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RESEARCH ARTICLE

# KUWAIT ENVIRONMENTAL REMEDIATION PROGRAM: INORGANIC AND ORGANIC CHARACTERIZATION OF WET OIL LAKES, DRY OIL LAKES AND OIL CONTAMINATED PILES IN BURGAN FIELDS OF KUWAIT

**Vangala K., Al-Kandari A., Al-Barood A., Al-Jumah K, Al-Rewaih K. and Vijay K.**

Soil Remediation Group, Kuwait Oil Company, Ahmadi, Kuwait

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****Corresponding Author:***
***Vangala, K.***

**ABSTRACT**

This paper describes the contaminated features in one of the project area under South Kuwait Excavation, Transportation and Remediation (SKETR) in Burgan oil fields of Kuwait. The contaminated areas were particularly comprised of three main features viz. Wet Oil Lakes (WOL), Dry Oil Lakes (DOLs) and Oil Contaminated Piles (OCPs). The various types and layers of these main features (WOLs, DOLs & OCPs) were further described in the paper. For the purpose of characterization in terms of both inorganic and organic, soil samples were collected as per the international standard and were analyzed for key parameters such as pH, Sodium Absorption Ratio, Electrical Conductivity, Nutrients, Chlorides and Total Petroleum Hydrocarbons. The test results of the analysis particularly under various layers of each type of feature was discussed with a focus on the minimum, average and maximum values. Based on the test results discussed, it is concluded that Wet Oil Lakes were characterized as severely contaminated with hydrocarbon contamination in comparison to Dry Oil Lakes and Oil Contaminated Piles. It was also seen that much of the contamination was confined to top two layers in both Wet Oil Lakes and Dry Oil Lakes out of the total three layers.

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# INTRODUCTION

The State of Kuwait is located in the north-east corner of the Arabian Peninsula. The Kuwait desert was severely damaged by the detonation and destruction of oil wells and associated infrastructure at the hands of Iraqi troops during the 1990-1991 Gulf War (Nada, 2020). Most of the damages were from the aftermath of the burning of around 800 oil wells which were exploded. The burning oil generated smoke plumes that extended hundreds of square kilometers and reached distant locations. The flowing oil and fallout from the oil fire plumes spread over the desert surface covering vast areas of the Kuwait oil fields. The deposited oil formed, in places close to the oil wells, lakes of various dimensions. The United Nations resolutions declared ending of the Gulf War and established the United Nations Compensation Commission (UNCC) to provide for reparations to adversely affected countries, companies and individuals. In 1994, the Government of the State of Kuwait appealed to the UNCC to procure funding through the UNCC's war reparations initiative to remediate and restore environmentally damaged areas throughout the State of Kuwait. Subsequently, the United Nations Compensation Commission (UNCC), Kuwait National Focal Point (KNFP) and Kuwait Oil Company (KOC) established a joint project known as the Kuwait Environmental Remediation Program (KERP) to undertake comprehensive and collaborative remediation of the contaminated land that has an estimated volume in the region of 26 million m3 (Nada, 2020).

One of the project which deals with the South Kuwait Excavation Transportation and Remediation (SKETR Zone 2) under KERP addresses oil contaminated soil and sludge located in the Greater Burgan oilfield of Kuwait which is identified as South Kuwait (SK).

**Description of Contaminated Features:** The Contaminated Features in Greater Burgan Oil field has comprised of 3 main features i.e. Wet Oil Lakes (WOLs), Dry Oil Lakes (DOLs) and Oil Contaminated Piles (OCPs) and the description of these features is given below.

***Wet Oil Lakes (WOLs):*** The term wet oil lake (WOL) is used loosely as it was derived from historical observations made soon after the 1991 Gulf War for trying to describe the nature of the features created by the damaged oil wells. These features were formed from overland flow of oil emitting from damaged wells and settling in low lying topographic depressions. These features have subsequently undergone over 25 years of weathering and are now highly variable and range from crusts and sludge to 'liquid oil'. A standardized classification has been developed to describe the WOL and underlying soils in the Greater Burgan oilfields. WOLs typically comprise of three distinct layers:

- Layer 1 forms an oil-rich component in the form of a crust or oily sludge;
- Layer 2 comprises oil-stained, contaminated sand; and
- Layer 3 is the underlying visually non-contaminated sand.

The summary below describes the five main typologies that have been observed to be present as wet oil lakes (WOL).

**Type 1 - Hardened crust:** The hardened crust is typically very thin, <0.05m, and often brittle. Occasionally free oil product entrained within. These lakes have typically formed where shallow wet oil lakes have dried out, leaving a crust. The crust is variable but can include highly viscous like free product.

