Nature Environment and Pollution Technology An International Quarterly Scientific Journal	p-ISSN: 0972-6268 e-ISSN: 2395-3454	Vol. 18	No. 1	pp. 125-132	2019

Original Research Paper

Open Access

The Role of Advanced Technologies in the Remediation of Oil-Spilled Environment: A Decision-Matrix Approach

C.I.C. Anyadiegwu*, A.C. Igbojionu, N.P. Ohia* and R.C. Eluagu***

*Department of Petroleum Engineering, Federal University of Technology, Owerri, Nigeria

**Mobil Producing Nigeria Unlimited, Port Harcourt Shore Base, Onne, Nigeria

Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 19-05-2018
Accepted: 02-08-2018

Key Words:
Oil spill
Remediation
Decision matrix
Effective score
Advanced technologies

ABSTRACT

The role of advanced technologies in the remediation of oil spilled environment was investigated. Oil spill remediation technologies for the clean-up of soil and groundwater contamination from petroleum industry activities have advanced considerably over the past decade. This has been the result of increasing regulatory pressures in many parts of the world, mounting liability exposure, changing public perceptions, and the drive towards enhanced remediation in terms of cost effectiveness, health and environmental concerns, operation and maintenance requirement, applicability and efficiency. This paper examined the state of remedial technologies for petroleum industry applications in ex-situ and in-situ conditions, and used an effective score drawn from research to develop a decision matrix for selection evaluation. Ex-situ technologies involve excavation and treatment of contaminated soil. These include methods such as pyrolysis, solvent extraction, oxidation/reduction, and bioremediation, designed to remediate the soil to acceptable standards. In-situ technologies involve alteration of sub-surface flow, pressure, chemical or biological regimes to achieve containment, redirection, removal or destruction of contaminants. They include soil vapour extraction, bioventing, bio-sparging, and the use of horizontal wells and semi-passive barrier systems. A decision matrix was then developed using Microsoft Excel to aid decision making. This was developed using an effective research score allocated to each evaluation criterion and weighted using the ratio of this effective score to the total score by hundred percent. The optimal remedial approach depends on the highest ranked score as computed and documented in the MS-excel spreadsheet. From the analyses shown in the ex-situ decision matrix, advanced bioremediation was found to the best placed technique with a weighted score of 7.048 and the highest rank of 1, while wet oxidation was found to be the least impressive technique with a weighted score of 2.022.

INTRODUCTION

Due to environmental, economic and social costs of hydrocarbon leaks, the oil and gas industry places great importance to the need to minimize ugly events of oil spill or pollution from occurring. Hydrocarbon contaminations of soil and groundwater are amongst the most evident negative effects of industrial life. There are multiple causes from oil well drilling, production, transportation and storage in the upstream industry, refining, transportation and marketing in the downstream industry (Seitinger et al. 1994).

Also, the recent oil spill incidents have shown that the cost is much more than the associated downtime and clean-up expenses as it goes a long way to affect the social welfare, aggravates poverty, population displacement, social conflict, production reduction and also affects the profit margin of the companies involved (McAllister 2005). Clean-up operations in response to an oil spill can generate large volume of oily liquid and solid wastes, (melanges of oil, seawater, sand and debris such as seaweed, sediments, pebble, flotsam, jetsam and probably dead fauna). The volume of the waste material generated from the clean-up depends on: type and volume of oil; oil characteristics (viscosity, pour point, etc.); oil weathering processes, environmental conditions (climate, weather); shoreline, salt marsh, mangroves, etc.) and the clean-up strategies employed (Massoura et al. 2009). The integrity of a leak detection system is not limited, but may be compromised by a poor oil spill response/remediation technique.

Marine oil pollution receives much attention all over the world due to the perception of the magnitude, longevity and extent of damage it inflicts on the environment. In reality the impacts on the marine environment and coastline when the incident is well managed are often short-lived. The waste generated, however, may present a longer-term problem if not correctly managed and treated (Massoura et al. 2009). Massoura et al. (2009), in their paper examined some of the remediation techniques now being used for treatment of oily wastes and the criteria for determining and selecting the most appropriate techniques. They examined various techniques and oil spill incidents in which they were used to illustrate the issues.

