Improving Management and Technology Selection Process for Petroleum Hydrocarbon-contaminated Sites by Innovation of 3D Mapping Technology for Soil Characterization

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The European Conference on Sustainability, Energy & the Environment 2016
Official Conference Proceedings

iafor
The International Academic Forum
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Summary

To apprehend the decision framework for technology selection, it is important to comprehend the universal principles of applicable technologies for the remediation of petroleum hydrocarbon-contaminated sites. One of the distinguishing characteristics of environmental technology is that the state-of-the-art continually changes.

In this paper, we illuminate the fact that sound strategies for contaminated site remediation must be developed based on comprehensive site investigation and soil characterization. The treatment technologies have been segregated into two major groups, which have also been sub-segregated into three minor groups, and that of which have been segregated into various numbers of treatment technologies.

In this paper we sanctioned that Innovation of 3D soil mapping and site characterization technology for hydrocarbon contaminated sites have a major contribution in gathering field data required to understand the soil spatial variation for both chemical and physical characteristics and properties under and adjacent of the hydrocarbon contaminated sites. Moreover, this have a significant reduction in time, effort, and the cost of the remediation strategy development, and provides exceptional support to the environmental technology selection process and procedure.

This paper assists the remediation projects decision makers for hydrocarbon contaminated sites in the following;

1- To cultivate and support their remediation strategies decisions.
2- To evaluate the technologies on the base of the contaminants and soil characterization
3- Introducing Soil characterization and soil treatment technology screening process and procedure
4- To develop functional hydrocarbon contaminated site project management process and frame work.
5- Screen for possible hydrocarbon contaminated site treatment technologies.
6- Assign a relative probability of success based on available performance data, field use, and engineering judgment.
7- provides rigorous and robust bias-free decision making procedures for remediation of contaminated sites in general and selecting the right remediation technology in specific..
8- Combined generic computational procedures and practical application for soil characterization, and technology selection process for remediating hydrocarbon contaminated sites.
9- The methods developed in this paper would be capable of handling the "relative importance" of decision factors criteria and involves developing a DSS for environmental technology selection.

The remediation technologies of soil contaminated by hydrocarbon and heavy metals, including physical remediation, chemical remediation and biological remediation were focused based on contaminants, and innovative soil and site characteristics technology.

Keywords: 3D Mapping, Soil Characterization, Oil Pollution, Environmental Remediation, Technology Selection .

1. Introduction

Site characterization, contaminant perspectives and site investigation are the major elements in any site remediation strategy decision, they are the gate opener in the process of developing the best environmental and economic treatment options for any hydrocarbon-contaminated site.

Furthermore, soil characteristics is a very important element in the remediation technologies selection process as site soil conditions frequently limit the selection of a treatment process. Soils are inherently variable in their physical and chemical characteristics throughout the contaminated site for some extent, and effected by internal and external conditions.

In any hydrocarbon-contaminated site, the environmental damages require intensive, characterization of the impact and spatial extent of the problems. This can be achieved through the formation of comprehensive and inclusive soil maps that define both the spatial and vertical variability of key soil properties. Detailed three-dimensional (3D) digital soil maps can be readily used and embedded into environmental models, this environmental models will assist in defining the best remediation technology and strategy to tackle complicated hydrocarbon contaminated sites.

For instance, if the 3D mapping illustrates that the soil composed of large percentages of silt and clay all over the hydro-carbon contaminated site and in various level (depth), Soil washing may not be effective because of the difficulty of separating the adsorbed contaminants from fine particles and from wash fluids. Fine particles may delay setting and curing times and can surround larger particles, causing weakened bonds in solidification/stabilization processes. Clays may cause poor performance of the thermal desorption technology as a result of caking. High silt and clay content can cause soil malleability and low permeability during steam extraction, thus lowering the efficiency of the process. Microbial diversity and activity in bioremediation processes also can be affected by extreme pH ranges and high temperature.

The first step for any remediation strategy of hydrocarbon-contaminated sites in analyzing the problem is site investigation and soil characterization, section Two below describe the top edge hydrocarbon site management and the initial concept in developing remediation strategy for hydrocarbon contaminated sites.

2. Contaminated Site Management and Technology Selection Process

The Contaminated Site Management Process and technology selection consists of seven steps from the time that contamination is discovered to final site remediation and closure. The following steps defines the overall management process in the technologies screening and selection process.

