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Study of Characterization of Oil Contaminated Soil in Kuwait" Hera Ag Ambiental Company Soil Remediation Project Kuwait

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Abstract

During the Gulf War (1991) more than 600 oil wells were set on fire. The gushed oil from Kuwait wells created what is known as oil lakes by filling natural depressions in the topography and artillery trenches which even contain live ammunition. Since the liberation of Kuwait, individual efforts tried to decontaminate the soil with only partial successes. Recently, a joint project between the United Nation Compensation Commission (UNCC), Kuwait National Focal Point (KNFP), and Kuwait University (KU) has been initiated to conduct a comprehensive work to eliminate the contaminated soil and its environmental impacts. The objective of this study is to characterize oil contaminated soil by the assessment of its physical, chemical, and geotechnical properties. Kuwait Oil Company is committed to a sustainable remediation solution to environmental damage resulting from the 1991 gulf war. A large number of oil wells in Kuwait were damaged and ignited by the retreating Iraqi troops during the 1991 Gulf War. The resulting spillage of huge volumes of crude oil on the surface gave rise to oil lakes and crude oil–impregnated soil. Moreover, products of crude oil combustion had spread over a large tract of the ground surface, causing widespread contamination of soil. Hydrocarbon contamination of ground water by the infiltrating runoff water carrying the contaminants from the surface soil to the water table and/or through direct contact with the crude oil leaking through the damaged casing in the subsurface was feared. This project was carried out to investigate the extent and nature of this possible contamination soil as well as ground water.

Introduction

The State of Kuwait lies at the northwestern corner of the Arabian Gulf; it covers an area of about 17,818 km2 and is bordered by the Republic of Iraq from North and West, and to the South and South-West by the Kingdom of Saudi Arabia. Kuwait has an approximately 290 km of coastline (Arabian Gulf) on the East. The state contains a total of 10 oil fields, which

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include 909 oil wells, divided based on their location into southern and northern parts. The northern oil fields include Ratga, Raudhtain, Sabriaya, and Bahra, fields containing 143 oil wells. The southern oil fields are Ahmedi, Burgan, and Maqwa, which are grouped together to form the “Greater Burgan” oil filed. Along with Greater Burgan oil field, Minagish, Umm Gudair, and Wafra are also southern fields, where altogether, the southern fields, contain 766 oil wells. After the Gulf war in 1991, it was estimated that 613- 798 oil wells were set on fire, 76 were gushing oil, 99 were damaged, and 155 remained in intact .Approximately 20-25 million barrels of ignited crude oil were extinguished using 12 billion gallons of seawater collected in artificial pounds.

The accumulated spilled oil in the slightly depressed area of Kuwait desert formed over 300 large spots consisting a mixture of water (28% on average), salt (more than 10%), oil and sand which are called “oil lakes” As a result, 114 km2 of the Kuwait desert was contaminated with oil causing environmental problems for air, land, coast, ground water, and surrounding life. Fortunately, Kuwait Oil Company (KOC) recovered approximately 21 million barrel of the oil lakes since the liberation of Kuwait leaving 34−49 km2 of oil lakes with (16.5-22.7) ×106 m3 in volume. The aim of this paper is to characterize the oil lakes based on its type, physical, chemical, and geotechnical properties in addition to its level of contamination.

Objective (s) and Scope

The objective of this project is to characterize oil contaminated soil by the assessment of its physical, chemical, and geotechnical properties.Kuwait Oil Company is committed to a sustainable remediation solution to environmental damage resulting from the 1991 gulf war. A large number of oil wells in Kuwait were damaged and ignited by the retreating Iraqi troops during the 1991 GulfWar. The resulting spillage of huge volumes of crude oil on the surface gave rise to oil lakes and crude oil–impregnated soil.Moreover, products of crude oil combustion had spread over a large tract of the ground surface, causing widespread contaminationof soil. Hydrocarbon contamination of ground water by the infiltrating runoff water carrying the contaminants fromthe surface soil to the water table and/or through direct contact with the crude oil leaking through the damaged casing in thesubsurface was feared. This project was carried out to investigate the extent and nature of this possible contamination soil as well as ground water.