The management of waste streams is dependent on the type of pollutant, the composition of the impacted area, cleanup methods employed, nature of removed material and finally the volume of waste generated. The remediation techniques available can be broadly grouped into physicochemical, biological and thermal techniques. While all have limitations such as increasing the area of contaminated material, potential groundwater contamination, air emissions or need for long-term management, these are more acceptable than the historic landfill disposal strategies. It has been determined that these techniques have potential separately, or in combination, to increase the rate of degradation of contaminants. The residual contamination concentrations, which will be acceptable are not universally agreed, but defined by an assessment of the health, ecological risks of the contaminants. Remedial technologies must be chosen based on their ability to achieve those goals in a cost-effective and timely manner (Massoura et al. 2009). Their paper looked to the future of each technique based on parameters such as effectiveness, reasonableness, cost, practicability, durability, technological and scientific advances, and discussed future implementation in accordance with good practice and quality assurance procedures.

According to Engler et al. (2017), an ongoing issue for many operators is the need to be able to safely and quickly remediate environmental issues. Of particular interest are the cleanup of petroleum products, and the cleanup of produced water, which often has extremely high levels of chlorides (Cl^-), and may include hydrocarbon components. Methods used in the past have been difficult and expensive, often causing issues with the disposal of contaminated soil. Attempts have been made for many years to perform in-situ remediation. In the 1950's, processes were developed that enhance the growth of naturally occurring microbes by applying a culture of microbes and enzymes to the affected area. The process studied has been used in over 1400 individual locations, providing a rich data set for analysis. Differences in how the processes were executed have resulted in variances in the results and the scope of the treatment required to meet environmental standards. In their paper, they discussed a methodology that has been applied in over 1400 locations. Their paper documented the work, and identified features and techniques that enhanced or diminished success rates. Processes were optimized to maximize the consistency of results at minimum cost. Six treatments were illustrated as representative examples of the effectiveness of the process. The first treatment reviewed involved remediation of a well site in West Texas near Garden City, TX. The treatment resulted in reductions of Cl^- contamination by 83% to 99%. The second treatment reviewed was completed on another site near Garden City, TX where a produced water spill had contaminated cotton fields. Reduction of contaminants at this site was over 99%. The third treatment reviewed was a site in Fisher County, TX, where a spill contaminated a pond on the site. Reductions of Cl^- up to 84% were observed, and hydrocarbon contaminants were reduced over 99%. The fourth description involved a site in Gaines County, Texas that experienced a produced water spill in April 2016. As a result of the spill, the initial contamination of the soil was tested to be 30,000 ppm. The area was treated using the process and the biological agent. Within twenty-one days, the salt level in the soil had been reduced to 900 ppm. Local plant life was observed to be growing in the formerly contaminated soil within twenty-eight days. The fifth description involved a site in Fisher County, Texas, where a pipeline leak contaminated soil. Samples were taken at several locations at the surface, and at depths of 48" and 60" to evaluate ground penetration. Post treatment, samples indicated reductions of 57% to 99.99%. The sixth description involved a site in Jal, New Mexico where crude oil was spilled into a storm sewer, and the oil flowed into a sewage treatment plant. The site and the sewage plant were treated, and reductions of hydrocarbons were observed to be 98%-99% of the original sample values. The processes described in their paper offered a significant benefit not only to the oil and gas producing community, but also to the general public in that the ability to restore previously damaged soil enhances the environment we live and work in.

Imtiaz et al. (2016) did a very great work on the use of advanced technology for the remediation of aquatic oil spills. According to Imtiaz et al. (2016), the utilization of automated unmanned boats for the skimming of oil has not been introduced. Their paper underscored on the feasibility and the advantages of deploying an autonomous vehicle for the same. The paper briefly discussed the trend in removal of slick, and put forward a revolutionary methodology for the same in the form of CSASSB, Cok Sorbent carrying Automated Sub-Surface Boats. It discussed the effectiveness of the use of CSASSB's and compared it with the currently used counterparts. It also discussed the suitability of cork as the appropriate absorbing material. The cork absorbent material was subjected to a heat treatment to increase its hydrophobicity, its lightness and absorption capacity. The working of CSASSB's involved a five step process and the paper discussed all the above-mentioned steps in detail. The CSASSB was found to be considerably more fuel effective and eco-friendly than the current ships that are used for the remediation of aquatic oil spills. The system is simple, yet effective. Moreover, the heat treated cork as a sorbent for oil removal in aquatic environment with advantage of being a natural and ecological product. Hence, the CSASSB system with the aid of cork sorbent keeps the ecosystem healthy by removing toxic slick.

