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Original Article

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Abstract

Many fundamental questions concerning the indiscriminate disposal of automobile effluent as a major non-point source of oil pollution, it induced impact and changes in soil physiochemical properties the application of phytotechnology remain unanswered in parts of eastern Niger Delta. This study was aimed at evaluating the phytoremediation potency of *Peltophorum pterocarpum*, *Leucaena leucocephala*, and *Crotolaria retusa* (Fabaceae family) with the objectives of quantifying the changes in the physicochemical properties of the soil under polluted and phytoremediated condition. The methodology adopted involved universally accepted ecological field and laboratory standards. Result revealed increased anionic content of nitrate (9.98±1.84mg/g) and phosphate (0.32±0.07mg/g), decreased chloride (0.01±0.00mg/g) and sulphate (1.82±0.30mg/g) in polluted condition, but increased across remediated soils with *Peltophorum* soil highest in content. Cations decreased under pollution, increased in remediated soils with magnesium (69.26±0.08mg/g) and potassium (17.40±7.05mg/g) higher in *Crotolaria*, calcium (187.87±0.45mg/g) in *Peltophorum* and sodium (6.38±1.01mg/g) in *Leucaeana* soils. Decreased pH (5.46±0.17), moisture (18.70±2.05%), clay (11.53±0.74%), silt (7.20±2.01%), particle density (2.49±0.05g/cm) and porosity (51.34%) decrease across pollution were recorded but increased among species treated soils with *Peltophorum* soil higher in restoration. The increased sand particle (81.60±2.43%), organic matter (3.15±0.43%), bulk density (1.21±0.09g/cm), oil & grease (1.52±0.32mg/g), Total hydrocarbon (3.97±0.26mg/g) and electrical conductivity (24.30±2.62µS/cm) in pollution, decreased in *Peltophorum* soil among species treatment with significant difference ($P<0.05$). The species in view of their variant tolerance to hydrocarbon and potency can thus be suggested as an integral part of remediation measure to soil environmental decontamination.

1. Introduction

Spent Lubricating Oil (SPO) or Waste Engine Oil (WEO) under its chemical formation is a viscous liquid or substance with dark brown or black colouration. It is often characterized with varying composite of constituent ranging from low to high molecular weight carbon compounds, lubricative additives, decomposition products and heavy metals (Adu *et al*., 2015; Beckley and Mathew, 2020). Spent oil is usually obtained following the services and repairs of automobile and other forms of energy generating machines and engines. Automobiles workshops and service stations in most part of Eastern Niger Delta find it difficult in managing spent oil disposal despite the natural means (evaporation, microbial natural attenuation, oxidation, thermal process and their associated inefficiency of deterioration and degradation of the indiscriminately disposed volume of this hydrocarbons waste product. Hence large volume of this oil is indiscriminately disposed to diverse segment of the ecosystem without a proper treatment and monitoring, this has contributed markedly to the problem of soil pollution. With the varying constituent of the waste oil, the soil environment of the study area in question is affected in different manners in light of its physicochemical properties at different levels of pollution.

Several studies have revealed the deteriorating impact of fluid characterized by properties that differ from water and of hydrocarbon-induced changes in soil physicochemical conditions (Inwite and Alu 2015; Victoria *et al*., 2016; Edwin-Wosu and Nkang 2017a; Edwin-Wosu and Nkang, 2019a; Edwin-

Wosu and Nkang 2020). Remediation studies have being evaluated, revealing the potency of plant species for phytoremediation in diverse trend of hydrocarbon impacted soil condition (Al-Baldawi *et al*., 2015; Xiao *et al*., 2015; Edwin-Wosu and Nkang 2017a). Phytoremediation, a subcategory of phytotechnology uses plants either solely or / and synergistically with number to absorb and degrade organic and inorganic pollutants from environmental media (Shanon, 2017). This technology has worked for the degradation of contaminant in soil, thus making the soil useful for other purposes (Izinyon and Seghosine, 2013).

There has been paucity of data on the effect of spent oil pollution on the physicochemical properties as well as phytorestoration of soils in eastern part of the Niger Delta particularly in area where automobiles workshop are springing up in large proportions with attendant consequences of improper waste oil disposal and management. Many fundamental questions concerning automobiles effluent discharges and distribution of soil physiochemical properties in relation to phytotechnology application remain unanswered. Based on the foregoing the study aims at evaluating the phytoremediation potency of three species (*Peltophorum pterocarpum*, *Leucaena leucocephala*, and *Crotolaria retusa*) members of the Fabaceae family with the objectives of quantifying the induced changes in the physicochemical properties of the soil under a polluted and phytoremediated condition. Further more information obtained shall be a source for exploit and application to other section of eastern Niger Delta area in Nigeria.

2. Materials and Methods

Field experimental design and sampling

Replicates of sandy loamy top soil (20 kg) were collected within 0 -15 cm depth (Stewarte *et al*., 1974; Song *et al*., 1990), from over 7-year old fallowed land in part of the experimental station, University of Calabar, eastern Niger Delta. The waste oil was collected from a road side mechanic workshop, located in Calabar. A split plot nested design (Akindele 1996) was adopted. The soil was polluted at different levels of waste oil concentration (V/W %) doses of 0 %, 0.4%, 0.8% and 1.5% per 1,809 cm^2 surface area and in replicates of five per level. The polluted and control replicates were after seven days subjected to post-pollution habitat reclamation using healthy seedlings (*Peltophorum pterocarpum (Pp)*; *Leucaena leucocephala (Ll);* and *Crotolaria retusa (Cr))* of 14 days old. The watering regime was twice at two days interval per week. Across phytoapplication the growth performance of these seedlings under observation was monitored for a period of 10 months. The phytorestoration of the soil after the 10 months period of ecological study was assessed relative to pre- and post-pollution soils by means of comparative analysis of the physicochemical parameters of the test soil.

Laboratory analyses

The pre- and post-pollution as well as phytoremediation phases of soil moisture content were determined as described by Stewarte, *et al*. (1974). Soil processing was by air drying at room temperature (25°C) and 70% relative humidity, and screened through a 2-mm sieve to give the 2 mm "fine earth" that was stored in screw capped receptacles from which samples were used for physicochemical analysis. Chloride (Cl) content determination adopted the British Standard Institution (1990) titration method. The Spectrophotometric Brucine IITA (1979) method was adopted for Nitrate (NO_3^-), and turbidimetric method (Fox *et al*., 1964; IITA 1979) for Sulphate (SO_4^{-2}). while Bray and Kuntz (1945), as modified by IITA (1979) method was adopted for Phosphate (PO_4^{-3}), the salinity was measured using Bench top meter Model 8600 mm (Sper Scientific, USA) in part per million (ppm) (Antai, *et al*., 2016). The cation determination adopted mixed acid digestion (wet oxidation) (IITA, 1979), as modified by the Aqua Regia method (Loring and Rantala 1992). The digested material was set for atomic absorption spectrophotometery analysis using UNICAM AAS 32. The "soil pH measured in water" was determined using Hanna pH meter (Model HI 9811-5N, Hanna Instrument, USA) on 1:2 (soil: water) suspension (Antai *et al*., 2016). Soil texture determination was by particle size analysis (Black, 1965) and Bouyoucos (1962) hydrometer method and various percentage components (sand, silt, and clay) extrapolated using the textural triangle model (Harry and Nyle, 1962). Organic matter (%OM) was extrapolated by multiplying the value of percentage organic carbon by the "Van Bermenalen factor" of 1.724 (Walkley and Black, 1934) method as modified in Nelson and Sommer (1982), bulk density (BDg/cm) determination was by the core method (Blake and Hartge, 1986).The ASTM (1958) method was adopted for particle density (PDg/cm) and porosity by extrapolation from bulk and particle density analyses. Oil content (mg/g) was determined spectrophotometrically by the toluene extraction method (Odu *et al.*, 1989) while photometric method (API, 1980) was adopted for Total hydrocarbon content (mg/g) determination. The electrical conductivity (ECµS/cm) was determined using the conductivity meter (Model HI 9811-5N) on mechanically shaken soil: water suspension (1:5 ratio) (Rayment and Higginson, 1992).