**Type 2 - Soft to hard bituminous skin / layer:** The thin (generally 0.05 m. or less) bituminous skin / layer can often, though not always, retain water beneath. These lakes show seasonal variability. During winter period, many though not all, of the Type 2 lakes can be readily traversed. During the summer months, the lakes can become more challenging to traverse as the Layer 1 material becomes less viscous.
Type 3 - Thin brittle crust overlying a wet oily slurry / sludge: The thin crust can be readily broken and does not support the weight of a person. Immediately beneath the crust there is water present. The water can either be a discrete layer of its own or form part of an oily emulsion, sediment slurry or jelly-like material. The thickness of Layer 1 depends on the condition of the emulsified oily sludge / slurry / jelly but can be in excess of 0.15m. This can make traversing these lakes more challenging, requiring additional works and/or equipment to readily access.

**Type 4 - Oily sediments:** These are found in the lowest lying lakes which act as natural drainage areas and have resultant sedimentation. Frequently wet with either standing water (typically in cooler periods) or perched/shallow groundwater presence. These lakes, during hotter periods, often evidence ground heave, sometimes with salt precipitation, and localized discrete free product presence. These lakes can also exhibit jellification. As such, these lakes are frequently, though not exclusively, non-traversable requiring additional support measures especially where shallow groundwater presence is likely. Thicknesses are highly variable and can range from very thin, <0.05m, to greater than 0.15m.

**Type 5 - Tar like weathered crude oil:** The lakes are black in appearance and in the height of summer some lakes have oil component that can be almost water-like. During cooler periods, the oil component can vary significantly from a hardened viscous mass to a thick paint consistently. After rainfall events, water ponding readily occurs. Type 5 lakes are anticipated to have some of the greater thicknesses of oil materials, typically > 0.15m and have estimated as being > 0.5m deep in larger lake features, though further characterization work is required to confirm. Access across these features is challenging, especially during the hotter summer periods.

***Dry Oil Lakes (DOL):*** A dry oil lake (DOL) typically comprises of several discrete layers as like Wet Oil Lake;

- Layer 1 is an overlying crust of weathered crude contaminated soil of variable thickness, dependent on the distance from the damaged source well. This layer comprise descriptions ranging from a friable crust to a bituminous skin. In most cases Layer 1 can appear as a black, moderately hard, tar-like dry surface layer.
- Layer 2 which comprises an oil rich, visually stained sand with varying concentrations of oil contamination.
- Layer 3 :Visually non-contaminated sands.

DOLs tend to comprise a predominance of Layer 2 material. This can either be exposed at surface or below a hardened oil crust or bituminous mat (referred to as Layer 1). The oil-stained sand (Layer 2) generally associated with the DOLs, is the result of oil leaching into the surface soils leaving the oil residues bound to sand particles. Where Layer 1 is present, it can have the appearance of being solidified / baked, in some cases from combustion. In other cases, it appears as a non-pumpable bituminous mat.

***Oil Contaminated Piles (OCPs) :***OCPs are defined under KERP as crude oil contaminated piles created where earth moving equipment has been used to consolidate oil-contaminated soil and/or liquid oil into mounds. In the immediate aftermath of the Gulf War, the OCPs were part of the effort to stop the spread of oil flow caused by the destruction of oil wells, and to clear areas of heavy oil contamination to facilitate fire-fighting activities. Since oilfield development in South Kuwait is on-going, as additional contaminated land (wet or dry oil lakes) is cleared for further production-related purposes, additional OCPs may be present. Based on field visits and visual assessment of the OCPs in SK, there is a portion of the piles with highly burnt and/or very hard, solidified material. OCPs exist as above ground piles but contamination associated with these features frequently extends below ground, within the OCP footprint, to varying depths. The various types of piles as observed at surface are summarized as follows:

Type A piles are visually clean or have a tarcrete-like covering with visually clean soils within. This is suggestive that either the area in which the pile exists did not have significant oilfield infrastructure damage or that the pile may have been present prior to the damage and destruction of oilfield infrastructure and was simply masked with a tarcrete-like covering. Type B piles appear to have low to moderate contamination levels evidenced by a light brown discoloration to the soil profile and, pile dependent, a broken crust like material. These OCPs, particularly on the extremities of the oilfield and where present as low-lying piles, have a wind-blown sand covering. Although not exclusively the case, where low-lying piles are present, these may be expedited for UXO (Unexploded Ordnance) clearance, or as a minimum UXO anomaly avoidance, to allow trial pitting and sampling from within the piles. Depending on the contaminant profile, minor remedial effort may be required. Type C piles appear to have moderate levels of contamination as evidenced by the medium brown discoloration to the surface soils. These piles have an absence of an outer crust or a broken-up crust though the surface soils are frequently cemented. These piles can have an increased presence of detritus, including damaged and broken flow lines and other metallic debris. In the areas of former Gathering Centers, metallic debris is more common. This debris is a consideration with respect to UXO anomaly avoidance and clearance activities. Type D piles are moderate to highly contaminated, evidenced by medium to dark brown soils. These piles frequently contain black coarse gravels and cobbles of consolidated and often burnt/fused crust material at surface. These generally larger piles are typically either domed or have been pushed into a raised flattened ramp profile. There can be metal debris embedded within these piles which needs to be considered during UXO clearance activities. Type E piles are highly contaminated and have dark brown to black colored sand with ponding and/or drainage of free product from within the pile during seasonal temperature variations. Frequently there are cobbles and/or boulders of fused soils present. These piles can be in areas with wet oil lakes present nearby. The pile shapes can vary significantly but are frequently either angular pyramidal or flattened with contamination ponding. These piles often have a large footprint.

# METHODS

The intrusive site investigation method BS5930:2015was used to characterize the Physical and Chemical/Biological properties of the existing hydrocarbon contaminated soils from all types of the features to interpret an appropriate remediation technology such as Bioremediation, Chemical and Mechanical treatment technologies (Soil washing). The various type of below listed parameters which were analyzed and their appropriate analytical practices / guideline specifications are described below:

***USEPA 9045 Method for pH:*** This method is an electrometric procedure for measuring pH in soils and waste samples. Contaminants may be soils, sludge, or non-aqueous liquids.

***EPA 430/9-86-004 Method for SAR and EC:*** In this method the level of soluble salts present in the contaminated soil can be classified by determining the electrical conductivity (EC) of the soil and it can be assayed for its elemental content. As the level of soluble salts increases, the usual effect is a decrease in plant growth due to reverse osmosis; therefore, soluble salt determination has considerable significance. Salinity will result from the high presence of Na-salt.

***USEPA 351.2 Rev2, USEPA 365.4, USEPA 7610 Method for NPK:*** This method covers the determination of total Kjeldahl nitrogen, phosphorus and Nitrogen in contaminated soil. This ratio provides the level of nutrients present in the contaminated soil.

***USEPA 300.0A Method Metals for Nitrate, Nitrite and Sulphate:*** This method determines the inorganic anions in reagent water, surface water, ground water, and finished drinking water.

**USEPA 325.1 Method for Chloride:** This analytical method is used for the determination of chloride from drinking, surface, and saline waters, domestic and industrial wastes.

***USEPA 310.1Method for Alkalinity:*** This automated method is applicable to drinking, surface, and saline waters, domestic and industrial wastes.

***ISO 10694:1995 Method for TOC:*** This method used for determination of the total carbon content in soil after dry combustion. The organic carbon content is calculated from this content after correcting for carbonates present in the sample.

***TPH (HEM) n-hexane extraction Method:*** As the objective is to remediate the contaminated soil to the required Remedial Target Criteria (RTC) of 1% Total Petroleum Hydrocarbons (TPH) based on the n-hexane extraction method (HEM) analyzed by USEPA Method 9071B. This method recommended to quantify low concentrations of oil and grease in existing contaminated soil, sediments, sludge.

***USEPA 8270Method for PAH (Polycyclic Aromatic Hydrocarbons):*** This method is used to determine the concentration of semi-volatile organic compounds in extracts prepared from various types of contaminated soils.

***USEPA 6010B Method Metals:*** This method has been validated for the ICP-OES analysis of 31 metal elements in various environmental matrices. It specifies quality control criteria for calibration validity, linear dynamic range, and method detection limits and describes the simultaneous, or sequential, multi-elemental determination of elements.

# RESULTS AND DISCUSSION

**Physical Characterization of Wet Oil Lakes, Dry Oil Lakes and Oil Contaminated Piles:** The Wet Oil Lake Soil Characteristics of Burgan Oil Fields (SKETR Zone 2) were presented in Table 1 for the parameters of inorganic and organic constituents. The Dry Oil Lake Soil Characteristics were presented in Table 2 and Oil Contaminated Piles characteristics were provided in Table 3. Although analysis was done for several parameters, only few parameters (pH, SAR, EC, Nutrients, & Miscellaneous) were discussed here under inorganic constituents and Total Petroleum Hydrocarbons (TPH) is discussed for organic constituent analysis.