3. Research Methodology

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 .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).

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 Schaffer Test (Post Hoc Test).

CHAPTER OUTLINE OF THE PROJECT

1. Crude oil contamination on the Sabkha facies of Kuwait

1.1Oil trench-B8

2. Oil Lakes Characteristics

2.1Oil lake types

2.1.1 Wet oil lakes

2.1.2. Dry oil lakes

2.1.3. Oil-Contaminated piles

2.1.4. Oil trenches and associated oil spill

2.2. Oil Lakes Distribution, Dimension, and Extent

2.3. Oil Lakes Properties

2.3.1 Physical and Chemical Properties

2.3.2. Geotechnical Properties

1. Crude oil contamination on the Sabkha facies of Kuwait:

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. 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.

1.1Oil 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.

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 N (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 solidity in the control pits.

2. Oil Lakes Characteristics:

2.1Oil lake types:

Oil lakes vary in their type, area, volume, and depth of penetration. They differ in type due to the different formation condition. Studies categorized them into four types.

2.1.1 Wet oil lakes

Which is formed in areas of shallow depression and drainage channels. It's described as black, highly weathered and viscous liquid or semi-solid oil sludge over a thickness of oil contaminated soil that in turn overlies clean soil.

2.1.2. Dry oil lakes

contamination: occurs in shallow depression and flat areas and it is comprised of a black, moderately hard, tar-like dry surface layer overlying dark brown oil contaminated soil that in turn overlies Clean soil.

2.1.3. Oil-Contaminated piles

Occur when earthmoving equipment has been used to consolidate oil contaminated and/or liquid oil into mound. These piles were made to stop the flow of oil from Kuwait wells, to clean areas of heavy oil contamination to facilitate firefighting or subsequent KOC field operation.

2.1.4. Oil trenches and associated oil spill

Which consist primarily of oil-contaminated soil from back-filled trenches. Including in this category are oil contaminated soils associated with oil spills from Iraqi constructed pipelines.

It shows the type of contamination in term of effected area, volume, materials, and depth of penetration represented from several studies. The data indicates that the majority of Kuwait oil lakes are represented in dry oil lake while the least contaminated volume is occupied by the Tarcrete. It also shows that the dry oil lakes have a maximum penetration of 25 cm while trenches have more than 3 m.

2.2. Oil Lakes Distribution, Dimension, and Extent

Oil lakes were formed in nine major oil fields with different contamination volume (Fig. 2). Burgan field corresponds to the largest contaminated field, it account for 40% of the total contaminated volume, hence, it was chosen as a case study for this research.

2.3. Oil Lakes Properties

2.3.1 Physical and Chemical Properties

Soil properties are categorized into physical, chemical and geotechnical properties. In this study physical and chemical properties of Burgan soil were analyzed while the geotechnical properties were found for similar soil sample. Physical Properties were determined for different soil layers In Burgan area .The soil was characterized with extremely low permeability [(1.15 – 10) × 10 −6 m/sec] due to the presence of oil deposit on the top layer. This hydrophobic layer prevents water penetration. On the other hand, soil chemical properties were examined by evaluating eight ions concentrations and other chemical properties Results indicate the high availability of several ions (Ca^{2+}, Mg^{2+}, K^+, Na^+, and Cl^-). This is possibly due to the formation and seawater used for fire extinguishing.

2.3.2. Geotechnical Properties

In 1995, several tests were carried out to determine the geotechnical properties of the oil lakes in order to find an alternative for the usage of the contaminated soil for engineering purposes rather than clean it. Actual contaminated site was inaccessible hence the study used a similar soil sample represented in Jahra sand mixed with 3-6% by weight of heavy crude oil

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to represent contaminated soil. Several soil tests like compaction, tri-axial, consolidation, and direct shear test were carried out for both clean and contaminated soil samples. The results shown below indicate that the strength of the soil decreased while the compressibility increased due to the presence of oil.

