Sustainable Remediation in Nigeria.

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Abstract

This research was carried out to evaluate the impact of the adoption and implementation of the emerging concept of sustainable remediation to the practice of remediation in Nigeria. The study strategy was by desktop site risk assessment, conceptual site modelling, remediation options appraisal and sustainability assessment of a simulated petroleum-contaminated site (AIREGIN) in the Niger Delta of Nigeria coupled with stakeholder engagement. The literature available on the environmental and industrial geography of the Niger Delta was drawn upon in the creation of the simulated site for the assessment. Questionnaires were used to identify readily available remediation options for the treatment of petroleum-contaminated soil in Nigeria. The questionnaire, which was sent to thirty (30) respondents (ten (10) each from operators, regulators and contractors) identified eight remediation options (Monitored Natural Attenuation, Enhanced *In-situ* Bioremediation, Bio-piles, Composting, Land farming, Incineration, Thermal desorption and Excavation, retrieval and offsite disposal) as widely used in Nigeria and six (6) options (Bioventing, Phytoremediation, Soil flushing, Soil Vapour Extraction (SVE), Chemical Reduction and Oxidation and Soil washing) as easily importable into Nigeria. Remediation options appraisal carried out identified seven (7) options (Enhanced *In-situ* Bioremediation, Bio-piles, Composting, Landfarming, Incineration, Thermal Desorption and Bio-venting) as feasible for the site. This reflects the general practice in Nigeria, as most remediation projects are mostly biological and thermal treatments. Face to face and telephone interviews conducted with ten practitioners revealed a lack of knowledge, the existing legal framework, funding and incessant site re-contamination as major setbacks to the adoption of risk based land management in general and sustainable remediation in particular. The sustainability assessment and sensitivity analysis resulted in identifying Enhanced *In-situ* Bioremediation as the most sustainable remediation option for the AIREGIN site. The research identified as critical limitations to the implementation of sustainable remediation the lack of regulatory framework, lack of awareness and expertise, ambiguous target and intervention values leading to lack of consensus on remedial objectives, poor implementation of the existing risk assessment and options appraisal methods, lack of transparency and commitment in the implementation of existing regulatory regime and general lack of literature on sustainable remediation in Nigeria. The research has shown that existing legislation and guidelines in contaminated land management need to be revised to include sustainability assessment, the harmonization of the target and intervention values using scientific means to determine background values, extensive training and education of regulators; and the clear definition of the involvement and strategy of engagement of local communities in the remediation process by the Nigerian regulators. The impact of the adoption and implementation of sustainable development in Nigeria were viewed from legal, economic, social and environmental dimensions. It has been concluded that sustainable remediation brings to bear a structured and transparent means of deciding how to remediate contaminated lands and is implementable in Nigeria if the recommendations of this research are taken into consideration.

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List of Abbreviations

ASTM	American Society for Testing And Materials
BMP	Best Management Practice
BTEX	Benzene, Toluene, Ethylbenzene and Xylenes
CBO	Community Based Organization
CIRIA	Construction Industry Research and Information Association
CL:AIRE	Contaminated Land: Applications In Real Environments
CoSC	Chemicals of Special Concern
CSM	Conceptual Site Model
CSR	Corporate Social Responsibility
DEFRA	Department for Environment, Food and Rural Affairs, UK
DPR	Department of Petroleum Resources, Nigeria
EGASPIN	Environmental Guidelines and Standards for the Petroleum Industry in Nigeria
GHG	Greenhouse Gas
GSR	Green and Sustainable Remediation
GW	Groundwater
ICCL	International Committee on Contaminated Land
IOC	International Oil Company
IOGP	International Association of Oil and Gas Producers
IPIECA	International Petroleum Industry Environmental Conservation Association
ITRC	Interstate Technology and Regulatory Council, USA
IUCN-NDP	International Union for Conservation of Nature And Natural Resources – Niger Delta Panel
NGO	Non Governmental Organization

NICOLE	Network for Industrially Contaminated Land in Europe
NNPC	Nigerian National Petroleum Corporation
NOSDRA	National Oil Spill Detection and Response Agency, Nigeria
PAH	Poly Aromatic Hydrocarbon
RENA	Remediation by Enhanced Natural Attenuation
mt	Metric Tonne
RoW	Right of Way
SPDC	Shell Petroleum Development Company
SuRF	Sustainable Remediation Forum
SuRF –ANZ	Sustainable Remediation Forum, Australia and New Zealand
SuRF – NG	Sustainable Remediation Forum, Nigeria
SuRF – NL	Sustainable Remediation Forum, Netherlands
SUrF – UK	Sustainable Remediation Forum, United Kingdom
SVE	Soil Vapour Extraction
TCLP	Toxicity Characterization Leaching Procedure
TEPNG	Total Exploration and Production Nigeria Limited
THC	Total Hydrocarbon Content
TPH	Total Petroleum Hydrocarbon
UK	United Kingdom
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
US	United States of America
US EPA	United States Environment Protection Agency

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Dedication

This work is dedicated to my wife,

Mrs. Nkem Nnamdi AHIAMADU

and my children

Master Chimdi Nnamdi AHIAMADU,

Miss Adanna Onyi AHIAMADU

and

Master Nnadozie Nnamdi AHIAMADU.

Affirmation

The work presented in this dissertation was undertaken at the Department of Geography, University of Nottingham, between August 2014 and June, 2016. I affirm here that this dissertation is the result of my work and that neither the present dissertation, nor any part thereof, has been submitted previously for a degree to this or any other university.

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Chapter 1 Introduction

1.1 Remediation of Hydrocarbon Contamination in Nigeria

Alvarez and Illman (2006) reported that the extensive use of petroleum hydrocarbons as both fuel and industrial raw materials has resulted in widespread soil and groundwater contamination all over the world; and that the common sources of petroleum hydrocarbon contamination include oil exploration activities, pipeline rupture, leakage from underground storage tanks and infrastructure, waste pits within production facilities and refinery wastes.

In Nigeria, the problem of land contamination by hydrocarbons is accentuated by the activities of vandals and oil thieves, leading to unwarranted releases or escapes of crude oil into the environment. UNDP (2006) noted that with the expansion of oil production, the incidence of oil spills has increased considerably in the Niger Delta area of Nigeria. Oil spills occur accidentally and through the deliberate actions of local people, who sabotage pipelines in protest against the operations of the Federal Government and oil companies. Also, there are recorded incidents of illegal oil bunkering and refining in the Niger Delta of Nigeria (UNEP, 2011). All these have added to the increasing number of oil spills and emanating petroleum-contaminated sites in the Niger Delta of Nigeria. A total of 6,817 oil spills were recorded between 1976 and 2001, which accounted for a loss of 3 million barrels of oil, of which more than 70% was not recovered (UNDP, 2006).

According to NNPC (2013), pipeline vandalism increased by 58% in 2013 over the previous year. "A total of 3,570 line breaks was reported on NNPC pipelines out of which 3,505 was as a result of vandalism, while 65 cases were due to system deterioration resulting in a loss of 327.48 thousand mt of petroleum products worth about N38.88 billion. Also 2.31 million barrels of Crude oil worth about N38,992 million was lost in the same period" (NNPC, 2013).

The Niger Delta of Nigeria, the oil hub of the nation, has been on the receiving end of these spills for several decades. According to UNDP (2006) the numerous oil spills and the gas flaring in much of the delta have taken an enormous toll on the environment. This has fostered serious political and social unrest in the country (UNDP, 2006 & UNEP, 2011).

Efforts by the oil and gas operators in the area to remediate and even cleanup crude oil spill sites have been hampered by security concerns and deployment of ineffective remediation strategies (UNEP, 2011 & IUCN-NDP, 2013). According to UNEP (2011) Remediation by Enhanced Natural Attenuation (RENA) of soil deployed by Shell Petroleum Development Company (SPDC) in the remediation of crude oil spill sites in Ogoniland, Niger Delta of Nigeria was found to be ineffective as most of the spill sites were found to have TPH values higher than prescribed limits in Nigeria even after RENA for three (3) years. Furthermore, SPDC claimed that the sites with post remediation TPH values above the regulatory limits were re-polluted by the activities of vandals and illegal oil thieves. In a similar vein, IUCN-NDP (2013) observed that in a concluded remediation site in Soku, the CoSC levels were far higher than the EGASPIN (2002) limits, even though the regulatory authorities had certified the site to have been remediated. Amnesty International (2008) reported that decision to remediate a site is significantly controlled by companies against the requirement of a joint analysis by company and regulators; and that the role of regulators has frequently been limited to assessing data presented by companies rather than carrying out independent investigations and analysis. Amnesty International (2008) further noted that certification process of remediated sites may not have involved site level inspections and scientific analysis by the regulators and was therefore concerned that some of the certified sites in the Niger Delta may not have been adequately treated.

It is therefore obvious that a gap exists in the process of selection, implementation and validation of remediation strategies in Nigeria. This dissertation therefore will review and evaluate the available remediation techniques in Nigeria, and their selection, implementation and validation in order to identify areas where improvement can readily be achieved.

According to Harbottle, Al-Tabbaa and Evans (2008) the remediation of contaminated land is considered a sustainable practice as it encourages the reuse and redevelopment of land but most remediation methods involve a wide range of activities that result in environmental, societal and economic impacts. Vegter, Lowe and Kasamas (2002) also stated that increasing concerns about fossil carbon use have led to questioning whether it is sustainable to apply energy intensive remediation processes, such as incineration/thermal treatment to relatively low levels of contamination and the increasing interest in the use natural processes to effect remediation. This brings to view the practice in Nigeria, where consideration is only given to cost and effectiveness of the solution but not to other sustainability factors.

In recent years, there has been a drive towards sustainable approach to remediation in many countries including the UK, USA, Netherland, Canada, Japan, China, Australia and New Zealand (Bardos, 2014) but Nigeria has not embraced this emerging trend.

This dissertation will therefore, review the application of sustainable remediation appraisal system in Nigeria and its implications.

1.2 Aim and Objectives of the Study

The aim of this study is to evaluate the applicability and implement-ability of sustainable remediation in Nigeria by identifying opportunities in the existing regulatory and legal framework and evaluating the net benefit of implementing sustainable remediation by exploring a sustainable **remediation strategy** for crude oil contaminated soil in a crude oil spill site, Niger Delta, Nigeria.

The objectives of this study are to:

a. Critically review the legal/regulatory context to establish soil remediation goals and other constraints in the Nigerian oil and gas industry;
b. Develop a simulated crude oil contaminated site (called the AIREGIN Site) in the Niger Delta of Nigeria (real case study information is not available);
c. Carry out human health, groundwater and surface water risk assessment of the simulated crude oil contaminated site to establish the drivers for remediation;
d. Establish currently and/or easily available soil remediation technologies in Nigeria;
e. Carry out remediation options appraisal of the established available remediation options for this Site;
f. Determine the most appropriate/sustainable remediation strategy for this Site given the legal context and available resources, expertise and equipment in Nigeria at the present time;
g. Evaluate the impact of sustainable remediation assessment on remediation options selection in Nigeria; and
h. Make recommendations on what is needed for sustainable remediation to be implemented in Nigeria.

1.3 Structure of the Dissertation

This dissertation is presented in eight chapters and the main contents of each chapter are detailed below.

Chapter 1 introduces the current practice of remediation in Nigeria, the driving the force, aim and objectives of this study.

Chapter 2 contains a review of the regulatory framework for the remediation of petroleum-contaminated sites in Nigeria.

Chapter 3 reviews relevant literature on remediation techniques for petroleum-contaminated sites and the general concept of sustainable remediation and some of the established frameworks around the world.

Chapter 4 presents the methodology adopted for the research and discusses the means through which this research work was carried out, providing insight into the assumptions and extrapolations used in the research.

Chapter 5 describes the AIREGIN site and its general geology, drawing extensively from literature on the physiography, geology and hydrogeology of the Niger Delta of Nigeria. It also contains site risk assessment and conceptual site model developed as part of the research to establish the objectives of remediation for the AIREGIN site.

Chapter 6 presents analysis of the responses from the questionnaire administered for establishing the currently and or easily available remediation options in Nigeria for the management of petroleum-contaminated soils and the results of the remediation options appraisal exercise.

Chapter 7 presents the opinion of the interviewees on sustainable remediation and the sustainability assessment exercise carried out as part of this research.

Chapter 8 discusses the findings of the research drawing extensively from the literature review, the risk assessment, conceptual site modeling, options appraisal and sustainability assessment exercises.

Chapter 9 discerns the impact of the implementation of sustainable remediation on the legal, economic, social and environmental dimensions in Nigeria. It also presents recommendations on what needs to be done to implement sustainable remediation in Nigeria.

Chapter 2 REGULATORY FRAMEWORK FOR REMEDIATION IN NIGERIA

This chapter reviews the regulatory framework for the remediation of petroleum-contaminated sites in Nigeria.

2.1 Legal and Regulatory Framework for Establishing Remediation Goals of Crude Oil Contaminated Soil in Nigeria

This section discusses the legal and regulatory framework for the establishment of remediation goals for crude oil contaminated soil in Nigeria. It reviews the Nigerian legal context and International Petroleum Industry guidelines and best practice guides.

In relation to the management of crude oil contamination in Nigeria, there are two main regulating bodies with defined regulatory frameworks; Department of Petroleum Resources (DPR) and the National Oil Spill Detection and Response Agency (NOSDRA). Other applicable frameworks are the guidelines and good industry practice guide provided by the International Association of Oil and Gas Producers (IOGP) and International Petroleum Industry Environmental Conservation Association (IPIECA) on the subject matter.

This section summarizes the provisions and guides offered by the Nigerian and industry frameworks.

2.1.1 DPR Environmental Guidelines and Standards for the Petroleum Industry in Nigeria (EGASPIN) 2002

The Department of Petroleum Resources (DPR) is the principal regulator of the petroleum industry in Nigeria. The DPR is the inspectorate arm of the Federal Ministry of Petroleum Resources established by the NNPC Act (1976). It draws its powers to make regulations from the Petroleum Act (1969), which empowers the Minister of Petroleum Resources to make laws as appropriate for the protection of the Nigerian environment from petroleum exploration and production activities. The main DPR's regulatory instrument for the management and remediation of contaminated sites is the Environmental Guidelines and Standards for the Petroleum Industry in Nigeria (EGASPIN) 2002.

EGASPIN was first issued in 1991 and revised in 2002 for the protection of the Nigerian environment from petroleum exploration and production activities. EGASPIN comprises Ten Parts (I to X). In relation to the management of crude oil contaminated sites, EGASPIN (2002) detailed the requirements in Part VIII Section F Titled Management and Remediation of Contaminated Land.

EGASPIN (2002) adopted the "suitable for use" approach in defining the framework for the management and remediation of contaminated land, which basically consists of three elements:

- Ensuring that land and water resources are suitable for their current use;
- Ensuring that land and groundwater are made suitable for any new use, as official permission is given for that new use; and
- Limiting requirements for remediation to the work necessary to prevent unacceptable risks to human health or the environment in relation to the current use or officially permitted future use of the land.

In Nigeria unacceptable risk related to petroleum contamination is vague and confusing. The only regulatory limits available are further complicating as it provides two limits defined as 'target' and 'intervention' limits.

It also provides an exception to the "suitable for use" approach in instance where contamination has resulted from the breach of a specific environmental license or permit. In such circumstances, the polluter is required to remove the remaining contamination as completely as is practicable and as may be directed by the Director, Petroleum Resources.

The guideline provided prescriptive target and intervention values for soil/sediment and groundwater in Table VIII-F1 (Appendix 1). The target values are indicative of the soil quality required for sustainability or expressed in terms of remedial policy, the soil quality required for the full restoration of the soil's functionality for human, animal and plant life; and indicate the soil quality levels ultimately aimed for (by implication all remediation projects must pursue objectives for the various contaminants below the target values) while the intervention values indicate the quality for which the functionality of soil for human, animal and plant life are or threatened with being seriously impaired (by implication at these values there is eminent danger). No national or regional background values exist in Nigeria like in South Africa (DEA-RSA, 2010) and UK (BGS, 2012), where background concentrations of many contaminants have been established. Edet (2014) stated that background, threshold and reference values for metals and hydrocarbons are yet to be defined in the Niger Delta of Nigeria.

There is no available evidence on how the target and intervention values were derived and EGASPIN (2002) in introduction of Part VIII Section F.8.1 stated that the target and intervention values were to be used for an interim period whilst suitable parameters are being developed but unfortunately the interim period has lasted from 1991 to the present time. This section indicates that the values were not arrived at by any scientific method but by mere extrapolation from other countries. Ja'Afaru (2014) citing UNEP (2011) noted that the use of the intervention and targets values was copied from the Netherlands as interim measure pending the development of suitable parameters.

It is mandatory that remediation goals are set to meet the prescribed values. Today, there is confusion in the interpretation of the target and intervention values. Whilst the DPR argues that all sites with concentrations above the target values shall be remediated and contaminants brought back to below the target values and that intervention values represent concentrations of contaminants which correspond to serious contamination and require urgent intervention; some operators argue that remediation is only necessary when the concentrations of the contaminants are at or above the intervention values. SPDC sets its remediation objective for Mineral Oil at 3000mg/kg dry material arguing that this is more stringent than the intervention value prescribed in EGASPIN (2002) (SPDC, 2013). In Total

E&P Nigeria, remediation is triggered for sites when concentrations are above the target values and remediation objectives set to bring down mineral oil to below 50mg/kg [TEPNG, 2014). This is still an issue not settled in the petroleum industry in Nigeria but it is worthwhile to follow the interpretations of the regulators who administer the regulation. UNEP (2011) stated that "…*EGASPIN form the operational basis for environmental regulation of the oil industry in Nigeria. However, this key legislation is internally inconsistent with regard to one of the most important criteria for oil spill and contaminated site management – specifically the criteria which trigger remediation or indicate its closure (called the 'intervention' and 'target' values respectively). The study found that the Department of Petroleum Resources and the National Oil Spill Detection and Agency (NOSDRA) have differing interpretations of EGASPIN. This is enabling the oil industry to close down the remediation process well before contamination has been eliminated and soil quality has been restored to achieve functionality for human, animal and plant life".* In a similar vein, IUCN-NDP (2013), noted that the EGASPIN (2002) target limits for the CoSC were higher than international limits especially in comparisons with the limits set by Canada, South Africa, the UK, the Netherlands and some states in the USA. IUCN-NDP (2013) also noted that DPR in preparing the EGASPIN and setting the limits the DPR had adopted most stringent values available at the time in 2002 in comparison with other countries and that these limits are out of sync with other countries that undertook reviews in 2010 and 2012. IUCN-NDP (2013) equally stated that for mineral oil (C15 – C40) the EGASPIN (2002) standards are stricter than the corresponding values in the Dutch and American guidelines because these countries have updated their mineral oil limits while Nigeria has not since 2002.

EGASPIN (2002) further provided for a voluntary and case-by-case application of Risk Based Corrective Action (RBCA) methodology in the management of contaminated sites. Part XIII F Section 1.3.2 provided that DPR was developing a sectoral guidance for the application of contaminated land risk management in the Nigerian environment but unfortunately this sectoral guidance is yet to be issued, but EGASPIN (2002) provides some information on the Tiered approach to RBCA as published by ASTM. No risk assessment models or matrices are provided by EGASPIN or any other guidelines in Nigeria as in the case of the UK, where DEFRA (2004) and CIRIA (2001) has published environmental and contaminated land risk assessment guidelines respectively.

2.1.2 The NOSDRA Establishment Act, 2006

This act officially established the National Oil Spill Detection and Response Agency with a mandate to manage the National Oil Spill Contingency Plan (FGN, 2006), oil spill incidents and the contaminated lands emanating from these incidents. The Act in Section 6(3) makes it mandatory for all operators in Nigeria to restore all crude oil polluted sites and failure to do so attracts a sanction of One Million Naira (approximately $3,200). Beyond this, the Act did not provide any further guidance or cleanup targets for the management of petroleum-contaminated sites.

2. 1.3 S.I. No.25 Oil Spill Recovery, Clean-up, Remediation and Damage Assessment Regulations, 2011

As part of its mandate to make regulations on oil spill and related matters, NOSDRA issued the S.I. No 25 in 2011. These regulations require operators of oil facilities to obtain approvals for the remediation of impacted sites and to identify the impacted site and report the same to NOSDRA. The regulations classify environmental impacts as current and historical; and advocate similar remediation procedures for both classifications. The operator is required to identify and characterize the land use of the site in the assessment of the human and ecological exposure to the pollutant and the regulation went further to classify land use into agricultural, residential or parkland, commercial and industrial. Remediation is expected to commence as soon as the need to do so in any given site is identified. Unfortunately, there are no explicit recommendations on how to establish the need to carry out remediation on a site. The regulation did not prescribe any screening values but recommends soil removal for soil with Total Hydrocarbon Content (THC) above 5000mg/kg and that replacement soil should have THC of 50mg/kg dry weight or less. The regulation stipulated that the clean-up levels or goals shall be established on a case-by-case basis in a consistent manner, invariably advocating a risk-based approach for setting remediation goals.

2.1.4 The IOGP Decommissioning, Remediation and Reclamation Guidelines for Onshore Exploration and Production sites (2008)

The IOGP guideline defines remediation as the management of contaminated soil, surface water and groundwater to prevent, minimize or mitigate risks to public health and safety or the environment. It further defined remediation objectives to include ensuring:

- Adequate protection of human health, safety and the environment;
- Suitability of the proposed land use; and
- Aesthetical acceptability.

Two remediation criteria; generic and site-specific were highlighted and guidelines for selection of remediation criteria outlined in three dimensions as follows.

- "For sites where remediation may not be necessary or can be deferred
    - There is no evidence of contamination, the concentrations of any contaminants are not significantly elevated above background levels or contaminant concentrations are less than the absolute assessment criteria recognized by local regulatory authorities.
    - Contamination is present, but has impacted modest material volumes and is permanently isolated from potential receptors.
    - Situations involving jurisdictions that allow the responsible deferral of remedial action.
    - Situations where natural attenuation will reduce contaminant levels to acceptable concentrations within reasonable timeframes.
    - Situations where remediation (through access or disturbance) will generate greater health and/or environmental risks than leaving residual contamination in place.

