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تقييم مخاطر تلوث التربة وإجراءات معالجتها في منطقة حقل برقان النفطي – الكويت

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الخلاصة

تعرضت البيئة في الكويت لدمار كبيير بسبب الغزو العراقي الدوله الكويت ما بين عامي 1990-1991. 734 بئر نفطي تم تدمييرها أو حرقها من قبل القوات العراقيه الغازيه. أدي ذلك الي تلوث مساحات من صحراء الكويت نتيجة تسرب النفط من الأبار المدمرة. يهدف الباحثون في هذه الدراسه الي تقييم مدى تلوث التربة بالمواد الكيميائية الخطرة حول الأبار المدمرة وأيضا معرفه التركيب الكيمائي للمواد الملوثة، ثم تحدييد الطرق المناسبه لحل هذه المشكله وإعادة تأهيل التربة الملوثة في صحراء الكويت. لقد تم إخذ عينات من خمسة آبار مختارة في منطقه برقان جنوب مدينه الكويت لقياس مدى تغلغل المواد الكيميائية في التربة. و قد تبين من خلال نتائج الدراسة وصول المواد الملوثة إلى عمق 4.3 م من التربه عند البئر رقم 3 وكان أقلها عند البئر رقم 1 بعمق 1.2 م. و قد تم إتخاذ الإجراءات العلاجية اللازمة باستخدام كميات مختلفة من المغذيات وخلطها بالتربة الملوثة. إن للتلوث البيئي مخاطر كبيرة على البيئة والصحة العامة، لذى هناك حاجة لمزيد من الدراسات طويلة الأجل لرصد الآثار الإيجابية لإجراءات علاج الملوثات على التربة و مدى تأثيرها على البيئة وصحة الإنسان.

Assessment of hazardous soils contamination and remediation actions in Burgan oil field-Kuwait

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ABSTRACT

The environment in Kuwait had suffered a massive damage by the Iraqi troops during the 1990-1991 military invasion. 734 oil wells were damaged and burned causing huge amount of oil spills on the soil surface and subsurface. Most of the soil around the oil fields was affected by hazardous contamination. This study aims to measure the extent of contaminated soil and to determine the contaminant composition, then we choose a suitable remediation action for rehabilitation of Kuwait's desert environment and ecosystem. Site soil samples taken from five well heads located in Burgan's field were investigated to measure the depth of the contaminated soil and its composition. The results showed that the contaminated soil was identified, wellhead number three had the deepest contamination of 4.3 meters, and the shallowest depth of 1.2 meter was found at the wellhead pit number one. The number of petroleum hydrocarbons resided in the soil can cause a serious health risk. The necessary remediation actions were made using different quantities and mixing of nutrients. Furthermore, epidemiology studies are needed to monitor the long-term positive impacts of the remediation actions for the pollutants on the ecology, environment, and human health.

Keywords: Environment; health and safety; oil lakes; contamination; nutrients.

INTRODUCTION

Hydrocarbon fuels are an essential source of energy supply for the world economy (Alkhaledi and Means, 2018). Health, safety, and environmental pollution risks associated with petroleum production and consumption activities in exchange for energy have become main concerns for many societies (Alkhaledi et al., 2017).

The State of Kuwait, a major oil producer in the world, was invaded by the Iraqi troops in 1990-1991. The assault lasted for about seven months and left behind ecological disasters. For example, the marine and terrestrial environments had suffered great harm due to the spilling of 22 million barrels of oil over the land and the sea shores of Kuwait (Alawadi et al., 1969).

Preliminary visual examination shows that the soil around wellhead pits remains highly contaminated with oil that spread from the discharge of wellheads, as well as from the Arial deposition of partially lined oil and combustion products from wells that turned unmet trolled for more than eight months. Large volumes of oil were discharged to the desert of Kuwait, and much of the oil was collected in small topographic depressions forming more than seventy oil leaks (Bufarsan, 1999 and Alawadhi et al., 2009).