Fortunately, the geotechnical properties tests are carried out again in 1997 to determinate the aging effect on oil contaminated soil within a period of six months. The results are shown in Table 6 shows that the impact of contamination is decreasing within time due to the evaporation of oil volatile compounds. As a result, the strength of the soil is increasing where the friction angle ö is increasing and the compression index Cc is decreasing within time. Hence, the represented data shows an improvement of the contaminated soil geotechnical properties due to the aging effects and the polluted soil can be used for engineering purposes.

3. Critical Assessment of the Environmental

3.1 Soils

Kuwait's 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%) [7]. Kuwait Institute for Scientific Research 144 S.A.S. Omar et al. [8] identified and characterized eight great soil groups (Petrogypsids, Torripsamments , Petrocalcids, Haplocalcids, Aquisalids, Calcigypsids, Haplogypsids, and Torriorthents). Of these, the Petrogypsids occur on level to gently sloping plains formed on the sand and gravel deposits of the Dibdibah Formation. The Torripsamments, on the other hand, normally occur on extensive sand sheets in the central and southeast directions. While Calcigypsid and Haplogypsid soil types are found in the northern part of Kuwait, the Haplocalcids occur in the north, south and central part of Kuwait. Aquisalids are found in the coastal areas and in Bubiyan and Failaka Islands [9, 10].

The land use is dominated by rangeland (75.12%), which is mainly used for grazing and recreational (camping) activities [7]. Oilfields and military activities occupy 7 and 4% of the total land areas, respectively.

3.2. Ecosystem Classification

Like in other Gulf Cooperation Council (GCC) countries, land resources in Kuwait are used for livestock grazing, water production, oil production, sand and gravel quarrying, agricultural production and camping/bird hunting during the winter season . As soil becomes extremely dry during the hot dry summer, it is vulnerable to erosion, particularly when it is disturbed or becomes barren On the basis of variations in the habitat characteristics (landform and soil characteristics), the floristic composition and the dominant species suggested six ecosystems: coastal plain and lowland ecosystem; desert plain ecosystem; alluvial fan ecosystem; escarpment, ridge and hilly ecosystem; wadi and depression ecosystem; and burchan sand dune ecosystem. Each of these ecosystems is characterized by a dominant plant community and associated with several other species.

4. Pre- and Post-War Impact on Terrestrial Environment

4.1Soil Compaction

Movement of heavy military machinery and personnel carriers in the open desert areas disrupted vegetation, wildlife and soils. Off-road transportation was concentrated in the southern border zone (about 175 km length, 10 km width), Ahmadi – Al Wafrah area, northeastern area and the area extending between Ali, Al-Salem Airbase and Al-Abraq Farm (western area) . It caused severe soil compaction to the majority of soil types. Depending on soil type, the degree of compaction and status of natural vegetation, soil compaction reduces the infiltration capacity of soils by 20–100% [2]. Consequently, the runoff erosion and terrain deformation increased. Off-road movement of vehicles has long been recognized as a major deleterious factor causing widespread damage to the vegetation and causing tracks on the soil surface. Apart from obvious damage to shrubs, annual vegetation is also affected, as soil compacts in the tire tracks. Soil compaction reduces the ability of the soil to hold water and decreases pore space.

5. Reversing the Damage to the Terrestrial Environment

5.1 Rehabilitation of Areas Damaged by Wellhead Storage Pits

Areas covered by the 163 wellhead storage pits are proposed to be rehabilitated by removing the berms around the pits, excavating the contaminated soil and treating it to remove the contamination and backfilling the pits with the treated soil. Application of a thin layer of gravel will stabilize the surface and facilitate the recovery of native vegetation.

