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Chapter

# The Assessment Strategy for Selecting and Evaluating Geoenvironmental Remediation

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## Abstract

A large volume of oil-contaminated sand remains in the Kuwaiti deserts, causing threat to the groundwater and ecological system. The main aims of this research are to evaluate the situation of Kuwaiti oil lakes and identify the impact of contaminated soil on ecology and humans in Kuwait. This consists of two phases; the first phase summarises the results from field demonstrations and discusses the prospective of using different techniques for remediation of the oil-contaminated soil in Kuwait, while the second phase aims to compare and select the appropriate soil remediation techniques based on UN requirements. In this chapter, decision mechanism was carried out in compliance with the House of Quality (HOQ) analysis system. The total weighted score for each soil remediation method was determined to obtain the final decision.

**Keywords:** oil lakes, house of quality, soil remediation, Kuwait, TPH

## 1. Introduction

The State of Kuwait sustained significant and widespread environmental damage resulting from the Iraqi invasion in August 1990 and during the 1991 Gulf War. The occupation of Kuwait by the Iraqi army caused substantial damage to Kuwait's environment. Several oil lakes, i.e. oil accumulation in depressions, were formed. During the 1991 Gulf War, estimates of 798 oil wells were set ablaze; out of 914 operational oil wells, 149 were damaged, 45 were gushing oil, and 155 were undamaged [1–3]. Approximately 25 million barrels of ignited crude oil were extinguished using around 12 billion gallons of seawater. The gushing oil was spreading over the desert surface from the oil fire plumes, which covered vast areas stretching from Kuwait to the Kingdom of Saudi Arabia. Within the neighbourhood of the oil wells, various sizes of oil lakes were formed and spread across areas far away from the oil wells. Consequently, combustion products from oil fire and oil spray were able to cause contaminations of soil and groundwater [4]. More than 300 large oil lakes in low-lying areas within Kuwait desert were created from the accumulation of spilled oil. These contamination soil consist of water, salt, 28% average, in excess of 10%, respectively, where the oil and sand known as "oil lakes" were spreading over the surface of ground. These oil lakes were classified into major and minor; around 45 major oil lakes were located in the Burgan oil field as well as between Ahmadi and Maqwa oil fields; there were another 23 minor oil lakes [5–7]. Saeed [8] reported that the oil lakes contain crude oil and partially combusted oil with soot. At present, most of the oil lakes are dry, with the contamination comprising a black, moderately

| Source of contamination | Average depth (cm) | Extent ($km^2$) | Volume ($\times 10^6$ $m^3$) |
|---|---|---|---|
| Dry oil lakes | 25 | 98.38 | 25.5 |
| Wet oil lakes | 64 | 7.19 | 4.6 |
| Oil-contaminated piles | 173 | 8.59 | 14.8 |
| Oil trenches and pipeline spills | 351 | 1.63 | 5.7 |
| Total | | 115.79 | 49.6 |

**Table 1.**
*Volume of oil trenches and oil lakes in Kuwait (source: [9]).*

hard, tar-like dry surface layer. Four categories of oil-contaminated soil layers, namely, soot, tar mat, oil lake, and dry oil lakes, were identified during the field investigation. The fifth category is clean, where no contamination was detected. As illustrated in **Table 1**, it is fortunate that the Kuwait Oil Company (KOC) has been successful in recovering around 21 million barrels from the oil lakes since the end of the Gulf War with approximately 49 $km^2$ of oil lakes with 16.5 × $10^6$ $m^3$ in volume left to be recovered [9].

This catastrophe has created one of the greatest environmental impact issues to the coast, air, soil, groundwater, and the vicinity. In addition, it has been noticed that the oil lake depth varies from a few metres to a few centimetres, which constitute more than 60 million barrels of crude oil. Overall, almost 660 million barrels of crude oil were spilled to the surface, and therefore, around 55 million tons of contaminated sand is present in the lakebeds. The persistence of such a phenomenal amount of oil over a large land area is considered as one of the main environmental concerns in the State of Kuwait. There are no similar petroleum catastrophes in history that has ever been as tragic as this incident [6, 7]. Furthermore, approximately 49 $km^2$ which constitutes 28% of the total Kuwait land area was covered by oil mist and soot. As time goes by, lighter oil evaporated, oil mist became hard, while smaller and shallower oil lakes became dry thus forming tar mats. Under the extreme weather conditions, these contaminants continue to disintegrate slowly. The thickness of tar mat varies from a few millimetres to approximately 2 cm. The soot changed the soil beneath to black in the long run. It has been found by investigator Kwarteng [7] many of these oil lakes could not be detected from the surface since they were covered with a veneer of sand. Moreover, the author noticed in the different effected area of Kuwaiti desert that, the occasional flash floods and heavy showers were placed when the oil travelled to new sites. There are limited large-scale remediation processes implemented to deal and treat the contaminated areas thus far. The Kuwaiti environment is exposed to these oil contaminated soil and oil lakes since 1991 therefore the contamination is become a weathered oil contamination, which is required special strategy to deal with this disaster. The State of Kuwait is considered as the first country in the world who filed claims from the United Nations Compensation Commission (UNCC) for seeking compensation to rehabilitate and remediate the areas that sustained environmental damage. In 1991 UNCC had decided to sell Iraqi oil for distributing money as recompense "the money to be taken from the Oil-for-Food Programme" for damages suffered from the Iraq invasion. In 2003, the pace of the clean-up is anticipated to significantly increase over years of researches and claims. The UNCC awarded the state of Kuwait about US$3 billion in order to rehabilitate the effected area in the Kuwaiti desert during the Gulf War [3]. The KOC, UNCC, and Kuwait National Focal Point (KNFP) are providing the combined effort for the rehabilitation task. Currently, KOC is planned to coordinate bidding for contracts worth hundreds of millions of dinars in the upcoming months which will remain afterward every year. According to experts, the entire process

is expected to take approximately 29 years. In fact, Kuwait is the first country that claimed for environmental disaster from the Iraq invasion through the United Nations (UN), to rehabilitate Kuwait's environmental damage.

## 2. Engineering approaches

"Soil remediation" is referred to as the efforts which aim to reduce or remove the risks related to the contamination site. This objective can be easily achieved by using various ways; however, the most appropriate remediation method is governed by many factors, such as the conditions of site, financial constraints, and category of contaminants. Nathanail and Bardos [10] proposed that the remediation process can take place by degrading, removing, or transforming contaminants to the acceptable level. In situ and ex situ remediation process for rehabilitation of weathered oil-contaminated soil can be classified based on their treatment process, for instance, biological, chemical, physical, thermal, and electrical [11]. A number of various methods of remediation are presently available. Remediation techniques such as soil vapour extraction, bioremediation, electrochemical remediation and electrokinetic soil remediation, and ex situ soil washing have been developed lately in an effort to remediate soils contaminated with petroleum [12, 13]. In accordance with Ellis et al. [14], appropriate engineering solutions should be taken into account to ensure the remediation zone is contained and migration of leachate beyond the treatment zone is avoided. Should the conclusion require soil remediation, it should be tackled after the evaluation of technologies. The following outlines the soil remediation technology in comparison with the typical treatment approach. This includes remediation technologies that can improve the quality of soil through design and application which are central to soil clean-up process. The remediation is achieved by reducing or removing contaminations such as total petroleum hydrocarbons (TPHs), volatile organic compounds (VOC), semi-volatile compounds (SVOC), and metal contents.