After more than twenty-eight years from the invasion, the surface of the soil horizon is still barreled with thin layers of oil mix with the sandy constituents. Most of the oil spilled in the lakes has turned into sludge due to evaporation and measuring of the crude oil (Alsarawi, 1996). These lakes become the major source of pollution to sediments. Major damage to flora and fauna has been reported with tremendous contamination levels in the surface and subsurface soil (Viswanathan et al., 1996).

The climate of Kuwait is hot and dry during summer and mild during winter. The annual average rainfall in Kuwait is variable and is about 135 millimeters/year from the period of November to February. The main temperature in the summer exceeds 45C$^{\circ}$ between May and August. Winter is colder and mild with mean temperature of about 18 C$^{\circ}$ between December and February (Kuwait Metrological Department, 2017).

Kuwait is a flat desert land with few hills. The highest land elevation is about 300 m above sea level. The soils are generally not well developed, predominately sandy, poor in organic matter, and low in water retention capacity. The dominant soil orders are arid sols 70.8% and Entisols 29.2% (Alsarawi, 1980).

The general dip of the area of Kuwait is toward the northeast and the east. Rock types and physical agents of weathering, as well as the structural geology, are factors affecting the topography of Kuwait (Alsarawi, 1980).

The Jal-Azor escarpment extends to the north of Kuwait Bay for about 15 km with maximum elevation of 143m. The second feature is Alahmadi’s ridge, which has an elevation of 15 m and separates the coastal plain from the Burgan. The eastern and western slopes of the Jal-Azor and Alahmadi Ridge are very gentle (Figure 1).

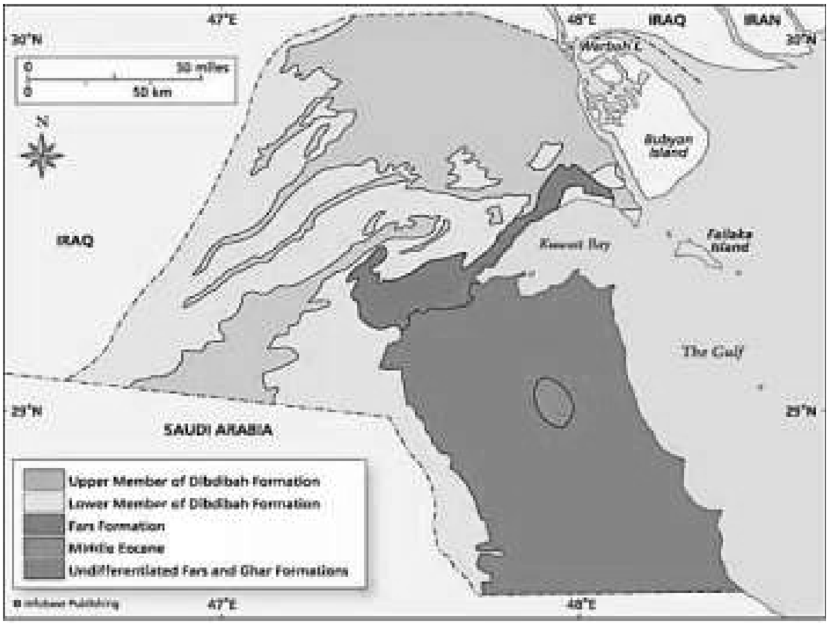

Figure 1. Topographic map of Kuwait (Khalaf et al., 1984).

Figure 2 shows the structure of the Kuwait and the main structural features that include the anticlines of the oil fields: Burgan, Managish, Umm Gadir, Wafra, and Sabriyan. Regionally, Kuwait lies on the unstable part of the Arabian shelf, which represents relatively horizontal sediments with gentle deformation. The stable shelf condition occurred in Kuwait, marked by the deposition of shallow water sediments, in Paleozoic to early Mesozoic times. Major episodes of uplift and erosion took place during the late Cretaceous to Oligocene (Alsarawi, 1996).