Oil spills are one of the major concerns of the up and downstream oil industry. Although land operations do not cause spill accidents and volumes like offshore, the damage and the loss in public credibility is severe and long term (Seitinger et al. 1994). Solubility of hydrocarbons (HC) in water is generally small. The movement of oil in porous media must be described using a two phase flow concept. The spread is a four stage process: migration in the subsoil; invasion into the capillary fringe; spreading on the water table; stabilization of the spill, HC solubility (plume). Seitinger et al. (1994) analysed these four steps in detail in their paper. According to Seitinger et al. (1994), the main concern of the environmental groups, authorities, etc. is the presence of a floating oil layer on the groundwater table. Further in-situ remediation methods are based upon the removal of the liquid hydrocarbons (bioremediation, soil-vapour extraction, etc.). Their paper presented various directional drilling techniques including their pros and cons for oil spill remediation. Also, a brand-new technology to drill directional wells in heterogeneous, unconsolidated sands was presented. The method was used to drill directional wells in unconsolidated, coarse gravel formations (river sedimentation). Directional changes of 25-30/30 m were reached. A case study and experience from oil spill production was also presented, including a comparison in cost and success to vertical extraction wells. In their study, they found out that horizontal or strongly deviated wells offer significant advantages in the cleanup of thin, floating oil spills. The advantages are similar to horizontal wells in oil production (linear drainage along wellbore instead of radial drainage, low drawdown during production, increased net pay, etc.). A moving groundwater table is one of the most obvious differences to traditional oil production. High angle wells combine inflow advantages of horizontal wells with moving water table.

According to Olayinka et al. (2013), the impacts of oil spills are not limited to the direct effect on the ecosystem; it goes a long way to affect the social welfare, aggravates poverty, population displacement, social conflict, production reduction and also affects the profit margin of the companies involved. Their study was aimed at providing a review and comparison of the remediation techniques currently in use and suggest the most suitable methods of oil spill cleanup and remediation in Nigeria Niger Delta region based on certain criteria and to also suggest ways of mitigating oil spill occurrences in this region. In the course of their research, data collection was on primary and secondary data. For the primary data, a structured questionnaire was drafted and used for survey relating to the research to rank and evaluate different perspectives of stakeholders on various remediation techniques that are in consideration. For the secondary data, the study was carried out with a literature study to gain an overview of the different remediation methods for PHCs contaminated soils. Finally, using specific criteria, including cost efficiency, operation and maintenance of the technique, environmental friendliness, time frame of achieving remedial objectives, health concerns, and applicability of the techniques were used to make an evaluation design for the different remediation techniques for hydrocarbons contaminated soils. The results from these studies showed that single remedial action cannot be used for cleanup, but the thermal desorption and remediation by enhanced natural attenuation (RENA) was the best placed technique ranking highest under the different criteria of the evaluation design and the sample survey of the remediation techniques considered.

Olayinka et al. (2013) was able to establish that in-situ vitrification is the most cost effective technique with little or no disturbance of site.

Also regarding costs, Esak et al. (2000) gave a good illustration of successful co-compost remediation practical project which was able to achieve about 45% reduction in oil spill contaminated soil remediation costs. The said project was a co-compost remediation program involving oil contaminated soil at a pipeline break located near Gilby, Alberta. This was undertook from the fall of 1998, by Millennium EMS Solutions Ltd. on behalf of Gulf Canada Resources Limited. Approximately 1100 m^3 of heavy clay textured, hydrocarbon contaminated soil (5,000 to 6,000 µg/g TPH) was windrowed, treated with soil amendments (manure, fertilizer and wood waste), windrow turned two times and left to digest over the cold winter months. In early spring, the windrows were turned two more times. The results of the soil sampling and analysis completed 210 days after initiation show the soil to have been remediated to below Alberta Tier 1 cleanup criteria (1000 µg/g). Toxicological tests for aquatic and terrestrial systems were also successfully conducted to confirm the clean levels of the remediated soil.

