***Kuwait J. Sci.* 42 (3)** pp. 191-209, 2015

Crude oil contamination on the Sabkha facies of Kuwait

WALEED YOUSEF ROY*, SAMIRA OMAR ASEM* AND MEALI AL-BURAIS**

**Environment and Life Sciences Research Center, Kuwait Institute for Scientific Research, P.O. Box 24885, Safat 13109, Kuwait.*

***Techno Economics Division, Kuwait Institute for Scientific Research, P.O. Box 24885, Safat 13109, Kuwait.*

Corresponding author email: sasem@hotmail.com; somar@kisr.edu.kw

Tel: (+965) 24956650/1 Fax: (+965) 24956274

ABSTRACT

Sabkha soils in Kuwait are developed as a result of the intersection between the highly saline groundwater table and the low ground surface. During the Iraqi occupation of Kuwait, the Iraqi troops dug a large number of trenches including Sabkha areas and filled them with crude oil. Crude oil is a mixture of mainly oxygenated and non-oxygenated hydrocarbons (Yemashova *et al*., 2007). Six boreholes (B4 to B9) along the oil trench in the saline coastal soils, in the northeastern and southeastern areas of Kuwait were excavated to assess the extent of oil pollution in comparison to the adjacent reference sites. Oil pollution in the soil matrix of the oil trenches is significantly high in percent total petroleum hydrocarbon (TPH) and total extractable matter (TEM) that penetrated through deep soils into the hard gatch layer. The highest concentration of TEM and TPH was 11.74% and 9.91% respectively measured at B7 in the southeastern areas at a depth of 60 to 160 cm and the lowest concentration was 0.67% and 0.41% respectively at B5 in the northeastern areas at a depth of 35 to 110 cm. The study also concluded that the amount and depth of oil contamination in the northeastern and southern coastal oil trenches should be considered equally important for future remediation.

Keywords: Environment; oil contamination; oil pollution ; salids; saline soil.

INTRODUCTION

Soil contamination with crude oil can be a source of groundwater contamination and reduces the usability of land for development (Davis & Jones, 2011). Many hypersaline environments are often contaminated with petroleum compounds. Among these, oil and natural gas production sites all over the world and hundreds of kilometers of coastlines in the more arid regions of Gulf countries are of major concern due to the extent and magnitude of contamination (Al-Mailem *et al*., 2012). Oil movement is affected by the sediment properties and their variability, resulting in the complex distribution of oil in the subsurface (Bennett *et al.*, 1993; Delin *et al.*, 1998). Oil residuals had caused some major changes in the chemical properties of soil in the Momoge wetland in China (Wang *et al.*, 2010).

Among the contaminated hypersaline environments, hydrocarbons pose a special problem due to their sheer numbers all over the world and due to their high salinity caused by salty brackish water generated during oil and natural gas extraction (Bonfá *et al*., 2011). Sabkhas, with their picturesque features, constitute one of the most common land features along the coastal plains and in some inland areas. Sabkhas are generally sandy in texture with high salinity soils that are classified as *Salids* (*Salids* are aridisols, which have a salic horizon that has its upper boundary within 100 cm of the soil surface) according to the Keys to Soil Taxonomy (Soil Survey Staff, 1996a). The coastal sabkhas are developed as a result of the intersection between the highly saline groundwater table (resulted from salt water intrusion) and the low ground surface. The coastal sabkhas are highly variable morphologically, lithologically, geochemically and biologically. Sabkha soils in Kuwait are usually barren with an exception of some halophytic plants that are common in the coastal areas (Omar *et al.*, 2002). The accumulation of salts in the top and subsurface soil layers of *Salids* is the result of geochemical and hydrological process. Soil type *Salids* cover about 10% of total area (about 1,800 km^2) of Kuwait according to the Soil Survey for the State of Kuwait project (KISR, 1999). As a part of this project, a soil information system was designed and implemented to manage the soil survey data (Grealish *et al*., 2004).

Trench warfare used by troops as shelters from artillery during World War 1 caused severe damage to the European environment (Davis, 1998). It changed the landscape due to the digging and trampling of grassland and the crushing of plants and animals, thereby disturbing the soil. During the Iraqi invasion of Kuwait (August, 1990 to February 1991), to impede any attack from the allied armies, the Iraqi Forces built trenches and filled them with crude oil. These trenches extend along the southern border zone of Kuwait (Figure 1) (Al-Ajmi *et al.,* 1998). Their average depth and width are 2 m and 2.5 m respectively and length is around 120 km (southern border zone). Vegetation cover, wildlife species, soils and micro relief were completely damaged by these oil trenches. The depth of oil penetration into the soils varied in different areas and was mainly controlled by the nature of soils. Omar *et al.* (2006) conducted an earlier study in Greater Al-Burqan area, which depicts the types and extent of soil contamination resulted from the detonation and damage of oil wells during the Gulf War.

The coastal sectors of the oil trench extend to several kilometers in the northeast and southeast of Kuwait. Since sabkha areas have shallow water table and are subject to wetting and drying during winter and summer, the oil trenches in these areas will have negative impact on the hydrological process and cause damage to the sabkha ecosystem (Al-Sulaimi *et al.*, 1993). Thus, it is necessary to assess the extent of damage on the sabkha ecosystem in order to justify the need for future remediation.