Data analyses

The remediation performance was estimated using the Statistical Analysis System (SAS) PROC. NLIN procedure (2016) software on the data acquired from the study. Treatment means were compared and significant differences by mean separation were based on the procedures of the Duncan's New Multiple Range Test (DNMRT) using least significant difference (LSD) tests at 5% probability level. Pearson correlation was applied to determine the degree of relationship of restoration among the parameters of the pre- and post-polluted and phytoremediated soils of species treatment.

3. Results

The result as presented in Fig. 1 has indicated a decreased anionic chloride content (mg/g) across pollution levels with non-significant difference ranging from 0.02±0.00 mg/g at 0% level of pre-polluted soil to 0.01±0.01 mg/g at 1.5% level. The phyto-remediated soils had variation with significant increase (0.04±0.02 mg/g) at 1.5% level *Peltophorum* soil. Nitrate content (9.33±2.89 mg/g) at 0% increased to 13.47±0.38 mg/g at 1.5% pollution level with non-significant difference but with significant ($P<0.05$) increase to 30.62±3.25 mg/g at 1.5% level *Peltophorum* treated soil and *Crotolaria* soil with the least (9.97±2.21 mg/g) nitrate content. Pre-pollution sulphate content decreased across pollution level ranging from 5.58±0.38 mg/g at 0% level to 2.20±0.33 mg/g at 1.5% pollution level. This was restored across phytoremediated soils with *Peltophorum* soil on the average recording the highest (10.93±2.63 mg/g). The phosphate content (0.22±0.02 mg/g) had non-significant ($P<0.05$) increase to 0.36±0.07 mg/g at 1.5% level across pollution levels. The phytoremediated soils had variation with significant difference ($P<0.05$) at 1.5% level with *Peltophorum* soil recording 0.67±0.28 mg/g phosphate content. The soil salinity increased in the pollution level ranging from 150.00±0.00ppm at pre-pollution soil (0% level) to 200.00±0.71ppm with significant difference ($P<0.05$) at 1.5% level. The phytoremediated soil with variation in salinity levels recorded the highest salinity level (182.53±3.85ppm) in *C. retusa* soil and least value of 161.67±25.73ppm in *Leucaena* soil.

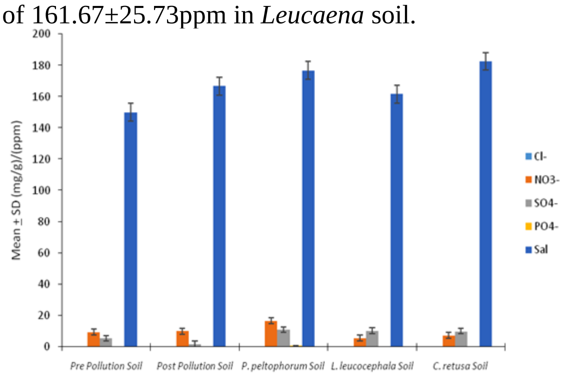

Fig. 1: Anionic restoration levels of the remediated eastern Niger Delta polluted soil.

The cationic content (Fig.2) recorded significantly a decreased Mg^{2+} (138.51±1.80mg/g) content at increased pollution levels, with the least Mg^{2+} content (80.38±1.24mg/g) at 0.4% level and the highest (98.02±5.85mg/g) at 0.8% level. *Crotolaria* treated soil on the average had increased Mg^{2+} content (69.26±0.08) among the variation across phytoremediated soils. Calcium content decreased across pollution levels ranging from 193.98±7.68mg/g at pre-pollution (0% level) to 178.02±0.41mg/g at 1.5% pollution level. The phytoremediated soils recorded variation in decreasing order of calcium content with *Peltophorum* soil highest (187.87±0.45mg/g) and *Leucaena* soil least (175.50±9.86mg/g) in content. The Na^+ content decreased significantly across pollution levels ranging from 7.74±0.01mg/g at the pre-pollution soil (0% level) to 4.17±0.00mg/g at 1.5% pollution level. The phytoremediated soils with variation in Na^+ increase had *Leucaena* soil significantly ($P<0.05$) highest (6.38±1.01mg/g) at 1.5% level and *Peltophorum* soil least (4.74±1.83mg/g) in content on the average. The pre-polluted potassium (K^+) content (8.92±1.09mg/g) decreased to 4.78±0.02mg/g at 1.5% pollution level. The phytoremediated soil had variation in the K^+ content with *Crotolaria* treated soil significantly different ($P<0.05$) at 1.5% level with the highest (17.40±7.05mg/g) and *Peltophorum* soil least (16.54±1.05mg/g) in content.

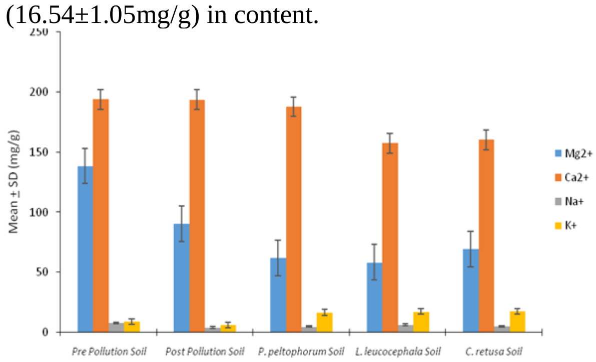

Fig. 2: Cationic restoration levels of the remediated eastern Niger Delta polluted soil

The physicochemical changes as exemplified in Fig. 3 indicated a pre-pollution soil pH decrease at increased pollution level ranging from 5.75±0.10 at 0% level to 5.47±0.24 at 1.5% pollution level. The phytoremediated soils recorded significant variation in pH levels with the highest pH (6.61±0.56) in *Peltophorum* and least (6.61±0.56) pH in *Leucaena* soils with significant difference recorded. Percentage moisture content (21.00±1.19) at pre-pollution soil (0% level) decreased to an average content (18.70±2.05) across pollution level. The phytoremediated soil had variation in the percentage moisture content, significantly different ($P<0.05$) at 1.5% level of *Leucaena* soil, with averagely highest moisture content (34.94±6.36) and least content (22.48±5.01) in *Crotolaria* soil.

