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Effects of crude oil on some soil types of Kuwait

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Abstract

This study investigated the impact of crude oil pollution on different types of soils in Kuwait. For this purpose the oil trench, which consisted of diversity of soils was studied. Several boreholes were made to determine the extent of oil contamination in the soil matrix and its effects on soil chemical properties. The highest depth of oil pollution was measured in the Typic Torripsamments and Typic Petrogypsids and the highest width was at the Typic Aquisalids. This variation is due to physical and chemical characteristics of soil and the depth of the hardpan. Soil samples were collected from the different soil type layers in the oil trenches and also from reference (control) sites to compare the total petroleum hydrocarbon (TPH), total extractable matters (TEM) levels, soil pH, $CaCO_3$ and electrical conductivity (ECe). The Typic Calcigypsids soils showed the highest concentration of TPH and TEM, which were significantly higher in the oil trench by 99% than control. The soil pH and $CaCo_3$ were reduced in presence of oil and the soil ECe was significantly altered at the 95% level of confidence. The study showed that soil types behaved differently with crude oil pollution.

Keywords: Contamination; hardpan; hydrocarbons; oil pollution; oil trench; remediation.

1. Introduction

The oil industry has a history of pollution from oil spills and oil well flaring that extensively contaminated soils, sediments and swampland by petroleum hydrocarbons affecting groundwater, vegetation, aquatic life and public health (Oyem & Oyem 2013). Oil spills can contaminate soils and alter physio-chemical properties to an extent that these soils can no longer be used for agricultural production (Emerson, 1983; Abosede, 2013). Barua *et al.* (2011) concluded that the effect of crude oil spill on soil caused decrease in soil moisturere tention (hydrophobic), porosity, water holding capacity, soil pH and extractable phosphorous, whereas it increased total nitrogen, organic carbon and exchangeable potassium. Marinescu *et al.* (2010) confirmed that oil spills on soil caused variations in chemical properties and at high pollution levels, inhibited the growth of crops. Khamehchiyan *et al.* (2007) also indicated that oil contamination on soil caused decrease in soil strength, permeability, maximum dry density, optimum water content and Atterberg limits.

The depth and lateral oil movement in the soil matrix is affected by sediment properties and their variability. This results in a complex distribution of oil in the subsurface (Bennett *et al.,* 1993; Delin *et al.,* 1998). A recent study showed that oil in the soil matrix of the coastal sabkha areas in Kuwait penetrated into the gatch layer (combined gypsum-limestone material) (Roy *et al.,* 2015). However, to our knowledge there are no studies that addressed the effect of crude oil pollution in relation to soil types. For this purpose data about the oil trenches of Kuwait were used in this study because the oil trenches are transecting different soil map units consisting of diversity of soils.

In 1990/1991, the Iraqi troops dug trenches (about 111 segments) and filled them with crude oil as part of their strategic defense belts (Omar *et al.,* 1999). These oil trenches are extended along the southern border zone of Kuwait that borders with Saudi Arabia (about 120 km). The chronology of these trenches consisted of two phases: (1) construction, and (2) rehabilitation. The first phase (1990-1991) involved the establishment of a complex oil transit system using oil pipelines for several hundreds of kilometers in the southern border zone and north eastern coastal zone of Kuwait, followed by filling them with crude oil and installation of detonation systems. During the second phase (1993-1994), the light crude oil from 81% of the oil trenches in the southern border zone was drained out and the trenches were backfilled with excavated or surface soil materials. It was reported that the crude oil spills impacted groundwater (Al-Sarawi *et al.,* 1998; Al-Sulaimi *et al.,* 1993; Hadi, 2002; Hamed, 2004; Khordagui, 1991; Literathy *et al.,* 2003; Muckhopadhyay *et al.,* 2008). Characterisation of the oil contaminated soils in Kuwait was reported in Al-Duwaisan & Al-Naseem (2011).

In this study efforts were made to assess the effects of crude oil on different types of soils in Kuwait. It specifically attempts to test the following hypothesis:

1. The level of oil pollution (depth and width) in the soil profiles do not vary among soil types
2. Total petroleum hydrocarbon (TPH) and total extractable matter (TEM) resulting from oil pollution in the different soil types are not different among soil types and the same applies for the soil pH, ECe and $CaCO_3$.