- For sites where generic remediation criteria may be appropriate
    - Contaminated material volumes and remediation costs are not sufficient to justify the time and expense associated with the development of site-specific, risk-based criteria.
    - Situations requiring quick remedial action.
    - Situations involving stakeholders that will not be receptive to owner/operator developed, risk-based criteria.
    - Situations involving jurisdictions that accepts above background, residual concentrations, which depend on, land use.
- For sites where risk-based remediation criteria may be appropriate
    - Contaminated material volumes and remediation costs are high enough to justify the time and expense associated with the development of site-specific, risk-based criteria.
    - The time required to develop defensible risk-based criteria does not result in significant incremental environmental degradation.
    - Situations involving stakeholders that will accept owner/operator developed risk-based criteria.
    - Situations involving jurisdictions that do not recognize generic criteria or that will not accept generic criteria above background levels."

The guideline further advised that it is not always necessary to develop site-specific criteria on the basis of detailed, quantitative risk assessments, depending on the contaminated material volumes and the anticipated cost of risk assessment but that it may be advantageous to apply generic standards that are readily available or comparatively easy to assemble. The guideline uses background levels as part of the invaluable factors for determining the remediation criteria to apply but unfortunately in Nigeria no background levels exist (Edet, 2014).

2.1.5 Management and remediation of sites in the petroleum industry. An IPIECA Good Practice Guide (2014)

The guide is a compilation of 'Good Practices' for managing and remediating petroleum-contaminated soil and groundwater from onshore exploration and production facilities, petroleum refineries, terminals and retail gas stations. In this guide, widely accepted principles and strategies as contained in standard reference documents issued by ASTM, the United Kingdom Environment Agency and the United States Environmental Protection Agency are summarized. Its core target group includes environmental specialists that work in countries with less developed or detailed legislative guidance on environmental land management. The guide provides that where in-country legislation or procedures are prevalent, these will supersede the guide.

The guide presents a generic, adaptable, and globally applicable risk-based framework for identifying and managing impacts of releases to soil and groundwater, and for assessing and implementing corrective action. The environmental impact management strategies described provides diverse solutions, and a thorough evaluation of potential management approaches. It described the process of site risk assessment, conceptual site modeling and the appraisal and selection of remediation techniques.

A risk-based management framework has been adopted. This management technique ensures that corrective actions, where necessary, can initially be focused on areas with the highest potential risks. This approach has a wide acceptance as the most resource-effective way to manage soil and groundwater impacts (IPIECA, 2014).

2.2 Legal framework for the Selection of Remediation Strategy in Nigeria

2.2.1 Environmental Guidelines and Standards for the Petroleum Industry in Nigeria (2002)

The EGASPIN (2002) provides that where site assessment indicated remedial treatment action a range of techniques can be carried out to address the significant pollutant linkage and further provided a flowchart to aid in the selection of appropriate remediation techniques (Figure 2.1). The Figure 2.1 considers only the nature and state of the contaminant in the selection of remediation option without provision for variations in site characteristics, which is a necessary factor in risk-based approach to managing contaminated sites. The techniques listed by EGASPIN (2002), which can be *in-situ* or *ex-situ*, are divided into four categories as highlighted below. The list of technologies was not restricted to treatment of petroleum contamination but included treatment of chemical and sanitary-effluent contaminations.

Stabilisation/Solidification

In this category EGASPIN listed the following methodologies

i. Excavation followed by replacement with clean material
ii. Isolation of the contaminated soil by covering with thick inert fill or hard cover.
iii. Mixing of the contaminated material with clean soil or sub-soil in order to reduce the maximum concentration to acceptable intervention and target values.
iv. Solidifying the contaminated soil by appropriate clay or cement ratio and subjecting the solidified material to hardness (compressive strength), TCLP and other tests.

Chemical Treatment

EGASPIN (2002) identified and listed chemical treatment methods to include:

i. Chemical Oxidation
ii. Chemical reduction
iii. Dechlorination
iv. Disinfection

Biological Treatment

Biological treatment methods identified included;

i. Plant uptake
ii. Indigenous bacteria preparation
iii. Nutrient enhancement

Thermal Treatment

In this category of options, EGASPIN (2002) listed;

i. Hot air stripping
ii. Steam stripping

The list above falls short of more recent and innovative techniques applied in the remediation of petroleum-contaminated land. It is therefore pertinent that EGASPIN be updated to reflect current best practice.

Furthermore, EGASPIN (2002) provided that the choice of an appropriate remediation scheme should involve balancing technical requirements with the practicalities of dealing with the site and the costs. When bio-augmentation is to be applied, EGASPIN (2002) requires that the microbial cultures/consortium must not contain genetically engineered organisms or known pathogens to human or indigenous flora or fauna. For the use of chemicals, such chemicals must not have been restricted anywhere in the world for use on land disposal sites without agreement and must be supported by data that demonstrate their effectiveness, toxicity (test to be performed on standard indigenous organisms found in fresh and brackish water, monitored by the officials of the DPR) and the practicality of usage on a large scale.

The formal approval to utilize a product or agent or method, on a large scale, will depend on the findings of pilot scale experimentation.

In practice, all chemical and microbial agents are subjected first to testing, which requires vendors to provide samples of their product to DPR Laboratory Department and pay an amount determined by the DPR, which should be enough to cover the testing in two independent laboratories. The results of the tests will inform the decision to provisionally approve the product to be used on pilot scale experimentation. The conditions of a provisional approval will usually require the company/consultant to be duly registered/accredited by the DPR to render remediation/environmental restoration services in the oil and gas industry, a formal application to use the particular agent, product or method, which should contain sufficient information to facilitate the screening and evaluation of the request, the pilot scale experimentation must be monitored by officials of the DPR and the submission of a report of the results of the pilot scale experimentation to the DPR. The report of the pilot scale experimentation will provide evidence for final decision to issue a formal/final approval for large-scale application of the agent, product or method. The choice of the listed techniques does not suffice for use on a large scale as the method must be subjected to pilot scale experimentation except there is evidence available that the method, agent or product had been used successful in Nigeria.

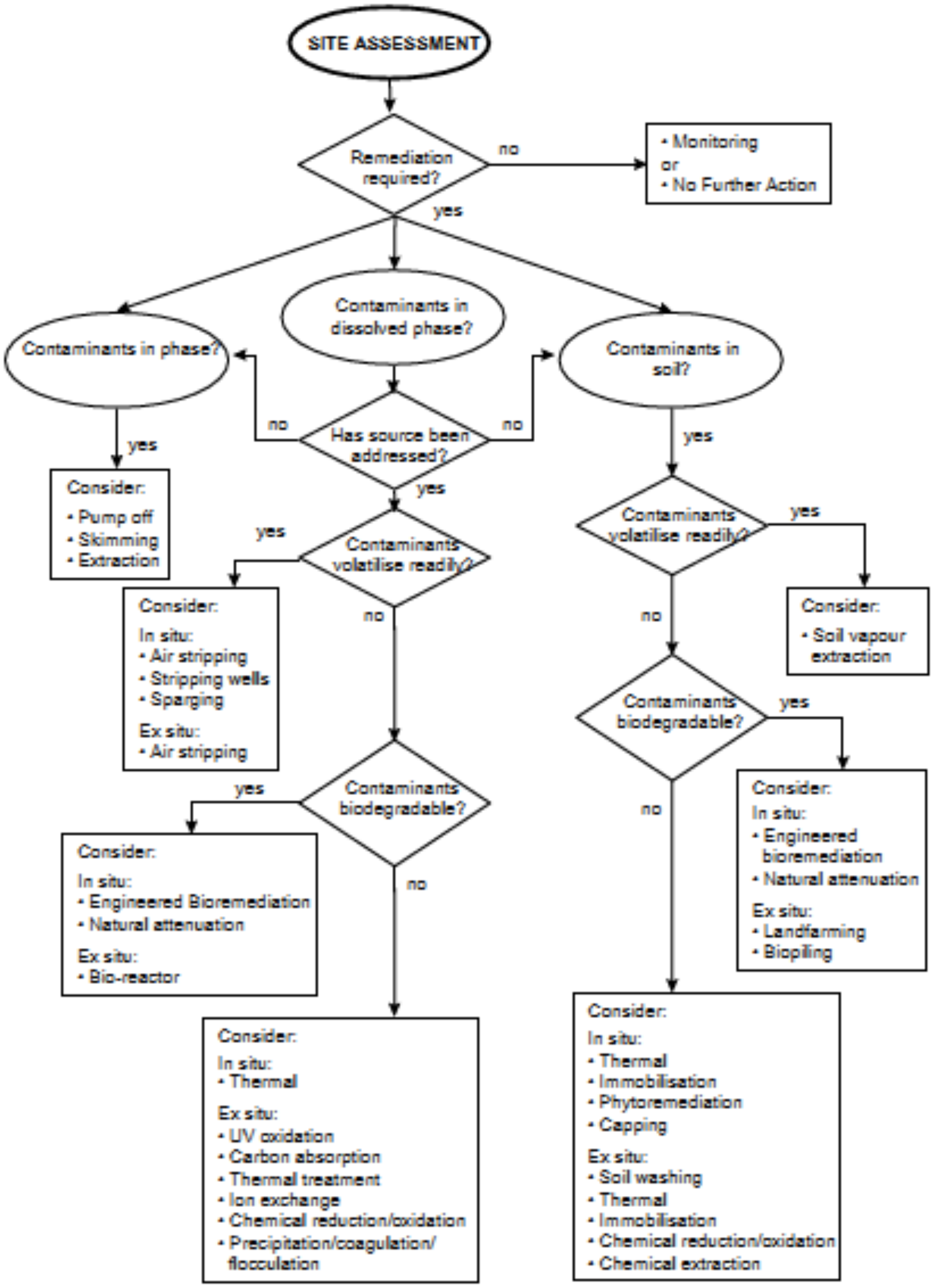

Figure 2.1 Remediation Options Selection Flowchart (EGASPIN, 2002)

2.2.2 S.I. No. 25 Oil Spill Recovery, Clean-up, Remediation and Damage Assessment Regulations, 2011

This regulation recommends generally that soil removal and replacement should be considered in cases where the Total Hydrocarbon Content (THC) of the contaminated soil is above 5000mg/kg dry weight and that replacement soil should have a THC of 50mg/kg or below. These limits differ from the limits of EGASPIN (2002) as it is based on THC rather TPH. Like EGASPIN (2002), this regulation is silent on how these limits were derived and under what environmental conditions it applies but generally recommends the consideration of the sensitivity of the area and the depth of penetration of the hydrocarbon in the application. This regulation published in 2011 did not therefore take consideration of the works of the Total Petroleum Hydrocarbon Criteria Working Group that had defined a fraction-based approach to petroleum contamination risk assessment.

The regulation also provided that remediation options should be approved by the agency before commencement of any remediation work. In the selection of remediation technique, the regulation provided that appropriate remediation technique should take consideration of the following.

i. The type and concentration of contaminants,
ii. The site specific geology and hydrology,
iii. The site specific engineering constraints,
iv. Environmental and public health effects and
v. The site assessment findings.

The regulation provided guidance tables for assessing the applicability of some remediation methodologies taking cognizance of known general parameters including clay, humic, silt, metal, solid and water content as well as the substrate particle size, composition, ph and salinity. These tables, the regulation claimed to have adapted from USEPA, 1993 and the USEPA (1993) document was not provided in the reference section of the regulation.

2.2.3 The IOGP decommissioning, remediation and reclamation guidelines for onshore exploration and production sites

This IOGP guideline states that the most appropriate remediation option is dependent on the site conditions, the types and concentrations of contaminants present, the resources that are readily available and the requirements of regulatory agencies and other stakeholders. The regulation provided that selection criteria for remediation options may include:

i. Proven technology effectiveness
ii. Risk reduction capabilities
iii. Ease of implementation
iv. Environmental and socio-economic impacts
v. Regulatory compliance
vi. Time requirements
vii. Capital costs and
viii. Operating, maintenance and monitoring costs

One critical criteria omitted by this list is the verification cost, which adds up to the general cost of the remediation.

In Table E-1 (Appendix 2) of the guideline provided information on the description, typical implementation times, relative costs and limitations for various remediation technologies for hydrocarbons by collating and analyzing data from various countries and IOCs.

Specifically, for the tropical rainforest, like the Niger Delta of Nigeria, the guideline provided the following remediation and reclamation suggestions.

- Land-spreading, land-farming and passive remediation as attractive options because of the favourable climate,
- Minimizing contaminant run-off by retention of surface soil,
- Installation of drainage channels to accommodate the intensity of rainfall,
- Re-establishment of ground cover via hydro-seeding to prevent soil erosion,

- Re-seeding using forest duff (According to Reardon J. (2007) forest duff is a layer of moderately to highly decomposed leaves, needles, fine twigs, and other organic material found between the mineral soil surface and litter layer of forest soil).
- Enhancement of natural regeneration,
- Minimization of the use of exotic plant species to avoid invasion,
- Windrowed debris to be rolled back for erosion control and
- The restriction of access during reclamation works.

Chapter 3 REMEDIATION

This chapter reviews literature on remediation techniques for petroleum-contaminated sites and the concept of sustainable remediation.

3.1 Remediation Techniques for Crude Oil Contaminated Soil

There are several tested and validated remediation techniques for petroleum-contaminated soils applicable all over the world. According to (Nathanail & Bardos, 2004) remediation strategies employ one or more of the following;

- Excavation and removal of materials off site;
- Containment approaches to limit the migration of contaminants and
- Treatment approaches to destroy, remove or detoxify the contaminants in the environmental media.

It is important to mention that remediation treatments could be *in-situ* or *ex-situ*, on-site or off-site. All *in-situ* options are on-site while *ex-situ* options could be on-site or off-site.

A plethora of remediation techniques exist and are discussed herein in five categories namely;

- Civil engineering methods,
- Biological treatments,
- Chemical treatments,
- Physical treatments and
- Thermal treatments.

The discussions on these five broader categories are based on the following references; Nathanail, Bardos and Nathanail, 2007; Nathanail and Bardos, 2004; CIRIA, 1995 a-c; US EPA, 1988; US EPA, 2012 a-j; FRTR, 2002; ITRC, 2005; CL:AIRE, 2010a; Khan, Husain and Hejazi, 2004; Lim, Lau and Poh, 2016; Agarwal and Liu, 2015; Gomes, Dias-Ferreira and Ribeiro, 2013 and Kuppusamy, S.; Palanisami, T.; Megharaj, M.; Venkateswarlu, K. and Naidu, R. (2016).

3.1.1 Civil Engineering Methods

Civil engineering methods are applicable to a range of ground conditions and contaminant types. They are generally grouped into excavation/abstraction and containment measures.

Excavation involves the removal of the contaminated soil from the ground for further treatment or disposal while groundwater abstraction, which can also be used as containment measure to prevent plume spreading, is the pumping out of contaminated groundwater for surface treatment and return to the aquifer, surface water or sewer system.

Land filling is often used for the disposal of the excavated solid materials on-site or off-site. The main advantage of excavation and off-site disposal is that it removes the contaminants completely from the site and its limitations are high cost associated with haulage of large volumes of excavated materials, the nuisance of vehicular movement to local populations and potential of secondary contamination during off-site disposal.

Containment measures involve the isolation of the contaminated media using barriers or cover systems to prevent migration to the surrounding environment. Barriers could be vertical (installation of physical walls round a contaminant source to isolate contaminants and minimize plume spreading) or horizontal (installation of physical impermeable material above or beneath a contaminated volume. While cover systems are engineered horizontal layer of uncontaminated material placed on the surface or sub-surface, could be single or multi-layered, intended to prevent the migration of contaminants, provide barrier between contaminated materials and potential receptors. Covers could be soil, soil-like materials or synthetics (geo-textiles and membranes). Containment measures are economical but they do not remove the contaminants from the environmental media and usually require long-term monitoring (CL:AIRE, 2010a).

3.1.2 Biological Treatments

Biological treatments involve the use of microorganisms to degrade or transform contaminants to non-toxic by-products or less toxic forms (Nathanail and Bardos, 2004). It accelerates the natural degradation process of contaminants via the supply of nutrients and oxygen required by the microorganisms or through external treatments such as aeration or temperature control (Lim, Lau and Poh, 2016). There are *in-situ* and *ex-situ* methods of bio-treatment.

In-situ bio-treatment include all biological methods carried out within the ground were the contaminant is found. The methods include monitored natural attenuation (which relies on natural physical, chemical and biological processes to reduce the load, concentration, flux or toxicity of contaminants within a specified time scale), enhanced bioremediation (which uses reagents to enhance aerobic or anaerobic biodegradation of organic contaminants or transform inorganic contaminants into less mobile or less toxic forms), bio-venting (where the movement of air is controlled so that the rate of *in-situ* biodegradation is maximized) and bio-sparging (involves the optimization of air-sparging in the saturated zone to enhance biodegradation in the groundwater and sorbed to the solid phase). They are generally cost effective methods and environmentally friendly. The major limiting factors are the timeframe for achieving remedial goals, in ability to achieve low remediation targets, not suitable for certain contaminants and can generate more toxic daughter/intermediate products.

Ex-situ bio-treatment exploits existing microbial processes to degrade or transform contaminants to non-toxic or less toxic byproducts in excavated soils. Basically five *ex-situ* biological treatment methods are identifiable: bio-piles (where static piles of contaminated soil are vented and irrigated), windrow turning (where heaps of contaminated soil often mixed with organic materials are regularly turned by mechanical means to improve aeration), land-farming (where contaminated material is cultivated in lined beds and periodically turned to improve soil structure and oxygen supply), composting (where soil is mixed with bulking agents and organic amendments to enhance porosity and nutrient content of the mixture in a controlled biological process) and slurry-phase bioreactor (where soil made into slurry is treated in a reaction vessel). These methods can result into complete degradation of contaminants but has potential to form toxic intermediate breakdown products.

3.1.3 Chemical Treatment Methods

Chemical treatment methods employ a range of chemical processes to destroy, immobilize or neutralize contaminants. They can be *in-situ* or *ex-situ*.

In-situ chemical methods include chemical oxidation (which involves the addition of solid (pellets or powder), liquid or gaseous oxidants to the subsurface to oxidize contaminants thereby degrading them, reducing their toxicity, changing their solubility or increasing their susceptibility to other treatment methods), electro-remediation (which involves physical/chemical method using electric field to move contaminants and water and also bring about chemical reactions at electrodes), permeable reactive barriers (used for treatment of groundwater by allowing passage of groundwater and contain reagents that degrade or remove contaminants) and stabilization and solidification (which involve a reaction between a binder and soil to immobilize the contaminants by physical encapsulation or chemical immobilization).

Ex-situ chemical method is basically chemical oxidation and reduction, which is as discussed above but applied to excavated soil. As well as stabilization and solidification applied to excavated soil.

Generally, chemical treatment methods are extremely fast (Agarwal and Liu, 2015) and result in complete degradation but limited by the environmental considerations of using chemical reagents.

3.1.4 Physical Treatment Methods

Physical treatment methods remove contaminants from the environmental media as concentrates, which are then treated or disposed of safely by land filling. They can be applied to treat a wide range of contaminants under varying site conditions and include both *in-situ* and *ex-situ* approaches.

In-situ physical methods include flushing, permeable reactive barriers, air sparging, venting and SVE.

Ex-situ physical methods include soil washing (which employs an aqueous solution to separate contaminants and or contaminated soil particles from uncontaminated materials), venting (which involves passing air through stockpile of excavated contaminated material to promote volatilization and/or biodegradation of contaminants from soil and the vapor phase) and water and gas/vapour treatment (which treats waste water and contaminated gaseous streams from other remediation techniques employing a range of materials and methods such as filters, activated carbon, membranes, scrubbers, reverse osmosis etc.) (CL:AIRE, 2010a).

Physical methods can be easily engineered to suit contaminant properties and remediation goals but limited by safety concerns and do not destroy the contaminants. Flushing can provide new pathways.

3.1.5 Thermal Treatment Methods

Thermal remediation of soil uses heat to remove contaminants (Lim, Lau and Poh, 2016). Thermal methods utilize heat to increase the volatility of contaminants for removal from the soil matrix (Gomes, Dias-Ferreira and Ribeiro, 2013) These methods employ elevated temperatures to achieve rapid physical and chemical processes such as volatilization, combustion and pyrolysis, which remove and/or destroy toxic substances from contaminated soil (Nathanail & Bardos, 2004). They can be applied *in-situ* or *ex-situ*.

In-situ thermal treatment method involves the use of steam, electrical energy, radio frequency or radiation to heat and enhance the mobility of organic contaminants in both the saturated and unsaturated zones, which can facilitate their recovery and treatment. Another *in-situ* thermal method is vitrification, which involves the use of high temperatures (1,400 to 2,000 ^{0}C) to destroy organic contaminants or immobilize inorganic contaminants within a glass-like material.

Ex-situ thermal treatments are either one-stage destruction by incineration (where contaminants are destroyed in a combustion chamber at high temperatures up to 1,300 ^{0}C with a secondary combustion chamber to treat volatilized contaminants in the off-gases or two-stage destruction by Low Temperature Thermal Desorption (where contaminants in soil are heated to about 600 ^{0}C leading to physical desorption and volatilization of contaminants, which are then combusted in a second chamber).

Thermal methods are applicable to a wide range of organic contaminants and have high potential for contaminant removal but limited by high cost, energy requirements and environmental concerns of emissions.

3.1.6 Summary of Remediation Methods for Petroleum Contaminated Soils

The common and conventional *in-situ* and *ex-situ* treatment methods for petroleum-contaminated soils are summarized in Tables 3.1 and 3.2 below respectively.

Table 3.1 Summary of Conventional Petroleum Contaminated Site *In-situ* Remediation Methods
(Nathanail, Bardos and Nathanail, 2007; Nathanail and Bardos, 2004; CIRIA, 1995 a-c; US EPA, 1988; US EPA, 2012 a-j; Ebuehi et al, 2005; FRTR, 2002; ITRC, 2005; CL:AIRE, 2010a; Khan, Husain and Hejazi, 2004; Lim, Lau and Poh, 2016; Agarwal and Liu, 2015; Gomes, Dias-Ferreira and Ribeiro, 2013; Gan, Lau and Ng, 2009; Hu, Li and Zeng, 2013 and Kuppusamy, S.; Palanisami, T.; Megharaj, M.; Venkateswarlu, K. and Naidu, R. (2016).).