### 2.1 Bioremediation

The biological remediation process is conducted by using microorganisms to degrade the contaminants to safe products and end products. Biological treatments have significant accomplishment by combining with other remediation processes and are easily implemented with contaminated soil [10]. Biological remediation is implemented at a low cost compared to the other alternative techniques [15], even though a wide variation occurs in terms of the environmental consequences, treatment time, and performance of these techniques [16]. As shown in **Figure 1**, bioremediation in 2008–2009 [17] comprised the most significant portion (21%) of the innovative activity which was reported by the Federal Contaminated Sites Action Plan (FCSAP) in Canada. Brief explanations of bioremediation process conducted in the remediation of contaminated soil are defined in the following section.

#### *2.1.1 Land farming*

Land farming is considered as an ex situ remediation process in which the contaminated soil is excavated and then applied into lined beds afterwards; the contaminated soil is tilled mechanically to aerate the waste. The contaminated soil is placed in several layers 0.4 m thick. A synthetic, concrete, or clay membrane is then used to cover the contaminated soil layer. Oxygen is added, and mixing occurs via ploughing, harrowing, or milling. Nutrients and moisture can be added to support the remediation method [18].

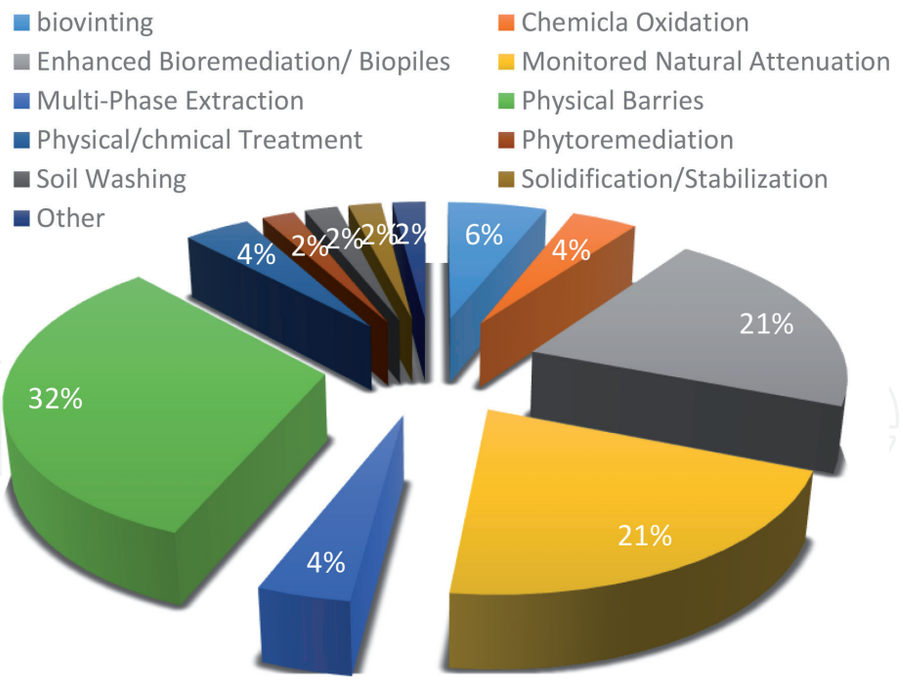



**Figure 1.**
*Distribution of innovative remediation activity (source [17]).*

### *2.1.2 Vermiremediation*

Vermiremediation is considered a less expensive and more acceptable remediation process for contaminated soil in the world. Generally, earthworms (especially *E. fetida*) have good resistance against contaminants including heavy metals and organic pollutants within the soil. This approach is carried out using the earthworms to bioaccumulate the contaminants within their bodies; moreover, these earthworms are able to biotransform or biodegrade the contaminants into harmless products with the presence of enzymes. Sinha et al. [19] reported that the earthworms have high resistivity to a number of chemical pollutants present in the soil. They concluded that 5 kg of earthworms (totalling to 10,000) are able to degrade 1000 kg of waste, converting the waste into vermicompost within only 30 days. One of the main features of this economic and environmental importance is that polluted land is not only cleansed but also improved in terms of its physical, chemical, and biological quality.

### *2.1.3 Bio-piles*

Bio-pile is considered as an ex situ remediation process in which the contaminated soils are excavated and combined with soil amendments and then placed on a treatment area. In order to enhance the remediation process, nutrients and oxygen are pumped into the contaminated soil using air injection system, which is buried under the contaminated soil during the remediation process to provide the required oxygen. This oxygen is supplied through the contaminated soil either by positive pressure or by vacuum to support the biodegradation process [10]. Many factors such as moisture, heat, nutrients, oxygen, and pH require to be controlled to enhance biodegradation process; the height of the soil piles should be up to 20 feet. This method has been conducted successfully to treat and rehabilitate soils contaminated with non-chlorinated VOCs and fuel-contaminated soil [19]; however, chlorinated VOCs, SVOC, or pesticides might be treated as well, but the effectiveness of the process varies [14].

### *2.1.4 Bioventing*

Bioventing is considered as an in-situ bioremediation process in which the contaminated soils inject by air pump to enhance and improve the existing soil microbial, where the movement of air is designed to maximise biodegradation while minimising volatilisation [10–19]. Bioventing process is for treating permeable soils because a huge volume of air is required to reduce and degrade VOC. Low air flow rate is required during the process to supply only enough oxygen to maintain the activity of the microorganisms in residual contamination in the soil. The current method provides oxygen using air injection system, which is inserted into the vadose zone. This technology has been implemented successfully to treat and rehabilitate soils contaminated with various levels of TPH or any chemical contaminants that can be aerobically biodegraded [19].

### *2.1.5 Windrow*

Windrows are considered as an ex situ remediation process in which the contaminated soils are excavated and combined with compositing materials such as bark, compost, or wood chips and then placed in windrows to increase and improve aeration process and enhance the structure of soil. Windrows are one of the waste management systems that use microbial activity to biodigest organic waste compounds and transform them into safe products. In order to transfer oxygen into contaminated soils, regular turning is conducted, thus enhancing aerobic degradation. Windrows system and waste composting are considered very similar in their methods [10–19]. Many aspects such as moisture, heat, nutrients, oxygen, and pH need to be maintained in order to improve the biodegradation process.