Step 1: Initial Notification.
Step 2: Initial Site Assessment and site characterization.
Step 3: Chose Technology Group (In Situ-EX Situ).
Step 4: Technology screening within the chosen group, (Treatment Technology Screening Matrix, http://www.frtr.gov/matrix2/section3/table3_2.pdf , May 2014).
https://frtr.gov/matrix2/section3/table3_2.pdf
Step 5: Prepare and submit Remedial Action Plan.
Step 6: Remedial Action Plan Implementation.
Step 7: Closure Report and issuing letter advising that no further remedial action is required, (Remediation of Petroleum-Contaminated Soils, National Cooperative Highway Research Program, David J. Friend, 1996).

These steps are summarized at Figure 1 below Contaminated Site Management and Technology Selection Process (CSM&TSP) (Hamad Almebayedh,2014).

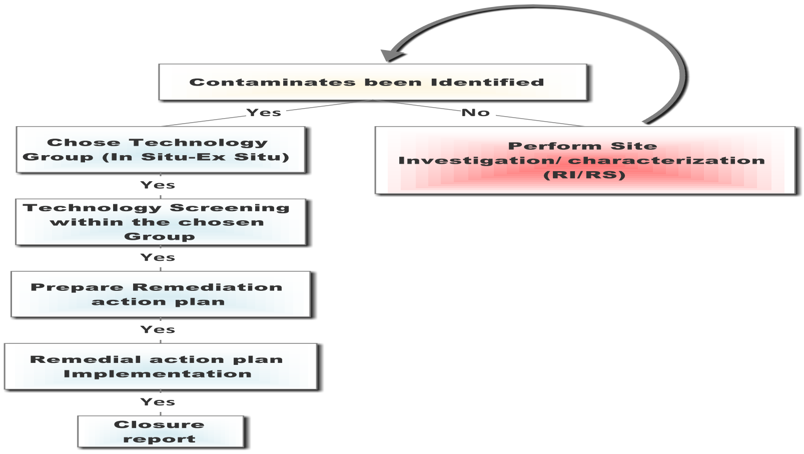


FIGURE 1 Contaminated Site Management and Technology Selection Process (CSM&TSP)

As described above site investigation and soil characteristics is the main element in the remediation technologies selection process, site soil conditions frequently limit the selection of a treatment process.

For all remedial investigation and cleanup sites, the vertical and horizontal contaminant profiles (Contaminant perspectives section below) should be defined as much as possible. Information on the overall range and diversity of contamination across the site is critical to determine the most efficient and effective treatment technology (The 3D mapping technology presented section below) is a major element in the site investigation and soil characterization. Obtaining this information generally requires taking samples and determining their physical and chemical characteristics (Sampling procedure and data requirement section below) describe the need for each of the element and data of the sampling information require with examples on the remediation technology selection and eliminating process. If certain types of technologies are candidates for use, the specific data needs for these technologies can be met during the initial stages of the investigation as provided on https://frtr.gov/matrix2/section3/table3_2.pdf (Remediation Technologies Screening Matrix and reference Guide, Version 4.0), May 2014.

3. Contaminant Perspectives

This is the first step in any site investigation process, addresses contaminant properties, their behavior and preliminarily identification of potential treatment technologies based on their applicability to specific contaminants and media. There are eight contaminant groups, as determined by the Federal Remediation Technologies Roundtable (FRTR), FRTR (Remediation Technologies Screening Matrix and reference Guide, Version 4.0), May 2014:

- Nonhalogenated Volatile Organic Compounds (VOCs).
- Halogenated Volatile Organic Compounds (VOCs).
- Nonhalogenated Semivolatile Organic Compounds (SVOCs).
- Halogenated Semivolatile Organic Compounds (SVOCs).
- Fuels.
- Inorganics.
- Radionuclides.
- Explosives.

More details concerning contaminant groups provided at FRTR (Remediation Technologies Screening Matrix and reference Guide, Version 4.0), May 2014.

4. Data required

For any hydrocarbon contaminated site a specific sampling procedure must be developed. In this research paper we are introducing one of the most cost-effective with a major consideration to the quality of the data.

a. Soil particle-size distribution;
b. pH, Soil homogeneity and isotropy;
c. Particle density,
d. Soil permeability,
e. $\mathbf{E_h}$ areas,
f. $\mathbf{K_{ow}}$,
g. Humic content,
h. Total organic carbon (TOC),
i. Volatile hydrocarbons,
j. Biochemical oxygen demand,
k. Electron acceptors,

The required data above could be determined by data collected from the field investigations, and lab analysis to be then implemented on our 3D mapping hydrocarbon contaminated soil technology.