2. Materials and methods

2.1. Location and climate of the study area

The State of Kuwait is located in the north-eastern part of the Arabian peninsula and share border to the east by the Arabian Gulf, in the north and west by Iraq and in the south by Saudi Arabia. The total area of Kuwait is about 17,818 km^2, extending between latitude 28^o 30' N and 30^o 05' N and between longitude 46^o 33' E and 48^o 30' E. The land surface of Kuwait is generally flat with a maximum elevation of 284 m above sea level. It slopes gradually north-eastward with an average gradient of 2 m/km. The soils of Kuwait are classified into eight soil great groups (map units) of two soil orders, that is Aridisols (Haplocalcids 8%, Petrocalcids 11%, Haplogypsids<1%, Calcigypsids 6%, Petrogypsids 33%, Aquisalids 7%) and Entisols (Torriorthents 1% and Torripsamments 27%). Other map units include miscellaneous (6%) (Figure 1) (KISR, 1999; Omar & Shahid, 2013, Omar *et al.,* 2001).

The climate is dry and hot in the summer and mild to relatively cold in the winter. The temperature varies between 30 and 51^{o}C during summer, while in winter the average is around 6^{o}C. The rainfall in Kuwait is low and erratic, with an average of 113 mm/year. The prevailing winds in Kuwait are from the north-westerly quadrant and to a lesser extent from the southeast. Winds from other directions are less frequent and of shorter duration. The average wind speed is 4m/second.

Based on two field surveys carried out in 1999 (Omar *et al.,* 1999; CIC, 2003), crosscuts traversing the oil trenches were excavated for soil sampling and to measure the depth and width of the oil contaminated soil. Two sets of data were used in this study. The first set included sites numbered B1-B14 and the second set was numbered 1-20. The first dataset was used mainly for studying the impact of oil pollution on chemical properties of soil and the second dataset was used for assessing the width and depth of oil pollution in the soil profiles. A total of 34 excavated sites were selected to represent various soil types and were distributed as shown in (Figure 1).

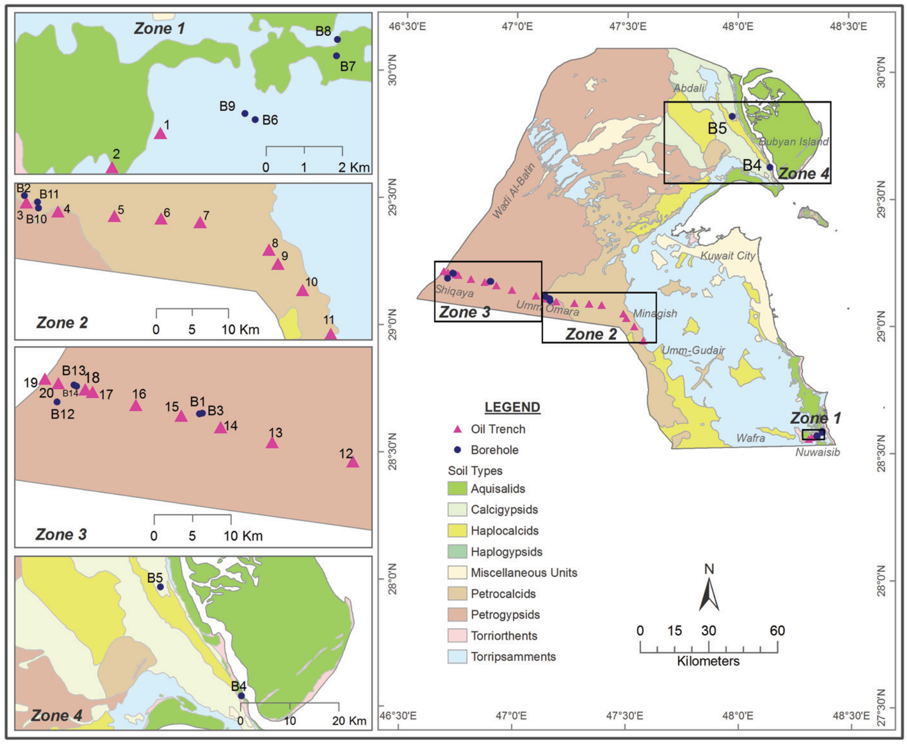

Fig. 1. Location of the study sites in four zones along the oil trenches overlaid on the soil map of Kuwait. Zone 1: Nuwaysib – Wafra (6 sites), Zone 2: Umm Gudair - Umm Omara (12 sites), Zone 3: Umm Omara – Wadi Al Batin (14 sites), and Zone 4: Al Subiyah-Umm Niqa (2 sites).

The following activities were conducted in each site:

- Determination of geographic coordinates of the selected sites using real-time differential corrected global position system (GPS) integrated with a personal digital assistant (PDA).
- Digging across the oil trenches to expose and measure the depth and width of the contaminated soil horizons.
- Collection of representative soil samples from the layers of contaminated and uncontaminated soils that exist in the trenches.
- Soil samples were also collected from uncontaminated land adjacent to the oil trenches for comparative study (control).