### *2.1.6 Phytoremediation*

Phytoremediation is the term used to describe a process based on biological technology which uses natural plant processes in improving degradation as well as eliminating contaminants in polluted groundwater or soil. In recent years, the emphasis in handling polluted ground has been slowly swung away from the conventional remove, dispose, and cap methods to a more on-site integrated technique. Attempts to develop these integrated approaches have caused a swing in awareness from reviewing the problems to addressing society's needs by devising potential solutions. It is possible to develop potentially sustainable methods such as phytorestoration and remediation which emphasise on restoring the usability as well as the land's social and economical significance. The utilisation of plants in reducing the volume, mobility, or toxicity of contaminants in soil, underground water, or any other polluted media is known as phytoremediation, which is a general term used since 1991 [20]. Several mechanisms are available to make use of plants in the process of phytoremediation for organic compounds, such as phyto-degradation, phytovolatilisation, and rhizodegradation. Many benefits can be offered by employing the phytoremediation method in either minimising risks or saving costs as compared with traditional excavation and landfilling methods, where contaminated materials or other usual methods of implementation are carried out on-site.

## 2.2 Thermal desorption

Thermal desorption aims to increase the volatility of contaminants to a gas phase or allow the contaminants to be melted by heating the contaminated soil. The preparation of this method is by means of rotary kiln plants, fluid bed, or sintering strand,

which is considered as fast method nevertheless; this method is classified as the most expensive remediation process. It is possible for contaminants such as VOC or SVOC to be vaporised and then rise to the unsaturated zone where they are collected using vacuum system to start another treatment procedure. For geological materials with moderate to high permeability, it is recommended to apply steam. The time it takes depends on three major factors: type and amounts of chemicals present, size and depth of the polluted area, type of soil and situations present [21].

*2.2.1 Ex situ thermal processes*

Ex situ thermal treatments convert pollutants from the soil to a gas phase. The pollutants are released by vaporisation and then burned at high temperatures. Ex situ thermal remediation depends on three factors: type and amounts of chemicals present, size and depth of the polluted area, and type of soil and conditions present [18]. In order to start the treatment process, the soil condition is required to be broken into small grains and sieved in preparation for thermal treatment. A low temperature range of 350–550°C is selected to heat the contaminated soil. Burning of the gases takes place at the top of the surface, but the VOC or SVOC are not destroyed. The gases at approximately 1200°C can be then combusted in an after-burner chamber; however, dioxins are destroyed [18, 19]. Moreover, ex situ thermal remediation processes are ideal for removing hydrocarbon compounds.

*2.2.2 In situ thermal processes*

The process involves injecting a steam-air mixture at 60–100°C into the contaminated soil to avoid the shifting of pollutants to the groundwater; the steam-air mixture should stay in that temperature range. After the injection, VOC and SVOC get converted from the soil to the gas phase. The gases are then removed from the subsurface using a soil vapour extraction (SVE) system and then remediated at the surface. Furthermore, in situ thermal remediation is used for homogeneous soils with high permeability and low organic content. In situ thermal processes are only appropriate for destroying pollutants, which can be stripped in the lower temperature range (e.g. BTEX) [10–18].

**2.3 Physical and chemical remediation**

Physical remediation method aims to rehabilitate and remediate contaminants by separating contaminants from soil. This method is focused on the physical differences between the contaminants and soil (e.g. volatility, behaviour in electric field) or among their physical properties (e.g. particle size, density, etc.) and soil properties [10–18]. There are several physical and chemical remediation techniques available for soil remediation which are described in the following section.

*2.3.1 Solidification/stabilisation*

Solidification/ Stabilisation (S/S) process is considered as an in-situ fixation or immobilization, which aims to alter the condition of contamination compounds to innocuous, and/or immobilize condition by using stabilizing agents into an area of contaminated soil. This process make the status of the contamination soil to be in low-permeability mass (solidification), or chemical reactions between the contaminants and stabilising agent which able to decrease their mobility (stabilisation) or physically bound. It is vital to have good knowledge of the hydrological regime, and it can be used to moderate- to high-permeability soils as well as different types of contaminants.

### *2.3.2 Electro-remediation*

Electro-remediation is an in situ remediation system which requires the use of low-intensity direct electrical current across pairs of electrode which is placed into the ground of the contaminated site. This ion migration are depending on their charge therefore, contaminates shifted towards respective electrodes. The remediation process can be supported using surfactant to accelerate the separation of contaminants at the electrodes. This technology is primarily a separation and removal procedure for extracting contaminants from various soils such as saturated or unsaturated soil, sludge, and sediment; additionally, this method is limited for sites where the soil is wet or saturated with water [22].

### *2.3.3 Soil venting and air sparging*

Soil venting and air sparging or SVE are used in treatment approaches by injecting gas (usually air or oxygen) into the saturated zone to volatile contaminants and stimulating biodegradation by augmenting subsurface oxygen concentrations [10–23]. The remediation system of SVE can be applied successfully for VOCs in relatively moderate- to high-permeability geologic soil. Among others, soil vapour is useful to extract compounds with high vapour pressure for low molecular weight (LMW) compounds. Nevertheless, this method is not suitable for organic compounds with low volatility, for example, polycyclic aromatic hydrocarbons (PAH), and unable to expel super heavy oil pollutants which contain high concentrations of resins and bituminous materials [24]. After airflow is switched off, contamination may transfer from these less accessible spots of contamination to recontaminate the soil atmosphere. Under high pressure of injection, it is easy to fracture the soil material which leads to pathways of air transfer to decrease the side effect of the treatment. In addition sparging must be activated with venting to detain the emissions of VOCs in air leaving the saturated zone. Treated soil, either from SVE in conjunction with air sparging or SVE alone, is usually collected for subsequent treatment, probably catalytic oxidation [25]. SVE has been conducted successfully to treat and rehabilitate soils contaminated with VOC, SVOC, or any chemical contaminants that can be aerobically biodegraded [19]; various factors need to be controlled during the remediation process such as moisture, heat, nutrients, oxygen, and pH to enhance the bioremediation process.

### *2.3.4 Soil washing*

Soil washing aims to use liquids such as water, occasionally combined with detergent or surfactant with mechanical processes, to separate the contaminants from soils. Frequently, the higher contaminated part of the soil is the fine fractions of soil. Moreover, if the fine fraction content is more than 30–40%, it may not be cost-effective to conduct the separation as a further remediation stage [26].