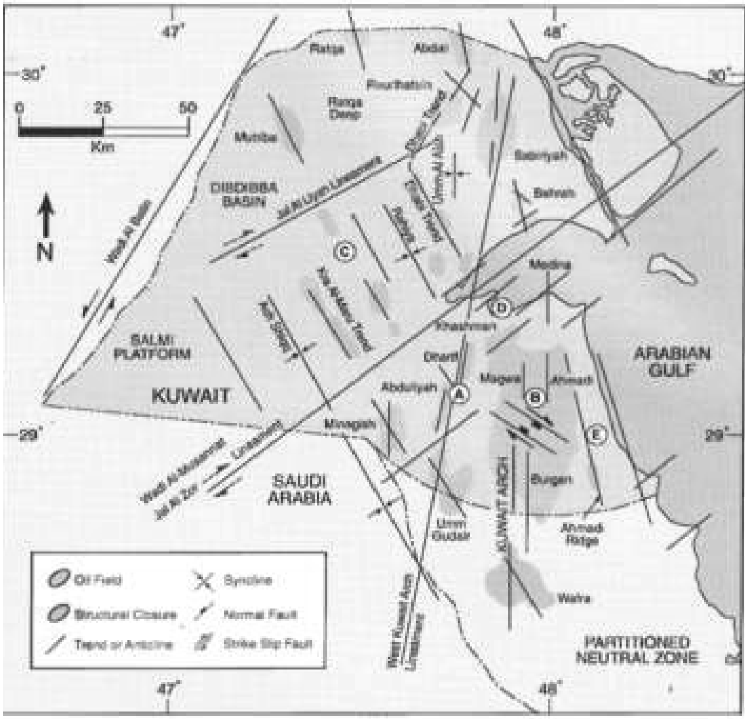

Figure 2. Structural elements of onshore Kuwait based on subsurface structure (Carman, 1996).

These anticlines have a northeasterly trend and have been formed by vertical movement since Cretaceous time. The Alahmadi ridge has been formed by horizontal compression in post-Eocene times, probably related to the Zagros Orogeny. The Jal-Azor escarpment is an erosional feature, while its origin may have begun as a Middle Eocene growth fault in Kuwait Bay (Carman, 1996). Wadi Al-Batin has been formed because of stream erosional processes and was controlled by the deep-seated lines of faulting of the late Eocene.

The physical properties of Alahmadi's soil were studied to find out if the oil residue can leak through the soil. Alahmadi's soil is mainly arid, brittle loss, and not well developed due to lack of water supply from rain fall (Alkhaledi et al., 2015). The density of a soil is inversely related to the porosity. Alahmadi's soil has high bulk density of an average of 1.6 gm/cm^{-3}. Permeability is a measure of how well porous media transmit a fluid. The permeability values of Alahmadi's soil are from $11.7x10^{6}$ to $1.6x10^{6}$ md or 1.6-11.7 Darcy, which is generally moderate. The permeability values decrease as the depth increases in Alahmadi area (Alsarawi et al., 1998).

The aim of this study is to assess the volume of contaminated soil and the contaminant composition and to estimate how deep the contamination penetrated the soil around the selected locations for testing. Then upon confirmation of the contaminant constituents, suitable remediation plan was put on action to mitigate the hazards associated with the exposed contaminated soil.

METHODOLOGY

Field work

In the study area, typical construction area sizes for the oil pits vary from 16 m x 17 m to 30 m x 30 m, and the depth ranges between 1 m and 4 m. They were typically surrounded by clean sand berms of 1 m to 2 m in height with 1m in width. Some well head pits were lined with a geomembrane layer. The integrity of geomembrane barrier at each pit, if present, is unknown and may be compromised.

Five vandalized and abandoned wellheads in the Burgan oil field, owned by Kuwait Oil Company (KOC), were chosen to be excavated to preselected depths to examine the contaminated soil around the well head pits (Figure 3A and 3B).