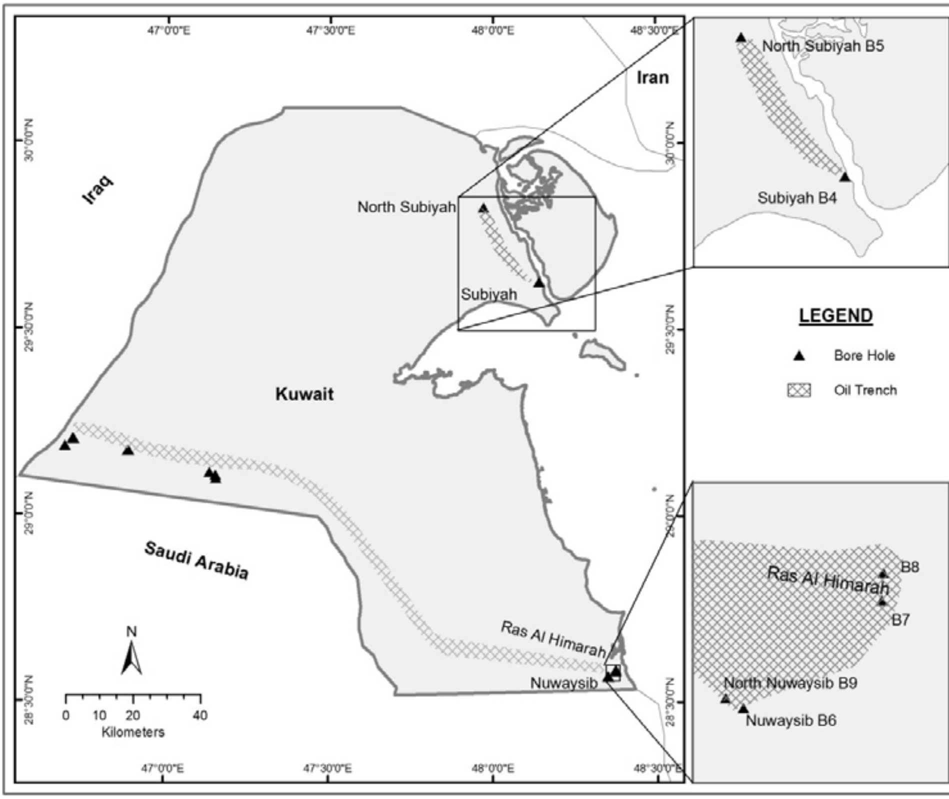

Fig. 1. Location of the oil trenches in Kuwait showing the northeastern coastal trenches and the study sites with borehole (B4 to B5) and the southeastern borehole (B6 to B9).

Site characteristics of the study area

In the northeastern part of the country the sabkhas are dominated by laminated silt and clay with high gypsum content, whereas the southern coastal plain is composed of sands, carbonate grains and evaporites (KISR, 1999). The water table is at 120 cm depth (Figure 2). In the southern coastal plain and in the local parts of Kuwait Bay, the seaward (Gulf ward) side of the coastal sabkhas is skirted by offshore bars, oolitic ridges and aeolian accumulations. In the northeastern coastal plain and the majority of Kuwait Bay, the sabkhas are not separated from intertidal flats. The study areas are located within the coastal sabkha ecosystem. The location of the study areas is shown in Figure 1 and a vertical section of the southeastern study areas is shown in Figure 2. The vertical section shows the location of the boreholes B6, B7, B8 and B9. Both B7 and B8 are located in the Aquisalids zones with very high salinity. The other boreholes are located in a sandy soil (Torripsamments) with relatively less salinity. The vertical view is about 2 m high and is at a distance of 870 m from the seashore. The soil contaminated with crude oil is within the sabkha area as shown in Figure 2.

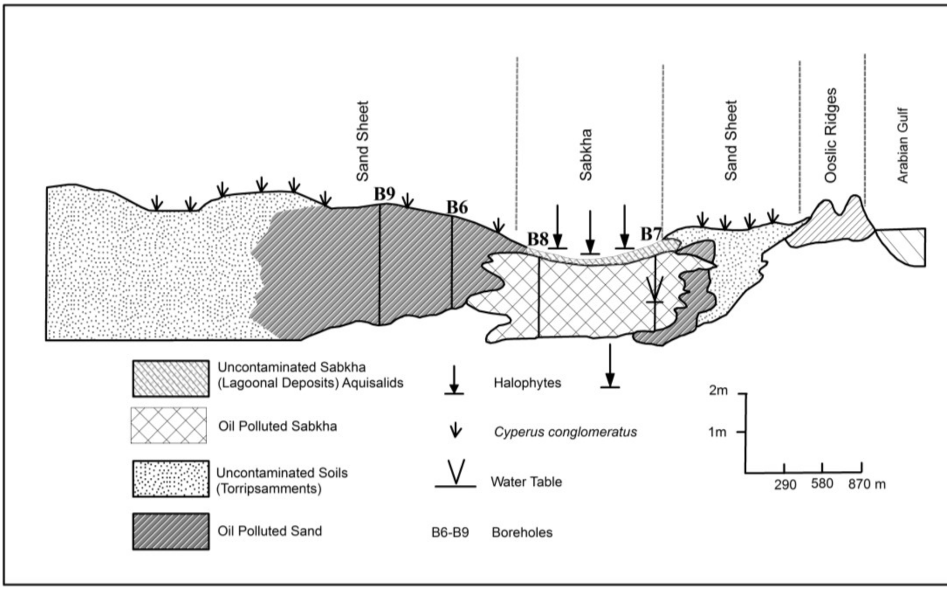

Fig. 2. Vertical view of the oil trench in the sabkha coastal area of Kuwait showing the location of the four boreholes.

METHODS

Soil analyses

Six boreholes in the oil trench were excavated; (two in the northeastern zone (B4 and B5) and four in the southeastern zone (B6 to B9) to a 200 cm depth using a backhoe machine (Figure 3). Table 1 and Figure 1 show the location of the coastal study areas numbered from pits B4 to B9. At each location, three sites were selected for investigation: the northern or eastern side of the oil trench (N/E) (control or reference sites), the oil trench itself (OT) and the southern or western side of the trench (S/W) (control or reference sites). General onsite investigation and soil profile investigation in the borehole of the OT were made and soil types at different layers were recorded according to soil survey of Kuwait information (KISR, 1999). Soil samples were collected at soil layers in the OT for laboratory analyses at the Central Analytical Laboratory (CAL) of Kuwait Institute for Scientific Research (KISR) to assess the level of damage to the soil matrix. The spread of petroleum oil pollutants in the soil matrix (depth), the nature of contaminants (i.e., oily soil, soot, tar mat or sludge) and the thickness of oil-polluted horizons in the soil profile were recorded to categorize the nature and extent of damage. At the reference sites from both sides of the oil trench ((N/E) or (S/W)), soil samples were collected by using hand augurs.

These sites, located 50 m away from the oil trench, were considered uncontaminated control sites and used as reference samples for comparison purposes with the oil trench (OT).