### *2.3.5 Geosynthetic applications*

As geoenvironmental applications are considered as a potential for rehabilitating contaminated soil, geosynthetic materials become vital in the industrial field, particularly geomembranes. The main role of a geomembrane is to reduce the migration of contaminants whether existing as liquid or vapour, either existing as a composite or a single liner barrier system, via base liners and into the surrounding environment [27]. Previous researches deduced that geomembranes could be used as protective layers nearby diesel tanks, in temporary containment barriers, landfill

and treatment walls, or in mining applications [28–30]. Geomembranes have been employed and evaluated for the first time in the soil remediation area, as a layer for biopile method in the composite liner barrier system used for treating hydrocarbon-contaminated soil [31]. Geomembranes have been used for a variety of applications during remediation of heavily contaminated sand with polychlorinated biphenyls (PCBs), hydrocarbons, and metal [32, 33]. They proposed to construct geomembranes in the landfill site as the base barrier system to filter and treat the contaminants from the spring thaw. This technique is required when contaminated soil or landfill needs to be isolated from the surrounding groundwater or ecological system to prevent the release of hazardous gases or liquids. Furthermore, Various advantage can be obtained by using geomembrane such as protecting people from contacting with hazards or reduce the impact of discharge water through the contaminated land which allow to decrease in leachate of these hazardous to the groundwater.

## 3. Methods

### 3.1 Site investigation

Field investigation was formulated to recognise, manage, and remediate the oil-contaminated sand. As the first step, the concentration and type of contamination present ought to be determined in the Greater Al-Burqan oil field. The data from the investigation will be utilised to plan future rehabilitation works. As such, the aim of this survey can be summarised as:

- Classify the types of damage.
- Assess the level of contamination in the affected soil.
- Provide information to assist in future land use planning and to determine remediation options using House of Quality (HOQ) analysis system.

The selected approached was based upon the concepts of soil survey. The main parameters measured were the depth of contamination (by site measurement), TPH level (using gravimetric method), colour of the soil (using Munsell colour chart), and the texture of the soil. The site investigation categorises the oil-contaminated soil into four layers, namely, liquid oil, tar mat, oily soil, soot and clean soil with no contamination. For remediation the bulk of the contaminated soil to be dealt with has oily soil characteristics; also in some areas the oily soil placed under the liquid oil requires to be treated. In addition, all of these areas may contain unexploded ordnance (UXO). Any method for remediation of the tar mat and soot would need to take into account that they occur over an extensive area and form a thin layer on the soil surface.

### 3.2 Preliminary survey

It is evident from the field data in **Figure 2** that these layers of contaminated oil can be segregated based on their colour and property consistency. Typically, weathered crude oil is black, oily soil is dark brown to black with a moderate to slightly hard consistency, while the colour of tar mat is black with a hard stability. The depth of these oil lakes is 70 cm below the surface; therefore, the crude oil has penetrated the soil to different depths subject to the condition and characteristics of the soil belowground (**Figure 2**).

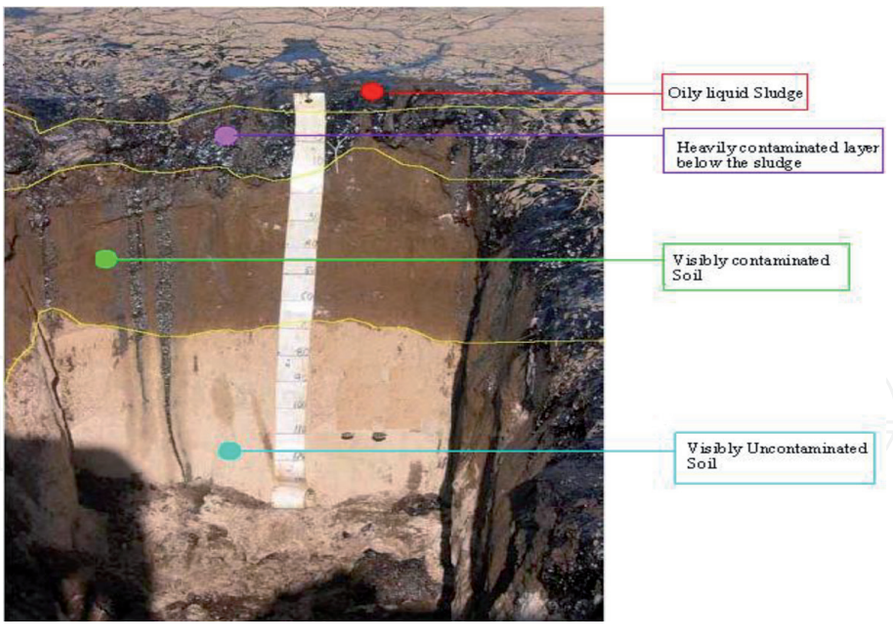



**Figure 2.**
*The layers in the oil lake at the Burgan oil field in the State of Kuwait (13 Jan 2012).*

A thick oily sludge deposit has covered the affected areas with a thicker layer beneath, and oil has seeped through aided by gravity and rainfall [6, 7]. Besides this, the quality of oil has deteriorated caused by prolonged exposure to the extreme weather. The volatile hydrocarbons within the oil structure have been lost, and the oil has endured changes in its chemical and physical properties causing its sale not as lucrative. The nature of layers and the manner they are arranged provide indication of the category of contamination, the three contamination categories in **Figure 2**. Different sorts of oil-contaminated soils might not be differentiated using only the analytical results. For example, field investigation is vital to classify these contaminations, as they require various remediation methods to remediate or rehabilitate the contaminated site or options of land use; furthermore, varying physical characteristics are noticed during the investigation.

### 3.3 Characterisation of oil lakes

It is vital to evaluate the characteristics of Kuwait's oil-contaminated sands such as organic and inorganic material contents and soil particle size distributions in order to select the appropriate treatment method. All analytical methods were conducted at the University of Portsmouth, UK.

#### *3.3.1 Soil sampling*

The soil samples were collected from the Burgan oil field in the south of the Kuwaiti desert. The sample was collected from the edge of lake no. 105, in September 2011 (**Figure 3**). Firstly, the KOC and Ministry of Defence (MOD) checked for unexploded bombs and landmines, and then a hand shovel was used to remove about 3 cm of oily sludge from the soil surface. Then, after which heavily oil-contaminated soil (concentration of oil 35%) was collected at a depth of approximately 30 cm below the surface level of oily sludge. Subsequently, the samples were placed into plastic containers after being excavated from the soil with a shovel. This project has been focused on the contaminated layer below the oil sludge layer, meanwhile the sludge will be taken by the KOC for reuse.