According to Lessard et al. (1998), the focus of industry and government activities with respect to oil spills is on prevention. Despite best prevention efforts, however, some spills will occur and industry and government must be fully prepared to respond. After 30 years of studies and practical experience, there is now a definitive body of evidence that the use of dispersants to counter the effects of an oil spill can result in lower overall environmental impact than relying on other countermeasures, and for many large spills, it is often the only practical at-sea response technique. This conclusion is supported by numerous international organizations. A number of countries, including the U.S. have recently become more pro-active in supporting and advocating dispersant use. One major reason for this support has been the development of new dispersants with increased capability and improved toxicity characteristics. Their paper focused on new capability to disperse heavy and/or weathered oils such as bunkers. It summarized the mechanism by which dispersants work, listed their advantages and reviewed the results of recent large-scale field tests in the North Sea which conclusively demonstrated the capability of new products to disperse heavy and weathered oils.

In recent years, advances in computer technology allowed the development of sophisticated software applications able to simulate the effects of oil spills on the marine environment. The need for such modelling arises from the perception of oil spills as long lasting and highly damaging events because of their wide range of potential impacts on the environment, human health and economic activities. Modelling tools can predict the consequences of these events and allow a targeted response planning to be made. Iazeolla et al. (2016), in their paper presented an innovative application of oil spill modelling tools aimed at supporting the emergency response system along the different stages of the project life-cycle. Three case studies were presented, from exploration, to response planning during production, to contingency response during an emergency. The oil spill modelling approach for each case study was detailed, as well as the specific support provided to the decision making process. Two different methods for oil spill modelling and environmental consequences assessment in Eni exploration and production activities were shown. Preventive modelling, based on a statistical approach, identifies the range of possible outcomes of an event. Through this simulation, the consequence assessment of a spill provides useful information for a targeted emergency response planning. Emergency modelling, on the other hand, is based on a deterministic approach and simulates the evolution of a single event, whose characteristics are known. In this case, oil spill models can predict the fate of an oil spill in an emergency, providing an insight on its future evolution and driving the decision on the most appropriate response actions. Their results highlighted the contribution of oil spill modelling in making the emergency response system an active player during all the project life-cycle, enabling its complete integration within the project management structure. Oil & gas operators may benefit of this advanced approach that contributes to the improvement of their emergency response management system. Through a prompt and proper response, the effect of oil spills can be excluded or mitigated, saving human lives as well as protecting the environment, the facilities and Company's reputation.

Still on oil spill modelling, Michel et al. (2012) explained the global methodology developed by Total Exploration and Production Limited to improve the reliability of oil spill drift modelling by developing metocean skills in-house. According to Michel et al. (2012), actually, model predictions should make it possible to forecast the drift of an oil slick, identify the areas where the intervention teams should take action, predict the period and areas that could be impacted, and inform neighbouring installations, authorities and NGOs. Total Exploration and Production Limited created a metocean oil spill modelling system to improve the quality and in turn bring an improvement to oil-spill drift modelling results. Thanks to the improvements, oil spill models can be considered as reliable tools for use in oil spill response.

Aiello et al. (2014) also developed a web application, SmartGIS based on a continuous improvement project focused on oil spill management processes to perform a large-scale harmonization of procedure and strategies. The main scope was the development of an Oil Spill Best Practice which provides a guideline addressed to Eni subsidiaries for oil spill preparedness and for the selection of the most suitable tactics and technologies for response and remediation. This is based on the habitat types present in each country where Eni operates. To reach this goal, the habitat mapping and benchmarking activities were performed as intermediate deliverables. Habitat mapping is based on the mapping and classification of all the habitat types using certified reference datasets. Three marine and seven terrestrial habitats were identified. Benchmarking analysis provides a detailed overview over the current status and development trends of oil spill response and remediation tactics and technologies applied worldwide. They have then been categorized into habitat types. A webGIS application was identified as the best solution to manage all the data and information acquired through the project. It works wherever an internet connection is available and allows an effective remote support of the accidental oil spill scenario. For this reason the SmartGIS was launched with the development of an environmental analysis tool within the 3Ter Advanced Emergency System, already applied in Eni in case of emergency. The environmental analysis tool is characterised by different layers on habitats, countries, marine regions, active concessions and protected areas. In addition it can be supplemented by other information such as meteomarine data, nautical charts, bathymetry and vessel tracking as well as thickness and concentration of oil. Aiello et al. (2014) illustrated how the data and information presented in the SmartGIS can be applied worldwide in case of an accidental oil spill, providing a fruitful contribution to handle the emergency.