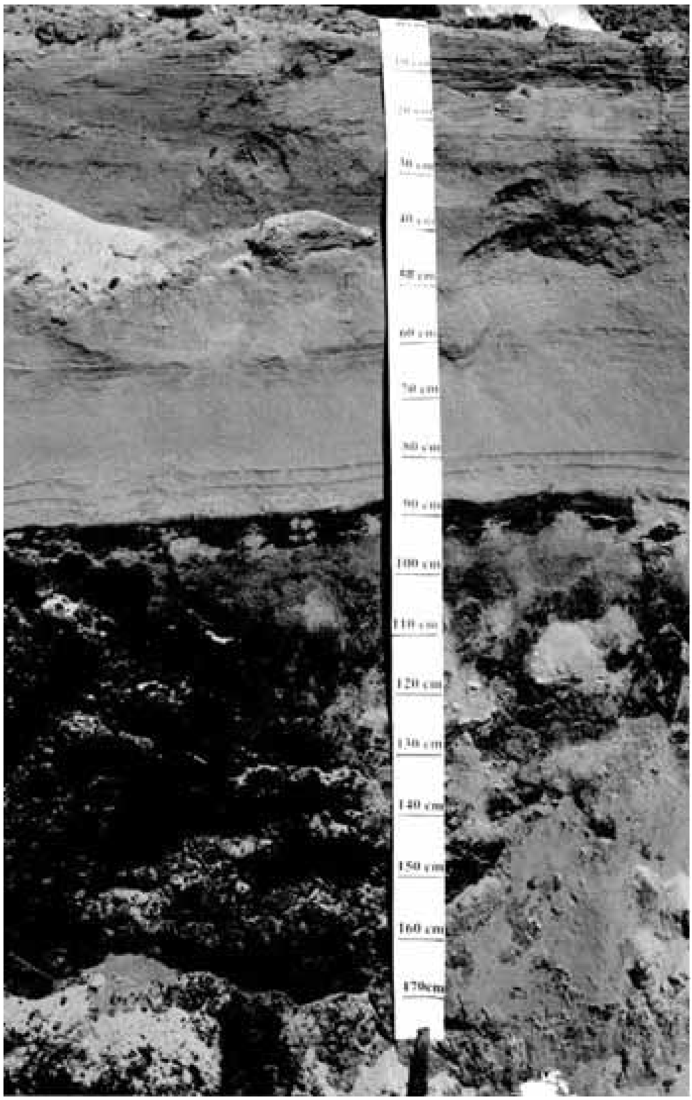

Fig. 3. A borehole showing crude oil contamination in the deep soil layer in the coastal area of Kuwait.

Table 1. Locations and coordinates of the study sites (B4 to B9)

Borehole	Locality	Coordinate
B4	Subiyah	29° 49' 428"N 47° 57' 817"E
B5	North Subiyah	29° 37' 418"N 48° 07' 930"E
B6	Nuwaysib	28° 34' 0806"N 48° 21' 0986"E
B7	Ras Al Himarah	28° 34' 62"N 48° 21' 88"E
B8	Ras Al Himarah	28° 34' 76"N 48° 22' 29"E
B9	North Nuwaysib	28° 34' 13"N 48° 20' 59"E

pH, electrical conductivity (EC) and calcium carbonate ($CaCO_3$) content were determined according to USDA methods 8C1b, 8A3 and 6E1g (Soil Survey Staff, 1996b) respectively. A saturated soil paste was used to measure pH, using a pH meter. Electrical conductivity was determined from the saturated paste extract, using a conductivity meter. For the estimation of $CaCO_3$, air dried soil smples were treated with hydrochloric acid (HCl) and the evolved CO_2 is measured manometrically to calculate the amount of carbonate, which is expressed as percentage equivalent of soil. The total extractable matter (TEM) was determined using the USEPA method (1996). The soil was extracted with dichloromethane (DCM) followed by evaporation, and gravimetric analysis, which required the drying of the dichloromethane extract of the contaminated soil. The following formula was applied to the results:

TEM= (weight of the residue (mg)) ÷ (initial weight of the sample (kg))

Total petroleum hydrocarbon (TPH) was determined by infrared spectroscopy after the organic solvent extraction of the contaminated soil (USEPA, 1978).

Data analysis

The data was analyzed by using a statistical package, IBM SPSS Statistics version 20.0 (2011). A two-way variance analysis (ANOVA) was carried out, followed by the Scheffe Test (Post Hoc Test).

RESULTS

Oil trench-B4

The trench B4 was excavated at Subiyah in the northeast of Kuwait. On-site investigation revealed the occurrence of gatch (limestone material) soaked with oil at a depth of 95 cm. The trench was dug to 180 cm; below that the material found was similar to the 95 to 180 cm zone. The upper 95 cm zone was devoid of gatch; it was of a refilled material rich in highly calcareous sand, presently contaminated with oil. Visually, it was apparent that the calcareous sand was highly contaminated compared with other depths, which also showed lower pH and $CaCO_3$ contents (Table 2). The depths below 60 cm presented similar EC values and were related to relatively high oil contamination. The relatively higher oil contamination (TEM and TPH) was at the surface (0 to 60 cm); however, no substantial difference was observed with depth.

Table 2. Characteristics of soil samples collected from northeastern oil trench-4 (B4-Subiyah), oil trench-5 (B5-North Subiyah) and control soil pits in Kuwait

Borehole No.	Case (Condition)	Nature	Depth (cm)	^{a}EC (µS cm^{-1})	pH	$CaCO_3$ (% eq)	^{b}TEM (%)	^{c}TPH (%)
Subiyah	Oil Trench B4	Oily soil	0-60	1400	8.35	20.40	4.43	3.76
		Oily soil	60-95	2880	8.09	36.40	2.143	1.98
		Oil-soaked gatch	95-180+	2620	7.75	16.50	3.34	2.92
	Reference Sites (both sides of B4)	East	0-15	2230	8.34	16.90	-	-
		East	15-80	5150	8.32	12.60	-	-
		West	0-30	220	8.65	10.90	-	-
		West	30-50	2830	8.29	24.00	-	-
		West	50-150	4080	8.27	25.90	-	-
North Subiyah	Oil trench B5	Oily soil	0-35	1240	8.04	0.90	1.96	1.62
		Oily gypsic soil	35-110	2450	7.69	2.10	0.67	0.41
		Oily gypsic soil	110-140	2490	7.67	0.50	0.76	0.59
		Oil-soaked gatch	140+	2660	8.03	1.20	0.93	0.77
	Reference Sites (both sides of B5)	East	0-10	1700	8.33	13.30	-	-
		East	10-75	3380	8.13	0.50	-	-
		East	75+	3840	8.20	5.60	-	-
		West	0-75	210	8.76	12.10	-	-
		West	75-110	320	8.65	12.20	-	-
		West	110+	440	8.78	8.50	-	-

^{a}EC = Electrical conductivity
^{b}TEM = Total extractable matter
^{c}TPH = Total petroleum hydrocarbon

The investigation of reference samples from both sides (50 m apart) of the trench showed that, on the eastern side, the pit showed the presence of a gypsic horizon at 15 cm depth (Leptic Haplogypsids), which also resulted in high EC values. Below 80 cm, it was not possible to use a hand auger due to the presence of a gravelly zone. Both the layers showed similar pH and $CaCO_3$ contents; however, the gypsic horizon yielded higher EC values, which was expected in this horizon. The soil pit dug on the western side showed calcareous sand (0 to 30 cm), laid down (30 to 50 cm) with a well-developed calcic horizon and a gypsic horizon at 50 to 150 cm depth (Typic Calcigypsids). Below 150 cm depth, a hardpan rich in $CaCO_3$ (Petrocalcic) was identified. The gypsic horizon (50-150 cm) showed higher EC values. The eastern and western pits divided the landscape into different soil classes. No oil contamination is observed in the pits.