Technology	Description	Strengths	Limitations
Monitored Natural Attenuation (MNA)	MNA involves physical, chemical and biological processes for remediation (reducing the load, concentration, flux or toxicity of contaminants) through the careful monitoring of the behavior of a contaminant source in time and space domain.	Generates no or minimal wastes. Has potential to destroy the contaminant completely and transformation of contaminants into innocuous by-products. Employs few equipment and labour compared to active remediation methods. There is little or no contact between remediation operators and the contamination.	It may take a long time to reach remediation goal. Require considerable site investigation activities. Substantial long time monitoring required - years/decades. Renewed mobility, desorption or re-solubilization of contaminants due to changes in the subsurface conditions, potential for continued contamination

Technology	Description	Strengths	Limitations
		Minimal disturbance to the environment and limited intrusive work required and site can be put to productive use. Can significantly reduce remediation cost. It can be used in conjunction with, or after, other remediation methods. Can be used to manage risks from contaminants (e.g. DNAPLs), which are hard to remove. It is potentially more acceptable to the public than other remediation technologies.	and cross-media transfer of contaminants. Heterogeneity of subsurface geological and geochemical conditions may make site characterization and prediction of natural attenuation difficult. Some intermediate or by-products may be as or environmentally more hazardous than the original contaminant. Rates of attenuation may drop as natural capacities are exceeded. Public acceptance is slow.
Bioventing	It is an innovative *in-situ* remediation technology that combines physical and	Can be operated with minimal site disturbance and in inaccessible areas e.g. beneath buildings and structures.	Not suitable in sites with shallow water table.

Technology	Description	Strengths	Limitations
	biological processes, involving the movement of air through the unsaturated zone to promote microbial proliferation and degradation of contaminants.	Equipment is readily available and easy to install. Cost effective and competitive. It can treat a wide range of contaminants. It requires short treatment times, from six (6) months to two (2) years. Bioventing can reduce the amount of air emissions and therefore may not require off-gas treatment. It is easy to combine with other technologies.	It is limited by low soil permeability, high clay content, insufficient delineation of subsurface conditions and depth of contamination. It is effective only in the unsaturated zone and may be difficult to treat contamination in the middle of soil matrix. Slow rate of remediation at low temperatures.
Soil flushing	*In-situ* soil flushing is used to deliver biological treatment to the saturated zone by supplying the saturated zone with	Less intrusive on the site. *In-situ* biodegradation results in contaminant destruction rather than extraction.	May produce more toxic or mobile compounds. Requires good understanding of the site geology and hydrogeology to predict

Technology	Description	Strengths	Limitations
	nutrients, or electron acceptors or donors.	Combination with MNA may be highly cost effective. It is effective as a pathway management and source control. May help prevent the need for excavation. It can be adapted to treat specific contaminants including both organic and inorganic compounds.	movement of flushing solutions and design of well system. Effectiveness can be hindered by shallow water table. Limited by low permeability and heterogeneous soils. Has potential to generate new pathways.
Electro-kinetics	A combination of physical and chemical processes using an induced electric field to move contaminants and water and also bring about chemical reactions at electrodes.	Highly effective with fine grained soils such as clay. May be used to enhance other treatment methods by controlling water and inducing movement of substances to *in-situ* treatment zones.	Effective in soils with water content >10%. The presence of buried services, metallic objects or ore deposits may lead to short-circuiting electric fields and damages. Soils may be heated up to temperatures that are harmful to soil flora and fauna.

Technology	Description	Strengths	Limitations
			May be limited by carbonate-rich materials.
Soil Vapour Extraction (SVE)	SVE involves the extraction of volatilized contaminants using extraction wells and subsequent treatment by sorption to activated carbon and possibly by catalytic oxidation. Can be enhanced by steam injection and or biosparging/bioventing.	Minimal site disturbance. It is cost effective. Can be used to treat a wide range of organic compounds, free products and dissolved phase. Can induce natural attenuation processes. May serve as pre-treatment for other remediation methods to prevent or limit emissions.	Limited by the depth of contamination, structure of the soil, degree of saturation, pore connectivity and porosity as well as shallow water table.
Enhanced Bioremediation	*In-situ* bio-treatment methods that employ reagents to enhance aerobic or anaerobic biodegradation of organic	Comparatively cost efficient. Can be used to treat soil, sludge and groundwater. Relatively simple technique.	May take long time to achieve remediation goal. Difficult to apply in heterogeneous subsurface.

Technology	Description	Strengths	Limitations
	contaminants or the transformation of inorganic contaminants into less mobile or less toxic forms. Biostimulation and bioargumentation are the principal variants of this method. The current practice in Nigeria involve the use of local farm implements – shovels, matchet, hoes and sometimes heavy duty machinery to till, homogenize and make windrows at contaminated sites. (Ebuehi et al, 2005).	Highly acceptable to the public. Minimal disturbances to site. Leads to destruction of contaminants. Lower monitoring cost in comparison to MNA.	Uncertainty about the supply and quantity of amendments. Toxic intermediate breakdowns products may be formed.

Technology	Description	Strengths	Limitations
Phytoremediation	*In-situ* biological method, which uses living plants for removal, degradation, immobilization or containment of organic and inorganic contaminants.	Cost effective approach. Environmentally friendly. Provides vegetative cover. May enhance biodiversity and provide physical restoration benefits. Land can be returned to productive use during the remedial work. It provides a long-term stabilization and containment.	Process is relatively slow. Extraction based process moves contaminants into biomass thereby inhibiting biomass use and creating hazardous waste. Phytoremediation is limited by depth of treatment as the processes are limited to the rooting depth. May require further waste management to dispose contaminated biomass. Potential for unwanted volatilization of toxins to the atmosphere through transpiration. Contaminants may bioaccumulate in the food chain.

Technology	Description	Strengths	Limitations
Thermal Treatment	*In-situ* thermal method involving the increase of ground temperature leading to enhanced contaminant removal by one or more methods by specifically increasing volatilization, solubility in water and air permeability, reducing viscosity and adsorption. Also the direct application of heat (steam injection, electrical resistivity, electromagnetic or thermal conductive heating) accelerates chemical reactions, which	Applicable to wide range of soil types. Minimal site disturbances. Applicable to difficult dense non-aqueous phase liquids (DNAPLs). Does not involve the use of chemical reagents in the removal of contaminants.	Heat application could damage soil structure, soil flora and fauna. Enhanced contaminants mobility may lead to migration outside the treatment zone. Incomplete removal of sources may result in elevated groundwater contamination. Increased health and safety risks due to increased levels of vapour and fire risk.

Technology	Description	Strengths	Limitations
	may lead to contaminant destruction.		
Thermally Enhanced SVE	Basically involves a combination of soil heating processes (hot gas/steam injection, electrical resistivity, electromagnetic, thermal conductive heating, radio frequency heating) to volatilize the contaminant and enhance soil vapor extraction.	Short to medium term technology. Commercially available. Cost effective. Minimal site disturbance.	Operation can be hampered by buried services and debris. Not very efficient in soils with high moisture content due to reduced air permeability. Not also very efficient in soils with high organic content because of high sorption capacity of VOCs. May require off gas treatment facility, which will increase the overall cost. The method is not effective in the saturated zone

Technology	Description	Strengths	Limitations
Stabilization and solidification	Relies on the reaction between a binder and the soil matrix to reduce the mobility of contaminants by physical encapsulation or chemical immobilization.	The process equipment occupies a relatively small footprint. The technique improves the overall soil physical properties. It can be used to treat recalcitrant contaminants.	Volume increases may restrict the use of the method in restricted areas where land contours could be seriously affected. The method does not destroy the contaminants. It may be difficult to predict the long term behavior of the encapsulated or immobilized contaminant. Requires long-term maintenance and or monitoring. It is sometimes difficult to achieve binder delivery and effective mixing ratio.
In-situ Chemical Oxidation (ISCO)	This involves the introduction or addition of chemical oxidants to subsurface soils or aquifers	Reactions are not hindered by contaminant concentrations hence viable in treating high concentrations.	It is considered to very environmentally unfriendly due to use of aggressive and hazardous materials.

Technology	Description	Strengths	Limitations
	to oxidize contaminants thereby degrading them or reducing their toxicity or changing their solubility or increasing their susceptibility to other treatment methods.	Reactions are rapid and can result in complete destruction of contaminant. Most reagents used are of low cost and are either short-lived or naturally occurring in the soil. The reagents are easily delivered to the subsurface.	High health and safety risks due to the use of chemicals. May require large volumes of reagents. May produce intermediate toxic breakdown products. Precipitation reactions may be reversible over time with changes in redox conditions. Difficulty in ensuring contact between reagents and contaminants may hinder the process. May be problematic to apply in low permeability soils. The reagents may color groundwater.

Technology	Description	Strengths	Limitations
Fracturing	Fracturing techniques enhance access to the subsurface by creating new fractures or enlarging existing fractures to enhance *in-situ* remediation processes. It is applied where hydraulic conductivity is $<10^{-6}$ m/s or pneumatic conductivity is $<10^{-7}$ m/s.	Can be used as pretreatment to enhance a wide range of *in-situ* treatment methods. Can be used in a wide range of ground conditions and at any depth. Makes *in-situ* techniques more economical by reducing the number of extraction wells, reducing labor and materials. Applicable to wide range of contaminant groups.	During fracturing there is risk of damage to buildings and structures. It increases mobility of contaminants and may lead to contaminants migrating out of the treatment zone. May also create new pathways. Fracturing can lead to vertical movement in the subsurface.
Capping	Capping involves placing a cover over contaminated material to isolate the contaminants from potential receptors and keep them in place to avoid spreading. A range of	Not expensive. Stops rain infiltration into the contaminated material. Protect the groundwater by preventing vertical migration of contaminants.	Does not remove or destroy the contaminant. Requires long-term inspection and maintenance. Cap can be destroyed by other human activities.

Technology	Description	Strengths	Limitations
	materials such as vegetation cover, clay material, concrete, asphalt and geo-membrane, may be used as cap.	Minimizes gaseous emissions from the contaminated material. Isolates contaminants from receptors. Can be effective for many years.	Requires groundwater monitoring to ensure that cap is not compromised.

Table 3.2 Summary of Conventional Petroleum Contaminated Site *Ex-situ* Remediation Methods
(Nathanail, Bardos and Nathanail, 2007; Nathanail and Bardos, 2004; CIRIA, 1995 a-c; US EPA, 1988; US EPA, 2012 a-j; FRTR, 2002; ITRC, 2005; CL:AIRE, 2010a; Khan, Husain and Hejazi, 2004; Lim, Lau and Poh, 2016; Agarwal and Liu, 2015; Gomes, Dias-Ferreira and Ribeiro, 2013; Gan, Lau and Ng, 2009; Hu, Li and Zeng, 2013 and Kuppusamy, S.; Palanisami, T.; Megharaj, M.; Venkateswarlu, K. and Naidu, R. (2016).).

Technology	Description	Strengths	Limitations
Biopiles	Biological method involving the construction of excavated soil into static heaps with a network of perforated pipes to help in aeration and nutrient delivery in a lined area. The conditions in the pile are optimized by aeration and delivery of water. A leachate collection system is usually installed to manage runoffs.	The technique has inbuilt process emissions containment system. Better optimization of environmental factors. Can be easily verified compared with *in-situ* techniques. Treatment time is relatively low compared to *in-situ* methods. It enhances soil structure, which can be reused on site.	It may have large space footprint. There is logistics and health and safety concerns of excavation. Variability in the rate of degradation of various organic compounds is a limiting factor. Toxic or mobile intermediate breakdown products may be formed.

Technology	Description	Strengths	Limitations
		Effective use of inoculums/nutrients/surfactants and other additives.	There is the need for monitoring during the process.
Landfarming	Excavated contaminated soil, sediment, or sludge is applied into lined beds, and periodically turned over or tilled to improve soil structure and oxygen supply.	Landfarming is extremely simple bioremediation process. It is inexpensive and requires no process controls Relatively unskilled personnel can carry out the activities. It is noninvasive.	Requires extensive space and time. May lead to the incorporation of contaminated into previously uncontaminated soil thereby creating large volumes of contaminated substrate. Environmental conditions affecting bioremediation are largely uncontrolled and may lead to increased time of remediation activities. There is the potential for contaminant migration from

Technology	Description	Strengths	Limitations
			contaminated area to previously uncontaminated areas.
Composting	Composting involves mixing the contaminated soil with an organic bulking agent and formed into piles or windrows while mechanically manipulating the soil to improve soil conditions; thereby accelerating the biodegradation rate of the contaminant. The bulking agent is usually a material of low density that lowers the contaminated soil bulk density, increase porosity and oxygen diffusion and can help to form water stable aggregate. These increase aeration and microbial activity, and hence biodegradation. Nutrient addition to the pile and or microbial	Commercially available. Has emissions control systems. Environmental conditions are better optimized compared to in-situ methods. It enhances soil structure, which can be reused on site. Effective use of inoculums/nutrients/surfactants	Requires substantial space and labour cost. Requires excavation of contaminated soil, which may lead to release of volatiles and dust. Potential to generate more toxic daughter/intermediate products

Technology	Description	Strengths	Limitations
	augmentation may as well accelerate the rate of biodegradation in the piles.		
Slurry Phase Bioreactor	An engineered system that is designed to optimize conditions for biological degradation. Contaminated soils are made into slurry by mixing with water and then treated in an enclosed reaction vessel, which gives greater control over the process.	It has rapid degradation kinetics when compared with other bioremediation techniques. Can be effective on clayey soils. Better optimized environmental conditions. Effective use of inoculants. Mixing process may enhance mass transfer rates and may increase contact between contaminants and microbes/inoculants.	Requires the excavation of the contaminated media. Sizing of contaminated materials must be performed as pretreatment. The process control is more complex than for solid phase bioremediation methods. Residues may require further treatment or appropriate disposal. Low soluble contaminants may be more difficult to degrade and may

Technology	Description	Strengths	Limitations
			require the addition of surfactants or other emulsifiers.
Chemical Oxidation and Reduction	*Ex-situ* chemical method involving the introduction of chemicals to excavated soils to oxidize or reduce contaminants thereby degrading them or reducing their toxicity or changing their solubility or increasing their susceptibility to other treatment methods.	As in ISCO. It is easier to ensure contact between contaminants and reagents in excavated soil compared to ISCO.	It is considered not very environmentally friendly due to use of aggressive and hazardous materials. High health and safety risks due to the use of chemicals. May require large volumes of reagents. May produce intermediate toxic breakdown products. Control systems are necessary to prevent leaching into water courses.

Technology	Description	Strengths	Limitations
			May affect soil structure and biochemistry of the soil.
Soil washing	*Ex-situ* physical process that uses aqueous solution (mainly water) to separate contaminated fine materials from relatively uncontaminated coarse in excavated soils. The method is a volume reduction/waste minimization process concentrating contaminants in smaller volumes of soil materials. The contaminated residue is further treated or disposed appropriately.	Can be applied to treat a wide range of contaminants. Volume reduction of the contaminated material may lead to reduced cost of treatment or disposal. Uncontaminated coarse can be recycled as graded fills thereby reducing the volume of imported fill needed. The treatment modules can be configured to manage contaminant combinations.	If carried out onsite can lead to large site footprint. It is uneconomical for treatment of small volumes of contaminated soil and materials with high fine (clay) content. It is environmentally intrusive requiring emissions control and noise abatement systems. Waste water treatment unit is likely to be required that will add to overall cost.

Technology	Description	Strengths	Limitations
		Can be used as pretreatment for other treatment methods to concentrate contaminants.	
Chemical Extraction	Separates contaminants from soil/sediments/sludge thereby reducing the volume of contaminant to be treated. Two basic processes are used solvent and acid extraction. Pretreatment may be required to separate the soil into coarse and fines.	Commercially available. Effective in treating sediments, soils and sludge containing petroleum waste. Applicable to a wide range of contaminants. Can be used to treat high concentrations.	Efficiency is limited by high clay content and may increase contact time. Process efficiency is hindered by detergents and emulsifiers. Acid/solvent traces may remain in treated substrate and require further treatment. Capital cost is relatively high for small sites.
Thermal Treatment	*Ex-situ* thermal treatments are either one-stage destruction by incineration (where contaminants are destroyed in a combustion chamber at high	Applicable to almost all organic and some inorganic contaminants.	Cost of thermal treatment is high. Requires residue management.

Technology	Description	Strengths	Limitations
	temperatures up to 1,300 ^{0}C with a secondary combustion chamber to treat volatilized contaminants in the off-gases or two-stage destruction by Low Temperature Thermal Desorption (where contaminants in soil is heated to about 600 ^{0}C leading to physical desorption and volatilization of contaminants, which are then combusted in a second chamber). Pyrolysis is another *ex-situ* thermal technique and is chemical decomposition induced in organic materials by heat in the absence of oxygen under pressure and at operating temperatures above 430ºC.	*Ex-situ* thermal methods have potential for high contaminant removal. There is potential for energy recovery. Does not involve the use of chemical reagents in the removal of contaminants. Treated soils may be reused or disposed cheaply. Time effective compared to biological treatment. Effectiveness can be validated easily.	Environmentally unfriendly due to gaseous emissions from plant and high energy requirement to run. Clay and silt soils and high humid soils increase reaction time as a result of binding of contaminants. Leads to changes in the physical and chemical properties of soil, which may restrict the reuse except otherwise enhanced/treated by other methods. Potential to produce incomplete combustion materials especially for thermal desorption.

Technology	Description	Strengths	Limitations
Stabilization and solidification	Relies on the reaction between a binder and the soil matrix to reduce the mobility of contaminants by physical encapsulation or chemical immobilization on excavated soil.	As in *in-situ* stabilization and solidification. Treated material can be reused to fill voids or reclassified for less expensive disposal.	As in *in-situ* stabilization and solidification.
Excavation, off-retrieval and off-site disposal	This is a civil engineering and more conventional method involving the removal of solid materials, including soil, from ground, haulage of the excavated materials and off-site disposal at landfills. There are no public engineered landfills in Nigeria, which makes this simple and traditional option to implement in Nigeria.	It removes completely the contaminants and the risk they pose from the site. All soil contaminants are removable. Technique is readily available. Easily sanctioned by regulators and has general acceptability.	It does not treat the contaminant. Technique limited to safe excavation depth. Cannot remove contaminations beneath buildings and structures. May require dewatering at site. Require the movement of large volumes of materials with the associated noise, nuisance of vehicular movement and emissions.

Technology	Description	Strengths	Limitations
			High cost of handling, transportation and disposal.
Infilling Void	Excavations create voids at site, which will require to be filled. Infill materials may be from primary (e.g. new aggregate) or secondary (e.g. reused materials from demolition) sources.	Infilling can improve the geotechnical conditions onsite. Materials recovered from the excavation can be reused if cleaned/treated. Reuse of material may have environmental and cost advantages.	The use of virgin fills fail tests of sustainability. Require transportation of fill materials to site with the associated noise, nuisance of vehicular movement and emissions. Fill material may be contaminated if not properly selected and tested.

Table 3.3: Cost Range and Availability of Remediation Technologies (USEPA, 1988; US EPA, 2012 a-j; FRTR, 2002; ITRC, 2005, Khan, Husain and Hejazi, 2004, and Reddy and Adams, 2015).

Technology	Cost Range (USD)	Availability
Monitored Natural Attenuation (MNA)	Variable	Generally available
Bioventing	45 – 140/ton	Generally available
Soil flushing	80 – 165/cu.yd (57 – 118/ton)	Very limited
Electro-kinetics	90 – 130/ton	Very limited
Soil Vapour Extraction (SVE)	<100/ton	Generally available
Enhanced Bioremediation	27 – 310/ton	Generally available
Phytoremediation	<100/ton	Very limited
Thermal Treatment	50 – 100/ton	Limited
Thermally Enhanced SVE	$29 - $62/cu.yd (21 – 44/ton)	Available
Stabilization and Solidification	100 – 150/cu.yd (71 – 107/ton)	Generally available
In-situ Chemical Oxidation (ISCO)	52 – 69/cubic yard (37 – 49/ton)	Generally available
Fracturing	8 - 13/ton for Pneumatic	Limited
Capping	≤225K/acre (≤56/sq.m)	Generally available
Biopiles	130 – 360/cubic metre (90 – 250/ton)	Generally available
Landfarming	45 – 140/ton	Generally available
Composting	80 – 165/cu.yd (57 – 118/ton)	Very limited
Slurry Phase Bioreactor	90 – 130/ton	Very limited
Chemical Oxidation and Reduction	<100/ton	Generally available
Soil Washing	27 – 310/ton	Generally available
Chemical Extraction	358 - 1,717/cubic meter (249 – 1192/ton)	Generally Available
Excavation, Off-retrieval and Off-site disposal	270 – 460/ton	Generally available

The cost of remediation in Nigeria for methods such as enhanced bioremediation, thermal treatment, stabilization and solidification, biopiles, landfarming and composting with available information to the researcher is within the range of costs in Table 3.3.

3.1.7 Treatment Trains

According to CIRIA (1995a) few contaminated sites exhibit a narrow, homogenous contamination profile restricted to a particular contaminant or group of chemically similar substances and few process-based remedial methods are able to deal effectively with the full range of contaminations likely to be encountered on most contaminated sites, therefore there may be the need to combine different remediation methods at the same site. Reddy and Adams (2015) share the same view. They stated that using one technology might not be sufficient to remediate some contaminated sites when different contaminants exist and or when the contaminants are present in a complex geological matrix. Reddy and Adams (2015) further stated that under these conditions different remediation technologies could be used sequentially to achieve the remediation goal. Writing on the subject of remediating polluted soils, Scullion (2006) concluded that there is a need to develop new treatment sequences or 'trains', particularly on sites with multiple pollution phases and types; and that these are likely to involve combinations of biological, physical and/or chemical processes designed to improve the reliability, predictability and efficiency of soil remediation. Also Vik et al (2001) in defining remediation technology stated that a remediation technology could be a set of technologies and or include a chain of different technologies. Gan, Lau and Ng (2009) identified the need to integrate remediation technologies as means of addressing the individual limitations of the various technologies.