For years, even decades, microbial biologists have been aware of the ability of some naturally-occurring microorganisms to degrade certain fractions of petroleum into simpler substances. This process is known as biodegradation and refers specifically to the natural process whereby, bacteria or other microorganisms alter and break down organic molecules into other substances, such as fatty acids and carbon dioxide. The possibility that this natural process could be harnessed as a practical oil spill response technology motivated some of the early investigations into the factors that affect biodegradation, the kinds of hydrocarbons capable of being degraded by microorganisms, rates of biodegradation, and the species and distributions of microorganisms involved in biodegradation. Research into these topics has led to the development of several types of methods for using microorganisms to restore sites polluted by oil. Collectively, they are known as bioremediation techniques, and they involve the addition of materials to contaminated environments to cause an acceleration of the natural biodegradation process. Fertilization is the bioremediation method of adding nutrients, such as nitrogen and phosphorus, to a contaminated environment to stimulate the growth of indigenous microorganisms. This approach is also known as nutrient enrichment. Seeding refers to the addition (usually of non-native) of microorganisms to a spill site. Such microorganisms may or may not be accompanied by nutrients. Current seeding efforts use naturally occurring microorganisms, but seeding with genetically engineered microorganisms may also be possible. This approach, bio-remediation is now widely considered for the remediation of oil spills (Westermeyer 1992).

So many oil spill remediation techniques abound, which have been described briefly in this section. However, most of the conventional oil spill response/remediation technologies to date, have in general failed to perform optimally within the criteria of cost and efficiency.

MATERIALS AND METHODS

Ex-situ Technologies

Ex situ treatment involves excavation of contaminated soils, followed by treatment or disposal. Ex-situ technologies have evolved from simple removal and landfill disposal (dig and dump), to technologies designed to treat contaminated soil and water onsite. Recently, many owners of contaminated sites have required that all treated soil and water remain on the site, to minimize future liability associated with transportation and off-site disposal. The move to on-site treatment has been accelerated in many countries by the increasing difficulty in siting fixed waste treatment facilities. Public concerns over the safety of such facilities, and the dangers of long-term exposure to nearby residents have led to the increased popularity of mobile treatment technologies. These systems can be moved quickly on-site, the waste treated over a relatively short period, and then moved away. This tends to improve public acceptance, reduce costs, and provide for a site-specific solution.

Pyrolysis or thermal phase separation or indirect fired thermal desorption: Thermal desorption is a process that uses high temperatures (usually below 400°C) to drive organics out of soil by volatilization. The method is done in the absence of oxygen and it uses temperature much less than that required for combustion. Unlike the incineration process that heats the soil to higher temperatures in an oxygenated atmosphere which both volatilizes and combusts the organics simultaneously, thermal desorption offers several advantages over incineration including reduced amount of gases produced, thereby reducing the size of the off-gas handling system.

Bioremediation: This refers to the degradation of organics in soil using indigenous or inoculated microbes in bio-piles or land spreading process. The process is natural and it usually takes longer time to achieve the intended aim. It requires large areas and control of fugitive emissions.

Leaching/soil washing: This involves an on-site set-up to scrub soil and remove hydrocarbons which are then treated separately. Soil flushing is flooding a zone of contamination with an appropriate solution to remove the contaminant from the soil. The two technologies are not well developed, but looks promising for some applications (Wilson 1994). The contaminants are mobilized by solubilisation, formation of emulsion, or a chemical reaction with the flushing solutions. After passing through the contamination zone, the contaminant-bearing fluid is collected and brought to the surface for disposal, recirculation, or on-site treatment and reinjection (US EPA 2008).