2.2. Soil sampling and analysis

Sixty soil samples from sites B1-B14 were collected for the determination of total petroleum hydrocarbon (TPH), total extractable matter (TEM), pH, Electrical conductivity (ECe) and $CaCO_3$. The samples were collected from different soil layers (ranging from 1-7 layers from the surface to the visibly "clean" layer underlying the deepest extent of the visibly contaminated zone, if possible, or from contaminated bedrock, if it was not possible to dig deeper to reach the underlying uncontaminated zone). Samples collected in the field were placed in screw-top 1000 ml plastic containers, labeled and transported to the laboratories for analysis. The excess samples, after analysis, have been stored in soil archives for future reference.

Sixty six soil samples from adjacent areas in the north east and south west of the oil trenches were collected at different depths using a soil auger and also analyzed for TPH, TEM, pH, ECe and $CaCO_3$. These sites were considered uncontaminated and thus were used for comparison.

Soil saturated paste was analyzed for pH (USDA 8C1b), and soil saturation extract for electrical conductivity (ECe) (USDA 8A3). Calcium carbonate ($CaCO_3$) content was determined by acid titration method (USDA 6E1g). Total extractable matter (TEM) was determined by the extraction followed by evaporation and gravimetric analysis (U.S. EPA 418.1 (IR)), which required the drying of the dichloromethane extract of the contaminated soil using the formula (1):

TEM= (weight of residue x volume of extract) / (volume evaporated x quantity of sample extracted) (1)

The total petroleum hydrocarbon (TPH) was determined by organic solvent extraction followed by ultraviolet fluorescent (UVF) and FTIR analysis methods (U.S. EPA 418.1 (IR). Full methodology, laboratory quality and control procedures were followed as specified by (ISO/IEC 17025:2005). Data were statistically analyzed using Microsoft Excel data sheets and Statgraphics Centurion (Version XVI) (Statistical graphics system by Statpoint Technologies Inc., Virginia, U.S.A.). Several statistical procedures were used such as: ANOVA, multiple range test, t-test and Fisher's least significant difference (LSD).

2.2.1. Site location and description of soil profiles

The global positioning system (GPS) coordinates of oil trenches collected during the field survey were downloaded into a geographic information system (GIS) and overlaid on the soil map of Kuwait to depict the location of the trenches (Figure 1). Soil properties and classification were as described in details in the Soil Survey of Kuwait (KISR, 1999; Grealish *et al.,* 2004, Grealish *et al.,* 2015; Omar & Shahid, 2013). Ten soil types were identified in this study as shown in Table 1. The main differentiating characteristics are the occurrence of a hardpan with a consistence of rigid or extremely hard, compared with loose to slightly hard for the sandy layers, and the widely varying concentration of calcium carbonate and gypsum (Grealish *et al.,* 2015).

Soil type Typic Petrogypsids had the highest rate of occurrence (23.5%) followed by soil type Calcic Petrocalcids (14%) in both zones 2 and 3. The soil profiles of four soil types are presented in Figures 2-5. The thickness and presence of the layers within the oil-contaminated zone varied considerably according to the soil types and its physical properties. For instance, the oil-contaminated zones of oil trenches in the Typic Aquisalids soils were mostly sandy to clayey oily soil. In these oil trenches, the contaminants leached through the shallow groundwater and changed its color from black to grey (Figure 2). Whereas, oil trenches in the Typic Torripsamments soils in zone 1 have a thick layer of sandy oily soil. This was due to the existence of deep, well sorted, highly porous layers that allowed the deep penetration of the crude oil (Figure 3). From profile observations, the oil trenches located in the Calcic Petrocalcids, Calcic Petrogypsids, Typic Calcigypsids and Petrocalcic Petrogypsids soils had very similar profiles for their oil-contaminated layers. Within these soil types, the oil-contaminated layers were recognized. In the upper part, the oil-contaminated zone was rimmed by rigid oil-sludge. This oil-sludge was formed as a result of drying out of the crude during the hot and dry summer times for several years. This layer was underlain by sandy and/or gravelly oily soil, calcrete- and/or gypcrete-rich oily soil and highly fractured oil-contaminated gatch (Figure 4).

Oil trenches in the main channel of zone 3 and in the oil fields of zone 2 present Typic Petrogypsids soils, which had only three oil-contaminated soil layers. The upper part was rimmed again by rigid oil-sludge underlain by sandy and/or gravelly oil-soil. Contaminated gatch was not observed in these oil trenches (Figure 5). Soil type Leptic Haplogypsids was found in zone 2; it consisted of deep to very deep sandy layers with gypsum. The Typic Haplocalcids soils as shown in zone 2 are very deep or deep sand or sandy loam; they are well drained or somewhat excessively drained containing carbonate masses.

Table 1. Location of the study areas categorized according to soil types with description of soils.