***pH:*** In the natural environment, the pH of the soil has an enormous influence on soil biogeochemical processes. Soil pH is, therefore, described as the "master soil variable" that influences myriads of soil biological, chemical, and physical properties and processes that affect plant growth and biomass yield (B.Minasny, 2016). As most of the microbial species survives only within suitable pH range of the soil, it is one of the factor that should be considered in the remediation especially bioremediation of petroleum contaminated soils. The pH of the contaminated soil plays important role in remediation due to its adverse effects on various factors of the soil such as microbial diversity, availability of nutrients, biodegradability of hydrocarbons, solubility and availability of contaminants in soil.

For the Wet Oil Lake, the minimum reported value of 6.5 was observed in Layer 1 and the maximum value of 8.1 was observed in Layer 3. The average value for Layer 1 was 6.8, Layer 2 was 7.4 and Layer 3 was 7.8 (Refer to Table 1) indicating much of the WOLs are in the range of neutral to alkaline. Similarly, For the Dry Oil Lake, the minimum reported value of 6.5 was observed in Layer 1 and the maximum value of 8.9 was observed in Layer 3. The average value for Layer 1 was 7.5, Layer 2 was 7.1 and Layer 3 was 8 indicating much of the DOLs are in the range of neutral to alkaline. The OCP's pH value varied between 6.9 to 8.4 with an average value of 7.6 indicating slightly alkaline in nature.

***Sodium Absorption Ratio (SAR):*** The information on spatial distribution of soil salinity has great importance for planning of remediation of contaminated soil due to the sensitivity of certain type of plants to salts. The appropriation of the soil can be determined by the SAR and EC of a similar non-contaminated layer at a nearby representative, control location in the course of contaminated soil remediation. In naturally saline soils, the suitability of SAR may be different than that for EC. In this case, SAR and EC should be considered separately, relative to each one suitability of the soil. Two different criteria are currently recognized in the scientific literature as indices of soil salinity. These are the soil Electrical Conductivity (EC) and the soil Sodium absorption Ratio (SAR). The soil Electrical Conductivity is abbreviated as EC with units of dS m -1 ormmhos cm scientific literature as indices of soil salinity. These are the soil Sodium Absorption Ratio (SAR) and soil Electrical Conductivity (EC). The soil Sodium Absorption Ratio is abbreviated as SAR and is defined as Eq.1 (Rengasamy P, 1999)

$$SAR = Na^{+}/((Ca^{2+} + Mg^{2+}))^{0.5}$$

Where $Na^{+}$, $Ca^{2+}$, $Mg^{2+}$ = Measured exchangeable Sodium (Na), Calcium (Ca) and Magnesium (Mg) respectively in cmol/Kg.

For the Wet Oil Lake, the minimum reported value of 2.9 was observed in Layer 3 and the maximum value of 10.9 was observed in Layer 2. The average value for Layer 1 was 8.9, Layer 2 was 7.5 and Layer 3 was 3.5.

Similarly, For the Dry Oil Lake, the minimum reported value of 1.2 was observed in Layer 1 and Layer 3 whereas the maximum value of 15.5 was observed in Layer 1. The average value for Layer 1 was 4.6, Layer 2 was 1.3 and Layer 3 was 2.7.

The SAR in OCP reported a minimum value of 6.0, maximum value of 10.7 and average value of 7.5 respectively.

***Electrical Conductivity (EC):*** Electrical conductivity provide meaningful insight of evaluating soil properties (Butler, 2005). Soil electrical conductivity (EC) is a measure of the amount of salts in soil. It is an excellent indicator of nutrient availability and loss, soil texture, and available water capacity. The existing range of the Electrical conductivity levels are an indirect indicator of the amount of water and water-soluble nutrients available for plant uptake such as nitrate-N and Soil microorganism activity declines as EC increases.

For the Wet Oil Lake, the minimum reported value of 2,046 µS/cm was observed in Layer 3 and the maximum value of 30,080 µS/cm was observed in Layer 2. The average value for Layer 1 was 20,369 µS/cm, Layer 2 was 14,944 µS/cm and Layer 3 was 3,096 µS/cm. Similarly, for the Dry Oil Lake, the minimum reported value of 177 µS/cm was observed in Layer 3 and the maximum value of 7,250 µS/cm was observed in Layer 1. The average value for Layer 1 was 2,286 µS/cm, Layer 2 was 387 µS/cm and Layer 3 was 1,517. The Oil Contaminated Pile has minimum of 9,480 µS/cm and maximum of 29,075. The average Electrical Conductivity value in OCP is 15,151 µS/cm.