Vitrification: This process involves melting of contaminated soil, buried wastes, or sludges in place to render the material non-hazardous. It uses electricity to heat soil to remove organics and encapsulate heavy metals into glass. Heating is as high as 1,600 to 2,000°C. The high temperature destroys organic pollutants by pyrolysis.

Acid extraction: This involves leaching of heavy metals using an acid based reagent. Its application is limited to use in inorganic environments since it may affect the treatments of organics.

Dechlorination: This involves the treatment of chlorinated contaminated soils using proprietary chemical systems. It's limited in application to chlorine contaminated environments and has no effect on non-halogenated organics.

Oxidation/reduction: This can be traced back to the concept of REDOX reaction where organics are treated using hydrogen and temperature. Oxidation involves the loss of hydrogen while reduction is the gain of hydrogen. It's limited in application to chlorinated organic compounds and it's not suitable for inorganics.

Solvent extraction: This requires the use of solvent to extract organics of high concentration from the soil. Organics of high concentration here are those ones that emanate from hydrocarbon operations/spills. Also, various applications identify weakness in its effectiveness with heavy metal contaminated soils.

Wet oxidation: In wet oxidation, slurry flows through reaction tube, oxygen is injected and oxidation of organics is achieved. No air is emitted during the process. It is successful in applications in organics and hydrocarbon contaminated environments.

In-Situ Technologies

Soil vapour extraction (SVE): SVE, also known as soil venting or vacuum extraction, is an in-situ remedial technology that reduces concentrations of volatile constituents in petroleum products adsorbed to soils in the unsaturated (vadose) zone.

Bio-venting: This is the stimulation of aerobic bioactivity through inducement of air flow in the unsaturated zone as part of conventional SVE, thereby reducing the concentration of contaminants in the unsaturated zone only.

Bio-sparging: This refers to the removal of volatile compounds from saturated zone by injection of air/oxygen below groundwater surface. It is also used in conjunction with SVE thereby stimulating aerobic bioactivity in the saturated zone.

In-situ bioremediation: This involves degradation by active microbes in soil. Microbes used are mainly indigenous or inoculated microbes. Delivery systems and stimulants used involve both aerobic and anaerobic processes.

Wetland treatment: This approach focuses on the treatment of pumped groundwater or contaminated discharge through natural or engineered systems.

Horizontal wells: This is an emerging technology where wells are screened horizontally or at an angle to intercept thin of oriented geologic zones or contaminant plumes.

In-situ passive barriers (funnel and gate) method: This is also an emerging technology yet to be adopted where an in-situ barrier is used to directly flow to a central point. Treatment occurs by natural gradient through-flow. Variation in treatment arises from the difference in the concentrations and compositions of contaminants.

Decision Matrix Development

Based on the findings in the literature study above, some criteria were set as guiding factors in order to determine the differences in each remediation technique with respect to the criteria. A decision matrix was developed using these criteria. This served as our basis of selection to the efficient deployment of a sole or hybrid technique. The decision matrix covers some of the main criteria influencing the selection of remedial methods for contaminated soils. It also determines the degree of overall importance of a remediation technique. Criteria used to design this decision matrix include:

1. Cost efficiency
2. Applicability of the technique
3. Operation and maintenance of the technique
4. Environmental Impact
5. Time frame of achieving remedial objectives/Ease of deployment
6. Health concerns
7. Efficiency/foot print after clean-up

Data Collection

Primary data: Primary data collection was carried out with a wide number of literature studies to gain an overview of the different remediation methods for Niger Delta contaminated soils. Through this study, different factors responsible for the design of the decision matrix table were identified and analysed. Specific literature studies include USEPA, UNEP report on Ogoni land, NOSDRA report and various SPE papers and thesis of different scholars collected from web searches.

Assessment/ranking scales: The study used the following assessment scales by allocating an effective score to each technique which is based on the assessment criteria discussed in the section above.

1-Very low, 3-Low, 5-Medium, 7-High, 10-Very High

RESULTS

Matrix Weight Computation

Preference Scale - 1 = about the same, 2 = preferred, 3 = strongly preferred.