**Figure 3.**
*Sample collection from Burgan Lake No. 105.*

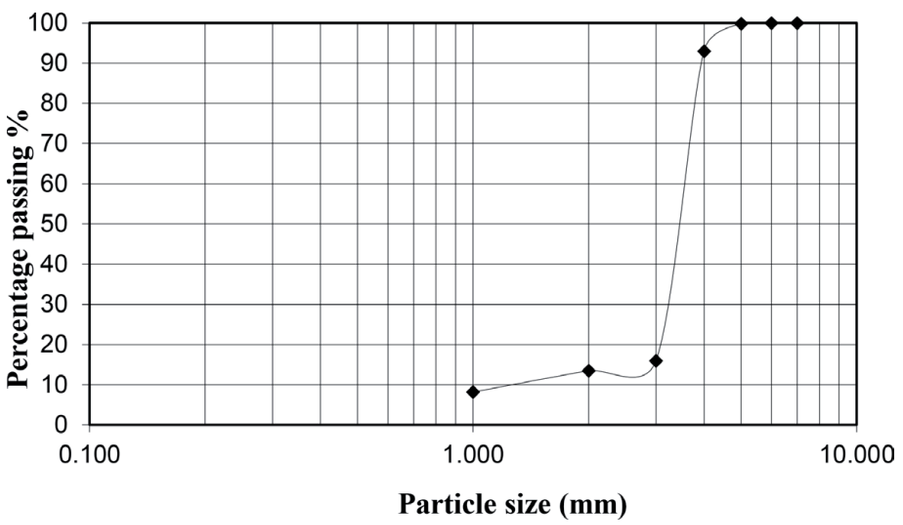



**Figure 4.**
*Particle size distribution on wet basis.*

### *3.3.2 Properties of oil lakes*

Soil properties are classified into two categories: chemical properties and physical properties. The soil samples were taken from the Burgan oil field to classify and analyse the physical properties according to the soil layers. The constant head permeability test were used to measure the soil permeability. These samples were considered as moderately permeable soil, with an average permeability rate of 0.064 mm/s having been recorded. Due to the presence of oil on the top layer, it prevented water from penetrating. Furthermore, mechanical sieve analysis (**Figure 4**) was carried out based on British Standards (BS 1377: Part 2:1990) [34] for wet sample to eliminate coarse fraction as well as to ensure homogeneity for the oil-contaminated soil. Chemical properties were investigated by determining TPH and measuring concentration of metal contents in Kuwaiti oil-contaminated sand.

As illustrated in **Table 2**, the results indicate the presence of some ions such as Ba, Cr, Fe, Ni, Pb, Cd, and Ag, as well as high concentration of TPH. The present preliminary study showed that with the high average value of electrical

| Parameters | Concentration of metals (mg/kg) | KEPA limit (mg/kg) |
|---|---|---|
| Barium (Ba) | 0.78 | 10 |
| Chromium (Cr) | 0.52 | 5 |
| Iron (Fe) | 8.10 | 5 |
| Nickel (Ni) | 0.43 | 10 |
| Lead (Pb) | 0.70 | 5 |
| Cadmium (Cd) | 1.1 | 1 |
| Silver Ag | 0 | 5 |
| TPH | 367,234 | 10,000 |
| pH | 7.8 | 5.5–7.5 |

**Table 2.**
*The concentration of metals during the washing of Kuwait oil residual [36].*

conductivity (EC) (2455 μS/cm), the existence of ions could be caused by using seawater to extinguish fires from oil well. Moreover, pH for the contaminated sample was found slight higher than the permissible level as shown in **Table 2**. For the purpose of selecting the most appropriate treatment method, the chemical and physical properties of the lake as well as unexploded ordnance, weathered soil, and local conditions are taken into consideration.

## 4. Determination of remediation options

In carrying out decision-making process, a number of techniques could be utilised, for example, pairwise comparison chart, decision matrix, force field analysis, cost-benefit analysis, and HOQ. HOQ is used in this study among various available methods. This decision-making tool is considered as a simple decision mechanism with potential of implementation at various stages of advertising and product manufacturing. Function deployment instrument is required to develop the specifications into the product and organise customer requirements as well as enhance procedure of work. This decision-making tool needs to assign weight to each specification also; upon outlining personnel responsible for decision-making ought to outline weighted symbols among the progressions that constitute the interlink between the proposed processes and specifications and non-weighted symbols between the processes themselves. Towards the end, the sum of the product of the specified weight by the equivalent symbol weight is determined by calculating the accumulated score for each process. Moreover, HOQ provides assistance to engineers in focusing on specified needs and deciding on the best sequence in the case that the process goes ahead. Because of this, HOQ was employed for this project to incorporate the requirements of UNCC and KNFP and choose the best technique of remediation method for which the remediation process will proceed.

### 4.1 Establishing house of quality

Within this research, relationships were established between pre-set objectives outlined by UNCC and KNFP and various methods of remediation chosen by the team. In contrast to the numerical evaluation matrix, HOQ utilises symbols to demonstrate the relationship between objectives and alternatives in addition to the connection between alternatives themselves. In an effort to compare the proposed

methods of remediation, all the needs were incorporated and translated into engineering characteristics. This is beneficial in assessing the available remedial methods with the pre-set engineering characteristics and comparing them with one another. The detailed description of the UN requirements is described hereunder:

a. Remediating various contaminated soil.

b. Operate with severe weather conditions (extreme temperature).

c. Simple to operate and assemble.

d. Produces least effect on groundwater, air, soil, employees, and neighbouring environment.

e. Short time duration.

f. In compliance with the requirements of Environmental Protection Agency (EPA).

g. Previous success percentage in Kuwait or comparable conditions.

h. The panel is of the opinion that remediation of oil-contaminated material by means of high-temperature thermal desorption is unjustifiable, given the conditions of this claim.

In an effort to weigh these criteria, Ejbarah et al. [35] carried out a series of discussions with consultants, environmental engineers, and scientists, and undertaking literature review, UN requirements were aimed to develop the weighted objective tree. Based upon the outcomes, weights are assigned to each objective creating the weighted objective, as listed in **Table 3**. The outcome of the study is utilised to distinguish, appraise various solutions, and determine the importance

| Engineering characterisation | Assigned weight |
|---|---|
| 1. Reduction in major contaminants | 0.36 |
| 2. Can be used in Kuwait's climatic conditions | 0.18 |
| 3. Does not cause health problems to the worker | 0.12 |
| 4. Simple to operate and assembly | 0.07 |
| 5. Generates least residuals | 0.03 |
| 6. Creates least equipment contaminants | 0.03 |
| 7. The least pollution to air | 0.027 |
| 8. Only small area needed | 0.02 |
| 9. The least pollution to groundwater | 0.018 |
| 10. Does not cause noise pollution | 0.015 |
| 11. Requires shorter duration | 0.01 |
| 12. In compliance with the requirements of EPA | 0.06 |
| 13. Previous experience in Kuwait or similar surroundings | 0.06 |
| Total score | 1 |