Oil trench-B5

The trench (B5) was also excavated in the north of the Subiyah area in the northeast of Kuwait. A gypsic hardpan soaked with oil was identified at 140 cm depth. The face of the excavated trench was divided into different depths, based on the level of oil contamination and the soil material. The upper 35 cm was of recently deposited sandy material contaminated with oil. The surface zone was highly contaminated. The zone from 35 to 140 cm was an oil-contaminated gypsic horizon, where loosely held gypsum crystals coated with oil were identified. The zone below 140 cm was an oil-soaked petrogypsic layer. It seems that the trench was probably dug to a depth of about 140 cm, before it was filled with oil. The hardpan seemed to be undisturbed, but was soaked with oil. Relatively higher oil pollution (TEM and TPH) was recorded at the surface (0 to 35 cm) (Table 2).

The EC values followed an increasing trend with depth, being the highest at the undisturbed soaked gypsic hardpan. The gypsic horizon also presented similar values. The minimum EC was recorded at the surface (0 to 35 cm), which was non-gypsic and lightly contaminated with oil. The trench was refilled with the gypsic material; therefore, only traces of $CaCO_3$ were recorded. The pH followed the reverse trend: it was lower in the oil-contaminated zones, compared with the freshly deposited lightly contaminated surface soil. Gypsum is a soluble soil component; slightly higher gypsum quantities may mask the EC and pH contributed by the oil contamination. Under these conditions, it is only the TPH that showed the difference of oil contamination.

Two soil pits were made on both sides of the trench (reference sites) at a distance of 50 m from the center of the trench. On the eastern side, a gypsic horizon was identified at 10 to 75 cm depth (Leptic Haplogypsids). Gypsum dissolution contributed to high EC values at 10 to 75 cm and 75+cm depths (Table 2). Below 75 cm, gypsum crystals were identified with a mixture of gravels. Up to 2 m depth, no calcrete layer was identified. On the western side, the pit was dug to 75 cm depth, and then hand-augered to 150 cm depth. The entire pit was calcareous sand without any horizon development (Typic Torripsamments); however, below 75 cm depth, relatively higher gravel contents were observed. Both the soils showed contrasting soil features and soil types with no sign of pollution from the crude oil. In the Eastern side, the high EC correlated with the presence of gypsum, but no such horizon was identified in the western side. Thus, the clean sand presented lower EC values.

Oil trench-B6

Oil trench-6 was excavated in north of the Nuwaysib area in the south of Kuwait. The features recorded in this trench were different from others. In this trench, oil moved preferentially upward into the refilled soil material. This preferential movement was due to the soil heterogeneity in structure development. An irregular pattern of oil contamination was observed; the trench was partially contaminated to about 1 m and uniform oil contamination was recorded below 1 m. At 140 cm depth, calcareous gatch was observed. However, it had become soft due to oil contamination, and the gatch pieces were also found on the nearby landscape. They were part of the trench excavation activity and remained intact. These $CaCO_3$ rich gatch pieces were very hard to break. High EC was recorded in oil-soaked gatch samples (Table 3). High $CaCO_3$ was recorded in the gatch zone below 140 cm depth. Relatively higher oil pollution (TEM and TPH) was found at 20 to 140 cm depth, and oil-soaked gatch showed lower oil pollution, compared with the 20 to 140 cm depth. The upper depth (0 to 20 cm) was clean soil and showed the lowest values of TPH and TEM. Figure 4 shows the vertical section of a borehole in the Nuwasib area with oil contamination in the calcareous gatch.

Table 3. Characteristics of soil samples collected from the southeastern oil trenches-B6 (Nuwaysib), B7 (Ras Al Himarah), B8 (Ras Al Himarah), B9 (north Nuwaysib) and control soil pits

Borehole No.	Case (Condition)	Nature	Depth (cm)	EC[a] (µS cm^{-1})	pH	$CaCO_3$ (% eq)	TEM[b] (%)	TPH[c] (%)
Nuwaysib	Oil trench B6	Clean soil	0-20	950	8.52	9.50	0.06	0.04
		Oily soil	20-90	480	8.53	8.40	6.05	4.80
		Oily soil	90-140	760	8.31	7.00	6.82	5.32
		Oil-soaked gatch	140+	1180	8.47	17.10	1.46	1.23
Ras Al Himarah	Oil trench B7	Clean soil	0-40	3690	8.25	8.20	0.05	0.03
		Oily soil	40-60	3570	7.78	6.30	1.91	1.01
		Sludge	60-160	4630	7.79	7.30	11.74	9.91
	Reference Sites (both sides of B7)	North	0-10	17430	8.57	8.50	0.808	0.730
		North	10-30	9590	8.44	10.90	-	-
		North	30-150	5850	8.22	8.90	-	-
		South	0-15	24700	8.53	7.00	-	-
		South	15-50	4560	8.28	5.20	0.047	0.040
		South	50-150	8650	8.33	8.10	-	-
Ras Al Himarah	Oil trench B8	Tar mat	0-5	3630	7.51	8.20	2.58	1.80
		Oily soil	5-20	2517	7.74	4.10	1.91	1.03
		Sludge	20-80	2620	7.63	8.20	4.57	3.76
		Clean soil	80+	5910	7.94	2.70	0.03	0.02
	Reference Sites (both sides of B8)	North	0-3	31900	8.12	5.3	0.046	0.039
		North	3-15	13890	8.72	9.4	-	-
		North	15-40	4190	8.05	2.6	-	-
		North	40-100	11180	8.20	12.5	-	-
		North	100+	10460	8.22	9.2	-	-
		South	0-3	99400	8.85	7.90	-	-
		South	3-15	5860	8.26	1.90	-	-
		South	15-40	10330	8.50	9.50	-	-
North Nuwaysib	Oil trench B9	Oily soil	0-40	330	8.18	9.30	3.97	3.55
		Oily soil	40-120	540	7.98	11.20	3.19	2.86
		Asphalt	120-180	2760	7.73	2.20	3.23	2.88
		Clean soil	180+	2470	7.89	1.80	0.04	0.02
	Reference Sites (both sides of B9)	North	0-10	730	8.23	11.60	-	-
		North	10+	240	8.35	14.90	-	-
		South	0-15	290	8.14	10.40	0.043	0.036
		South	15+	430	8.36	12.20	-	-

[a] EC = Electrical conductivity
[b] TEM = Total extractable matter
[c] TPH = Total petroleum hydrocarbon