No	Soil Types	Site ID	Longitude (X) DD	Latitude (Y) DD	Soil Description*
1	Calcic Petrocalcids	5	48.3747	28.5878	Sand, loamy sand or sandy loam overlying a calcic hardpan within the upper 100 cm depth.
		6	48.3497	28.5703	
		7	47.1383	29.1075	
		8	47.1833	29.0967	
		9	47.2642	29.0911	
2	Calcic Petrogypsids	16	47.1356	29.1164	Sand or loamy sand overlying gypsic hardpan within the upper 100 cm depth.
		17	47.1558	29.1008	
		18	47.1542	29.1086	
		19	47.0922	29.1186	
3	Gypsic Aquisalids/ Typic Aquisalids	B8	48.3747	28.5878	Poorly drained sandy to clayey, with a high concentration of salts (salic horizon) often near the surface.
		2	48.3136	28.5575	
4	Leptic Haplogypsids	B7	48.3744	28.5839	Deep sand or loamy sand with a layer of gypsum starting within upper 18 cm depth.
		B4	47.9725	29.8283	
5	Petrocalcic Petrogypsids	3	48.3525	28.5689	Moderately deep sand overlaying hardpan (calcic and gypsic). Moderately well drained to well drained.
		4	48.3744	28.5839	
		20	46.9836	29.1406	
6	Typic Torripsamments	1	48.3269	28.5656	Deep, loose, sand or loamy sand soils. Well drained or somewhat excessively drained.
		B6	48.3744	28.5839	
		B9	48.3497	28.5703	
		B1	46.8858	29.1736	
7	Typic Calcigypsids	B10	47.1558	29.1008	Deep, sand or loamy sand with a layer of gypsum and $CaCO_3$.
		B5	48.1425	29.6281	
8	Typic Haplocalcids	B12	46.6947	29.2058	Deep, loamy sand or sandy loam with clayey, containing carbonate masses.
9	Typic Petrocalcids	10	47.3311	29.0883	Moderately deep sand overlying calcic hardpan.
		11	47.3867	29.0842	
		B2	47.1356	29.1164	
10	Typic Petrogypsids	B11	47.1542	29.1086	Moderately deep sand overlaying a gypsic hardpan.
		12	47.485	29.0503	
		13	47.4983	29.0325	
		14	47.5336	29	
		15	47.5739	28.945	
		B3	46.8897	29.1742	
		B13	46.7172	29.2058	
		B14	46.7208	29.2044	

*After KISR (1999) and Grealish *et al.*(2015).

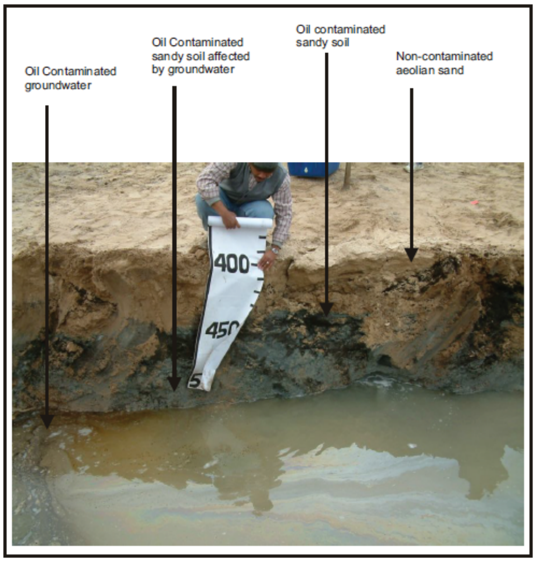

Fig. 2. Profile of an oil trench in a Typic Aquisalid soil type between Nuwaysib and Wafra oil fields (Zone 1).

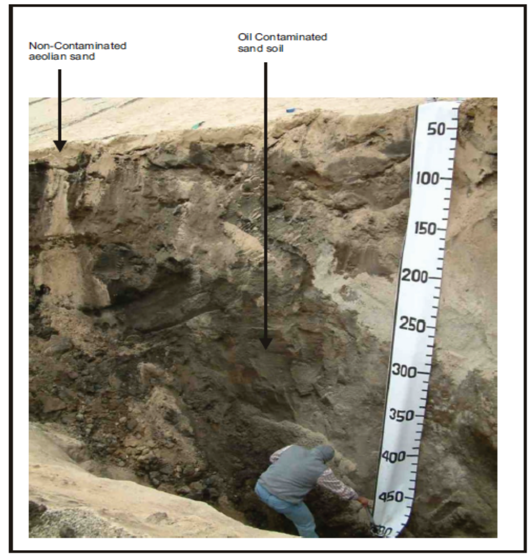

Fig. 3. Profile of an oil trench in a Torripsamment soil type between Nuwaysib and Wafra oil fields (Zone 1).