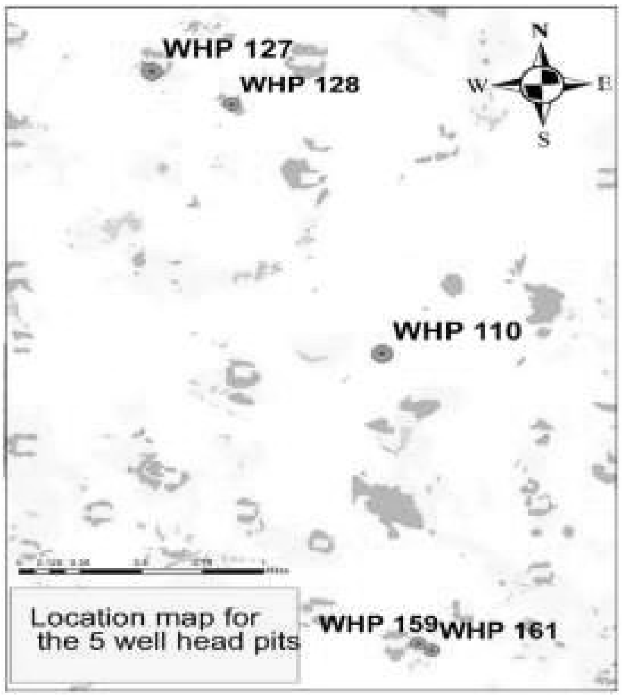

Figure 3A. Sampling Area for Well Heads 127 (No.1), 159 (No.2), 161 (No. 3), 110 (No. 4), and 128 (No. 5).

Figure 3B. Arial photograph for well heads 161 (No: 3) and 159 (No: 2).

Subsurface drilling was carried out using mechanical auger drilling techniques without betonies mud flush. The mechanical augers used for investigation in wellhead pits were 4 inches (Figure 4).

The vertical depth of boreholes dug in the study area ranges from 5 m to 10 m with 4-inch diameter. The borehole samples were collected from the surface downwards to the top of the uncontaminated soil. The vertical soil sampling was taken to visually find out the border line between the contaminated and uncontaminated zone; therefore, the depths of the contamination soil could be identified for each wellhead pit.

Then the collected soil samples were sent to the Total Petroleum Hydrocarbons (TPH) Kuwait Oil Company laboratory to be analyzed to determine the level and extent of residual contamination, to estimate the volume of contamination, and to choose the suitable remediation action.

Figure 4. Soil sampling process using auger boreholes drilling techniques at the tested area.

Figure 5. Wellhead pit photos show the present oil contamination.

Soil Sampling

Seventy-two discrete grab samples were collected from twenty boreholes vertically within the five wellhead pits. Samples were collected in a safe manner after switching off the rig machine temporarily and removal of the machine guard, then the samples were picked (after identifying different layer type) and collected into jars manually by using scoop provided by the laboratory.

Remediation Strategy for the deeper contaminated soils

Upon confirmation of the contaminated volume and depth, a suitable remediation action for the residual contamination in each wellhead was carried out (Mostagab et al., 2018). Remediation Methodology in the selected location or wellhead pits consists of mixing the contaminated bottom surface of wellhead pits with nutrients (chemicals).

For every wellhead pit, the identified quantities of the contaminated soil were assigned based on the size of the contaminated area and depth of contamination. The contaminated soil was excavated and shuffled, then it was mixed with calculated quantities of nutrients mixed with shredded chips. Addition of water moisture was sprayed over the mixture. Then compaction, leveling, and grading of the backfilled clean soil were done till the ground level.

RESULTS AND DISCUSSION

The destruction of Kuwait oil production facilities at the end of second Gulf War in 1991 resulted in catastrophic pollution of the soil, water, and air and the ground covering extensive areas, many of which are several kilometers long. Two levels of ground contamination are identified, one resulting from discharge of oil wells in ground soils and the other resulting from the aerial fall out of oil products blown out from oil wells.

The assessment of the present status of the well head pits (WHPs) after subsurface boreholes drilling methods showed the following details as summarized in Table 1.

Table 1. Details of each borehole volume and area for each wellhead pit.
Borehole locations are shown in Figure 3.

Sample No.	Company ID	Easting	Northing	Area (m^2)	Contamination Depth (m)
1	WHP127	786714	3204333	2500	1.2
2	WHP159	788472	3199688	960	2
3	WHP161	788556	3199633	987	4.3
4	WHP 110	788198	3202133	1245	1.53
5	WHP 128	787241	3204070	834	1.81

The results showed that the permeability of the soil decreases as the soil depth increases in the Alahmadi's area. The lower part of the ground soil appears to have created a barrier to the leaking oil and did not allow the oil to penetrate more than 4.3 meters around wellhead pit number three.