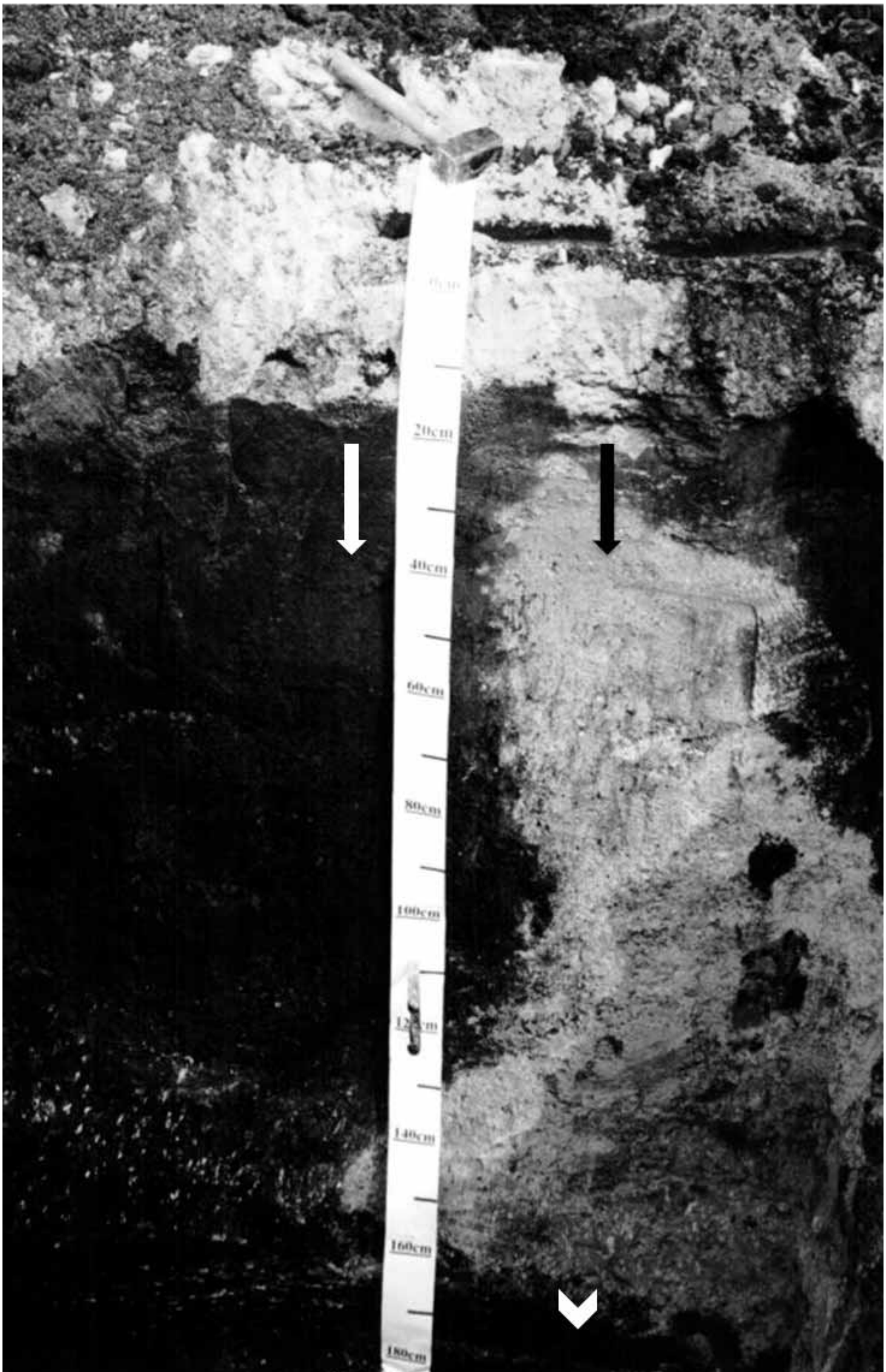

Fig. 4. Vertical section of a borehole in the Nuwasib area of Kuwait showing the hard calcareous gatch (black arrow), oil penetration in the calcareous gatch (white arrow) and hardpan at 180 cm (white arrow head).

Oil trench-B7

Bore number B7 was made in the sabkha area, situated in the Ras Al Himarah coastal area (north of Nuwaysib). The upper 40 cm was visually clear of any oil contamination. A gypsum-rich zone was identified at 20 to 50 cm depth. The zone from 40 to 60 cm was lightly contaminated with oil. Sludge was found at 60 to 160 cm depth and was categorized as a highly oil-contaminated zone in this excavation site. The trench was dug up to 160 cm depth and samples were collected. Later, the trench was filled with water, and the water was leveled at 100 cm, showing the level of water table. This masked the layers below 100 cm. Relatively high EC and low pH (Table 3) were recorded in the sludge zone. In this site, oil-contaminated groundwater was observed. The Sabkhas collect rainwater in depressions; hence, the rainwater runoff is prone to oil contamination. The standing water attracts grazing animals; therefore, the oil-contaminated water most likely enters the food chain through the animal's body and poses health risks to both animals and humans. The higher oil pollution (TPH and TEM) was found at 60 to 160 cm, where the zone was identified as sludge. Heavy metals were uniformly distributed in the oil trench.

The pits on both sides of the excavated trench were identified as Leptic Haplogypsids. At both reference sites, the water table was observed at 160 cm depth. In the southern side of the trench, a gypsum-rich horizon was identified at 15 to 50 cm depth, whereas on the northern side, it occurred at 10 to 30 cm depth. A surface salt crust was present on both control pits and presented very high EC values. Relatively higher pH values were recorded at the salt-crusted zones. The TPH and TEM values from only one depth of each reference pit showed lower values than the oil contaminated oil trench.

Oil trench-B8

Trench number B8 was also excavated in the sabkha situated in the Ras Al Himarah coastal area (north of Nuwaysib). The sabkha measured approximately 40 to 50 ha and was devoid of any vegetation. Patches of white salt crust were found in this area. A 0 to 5 cm thick tar mat covered an area of about half a hectare; nearby, signs of an oil trench were found. The excavation was undertaken here and the excavated trench revealed a 5 cm thick surface tar mat. A zone of 5 to 20 cm was found to have soil material contaminated with oil, and a zone of 20 to 80 cm was found to have highly contaminated soil material identified as sludge. The zone below 80 cm was visually non-contaminated with oil and had gypsum-rich material. The water table was observed at 100 cm depth. Visual oil contamination was recorded above the water table. It was apparent that the trench was dug to the depth of the water table. The water table was observed to be contaminated with oil. Such contamination could be harmful and pose health risks. Relatively lower pH values were recorded (Table 3) at oil-contaminated depths, the highest being in the non-contaminated zone (80 cm). The gypsum-rich non-oil-contaminated depth presented the highest EC value and showed an aggregate effect of gypsum dissolution and non-visual oil contamination. As expected, the values of TPH and TEM were higher, where sludge was identified (20 to 80 cm).