The matrix weight percent was computed in MS-Excel using an effective computational score allocated to each criterion stipulated. Stated clearly below is the equation used for this computation:

Table 1: Selection criteria ranking for oil spill remediation techniques (paired comparison).

	B	C	D	E	F	G	SELECTION CRITERIA	SCORE	WEIGHT(%)	RANKING
A	A1B1	A1C1	A1D1	E2	F2	A1G1	A: Applicability	4	9.30	1
B		B1C1	B1D1	E2	F2	B1G1	B: Ease of Deployment	4	9.30	1
C			C3	C1E1	C1F1	C1G1	C: Operation and maintenance Requirement	8	18.60	2
D				E2	F2	G2	D: Health Concerns	2	4.65	2
E					E1F1	E1G1	E: Environmental Impact	9	20.93	3
F						F1G1	F: Cost Effectiveness	9	20.93	3
G							G: Efficiency	7	16.28	2
							TOTAL	43		

Table 2: Ex-situ technologies decision matrix.

		Ex-Situ Technologies Decision Matrix								
		Applicability +	Time Frame/Ease of Deployment +	Operation & Maintenance Requirement -	Health effectiveness +	Environmental Friendliness +	Cost-effectiveness +	Efficiency +	Weighted Score	Ranking
Criteria Weight		0.093	0.093	0.186	0.047	0.209	0.209	0.163		
TYPE OF REMEDIATION TECHNIQUE	Pyrolysis	10	5	5	3	1	5	5	2.675	5th
	Bioremediation	10	7	1	10	10	7	10	7.048	1st
	Soil Washing	10	3	5	3	5	5	7	3.325	2nd
	Vitrification	7	5	5	3	5	3	1	2.162	7th
	Acid Extraction	3	5	5	1	5	5	7	3.092	3rd
	De-chlorination	3	5	5	1	5	5	7	3.092	3rd
	Solvent Extraction	10	5	7	1	5	5	3	2.719	4th
	Wet Oxidation	3	5	5	1	5	3-5	3	2.022	8th
	REDOX	5	7	5	3	5	3	3	2.488	6th

$$\text{Weight Percent} = \text{Score/Total} \times 100 \quad \text{...(1)}$$

Results from this computation can be seen in Table 1.

Application of Weight Percent

Based on the weight matrix developed in Table 1, the different remediation techniques were ranked and displayed in Table 2 to explain the results. The results show, in general, that how different techniques compare with each other and how each technique outweighs the other.

DISCUSSION AND CONCLUSION

From the ex-situ decision matrix in Table 2, advanced bioremediation is the best placed technique with a highest rank of 1 as seen in the second row.

Bioremediation is the most efficient and cost effective technique with little or no disturbance on site. It has very low health risks as it is a natural process despite the fact that it takes quite considerable amount of time to complete. Its applicability is high as regulatory bodies are seriously buying the idea. In terms of management, it requires virtually no or low cost to operate and maintain processes/equipment used.

Pyrolysis requires professionalism and technicality to operate and maintain. Its wide applicability can be attributed to successful applications in various spill sites (Someus 1994) with high moderation in terms of cost, time frame of deployment and efficiency. Professionalism and technicality as stated before is highly needed to manage its health and environmental implications.

Conclusively, an extensive review has been done based on the role played by technology in remediating oil spilled sites. The review was grouped under two broad categories - the Ex-situ and In-situ remediation technologies.

Ex-situ technologies involve excavation and treatment of contaminated soil. These techniques tend to be more intensive and expensive than in-situ methods, but a higher degree of clean-up certainty is provided more quickly.

In-situ technologies deal with soil and groundwater contaminants in place. Because of the heterogeneity of the subsurface, remediation is rarely complete, and processes are slower. However, on the whole, costs tend to be lower.

A decision matrix was developed during the course of this work to serve as a guide for selection of remediation technique based on different criteria clearly stated in the paper.

The criteria are peculiar to different arms of the business. For example, applicability and operation are peculiar to the cleanup contractors; cost, time and health concerns are peculiar to government regulators; environmental friendliness, time frame and also health concerns are peculiar to the public.

Finally, bioremediation has been identified as the most favourable of all the Ex-situ techniques that were in consideration.

