that the least value of soil resistivity was obtained in palm oil–treated soil at 100 ml in both sampling locations. However, soil pH and soil textural class show no considerable change in status in all treated soils relative to control soil at both locations. There is expected strong negative correlation at 1% level between BD and porosity and between any two of organic parameters (TC, TN, and OM) in both soil types. ANOVA result revealed no significant differences in particle size distribution, AWC, and soil resistivity for any of the treatments at the two locations at 5% level. However, BD, TP, Na, and K varied significantly at 5% level based on locations while significant differences exist in values of $K_{sat}$, pH, TC, TN, and OM for soils under various treatments. Comparison among the regression models showed that $K_{sat}$ predicted from all the generated models with selected impurities had $R^2$ values varying from 0.999 to 1.000. There should be further investigation to evaluate the effects of more petroleum-derived and vegetable oils on soil properties in different soil types within southwest Nigeria.

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