Both the soil pits on the northern and southern reference sites were classified as Gypsic Aquisalids. Both showed a 3 cm thick surface salt crust and the highest EC value was shown in the northern pit. A zone of 15 to 40 cm was identified as gypsic horizon, and gypsum crystals were very apparent and flickered under sunlight. They were identified as accumulations of about 3 cm diameter. The zone between 40 and 100 cm was a sandy gypsic horizon, where gypsum was uniformly distributed. Strong effervescence was observed at this depth. The water table was recorded at 95 cm depth. Identical soil features were recorded in the soil pit dug on the south control site of the trench, where the water table was recorded at 80 cm depth. The pH values of all the depths in both pits showed higher values compared with those in the oil-contaminated depths and are associated to relatively higher salinity and sodicity in the control pits.

Oil trench-B9

Oil trench number B9 was excavated along the Kuwait - Nuwaysib Road (100 km) in north Nuwaysib area. Soil types in the surroundings of the oil trench were Typic Torripsamments. The entire trench was contaminated with oil. A zone of 0 to 120 cm was lightly contaminated with oil. At 120 to 180 cm depth, $CaCO_3$ concentrations were recorded, showing a well-developed calcic horizon. The zone below 180 cm was identified as $CaCO_3$ rich oil contaminated gatch. It was difficult to excavate deeper than 180 cm; however, the gatch showed contamination with oil. The refilled material of the oil trench was different from excavated material from the trench site (asphalt). The features of the oil trench indicated that the trench was excavated to a depth of about 1.25 m. Oil was filled in the trench that also got soaked into the calcic as well as petrocalcic (gatch) horizons. The pH was higher in the lightly contaminated depth (Table 3) compared with where it was heavily contaminated with oil. Similar values of TEM and TPH were recorded at all depths to 180 cm (oily soil).

Both the pits on the northern and southern reference sites of the oil trench were classified as Typic Torripsamments. The gravel was distributed throughout the profile, forming an armour layer. The pit on the north side showed comparatively more gravel contents. Moderate levels of $CaCO_3$ were observed at all depths of both the pits. The pH values at all depths of the pits were higher than those recorded at all oil-contaminated depths in the oil trench. They were related to higher $CaCO_3$.

DISCUSSION

Crude oil is an extremely complex and variable mixture of organic compounds, which consists mainly of hydrocarbons in addition to heterocyclic compounds that contain sulphur, nitrogen and oxygen (Dastgheib *et al*., 2012). Significant variation is found in the soil pH, TEM and TPH between the control/reference sites and the OT (Table 4). The Oil trench showed significantly higher values of TEM and TPH and lower values in pH. The acidic nature of crude oil neutralized the alkaline soil and lowered the pH level, particularly at higher concentrations in deeper soils. Some authors also reported that the soil pH tends to shift to neutral values after the hydrocarbon addition to both acidic and alkaline soils (Emerson, 1983; Vanloocke *et al.*, 1975).

Table 4. Comparison of mean values of studied parameters in the oil trench and control sites

Mean	Mean	
	Oil Trench (N=22)	**Control (N=29)**
pH	7.99b	8.38a
$CaCO_3$ %	8.61a	10.29a
EC (µS cm^{-1})	2353.50a	9796.00a
TEM %	2.81a	.03b
TPH %	2.28a	.03b

[a, b] Variants possessing the same letter at the same raw are not significantly different at P ≤0.05

From Tables 2 and 3 the percent concentration of TEM, $CaCO_3$%, EC (µS cm-1) and TPH in the soil profile showed the following order of contamination: B7 and B6 very high, B8 and B9 moderately high and B4 and B5 moderately low concentrations. The highest concentration of TEM and TPH was 11.74 and 9.91% respectively, measured at B7 depth 60-160 cm and the lowest concentration was 0.67 and 0.41% respectively measured at B5 depth 35-110 cm (Figure 5). The EC varied among boreholes it showed the highest concentration in boreholes B7 and B8 (Figure 6). The mean values of soil pH, $CaCO_3$ and EC showed a significant difference among the six boreholes (Table 5). However, no significant difference was found in TEM and TPH among the boreholes. This shows that the amount of contamination in the boreholes is equally important to be considered for remediation.

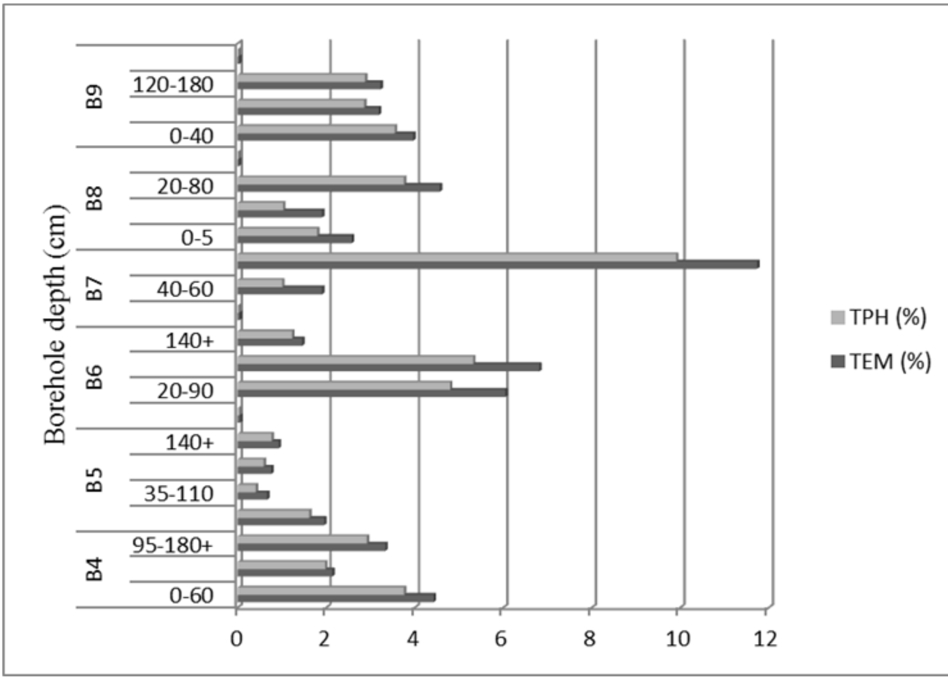

Fig. 5. The level of TPH and TEM (%) at different depths of six coastal oil trenches in Kuwait (boreholes from B4 to B9).