The percentage sandy component of the particle size recorded increase on the average from (79.20±2.49) at pre-pollution level (0%) to 81.60±2.43 across polluted condition. The phytoremediated soil significantly had varying increase in sandy particle with the highest average percentage (88.67±144) in *Peltophorum* soil and least average (84.80±1.44) in

Table 1: Ionic and physicochemical restoration level of the remediated parts of eastern Niger Delta waste oil polluted soil

Soil Index	Pre-poll. (0%)	% Post pollution levels			% Levels of Post phytoapplication soil												Mean	LSD (P<0.05)
		0.4%	*0.8%*	*1.5%*	*Pp (0%)*	*Pp 0.4%*	*Pp 0.8%*	*Pp 1.5%*	*Ll (0%)*	*Ll 0.4%*	*Ll 0.8%*	*Ll 1.5%*	*Cr (0%)*	*Cr 0.4%*	*Cr 0.8%*	*Cr 1.5%*		
Cl^- (mg/g)	0.02 ± 0.00^{bc}	0.01 ± 0.00^{cd}	0.01 ± 0.00^{cd}	0.02 ± 0.01^{cd}	0.02 ± 0.00^{bc}	0.02 ± 0.00^{bc}	0.03 ± 0.01^{b}	0.04 ± 0.02^{a}	0.02 ± 0.00^{bc}	0.02 ± 0.00^{bc}	0.02 ± 0.00^{bc}	0.02 ± 0.00^{bc}	0.02 ± 0.00^{bc}	0.02 ± 0.00^{bc}	0.03 ± 0.01^{b}	0.03 ± 0.01^{b}	0.01	0.01
NO_3^- (mg/g)	9.33 ± 2.89^{b}	7.36 ± 3.19^{b}	9.10 ± 1.95^{b}	13.47 ± 0.38^{b}	9.55 ± 2.48^{b}	7.72 ± 4.13^{b}	11.52 ± 1.62^{b}	30.62 ± 3.25^{a}	10.73 ± 1.30^{b}	4.40 ± 1.30^{b}	5.38 ± 3.82^{b}	7.37 ± 4.27^{b}	25.25 ± 2.56^{a}	6.17 ± 1.81^{b}	7.85 ± 3.66^{b}	8.25 ± 3.71^{b}	10.88	11.65
SO_4^{-2} (mg/g)	5.58 ± 0.38^{b}	1.71 ± 0.39^{b}	1.54 ± 0.18^{b}	2.20 ± 0.33^{b}	38.43 ± 3.28^{ab}	8.82 ± 0.00^{bc}	11.03 ± 4.54^{b}	12.94 ± 3.36^{b}	11.91 ± 2.23^{b}	8.16 ± 2.36^{b}	9.41 ± 1.68^{b}	13.24 ± 7.90^{b}	13.32 ± 5.82^{b}	8.45 ± 1.72^{b}	9.85 ± 1.23^{b}	11.62 ± 3.69^{b}	10.52	10.30
PO_4^{-3} (mg/g)	0.22 ± 0.02^{b}	0.28 ± 0.08^{b}	0.31 ± 0.06^{ab}	0.36 ± 0.07^{ab}	0.24 ± 0.04^{b}	0.44 ± 0.26^{ab}	0.50 ± 0.35^{ab}	0.67 ± 0.28^{a}	0.47 ± 0.36^{ab}	0.24 ± 0.03^{b}	0.49 ± 0.34^{ab}	0.56 ± 0.39^{ab}	0.36 ± 0.21^{ab}	0.24 ± 0.04^{b}	0.39 ± 0.17^{ab}	0.50 ± 0.25^{ab}	0.39	0.29
Salinity (ppm)	150.00 ± 0.00^{c}	135.0 ± 41.83^{cd}	165.0 ± 41.83^{abc}	200.0 ± 70.71^{abe}	200.0 ± 0.00^{abe}	135.00 ± 41.83^{cd}	195.00 ± 75.83^{abe}	200.00 ± 0.00^{abe}	100.00 ± 0.00^{d}	135.00 ± 41.83^{cd}	150.00 ± 35.36^{c}	200.00 ± 0.00^{abe}	170.00 ± 44.72^{abce}	165.00 ± 41.83^{abc}	165.00 ± 41.83^{abc}	217.60 ± 20.89^{e}	167.66	49.88
Mg^{2+} (mg/g)	138.51 ± 51.80^{a}	80.38 ± 15.24^{bc}	98.02 ± 5.85^{b}	93.09 ± 0.02^{b}	60.60 ± 0.04^{cd}	68.10 ± 0.04^{cd}	60.99 ± 4.61^{cd}	57.15 ± 0.04^{d}	60.62 ± 0.02^{cd}	68.50 ± 25.52^{cd}	53.03 ± 2.49^{d}	51.12 ± 0.02^{d}	60.58 ± 0.02^{cd}	71.54 ± 0.16^{cd}	68.12 ± 0.05^{cd}	68.12 ± 0.02^{cd}	72.53	19.03
Ca^{2+} (mg/g)	193.98 ± 7.68^{b}	212.94 ± 41.94^{a}	190.11 ± 14.88^{b}	178.02 ± 0.41^{bc}	138.83 ± 0.42^{d}	186.18 ± 0.02^{b}	188.17 ± 1.31^{b}	189.27 ± 0.01^{b}	135.34 ± 4.59^{de}	189.27 ± 0.02^{b}	164.55 ± 29.54^{c}	118.67 ± 0.03^{ef}	138.89 ± 0.44^{d}	108.76 ± 0.05^{f}	186.14 ± 0.05^{b}	186.12 ± 0.04^{b}	169.08	17.11
Na^{+} (mg/g)	7.74 ± 0.01^{a}	4.02 ± 0.18^{cd}	4.06 ± 0.00^{cd}	4.17 ± 0.00^{cd}	2.63 ± 0.00^{d}	5.47 ± 0.00^{bc}	4.32 ± 2.71^{cd}	4.43 ± 2.77^{c}	2.63 ± 0.00^{d}	6.74 ± 0.00^{ab}	4.72 ± 2.93^{c}	7.67 ± 0.10^{a}	2.63 ± 0.00^{d}	3.78 ± 0.00^{cd}	5.47 ± 0.00^{bc}	5.47 ± 0.00^{bc}	4.75	1.54