The laboratory analysis of the selected five wellheads pits showed that the concentration of petroleum hydrocarbons (TPH) was around 1% 8% and 4% of TPH in the center of pits #1, #8, and #3, respectively, whereas pits #4 and #5 had 7 % and 4% concentration of TPH. The results of the lab analysis show slight variations in the TPH percentages of oil in the soil samples (Table 2).

The present study of the lab measurements show low concentration of chemical compounds compared with what was reported in the early days of the oil spill incidents in 1991 (AlSarawi, et al., 1989, Al-Duwaisan and Al-Naseem, 2011 and Asem et al., 2016). This might be explained in different ways. One of the major causes is that after the wellhead pits were hit by Iraqis, Oil was blown away from the wellheads, and the slopes in the area of such pits made the surface movement of the oil very easy away from the surface of destroyed production wells in the Burgan area. Therefore, less oil accumulated near and at the locations of the wells. Another reason for less oil accumulations is that oil was not contained by soil barriers as it was done for the spills at low lands in Burgan field. The exposed oil accumulations in the Kuwaiti desert from twenty-eight years are highly affected by the weather conditions: heat, evaporation, and rainfall that worked its way in shrinking the size and the volume of hydrocarbons in the aggregates oil. The laboratory results for the total petroleum hydrocarbon weight in grams - TPHCWG (mg/kg) are shown in Tables 2 to 6.

In addition, the aromatics compounds (C6 to C35) were dissolved chemically by rainfall water mixed with the soil in the area. The annual rain fall in the desert of Kuwait is 135 mm/ year (Kuwait metrology department); some rain seasons might exceed the average rainfall. When this happens, it would accelerate the solubility of aromatic compounds of the petroleum hydrocarbons (TPH).

Table 2. Chemical composition at WHP-1.

Chemical Composition	Concentration mg/kg
C6 – C10	0.34
C10 – C12	0.48
C12 – C16	0.48
C16 – C21	0.43
C21 – C35	0.43
C35 – 44	0.093

Table 3. Chemical composition at WHP-2.

Chemical Composition	Concentration mg/kg
C6 – C10	0.34
C10 – C12	0.43
C12 – C16	0.46
C16 – C21	0.49
C35 – 44	0.43

Table 4. Chemical composition at WHP-3.

Chemical Composition	Concentration mg/kg
C6 – C10	0.34
C10 – C12	0.43
C12 – C16	0.43
C21 – C35	0.43
C39 – C44	0.43

Table 5. Chemical composition at WHP-4.

Chemical Composition	Concentration mg/kg
C6 – C10	0.34
C10 – C12	0.43
C12 – C16	0.43
C16 – C21	0.43
C21 – C35	0.43
C35 – C44	0.43

Table 6. Chemical composition at WHP-5.

Chemical Composition	Concentration mg/kg
C6 – C10	0.34
C10 – C12	0.43
C12 – C16	0.46
C16 – C21	0.43
C21 – C35	0.43

The moisture results for the soil samples range between 2.3% and 3.8% (Table 7). The Moisture content variation is due to long drought period in the desert environment of the area of Burgan oil field.

Table 7. Moisture Measurement & Percent.

Number well head	% Measurement
1	2.5
2	2.3
3	3.8
4	2.8
5	2.7

The electrical conductivity values, which measures the level of salinity in the soil, ranged from 45 MS/cm to 2600 MS/cm (Table 8).

Table 8. Electrical conductivity of soil samples.

Well head Number	(MS/cm) Measurement
1	2303
2	23330
3	2448
4	6299
5	2600

The electrical conductivity data values are consistent with the desert dry weather environment, with less influx of water from rain. More salt accumulates in the soil over time, but there is not enough rainfall water to wash salt from the desert soil environment; therefore, more salt dissolved on it.