5.2 Rehabilitation of Tarcrete-Covered Areas

An area of approximately 270 km 2 in the Kuwaiti desert is covered by tarcrete contamination. The tarcrete layer can be removed, treated to remove oil contamination and disposed of safely. After the removal of tarcrete, the surface can be stabilized with a thin layer of gravel. Alternatively, the tarcrete layer can be broken up manually with application

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of organic amendments in holes (fully decomposed bio solids, composts, etc.) to provide additional nutrients, enhance soil processes and improve the moisture retention capacity of the soil to accelerate the natural recovery process. Reseeding with native plants can further accelerate the recovery process.

6. Monitoring of Ground Water

A long-term monitoring of the fresh water fields in North Kuwait and brackish water fields in Central and Southern Kuwait was undertaken to assess the extent of actual pollution of the ground water resources from the damaged oil wells. The 23 monitoring wells, drilled and completed by the Kuwait Institute for Scientific Research (KISR) for the Ministry of Electricity and Water (MEW) during 1995–1996, were used for monitoring hydrocarbon pollution in the fresh water fields of North Kuwait (Figure 3). Monitoring of 30 to 35 wells, spread over the brackish water fields of Central and Southern Kuwait, was carried out for the same purpose. Methods of ultraviolet-visual-near-infrared spectrophotometry, Fourier transform infrared (FTIR) spectroscopy (U.S. EPA method 418.1), and laser-induced fluorescence (LIF) were used for the quantitative and qualitative assessment of hydrocarbon contamination of the ground water samples collected from the field. Fresh Water Fields, Before March 1999, the total petroleum hydrocarbon (TPH) content of water samples from selected monitoring Wells in the Raudhatain and Umm Al-Aish areas was being measured using U.S. EPA method 418.1 (U.S. EPA 1979, 1982), which uses the FTIR technique, modified to some extent to suit the local needs.

7. Health Effects of soil Contaminations

7.1 Pregnancy and Early Childhood Development

Exposure to crude oil in everyday life can lead to birth defects, miscarriages, and problems in early childhood to children. In the scientific data we gathered on health effects in Northeast Ecuador, there was one study devoted to pregnancy. There was one other document from Ecuador regarding early childhood leukemia, but no other documents specifically were devoted to pregnancy. From Kuwait, we found a total of seven studies that referenced pregnancy or early childhood development, especially in terms of birth defects, which are summarized and cited in Appendix B. For other spills, we found no studies that were devoted entirely to pregnancy. We did not find any documents regarding this topic in our search for scientific studies on the Exxon-Valdez oil spill and found only one advisory document on the Deep-water Horizon spill in the Gulf.

CONCLUSION AND RECOMMENDATIONS

During the Gulf War, Highly contaminated oil lakes were formed covering a large area of Kuwait desert. As a result of Oil presence, soil properties including physical, chemical, and geotechnical properties were affected negatively. Moreover, the contamination levels were sufficiently high compared with the clean soil. Hence, it is recommended to remediate the contaminated soil in order to reduce its impact on the environment or use the contaminated soil for engineering purposes. In the above 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.

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Abbreviations:

KOC- Kuwait Oil Company

KPC - Kuwait Petroleum Corporation

UNCC- United Nation Compensation Commission

KNFP- Kuwait National Focal Point

KERP- Kuwait Environmental Remediation Program (KERP)

KU- Kuwait University

TPH- Total Petroleum Hydrocarbon

TEM-Total Extractable Matter

TOC-Total Organic Content

OT- Oil Trench Itself

CAL - Central Analytical Laboratory

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CAL- Kuwait Institute for Scientific Research

DCM- dichloromethane

GCC- Gulf Cooperation Council

TDS- Total Dissolved Salts

EOD- Explosive Ordnance Detonation

OB -Open Burning

ROPME- Protection of theMarine Environment

NOAA- National OceanGraphic andAtmospheric Administration

HTTD- High Temperature Thermal Desorption

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