K^+ (mg/g)	8.92 ± 1.10^{de}	6.58 ± 2.16^{de}	6.81 ± 1.38^{de}	4.78 ± 0.02^{e}	2.39 ± 0.02^{e}	12.47 ± 0.08^{cd}	17.33 ± 3.05^{bc}	19.82 ± 0.02^{bc}	2.38 ± 0.00^{e}	20.33 ± 0.58^{b}	17.74 ± 2.53^{bc}	13.84 ± 0.02^{bcd}	2.48 ± 0.07^{e}	9.52 ± 0.09^{de}	12.69 ± 0.10^{bcd}	$30.00 \pm 20..96^{a}$	11.76	6.80
pH	5.75 ± 0.10^{cd}	$5..45 \pm 0.23^{d}$	5.45 ± 0.03^{d}	5.47 ± 0.24^{d}	6.55 ± 0.09^{ab}	6.57 ± 0.15^{ab}	6.35 ± 0.07^{ab}	6.90 ± 1.47^{a}	6.58 ± 0.06^{ab}	6.39 ± 0.14^{ab}	6.31 ± 0.13^{b}	6.07 ± 0.07^{bc}	6.41 ± 0.17^{ab}	6.51 ± 0.13^{ab}	6.41 ± 0.12^{ab}	6.29 ± 0.06^{b}	6.22	0.49
% Moisture	20.93 ± 1.19^{defg}	16.84 ± 1.13^{gh}	17.85 ± 2.40^{fgh}	21.40 ± 2.61^{defgh}	21.67 ± 1.75^{defgh}	14.89 ± 1.42^{h}	24.00 ± 3.74^{defgh}	26.51 ± 3.27^{cdef}	29.68 ± 6.70^{bcd}	27.78 ± 6.99^{cde}	34.54 ± 3.64^{abc}	42.50 ± 8.46^{a}	37.72 ± 13.65^{ab}	20.16 ± 3.65^{efgh}	21.69 ± 7.80^{defgh}	25.60 ± 3.58^{defg}	25.23	7.80
% Sand	79.20 ± 2.49^{h}	$82..40 \pm 2.19^{efg}$	82.40 ± 3.36^{gh}	82.00 ± 1.73^{fgh}	88.00 ± 0.71^{abc}	87.80 ± 1.48^{abc}	88.60 ± 2.30^{ab}	89.60 ± 0.55^{a}	85.80 ± 1.10^{bcd}	88.00 ± 0.00^{abc}	85.20 ± 1.92^{cde}	81.20 ± 2.39^{gh}	88.20 ± 0.48^{abc}	85.00 ± 0.71^{cdef}	84.60 ± 5.55^{def}	89.00 ± 0.00^{ab}	85.31	2.85
% Clay	13.20 ± 0.84^{a}	$11..80 \pm 0.45^{ab}$	11.40 ± 0.89^{b}	11.40 ± 0.89^{b}	5.80 ± 2.17^{def}	4.00 ± 0.71^{fg}	6.60 ± 2.30^{cd}	5.00 ± 0.71^{def}	4.00 ± 1.82^{efg}	4.00 ± 0.71^{fg}	5.20 ± 1.30^{def}	8.20 ± 0.84^{c}	4.60 ± 1.82^{efg}	6.40 ± 0.80^{de}	5.80 ± 1.48^{def}	2.80 ± 0.45^{g}	6.93	1.66
% Silt	7.60 ± 2.97^{cdef}	$6..60 \pm 2.07^{ef}$	8.20 ± 2.49^{bcdef}	6.80 ± 1.48^{def}	6.20 ± 2.86^{f}	8.20 ± 0.84^{bcdef}	9.40 ± 3.36^{abcd}	6.40 ± 0.89^{abcd}	10.00 ± 0.71^{abc}	8.00 ± 0.71^{bcdef}	10.40 ± 0.89^{ab}	11.00 ± 1.58^{a}	8.00 ± 1.23^{bcdef}	9.00 ± 0.00^{abcde}	6.00 ± 0.71^{f}	8.20 ± 0.84^{bcdef}	8.13	2.26
% OM	1.46 ± 0.21^{h}	$2..40 \pm 0.34^{defg}$	3.40 ± 0.65^{ab}	3.64 ± 0.31^{a}	2.08 ± 0.29^{efgh}	2.37 ± 0.47^{defg}	2.58 ± 0.35^{cde}	3.00 ± 0.63^{abcd}	1.73 ± 0.91^{fgh}	2.49 ± 0.61^{def}	2.61 ± 0.81^{cde}	3.74 ± 0.57^{a}	1.64 ± 0.39^{gh}	2.41 ± 0.49^{defg}	2.72 ± 0.48^{bcde}	3.32 ± 0.86^{abc}	2.60	0.71
BD (g/cm)	1.10 ± 0.01^{a}	$1..20 \pm 0.07^{ab}$	1.20 ± 0.07^{ab}	1.23 ± 0.13^{ab}	1.09 ± 0.03^{abc}	0.44 ± 0.51^{d}	0.81 ± 0.45^{c}	1.05 ± 0.05^{bc}	1.18 ± 0.05^{ab}	1.07 ± 0.06^{bc}	1.11 ± 0.01^{abc}	1.12 ± 0.02^{abc}	1.25 ± 0.04^{ab}	0.82 ± 0.46^{c}	1.04 ± 0.06^{bc}	1.11 ± 0.01^{abc}	1.10	0.27
PD (g/cm)	2.61 ± 0.03^{bc}	$2..49 \pm 0.03^{fg}$	2.49 ± 0.03^{fg}	2.48 ± 0.10^{g}	2.62 ± 0.02^{ab}	2.66 ± 0.04^{a}	2.58 ± 0.02^{bcd}	2.59 ± 0.01^{bcd}	2.62 ± 0.06^{ab}	2.59 ± 0.00^{bc}	2.57 ± 0.02^{cde}	2.54 ± 0.00^{de}	2.61 ± 0.01^{bc}	2.60 ± 0.01^{bc}	2.56 ± 0.01^{cde}	2.53 ± 0.00^{ef}	2.57	0.04

Porosity	57.85^{a}	51.81^{a}	51.81^{a}	50.40^{a}	58.40^{a}	75.94^{b}	68.61^{bc}	59.46^{ac}	54.96^{a}	66.80^{c}	56.81^{a}	55.91^{a}	52.11^{a}	68.46^{c}	59.38^{ac}	55.73^{a}	59.03	10
OG (mg/g)	0.64 ± 0.09^{efg}	0.96 ± 0.21^{de}	1.36 ± 0.20^{c}	2.24 ± 0.55^{b}	0.38 ± 0.09^{g}	0.83 ± 0.05^{ef}	0.89 ± 0.15^{ef}	1.25 ± 0.56^{cd}	0.46 ± 0.08^{g}	0.79 ± 0.02^{ef}	0.89 ± 0.06^{ef}	1.27 ± 0.09^{cd}	0.56 ± 0.14^{fg}	0.94 ± 0.22^{de}	0.97 ± 0.08^{de}	2.64 ± 0.22^{a}	1.07	0.30
THC (mg/g)	1.25 ± 0.16^{ef}	3..26 ± 0.08^{b}	4.08 ± 0.45^{a}	4.56 ± 0.25^{a}	0.98 ± 0.18^{f}	1.50 ± 0.21^{def}	1.75 ± 0.16^{de}	2.15 ± 0.22^{cd}	1.10 ± 0.04^{ef}	1.09 ± 0.47^{ef}	2.52 ± 0.68^{c}	3.18 ± 1.54^{b}	1.19 ± 0.17^{ef}	1.66 ± 0.12^{de}	1.72 ± 0.14^{de}	2.66 ± 0.22^{bc}	2.17	0.60
EC μS/cm	21.90 ± 0.93^{e}	21.96 ± 3.94^{de}	23.70 ± 0.42^{de}	27.23 ± 3.49^{cd}	12.95 ± 7.87^{e}	30.12 ± 2.36^{bcd}	33.32 ± 12.27^{bcd}	50.78 ± 14.20^{a}	37.40 ± 3.07^{bc}	27.32 ± 3.14^{cd}	27.68 ± 5.67^{cd}	33.25 ± 15.80^{bcd}	36.06 ± 7.70^{bc}	22.86 ± 6.39^{de}	36.88 ± 6.64^{bc}	40.12 ± 8.81^{a}	30.22	9.84

Note: *Pp* = *Peltophorum pterocarpium*, *Ll* = *Leucaena leucocephala*, *Cr* = *Crotolaria retusa*. 0.4% = low pollution, 0.8% = medium pollution, 1.5% = high pollution. *means ± SD of five replicates and with the same superscript letter are not significantly different, using the Duncan's New Multiple Range Test (DNMRT).