RECOMMENDATION/FURTHER WORK

There is no universally acceptable remediation technique for a particular area or type of spill. This study only serves as a guide to select remediation measures based on our preferences.

Further research should be carried out in the area of hybrid remediation technique application to ascertain its feasibility in terms of cost, applicability, health and efficiency.

Proactive measures like oil spill prevention techniques should be strengthened and regulatory agencies empowered to carry out their work without prejudice.

A secondary data collection approach in form of questionnaire should further be conducted amongst stakeholders/ professionals involved in the decision making process of the various remediation techniques applied in events of oil spill.

REFERENCES

Aiello, G., Buffagni, M., Pavanel, E., Bracco, L., Thorbjornsen, S. and Meregaglia, M. 2014. SmartGIS project: a web application for global oil spill management. In: SPE International Conference on Health, Safety, and Environment. Society of Petroleum Engineers, 17-19 March, Long Beach, California, USA.

Engler, R.A., Rome, G., Rainey, R., DeLeon, V. and Good, M. 2017. Environmental remediation using advanced microbial techniques. In: SPE Health, Safety, Security, Environment, & Social Responsibility Conference-North America. Society of Petroleum Engineers, 18-20 April, New Orleans, Louisiana, USA.

Esak, L.K. and Osborne, A.E. 2000. Successful co-compost remediation project points the way to 45% reduction in oil spill contaminated soil remediation costs. In: 16th World Petroleum Congress, 11-15 June, Calgary, Canada.

Iazeolla, G., Mariani, M., Cassina, L., Marconi, M., Deffis, J.M. and Buffagni, M. 2016. Advanced oil spill modelling in the offshore oil & gas industry: Improving the emergency response management along the project life-cycle. In: SPE International Conference and Exhibition on Health, Safety, Security, Environment, and Social Responsibility. Society of Petroleum Engineers, 11-13 April, Stavanger, Norway.

Imtiaz, M., Rajak, V.K., Dei, S., Chhateja, J. and Biswas, A., 2016. Aquatic oil spill remediation by using automated unmanned boat AUB. In: Offshore Technology Conference Asia, 22-25 March, Kuala Lumpur, Malaysia.

Lessard, R.R., DeMarco, G., Fiocco, R.J., Lunel, T. and Lewis, A. 1998. Recent advances in oil spill dispersant technology with emphasis on new capability. In: SPE International Conference on Health, Safety, and Environment in Oil and Gas Exploration and Production. Society of Petroleum Engineers, 7-10 June, Caracas, Venezuela.

Massoura, S.T. and Sommerville, M. 2009. Realities of spill: Waste remediation strategies. In: Asia Pacific Health, Safety, Security and Environment Conference & Exhibition, Jakarta, Indonesia, 4-6 August.

McAllister, E. W. 2005. Pipeline Rules of Thumb Handbook: Quick and Accurate Solutions to Your Everyday Pipeline Problems. 6th Edition, pp. 547-556.

Michel, C., Quiniou, V. and Vigan, X. 2012. Metocean and oil spill modelling. International Conference on Health, Safety and Environment in Oil and Gas Exploration and Production, 11-13 September, Perth, Australia.

Olayinka, E. D. and Ogbonna, F. J. 2013. Environmental remediation of oil spillage in Niger delta region. In: SPE Nigeria Annual International Conference and Exhibition, 5-7 August, Lagos, Nigeria.

Seitinger, P. and Baumgartner, A. J. 1994. Oil spill remediation: An integrated approach for in-situ site clean-up. SPE Health, Safety and Environment in Oil and Gas Exploration and Production Conference, 25-27 January, Jakarta, Indonesia.

Someus, G. E. 1994. Advanced waste management: Indirect fired thermal treatment technologies. USEPA 5th Forum on Innovative Hazardous Waste Treatment.

U.S. EPA 2008. Green Remediation: Incorporating Suitable Environmental Practices into Remediation of Contaminated Sites. EPA 542-R-08-002.

Westermeyer, W. E. 1992. Bioremedlation: A new tool for marine oil spill response? The Second International Offshore and Polar Engineering Conference, 14-19 June, San Francisco, California, USA.

Wilson, D. J. and Clarke, A. N. 1994. Hazardous Waste Site Remediation. Marcel Dekker, New York.