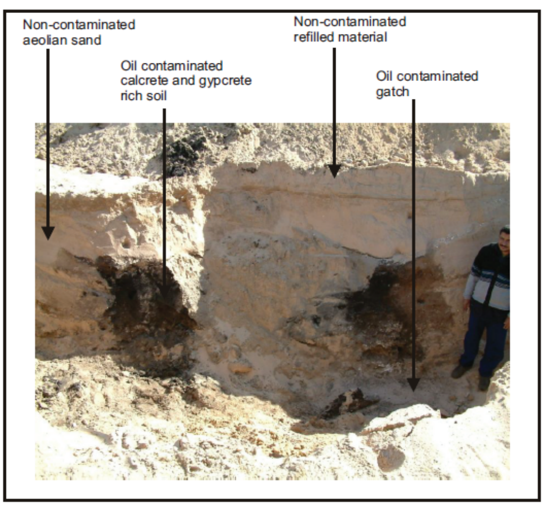

Fig. 4. Profile of an oil trench in a Calcic Petrocalcids soil type between Umm Omara and Minagish (Zone 2).

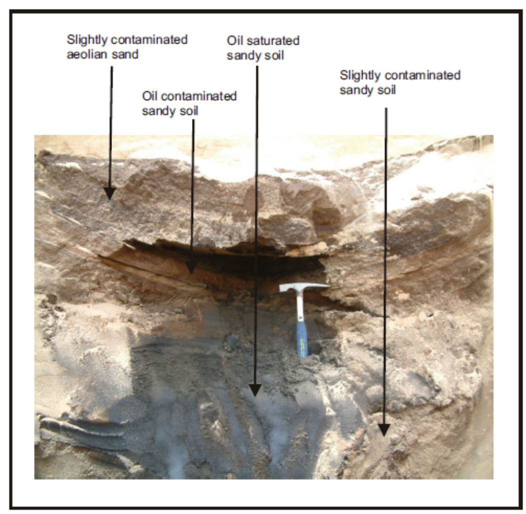

Fig. 5. Profile of an oil trench in a Typic Petrogypsids soil type in the Wadi Al Batin (Zone 3).

3. Results and discussion

3.1. Depth and width of pollution in soil

The depth and width measurements were determined from the 20 excavated sites. These sites showed a contaminated depth of 1.6m and 6.4 m in Typic Aquisalids (Site 2) and Typic Petrogypsids (Site 14) respectively. The width was recorded as 4.1m and 9.2 m in the soil type Petrocalcic Petrogypsids (Site 4) and Typic Aquisalids (Site 2) respectively. The average contaminated depth was 3.47 m and width 5.91 m (Table 2).

Table 2. Depth and width measurement at different soil types in 20 sites along the oil trenches of Kuwait.

Site ID	Soil Type	Depth (m)	Width (m)
1	Typic Torripsamments	5.0	6.5
2	Typic Aquisalids	1.6	9.2
3	Petrocalcic Petrogypsids	2.0	6.5
4	Petrocalcic Petrogypsids	3.7	4.1
5	Calcic Petrocalcids	3.1	4.5
6	Calcic Petrocalcids	3.4	4.9
7	Calcic Petrocalcids	3.2	5.7
8	Calcic Petrocalcids	2.6	6.2
9	Calcic Petrocalcids	2.5	8.0
10	Typic Petrocalcids	3.7	5.7
11	Typic Petrocalcids	3.3	5.8
12	Typic Petrogypsids	3.3	6.4
13	Typic Petrogypsids	4.8	4.9
14	Typic Petrogypsids	6.4	5.4
15	Typic Petrogypsids	3.7	7.7
16	Calcic Petrogypsids	3.7	4.7
17	Calcic Petrogypsids	3.2	5.0
18	Calcic Petrogypsids	3.0	5.2
19	Calcic Petrogypsids	4.2	5.4
20	Petrocalcic Petrogypsids	3.7	6.6
	Average	3.47	5.91
	0.95 Confidence Interval	0.48	0.56
	Lower 0.95 Confidence Limit	2.99	5.36
	Upper 0.95 Confidence Limit	3.95	6.47

In order to test the hypothesis that the level of oil pollution (depth and width) in the soil profiles do not vary among soil types, the depth and width mean values in the different contaminated soils were tested at 95% LSD Intervals (Table 3). The differences among soil types showed statistical differences in both variables. The soil types Typic Petrogypsids, Typic Torripsamments and Typic Petrocalcids were significantly different at 0.05 level of probability in the depth of oil contamination. The highest mean width was measured at the soil type Typic Aquisalids that was significantly different from other soil types. This variation is due to soil taxonomic, physical and chemical characteristic and the depth of the hardpan layer that affected the spread of oil pollution in the soil matrix. The Typic Torripsamments deep penetration of contamination is also shown in the soil profile in Figure 3. Figure 5 shows a profile of soil type Typic Petrogypsids with deep layer of oil saturated sandy soil. The physical effects of crude oil on soil was investigated by Abosede (2013), who concluded that crude oil can have effect on pore spaces within the affected soil. This may impair aeration and infiltration of water into the soil and inhibit plant growth. The soil type Torripsamments has deep sandy layers with high infiltration rate thus, allowing seepage of oil into deeper layers.