Table 2: Pearson correlation coefficient of Ionic and physicochemical restoration level of the remediated parts of eastern Niger Delta waste oil polluted soil

Soil index	Cl^-	NO_3^-	SO_4^{-2}	PO_4^{-3}	Sal.	Mg^{2+}	Ca^{2+}	Na^+	K^+	pH	Moist	Sand	Clay	Silt	OM	BD	PD	Porosity	OG	THC
Cl^-	1.00																			
NO_3^-	0.47	1.00																		
SO_4^{-2}	0.19	0.11	1.00																	
PO_4^{-3}	0.20	-0.002	-0.11	1.00																
Salinity	0.28	-.0.04	0.09	0.18	1.00															
Mg^{2+}	-0.25	-.0.07	-0.28	-0.27	0.03	1.00														
Ca^{2+}	0.03	0.04	-0.32	-0.07	0.02	0.31	1.00													
Na^+	-0.01	-0.12	-0.16	-0.04	0.09	0.23	0.15	1.00												
K^+	0.32	-.0.09	-0.06	0.17	0.25	-0.18	0.29	0.33	1.00											
pH	0.26	0.05	0.29	0.28	-0.05	0.41	-0.26	0.02	0.18	1.00										
Moist.	0.15	-0.001	0.23	0.18	0.13	0.34	-0.38	0.12	0.05	0.14	1.00									
% Sand	-0.08	-.0.10	-.0.15	-0.10	0.25	-0.20	-0.25	-0.10	-0.15	0.40	0.45	1.00								
% Clay	0.55	0.30	0.45	0.40	0.65	0.40	0.60	0.65	0.20	0.15	0.65	-0.77	1.00							
% Silt	0.40	0.15	0.20	0.30	0.50	0.35	0.60	0.75	0.65	0.20	0.30	-0.47	-0.15	1.00						
OM	0.04	-.0.05	-0.11	0.16	0.22	-0.13	0.07	0.22	0.34	0.19	0.11	-0.15	-0.19	-0.04	1.00					
BD	-0.23	0.05	-0.01	-0.15	0.01	0.28	0.02	0.11	-0.18	-0.24	0.19	-0.20	0.30	-0.07	0.05	1.00				
PD	0.19	0.04	0.28	0.09	-0.16	-0.18	-0.20	-0.06	-0.04	0.54	0.05	0.25	-0.40	0.15	-0.59	-0.28	1.00			
Porosity	0.25	0.30	0.40	0.15	0.35	0.55	0.60	0.45	0.35	0.15	-0.45	0.35	-0.08	0.12	0.50	-0.30	0.50	1.00		
OG	0.02	-0.03	-0.26	0.20	0.30	0.07	0.25	0.11	0.44	0.18	-0.09	0.08	0.45	0.10	0.55	0.06	-0.46	0.10	1.00	
THC	0.25	.0.04	0.33	0.02	0.16	0.14	0.22	0.07	0.04	0.53	0.04	0.42	0.30	0.23	0.62	0.16	0.72	0.25	0.62	1.00
EC	0.40	0.15	-0.15	0.58	0.14	-0.29	0.07	-0.03	0.42	0.41	0.27	0.15	0.50	0.35	0.22	-0.15	0.03	0.40	0.25	0.10
Pp	0.65	0.75	0.55	0.50	0.20	-0.45	-0.25	0.15	0.47	0.45	0.40	0.55	-0.28	0.25	0.28	0.35	0.40	0.65	0.30	0.65
Ll	0.30	0.40	0.46	0.38	0.10	-0.48	-0.40	0.32	0.55	0.23	0.70	0.20	-0.15	0.30	0.55	0.55	0.20	0.20	0.18	0.35
Cr	0.45	0.55	0.35	0.25	0.38	-0.30	-0.32	0.25	0.65	0.30	0.55	0.45	-0.35	0.10	0.40	0.47	0.15	0.35	0.08	0.25
	EC	**Pp**	**Ll**	**Cr**																
EC	1.00																			
Pp	0.55	1.00																		
Ll	0.28	-0.07	1.00																	
Cr	0.40	-0.15	-0.10	1.00																

Note: *Pp = Peltophorum pterocarpium, Ll = Leucaena leucocephala, Cr = Crotolaria retusa*

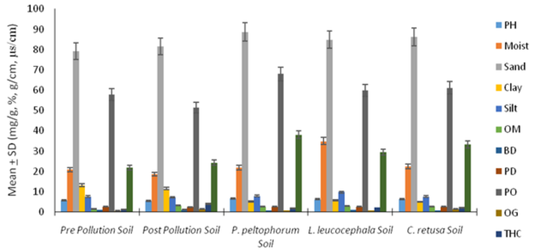

Fig. 3: Physicochemical restoration level of the remediated eastern Niger Delta polluted soil

Clay component decreased significantly ranging from 13.20±0.84% at pre-pollution to average percentage of 11.53±0.74% across pollution levels. The phytoremediated soils significantly (*P<0.05*) had decreased variation with average highest percentage (5.80±0.95%) in *Leucaena* and least percentage (5.00±0.94%) in *Crotolaria* soils recorded. The silt component had non-significant decrease ranging from 7.60±2.97% to average percentage of 7.20±2.01% across pollution level. The phytoremediated soils had variation in silt content with significant difference (*P<0.05*) at 1.5% level in *Leucaena* soil with highest percentage (9.80±1.06%) and least percentage (7.73±0.52%) in *Crotolaria* soil.

Table 3: Baseline analyses and data of the spent oil pollutant.

S/N	Parameters	Mean value
1	Chloride (Cl^-)	13.60mg/g
2	Nitrate (NO_3^-)	0.05mg/g
3	Sulphate (SO_4^{-2})	0.04mg/g
4	Phosphate (PO_4^{-3})	0.70mg/g
5	Magnesium (Mg^{2+})	0.33mg/g
6	Calcium (Ca^{2+})	0.28mg/g
7	Sodium (Na^+)	0.89mg/g
8	Potassium (K^+)	0.31mg/g
9	pH	4.03
10	% Organic Carbon	19.80%
11	% Organic Matter	35.00%
12	Oil and Grease	9.76mg/g
13	Total Hydrocarbon (THC)	0.41mg/g
14	Electrical conductivity (EC)	0.90µS/cm
15	Base water sediment (BWS)	0.56%

Percentage organic matter content of the soil increased significantly (*P<0.05*) ranging from 1.46±0.21% at 0% level pre-pollution to average percentage (3.15±0.43%) across pollution levels. The phytoremediated soil had significant variation in a decreasing order of organic matter content with *Leucaena* soil on the average recording the highest (2.95±0.66%) and *Peltophorum* soil with least content (2.65±0.48%) of organic matter. The bulk density (1.10±0.01g/cm) at pre-pollution increased to averagely 1.21±0.09g/cm across pollution level. The phytoremediated soils with varying decrease in bulk density, significantly reduced at 0.8% and 1.5% levels of *Peltophorum* soil. On the average *Leucaena* soil with highest bulk density (2.95±0.66g/cm) and *Peltophorum* soil with least bulk density (2.65±0.48g/cm) were recorded. The particle density of the soil decreased significantly ranging from 2.61±0.03g/cm at 0% level pre-pollution to averagely 2.49±0.05g/cm across pollution levels. The phytoremediated soil with variation had significant increase in particle density with the highest particle density (2.61±0.02g/cm) for *Peltophorum* soil and least particle density (2.56±0.01g/cm) in *Leucaena* soil being recorded. The porosity decrease at pollution levels ranges from 57.85% at 0% pre-pollution level to 51.34% across pollution levels. The phytoremediated soils with significant variation in porosity increase at 0.8% and 1.5% level of *Peltophorum* soils averagely had highest porosity (68%) and least porosity (59.84%) in *Leucaena* soil recorded.