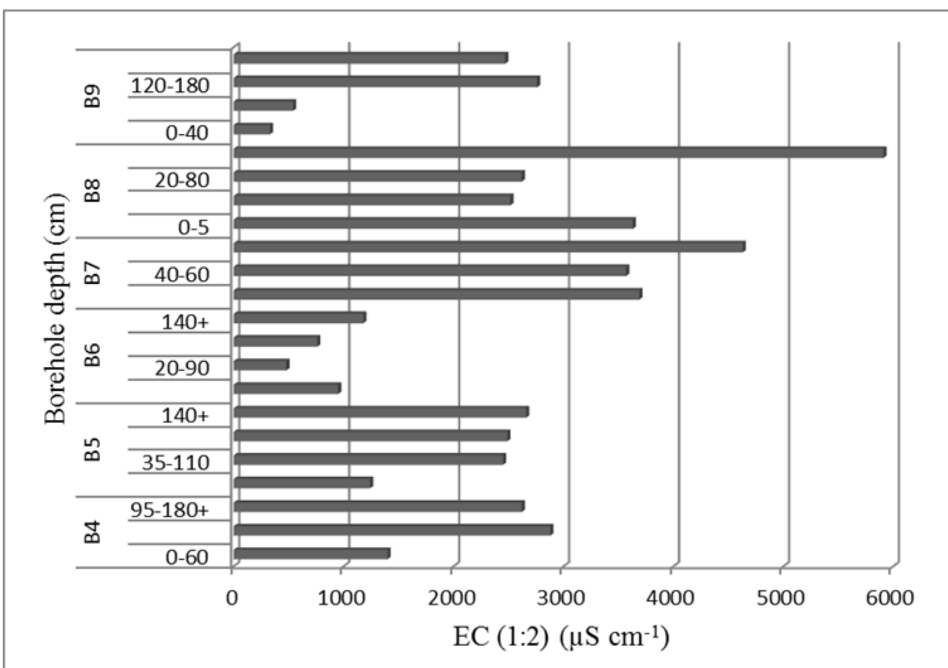

Fig. 6. Electric conductivity at different depths measured in boreholes from B4 to B9.

Table 5. Differences among six boreholes in the oil trenches (B4-B9) for five parameters

Borehole in the Oil Trench and number of variables (N)	Mean values				
	pH	$CaCO_3$ %	EC (µS cm^{-1})	TEM %	TPH %
B4 (3)	8.25a	24.43a	2300.00b	3.30a	2.88a
B5 (4)	7.86b	1.17b	2210.00b	1.08a	0.85a
B6 (4)	8.46a	10.50a	842.50b	3.59a	2.84a
B7 (3)	7.94b	7.27b	3963.33a	4.56a	3.65a
B8 (4)	7.70b	5.80b	3669.25a	2.27a	1.65a
B9 (4)	7.99b	6.12b	1525.00b	2.61a	2.32a

a, b: Variants possessing the same letter at the same column are not significantly different at $P \leq 0.05$

The study showed no significant variation in the amount of pollution (TEM and TPH) with depth in the oil trenches (Table 6) as well as with the EC. Therefore, all depths are considered equally important for remediation planning of the oil trench.

Table 6. Mean values variation among three depths in the oil trenches for three parameters

Depth		EC (µS cm^{-1})	TEM %	TPH %
Shallow	Mean (N=7)	1965.28a	2.1371a	1.6900a
Medium	Mean (N=7)	2635.71a	2.6519a	2.1200a
Deep	Mean (N=8)	2446.25a	3.5400a	2.9550a
Total	Mean (N=22)	2353.50	2.81	2.28

a: Variants possessing the same letter at the same column are not significantly different at $P \leq 0.05$

CONCLUSION

In the current study, efforts were made to find out the extent of soil contamination in the coastal oil trenches in order to justify the need for soil remediation. This study showed that oil pollution in the sabkha soil matrix ranged from 11.74% and 9.91% for TEM and TPH respectively measured at B7 in the southeastern at a depth of 60 to 160 cm. This shows that oil contamination in the soil matrix of the oil trenches in the coastal sabkha areas of Kuwait is significantly high and penetrated through deep soils into the hard gatch layer. The study also concludes that the amount and depth of contamination in the northern and southern oil trenches should be equally considered important for remediation efforts. A remediation plan considering available technologies to remediate the contaminated soil at sabkha oil trench can be implemented. However, some mechanical operations in the sabkha sites need to be considered. This has been recommended by McGill & Nyborg (1975), who found that wet sites are difficult to manage mechanically and thus create problems in conducting reclamation operations. There has been also a concern that the surface water and groundwater in these sabkha zones would be contaminated (Al-Sulaimi *et al.,* 1993), which requires further research studies and monitoring to assess the long-term impact of oil pollution on the hydrological process of the sabkha ecosystem.

ACKNOWLEDGEMENTS

The financial assistance from the Public Authority for Assessment of Compensation for Damages resulting from Iraqi Aggression (PAAC) for funding the project, "Assessing damage magnitude and recovery of the terrestrial ecosystem and follow-up of natural and induced desert recovery" (FA015C) is duly acknowledged. The authors would also like to thank the Kuwait National Focal Point (KNFP) for approving the publication of the manuscript. Thanks are also due to Dr. Seena Jose and Dr. P. Niranjan Kumar for their contributions to the manuscript.

REFERENCES

Al-Ajmi, D., Misak, R., Al-Ghunaim, M. & Mahfooz, S. 1998. Oil trenches and environmental destruction in Kuwait: One of Iraq's crimes of aggression. Centre for Research and Studies on Kuwait, Kuwait.

Al-Mailem, D. M., Eliyas, M. & Radwan, S. S. 2012. Enhanced haloarchaeal oil removal in hypersaline environments via organic nitrogen fertilization and illumination. Extremophiles **16**: 751–758.

Al-Sulaimi, J., Viswanathan, M. N. & Szekely, F. 1993. Effect of oil pollution on fresh groundwater in Kuwait. Environmental Geology **22:** 246-256.

Bennett, P. C., Siegel, D. E., Baedecker, M. J. & Hult, M. F. 1993. Crude oil in a shallow sand and gravel aquifer-I. Hydrogeology and inorganic geochemistry. Applied Geochemistry **8** (6): 529-549.

Bonfá, M. R. L., Grossman, M. J., Mellado, E. & Durrant, L. R. 2011. Biodegradation of aromatic hydrocarbons by Haloarchaea and their use for the reduction of the chemical oxygen demand of hypersaline petroleum produced water. Chemosphere **84**: 1671–1676.