**Table 3.**
*Weights of engineering characteristics (source: [34]).*

| Row # | Weight Chart | Relative Weight | Customer Importance | Maximum Relationship | UN Requirements (Explicit and Implicit) / Remediation Options | land farming | Windrow | Biopiles | Phytoremediation | Vermiremediation | Bioventing | Soil washing | Electro-remediation | Thermal treatment | Solidification/stabilization | land farming | Windrow | Biopiles | Phytoremediation | Vermiremediation | Bioventing | Soil washing | electro-remediation | Thermal adsprption | Solidification/stabilization | Row # |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Column # | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Customer Competitive Assesment | | | | | | | | | | |
| | | | Direction of Improvement | | | ▼ | ▼ | ▼ | ▼ | ▼ | ▼ | ▲ | ▼ | ▲ | ◇ | | | | | | | | | | | |
| 1 | | 1% | 1 | 9 | Short treatment time | ▽ | ○ | ▽ | ▽ | ○ | ○ | ● | ○ | ● | ● | 1 | 3 | 1 | 1 | 3 | 3 | 7 | 3 | 7 | 7 | 1 |
| 2 | | 7% | 7 | 9 | Easy to operate | ○ | ○ | ○ | ● | ● | ○ | ○ | ▽ | ▽ | ● | 3 | 3 | 3 | 7 | 7 | 3 | 3 | 1 | 1 | 7 | 2 |
| 3 | | 2% | 2 | 9 | Requires small area | ▽ | ▽ | ○ | ○ | ○ | ○ | ● | ○ | ● | ● | 1 | 1 | 3 | 3 | 3 | 3 | 7 | 3 | 7 | 7 | 3 |
| 4 | | 6% | 6 | 9 | Experience in Kuwait | ● | ● | ● | ○ | ▽ | ▽ | ● | ▽ | ▽ | ▽ | 7 | 7 | 7 | 3 | 1 | 1 | 7 | 1 | 1 | 1 | 4 |
| 5 | | 18% | 18 | 9 | Applicable for Kuwait's weather | ▽ | ▽ | ▽ | ▽ | ▽ | ○ | ● | ● | ● | ● | 1 | 1 | 1 | 1 | 1 | 3 | 7 | 7 | 7 | 7 | 5 |
| 6 | | 36% | 36 | 9 | Reduces high contaminants | ○ | ○ | ○ | ○ | ○ | ● | ● | ○ | ● | ▽ | 3 | 3 | 3 | 3 | 3 | 7 | 7 | 3 | 7 | 1 | 6 |
| 7 | | 3% | 3 | 9 | Minimum residuals | ● | ● | ● | ● | ● | ● | ▽ | ○ | ● | ● | 7 | 7 | 7 | 7 | 7 | 7 | 1 | 3 | 7 | 7 | 7 |
| 8 | | 2% | 2 | 9 | Minimum ground water pollution | ▽ | ▽ | ▽ | ▽ | ▽ | ○ | ● | ▽ | ● | ● | 1 | 1 | 1 | 1 | 1 | 3 | 7 | 1 | 7 | 7 | 8 |
| 9 | | 3% | 3 | 9 | Minimum air pollution | ▽ | ▽ | ▽ | ▽ | ○ | ▽ | ● | ▽ | ▽ | ○ | 1 | 1 | 1 | 1 | 3 | 1 | 7 | 1 | 1 | 3 | 9 |
| 10 | | 2% | 2 | 3 | Not cause noise pollution | ○ | ○ | ○ | ○ | ○ | ○ | ▽ | ▽ | ▽ | ○ | 3 | 3 | 3 | 3 | 3 | 3 | 1 | 1 | 1 | 3 | 10 |
| 11 | | 6% | 6 | 3 | UN and EPA recommended | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ▽ | ▽ | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 1 | 1 | 11 |
| 12 | | 12% | 12 | 9 | Not cause human health effect | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ▽ | ○ | 3 | 3 | 3 | 3 | 3 | 3 | 7 | 3 | 1 | 3 | 12 |
| 13 | | 3% | 3 | 9 | Minimum equipment contaminants | ● | ● | ○ | ● | ● | ○ | ○ | ○ | ○ | ○ | 7 | 7 | 3 | 7 | 7 | 3 | 3 | 3 | 3 | 3 | 13 |
| | | | | | Target | land farming | windrow | biopiles | phytoremediation | vermiremediation | bioventing | soil washing | electro-remediation | Thermal treatment | solidification/stabil | | | | | | | | | | | |
| | | | | | Max Relationship | | | | | | | | | | | | | | | | | | | | | |
| | | | | | Technical Importance Rating | 321 | 323 | 307 | 331 | 326 | 517 | 768 | 370 | 600 | 401 | | | | | | | | | | | |
| | | | | | Relative Weight | 8% | 8% | 7% | 8% | 8% | 12% | 18% | 9% | 14% | 9% | | | | | | | | | | | |
| | | | | | Weight Chart | | | | | | | | | | | | | | | | | | | | | |
| | | | | | Technical Competitive Assesment | 7 | 3 | 1 | | | | | | | | | | | | | | | | | | |

**Table 4.**
*Interrelationship matrix among several soil remediation methods.*

between the objectives listed. These engineering techniques are effective in removing potential risks posed by contaminants, require comparatively shorter duration to operate, and can frequently be used extensively.

## 4.2 Investigating alternative methods

The "soil remediation" terminology relates to the efforts which seek to eradicate or reduce the risks connected to contaminated soil. Several soil remediation methods have been considered in an attempt to remove the impact of crude oil pollution on the environment. There are large variances in the biological, chemical, and physical characteristics of the contaminants, as well as a number of soil remediation methods are available in the market; selection of suitable and economical technology for the remediation of specific contaminants may not be an easy. In this study using a HOQ analysis system, only 10 remediation technologies have been considered: land farming, windrow, phytoremediation, vermiremediation, bioventing, soil washing, biopiles, electro-remediation, solidification/stabilisation, and thermal. These approaches have been selected in accordance with previous successful investigations into the remediation of hydrocarbon-contaminated soil. For each of

these techniques, the chosen methodology and theories are discussed in a comparative evaluation based on the specialised research conducted.