The oil and grease content (mg/g) increased with significant difference (*P>0.05*) with increase in soil pollution levels ranging from 0.64±0.09mg/g at 0% pre-pollution level to averagely 1.52±0.32mg/g across pollution levels. The phytoremediated soil recorded variation in decreasing order of oil and grease, with *Crotolaria* soil on the average highest (1.52±0.17mg/g) in oil and grease and least (0.98±0.06mg/g) in *Leucaena* soil recorded. The pre-polluted soil THC (mg/g) increased with significant difference (*P<0.05*) ranging from 1.25±0.16mg/g at 0% level to averagely 3.97±0.26mg/g across the pollution level. The phytoremediated soil had variation with significant decrease in THC with an average least THC (1.80±0.90mg/g) content in *Peltophorum* and highest THC (2.26±0.90mg/g) in *Leucaena* soils recorded. The electrical conductivity had increase ranging from 21.90±0.93uS/cm at 0% pre-pollution level to 24.30±2.26uS/cm across pollution levels. The phytoremediated soil recorded variation with significant increase in electrical conductivity, at 1.5% level of *Peltophorum* soil and 0.8% and 1.5% levels at *Crotolaria* soils. On the average highest electrical conductivity (38.07±9.61 uS/cm) in *Peltophorum* and least electrical conductivity (29.42±8.20uS/cm) in *Leucaena* soils were recorded.

4. Discussion

The occurrence of hydrocarbon induced changes in spent oil polluted soil are imminent in areas with diverse anthropogenic activities as recorded in several studies (Milala *et al*., 2015; Vwioko *et al*., 2018; Nwite and Alu, 2015; Edwin-Wosu and Nkang, 2019a). The physicochemical properties of soil in parts of Eastern Niger Delta are persistently exposed to induced changes due to anthropogenic automobile sources of untreated and unregulated waste oil discharge to the environmental supporting system. This corroborates similar assertion of waste oil soil pollution (Uquetan *et al.,* 2017; Edwin-Wosu and Nkang 2019a; Beckley and Mathew, 2020). Variation and changes in the status of polluted soil due to diverse waste oil hydrocarbon inducement has recorded variant levels of physicochemical properties (Table 1), besides the correlating pattern of the various properties as exemplified in Table 2.

The non-significant ($P<0.05$) decrease across polluted condition when compared to increase in the phytoremediated soil condition of chloride (Cl^-) and sulphate (SO_4^{-2}) content implies the sensitivity of these anions despite their maximum baseline content in the waste oil (Table 3). This corroborate the assertion that sensitivity might be due to the fact that hydrocarbon has affected the soil of the area (Edwin-Wosu and Nkang, 2019b). This must have as well decreased the Cl^- and SO_4^{-2} in waste oil polluted soil as exemplified in a positive correlation (r = 0.25; r = 0.33; $P<0.05$) between THC and Cl^- and SO_4^{-2} respectively, indicating dependent variable decrease and independent variable increase though with a non-significant variation. Decreased Cl^- and SO_4^{-2} content in soil polluted with crude hydrocarbon has similarly been reported (Edwin-Wosu and Nkang, 2020). However study has also shown elevated Cl^- content of soil under hydrocarbon pollution (Seifi *et al*., 2010).

In like manner such ionic elevation due to hydrocarbon pollution has been recorded in NO_3^- and PO_4^{-3} content of the waste oil polluted soil as exemplified in a weak positive correlation (r = 0.04; r = 0.02; $P<0.05$) with THC respectively indicating dependent variable increase with independent variable increase. This corroborate the study on hydrocarbon-induced changes including nitrate increase in a crude oil polluted tropical Niger Delta soils (Nwite and Alu, 2015; Edwin-Wosu and Nkang, 2020). It has been revealed that soil salinity can be determined by the concentration of dissolved salt. This is in tandem with the fact that low level salinity in soil of most humid regions are link to ionic salt concentration and when elevated due to pollution has consequently increased salinity (Abdulfattah *et al*., 2016, Edwin-Wosu and Nkang, 2020). This can also be reflected in the present research in which salinity increased in relation to NO_3^- and PO_4^{-3} increase beside Cl^- and SO_4^{-2} decrease across pollution as exemplified in a positive correlation (r = 0.16; $P<0.05$) between salinity and THC as well as positive correlation (r = 0.28; r = 0.09; r = 0.18; $P<0.05$) between salinity and Cl^-, SO_4^{-2} and PO_4^{-3} respectively beside a weak negative correlation (r = - 0.04; $P<0.05$) with NO_3^-. The phytoremediated soils had variation in the trend of anionic salinity content among the macrophytes with non-significant difference, despite *Peltophorum* soil being significant in NO_3^- content at 1.5% level. The trend observed among the phytoremediated soil condition can imply changes in the hydrocarbon soil condition as suggested in Edwin-Wosu and Nkang (2019b). This can be exemplified in negative correlation (r = - 0.65; r = - 0.35; r = - 0.25; $P<0.05$) between THC and *Pp, Ll* and *Cr* respectively (Table 2) with a corresponding weak negative correlation (r = -0.30; r = -0.18; r = - 0.08) with OG. Generally the slight increase in SO_4^{-2} and PO_4^{-3} across species remediated soils and with 1.5% levels of *Peltophorum* soil for Cl^- and NO_3^- was observed in *Peltophorum* treated soils with higher content among the macrophytes and with a corresponding positive correlation (r = 0.65; r = 0.45; r = 0.30; $P<0.05$) in the order *Pp> Cr>Ll* for Cl^-; positive correlation (r = 0.75; r = 0.55; r = 0.40; $P<0.05$) in the order *Pp>Cr>Ll* for NO_3^-; with positive correlation (r = 0.55; r = 0.46; r = 0.35; P<0.05) in the order *Pp>Ll>Cr* for SO_4^{-2} , while a positive correlation (r = 0.05; r = 0.38; r = 0.25; P<0.05) order of *Pp>Ll>Cr* was recorded for PO_4^{-3} content. The dynamics of the anions either in a decreasing or increasing order among the phytoremediated soils have also been discussed in Odunze *et al*. (2015), Anna *et al*. (2020); Edwin-Wosu and Nkang (2019b). The salinity of the phytoremediated soil has recorded increased variation at increasing levels of remediated soils with *C. retusa* treated soil recording higher salinity across the species soil in the order *Cr>Pp>Ll* with corresponding positive correlation (r = 0.38; r = 0.20; r = 0.10; $P<0.05$) respectively.

The decrease in cationic content across the waste polluted condition as exemplified in positive correlation (r = 0.14; r = 0.22; r = 0.07; r = 0.04, $P<0.05$) between THC and Mg^{2+}, Ca^{2+}, Na^+ and K^+ respectively with a corresponding positive correlation (r = 0.07; r = 0.25; r = 0.11; r = 0.44) between OG and Mg^{2+}, Ca^{2+}, Na^+ and K^+ (Table 2) indicating dependent variable decrease and independent variable increase, agrees with the earlier assertion on the effect of spent oil on soil properties (Uquetan *et al*., 2017; Bassey and Ebele, 2016; Milala *et al*., 2015; Nwite and Alu, 2015). The phytoremediated soil though non-significantly varying with decreasing trend of Mg^{2+} and Ca^{2+} across species treated soil as compared to the polluted condition, their was increasing trend in K^+ content of the remediated soils (Table1) with significant difference ($P<0.05$) at 0.8% and 1.5% levels of *Peltophorum* and *Leucaena* soils and 1.5% level of *Crotolaria* soil besides the non-significant increase in Na^+ across the species treated soils. Generally, the non-significant decrease in Mg^{2+} and Ca^{2+} among the macrophyte was observed in *Crotolaria* soil with higher content in the order *Cr>Pp>Ll* as exemplified in a strong negative correlation (r = -0.30; r = -0.45; r = -0.48) between Mg^{2+} and *Cr, Pp* and *Ll* respectively. Similarly was a higher content of the decreased Ca^{2+} in *Peltophorum* treated soil in the order *Pp>Cr>Ll* represented in a strong negative correlation (r = -

0.25; r = -0.32; r = -0.40) between Ca^{2+} and *Pp, Cr* and *Ll* respectively. The increased Na^+ and K^+ content of species treated soils were higher in *Leucaena* soil (*Ll>Cr>Pp*) and *Crotolaria* soil (*Cr>Ll>Pp*) respectively and exemplified in positive correlation (r = 0.32; r = 0.25; r = 0.15) between Na^+ and *Ll, Cr* and *Pp* respectively as well as positive correlation (r = 0.56; r = 0.55; r = 0.47) between K^+ and *Cr*, *Ll* and *Pp* respectively.