Dastgheib, S. M. M., Amoozegar, M. A., Khajeh, K., Shavandi, M. & Ventosa, A. **2012**. Biodegradation of polycyclic aromatic hydrocarbons by a halophilic microbial consortium. Applied Microbiology and Biotechnology **95**: 789–798.

Davis, L. 1998. Environmental Disasters: A Chronicle of Individual, Industrial, and Governmental Carelessness. Facts on File, Inc., New York.

Davis, T. & J. Jones (Eds). 2011. Environmental Assessment of Ogoniland, Nigeria. United Nations Environment Program Post-Conflict and Disaster Management Branch. DEP/1337/GE. Pp. 257. UNEP, Nairobi, Kenya. (http://www.unep.org/nigeria)

Delin, G. N., Essaid, H. I., Cozzarelli, I. M., Lahvis, M. H. & Bekins, B. A. 1998. Ground water contamination by crude oil near Bemidji, Minnesota. United States Geological Survey. Bemidji Crude-Oil Research Project.

Emerson, R. N. 1983. Oil Effects on Terrestrial Plants and Soils: A Review. Ontario Ministry of the Environment, Toronto. Pp. 66.

Grealish, G., King, P., Omar, S. & Roy, W. 2004. Geographic information system and database for the soil survey for the State of Kuwait – design and outputs. Kuwait Journal of Science and Engineering **31**(1): 135-148.

KISR. 1999. Soil Survey for the State of Kuwait. Volume II. Reconnaissance survey. AACM International Pty. Ltd. Adelaide, Australia. Submitted to Kuwait Institute for Scientific Research (KISR) and Kuwait Public Authority for Agriculture and Fish Resources.

McGill, W. D. & Nyborg, M. 1975. Reclamation of wet forest soils subjected to oil spills. Alberta Institute of Pedologyl. Pub. No. G-75-1, 129.

Omar, S. A. S., Misak, R. & Shahid, S. A. 2002. Sabkhat and halophytes in Kuwait. In: Barth, H. J. & Böer, B. (Eds.). Sabkha Ecosystems, Volume 1: The Arabian Peninsula and Adjacent Countries. Pp. 71-81. Kluwer Academic Publishers, The Netherlands.

Omar, S., Grealish, G. & Roy, W. 2006. Types and extent of soil contamination in Greater Al-Burqan oil field, Kuwait. Kuwait Journal of Science and Engineering **33**(2): 89-99.

Soil Survey Staff. 1996a. Keys to Soil Taxonomy. Seventh edition, U.S. Department of Agriculture, US Government Printing Office, Washington D.C.

Soil Survey Staff. 1996b. Soil Survey Laboratory Methods Manual. Soil Survey Investigations Report No. 42 (Version 3.0.), U.S. Department of Agriculture, US Government Printing Office, Washington D.C.

USEPA. 1978. Test method for evaluating total recoverable petroleum hydrocarbon, method 418.1(spectrophotometric, infrared), US Government Printing Office, Washington D.C.

USEPA. 1996. Total extractable material in drilling mud by SDS extraction and gravimetry, method 1662. In: USEPA Test Method for the Evaluation of Solid Waste (SW-846), 3rd Edition, 821/R-92-008. US Government Printing Office, Washington D.C.

Vanloocke, R., DeBorger, R., Voets, J. P. & Verstraete, W. 1975. Soil and groundwater contamination by oil spills: problems and remedies. International Journal of Environmental Studies **8:** 99-111.

Wang, X., Feng, J. & Zhao, J. 2010. Effects of crude oil residuals on soil chemical properties in oil sites, Momoge Wetland, China. Environmental Monitoring and Assessment **161**(1-4): 271-280.

Yemashova, N. A., Murygina, V. P., Zhukov, D. V., Zakharyantz, A. A., Gladchenko, M. A., Appanna, V. & Kalyuzhnyi, S. V. 2007. Biodeterioration of crude oil and oil derived products: a review. Reviws in Environmental Science and Bio/Technology **6**: 315–337.

Submitted **:** 13/07/2014

Revised **:** 07/12/2014

Accepted **:** 10/12/2014

التلوث بالنفط الخام على أسطح السبخات في الكويت

***وليد يوسف روي، *سميرة عمر عاصم، **معالي البريص**

*مركز أبحاث البيئة والعلوم الحياتية – معهد الكويت للأبحاث العلمية – ص.ب 24885 – الصفاة – 13109 – الكويت.

**دائرة الإقتصاد التقني– معهد الكويت للأبحاث العلمية – ص.ب 24885، الصفاة – 13109 – الكويت.

مراسلة المؤلف: بريد إلكتروني: somar@kisr.edu.kw ; sasem@hotmail.com

خلاصة

لقد انتشرت السبخات في الكويت نتيجة تداخل منسوب المياه الجوفية عالية الملوحة مع الطبقة السطحية المنخفضة من الأرض. وخلال فترة الاحتلال العراقي الغاشم على الكويت حفرت القوات العراقية عدداً كبيراً من الخنادق بما في ذلك مناطق السبخات وقامت بتعبئة تلك الخنادق بالنفط الخام. والنفط الخام هو عبارة عن خليط من الهيدروكربونات الأساسية المؤكسدة والغير مؤكسدة (بماشوفا وآخرون، 2007). تم حفر ستة آبار (B4 إلى B9) بامتداد خندق النفط في التربة الساحلية المالحة في المناطق الشمالية الشرقية والجنوبية الشرقية من الكويت بهدف تقييم مدى التلوث النفطي بالمقارنة مع المواقع المرجعية المجاورة. إن نسبة التلوث النفطي في التربة المجاورة لخنادق النفط مرتفع بشكل ملحوظ بالنسبة لإجمالي الهيدروكربونات النفطية (TPH) وإجمالي المستخرجات (TEM) والتي اخترقت سطح التربة عميقا حتى وصلت إلى طبقة صلبة بعيدة. إن التركيز المرتفع لنسبة الهيدروكربونات النفطية و المستخرجات كان 11.74% و 9.91% على التوالي حيث تم قياس ذلك في البئر B7 في المنطقة الجنوبية الشرقية على عمق من 60 إلى 160 سم وكان أقل تركيز 0.67% و 0.41% على التوالي في B5 في المنطقة الشمالية الشرقية على عمق 35 إلى 110 سم. وخلصت الدراسة أيضا إلى أن كمية وعمق التلوث النفطي في مناطق النفط الساحلية في المنطقة الشمالية الشرقية والجنوبية ينبغي النظر إليها بنفس القدر من الأهمية بالنسبة لعمليات التأهيل المستقبلية.

الكلمات الرئيسية: التربة الصلبة؛ البيئة؛ التربة المالحة؛ التلوث النفطي،