The volatile organic compounds measured for the five wellhead pits appear to occur in small weight numbers 0.5 mg/kg, (Table 9). This is explained by the disappearance of all or most of the volatiles by evaporation that originated from the broken well pipes. This has led to accumulation of the crude oil around the pits. Moreover, the migration of dunes to the Burgan oil field desert caused the burial of most of the volatiles.

Table 9. Volatile organic compound for the five wellheads.

Wellhead Number	Value
1	0.5
2	0.5
3	0.5
4	0.5
5	0.5

The data recorded for the sulfur content of the five wellhead pits showed that the crude oil of Burgan has high percentage of sulfur or 3.31% (Tables 10 and 11). Sulfur is a natural component of oil trapped in oil reservoir of Burgan field. Albesharah (1991) had similar finding for the crude oil of Burgan with reference to high sulfur content.

Table 10. The physical and chemical properties of typical crude oil of Kuwait.

Properties	Burgan
- Viscosity at 30 C°	64.9
- Density at 15C°	0.9
- Salt (1b11)	1.5
- Ash	0.1
- Sulfur (wt10)	3.31
- Nitrogen (wt10)	0.21
- Carbon (wt10)	80.2
- Hydrogen sulfides (mg1L)	0.18
- Heating value (ATU/1b)	18.600

Table 11. Sulfur content in the five wellhead pits soil samples.

% Well head No. 1	% Well Head 2	% Well Head 3
1	1.25	2
1.5	1	1.64
1.75	2.75	2.22
2	2.35	1.35
2.1	2	2.6

When the fires broke down in the wellheads, they produced distinct plumes of different sizes. The distance of the plumes originated from the wellheads depended on the heat developed from the burning wells, the wind speed, the size of plumes (with high heat), and the pressure of wind. Some plumes were reported to be about 20–25 km from the wellheads (Husain, 1994). This explains the scattering of the sulfur content over a large area around the wellheads. The sulfur content in each wellhead pit is shown in Figure 6.

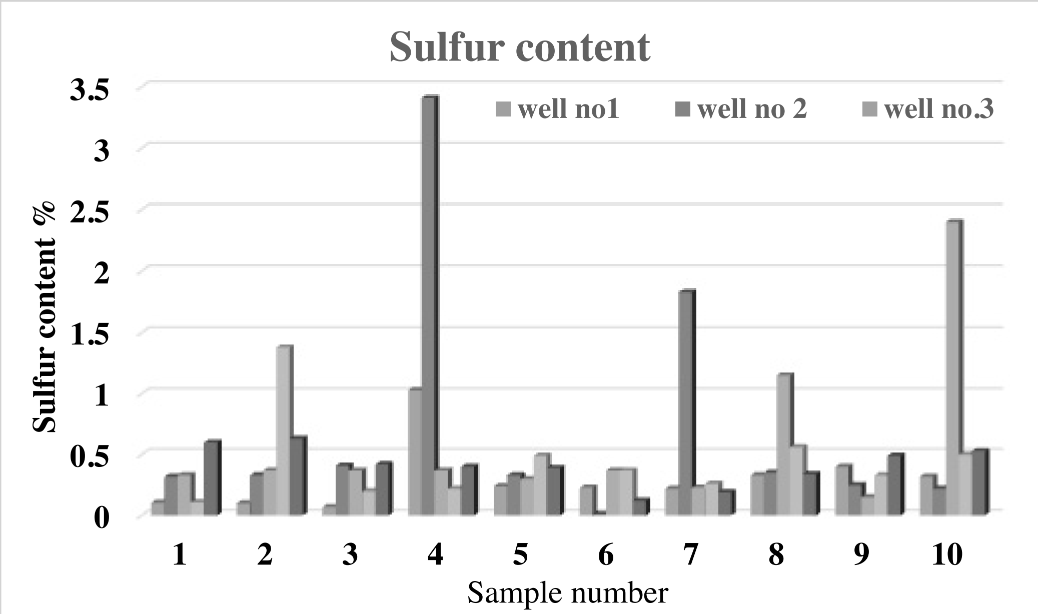

Figure 6. The sulfur content of each wellhead pit.