In summary, therefore, treatment trains are the sequential and or concurrent application of different remediation technologies at a site to achieve the overall remediation goals. These may also be a pre-treatment or post-treatment of one remediation technology. Examples of treatment trains include soil flushing followed by bioremediation, soil vapour extraction combined with bioventing, electro-kinetics combined with bioremediation.

Furthermore, some of the remediation technologies produce waste streams that must be disposed or treated at the end of the project (CIRIA, 1995a). A typical example is incineration that produces final solid residue, which must be treated or disposed responsibly. Therefore, integrating a final stage of stabilization/solidification of the residue in an incineration based remediation project would be appropriate.

3.1.8 Importation of Remediation Method into Nigeria

The Department of Petroleum Resources has published some basic guidelines for using any remediation method or material in Nigeria. EGASPIN (2002) established that for any method requiring the use of bacteria, microbial cultures/consortium or chemical substances**:**

- The microbial culture, bacteria must not be genetically engineered organism or a know pathogen to human or indigenous flora or fauna;
- Chemicals must not be ones restricted anywhere in the world for use on land;
- For all new methods to be adopted on a field scale, a pilot scale experimentation, monitored by officials of DPR must be carried out to establish the effectiveness and applicability of the methodology to the Nigerian environment; and
- A final/formal approval for large-scale application of the methodology can be granted if the results obtained from the pilot scale experimentation is adjudged by the DPR to be effective in the Nigerian environment.

The process is time consuming and may take several months to complete. The completion period of this pilot testing depends on the availability of a DPR official, who will monitor the experimentation and agree with the findings of the pilot trial. It is easier for the oil and gas companies to complete this process as one key constraint for consultants proposing options is getting real petroleum-contaminated site to perform the experimentation. In general, therefore the process of importation of new remediation methodology (cost of experimentation and time scale for completion of the approval) must be considered in the appraisal and selection of remediation options.

3.2 Remediation Options Appraisal and Selection of Remediation Strategy

DEFRA (2004) defines remediation option as a means of reducing or controlling the health or environmental risks associated with a pollutant linkage and remediation strategy as a plan that involves one or more remediation options to reduce or control the risks from all the relevant pollutant linkages associated with a site.

CIRIA (1995a) identified five major stages in the remediation of a contaminated site and the selection and evaluation of remedial methods and strategies as the third stage. Therefore, the selection of appropriate, cost effective, suitable, feasible and sustainable remediation strategy is one of the critical elements in a remediation project. There exists a plethora of remediation options for the management of petroleum-contaminated soils (Section 2.3.6) but there is usually the need of selecting from amongst these options the most suitable and feasible for a remediation project. The remediation option selection process is activated when the risk assessment process indicates that there is/are significant pollutant linkage(s) at the site, thereby requiring action to reduce the associated risk to acceptable level.

According to DEFRA (2004) Remediation options appraisal generally involves three main stages;

- The identification of feasible (can demonstrably break the Source – Pathway – Receptor linkage) remediation options for each significant pollutant linkage[1]
- Detailed evaluation of the identified feasible remediation options to determine which remedial option is most appropriate option and best able (in whole or in part) to handle any pollutant linkage, achieve the project objectives within the project specific constraint and
- The production of a remediation strategy that can handle all significant pollutant linkages and meet the remediation objectives,

[1] Pollutant Linkage now called contaminant Linkage by DEFRA (2012)

where appropriate and necessary by combining these remediation options to produce an effective remediation strategy for the site taking consideration of all site-specific conditions and circumstances.

During the first stage of the appraisal process, each relevant pollutant linkage is considered on an individual basis in the first instance and for sites with multiple pollutant linkages DEFRA (2004) suggest that it is best to consider combined approaches after an appraisal of the individual pollutant linkages.

According to CIRIA (1995a) there are basically six (6) steps in the options selection process, which are as follows,

- Establishment of remedial action objectives and identification of site specific constraints;
- Identification, evaluation and selection of specific remedial options appropriate for each environmental medium or area of concern;
- Integration of selected options to produce a number of alternative remedial strategies (for example for the whole site);
- Checking if alternative remedial strategies continue to offer the necessary degree of protection and remain practicable;
- Detailed appraisal of alternatives and
- Selection of the preferred strategy.

The strategy finally selected, depending on the site conditions may apply to the whole site or to individual areas of the site and or specific environmental medium (for example soil). The strategy selection process may be carried out as a series of individual exercises or combined to provide a holistic solution to the entire site.

It is important to note that all stages undertaken to select the final strategy for a given site must be comprehensively documented.

3.2.1 Factors to consider in the Selection of Remediation Strategies

To adequately evaluate and select a remediation option/strategy from amongst the numerous techniques available several factors are considered which include the following.

Drivers and goals for the remediation project

The key driving force and goal of any remediation project is to reduce the risks posed by the contamination to an acceptable level, though engineering and management objectives may have to be met as well. These objectives play important role in the screening and selection of the most viable remedial strategy. These objectives will help during risk assessment to establish the necessary constraints and opportunities that assist in the overall remediation options appraisal exercise.

It is therefore important that the principal objectives of a remedial project are clearly defined (Vik et al, 2001) early in consultation with the regulatory authorities/stakeholders.

Remediation Boundary Conditions

The remediation option/strategy selected for any given contaminated site may also be constrained by the site boundary conditions (Bardos, Nathanail and Pope, 2002). These site-specific constraints include the site physiography, geology and hydrogeology, nature of the contaminant(s), site accessibility, availability or lack of services (electricity, water supply etc), proximity to sensitive receptors (houses, sensitive habitats, surface water, drinking water abstraction wells), the site ownership, licensing and permitting requirements, distance from landfill facilities and current/future site use.

It is therefore important to establish these constraints and apply them in the choice of the appropriate remediation strategy.

Risk Management

Risk management helps to set out in clearer terms the objectives of the remediation, identifies the extent to which contaminants need to be addressed as well as the optimal means of dealing with the identified significant pollutant linkages. In the context of contaminated land management, risk assessment is used to provide an objective, scientific evaluation of the likelihood of unacceptable impacts to human health and the environment (Bardos, Nathanail and Pope, 2002). Risk management defines the appropriate approach to achieving the remediation goals, which can be done either by reducing or modifying the source, managing or breaking the pathway or modifying the exposure to the receptor. Identification of the appropriate control measure will assist in the selection of remediation strategy.

Technical Suitability and Feasibility

A suitable technology is one, which meets the technical and environmental criteria for dealing with a contamination problem ((Bardos, Nathanail and Pope, 2002; Vik et al, 2001). Not all identified suitable solutions are feasible because of concerns related to the track record of the solution for the particular risk, availability of validated performance information from previous project, expertise of proponent, ability to verify effectiveness of the solution when applied, confidence of stakeholders, acceptability of the solution to stakeholders who may have expressed preferences for a favored solution or have different perceptions and expertise, availability of services (electricity, water etc), cost implications and duration of activities (Vik et al, 2001).

Feasible solutions are therefore a subset of those generally assessed as suitable candidates for dealing with the contamination problem in question. In a nutshell, therefore technical feasibility considers the difficulties in the implementation, operation and maintenance of the remediation option within the context of the site conditions, infrastructure and facilities, hydro-geological setting and nature of the contaminants. It also considers the availability of equipment and expertise.

Only technically feasible options are appropriate for the remediation of a given site.

Applicability

Effective remedial strategy must be applicable to both the contaminant of concern and the contaminated environmental media. The type of treatment and the likely success of any technique will depend upon the nature of the material treated as well as the type of contamination (Vik et al, 2001). Consideration must be given to the applicability of the remedial strategy to both the type of contaminant and the media. If necessary, process parameters may have to be modified for specific strategy to extend the applicability of that strategy. Pre-treatment techniques may be applied to tackle issues related to media type for various remediation methods.

Time Scale

Various remediation options require different time scale for execution of the project and achievement of the overall remediation objective. In appraising remediation options, it is important to consider the duration for the implementation of the option from commencement to cessation. Time may invariably impact on safety, costing and other factors.

Cost Effectiveness

A technically feasible solution must as well be within budgetary limits. According to CIRIA (1995a), cost is probably the single most important non-technical parameter likely to influence the remedial strategy selection process. It is therefore necessary that the remediation solution be cost effective. The aim of determining the cost effectiveness of the remediation solution is to provide a clear view of the value of the remediation investment and to allow comparisons between different remediation options. The cost implications assessed would include estimates of capital expenditure as well as operations and maintenance expenditure as well as verification costs. Table 2.4 and Appendix 2 indicate average cost range of various remediation methods.

Development Status and Availability of the Remedial Option

Various remedial methods are at different stages of development for handling contamination problems in various media. Some have long track record of field-scale use while others may be at an emerging and trial stages

CIRIA (1995a). Methods, which have common full-scale use is said to be established and far more reliable than emerging techniques with, limited full-scale use. Availability is linked to the development status, generic or proprietary nature of the method and the country of operation (CIRIA, 1995a). Established methods are more widely available on a commercial scale and less likely to be subjected to proprietary restrictions than emerging and innovative techniques, which may only be available under certain terms and conditions. It is therefore important that the selection process consider the development status and availability of the strategies been screened. Table 2.4 also provides the availability of various remediation techniques.

Propensity for combination and integration with other options

Remediation, according to Dunce, Iordache, Pohoata and Frasin (2014) is not limited to the use of a single treatment technique but in most cases, require a complex pathway of sequential operations and as discussed in Section 3.1.7 of this research, most contaminated sites due to the complexities of the contamination profile and geological matrix require a combination of remediation methods to deal with.

Therefore, it is important to consider in the selection process the ability of a remedial option to integrate with other options to provide a holistic solution to the site taking consideration of all contaminants of concern and the impacted environmental media.

Post-Remediation Site Management

Post remediation management involves any action or measure undertaken after the remediation activities have been completed, whether in the short-term or long-term. Overall post remediation site management will lead to additional cost to the remediation methods and therefore should be considered in the options appraisal and selection process.

Stakeholders' Acceptability

It is important to determine and appraise stakeholders' perception of the remediation approach and potential response of the community as stakeholders will have their own perspectives, priorities, concerns and ambitions regarding any site (Bardos, Nathanail and Pope, 2002).

Institutional Feasibility

A technically feasible option may not be acceptable to the regulators and may therefore suffer some permitting and licensing setbacks. Therefore, it is important to consider the institutional feasibility of the proposed options within the legal and regulatory framework of the site location. For new methodology, it will be expedient to consider the approval requirements within the regulatory framework of the country and the consequences on other selection parameter like time and cost.

Sustainability

With the emergence of the concept of sustainable remediation it is important that technically feasible options are subjected to sustainability assessment. Major decision factors, according to Vik et al (2001) for sustainability assessment are;

- The technical feasibility of the solution in dealing with the identified risks;
- The wider environmental effects of the remediation solutions including energy consumption, resource consumption, waste minimization and the objectives of minimizing carbon emission and conserving fossil fuels; and
- General consideration of the relevant economic, social and political values that apply to the circumstances including impacts on local business, impacts on local employment, amenity value of the site, provision of infrastructure and community concerns.

Not all technically suitable and feasible options are sustainable in every situation.

3.3 Sustainable Remediation

This section of this research work examines the concept of sustainable remediation and the available literature on this subject matter.

3.3.1 Concept of Sustainable Development

The concept of sustainability, according to Phillis and Andriantiatsaholiniaina (2001) is broad and polymorphous while Ellis and Hadley (2009), CL:AIRE (2010b) and ITRC (2011) argued that the concept is often broadly defined to allow for flexibility in its application. ITRC (2011) further stated that such broad definitions though allow a wider acceptance of the concept but is also responsible for the current lack of consensus on applying measures of sustainability. There is therefore no industry wide consensus on the definition of sustainability. A U.S. Federal Executive Order defined it as *"to create and maintain conditions, under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic and other requirements of the present and future generations"* (Reddy and Adams, 2015).

A definition of sustainable development, which is more or less acceptable and driving the concept of sustainability is the one given by the Brundtland Commission in April 1987, as *"development that meets the needs of the present without compromising the ability of future generations to meet their own needs"* (Brundtland, 1987). This definition of sustainable development is commonly interpreted as those actions that, taking account of environmental, social and economic factors, optimize the overall benefit (CL:AIRE, 2010b). Sustainable development is therefore a balance between environmental, social and economic factors as depicted in the Figure 3.1 below;

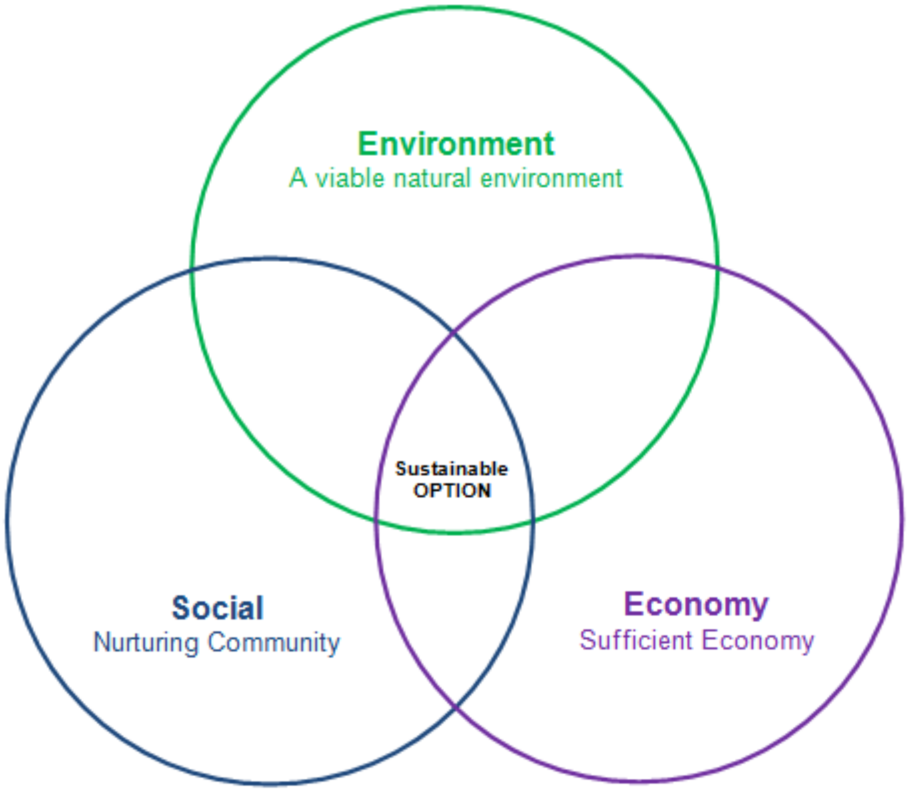

Figure 3.1: Depiction of Sustainable Development

According to ISO 26000:2010, sustainable development is about integrating the goals of a high quality of life, health and prosperity with social justice and maintaining the earth's capacity to support life in all its diversity. These social, economic and environmental goals are interdependent and mutually reinforcing. Sustainable development can be treated as a way of expressing the broader expectations of society.

3.3.2 The Concept of Sustainable Remediation

Sustainable remediation forms one part of a much broader sustainable development agenda (CL:AIRE, 2010b) and is defined by SuRF-UK as the practice of demonstrating, in terms of environmental, economic and social indicators, that the benefit of undertaking remediation is greater than its impact, and that the optimum remediation solution is selected through the use of a balanced decision making process. It encompasses sustainable approaches to the investigation, assessment and management of potentially contaminated land.

Hou and Al-Tabbaa (2014) stated that the sustainability of remediation is a complex and multifaceted issue, and that a common theme of sustainability classification is a division into three aspects: environmental impacts, economic viability, and social impacts. They further defined environmental sustainability of remediation to encompass its core mission of reducing the risk of harm from contamination but also includes minimizing secondary adverse effects associated with remediation operations; economic sustainability to include the cost associated with remediation operations and the consequential impact of the site restoration to the broader economy; and social aspects as including impacts on remediation worker safety, impacts on community, stakeholder engagement and public participation, environmental justice and social inclusion.

Sustainable remediation has also been defined by Ellis and Hadley (2009) as a remedy or combination of remedies whose net benefit on human health and the environment is maximized through the judicious use of limited resources while ITRC (2011) defined green and sustainable remediation as a remedy or combination of remedies whose net benefit on human health and the environment is maximized through the judicious use of limited resources and the selection of remedies that consider how the community, global society, and the environment would benefit or be adversely affected by, remedial investigations (RI) and corrective actions. Reddy and Adams (2015) while comparing green and sustainable remediation stated that sustainable remediation reflects a broader and more holistic approach aimed at balancing the impacts and influences of the triple bottom line of sustainability (i.e. environmental, societal and economic) while protecting human health and the environment.

"Sustainable remediation is the application of the principles of sustainable development, as described by the Brundtland Report, to risk-based contaminated land management. As such, sustainable remediation encompasses four broad aims: achieving risk-based land management; ensuring that the wider effects of this risk management action are acceptable; ensuring the engagement of stakeholders and transparency of decision-making process; and supporting balanced outcomes in terms of the environmental, social and economic elements of sustainable development". (Bardos et al, 2011). Bardos et al (2011) further stated that the basic rationale behind contaminated land management is retained in the risk assessment process but that sustainable remediation requires that the means of managing those risks must not place unreasonable demands and or burdens on the environment, economy, and society, in either the short or long term. Many more of these definitions of SR exist but there is a high degree of consistency based on the wordings of the definitions (Rizzo et al., 2016) and about its broad purpose (Ridsdale and Noble, 2016).

According to CL:AIRE (2010b) the balancing of environmental, social and economic costs and benefits in identifying the optimal remediation solution needs to be carried out while complying with this set of key principles, which should be considered by practitioners in the design, implementation, and reporting of sustainable remediation schemes. These key principles are defined as follows;

- **Protection of human health and the wider environment.** Remediation should remove unacceptable risks to human health and protect the wider environment now and in the future for agreed land use, and give due consideration to the costs, benefits, effectiveness, durability, and technical feasibility of available options.
- **Safe working practices.** Remediation works should be safe for all workers and for local communities, and should minimize impacts on the environment.
- **Consistent, clear, and reproducible evidence-based decision-making.** Sustainable risk-based remediation decisions are made with regard to environmental, social and economic factors, and consider both current and likely future implications. Such sustainable and risk-based remediation solutions maximize the potential benefits. Where benefits and impacts are aggregated or traded in some way, this process should be explained and a clear rationale provided.
- **Recordkeeping and transparent reporting.** Remediation decisions, including assumptions and supporting data used to reach them, should be documented in a clear and easily understood format

in order to demonstrate to interested parties that a sustainable (or otherwise) solution has been adopted.

- **Good governance and stakeholder involvement.** Remediation decisions should be made with regard to the views of stakeholders and following a clear process within which they can participate.
- **Sound science.** Decisions should be made based on sound science, relevant and accurate data, and clearly explained assumptions, uncertainties, and professional judgment. This will ensure that the decisions are based upon the best available information and are justifiable and reproducible.

3.3.3 Driving Forces for sustainable practices in remediation

Hou and Al-Tabbaa (2014) suggested three key driving forces of sustainable remediation based on a questionnaire survey and a review of existing theories and empirical evidence. These three driving forces are;

- Accounting for secondary adverse effects of remediation
- Stakeholder demand for sustainable remediation, and
- Institutional drivers.

Accounting for secondary adverse effects of remediation

The increased recognition of secondary adverse effects associated with remediation projects was identified as a key driving force toward the shift from traditional remediation strategies to sustainable remediation practice. The traditional dig and haul for contaminated soil remediation, and pump and treat for groundwater remediation are associated with large GHG emissions while other remediation techniques are equally associated with GHG emissions, acidification, eutrophication, ozone depletion, ecological toxicity etc. The recognition of these various secondary adverse effects of remediation process makes it therefore imperative in selecting appropriate remediation strategy to consider techniques with minimal secondary adverse effects.

Stakeholder demand for sustainable remediation

Contaminated land management involves a wide range of stakeholders, each of which having their own unique demand in driving the adoption of sustainable remediation. Hou and Al-Tabbaa (2014) identified four key stakeholders (regulators, site owners, primary consultants and top management) as having various levels of influence in the promotion of sustainable remediation as highlighted below.

- **Regulators**

The regulatory agencies saddled with the function of leading oversight of remediation activities are key stakeholders in any remediation project. The regulators can act as coercive force by communicating the sustainability concept to contaminated site managers and workers, as well as providing technical guidance for achieving sustainability in remediation activities. Regulators may also retract withholding pressure in exchange for sustainable remediation practices. Though, some existing regulatory framework may pose a barrier to the application of sustainable remediation. For instance, in Nigeria where the frameworks for management of petroleum-contaminated lands are prescriptive, the application of sustainable remediation practices may be seen as non-compliance to legislation.

- **Site Owners and Top Management**

The final decision on remediation is usually saddled on site-owners, as they are responsible for the funding of the entire project. Their main objective is to minimize cost, regenerate valuable land and enhance economic sustainability. The tradeoff here is between low cost/passive remediation and high cost/active remediation. Site-owners, which are mostly enterprises, are under pressure to achieve better social and environmental sustainability as part of their overall CSR. Furthermore, companies avoid negative publicity and public perception due to lack of action or inappropriate action in the management of contaminated land especially for petroleum-contaminated land emanating from oil spillages in exploration and production activities.

As most contaminated landowners are mostly large national and international companies (Hou and Al-Tabbaa, 2014), they provide coercive and mimetic forces in institutional homogenization, and can transmit organizational techniques across borders to subsidiaries. In Nigeria this is common fact especially as the multinational oil and gas companies, which also provide standardized guidance from Europe and the United States to their Nigerian subsidiaries, own most petroleum-contaminated sites. Hence, large companies can serve as key drivers for the adoption of sustainable remediation practices in developing countries.