5. Technology Treatment Groups

In this paper we have segregated the remediation technology in to Tow groups, these groups are In Situ and Ex situ, these Two groups have been segregated in to Three groups, this is to enhance our technology decision screening process and to eliminate the non-suitable technology. The in situ and Ex situ technologies are categorized into three major groups based on the primary mechanism by which treatment is achieved:

- Physical/Chemical Treatment Technologies
- Biological Treatment Technologies
- Thermal Treatment Technologies

Table 1, (Remediation of Petroleum-Contaminated Soils, National Cooperative Highway Research Program, David J. Friend, 1996).

General Category	Type of Process	Technology applied in-Situ	Technology Applied Ex-Situ
Treatment	Biological	• Passive biodegradation • Bioventing • In-Situ Biodegradation	• Biopiles • Land treatment or landfarming • Slurry biodegradation • Composting
	Physical	• Soil Venting - Conventional - Hot air or steam stripping • Soil flushing	• Soil washing • Coal tar agglomeration
	Chemical	• Chemical Oxidation/reduction	• Chemical Oxidation/reduction • Solvent extraction
	Thermal	• Radio frequency (RF) heating • Vitrification	• Thermal desorption by: -Low and high temperature. -Thermal strippers - Hot-mix asphalt plants • Virification
Containment	Other	• Solidification/stabilization • Capping	• Solidification/stabilization • Microcantaminated by cold-mix asphalt • Capping or re-use • Land disposal or Land filling

Table 1 Technology Treatment Groups

6. 3D mapping technology for soil characterization of hydrocarbon contaminated sites

Fabio Veronesi (2012) concluded that high resolution 3D mapping technology can be used to estimate soil properties achieving a reasonable accuracy even with relatively poor data support, thus minimizing the cost of the survey, and which can practically be applied over large areas. In the first stage the primary objective was the development of a new method for accurately mapping soil properties in 3D; a method that was easier to use than 3D geostatistics and sufficiently flexible to be used with less dense datasets. The method was extensively tested, validated and compared to the established method of 3D ordinary kriging. This stage of research concluded that a novel method had been developed, which can obtain high level of accuracy in mapping soil compaction, performing much better than 3D ordinary kriging. This method is much easier to use compared to 3D geostatistics, because it relies on bi-dimensional interpolation; it is also flexible as it can be used with much less analytical data losing only a fraction of its accuracy.

7. Hydrocarbon contaminated soil Treatment Technology recommended according to data acquired

Site soil conditions frequently limit the selection of a treatment process. Process-limiting characteristics such as pH or moisture content may sometimes be adjusted. In other cases, a treatment technology may be eliminated based upon the soil classification (e.g., particle-size distribution) or other soil characteristics presented at section 4 above and presented below.

- Soil particle-size distribution is an important factor in many soil treatment technologies. In general, coarse, unconsolidated materials, such as sands and fine gravels, are easiest to treat. Soil washing may not be effective where the soil is composed of large percentages of silt and clay because of the difficulty of separating the adsorbed contaminants from fine particles and from wash fluids. Fine particles also can result in high particulate loading in flue gases from rotary kilns as a result of turbulence. Heterogeneities in soil and waste composition may produce nonuniform feedstreams for many treatment processes that result in inconsistent removal rates. Fine particles may delay setting and curing times and can surround larger particles, causing weakened bonds in solidification/stabilization processes. Clays may cause poor performance of the thermal desorption technology as a result of caking. High silt and clay content can cause soil malleability and low permeability during steam extraction, thus lowering the efficiency of the process.
- Soil homogeneity and isotropy may impede in situ technologies that are dependent on the subsurface flow of fluids, such as soil flushing, steam extraction, vacuum extraction, and in situ biodegradation. Undesirable channeling may be created in alternating layers of clay and sand, resulting in inconsistent treatment. Larger particles, such as coarse gravel or cobbles, are undesirable for vitrification and chemical extraction processes and also may not be suitable for the stabilization/solidification technology.
- Particle density is the specific gravity of a soil particle. Differences in particle density are important in heavy mineral/metal separation processes (heavy media separation). Particle density is also important in soil washing and in determining the settling velocity of suspended soil particles in flocculation and sedimentation processes.
- Soil permeability is one of the controlling factors in the effectiveness of in situ treatment technologies. The ability of soil-flushing fluids (e.g., water, steam, solvents, etc.) to contact and remove contaminants can be reduced by low soil permeability or by variations in the permeability of different soil layers. Low permeability also hinders the movement of air and vapors through the soil matrix. This can lessen the volatilization of VOCs in SVE processes. Similarly, nutrient solutions, used to accelerate in situ bioremediation, may not be able to penetrate low-permeability soils in a reasonable time. Low permeability may also limit the effectiveness of in situ vitrification by slowing vapor releases.
- The pH of the waste being treated may affect many treatment technologies. The solubility of inorganic contaminants is affected by pH; high pH in soil normally lowers the mobility of inorganics in soil. The effectiveness of ion exchange and flocculation processes may be negatively influenced by extreme pH ranges. Microbial diversity and activity in bioremediation processes also can be affected by extreme pH ranges.