### 4.3 Define the relationship symbol and weights

The relationship between the characteristics and each remediation method was clarified in **Table 4**; the main target of this section is to find the appropriate remediation method among other alternative methods. The symbols used with their corresponding values are defined and listed below:

1. Strong positive ● with a weight of 7
2. Positive ○ with a weight of 3
3. Moderate ▽ with a weight of 1

The interrelationship symbols were set to identify the potential of implementing the selected remediation process in sandy soil. The symbols are used and listed below:

1. More suitable ▲ without problems
2. Suitable ◇ with a few concerns
3. Less suitable ▼ to work

## 5. Results and discussion

### 5.1 Evaluating alternatives

A range of remediation alternatives are briefly presented in **Table 4**, and it explains why it is the treatment alternative of choice for Kuwait's oil-contaminated sand. This chapter explains the decision-making process behind using soil washing and other remediation techniques. In order to choose the most appropriate method, an exhaustive list of each remediation option was reviewed. As shown in Section 2, each treatment was briefly described after thorough research in order to develop an interrelationship between these methods. As a result, the matrix was formulated and evaluated to show the interrelationship, although the requirements were assessed and ascertained against the alternatives and the weights. Therefore, weighted alternatives have been formulated. The process can be started by altering the set symbols to their corresponding values. The characteristic weight is multiplied by each value. This procedure was repeatedly employed for all the characteristics, and the total sum was kept at the last phase.

As seen in **Table 4**, the relative weight for biopiles is 7%; there is a similar weight score recorded among land farming, windrow, phytoremediation, bioventing, and vermiremediation; the outcome showed that the score of relative weight was about 8%. Similarly, the result also demonstrated that the scores of relative weight for thermal adsorption and soil washing were 14 and 18%, respectively, and that the score for both electro-remediation and solidification/stabilisation was 9%.

Correspondingly, **Table 4** also showed that there were no real concerns for all the methods employed except for one: soil washing. From the results, soil washing

appears to be the best method in view of their total score, while thermal cannot be employed based on UN requirements. This method was the most appropriate and hence employed in selecting an optimised treatment method to match the conditions under study. Each of the remedial methods was assessed against the set requirements, and their capability to treat sandy soil was investigated. The results obtained in this study showed that the soil washing was the best method to meet the objectives of the project. This method can be employed on its own or performed in series. The selection of the method for remediation is also essential for subsequent soil or site use. Later restrictions of land use may be as a result of groundwater pollution from the application of nitrates and due to the nitrogen release from the endogenous decomposition of microorganism [36]. Using (ex situ) techniques for soil washing, the coarser material which has been cleaned is without any clay or organic materials, which can be used for construction use such as subgrade fill or backfill. The major change in the soil materials takes place during the thermal treatment. Usually, high-temperature procedures damage the organic compounds and clay minerals; hydroxides are being transformed into oxides, and main minerals are changed to fines. For thermally treated soils which are transformed to slurry, their values of pH are quite high (pH 11); therefore the products are not ideal for future use; however, the UN requirement does not allow to use it for remediation of Kuwait's oil lakes. In addition, compared with other thermal and bioremediation technologies, soil washing method has some major benefits. Some of the benefits are their cost-effectiveness, scalability, and exceptional ability to remove oil from contaminated soil in short time. Limited successes have been reported with different remediation process. Thus it encourages researchers to develop and enhance the selected techniques of soil washing, so as to make it cost-effective, environmentally friendly, and effectiveness. The standard removal efficiency of TPH shall be tested and observed over a period of time. This involves developing methods for extraction of TPH from soil samples.

A large number of remediation methods have been designed in an attempt to reduce the effects of petroleum pollution on the environment. Due to the large differences in the physical, chemical, and biological characteristics of the contaminants, as well as the large number of soil remediation methods available, selection of an appropriate and economical technology for the remediation of particular contaminants can be difficult. In this study using a multi-criterion analysis system, only nine remediation technologies have been considered: land farming, windrow, phytoremediation, vermiremediation, bioventing, soil washing, biopiles, electro-remediation, and solidification/stabilisation. Various criteria were evaluated and assessed to select appropriate methods such, soil constraints, implement in surface soil, if any further treatment is required when the remediation process is completed, which compounds can be removed, time for clean-up and cost. Among others, the ability of wastewater treatment was investigated. The evaluation study shows that bioventing, electro-remediation, and the solidification/stabilisation approaches are not applicable for use in sandy soil, once the bioventing required low permeable soil, while electro-remediation needs saturated soil with water. Furthermore, solidification/stabilisation is used at the subsurface soil. Solidification/stabilisation, electro-remediation, bioventing, and biopiles are generally considered to be the most expensive treatments. However, land farming and bioventing need around 2 years to complete the remediation process and were not effective for HMW. In this study, soil washing techniques were selected as well. It has less profound side effects, while removal of contaminants can be controlled by enhancing washing factors. The selected techniques require 1 year or less to achieve the remediation target and are the cheapest of the available approaches.

## 6. Conclusion

The scenario in Kuwait is somehow exceptional as the contamination is primarily caused by crude oil, which has been weathered under open environment for 25 years. The exposure to the environment has caused most of the volatile substance within the crude oil to evaporate into the atmosphere with heavy compounds left as residue. Due to the complex nature of contaminated soil and the undeniable fact that contaminations in different situations present a "cocktail" of various types of pollutants, therefore, different types of remediation dealing with different ranges of contaminants, limited success have been reported in remediation of contaminated soil. The higher levels and wider ranges of TPH have shown interesting patterns at Kuwait's oil lakes. Most importantly, these contaminated sites have not yet been restored, which poses continued potential hazards to the environment and human health. Therefore, it is also important to estimate the characteristic of the contaminated soil; the tests can be performed to simulate the field conditions and provide categorisation for the sample. Without this key information, it is impossible for the planning of land use and options of remediation to be taken into account. Based on the literature, bioremediation is unlikely to be successful given the high concentration of TPH and high concentration of the metal salt in Kuwaiti contaminated soil. Furthermore, thermal system is not allowed to be used in this project (UN conditions), and hence the technique based on decision tool with HOQ, soil washing, was selected to deal with this issue. Selecting a remediation scheme challenges decision-makers to compare and select the appropriate soil remediation techniques by making a tool of engineering decision based on a set of UN requirements.

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## References

[1] Petroleum Economist. The oil fires story. International Energy Journal. 1992;**59**:21-28

[2] PAAC. Environment Damage Claims Prioritization Report. Kuwait: Public Authority for the Assessment of Compensation Resulting from Iraqi Aggression (PAAC); 1999

[3] United Nations Compensation Commission (UNCC). Claim of the State of Kuwait. Claim No. 5000454. Report No. S/AC26/2004/17. United Nations Compensation Commission; 2004

[4] Al-Awadhi N, Al-Daher R, Balba M, Chino H, Tsuji H. Bioremediation of oil-contaminated desert soil: The Kuwait experience. Environment International. 1998;**24**(1/2):163-173

[5] Al-Ajmi D, Misak F, Khalaf M, Al-Sudairawi M, Al-Dousari A. Damage Assessment of the Desert and Coastal Environment of Kuwait by Remote Sensing. Report KISR 4405. Kuwait: Kuwait Institute for Scientific Research; 1994