Table 3. Multiple range tests for depth and width means by soil type impacted by oil pollution.

Soil Type Code	Depth Mean*(N=20)	Width Mean*(N=20)
Typic Aquisalids	1.6d	9.20a
Typic Torripsamments	5.0ab	6.50ab
Calcic Petrocalcids	2.95cd	5.86b
Typic Petrogypsids	5.05a	6.55ab
Petrocalcic Petrogypsids	3.13bcd	5.73b
Typic Petrocalcids	3.78abc	5.70b
Calcic Petrogypsids	3.53bcd	5.08b

*abcd: denotes a statistically significant difference in the same column according to Fisher's least significant difference (LSD) procedure (95.0 percent LSD).

3.2. Chemical analysis

Soil chemical analysis were presented by averaging soil parameters for each borehole layer (Table 4) and by comparing the mean values of each parameter between polluted and reference soils (Table 5) as well as among the different soil types (Table 6).

The soil type Typic Calcigypsids (B10) showed the highest contamination level for both TEM and TPH scoring 6.43% and 6.04% respectively (Table 4). Soil salinity, pH, and $CaCO_3$ varied among sites with different soil types. The highest ECe level was measured in soil types: Leptic Haplogypsids (B7) and Gypsic Aqualalids (B8), where it measured 3963.33 $\mu S\ cm^{-1}$ and 3669.25 $\mu S\ cm^{-1}$ respectively. Similarly, the average value of $CaCO_3$ showed that soil classified as Leptic Haplogypsids had the hightest concentration of $CaCO_3$ measuring 24.43 % eq.

Table 4. Average values of soil parameters in the oil polluted sites (B1-B14) with different soil types.

Site ID	Soil type	No. of soil layers (Total:60)	Max depth (m)	ECe[a] ($\mu S\ cm^{-1}$)	pHs	$CaCO_3$ (% eq)	TEM[b] (%)	TPH[c] (%)
B1	Typic Torripsamments	7	1.90	1658.57	8.24	6.60	1.72	1.47
B2	Typic Petrocalcids	3	1.10	2686.67	8.06	7.50	3.38	3.01
B3	Typic Petrogypsids	4	1.30	2177.50	7.97	14.38	5.01	4.09
B4	Leptic Haplogypsids	3	1.80	2300.00	8.06	24.43	3.30	2.89
B5	Typic Calcigypsids	4	1.40	2210.00	7.86	1.18	1.08	0.85
B6	Typic Torripsamments	4	1.40	842.50	8.46	10.50	3.60	2.85
B7	Leptic Haplogypsids	3	1.60	3963.33	7.94	7.27	4.57	3.65
B8	Gypsic Aquisalids	4	0.80	3669.25	7.71	5.80	2.27	1.65
B9	Typic Torripsamments	4	1.80	1525.00	7.95	6.13	2.61	2.33
B10	Typic Calcigypsids	3	1.80	1213.33	7.47	3.08	6.43	6.04
B11	Typic Petrogypsids	4	2.40	1592.50	6.88	7.38	4.89	4.39
B12	Typic Haplocalcids	6	2.80	395.00	7.75	9.13	1.42	1.09
B13	Typic Petrogypsids	6	3.00	185.00	8.02	3.03	1.09	0.97
B14	Typic Petrogypsids	5	1.40	1497.50	7.91	9.53	0.63	0.55
	Mean		1.75	1851.15	7.88	8.01	3.00	2.56
	Standard Deviation		0.60	1054.16	0.36	5.52	1.69	1.54
	0.95 Confidence Interval		0.31	552.19	0.19	2.89	0.89	0.81

a: ECe = Electrical conductivity of soil saturation extract; b: TEM= Total Extractable Matter; c: TPH = Total Petroleum Hydrocarbon.