| **Parameters** | **Methods used** |
|---|---|
| **Chemical** | |
| TPH (HEM) | -*USEPA – Method 9071B* |
| PAH (USEPA-16 + Coronene) | -*USEPA 8270* |
| Metals (As, Ba, Be, Cd, Cr (as Cr (III), Cr (VI) and total Cr), Cu, Hg, Ni, Pb, Se, V, Zn, Boron (Hot Water Soluble) | -*USEPA 6010B* |
| pH | -*ISO 10390, EPA 9045* |
| Salinity (SAR and EC) | -*EPA 430/9-86-004, Saturated Paste Extract, AAS orICPES or EPA equivalent* USEPA – Method 120.1, 9050AElectrical Conductivity |
| Available nutrients (NPK) | -USEPA 351.2 Rev2, USEPA 365.4, USEPA 7610 |
| Nitrate, Nitrite and Sulphate | -*USEPA 300.0A* |
| Chloride | -*USEPA 325.1, 325.2* |
| Alkalinity | -EPA 310.1 |
| Total Organic Carbon | -ISO 10694:1995 BS7755-3.8:1995 |

**Table 1. Wet Oil Lake Soil Characteristics – SKETR Zone 2**

| Parameters | Layer 1 | | | Layer 2 | | | Layer 3 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Min. | Max. | Ave. | Min. | Max. | Ave. | Min. | Max. | Ave. |
| TPH (HEM) (mg/kg) | 120,587 | 330,788 | 235,852 | 8,457 | 173,311 | 31,809 | 563 | 1,279 | 841 |
| pH | 6.5 | 7.1 | 6.8 | 7 | 7.8 | 7.4 | 7.5 | 8.1 | 7.8 |
| Moisture Content (%) | 2.1 | 14.3 | 9.7 | 2.8 | 13 | 8.6 | 3.6 | 7.8 | 5 |
| Sodium Adsorption Ratio | 8.4 | 9.4 | 8.9 | 6.4 | 10.9 | 7.5 | 2.9 | 4 | 3.5 |
| Electrical Conductivity (µS/cm) | 17,988 | 22,665 | 20,369 | 10,450 | 30,080 | 14,944 | 2,046 | 4,130 | 3,096 |
| Phosphorus (mg/kg) | - | - | - | 105.2 | 134.2 | 120.9 | - | - | - |
| Potassium (mg/kg) | - | - | - | 17 | 58.1 | 39.7 | - | - | - |
| Nitrogen (mg/kg) | - | - | - | 5.1 | 16.5 | 11.3 | - | - | - |
| Nitrate (mg/kg) | - | - | - | 1.1 | 3.8 | 2.6 | - | - | - |
| Nitrite (mg/kg) | - | - | - | <0.5 | <0.5 | <0.5 | - | - | - |
| Sulphate (mg/kg) | - | - | - | 620.6 | 1841.1 | 1275.8 | - | - | - |
| Chloride (mg/kg) | - | - | - | 380.8 | 1129 | 803.3 | - | - | - |
| Arsenic (mg/kg) | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| Cadmium (mg/kg) | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| Chromium III (mg/kg) | 16.1 | 26.5 | 23 | 11.5 | 23.6 | 18.6 | 8.1 | 19.2 | 13.7 |
| Chromium VI (mg/kg) | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| Chromium Total (mg/kg) | 16.1 | 26.5 | 23 | 11.5 | 23.6 | 18.6 | 8.1 | 18.2 | 13.7 |
| Copper (mg/kg) | 3.7 | 6.1 | 5.3 | 2.7 | 5.4 | 4.3 | 1.9 | 4.2 | 3.2 |
| Nickel (mg/kg) | 14.5 | 23.9 | 20.7 | 10.3 | 21.2 | 16.7 | 7.3 | 16.4 | 12.4 |
| Lead (mg/kg) | 1.8 | 2.9 | 2.5 | 1.3 | 2.6 | 2 | 0.9 | 2 | 1.5 |
| Zinc (mg/kg) | 11.8 | 19.4 | 17.4 | 8.4 | 17.3 | 14.1 | 5.9 | 13.9 | 10.3 |
| Mercury (mg/kg) | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| Vanadium (mg/kg) | 12.4 | 28.8 | 23.1 | 8.9 | 23.9 | 19.5 | 6.2 | 20.7 | 5.5 |
| Beryllium (mg/kg) | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| Water Soluble Boron (mg/kg) | 5.1 | 9.6 | 8.4 | 3.6 | 8.3 | 7 | 2.6 | 7.2 | 5 |
| Selenium (mg/kg) | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| Barium (mg/kg) | 133.2 | 165.8 | 153.1 | 95 | 139.5 | 125 | 66.7 | 120.6 | 91.4 |
| PAH (mg/kg) | - | - | - | <0.5 | <0.5 | <0.5 | - | - | - |
| Porosity (%) | - | - | - | 44.9 | 48.7 | 46.9 | - | - | - |
| Bulk Density (g/cm3) | - | - | - | 1.3 | 1.5 | 1.4 | - | - | - |
| Speciated Phenols (mg/kg) | - | - | - | - | - | - | - | - | - |
| Total Alkalinity (mg/kg) | - | - | - | 65.3 | 279 | 163.8 | - | - | - |
| TOC % | - | - | - | 1.3 | 4.2 | 2 | - | - | - |
| COD (mg/kg) | - | - | - | 1,649 | 3,891 | 2,501 | - | - | - |
| BOD (mg/kg) | - | - | - | 471 | 846 | 670 | - | - | - |
| VOC (mg/kg) | - | - | - | - | - | - | - | - | - |
| SVOC (mg/kg) | - | - | - | - | - | - | - | - | - |
| Bacterial Count (CFU/gm) | - | - | - | 410 | 9,422 | 2,295 | - | - | - |