- **Primary Consultants**

The primary consultants have high interdependence with site-owners as they rely on the site-owners for funding while the site-owners rely on their professional expertise to achieving efficient remediation. The recommendations of the primary consultants usually shape the thinking of the site owners and regulators and their design of the remediation determines sustainability of the project (Hou and Al-Tabbaa, 2014). There is currently an increasing recognition of sustainable remediation by remediation consultants and major players using sustainability as comparative advantage in the remediation industry, though this may not be the case in Nigeria today.

Institutional Drivers

The third key driver of the emergency of sustainable development as suggested by Hou and Al-Tabbaa (2014) is institutional pressure, which emphasize the role of social and cultural pressures in organizational behavior. Institutional theories have identified coercive, mimetic and normative mechanisms as main influential factors in decision making in organizations. Coercive force is seen to originate from political influence, mimetic forces as standard responses to uncertainty and normative force is associated with professionalism. The theory states that when an organizational field is formed (in this instance remediation field), these organizational forces tend to constrain the field actors' ability to change, and that during critical interventions; the old norms can be replaced by new norms. The sustainability movement represents such a time of opportunity in the remediation field. Hou and Al-Tabbaa (2014) further identified society's increasing interest in sustainability, growing numbers of principles and guidance publication on the subject of sustainability and expanded reporting requirements associated with corporate social responsibility, as major institutional and societal drivers for the emergency of sustainable remediation practice.

3.3.4 Benefits of adopting sustainable remediation

Remediation activities are general designed to provide remedy for contamination problems and to reduce risks to human health and the environment. The implementation of the remediation project has potential to cause adverse environmental, economic and social impacts. Any remediation solution, which meets this objective of controlling unacceptable risks in safe and timely manner and maximizes the overall environmental, social and economic benefits of the remediation activity, is termed sustainable remediation. The adoption of sustainable remediation practice in contaminated land management offers the following benefits as outlined in CL:AIRE (2010b) and CL:AIRE (2014) ;

- Maximizing the value delivered by remediation works, by optimizing the overall benefit to cost ratio;
- Cost savings through avoidance of unnecessary or unsustainable remediation;
- Effective management of risks to human health and the environment associated with soil and/or water contamination;
- Minimizing the impact of remediation works on the environment and surrounding communities;
- Demonstrable commitment to sustainable development in remediation works;
- Public impact on reputation and public relations, demonstrating corporate environmental and social responsibility;
- Improving the robustness of remediation decision-making; and
- Contributing to sustainable development, which now forms a cornerstone of many government and corporate policies.

3.3.5 Sustainable Remediation Frameworks and Guidance Documents

This section of this research work reviews some of the available sustainable remediation frameworks and guidance documents that have evolved over time. According to Reddy and Adams (2015), a sustainability framework is a systematic basis by which the sustainability of a remediation project may be assessed in the three dimensions of environmental, social and economics. They also reported that though there is no universally acceptable framework, several agencies/organizations/countries have been active in developing frameworks for measuring and facilitating sustainability in the remediation of contaminated sites. Some of the efforts and frameworks are discussed here-under.

SuRF Framework

The Sustainable Remediation Forum (SuRF) based in the United States was the first sustainable remediation initiative and is a collaborative initiative of industry and consultancy members, with the participation of federal and state regulators; that seeks to develop understanding and methods for sustainable remediation principles. According to Ellis and Hadley (2009), the SuRF published a White Paper, which detailed the status of sustainable remediation practices and highlighted the need for well-defined framework for incorporating sustainability into remediation projects in 2009 and in 2011 published a systematic, process-based and holistic framework that can be used by professionals in integrating sustainability into all phases of a remediation project. The framework emphasized that the main remedial objective of protection of human health must be pursued and achieved simultaneously with sustainability objectives. According to Reddy and Adams (2015), the framework offered a tiered decision-making process that considers each phase of the remediation project and allows for the use of qualitative and quantitative assessment, ongoing revision of the CSM based on assessment results, identification and implementation of sustainability impact measures, and decision throughout the remediation project to address sustainability. Communication amongst the principal stakeholders was encouraged. The framework consists of three tiers of evaluation.

- Tier 1 being the simplest and comprising of a qualitative, standardized evaluation based on the most significant sustainability elements of the project. This is mostly applicable to small scale, low budget and low complexity sites that may not benefit significantly from higher tier evaluation. The use of checklist, rules of thumb, rating system and matrices suffices for this tier.
- Tier 2 is a semi-quantitative approach focusing on little site-specific information. Tier 2 evaluations are applicable to moderately complex sites that necessitate greater consideration and involvement of stakeholders. Assessment tools include spreadsheet-based tools, scoring and weighting systems, exposure simulations, emissions calculations and simple cost benefits analysis.
- Tier 3 a much more comprehensive quantitative assessment requires detailed site-specific information. This level of evaluation is applicable more to sites that are significantly complex, necessitate significant consideration and involvement of stakeholders and have readily available data. Tier 3 evaluations may use life-cycle assessments, detailed cost-benefit analysis, spatial and temporal boundary evaluations, social accounting and auditing, net benefit models and other more sophisticated tools.

SuRF-UK Framework

SuRF-UK is the sustainable remediation forum variant for the United Kingdom, an initiative to drive the UK understanding and practice of sustainable remediation. The SuRF-UK has published a framework for assessing the sustainability of soil and groundwater remediation. This framework which was developed by engaging a wide range of stakeholders provides a nexus between the general principles of sustainable development and the sustainability criteria of environment, economics and social, for assessing and selecting sustainable remediation options. The framework also reinforces the simultaneous pursuit and achievement of the key remedial objective of protecting human health and the sustainability objectives in any remediation project. Like the SuRF framework, it emphasizes the consideration of sustainability concerns at all the stages of a remediation project. It also advocates the three tier levels of evaluation. This framework has been widely cited/used especially in the draft ISO/DIS 18504 document, SuRF-ANZ framework and the IPIECA Guideline. It is presently the widely-used framework. IPIECA (2014) succinctly stated that sustainability indicator categories have been developed by the SuRF-UK, which has found wide international favour.

NICOLE Roadmap

The Network for Industrially Contaminated Land in Europe (NICOLE) is a European forum focusing on contaminated land management and promoting industrial, academia and consultants cooperation on contaminated land management. NICOLE has established a working group on sustainable remediation that promotes the practice of sustainable remediation amongst the European states. In 2010, NICOLE published the Sustainable Remediation Roadmap with the overall intention of providing practitioners, landowners and operators of contaminated lands and related stakeholders, with a structured approach to facilitate cooperation and implementation of sustainable remediation best practices over a wide range of regulatory and policy framework.

The Roadmap was cited in the IPIECA (2014) and the NICOLE Indicators partly used in the preparation of the ISO/DIS 18504 document.

SuRF-ANZ Framework

SuRF-ANZ is the sustainable remediation forum for Australia and New Zealand, established in 2009 under the coordination of Cooperative Research Centre for Contamination, Assessment and Remediation of the Environment. The main objective of the forum being to provide drive for domestication of the sustainable remediation practices in line with applicable regulatory and policy framework in Australia. In 2011 SuRF-ANZ published a framework for assessing the sustainability of soil and groundwater remediation. SuRF-ANZ has close link with SuRF-UK and this framework draws heavily on the principles, definitions and approaches already described in the SuRF-UK framework. *"It is this SuRF-UK framework* *that has been drawn upon in formulating this SuRF ANZ framework"* (SuRF-ANZ, 2011).

US EPA Framework

US EPA Incorporating Sustainable Environmental Practices into Remediation of Contaminated Sites framework is rather green remediation framework than a sustainable remediation framework. The goal of the framework developed in 2008, as reported by Reddy and Adams (2010) is to evaluate and select remediation alternatives and options that achieve maximum net environmental benefit during all phases of site characterization, remediation system implementation and operation, post-remediation monitoring. The framework emphasizes only environmental aspects with respect to sustainability without explicit consideration of social and economic aspects of sustainability.

This framework though an excellent work on the concept of green remediation comes short of the overall requirements of sustainable remediation as it does not consider the other two legs of sustainability. The SuRF-UK framework referred to this framework, even though it is more of a green remediation framework.

ITRC Framework

Interstate Technology and Regulatory Council (ITRC), in 2011 developed and published GSR: A Practical Framework. This framework highly tailored for use by the US State regulators is a generalized and flexible framework, which elucidates the planning and implementing processes for integrating environmental, economic and social aspects in each stage of the remediation project. The framework establishes a five-step process of GSR planning, which are;

- Evaluation and updating of CSM;
- Establishment of GSR goals for the project;
- Stakeholder involvement;
- Selection of GSR matrices, evaluation level and boundaries; and
- Documentation of GSR efforts.

The framework also recommends a three-level approach to evaluating and selecting GSR matrices, which are similar to the three-tier of the SuRF framework except for terminologies and these are;

- Level 1 consisting basically of common sense based Best Management Practices (BMPs) basically to promote resources conservation and process efficiency. This level does not consider the net impact on environment, community and economics;
- Level 2 further to the use of BMPs involves some degree of qualitative and semi-quantitative evaluations. This level involves accounting for relevant environmental, economic, and social impacts of remediation; and
- And level 3 involves selection and implementation of BMPs and detailed quantitative evaluation. Level involves rigorous methods of assessing environmental, social, and economic impacts of remediation.

This framework was referenced in IPIECA (2014) and in the ISO/DIS 18504 document.

ASTM Framework

ASTM E2876-13 Standard Guide for Integrating Sustainable Objectives into Cleanups, provides a framework for integrating all sustainability criteria of environment, economics and social into remediation projects. Under this guide the BMPs selected and implemented can incorporate all three criteria of sustainability into remediation with the goal of addressing human, public safety and ecological risks. This framework was also referenced in IPIECA (2014).

ISO/DIS 18504 Guideline on Sustainable Remediation

This document developed by a working group (12) of the Technical Committee 190 (Soil Quality) Subcommittee 7 (Soil and Site Assessment) serves as a guide rather than a standard specification or normative document. It will help establish a common internationally accepted terminology and understanding of the concept of sustainable remediation. Finally, the document has distilled available information on the subject matter of sustainable remediation and provided a one-stop shop of information on the subject matter, which invariably will encourage the application of sustainable remediation globally. The IPIECA Good Practice guide (2014) mentioned this document even though it is in the earlier stages of preparation and adoption.

IPIECA Good Practice Guide

The Management and remediation of sites in petroleum industry: An IPIECA Good Practice Guide published in 2014 has a section on sustainable remediation. The section recognizes the SuRF, SuRF-UK, ITRC, and ASTM frameworks as well as the draft ISO document. The guide recognizes the emphasis of the published frameworks on the requirement that land management and remediation must manage unacceptable risks to human health and environment and that some approaches may be more sustainable than others. IPIECA (2014) agrees that the outcomes of sustainable remediation approach based on sound science and risk assessment would lead to effective protection of human health and the environment in environmentally, socially and economically responsible ways.

Though, no specific prescriptions are provided, the guide encourages the industry to apply sustainable remediation approaches to managing petroleum-contaminated sites in a subtle manner.

3.3.6 Sustainable Remediation Indicators

Sustainable remediation assessment is generally based on an assessment of the performance of different remediation options against a list of sustainability indicators (CL:AIRE 2010b). According to Reddy and Adams (2015), sustainability indicators are measurable aspects of environmental, economic, or social dimensions associated with potential remediation alternatives for a project while ISO/DIS 18504 defined indicator as a single characteristic that represents a sustainability effect, whether benefit or negative impact, which may be compared across alternative remediation strategies, comprising one or more remediation techniques and /or institutional controls to evaluate their relative performance. Furthermore, Reddy and Adams (2015) stated that as with many goals and objectives, sustainability indicators should have the SMART attributes.

- Specific, the indicator should target a specific area of consideration and analysis. It should identify exactly what is to be achieved.
- Measurable, the indicator should be capable of being counted, compiled, analyzed, or tested so that a data set can be established to determine the degree to which the indicator effect – positively or negatively the sustainability of the project.
- Actionable or achievable, the indicator should have a clear performance target that is easily understandable and may be realistically achieved with methods to be applied to the project.
- Relevant, the indicator should have a meaningful contribution to the environmental, economic, or social dimensions of the sustainability of the project.
- Timely, the indicator should be achieved within an appropriate time frame or subjected to the time constraints of the project.

Reddy and Adams (2015) also identified the need to consider indicators representative of all three dimensions of sustainability in the assessment of the sustainability of any given remediation project. The SuRF-UK framework identified 18 indicator categories from internationally peer-reviewed literature on sustainability. This was adopted in the SURF Framework, SuRF-ANZ Framework, IPIECA Guide and the ISO/DIS 18504 document. However, Reddy and Adams (2015) has suggested several indicators, which are summarized in Table 3.4 below.

Table 3.4 Sustainability Indicators (Reddy and Adams, 2015:150)

Environmental	**Economic**	**Social**
GHG and other air emissions	Direct and indirect job creation within the community	Enhancement of community aesthetics
Contributions to climate change	Direct and indirect investment within the community	Enhancement of quality of life features
Use of fresh water resources	Facilitation of government grants for	Public participation in decision-making

	the project and community as a whole	
Impacts on soil	Long-term tax and revenue generation within the enhanced community	Educational and job training opportunities
Utilization of raw natural resources	Degree of highest and best use achieved by the remediated property	Interaction between community groups
Impacts on surface water or groundwater	Potential to upzone the property and nearby properties due to remediation activity	Emotional ownership of the community in a remediation project
Use of recycled or repurposed materials		Improved physical and mental health and well-being of members of the community
Overall waste generation		Enhanced social opportunities for members of the community
Diversion of waste materials from or to landfill facilities		Strengthening or enhancement of existing community institutions

These indicators suggested by Reddy and Adams (2015) show wide coverage of all three dimensions of sustainability and fit well into the indicator categories identified by SuRF-UK and adopted in the ISO/DIS 18504 document. They are therefore a useful reference.

3.3.7 Stakeholder Involvement

Stakeholder involvement is a key theme in the definitions and principles proposed by SR frameworks (Rizzo et al., 2016). All the frameworks discussed in Section 3.3.5 above recognized the involvement of key stakeholders in the entire process of sustainability assessment for remediation projects. The importance of stakeholders' engagement and involvement in the process is underpinned by the followings reasons, according to CL:AIRE (2010b):

- The opinion of stakeholders can provide important information about particular aspect of sustainability of the project;
- Consultation makes decisions more robust; and
- Consultation with stakeholder is part of good governance and underscores best practice in CSR.

The key stakeholders making decision of remediation and sustainable remediation processes are the site owner, the primary consultant, the regulators and planners. However, site workers, local communities and CBOs, NGOs – local and international, and pressure groups might exert some influence on the choices and decisions in a remediation project.

There has been serious pressure from Amnesty International on IOCs in Nigeria on the management of crude oil spill sites. Amnesty International (2011) has accused some IOCs in Nigeria of not adequately involving local communities in the process of investigating the cause of an oil spill, quantification of the spill volume and in the management of the site. Amnesty International (2011) recommended based on assessment of SPDC case in Bodo, amendment of the regulation of the petroleum industry to ensure that it addresses the social and human rights impacts of the oil industry, including a mandatory assessment of the potential impacts on human health; access to clean water and livelihood; meaningful consultation with communities; greater transparency and access to information for affected communities. Also, IUCN-NDP (2013) noted that in three sites visited in the Niger Delta of Nigeria, the community stakeholders were eager to be involved in the remediation activities and felt that it was unacceptable for such weighty decision with far reaching impact on their environment and community to be made without involving them.

It is important to note that if any stakeholder does not agree with the underlying assumptions or methods on which a sustainability assessment is based, they are also very unlikely to support its findings (Bardos et al., 2011). Therefore, stakeholders should be engaged early in the sustainable remediation assessment process (SuRF-UK, 2010 and NICOLE, 2010).

3.3.8 Sustainability Assessment

There is international consensus on the application of the Tiered approach in sustainability assessment (Bardos, 2014). The SuRF-UK assessment process is highlighted in this section of this literature review. The SuRF-UK tiered approach is set out in Figure 3.2 below;

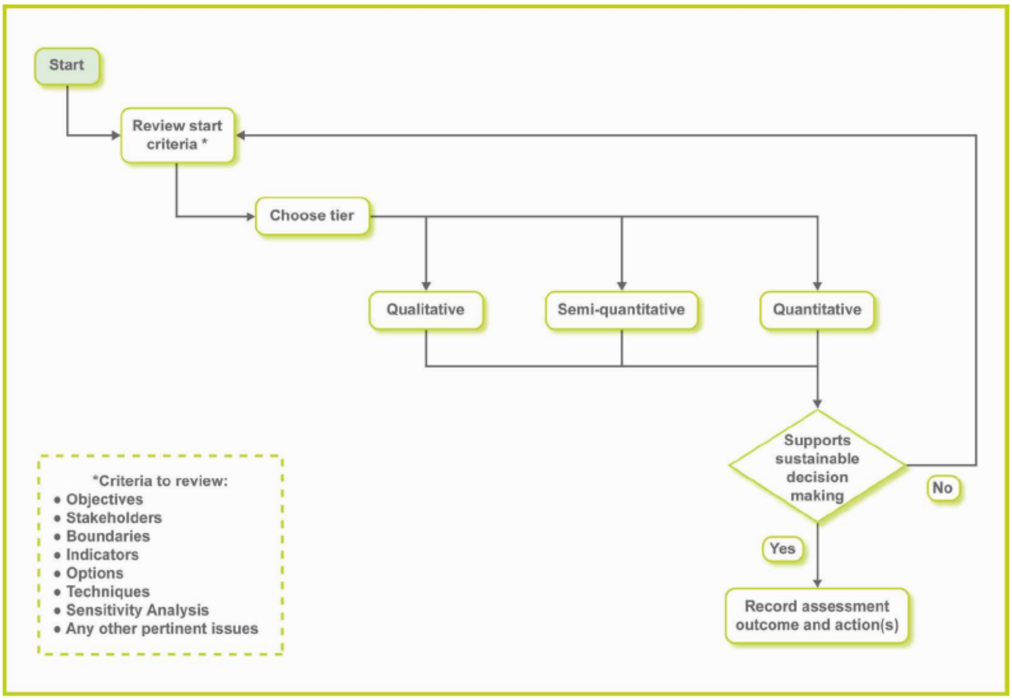

Figure 3.2 Tiered Approach to Assessing the Sustainability of Remediation

The approach starts with a simplistic qualitative assessment and then moving to more complex and time-consuming semi-quantitative and quantitative assessments, only when there is the obvious need to do so. The procedure provides a step-by-step method to sustainability assessment, thereby providing better opportunity for consultation and agreements. As noted earlier, early consensus on the sustainability assessment approach amongst stakeholders makes the process more acceptable and transparent. The key steps in sustainability assessment detailed by SURF-UK are discussed below:

- Step 1: Identifying a need usually triggered by the willingness of the project proponents, or by regulatory or planning request to make sustainability decision criteria for the project.
- Step 2: Identifying which stakeholders to involve. Identifying stakeholders relate to the need (does the stakeholders have

controlling influence in decision making?) and to inclusivity (is there a policy or wish for wider engagement with potentially affected parties?). Bardos et al (2011) commenting on this step elucidated that for sustainability assessment to be used to support decision making, those involved in making that decision ought to be involved or at least comment on the assessment and if the results of the assessment are to be used to influence a stakeholder, that stakeholder should also have an opportunity for involvement or make comment on the assessment.

- Step 3: Agreeing on Objectives of Assessment. The objectives, which should include the purpose of the sustainability assessment, the goals under consideration, the options being compared by which those goals might be reached, and how the sustainability assessment findings will be used; defines the sustainability assessment, and all other decisions are contingent on this definition (Bardos et al., 2011). Agreement with all stakeholders is paramount for the findings of the assessment to be acceptable.
- Step 4: Agreeing the scope of assessment. This forms the part of the assumptions supporting the assessment and must be agreed upon by all stakeholders. The scope to agree upon includes boundary conditions, sustainability indicators, and any considerations of importance and how to address them.
- Step 5: Agreeing on sustainability assessment approach. All stakeholders must agree upon method of assessment if the findings of the assessment will be acceptable. The sustainability assessment approach describes the tools and techniques used to aggregate the findings from individual considerations of indicator criteria into an overall understanding of sustainability (Bardos et al., 2011). Table 3.5 below highlights most techniques likely to be applied in a sustainability assessment.

Table 3.5: Selected Decision Support Techniques with relevance to Sustainable Remediation Assessment (Bardos et al., 2011)

Technique	Environment	Economy	Society	Type	CLM Application
Scoring and ranking systems (including Multi-criteria analysis)	Narrow to wide	Narrow to wide	Narrow to wide	Both	Yes
Best Available Technique	Narrow to wide	Narrow	-	Qual	Yes
Carbon footprint ("area")	Narrow	Narrow	-	Quan	Yes
Carbon balance (flows)	Narrow	-	-	Quan	-
Cost-benefit analysis	Narrow to wide	Narrow to wide	Narrow to wide	Quan	Yes
Cost-effectiveness analysis	Narrow to wide	Narrow to wide	Narrow to wide	Both	Yes
Eco-efficiency	Narrow	-	-	Quan	-
Ecological footprint	Narrow	-	-	Quan	-
Ecosystem services (Vejre et al., 2009)	Wide	-	-	Both	Yes
Energy/intensity efficiency	Narrow	-	-	Quan	Yes
Environmental risk assessment	Narrow to wide	-	-	Both	Yes

Human health risk assessment	-	-	Narrow	Both	Yes
Environmental impact assessment/strategic environmental assessment	Narrow to wide	-	-	Qual	Yes
Financial risk assessment	-	Narrow	-	Quan	Yes
Industrial ecology	Narrow to wide	Narrow to wide	-	Quan	-
Life-cycle assessment (based)	Narrow to wide	-	-	Quan	Yes
Quality-of-life assessment	Wide	Wide	Wide	Quan	-

Notes:

Qual = Qualitative

Quan = Quantitative

Both = qualitative and or Quantitative

CLM = Contaminated Land

\- = Technique has no known coverage

Note: CL:AIRE (2010b) defined "narrow" as very limited scope of analysis for a particular sustainability aspect and "wide" as wide-ranging coverage of particular aspects of sustainability.