3.2.1. Comparison between polluted and reference sites

The result showed that the soil pH, TEM and TPH in polluted sites were significantly differentat p=0.05 compared with the non-polluted sites (Control) (Table 5). The soil pH was decreased significantly by 7.8%. In the arid and semi-arid regions, soils tend to be basic with higher concentrations of calcium, magnesium and sodium carbonates. Kuwait's soil pH is usually alkaline ranging from 7.4-8.4 (Grealish *et al*., 2015; Wang *et al*., 2013) indicated that crude oil contamination significantly increased the soil pH up to 8.0, and reduced available phosphorus concentrations in the wetlands of China. Also, Talukdar & Saikia (2010) indicated that the soil pH value was not significant between contaminated clayey soils and control. However, in this study the increase in hydrocarbons in the soil matrix caused significant decrease in the soil pH from control sites. The acidic nature of the crude oil reduced the soil pH, which is alkaline in nature and reduced salinity effect of the soil. These results are in agreement with Barua *et al.* (2011), who indicated that crude oil contaminated soils are slightly more acidic due to formation of toxic acids in the spilled oils. This is also true as oil contamination also increases sulfur, which oxidizes to sulfuric acid and hence reduction in resultant soil pH. Electrical conductivity (ECe) is a measure of ionic concentration in the soils and is therefore related to dissolved solutes. As salt content increases, so does ECe (Oyem & Oyem, 2013). The acidic nature of crude oil lowered the soil ECe by 38.7%, but not to a significant level at p=0.05 (Table 5). This result is in agreement with Talukdar & Saikia (2010), who indicated that electrical conductivity (ECe) of clayey soils decreased linearly with the increase in the percentage of crude oil contamination.

$CaCO_3$ was also significantly reduced by 28.8% in the contaminated soil, due to the acidic nature of oil. The percentage of TEM and TPH was significantly higher by 99% in the contaminated soil than that in the adjacent control sites with a mean value of 2.88 and 2.44% respectively. The behavior of calcareous soils (high in $CaCO_3$) was tested by Awn & Zakaria (2014). They found that crude oil has an impact on soil properties in presence of $CaCO_3$ and that Crude oil caused leaching of $CaCO_3$ salt particles to lower layers.

Table 5. Means of Soil Parameters in Oil Polluted Soil and Reference Sites (Control).

Parameter	Mean (N=47)* Control	Mean (N=47)* Oil Polluted
ECe(µS cm^{-1})	2937.45a	1801.64a
pH	8.35a	7.79b
$CaCO_3$ (% eq)	10.40a	7.40b
TEM%	0.03b	2.88a
TPH%	0.02b	2.44a

ab: Means in the same row are statistically significantly different at the 95.0% confidence level according to t-test.

3.2.2. Comparison among soil types

Each soil parameter was compared among seven soil types under natural and contaminated conditions (Table 6). In respect to polluted soils, the ANOVA analysis showed a significant difference among soil types at the 95% confidence level for the soil electrical conductivity parameter (ECe) (Table 6). This variation was shown mainly in the soil type Typic Aquisalids, which is strongly saline (Figure 2). The soil type Typic Aquisalids had the highest ECe that is significantly different from the other soil types.

The soil pH in the impacted soils did not show a significant difference among soil types. The $CaCO_3$ level showed no significant difference in the affected soils. However, it showed some significant variation in the control sites. The TPH and TEM in the affected soils did not show statistical differences among soil types. Therefore, the hypothesis that oil pollution (TPH and TEM) in the different soil types are not different among soil types and the same applies for the soil pH, and $CaCO_3$ is accepted. However, for the ECe this hypothesis is rejected. This is a significant result to be considered in future soil remediation projects, as the soil ECe will behave differently among soil types.

A simple regression model was conducted to test the correlation between TPH and TEM for all the layers in the polluted soils. The R-Square statistic indicated that the model as fitted explains 99% of the variability in TPH. The correlation coefficient equals (0.9953), indicating a relatively strong relationship between these variables (Figure 6). Equation (2) shows the fitted model:

$$TPH = -0.153122 + 0.902631*TEM \quad (2)$$

For the other parameters (ECe, pHs and $CaCO_3$) a weak relationship between the variables was found.

Table 6. Multiple range tests for mean values of five soil parameters by seven soil types affected by oil pollution and control.