The variation and changes in the physicochemical properties of the polluted and phytoremediated soils as presented in Table 1 showed non-significant decrease in pH across polluted soils; exemplified in the strong positive correlation (r = 0.53; $P<0.05$) with THC and a corresponding positive correlation (r = 0.18; $P<0.05$) with OG, indicating dependent variable decrease and independent variable increase. This corroborates similar study on pH reduction due to hydrocarbon pollution (Milala *et al*., 2015; Edwin-Wosu and Nkang, 2020) beside an increase earlier reported by Nwite and Alu (2015). The decrease in soil pH can be attributed to organic matter as well hydrocarbon degradation in tandem with a weak positive correlation (r = 0.19; $P< 0.05$) between pH and OM and a corresponding positive correlation (r = 0.53; $P< 0.05$) between pH and THC. This may have resulted in the release of acidic metabolite and final product that possibly lowered the pH. This corroborate the assertion by Bassey and Ebele (2016) who has revealed a decrease in soil pH in parts of Niger Delta under pollution on types of soil properties. Similarly low pH can be attributed to loss of exchangeable bases as earlier exemplified in the positive correlation between THC and cations (Mg^{2+} Ca^{2+}, Na^{2+}, K^+) and consequently a positive correlation (r = 0.41; r = 0.26; r = 0.02; r = 0.18; $P<0.05$) between pH and Mg^{2+} Ca^{2+}, Na^+, and K^+ respectively, due to displacement reactions in the soil. Colloidal complex following the watering regime as exemplified in positive correlation (r = 0.34, r = 0.38; r = 0.12; r = 0.05) between moisture and Mg^{2+} , Ca^{2+}, Na^+, and K^+ could lead to eluviations and leaching loses respectively. This corroborate similar findings of Ngobri *et al*. (2007) and Ezeaku and Egbemba (2014) on organic acid metabolism and release of acidic intermediates and product as well as displacement reaction due to excessive rainfall. There has being significant ($P<0.05$) variation in restoration of the decreased pH across the species treated soil at various levels. Generally *Peltophorum* soil had greater pH among the species in the order *Pp>Cr >Ll,* with corresponding positive correlation (r = 0.45; r = 0.03; r = 0.23; $P<0.05$) between pH and *Pp, Cr* and *Ll* respectively. Study has revealed pH toward alkalinity as well as pH values of 5.20 and 6.30 for soil in the Niger Delta area under hydrocarbon inducement (Bassey and Ebele, 2016; Victoria *et al*., 2016; Edwin-Wosu and Nkang, 2020).

The decrease in soil moisture content though non-significantly different ($P<0.05$) was represented in weak positive correlation (r = 0.04; $P<0.05$) with THC across pollution. The impacts of spent oil as well as related hydrocarbon compound have been reported (Nwite and Alu, 2015; Edwin-Wosu and Nkang, 2020). The phytoremediated soils recorded varying increase in moisture content restoration across the species treated soils, with *Leucaena* soil showing significant difference ($P<0.05$) in the order *Ll>Cr>Pp*. This was exemplified in strong positive correlation (r = 0.70; r = 0.55; r = 0.40, $P<0.05$) between moisture and *Ll, Cr* and *Pp* respectively. The significant percentage moisture content in *Leucaena* soil can be related to its high clay content as exemplified in a positive moisture correlation (r = 0.35; r = 0.23; r = 0.15) with clay despite significant reduction in the order *Ll>Pp>Cr* across remediated soil when compared to polluted soil. Study has revealed that high moisture content can be associated to high clay content which has ability to retain water (Ezeaku and Egbemba, 2014). This can be exemplified in a positive correlation (r = 0.65; $P<0.05$) between clay and moisture in the present study (Table 2).

The non-significant variation from pre polluted to polluted condition as exemplified in a positive correlation (r = 0.42) between sand and THC has however recorded increased sandy component across polluted levels, reflecting a dependent variable increase across independent variable increase. The increase in the sand particle of sandy loam soil texture of the study area can corroborate the assertion by Ezeaku and Egbemba (2014) that greater sandy particle was dependent on the nature of parent materials and water regime that could favour washing away and leaching of silt and clay sized fraction. This can be exemplified in a positive correlation (r = 0.45; r = 0.30; r = 0.65; $P<0.05$) between moisture and sand, silt and clay respectively in the present study. The reduction in the silt and clay particle as exemplified in positive correlation (r = 0.23; r = 0.30) respectively with THC can also corroborate earlier assertion of enhanced distortion of structural aggregate by solvent and hydrophobic component of waste oil (Edwin-Wosu and Nkang, 2017a, 2019a). The phytoremediated condition had significant variation with increased sandy and silty and reduced clay components of the treated soils.

The increase in particle size of sand with *P. pterocarpum* soil recording greater percentage in the order *Pp>Cr>Ll* can be represented in a positive correlation (r = 0.55; r = 0.45; r = 0.20) between sand and *Pp, Cr, Ll* respectively, while the silty particle restoration among species (*Ll>Pp>Cr*) was higher in *Leucaena* soil with a corresponding positive correlation (r = 0.30; r = 0.25; r = 0.10) respectively. This was in tandem with the assertion that plant species through dense and highly ramified fibrous root system can enhance phytoremediation hence they can penetrate impermeable layers such as hydrocarbon pollution sites ((Edwin-Wosu and Nkang, 2017b). Similar study has revealed leguminous plant improvement of aggregate sizes of degraded soils due to improved changes in physicochemical condition (April *et al*., 2020; Edwin-Wosu and Nkang, 2019a; Udom and Nuga, 2015).

A significant reduction in clay content across species treated soil when compared with the polluted condition was recorded. Though *Leucaena* soil (*Ll>Pp>Cr*) been higher in clay content there was no restoration of clay particle as exemplified in the weak negative correlation (r = -0.15; r = -0.25; r = -0.35) with the respective species. Soil texture does affect phytoremediation process due to its influence on the bioavailability of contaminant as been suggested that clay is capable of binding molecules more than silt and sand resulting in low bioavailability of contaminant (Izinyon and Seghosime, 2013).

The significant increase in organic matter (OM) content across the polluted condition is in tandem with the positive correlation (r = 0.62) with THC, indicating dependent variable increase and independent variable increase. Similar increase in OM have been reported due to exogenous carbon source in the waste oil added to the carbon present in the soil (Milala *et al*., 2015). Organic matter has the potential to bind with hydrocarbon molecules (Edwin-Wosu and Nkang 2017a, 2019a). The impact of phytoremediation has revealed significant reduction in the soil organic matter across species treated soil in the order *Pp<Cr<Ll* and supported by the positive correlation (r = 0.28; r = 0.40; r = 0.55) between organic matter and respective species (Table 2). Study has also recorded reduction in organic matter due to its use as nutrient for plant growth resulting to lesser accumulation in species treated soils than non polluted species soil (Edwin-Wosu and Nkang 2017a). This also supports organic matter mineralization in polluted and non-polluted soil under vegetated condition (Fabio *et al*., 2017; Albert, 2015; Edwin-Wosu, 2013). However study has recorded improved organic matter by the combination of poultry manure and / or leguminous plant (Preissel *et al*., 2015; King and Blesh, 2018).