- Step 6: Execution of sustainability appraisal, involving the execution of the valuations and the aggregations, testing the findings using sensitivity analysis, agreeing on verification requirements, and reporting.
- Step 7: Verification, the monitoring of the sustainability parameters agreed as necessary for verification.

3.3.9 Sustainable Remediation Assessment: Case Studies

This section summarizes some remediation case studies involving sustainability assessment.

Shell Terminal Facility, Madeira (CL:AIRE, 2013)

The site was a marine distribution terminal of Shell operated from 1962 to 2007. Site surface infrastructure was decommissioned and demolished between 2007 and 2008. Investigations indicated that the soils beneath the site were impacted by heavy fuel oil (TPH >C22) with moderate concentrations of PAHs and to a minor extent, middle distillate hydrocarbons (diesel and kerosene). The future use of the site was uncertain thereby imposing the study a number of alternative risk assessment scenarios based on speculated redevelopment option. Shell's aim was to undertake appropriate remediation programme that will manage all identified unacceptable risks to human health and the environment. The assessment carried out was therefore to review alternative remedial options, taking greater account of sustainability factors and to establish if an alternative approach to thermal treatment may have more favourable economic, environmental and social impacts. A semi-quantitative approach was adopted and the SuRF-UK sustainable remediation indicator categories were used. Before the assessment was undertaken the preferred remediation options were excavation and thermal desorption but at the end of the assessment enhanced bioremediation was the adopted option based on a number of sustainability benefits including;

- A reduction in CO_2 emissions;
- A reduction in cost;
- A reduction in fuel use;
- A reduction in neighborhood disturbance caused by noise; and
- Potential for local employment. (CL:AIRE, 2013).

According to CL:AIRE (2013) evident from this pilot case study are;

- The need for remedial options to be developed to an appropriate degree before proceeding with the sustainability assessment;

- The need for the project team to discuss the context of the assessment at an early stage;
- Continual engagement of stakeholders is very beneficial; and
- The assessment illustrates a balanced picture with the overall sustainability score.

A major weakness of this case study was the limited involvement of stakeholders, which otherwise would have helped in clarifying and developing understanding of the average score assigned to the social aspects (CL:AIRE, 2013)

Military Port, Taiwan (Chen et al, 2014)

The site for this case study in Taiwan was a military port for ship maintenance with multi-factories and outdoor fuel storage area. The soil beneath the site was contaminated with Total Petroleum Hydrocarbon (TPH) and heavy metals. The key stakeholders for the assessment were the Navy and the local environmental protection bureau and the objective was to select a remedial option using the GSR assessment process. After consideration of the stakeholders' needs excavation and soil replacement; and soil washing were considered suitable remedial options.

This case study highlighted remediation by the military that also assessed the change in land value and job creation while minimizing the environmental footprint.

Kindergarten Development, Hamilton, New Zealand (Smith, 2014)

The site was a former suburban petroleum service station, vehicle workshop and has been zoned for commercial use. The site is near communities and Public Park. Land is to be redeveloped into a kindergarten and cleanup to be achieved at a minimal cost. The GSR strategy adopted included;

- Excavation and off-site disposal of hydrocarbon contaminated soil;
- Risk assessment of soil contamination and importation of clean soil for growing vegetables;
- Management plan for asbestos contaminated soil and
- Increased tax base for council and value for community.

This case study demonstrated, according to Smith (2014) how the land legacy did not compromise the vision of a not-for-profit Kindergarten association to build a school for community in need.

New Aiyansh, B.C. Sustainable Remediation, Canada (SuRF Canada, 2014)

The site is department of fisheries and oceans field office and contaminated with petroleum hydrocarbon (heating oil) in soil and groundwater. Remediation optimization processes were applied and incorporated into the sustainable remediation assessment. Potential remediation approaches were evaluated using "triple bottom line" (framework with three parts of economics, environment and social) approach. Limitations of the potential remediation approaches were considered and then the sustainability indicators. The key drivers of the project were the local community interests, the need to reduce project cost and to reduce the environmental impacts associated with remediation activities. A major challenge was the remoteness of the project site. At the end of the appraisal process off-site land-farming was selected. Sustainability benefits of the exercise included reduced carbon emissions intensity, low environmental impact (reduced greenhouse gases and waste generation, conserved water), high social benefits and high economic stimulus to the local community; and lowered project cost.

This project demonstrated how to achieve small environmental footprint and high social benefit and high economic stimulus, with the local First Nations community providing the prime remediation contractors.

Vienna Tetrachloroethene Superfund Site and Ravenswood PCE Ground Water Plume Superfund Site (SURF, 2014)

Two tetrachloroethene plumes from former dry cleaners had led to the shutdown of six city drinking water wells with two more down-gradient city well at risk in Vienna while PCE from undefined sources was also detected in five municipal drinking wells at a nearby Ravenswood PCE GW Plume Superfund site. The key drivers were sustainability, waste minimization and cost effectiveness and the remedial objectives were to reduce the tetrachloroethene to below target levels and protect public water supplies.

The remediation strategy involved a combination of air sparging and soil vapour extraction with hydraulic control system, institutional controls to prevent the installation/use of private drinking water wells. GSR Best Management Practices (BMPs) were implemented at the site. In the overall the implementation of GSR BMPs and ongoing system optimization resulted in cost savings during construction and ongoing cost savings during operations, without sacrificing system operational effectiveness.

This case study demonstrated a synergistic approach to managing two sites with same contaminant as the decommissioned treatment unit from Vienna site was relocated to the Ravenswood site, eliminating the need for the fabrication and shipment of new pilot treatment unit. The reuse of excavated materials (sand and road base) as pipe bedding and road base was key in the sustainability justification of the project.

3.3.10 Challenges of Sustainable Remediation

The demand for more sustainable practices is a driving factor for the implementation of sustainable remediation (Hou and Al-Tabbaa, 2014) but the adoption and implementation of the concept is hindered by some challenges.

Ellis and Hadley (2009) reviewed the challenges of sustainable remediation in four components as follows.

1. Societal challenges and these include;
    - Lack of knowledge and awareness of sustainable remediation principles.
    - Existence of well-defined and appreciated remedy selection process, which will impede new ways advocated by sustainability assessment.
    - Poor knowledge base of sustainability remedies. Very little literature exists on sustainable remedies, and few validated, successful sustainable remedies have been documented.
    - Poor understanding of how to create the balance between the protection of human health and the environment with other societal risks/goals to achieve sustainability.
2. Technical;

    - Lack of established technical guidance.
    - Lack of a unified and agreed upon knowledge base.
    - Lack of a validation system for the methods and criteria used in sustainable remediation evaluation.
3. Economic
    - Potential initial upfront cost.
    - Resistance of regulators/stakeholders to new, unproven approaches that may be seen as an attempt by business to avoid thorough clean-ups.
    - Increased risk of remedy failure because of the use of innovative technologies (Ellis and Hardy, 2009).
4. Regulatory and legal
    - No explicit requirement in current legal regime for the selection of sustainable remedial strategies.

In summary Ellis and Hadley (2009) stated that the significant challenges to the implementation of sustainable remediation are lack of a well-defined framework and agreed upon metrics, lack of regulatory consensus of how to integrate these metrics and frameworks within the current regulatory structure and the lack of financial or certification incentives to encourage the adoption of sustainable remediation practices.

Hou and Guthrie (2014) identified no regulatory mandate, lack of client demand and cost considerations as three most influential challenges to sustainable remediation. Other key challenges identified included lack of consistent standards and lack of expertise/training/resource while concerns such as lack of tools, lack of awareness, lack of sustainable remediation technologies and lack of scientific evidences of its benefit were ranked low by their study.

The Horinko Group (2014) further identified the lack of universal definition for the concept, lack of knowledge/awareness, higher upfront costs, not explicitly included in existing regulations/lack of authority and lack of ability to offer incentives as key challenges. They noted that progress has been made in addressing some of these challenges. The survey also identified lack of awareness as the most easily overcome challenge. On cost, The Horinko Group (2014) stated that "*the frequency with which companies cut* *costs by implementing GSR and the competitive advantage that firms stand to gain should serve more often as encouraging factors for these practices to be used more widely*".

On the challenges of implementing sustainable remediation, Reddy and Adams (2010 & 2015), identified lack or absence;

- Education and training for stakeholders,
- Guidance documents with clear and consistent definitions,
- Standardized sustainability metrics and validated evaluation tools,
- Well-defined frameworks and processes to evaluate sustainability
- Well documented pilot studies/case studies,
- Funding to support the research and development of sustainable approaches,
- Specific regulations requiring sustainability assessments for remediation projects,
- Academic basis of the concept, and
- The backlash of green washing.

Hou, Guthrie and Rigby (2016) identified nine (9) barriers to SR and the top five (5) of these are lack of client demand, lack of consistent standard, lack of expertise/training/resource, cost considerations and no regulatory mandate.

There have been good efforts towards addressing some of these challenges indentified by the various studies. There are clear frameworks established by SuRF in various countries especially in the USA, UK, Australia/New Zealand but no work in this direction was found in most developing nations of Africa except for the ICCL 2013 meeting in South Africa with a dedicated session of GSR. Also, SuRF-US has published case studies as well as the SuRF-UK (Section 3.3.9).

3.3.11 Overcoming the Challenges

To overcome the various challenges indentified in section 3.3.10 above, Ellis and Hadley (2009) recommended,

- Education in sustainable remedy, decision process and guidance for sustainable remediation design and implementation;

- Development of consistent, comparable and standardized sustainable remediation metrics, frameworks and guidance;
- Consolidation and validation of tools and references and the compilation of data used to evaluate sustainability;
- Development of a system for validating/certifying the methods, processes and/or criteria used;
- Enacting legislation and/or promulgating regulations and establishing regulatory guidance that includes sustainability; and
- Government promotion of sustainable remediation by encouraging sustainable approaches in its regulations and guidance documents.

3.3.12 Progress in Sustainable Remediation

Bardos (2014) reviewed the progress made in the adoption of sustainable remediation in various parts of the world and identified the established national initiatives such as SURF in the USA, SuRF-UK, SuRF-NL, SuRF-ANZ and SURF-Canada as well as newer initiatives in other countries, e.g. Italy, Brazil, Taiwan, Japan and China; two major European stakeholder networks, NICOLE and COMMON FORUM and International Committee on Contaminated Land (ICCL) as driving the concept in the various areas. It is worth noting that ICCL 2013 meeting in Durban, South Africa, hosted by the South African Department of Environmental Affairs, included a session on "green and sustainable remediation".

Bardos (2014) also identified emerging areas of international consensus in the subject of SR and these are;

- It's vision as an achievement of a net benefit across a range of environmental, economic and social concerns.
- Sustainability as a site-specific assessment and dependent on opinions from a range of stakeholders.
- A tiered approach as a likely most efficient route beginning with simple qualitative methods.
- Acceptance of the six principles of SR (CL:IARE, 2010) as the underpinning principles.

However, Bardos (2014) stated that methodologies proposed by different networks differ in details and these differences include the following.

- The order in which deliberations are made.
- The use of quantitative metrics.
- The extent to which indicators are predetermined against selection on a project-by-project basis.
- The extent to which weightings are used.

Bardos (2014) suggested that these differences between approaches depending on country is intrusive and may likely reflect cultural differences making a direct importation of the sustainability assessment used in one to another somewhat impossible, despite the consensus on the underpinning principles.

Bardos (2014) and Bardos et al (2016) have noted a developing consensus about the definitions and concepts of SR while Bardos et al (2016) has reported a planned special issue of Journal of Environmental Management on SR in 2016.

Substantial progress has also been made in the finalization of the ISO/DIS 18504, which has received approval unanimously with only minor technical comments (Nathanail, 2016). According to Nathanail (2016) this document, which will provide a standard methodology, terminology and information about the key components and aspects of sustainable remediation assessment; and informative advice on the assessment of the relative sustainability of alternative remediation strategies is expected to be published as a full ISO standard late 2016. This is a major milestone in the emergence of SR as the standard will provide basic framework and information for the adoption and implementation of sustainable remediation in countries that have not established SuRF such as Nigeria.

It is worth noting that four international sustainable remediation conferences (Copenhagen 2009, Vienna 2012, Ferrara 2014 and Montreal 2016) have been held to share experiences amongst practitioners and countries.

Chapter 4 Methodology

This chapter of the research presents a detailed explanation of the methodology adopted in this work.

4.1 General Approach

In order to achieve the goal and objectives of this research, which is focused on evaluating the impact of the emerging concept of sustainable remediation in the remediation of petroleum-contaminated soil in Nigeria, desktop study was adopted using peer reviewed literature and other published works and regulatory frameworks on the subject matter of sustainable remediation, remediation options appraisal, remediation and management of petroleum-contaminated sites, Niger Delta geography and the administration of questionnaire to identify available remediation strategies in Nigeria. Personal and telephone interviews were also employed. Extrapolations of the impacts of the application and implementation of sustainable remediation processes were then undertaken from the results and challenges of the desktop study.

4.2 The AIREGIN Site

A AIREGIN site was simulated to replicate the common and typical crude oil spill site in the Niger Delta of Nigeria. The site is a farmland, where there was a crude oil pipeline rupture releasing some volume of crude oil into the environment. The physiography, geology and hydrogeology of the site are simulated based on available literature. For the purpose of this research, the site was created to be contaminated only at the vadose zone by TPH and PAH to replicate current remediation activities in Nigeria. Levels of contamination were simulated; no assessments and laboratory analytical activities were carried out. The site risk assessment and conceptual site model were developed based on the simulated data created for this site.

The use of a simulated site was adopted because no actual site was available for this research. Due to concerns of liability, operators and partners are not willing to allow academic research on sites, as some are already subjects of litigation. In literature, Hunt and Smith (2012), Kueper, Stroo, Vogel and Ward (2014), and ITRC (2007) have reported the use of hypothetical sites for various remediation studies and Shell has developed the Lorax vitual site for simulating petrol retail stations contamination and developing CSM (http://www.lorax.biz/AIS/).

The AIREGIN site was developed using information on the Niger Delta of Nigeria and common scenario of remediation activities. The experience of the researcher (being responsible for managing oil spills and remediation sites for one of the IOC for a decade) was drawn upon while building the site for the research.

4.3 Remediation Project Objectives

The project objectives were established based on review of the regulatory framework for the establishment remediation objectives in Nigeria and taking into consideration site specific and project proponent institutional requirements. Consideration was also given to the site risk assessment.

4.4 Remediation Options Appraisal

Remediation options were shortlisted based on the responses from the questionnaire (Appendix 3) administered to thirty (30) respondents comprising ten regulators, ten service providers/contractors/consultants and ten petroleum industry personnel on the availability and application of petroleum-contaminated soil remediation options in Nigeria. No community or general public respondents were used because knowledge in the field of remediation within Nigeria is resident within these three stakeholders and secondly, to avoid generating unnecessary speculations of real contamination problem as the researcher is a staff of one of the IOCs. No pilot tests were carried out.

The responses from the questionnaire were analyzed using simple mean, percentages and weighted average. Identified remediation options from the responses from the questionnaire were then subjected to appraisal based on the peculiarities and regulatory framework of Nigeria.
The questionnaire was designed by the researcher and then discussed during a session of the dissertation supervision and agreed to suffice for this purpose. No pre-testing of the questionnaire was carried.

4.5 Stakeholder Engagement

Stakeholders' engagement was simulated for this research with my team members in the office. My five-team members were assigned roles as regulator, planner, community representative, NGO and consultant. The consultant was included in the stakeholders' engagement to provide insight into the capability of the indigenous remediation contractors on the various options to be considered and as defined by Hou and Al-Tabba (2014) as a stakeholder with influence in the promotion of SR. Before the consultation meetings, each member's roles and responsibilities were discussed within the contest of remediation and the member instructed to discuss freely during the consultation and make independent submissions that may improve the research. Attempts were made to remove the boss-subordinate relationship from this role-playing. In the sustainability assessment of the Shell Terminal Facility, Madeira the wider stakeholders were not involved (CL:AIRE, 2013). Though in this case, the stakeholders had been consulted as part of a previous work and sustainability assessment team were familiar with their views.

4.6 Risk Assessment

There is no available risk assessment matrix or clear risk assessment methodology supported by Nigerian regulations. Risk assessments are carried out in the organizations based on those developed by the parent companies and are generally not focused on environmental management and contaminated lands. The risk assessment matrices in Guidelines for Environmental Risk Assessment and Management: Green Leaves 111 (DEFRA 2004) and CIRIA C552: Contaminated land Risk Assessment: A Guide to Good Practice, (CIRIA 2001), were reviewed for this research. The matrix in Green Leaves 111 was found to be general while the risk assessment matrix in C552 was more focused on contaminated land management. The site risk assessment therefore was carried out using the risk classification matrix proposed in CIRIA C552. For a contamination liability to be realized there must be a source, a receptor and a viable pathway between them. If all three are present, then the magnitude of the risk is a function of the toxicity and mobility of the contaminant, the sensitivity of the receptor and the nature of the migration pathway. The potential risk is assessed based upon the severity of the potential consequence and the probability of it occurring. The risk classification process according to CIRIA C552 is summarized in Tables 3.1 to 3.4.

Table 4.1 Consequence of Risk Being Realized (CIRIA, 2001)

Classification	Definition
Severe	Acute risks to human health, major pollution to controlled waters, catastrophic damage to buildings/property, acute risk to sensitive ecosystem or species.
Medium	Chronic risk to human health, pollution of sensitive controlled waters, significant effects on sensitive ecosystem or species, significant damage to buildings or structures.
Mild	Pollution of non-sensitive water resources, minor damage to buildings or structure, significant damage to crops.
Minor	Requirements for personal protective equipment during site works to mitigate non-permanent health effects, damage to non-sensitive ecosystem.

Table 4.2 Probability of Risk Being Realized (CIRIA, 2001)

Classification	Definition
High Likelihood	Pollutant linkage is present and risk is almost certain in the long run or there is evidence of harm to the receptor.
Likely	Pollutant linkage is present and it is probable that the risk will be realised in the long term.
Low Likelihood	Pollutant linkage is present and there is probability of the risk occurring, although there is no certainty that it will be realised.
Unlikely	Pollutant linkage is present but circumstances are such that it is improbable that the risk would be realised even in the long term.

Table 4.3 Risk Classification Matrix (CIRIA, 2001)

		Consequence			
		Severe	**Medium**	**Mild**	**Minor**
Probability (Likelihood)	**High likelihood**	Very high risk	High risk	Moderate risk	Moderate/ low risk
	Likely	High risk	Moderate risk	Moderate/ low risk	Low risk
	Low likelihood	Moderate risk	Moderate/low risk	Low risk	Very low risk
	Unlikely	Moderate/lo w risk	Low risk	Very low risk	Very low risk

Table 4.4 Risk Classification Definitions (CIRIA, 2001)

Risk Classification Definitions	
Very High	There is a high probability that severe harm could arise to a designated receptor from an identified hazard, OR, there is evidence that severe harm to a designated receptor is currently happening. This risk, if realised, is likely to result in a substantial liability. Urgent investigation (if not undertaken already) and remediation are likely to be required.
High	Harm is likely to arise to a designated receptor from an identified hazard. Realisation of the risk is likely to present a substantial liability. Urgent investigation (if not undertaken already) is required and remedial works may be necessary in the short term and are likely over the longer term.
Moderate	It is possible that harm could arise to a designated receptor from an identified hazard. However, it is either relatively unlikely that such harm would be severe, or if any harm were to occur it is more likely that the harm would be relatively mild. Investigation (if not already undertaken) is normally required to clarify the risk and to determine the potential liability. Some remedial works may be required in the longer term.
Moderate/Low	
Low	It is possible that harm could arise to a designated receptor from an identified hazard, but it is likely that this harm, if realised, would at worst normally be mild.
Very Low	There is a low possibility that harm could arise to a receptor. In the event of such harm being realised it is not likely to be severe.

4.7 Sustainable Remediation Practice

To establish the status of knowledge and practice of sustainable remediation in Nigeria, personal and telephone interviews with practitioners was adopted. A total of ten (10) individuals were interviewed comprising of 3 regulators, 4 industry personnel and 3 remediation contractors/consultants. The standardized open-ended interview methodology was adopted, which according to Valenzuela and Shrivastara (online) facilitates faster interviews that can be more easily analysed and compared. The researcher, therefore developed a set of structured questions, which were posed to the interviewees and their responses recorded. Interview was adopted for this component of the research rather than the use of questionnaire to enable knowledge sharing on the subject matter and for the interviewee to gain some insight from the researcher on the subject, which the researcher believed would enhance the quality of the information collected. According to Gill, Stewart, Treasure and Chadwick (2008) interviews provide a deeper understanding of social phenomena than would be obtained by the use of questionnaires. The list of interviewees is provided in Appendix 4.

4.8 Sustainability Assessment Method

A range of tools and methods are available for undertaking a sustainability assessment, but they all seek to achieve the same goal to assess the relative environmental, social, and economic benefits and costs for a range of suitable options that meet the project goals (Smith and Kerrison, 2013). Consistent with the SuRF-UK sustainability assessment framework, a Tier-1 qualitative method was used for this research. A simple scoring qualitative assessment for the sustainability assessment was adopted with a scoring scheme of +2 to -2 as defined in the table below for the respective sustainability assessment criteria. The table was rigorously developed by the researcher, adapting expensively from Mouchel (2010) detailed remediation options appraisal – scoring categories.