Soil Type	ECe (µS cm^{-1})		pHs		$CaCO_3$ (% eq)		TPH %		TEM %	
	Control (N=66)	Polluted (N=60)	Control (N=66)	Polluted (N=60)	Control (N=66)	Polluted (N=55)	Control (N=66)	Polluted (N=58)	Control (N=66)	Polluted (N=58)
Typic Aquisalids	23401.30a	3669.25a	8.24a	7.71a	7.13b	5.8a	0.23a	1.65a	0.33a	2.27a
Leptic Haplogypsids	7753.64b	3131.67a	8.39a	8.0a	12.63a	15.85a	0.07a	3.27a	0.08ab	3.94a
Typic Calcigypsids	1185.83b	1711.67ab	8.42a	7.67a	9.37ab	2.13a	0.01a	3.45a	0.00b	3.76a
Typic Haplocalcids	250.00b	395.0b	8.22a	7.75a	12.55a	9.13a	0.01a	1.09a	0.17ab	1.42a
Calcic Petrocalcids	2520.00b	2686.67ab	8.24a	8.06a	9.18ab	7.5a	0.02a	3.01a	0.17ab	3.38a
Typic Petrogypsids	1108.95b	1296.25b	8.34a	7.69a	10.43ab	8.58a	0.10a	2.50a	0.08ab	2.91a
Typic Torripsamments	518.75b	1342.02b	8.40a	8.23a	11.69ab	6.49a	0.012a	2.22a	0.12ab	2.64a
P-Value	0.0008	0.0000	0.4717	0.1893	0.2921	0.0808	0.713	0.9037	0.509	0.9244

*ab: denotes a statistically significant difference in the same column according to Fisher's least significant difference (LSD) procedure (95.0 percent LSD).

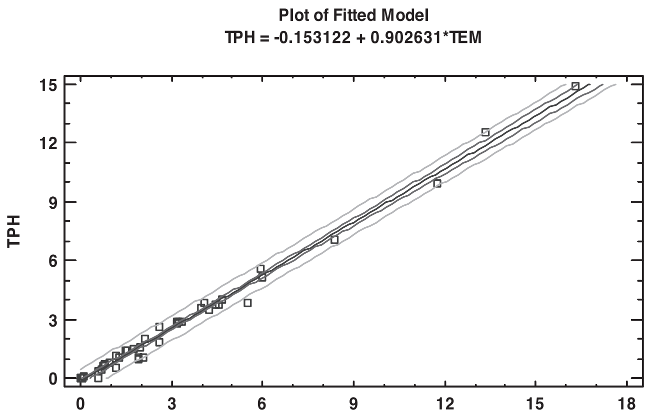

Fig. 6. Correlation between TPH and TEM % in the polluted soils of Kuwait

4. Conclusions

This study provided understanding of the impact of oil pollution on the different types of soils in Kuwait. It showed that there are some differences in the extent of pollution among soil types and that soil types behave differently under crude oil contamination. The width and depth of oil pollution in the soil matrix depends on the soil types. However, the level of oil pollution (TPH and TEM) does not vary significantly with the soil types. Some chemical parameters, such as $CaCO_3$, ECe and the soil pH are lowered in presence of oil contamination.

The findings of this study showed the importance of soil taxonomy and justify the need for a comprehensive remediation plan that takes into consideration chemical and physical characteristics of soil. More studies are needed to monitor the extent of pollution in the oil trenches and to evaluate the susceptibility of the different types of soils to oil pollution.

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آثارالنفط الخام على بعض أنواع التربة في الكويت

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خلاصة

هذه الدراسة تحقق في تأثير التلوث النفطي الخام على أنواع مختلفة من التربة في الكويت. لهذا الغرض تم دراسة الخندق النفطي، الذي يتألف من عدة أنواع من التربة. تم عمل عدد من الحفر لتحديد مدى التلوث النفطي في مصفوفة التربة وتأثيرها على الخواص الكيميائية للتربة. وقد تم قياس أعلى عمق التلوث النفطي في التربة من نوع *Torripsamments* و*Petrogypsids*، وكان أكثر عرض في *Aquisalids*.

هذا الاختلاف يرجع إلى الخصائص الفيزيائية والكيميائية للتربة وعمق الحوض الصلد. تم جمع عينات من التربة من مختلف طبقات نوع التربة في خنادق النفط وأيضا من المواقع المرجعية (مراقبة) لمقارنة مستويات المواد الهيدروكربونية البترولية الإجمالية (TPH)، و المواد القابلة للاستخراج (TEM)، وحموضة التربة، و كربونات الكالسيوم $CaCO_3$ والتوصيل الكهربائي (ECe). أظهرت التربة *Calcigypsids* أعلى تركيز من الهيدروكربونات النفطية والمواد القابلة للاستخراج، والتي كانت أعلى بكثير في خندق النفط بنسبة 99% من المواقع المرجعية. حدث انخفاض في مستوى حموضة التربة وكربونات الكالسيوم في وجود النفط، و تغير مستوى التوصيل الكهربائي للتربة بشكل كبير على مستوى 95% من الثقة. وأظهرت الدراسة أن أنواع التربة المختلفة تعاملت بشكل مختلف مع التلوث النفطي الخام.

كلمات البحث: تلوث، الحوض الصلد، المواد الهيدروكربونية. التلوث النفطي؛ خندق النفط؛ معالجة.