***Nutrients:*** Soil nutrients are important for healthy plant growth. Some soil nutrients such as nitrogen (N), phosphorus (P), potassium (K), sulfur (S), magnesium (Mg), and calcium (Ca) are key components of organic compounds in plants, such as proteins and nucleic acids, or contribute to the internal control of cellular pH and osmotic potential. These elements are collectively described as macronutrients (M.B. Peoples, 2014). Although the existing soil microorganisms have apparent pollution remediation potential, a shortage of necessary nutrients or activation of the degradation metabolic pathways inhibits or delays microbial repair.

The addition of nutrients Nitrogen, Phosphorus and Potassium promotes the efficient oxidation of carbon substrates and also accelerating bacterial growth, hydrocarbon catabolism. For the Wet Oil Lake layer 2, the minimum reported values of nitrogen, phosphorus and Potassium are 5.1 mg/kg, 105.2 mg/kg and 17 mg/kg respectively. The maximum reported values of nitrogen, phosphorus and potassium are 16.5 mg/kg, 134.2 mg/kg and 58.1 mg/kg respectively. For the Dry Oil Lake, the minimum reported value of nitrogen is 8.9 mg/kg, phosphorus 26.5 mg/kg and Potassium 9.7 mg/kg.

**Table 2. Dry Oil Lake Soil Characteristics – SKETR Zone 2**

| Parameters | Layer 1 | | | Layer 2 | | | Layer 3 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Min. | Max. | Ave. | Min. | Max. | Ave. | Min. | Max. | Ave. |
| TPH (HEM) (mg/kg) | 31,241 | 85,740 | 61,380 | 7,152 | 58,414 | 22,850 | 311 | 1,254 | 704 |
| pH | 6.5 | 8.8 | 7.5 | 7.1 | 7.1 | 7.1 | 7.3 | 8.9 | 8 |
| Moisture Content (%) | 0.4 | 4.06 | 2.22 | 8.9 | 0 | 0.2 | 0.3 | 5.3 | 2.5 |
| Sodium Adsorption Ratio | 1.2 | 15.5 | 4.6 | 5.6 | 0 | 1.3 | 1.2 | 5.8 | 2.7 |
| Electrical Conductivity (µS/cm) | 195 | 7,250 | 2,286 | 6,203 | 0 | 387 | 177 | 6,080 | 1,517 |
| Phosphorus (mg/kg) | N/A | N/A | N/A | 26.5 | 155.5 | 108.9 | 78.1 | 105 | 87.3 |
| Potassium (mg/kg) | N/A | N/A | N/A | 9.7 | 83.7 | 43.9 | 21.9 | 31.8 | 26.4 |
| Nitrogen (mg/kg) | N/A | N/A | N/A | 22 | 85.5 | 41 | 8.9 | 17.4 | 12.9 |
| Nitrate (mg/kg) | 2.3 | 6.8 | 4.2 | 1.3 | 7.5 | 4.3 | 0 | 2 | 0.4 |
| Nitrite (mg/kg) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Sulphate (mg/kg) | 113.5 | 335.5 | 200 | 64.9 | 339.2 | 181 | 67.8 | 135.6 | 96.4 |
| Chloride (mg/kg) | 99.3 | 468.1 | 237.5 | 35.6 | 545.5 | 219.8 | 17.3 | 86.7 | 51.5 |
| Chromium III (mg/kg) | 11.4 | 43.2 | 27.7 | 10.2 | 45.2 | 24.4 | 5.3 | 40.5 | 18 |
| Copper (mg/kg) | 3.2 | 5.8 | 4.9 | 1.8 | 6.5 | 4.1 | 1.1 | 12 | 4.5 |
| Nickel (mg/kg) | 15.9 | 25.5 | 19 | 12 | 21.5 | 16.4 | 4.3 | 21.5 | 12.6 |
| Lead (mg/kg) | 1.2 | 5.5 | 2.7 | 1 | 5.2 | 2.1 | 0.9 | 5.5 | 1.8 |
| Zinc (mg/kg) | 10.5 | 20.5 | 14.2 | 8.5 | 19.7 | 15.9 | 4.6 | 18.5 | 12.1 |
| Mercury (mg/kg) | | | | | | | | | |
| Vanadium (mg/kg) | 5 | 31.5 | 19.6 | 9.2 | 35 | 20.1 | 2.7 | 32.5 | 12.5 |
| Beryllium (mg/kg) | | | | | | | | | |
| Water Soluble Boron (mg/kg) | 2 | 11.3 | 6.5 | 1.8 | 11.3 | 6.5 | 0 | 12.5 | 4.6 |
| Barium (mg/kg) | 43.5 | 95.5 | 57.3 | 10.5 | 102.3 | 57.8 | 25.1 | 85.5 | 47.7 |