Table 4.5 Detailed Sustainability Assessment Scoring Matrix (Adapted: Mouchel, 2010)

Score	Code	+2	+1	0	-1	-2
General Definition		Has a significant positive contribution under the assessment criterion and/or provides a very low risk of adverse impact.	Has a generally positive contribution under the assessment criterion and/or provides low risk of adverse impact.	Has little or no direct effect on the assessment criterion and/or provides medium risk of adverse impact.	Has some negative contribution under the assessment criterion and/or provides high risk of adverse impact.	Has significant negative contribution under the assessment criterion and/or provides very high risk of adverse impact.
Air Pollution	ENV1	No significant air pollution issues	Low air pollution issues	Medium air pollution issues	High air pollution issues	Very high air pollution issues
Potential creation of pathway for contaminant to reach groundwater	ENV2	No potential for the creation of new pathways	Low potential for the creation of new pathways	Medium potential for the creation of new pathways	High potential for the creation of new pathways	Very high potential for the creation of new pathways
Adverse Impact on the soil fauna and flora	ENV3	Very low adverse impact on soil fauna and flora	Low adverse impact on soil fauna and flora	Medium adverse impact on soil fauna and flora	High adverse impact on soil fauna and flora	Very high adverse impact on soil fauna and flora
Energy requirement/use of natural resources	ENV4	Requires no/very low energy input and/or none/minimal use of natural resources	Requires low energy input and minimal use of natural resources	Requires average energy input and/or average use of natural resources	Requires high energy input and/or high use of natural resources	Requires very high energy input and/or extensive use of natural resources
Extent of risk to site workers.	SOC1	Very low risk	Low risk	Medium risk	High risk	Very high risk
Noise, odour, dust, and vibration impacts on	SOC2	No or very low noise, odour, dust and vibration	Low noise, odour, dust and vibration impacts on community	Medium noise, odour, dust and vibration	High noise, odour, dust and vibration impacts on community	Very high noise, odour, dust and vibration

local community		impacts on community		impacts on community		impacts on community
Compliance of work with regulatory standards and international best practice	SOC3	Very positive view from regulations	Positive view from regulations	Neutral view from regulations	Negative view from regulations	Very negative view from regulations
Potential for stoppage of work by local community.	SOC4	Very low potential	Low potential	Medium potential	High potential	Very high potential
Cost implication of remediation option	ECO1	Very low	Low	Medium	High	Very high
Potential for local labour employment during remediation	ECO2	Very high	High	Medium	Low	Very low
Adaptation to changing site circumstances	ECO3	Very highly adaptable	Highly adaptable	Medium adaptability	Low adaptability	Very low adaptability
Potential for local supplies	ECO4	Very high potential for low supplies	High potential for low supplies	Medium potential for low supplies	Low potential for local supplies	Very low potential for local supplies

The adoption of the Tier 1 qualitative method aligns with the suggestions of CL:AIRE (2010b) that the sustainability assessment should normally be undertaken at the lowest tier that allows a robust management decision to be made and for this case study a Tier 1 assessment was very adequate and was agreed as adequate with the simulated stakeholders.

The SuRF-UK indicator categories formed the basis for the stakeholders' engagement, where the indicators for the assessment were finally agreed taking cognizance of the specific situations of the Niger Delta of Nigeria.

Chapter 5 Conceptual Site Model

This chapter provides a description of the project problem, the conceptual site model (CSM), site risk assessment and the overall project objectives. As mentioned earlier the site was simulated using the baseline information of the Niger Delta of Nigeria and experience of the researcher from managing contaminated-petroleum sites in the Niger Delta of Nigeria.

5.1 Site History

The AIREGIN site is in the Niger Delta of Nigeria and was impacted by a crude oil spill from a delivery pipeline due to the activities of some vandals in 2010. It was estimated that about 10,000 barrels of crude oil was spilled at the site during the incident. An area of 6,000 square meters of land was impacted. Empirical site characterization of the site revealed contamination of the soil in the area by Total Petroleum Hydrocarbon (TPH) to maximum value of 8,450mg/kg and Poly Aromatic Hydrocarbons (PAH) to maximum value of 12.33mg/kg to a depth of about 0.3m. These values are above the Nigerian regulatory target and intervention limits (Appendix 1). The groundwater investigation did not indicate any significant contamination as the values for contaminants of concern were below regulatory limits. The site is about 500m away from the nearest community.

5.2 Site Physiography and Land Use

The site is in the Niger Delta of Nigeria with the land elevation generally below 20m above sea level. There are no marked imposing hills that rise above the general land surface. The area is gently sloping and transversed by a seasonal swamp running from northeast to southwest joining the bigger Delta River. The natural vegetation of the area is of the tropical rain forest with swamp forest occurring in flat-floored valleys and adjoining low-lying areas that are seasonally waterlogged. The Niger Delta rain forest is floristically diverse and structurally complex, with several layers of trees (UNDP, 2006). The proposed site has vegetation made up of grasses and shrubs with few scattered trees indicative of a secondary jungle forest (TEPNG, 2012).

The major land use of the site is for subsistence agriculture involving the cultivation of local crops mainly cassava, yam, cocoyam, maize and native vegetables. The agricultural practice is bush fallowing, which involves cultivating a piece of land in one farming season and allowing same uncultivated for a period (5 to 6 years) so that the fertility of the land will be restored before returning to cultivate the same piece of land. Bush burning is common practice in this area (TEPNG, 2012).

The site is to be remediated to a condition where it can support local and subsistence farming. The stakeholders envisage no change of land use.

The site lies in a humid sub-equatorial climate characterized by wet and dry seasons. The wet season is longer and extends from March/April to October while the dry season extends from November to February. The mean annual temperature of the area is 27 (±3) degrees Celsius and the annual average rainfall is about 3000mm with average evapotranspiration of about 1000mm/year, leaving an effective rainfall of 2000mm/year. (Dehez, 2014)

5.3 Site Geology and Lithostratigraphy

The site is a low-lying River Niger flood plain consisting mainly of recent unconsolidated sediments of Quaternary age, which are partly marine and partly fluvial in origin from the upper part of the Benin Formation.
The conceptual lithology indicated a top clay layer overlying a sand formation. There is a thick clay layer, which is continuous and indicative of a protection layer for the shallow aquifer in this area. (Dehez, 2014; Amajor 2013a, 2013b, 2013c, and GEORIM 2013). This is responsible for keeping the petroleum contaminants within the first 0.3m of the unsaturated zone.

5.4 Site Hydrogeology

The topographic elevation of the site varies from 14m to 18m above ordinance datum and this variation influences the configuration and behaviour of the groundwater flow, which in turn controls the mass transport pattern in the saturated zone. The depth to groundwater at the site varies with season. During the wet season the depth is about 0.6m to 1.5m below ground level while during the dry season the depth is about 3m to 4m below ground level. The aquifer in the area is a confined and the aquiferous materials are mainly sands. The average hydraulic conductivity of the area is 1.94 X 10^{-1}cm/s and the average flow velocity is estimated at 0.14m/day. The groundwater flow direction is from North-East (NE) to South-West (SW). (Dehez, 2014; Amajor 2013a, 2013b, 2013c, and GEORIM 2013)

5.5 Surface Water, Ecological Resources and Sensitive Land Use

The AIREGIN site is located about 300m east of the Delta River (Simulated-name), a tributary of the main river Niger channel. No other distinct special ecological resources and sensitive land use was identified within the vicinity and or broader buffer zone of about 1km radius of the project site.

5.6 Infrastructure and Services

Access to the site is across difficult terrain of the Niger Delta going through a 100m of swamp with track paths created by local community and truck accessible through the muddy pipeline Right of Way (RoW). Electricity and power supply is not available at the site and the nearest portable water supply is about 1km away from the site. Mobile telephone network is available for telecommunication.

5.7 Pollution Incidents

The area has recorded several spills from this pipeline and other adjacent pipelines. Regulatory records show that remediation works have been carried out successfully at this site for three consecutive times. Certificates of remediation issued by Nigerian regulators were available. But suffice it to mention that UNEP (2011) had challenged the validity of remediation certifications elsewhere in the Niger Delta, as some sites that were recorded to have been remediated and certified were found to have concentrations of hydrocarbon contaminants above the regulatory target levels.

5.8 Potential Sources of Contamination

The basic contaminating activity at the site is pipeline rupture causing the release of crude oil into the environment. The main sources therefore are hydrocarbon contaminants especially TPH, PAH, phenols and BTEX, and heavy metals associated with oil exploration and production activities. The AIREGIN site characterization exercise indicated values of TPH and PAH higher than regulatory limits while phenols, BTEX and metals were below regulatory limits.

5.9 Potential pathways

Potential pathways for the site include the following.

1. Direct ingestion of soil and dust by community farmers.
2. Dermal contact with soil and dust with farmers and site workers.
3. Inhalation of soil and dust by farmers and site workers.
4. Vegetable uptake (some cocoyam, pineapples were observed to be sprouting within the project site).
5. Inhalation of vapour by workers and farmers.
6. Migration through the unsaturated zone and soil leachate.
7. Ingestion of contaminated fisheries from the seasonal swamp.

5.10 Potential Receptors

The potential Receptors identified included;

1. Community residents
2. Farmers
3. Fishermen
4. Site workers
5. Groundwater
6. Swamp water
7. The River

5.11 Site Risk Assessment

Based on the empirical characterization, site geology and hydrogeology, the potential pathways and receptors identified, the preliminary risk assessment in Table 5.1 below was carried out. The risk assessment was carried out using the risk classification matrix in Table 4.3 (CIRIA, 2001).

Table 5.1: AIREGIN Site Preliminary Risk Assessment

Contaminant	Pathway	Receptor	Probability	Consequence	Risk Classification	Explanations
Hydrocarbons • TPH • PAH • VOC	Ingestion of Soil	• Community Farmers	High Likelihood	Medium	High	
	Dermal contact with soil	• Community Farmers	High Likelihood	Mild	Moderate	
	Inhalation of soil dust	• Community Farmers •	High Likelihood	Medium	High	Especially during the dry season, when the seasonal swamps are dry and farming activities at their peak.
	Ingestion of soil	• Site workers	Unlikely	Medium	Low	Site workers are expected to use appropriate personal protective equipment
	Dermal contact with soil	• Site workers	Unlikely	Medium	Low	
	Inhalation of soil dust	• Site workers	Low Likelihood	Medium	Moderate/low	
	Inhalation of vapour	• Site workers • Community farmers	Likely	Severe	High	
	Migration through vadose zone	• Groundwater	Unlikely	Severe	Moderate/low	
	Contaminated soil leachate	• Groundwater	Unlikely	Severe	Moderate/low	
	Groundwater flow	• River	Unlikely	Medium	Low	
	Domestic use of shallow	• Community members	Unlikely	Severe	Moderate/low	Characterization results did not indicated

	groundwater from dug wells	• Farmers • Neighbours				pollution of groundwater
	Ingestion of contaminated vegetation	• Community members • Farmers • Neighbours	Likely	Medium	Moderate	Vegetation studies will be necessary to establish this linkage

Assumptions and uncertainties.

It has been assumed that;

- All relevant contaminative processes have been identified,
- The site investigation works have identified all significant areas of contamination at the Site, and
- The alluvial clay is continuous (i.e. no high permeability lenses or pathways exist) and provided adequate protection of the underlying aquifer

5.12 Conceptual Site Model

The Conceptual Site Models in Figure 5.1 and Figure 5.2 below were developed based on the characteristics of the AIREGIN site as defined in Sections 5.1 to 5.10 and result of the risk assessment presented in Table 5.1.

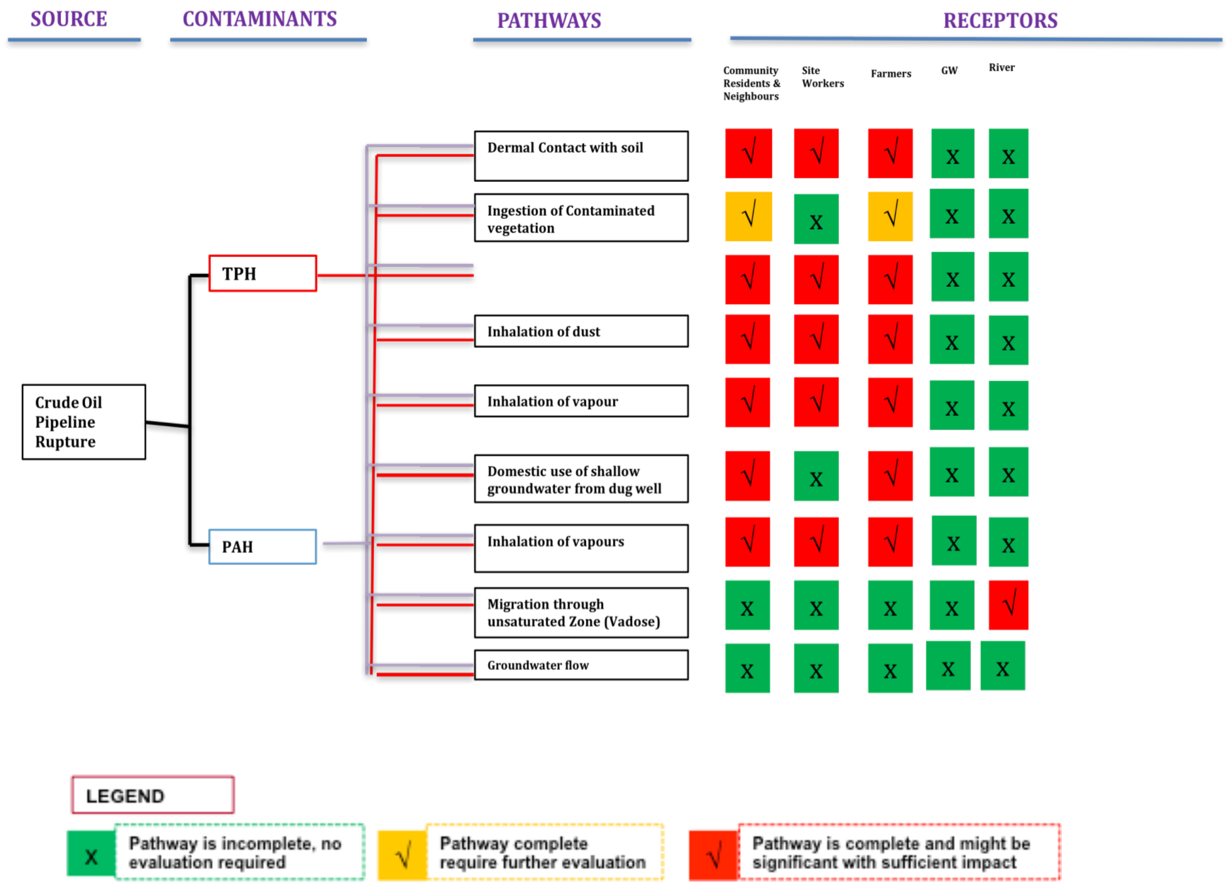

Figure 5.1 Conceptual Site Model (CSM) - Schematic

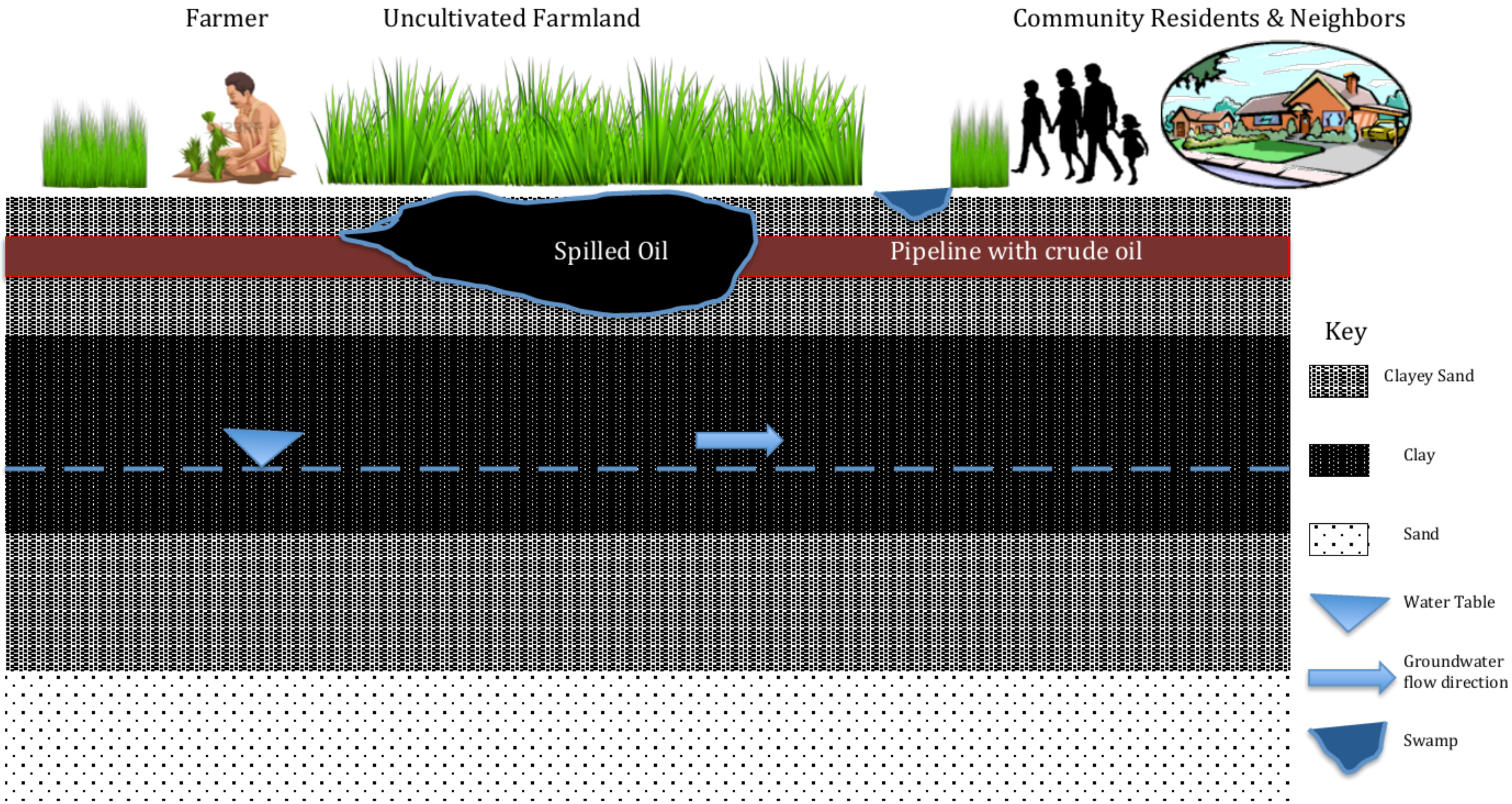

Figure 5.2 Conceptual Site Model (CSM) – Cross Section

5.13 Remediation Objectives

The objectives of the remediation of the AIREGIN site are;

- To reduce the concentrations TPH and PAH at the site to below 50mg/kg and 1mg/kg of dry soil respectively (Appendix 1);
- To restore the site to support subsistence agriculture;
- To protect human health;
- To make the site reusable within 36 months;
- To carry out the project in cost efficient manner; and
- To resolve the social issues with the immediate and neighboring communities.

Chapter 6 Remediation Options Appraisal

This chapter describes the processes used to shortlist suitable remediation options for managing the simulated site and the options appraisal for selecting most feasible options for sustainability assessment.

6.1 Short-listing of Remediation Options

The short-listing of the available remediation options suitable for the site was carried out by analyzing the responses from the questionnaire (Appendix 3) administered on the availability and application of remediation technologies in Nigeria to thirty (30) respondents made up of ten (10) regulators, ten (10) consultants/contractors and ten (10) petroleum industry personnel. The outcomes of the responses from the questionnaire are analyzed below.

6.1.1 Total Number of Responses

A total number of thirty (30) respondents were selected, ten (10) each from three categories of stakeholders namely regulators, consultants/contractors and petroleum industry personnel. Of the thirty (30) respondents 28 (9 regulators, 9 consultants/contractors and 10 industry) filled and returned the questionnaire to the researcher either through the survey monkey or hard copy by email. Figure 5.1 below depicts the responses in percentages by category.

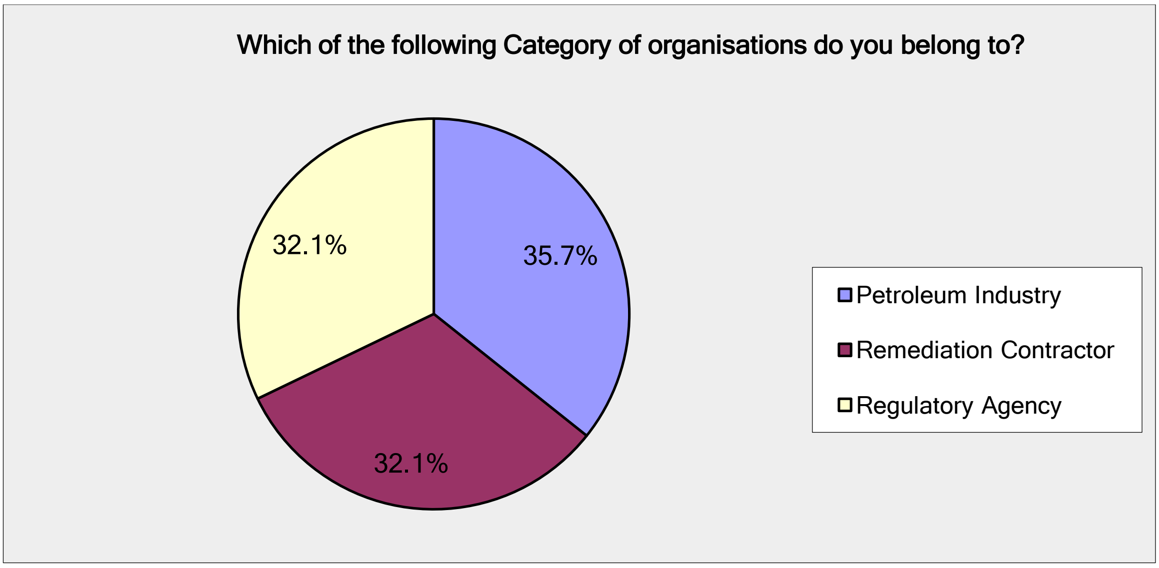

Figure 6.1 Responses by Category of Respondents

All 28 respondents are involved in remediation activities in the petroleum industry in Nigeria as indicated in their responses to question No. 2 of the questionnaire.