[6] El-Baz F, Abuelgasim A, Koch M, Pax-Lenney M, Lambin E, Al Dosari A, et al. Detection by satellite images of environmental change due to the Gulf war. In: El-Baz F, Makharita RM, editors. The Gulf War and the Environment. Lausanne: Gordon and Breach Science Publishers; 1994. pp. 1-24

[7] Kwarteng A. Multitemporal remote sensing data analysis of Kuwait's oil lakes. Environment International. 1998;**24**:121-137

[8] Saeed T, Al-Bloushi A, Al-matrouk K. Kuwait Oil Lakes: Composition of the Oil and Effects of Weathering. Kuwait: Kuwait Institute for Scientific Research; 1997

[9] Al-Naseem A, Al-Duwaisan D. Characterization of oil contaminated soil, Kuwait oil lakes. In: 2nd International Conference on Environmental Science and Technology (IPCBEE). Vol. 6. Singapore: IACSIT; 2011

[10] Nathanail CP, Bardos RP. Reclamation of Contaminated Land. John Wiley & Sons Ltd; 2004. ISBNS: 0-471-98560-0

[11] Riser-Roberts E. Remediation of Petroleum Contaminated Soil: Biological, Physical, and Chemical Processes. Boca Raton: Lewis Publishers; 1998

[12] Bennett B, Larter S, Carbognani L, Pereira-Almao P. Identification and characterization of reaction proxies for monitoring the progress of thermal processing of heavy oils and tar sands under vis-breaking conditions. Energy and Fuels. 2008;**22**:440-448

[13] Sui X, Ji D. Impact of ultrasonic power density on elution of super heavy oil and its biomarkers from aging soils using triton X-100 micellar solution. Journal of Hazardous Materials. 2010;**176**:473-480

[14] Ellis R, Balba MJ, Theile P. Bioremediation of oil contaminated land. Environmental Technology. 1990;**11**:443-454

[15] Zhao D, Liu C, Liu L, Zhang Y, Liu Q, Wu W. Selection of functional consortium for crude oil-contaminated soil remediation. International Biodeterioration & Biodegradation. 2011;**65**:1244-1248

[16] Banerji SK, Zappi ME, Teeter CL, Gunnison D, Cullinane MJ. Bioremediation of Soils Contaminated with Petroleum Hydrocarbons Using Bioslurry Reactors. Miscellaneous Paper IRRP-95e2, Final Report. U.S. Army Corps of Engineers; 1995

[17] Federal Contaminated Sites Action Plan (FCSAP). Federal Contaminated Sites Action Plan Annual Report 2007-08; 2009

[18] Van Deuren J, Lloyd T, Chhetry S, Raycharn L, Peck J. Remediation Technologies Screening Matrix and Reference Guide. Vol. 4. Federal Remediation Technologies Roundtable; 2002

[19] Sinha RK, Herat S, Valani D. Earthworms—The environmental engineers: Review of Vermiculture Technologies for Environmental Management & resource development. International Journal of Environmental Engineering. Special Issue on Vermiculture Technology for Environmental Management and Resource Development. Agricultural sciences. 2010;**3**(7)

[20] McCutcheon SC, Schnoor JL. Overview of phytotransformation and control of wastes. In: Phytoremediation: Transformation and Control of Contaminants. Hoboken, NJ: John Wiley & Sons, Inc.; 2003

[21] Koning M, Hupe K, Stegmann R. Thermal processes, scrubbing/ extraction, bioremediation and disposal. Biotechnology. 2000;**11b**:306-317

[22] Yang JW, Lee YJ, Park JY, Kim SJ, Lee JY. Application of APG and Calfax 16L–35 on surfactant-enhanced electrokinetic removal of phenanthrene from kaolinite. Engineering Geology. 2005;**77**:243-251

[23] Bardos R, Morgan P, Swell RPJ. Application of in situ remediation technologies-11. Contextual frame work. Land Contamination & Reclamation. 2000;**8**:1-22

[24] Ji GD, Guo F. Impact of ultrasonic power density on hot water elution of severely biodegraded heavy oil from weathered soils. Chemosphere. 2010;**79**(2):210-215

[25] Evans D, Jefferis SA, Thomas AO, Cui IS. Remedial Process for Contaminated Land. Principle and Practice Publication C549. London: CIRIA; 2001. ISBN 0 86017 5499

[26] Wallace S, Cork J. Remediation of Basford Gasworks Using Soil Washing Contaminated Soil. London: Thomas Telford Ltd; 1998. pp. 65-74

[27] Shackelford CD. The ISSMGE Kerry Rowe lecture: The role of diffusion in environmental geotechnics. Canadian Geotechnical Journal. 2014;**51**(11):1219-1242

[28] Mumford K, Rayner J, Snape I, Stark S, Stevens G, Gore D. Design, installation and preliminary testing of a permeable reactive barrier for diesel fuel remediation at Casey Station, Antarctica. Cold Regions Science and Technology. 2013;**96**:96-107

[29] Hosney MS, Rowe RK. Performance of GCL after 10 years service in the Arctic. Journal of Geotechnical and Geoenvironmental Engineering. 2014;**140**(10):1-12

[30] McWatters RS, Rowe RK, Wilkins D, Spedding T, Jones DD, Terry D, et al. Geosynthetics in Antarctica: Performance of a composite barrier system to contain hydrocarbon-contaminated soil after 3 years in the field. Geotextiles and Geomembranes. 2016;**44**(5):673-685

[31] McWatters R, Rowe RK. Permeation of volatile organic compounds through EVOH thin film membranes and coextruded LLDPE/ EVOH/LLDPE geomembranes. Journal of Geotechnical and Geoenvironmental Engineering. 2015;**141**(2):1-15

[32] Poland JS, Riddle MJ, Zeeb BA. Contaminants in the Arctic and the Antarctic: A comparison of sources, impacts, and remediation options. Polar Record. 2003;**39**(04):369-383

[33] Kalinovich I, Rutter A, Poland JS, Rowe RK, et al. Surface permeable reactive barriers for PCB remediation in the Canadian Arctic. Journal of Environmental Management. 2012;**101**:124-133

[34] British Standard. Methods of Test for Soils for Civil Engineering Purposes. Classification Tests. BS 1377-2:1990; 1990

[35] Ejbarah N, Al-Jarallah R, Al-Duwaisan D. House of quality application in soil remediation. Kuwait oil lakes. In: 2nd International Conference on Environmental Science and Technology IPCBEE. Vol. 6. Singapore: IACSIT Press; 2011

[36] Slenders H, de Wit H, Staijn B, Kok T. Dutch Handbook on Soil Remediation Techniques; an Evaluation of Remediation Techniques. Final Report 1057570; 1997

[37] Kuwait Environmental Public Authority (KEPA). Maximum Limits Allowance for Occupational Exposure to Chemical Substances. Appendix No. 3-1; 2014