➢ Total organic carbon (TOC) provides an indication of the total organic material present. It is often used as an indicator (but not a measure) of the amount of waste available for biodegradation. TOC includes the carbon both from naturally-occurring organic material and organic chemical contaminants; however, all of it competes in reduction/oxidation reactions leading to the need for larger amounts of chemical reagents than would be required by the contaminants alone.

Furthermore, the effectiveness of technology section 5.3 must be considered during the technology selection process.

8. Case Study: Characterization of Soils beneath Oil Lakes in Kuwait

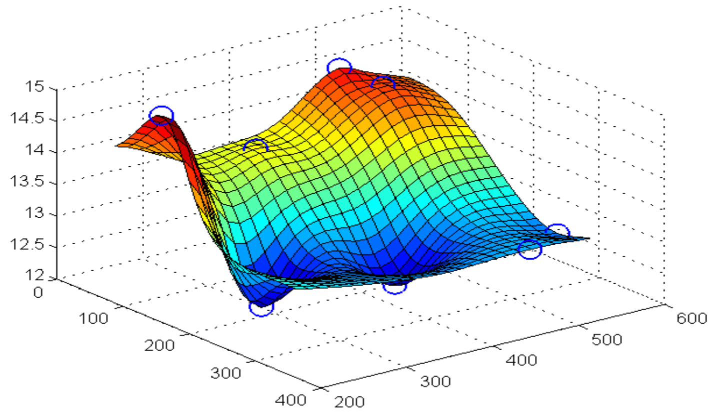
There are currently a few thousand oil lakes in Kuwait, which represent a serious threat to human health and ecosystems. The soils underneath and adjacent to the oil lakes were heavily contaminated by petroleum hydrocarbons and therefore requires remediation.

Selection of appropriate soil remediation methods and techniques needs to be informed by accurate soil characterization. Currently, soil investigation into petroleum hydrocarbon-contaminated soils in oil lake area involves grid sampling with a high horizontal sampling density. However, vertical variation in petroleum hydrocarbon concentration along the soil profile is not sufficiently considered. This approach could lead to substantial costs due to intensive horizontal sampling on one hand and inaccurate estimation of the volume of soils that need to be treated.

Our proposed methods to improve the cost-effectiveness of soil characterization include: (a) taking into account the vertical variation in both total petroleum hydrocarbon and various hydrocarbon species; and (b) using 3-D mapping technology to establish models for spatial distribution of petroleum hydrocarbons in oil lake-affected soils with markedly reduced sampling density.

Figure2

The *Inverse Distance Weighting* (IDW) is an effective method for spatial interpolation. IDW method estimates the degree of contamination by weighting of values of sampling data in each cell. This method assumes that value of variables on the map decreases with the increase of the distance from their sampling sites (*N. Drešković and S.Đug, 2012, Application of the Inverse Distance Weighting and Kriging methods of the Spatial Interpolation on the mapping the Annual Amount of Precipitation in Bosnia and Herzegovina, International Environmental Modelling* *and Software Society (iEMSs) 2012 International Congress on Environmental Modelling and Software Managing Resources of a Limited Planet, Sixth Biennial Meeting, Leipzig, Germany R. Seppelt, A.A. Voinov, S. Lange, D. Bankam (Eds.)*). In this case, the spatial distribution of contamination value influence decreases directly proportionally with the increase of the distance from the sampling points. Using this method, we can control sampling sites in terms of the importance of known points. In addition, IDW method can take account the influences of different variables together. Seeing that the contamination degree closely related to the geo-composition and geo-transportation parameters, These factors will be incorporated into the mapping algorithm in our research.