**Table 3. Oil Contaminated Pile Soil Characteristics – SKETR Zone 2**

| Parameters | Oil Contaminated Pile | | |
|---|---|---|---|
| | Min. | Max. | Ave. |
| TPH (HEM) (mg/kg) | 40,450 | 122,114 | 81,664 |
| pH | 6.9 | 8.4 | 7.6 |
| Moisture Content (%) | 0.5 | 6.9 | 3.3 |
| Sodium Adsorption Ratio | 6 | 10.7 | 7.5 |
| Electrical Conductivity (µS/cm) | 9,480 | 29,074 | 15,151 |
| Phosphorus (mg/kg) | 79 | 133 | 106 |
| Potassium (mg/kg) | 24 | 40 | 32 |
| Nitrogen (mg/kg) | 17 | 26 | 21 |
| Nitrate (mg/kg) | 2 | 3 | 2 |
| Nitrite (mg/kg) | <0.5 | <0.5 | <0.5 |
| Sulphate (mg/kg) | 695 | 1,156 | 823 |
| Chloride (mg/kg) | 2,038 | 4,221 | 2,751 |
| Arsenic (mg/kg) | <0.5 | <0.5 | <0.5 |
| Cadmium (mg/kg) | <0.5 | <0.5 | <0.5 |
| Chromium III (mg/kg) | 11.1 | 19.5 | 14.6 |
| Chromium VI (mg/kg) | <0.5 | <0.5 | <0.5 |
| Chromium Total (mg/kg) | 11.1 | 19.5 | 14.6 |
| Copper (mg/kg) | 2.2 | 4.9 | 3.1 |
| Nickel (mg/kg) | 15.4 | 22.2 | 18.4 |
| Lead (mg/kg) | 2.5 | 5.5 | 4.4 |
| Zinc (mg/kg) | 14.6 | 25.8 | 18.7 |
| Mercury (mg/kg) | <0.5 | <0.5 | <0.5 |
| Vanadium (mg/kg) | 4.9 | 20.6 | 15.8 |
| Beryllium (mg/kg) | <0.5 | <0.5 | <0.5 |
| Water Soluble Boron (mg/kg) | 2.4 | 6.2 | 3.7 |
| Selenium (mg/kg) | <0.5 | <0.5 | <0.5 |
| Barium (mg/kg) | 109 | 142 | 127 |
| PAH (mg/kg) | <0.5 | <0.5 | <0.5 |
| Porosity (%) | 25 | 37 | 30 |
| Bulk Density (g/cm3) | 2 | 2 | 2 |
| Speciated Phenols (mg/kg) | <0.5 | <0.5 | <0.5 |
| Total Alkalinity (mg/kg) | 40 | 128 | 96 |
| TOC % | 3.1 | 6.8 | 4.7 |
| COD (mg/kg) | 859 | 2,209 | 0 |
| BOD (mg/kg) | 245 | 631 | 441 |
| VOC (mg/kg) | <0.5 | <0.5 | <0.5 |
| SVOC (mg/kg) | <0.5 | <0.5 | <0.5 |
| Bacterial Count (CFU/gm) | 6,750 | 26,354 | 19,507 |

The maximum reported values of nitrogen 85.5 mg/kg, phosphorus 155.5 mg/kg and Potassium are 83.7 mg/kg. The Oil Contaminated Pile the minimum reported value of nitrogen is 17 mg/kg, phosphorus 79 mg/kg and Potassium 24 mg/kg. The maximum reported values of nitrogen 26 mg/kg, phosphorus 133 mg/kg and Potassium are 40 mg/kg.