The increase in BD across the polluted condition with significant difference (*P<0.05*) indicating dependent variable increase and independent variable increase and non-significant porosity decrease indicating dependent variable decrease and independent variable increase can be justified in a positive correlation (r = 0.16) with THC and (r = 0.06) with OG for BD and (r = 0.25) with THC and (r = 0.10) with OG for porosity. Compaction among soil aggregate by increased hydrocarbon pollution, high negative charges in clay and colloidal nature of organic matter have been implicated for high adsorption capacity and ability of binding hydrocarbon molecules resulting to increased BD and reduced porosity. (Uquetan *et al*., 2017; Edwin-Wosu and Nkang 2017a, 2020). This can be represented in a positive correlation (r = 0.30; r = 0.62; *P<0.05*) of THC with clay and OM respectively and a corresponding positive correlation (r = 0.45; r = 0.55; *P<0.05*) of OG with clay and OM in this present study. Similar study has indicated that increased BD and decreased porosity across polluted levels is a function of waste oil filling the micro and macro pore spaces by hydrophobic portion, base water sediment and viscosity leading to compaction and adhesion among soil aggregate (Edwin-Wosu and Nkang 2019a). Increased bulk density suggests compaction and decreased porosity due to prevalent water regime and oil deposit that clog soil layer (Ezeaku and Egbemba, 2014). This can be supported by a positive correlation (r = 0.19) between BD and Moisture and negative correlation (r = -0.45) between porosity and moisture as well as negative correlation (r = -0.30) between porosity and BD. The phytoremediated soils have significant variation with decrease in BD and increase in porosity with *Peltophorum* soil having the least BD in the order (*Pp< Cr<Ll*) and vice versa in the order (*Pp>Cr>Ll*) with the highest porosity. This can be exemplified in a positive correlation (r = 0.35; r = 0.47; r = 0.55) of BD with the respective species indicating dependent variable decrease and independent variable increase and a corresponding positive correlation (r = 0.65; r = 0.35; r = 0.20) between porosity and respective species (Table 2) indicating dependent variable increase and independent variable increase. A higher degradation and removal of hydrocarbon in vegetated soil than non vegetated soil have been reported (Udom and Nuga, 2015); as well as enhanced root formation resulting to increase in pore spaces with grater PD (Edwin-Wosu and Nkang, 2017a). The increased BD in *Leucaena* soil could be as a result of the increased clay content that has the potential to bind water molecules as exemplified in a positive correlation (r = 0.65) with moisture as well as positive correlation (r = 0.30) with THC.

The soil PD across polluted condition had significant reduction as exemplified in a positive correlation (r = 0.30; r = 0.23; *P<0.05*) with clay and silt respectively and a strong positive correlation (r = 0.72; *P<0.05*) between PD and THC, indicating dependent variable decrease and independent variable increase. Study has revealed the distribution of soil aggregated component by the solvent and hydrophobic component of waste oil (Jersy *et al.*, 2015, Edwin-Wosu and Nkang 2017a, 2019a). The restoration of PD in terms of particle size of sand clay and silt across the species treated soils when compared to the polluted condition has revealed improvement. There was significant variation among the species treated soil with the *Peltophorum* soil recording a higher PD in the order *Pp>Ll>Cr*. This can be exemplified in a positive correlation (r = 0.25; r = 0.15) of PD with sand and silt respectively despite the negative correlation ((r = -0.40) with clay particles. Leguminous plant does improve aggregate sizes of degraded soil due to improved changes in physicochemical condition (Nouri *et al*., 2019; King and Blesh, 2018; Lupwayi *et al*., 2017, May and Entz, 2016). This can be justified in the present study in a positive correlation (r = 0.40; r = 0.20; r = 0.15) of PD with *Pp*, *Ll* and *Cr* respectively Indicating dependent variable increase and independent variable increase

The increase in the THC and OG content across polluted condition was significantly higher than the pre-polluted soil. This observation is in tandem with Uquetan *et al*. (2017) Colloidal nature of organic matter and clay has been implicated for their potential in binding hydrocarbon molecules (Edwin-Wosu and Nkang 2019a, 2020). This can also imply a positive correlation (r = 0.62; r = 0.30) of THC with OM and clay as well as a corresponding positive correlation (r = 0.55; r = 0.45) of OG with OM and clay, indicating dependent variable increase and independent variable increase. The phytorememdiated soil had recorded reduction with significant variation in the decreased THC and non-significant variation in the decreased OG, indicating dependent variable decrease and independent variable increase. This has revealed that phytoremediation can enhance polluted soil attenuation in which *Peltophorum* soil had greater performance in hydrocarbon reduction in the order *Pp< Cr<Ll* and supported by a positive correlation (r = 0.65; r = 0.25; r = 0.35) of THC with *Pp*, *Cr*, and *Ll* respectively. Similarly the reduction in OG was observed with greater performance in *Leucaena* soil in the order *Ll<Pp<Cr* as exemplified in a corresponding positive correlation (r = 0.18; r = 0.30; r = 0.08) of OG with *Ll*, *Pp*, and *Cr* respectively. A similar degradation and removal of hydrocarbon compounds in vegetated soil than non vegetated bulk soil has been reported (Udom and Nuga 2015, Edwin-Wosu and Nkang 2017a, 2019a). The performance of the species can also be attributed to its detoxifying enzymes potency as earlier observed in Edwin-Wosu and Nkang (2016). The non-significant increase in EC across the polluted condition was exemplified in a weak positive correlation (r = 0.10; $P<0.05$) with THC. Increased changes of EC in hydrocarbon polluted soils, has also been recorded by Edwin-Wosu and Nkang (2020), and Milala *et al*. (2015). The phytoremediated soil has recorded increased variation among species treated soil with significant difference in *Peltophorum* and *Crotolaria* soils and non-significant difference in *Leucaena* soil in the order *Pp>Cr>Ll*. This can be justified in a positive correlation (r = 0.55; r = 0.40; r = 0.28) of EC with the respective species. Beside the restored increase in EC research has also revealed a decreased EC in remediated hydrocarbon crude oil soil (Edwin-Wosu and Nkang 2020).

Conclusion

Based on the result of the study the following conclusions are made: Waste oil has deleterious effect with induced physicochemical changes of the soil properties. The induced changes across pollution levels caused both significant and non-significant variation in the ionic and other physicochemical properties of the soil. An ionic content had decrease in Cl^- and SO_4^{-2} and increase in NO_3^- and PO_4^{-3} as well as salinity status. Decrease in cationic content was recorded across Mg^{2+}, Ca^{2+}, Na^+ and K^+ ions respectively. Other induced changes in physicochemical properties have revealed decrease in pH, moisture content, clay and silt, particle density, and porosity while increase was revealed among sandy particle, OM, BD, OG, THC and EC. The study has also identified some degree of potency among the phytorestoration macrophytes in both significant and non-significant levels of variation. *Peltophorum* had improvement in restoration by the increase in anionic content, pH, sand, PD, porosity, EC and Ca^{2+} and decrease in THC, OG, OM, and BD of the soil among the test plants. However, the species are promising alternatives for remediation of waste oil polluted soil. They are inexpensive, efficient and environmentally compatible and may be viable choice for oil polluted soil remediation in parts of eastern Niger Delta.

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Conflict of interest

The author(s) have not declared any conflict of interest.

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