3D Mapping Technology for Soil Characterization of Hydrocarbon Contaminated Sites
(Figure 3)
Figure 3 above demonstrates the IDW interpolated hydrocarbon distribution in the highly hydrocarbon contaminated areas in Red which required a remediation treatment technology, the volume and the contamination distribution easily could be calculated. Soil particle-size distribution, pH, Soil homogeneity and isotropy, Particle density, Soil permeability, Eh areas, Kow , Humic content, Total organic carbon (TOC), volatile hydrocarbons, Biochemical oxygen demand, electron acceptors, Oil and grease. This all could be determined by the data collected from the field, and lab investigations analysis obtain through our sampling procedure provided in 5.1. This 3D mapping innovative technology will provides great information to develop our cost and time effective remediation strategy. Subsequent to analyzing the information provided from our 3D hydrocarbon contaminated mapping technology our segregation and technology selection process will be generated by excluding the not acceptable remediation technology for the related contaminated site as per section 7of our research.

6. Effectiveness of Technologies

There are many applicable technologies for treating sites contaminated with petroleum hydrocarbon as demonstrated in section 5 below, Table 1, and section 7. The effectiveness of these technologies, however, is dependent on contaminant and site characteristics, regulatory requirements, cost and time limitations (Figure 4). This guideline describes the process that is used to manage (e.g. identify, assess, remediate) contaminated or potentially contaminated sites. In some cases, it is possible to focus on specific remedies technology that have been proven under similar conditions.

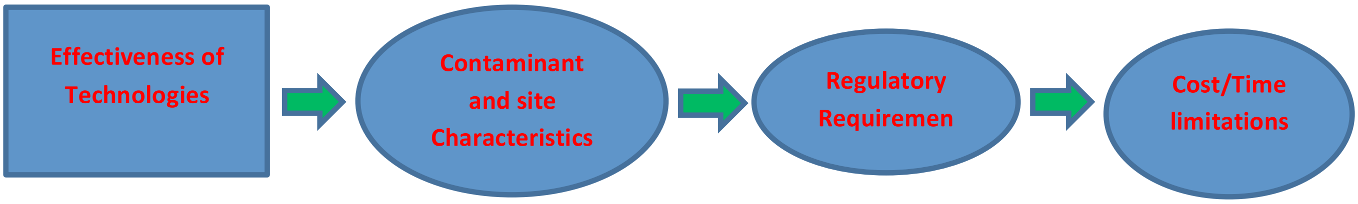


FIGURE 4 Effectiveness of Technologies Dependency (ETD)

Conclusions

In this research paper we concluded that to build up any remediation strategy for any hydrocarbon contaminated site the steps presented in this research paper must be followed to achieve the optimum QA/QC, cost effective and time objective of remediation project This concludes the fact that for all remedial investigation and cleanup sites the following information are needed; site characteristics, site contaminants, regulatory acceptance of technology, technology availability, treatment time objectives, and project life-cycle costs/time. The specific data needs for screening these technologies can be met during the initial stages of the investigation as presented on section 2 of this to support and develop the environmental technology selection process and procedure

The developed 3D mapping for hydrocarbon contaminated soil innovative technology presented in this paper provides great information to develop cost and time effective remediation strategy. Subsequent to analyzing the information provided from our 3D hydrocarbon contaminated mapping technology our segregation and technology selection process will be generated by excluding the not acceptable remediation technology for the related contaminated site as per section 7 of our research paper. The remediation technologies of soil contaminated by hydrocarbon including physical remediation, chemical remediation and biological remediation presented in this research. This research project provides a reference and guide to evaluate the technologies in scientific and engineering manors, developing novel environmental remediation strategies and risk based approach for environmental remediation projects in general, and provide novelty in screening the right technologies for a certain environmental problem.

This research provides rigorous and robust bias-free decision making procedures by selecting the best projects/options to get best value. This research project combine development of generic computational procedures and/or practical application based on the case studies. The methods developed capable of handling the “relative importance” of decision factors criteria and involves developing a DSS for environmental technology selection.

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