***Other Parameters:*** Other parameters such as Nitrate, Nitrite, Sulphate and Chloride are also been analyzed for WOL, DOL and OCP. For Wet oil lakes the minimum value recorded for Nitrate, Nitrite, Sulphate and Chloride are 1.1 mg/ kg,<0.5 mg/kg, 620.6 mg/kg and 380.8 mg/kg respectively. And the maximum value recorded for Nitrate, Nitrite, Sulphate and Chloride are 3.8 mg/kg,<0.5 mg/kg,1841.1 mg/kg and 1129 mg/kg respectively. The average value recorded for Nitrate, Nitrite, Sulphate and Chloride are 2.6 mg/kg,<0.5 mg/kg,1275.3 mg/kg and 803.3 mg/kg respectively. For Dry oil lakes the minimum value recorded for Nitrate, Nitrite, Sulphate and Chloride are 0 mg/kg, 0 mg/kg, 64.9 mg/kg and 17.3 mg/kg respectively. And the maximum value recorded for Nitrate, Nitrite, Sulphate and Chloride are 6.8 mg/kg, 0 mg/kg, 339.2 mg/kg and 545.5 mg/kg respectively. The Oil Contaminated Pile the minimum reported value recorded for Nitrate, Nitrite, Sulphate and Chloride are 2 mg/kg, <0.5 mg/kg, 695 mg/kg and 2,038 mg/kg respectively. And the maximum value recorded for Nitrate, Nitrite, Sulphate and Chloride are 2 mg/kg, <0.5 mg/kg, 823 mg/kg and 2,751 mg/kg respectively.

**Organic Characterization of Wet Oil Lakes, Dry Oil Lakes and Oil Contaminated Piles**

***Total Petroleum Hydrocarbons (TPH - Hexane Extractable Matter)*:** Crude oil contains petroleum hydrocarbons which consist of three major groups of compounds. These are alkanes (paraffins), alkenes (olefins) and aromatics. Total petroleum hydrocarbon (TPH) is a term used to describe a large family of several hundreds of chemical compounds that originally come from crude oil. Crude oil is used to make petroleum products, which can contaminate the environment (Gustafson, 2007). Because there are so many different chemicals in crude oil and in other petroleum products, it is not practical to measure each one separately. However, it is useful to measure the total amount of TPH at a site (ATSDR, 1999). TPH (Hexane Extractable Matter – HEM) analysis used a hexane extraction and is analyzed to provide a single total hydrocarbon result. This analysis is designed for “oil and greases” and is not suited for defining volatile hydrocarbons that can be lost during the extraction process.
For the Wet Oil Lake, the minimum reported value was observed in Layer 3 at 563 mg/kg. and the maximum value was in Layer 1 at 330,788 mg/kg. The average value for Layer 1 was 235,852 mg/kg, Layer 2 was 31,809 mg/kg and Layer 3 was 841 mg/kg. Similarly, for the Dry Oil Lake, the minimum value was in Layer 3 at 311 mg/kg and maximum was in Layer 1 at 85,740 mg/kg. On the average, Layer 1 was 61,380 mg/kg, Layer 2 was 22,850 mg/kg and Layer 3 was 704 mg/kg. The Oil Contaminated Pile has an average TPH value of 81,664 mg/kg. The minimum and maximum reported value is 40,450 mg/kg and 122,114 mg/kg.

# CONCLUSION

Out of 3 Layers, for most of the inorganic constituents including pH, SAR, EC & Other Parameters, it appears that Layer 3 of both DOL and WOL is highly alkaline in comparison to other layers. In case of SAR, the Layer 1 of both DOL and WOL exhibited high value compared other in-depth layers of 2 & 3.

For TPH (HEM), Layer 1 of DOL and WOL is characterized with very high value indicating much of the hydrocarbon contamination is confined to top two layers of 1 & 2. The OCPs containted moderate levels of TPH ranging from 4% to 12.2%. Although one can get an idea of what type of remediation to be deployed for soils in WOLs, DOLs and OCPs based on the reported minimum, maximum and average values, a site specific soil characterization (SSLC) would be required. The excavation of soils and segregation in to various TPH bands (Low, Medium & High) would enable to plan the remediation based on the TPH band in an economical and environmental friendly manner.

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