Health and Safety Risk Assessment of Hydrocarbons and Sulfur

The atmosphere is the major receiver of the Petroleum Hydrocarbons (PAH) dispersed particles, which cause a serious threat to the environment. PAH particles are usually generated during the incomplete burning of the organic hydrocarbons (Kim et al., 2013). PAH particles are flammable airborne in the atmosphere and very rapidly they can enter into the human body through inhalations (Figure 7). The major source of PAH in soil is the atmospheric deposition. The tendency of PAH to be sorted in the soil depends on the type of hydrocarbons and the soil as well.

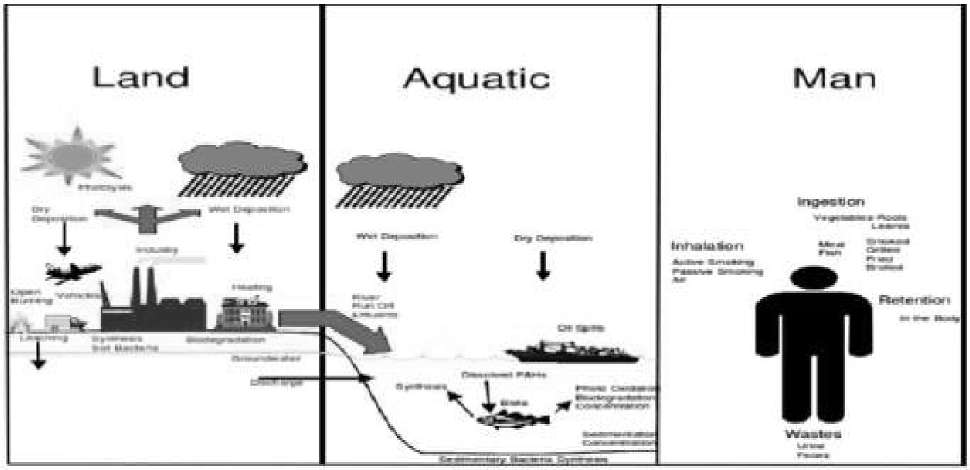

Figure 7. The hydrocarbons reach human body (Kim et al., 2013).

PAH dispersed particles can cause high risk to public health due to their wide spread diffusion in the air. Some of these particles can cause serious threat to human organs. Cancer is one of the common diseases associated with PAH effects on the human body (Kim et al., 2013). Some diseases can be, more or less, due to the sulfur dissolved within

PAH, no matter if sulfur reached soil or inhaled in the lungs. One of the benefits of cleaning oil spills is lowering the risk associated with the spilled and burned hydrocarbons. Reducing dispersed PAH would bring clean air quality (Alkhaledi, 2015).

Remediation actions

After the five wellhead pits were sampled, and the total petroleum hydrocarbons were characterized based on volume and depth of oil contamination at each wellhead (Table 12). The remediation plan was implemented by selecting nutrients required for remediation by mixing the nutrients with contaminated soil to remove the sulfuric hydrocarbons (PHS) from it (Figure 8).

Table 12. Nutrients required for remediation.

Sample No.	Nutrients Requirements (kg)	WHP 159	WHP 161	WHP-127
1	Urea (Nitrogen Source)	500	500	150
2	Super Phosphate (Phosphate Source 0.27)	200	200	50
3	Potassium Sulphate (Potassium Source 0.45)	150	150	40
4	Compost Material (Bio- Compost)	150	150	40
5	Wood Chips	150	150	40

(A)

(B)

Figure 8 (A & B). Remediation of the contaminated soil using the nutrients at the designated sites.

CONCLUSSION AND RECOMMENDATION

After analyzing the results of the collected boreholes samples, the greatest depth to the base of contamination soil section (4.3m) was found at wellhead No. 3, whereas the lowest was (1.2m) found at wellhead No. 1. The spilled hydrocarbon remains in the soil since the explosion of the wellheads in the Kuwaiti desert and can cause series health risk potential and economic problems. This study promises to represent a substantial improvement to environment and health. The contaminated soils in the area were identified. The necessary remediation actions were made using different quantities and mixing of nutrients.

Future studies are recommended to collect remediated soils to evaluate the effectiveness of the remediation plans, and for further actions.

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