6.1.2 Availability and Applicability of Remediation Options in Nigeria

The analysis of the twenty-eight (28) responses to question No. 3 of the questionnaire using weighted average identified the most available and applied remediation options for petroleum-contaminated soils in Nigeria. Table 6.1 below shows the responses and analysis.

Table 6.1 Availability and Applicability of Remediation Options in Nigeria

S/N	Remediation Options	Not Applied in Nigeria	1 Project	2-3 Projects	4 Projects	5 Projects	>5 Projects	No of Responses	Weighted Average
	Weighting	**0**	**1**	**2**	**3**	**4**	**5**		
1	Monitored Natural Attenuation	0	0	4	2	7	15	28	4.
2	Bio venting	24	1	3	0	0	0	28	0.
3	Enhanced *In-situ* Bioremediation	0	0	2	0	4	22	28	4.
4	Phytoremediation	20	8	0	0	0	0	28	0.
5	Electrokinetic Separation	28	0	0	0	0	0	28	
6	Fracturing	28	0		0	0	0	28	
7	Soil Flushing	21	1	2	0	1	3	28	0.
8	Soil Vapour Extraction (SVE)	28	0	0	0	0	0	28	
9	Solidification/Stabilization	13	8	5	0	1	1	28	0.
10	Thermally Enhanced SVE	28	0	0	0	0	0	28	
11	Bio-piles	4	2	6	5	3	8	28	2.
12	Composting	0	9	3	0	10	6	28	3.
13	Land Farming	2	0	1	2	5	18	28	4.
14	Slurry phase biological treatment	28	0	0	0	0	0	28	
15	Chemical Extraction	28	0	0	0	0	0	28	

S/N	Remediation Options	Not Applied in Nigeria	1 Project	2-3 Projects	4 Projects	5 Projects	>5 Projects	No of Responses	Weighted Average
	Weighting	**0**	**1**	**2**	**3**	**4**	**5**		
16	Chemical Reduction/Oxidation	26	2	0	0	0	0	28	0.0
17	Soil Washing	18	2	8	0	0	0	28	0.6
18	Incineration	0	0	0	0	3	25	28	4.8
19	Pyrolysis	28	0	0	0	0	0	28	
20	Thermal desorption	0	3	4	15	0	6	28	3.0
21	Landfill cap	28	0	0	0	0	0	28	
22	Excavation, retrieval and offsite disposal	7	2	5	2	5	7	28	2.6

Using a weighted average of 2.5, which represents a 50% response and application of the remediation option, the following remediation options were selected as available and applied in Nigeria for the remediation of petroleum-contaminated soils.

- Monitored Natural Attenuation;
- Enhanced *In-situ* Bioremediation;
- Bio-piles;
- Composting;
- Land farming;
- Incineration;
- Thermal desorption; and
- Excavation, retrieval and offsite disposal

These remediation options formed the first shortlist of options for the strategy appraisal and selection.

6.1.3 Remediation Options Importable into Nigeria

The responses to question No. 4 of the questionnaire identified the following remediation options as easily importable into Nigeria as shown in Table 6.2.

Table 6.2 Remediation Options Importable into Nigeria

Remediation Options	No. of Responses	Response Percent
Bioventing	24	85.7%
Enhanced *In-situ* Bioremediation		0.0%
Phytoremediation	20	71.4%
Electrokinetic Separation	10	35.7%
Fracturing	8	28.6%
Soil Flushing	21	75.0%
Soil Vapour Extraction (SVE)	28	100.0%
Solidification/Stabilization	13	46.4%
Thermally Enhanced SVE	8	28.6%
Biopiles	4	14.3%
Composting		0.0%
Land Farming	2	7.1%
Slurry Phase Biological Treatment	11	39.3%
Chemical Extraction	8	28.6%
Chemical Reduction/Oxidation	26	92.9%
Soil washing	18	64.3%
Incineration	0	0.0%
Pyrolysis	6	21.4%
Thermal Desorption	0	0.0%
Landfill Cap	6	21.4%
Excavation, Retrieval and Offsite Disposal	7	25.0%
Total Number of Responses		**28**

Options shortlisted from this analysis are options with greater than or equal to 50% response and are as listed below.

- Bioventing;
- Phytoremediation;
- Soil flushing;
- Soil Vapour Extraction (SVE);
- Chemical Reduction and Oxidation; and
- Soil washing

6.1.4 Short-listing of Remediation Options

Based on the outcomes of Sections 6.1.2 and 6.1.3 the following remediation options were shortlisted for the options appraisal exercise.

- Monitored Natural Attenuation;
- Enhanced *In-situ* Bioremediation;
- Bio-piles;
- Composting;
- Land farming;
- Incineration;
- Thermal desorption;
- Excavation, retrieval and offsite disposal;
- Bioventing;
- Phytoremediation;
- Soil flushing;
- Soil Vapour Extraction (SVE);
- Chemical Reduction and Oxidation; and
- Soil washing

The remediation options listed above have been described in Tables 3.1 and 3.2.

Taking consideration of the remediation objectives, a preliminary options assessment was carried and the following remediation options were eliminated.

- Monitored Natural Attenuation because this option will not produce the require reduction in contaminants concentration within the time limit of the project;
- Phytoremediation will not produce the required results within project timeframe and is a pilot phase remediation option that has not been fully developed;
- Soil flushing, due to the presence of surface water within the project catchment area could provide a pathway for the contaminants to be washed into the river;
- Soil washing, as the geology of the site indicates that the contaminated soil is mainly made of clay fines, which will make soil washing not as effective and lead to production of large residues for subsequent treatment; and

- Excavation, retrieval and offsite disposal, there are no engineered landfills in the Niger Delta of Nigeria and therefore no suitable disposal sites for petroleum-contaminated soil.

Hence only nine (9) were moved further for remediation options appraisal.

6.2 Remediation Options Appraisal

Bearing in mind the objectives of the remediation project, the following options appraisal criteria defined in Table 6.3 were employed. The researcher developed Table 6.3 after a rigorous study of literature within a period of about three months. Table 6.4 provides the result of the options appraisal exercise carried out for the AIREGIN site.

Table 6.3 Remediation Options Appraisal Scoring Matrix

Score	1	2	3	4	5
General Definition	**Very low positive and very high negative**	**Low positive and high negative**	**Medium impacts or neutral**	**High positive and low negative**	**Very high positive and zero/very low negative**
Applicability	Very limited applicability or no track records	Limited applicability	Some applicability	Good applicability	Very good applicability and proven track record
Timescale	Very long time (>18 months)	Long time (< 18 months but >12 months)	Medium time (7 – 12 months)	Short (4-6 Months)	Very short (<4 months)
Cost	Very high	High	Medium	Low	Very low
Stakeholder Acceptability	Very low acceptability	Low acceptability	Medium acceptabilit y	Highly acceptability	Very highly acceptability
Regulatory feasibility	Not/very low feasibility	Low feasibility	Medium feasibility	High feasibility	Very high feasibility
Propensity for combination	Very low propensity for combination with other methods	Low propensity for combination with other methods	Medium propensity for combinatio n with other methods	High propensity for combination with other methods	Very high propensity for combination with other methods
Likely Impact on Community	Significantly very negative impact	Very negative impact	Negative impact	Slightly negative impact	Very low negative impact

Table 6.4 Remediation Options Appraisal

S/NO	REMEDIATION OPTION	APPLICABILITY	TIMESCALE*	COST	STAKEHOLDERS' ACCEPTABILITY	REGULATORY FEASIBILITY	PROPOSENSITY FOR COMBINATION	LIKELY IMPACT ON COMMUNITY	TOTAL SCORE
1.	Enhanced *In-situ* Bioremediation	5	2	5	5	5	5	3	30
2.	Bio-piles	5	3	4	4	4	5	3	28
3.	Composting	5	3	4	4	4	5	2	27
4.	Landfarming	5	3	5	5	5	5	2	30
5.	Incineration	5	5	2	3	3	5	2	25
6.	Thermal Desorption	4	4	4	3	3	5	2	25
7.	Bio-venting	3	1	4	5	3	5	4	25
8.	Soil Vapour Extraction	5	1	3	3	3	5	4	24
9.	Chemical Reduction and Oxidation	5	2	3	2	2	3	2	19

* Includes time for regulatory approval of methodology in line with Nigerian regulatory framework

- Bio-piles;
- Composting;
- Landfarming;
- Incineration;
- Thermal Desorption; and
- Bio-venting.

Chapter 7 Sustainable Remediation Assessment

In this chapter the researcher evaluated the responses from the interviews conducted and carried out a Tier-1 sustainability assessment of the identified feasible remediation options (Section 6.2).

7.1 Sustainable Remediation Practice in Nigeria

Nine specific questions were posed to the interviewees and their responses for each question recorded. The main results from the interviews by question are highlighted below.

Question No. 1: Are you aware of the emerging concept of sustainable remediation? Yes/No

Only three of the interviewees were aware of the concept. The other seven could distinguish individually the concepts of remediation and sustainable development, which is seen from the perspective of societal engineering. This indicates a substantial (70%) lack of awareness of the concept of sustainable remediation amongst the interviewees and by extrapolation, amongst practitioners in Nigeria.

Question No. 2: Are you conversant with the principles of sustainable remediation and what are the key principles?

All but one interviewee showed no clear understanding of the principles of sustainable remediation. The only interviewee conversant with the principles had only general knowledge from internet sources.

For all the interviewees, the researcher at this point discussed the general principles of sustainable remediation to help improve the understanding of the interviewees before proceeding with the other questions.

Question No. 3: Is the present practice of remediation in Nigeria sustainable? If "yes" how?

All the interviewee agreed that the present practice in Nigeria does conform to sustainable remediation and cannot be assessed as sustainable.

Question No. 4: Are aware of the application of sustainability assessment in remediation projects in Nigeria? Kindly give example of any such project.

Based on the discussions of the principles of sustainability assessment for remediation, the interviewees agreed that there is no application of sustainability assessment in remediation projects in Nigeria.

Question No.5: Do you know of any source of information/literature/case studies on the subject of sustainable remediation? If yes, what are these sources?

Two of the interviewee referred the researcher to SuRF-UK and the US Department of Energy for information while the other eight had no knowledge of sources of information on the subject matter.

Question No.6: Is there any legal framework/guidance manual that support the application of sustainability assessment in remediation projects in Nigeria? If yes, kindly name these documents.

All interviewees agreed that the extant legal framework and guidance documents do not provide for sustainability assessment but one of the interviewees stated that the risk based corrective action strategy embodied in EGASPIN (2002) has some elements of the general approach to sustainability. He further stressed that the challenge is the voluntary requirement for the application of RBCA by EGASPIN (2002) and the virtually near non-application of it.

Question No.7: Do you think Nigeria will benefit from adopting and implementing sustainable remediation? If yes, what are these benefits?

There was 100% affirmative response that Nigeria will benefit from implementing sustainable remediation. A summary of the various benefits mentioned by the interviewees included,

- Reinforcement of the risk-based approach to remediation;
- Reinforcement of early stakeholders' engagement in the entire process of the project;
- Elimination/reduction in rampant cosmetic remediation activities often carried out to satisfy community demands;
- Protection of the ecosystem and conservation of natural resources;
- Encouraging easy importation of expertise and more innovative technologies already developed elsewhere; and
- Improved transparency in the remediation process.

Question No. 8: What challenges do think Nigeria will face in adopting and implementing sustainable remediation?

Summary of the challenges identified by the interviewees included;

- Incessant recontamination of remediated sites due to the activities of vandals, oil thieves, illegal/local oil refineries;
- Lack of regulatory backing and information base for carrying out such a rigorous exercise;
- Lack of knowledge and expertise in the process of sustainability assessment in remediation project;
- Lack of funding support for the implementation of the process of adopting and implementing sustainable remediation;
- Usual human resistance to change. Regulators saw it as much more cumbersome and demanding to regulate, the operators as more stringent process and time/resources consuming while the remediation contractors saw it as means of providing cover for operators to do nothing at some sites.
- The industry representatives interviewed identified community pressure to remediate sites even when there are no elevated concentrations of contaminants and no identifiable risk as a challenge. This they argued leads to several remediation projects, which are generally unnecessary and performed for cosmetic reasons to maintain the social permit to operate. They argued that huge sums of money are spent on these projects without realizing any value. The regulators representatives interviewed agreed that

most of the sites proposed for remediation due to community pressure usually do not need active remediation activities.

Question No. 9: Is there anything else you would want the researcher to know related to remediation and sustainable remediation in Nigeria.

All interviewees were of the opinion that the present practice could be improved upon but gradually. Furthermore, requests for resource materials on the subject matter of sustainable remediation were made by some of the interviewees.

It was generally surprising that most of the interviewers, who are routinely involved in remediation works as part of their respective job schedules, were not aware or had very little knowledge of the concept of sustainable remediation. Further, with the advent of the internet was more worrisome that they were equally unaware of sources of information.

7.2 Sustainability Assessment Process

The sustainability assessment undertaken for the AIREGIN site was simulated to reflect the practice of sustainable remediation assessment as advocated in the SuRF-UK framework. The main activities were;

- The compilation of relevant site information (detailed in Chapter 5 of this research);
- Identification of potential stakeholders to facilitate an assessment workshop;
- A workshop of the relevant stakeholders to establish the context of the sustainability assessment, define the objectives and boundaries of the assessment; and to determine the nature of the assessment and
- The completion of the sustainability assessment, which is reported in Sections 7.2.6 and 7.2.7.

7.2.1 Objectives of the Sustainability Assessment

The key objective of this sustainability assessment was to identify within the prevailing context in Nigeria a remediation option for the treatment of petroleum-contaminated soil in the Niger Delta of Nigeria, which has consideration of the general sustainability factors of environment, economics and social.

7.2.2 Identification of Stakeholders

The following stakeholders were identified for this project.

- The operator
- The regulators (DPR and NOSDRA)
- Immediate community of impact
- Project consultant
- CBOs
- Local and International NGOs

The work being an academic exercise, the researcher assigned the roles of the various stakeholders to individual members of his work team and clarified their roles. The researcher acted the role of the operator and proponent of the remediation project.

7.2.3 Scope

The key driver for the completion of the remediation works was community pressure. The members of the impacted community have continued to mount pressure on the operator to return their farmland to original state where subsistence farming can be resumed. Several petitions have been written to government agencies and operator threatened with blockage/disruption operations if the site remediation work is not commenced and finalized in the next 36 months.

Furthermore, the requirements of EGASPIN (2002) that contaminated land must be restored to as much as is practically possible to its original state or at least to support the original land use was also a critical driver of the project. So the scope is to restore the site to a state where subsistence agriculture is supported without any substantial risk to the farmers and users of the farm produces. Both the regulatory and community requirements are aligned.

7.2.4 Options

The remediation options considered in this sustainability assessment exercise were identified from Section 6.2.

7.2.5 Sustainability Assessment Criteria/Indicators

During the workshop with the stakeholders, the SuRF-UK categories of indicators for sustainability assessment of remediation options detailed in Table 7.1 were reviewed and used as basis for the identification of indicators for this exercise.

Table 7.1 SuRF-UK Categories of Indicators for Sustainability Assessment of Remediation Options (CL:AIRE, 2010b & 2011)

Environmental	Social	Economic
1. Impacts on air (including climate change); 2. Impacts on soil; 3. Impacts on water; 4. Impacts on ecology; 5. Use of natural resources and generation of wastes; 6. Intrusiveness.	1. Impacts on human health and safety; 2. Ethical and equity considerations; 3. Impacts on neighbourhoods or regions; 4. Community involvement and satisfaction; 5. Compliance with policy objectives and strategies; 6. Uncertainty and evidence.	1. Direct economic costs and benefits; 2. Indirect economic costs and benefits; 3. Employment and capital gain; 4. Gearing; 5. Life-span and 'project risks'; 6. Project flexibility.

After a brainstorming session and bringing to bear the peculiarities of the Niger Delta of Nigeria, the following indicators were agreed for this exercise as detailed in Table 7.2.

Table 7.2 Sustainability Assessment Indicators for the Research

Indicatory Category	Key Indicator	Code	Explanation
Environmental	Air Pollution resulting from remediation option implementation.	**ENV1**	Emanating from burning fossil fuels
	Potential creation of pathway for contaminant to reach groundwater.	**ENV2**	Impact on soil matrix and structure that may increase leaching and vertical migration of contaminants.
	Impact on the soil fauna and flora.	**ENV3**	Impact on soil microbial population and activities.
	Energy requirement/use of natural resources.	**ENV4**	Energy and services required for the implementation of the option.
Social	Extent of risk to site workers.	**SOC1**	Indicator relates to exposure of site workers to VOCs, risk due to operating machinery etc.
	Noise, odour, dust and vibration impacts on local community.	**SOC2**	Nuisance due to dust, odour and vibrations from equipment to local neighbourhood.
	Compliance of work with regulatory standards and international best practices.	**SOC3**	Ability to meet objectives and show proof/verification.
	Potential for stoppage of work by local community	**SOC4**	How easily community members can stop the works at site during project life.
Eco nom ics	Cost implication of remediation option.	**ECO1**	Overall cost of the remediation option including haulage cost,

Indicatory Category	Key Indicator	Code	Explanation
			waste management cost and long term monitoring costs.
	Potential for local labour employment during remediation.	**ECO2**	The potential for engaging community labour in the remediation project taking consideration all health and safety issues and how long they may be involved.
	Adaptation to changing site circumstances.	**ECO3**	Ability of the remediation option to adapt to changes including difference is soil types, discovery of new contamination.
	Potential for local supplies	**ECO4**	The potential to engage community members in the supply for materials and equipment for the implantation of the remediation option.

7.2.6 Sustainability Assessment

A simple scoring qualitative assessment for the sustainability assessment was adopted with a scoring scheme of +2 to -2 as described earlier in Table 4.5 of this research work.

The assessment was carried out for all twelve (12) agreed assessment indicators and the results of the assessment detailed in Table 7.3 below subjected to sensitivity analysis from three perspectives;

- Ideal perspective, with equal weighting for all three sustainability dimensions of environment, social and economics (Table 7.4);
- Environmentalist perspective, with 50% (2) weighting for Environment, 25% (1) weighting for social and 25% (1) weighting for economics (Table 7.5); and

- Economics perspective, with 50% (2) weighting for Economics, and 25% (1) weighting for environment and 25% (1) weighting for social (Table 7.6).

Table 7.3: Summary of the Sustainability Assessment using Simple Qualitative Scoring

Remediation Option/Indicator	**ENV1**	**ENV2**	**ENV3**	**ENV4**	**Sub-Total ENV**	**SOC1**	**SOC2**	**SOC3**	**SOC4**	**Sub-Total SOC**	**ECO1**	**ECO2**	**ECO3**	**ECO4**	**Sub-Total ECO**	**T**
Enhanced *In-situ* Bioremediation	2	1	2	2	**7**	2	2	0	-2	**2**	2	2	-1	1	**4**	1
Bio-piles	2	-1	1	2	**4**	1	-1	1	-2	**-1**	1	1	1	1	**4**	7
Composting	0	-1	1	2	**2**	1	-1	1	-1	**0**	1	1	1	1	**4**	6
Land-farming	1	-1	2	2	**4**	1	0	1	-2	**0**	2	2	-1	1	**4**	8
Incineration	-2	-1	-2	-1	**-6**	0	-1	2	1	**2**	-1	0	2	-1	**0**	-
Thermal Desorption	-2	-1	-2	-1	**-6**	0	-1	2	1	**2**	-1	0	2	-1	**0**	-
Bio-venting	2	0	2	-1	**3**	0	2	0	-2	**0**	1	1	0	1	**3**	6

Table 7.4 Sustainability Assessment Result – Ideal Perspective

Remediation Option/Dimension	ENV	SOC	ECO	TOTAL	RANKING
Weighting	**1**	**1**	**1**		
Enhanced *In-situ* Bioremediation	7	2	4	**13**	**1st**
Bio-piles	4	-1	4	**7**	**3rd**
Composting	2	0	4	**6**	**4th**
Land-farming	4	0	4	**8**	**2nd**
Incineration	-6	2	0	**-4**	**5th**
Thermal Desorption	-6	2	0	**-4**	**5th**
Bio-venting	3	0	3	**6**	**4th**

The ideal perspective selected enhanced *in-situ* bioremediation as most sustainable option.

Table 7.5 Sustainability Assessment Result – Environment Perspective

Remediation Option/Dimension	ENV	SOC	ECO	TOTAL	RANKING
Weighting	**2**	**1**	**1**		
Enhanced *In-situ* Bioremediation	14	2	4	**20**	**1st**
Bio-piles	8	-1	4	**11**	**3rd**
Composting	4	0	4	**8**	**5th**
Land-farming	8	0	4	**12**	**2nd**
Incineration	-12	2	0	**-10**	**6th**
Thermal Desorption	-12	2	0	**-10**	**6th**
Bio-venting	6	0	3	**9**	**4th**

This perspective still selected enhanced *in-situ* bioremediation as most sustainable but preferred bioventing to composting against the ideal perspective that ranked both as equal.

Table 7.6 Sustainability Assessment Result – Economics Perspective

Remediation Option/Dimension	**ENV**	**SOC**	**ECO**	**TOTAL**	**RANKING**
Weighting	**1**	**1**	**2**		
Enhanced *In-situ* Bioremediation	7	2	8	**17**	**1st**
Bio-piles	4	-1	8	**11**	**3rd**
Composting	2	0	8	**10**	**4th**
Land-farming	4	0	8	**12**	**2nd**
Incineration	-6	2	0	**-4**	**6th**
Thermal Desorption	-6	2	0	**-4**	**6th**
Bio-venting	3	0	6	**9**	**5th**

This perspective also selected enhanced *in-situ* bioremediation as most sustainable but preferred composting to bioventing against the ideal perspective that ranked both as equal and the environment perspective that preferred bioventing.

Table 7.7 Result of the sensitivity analysis

Remediation Option/Perspective	**Ideal**	**Environment**	**Economics**
Enhanced *In-situ* Bioremediation	1st	1st	1st
Bio-piles	3rd	3rd	3rd
Composting	4th	5th	4th
Land-farming	2nd	2nd	2nd
Incineration	5th	6th	6th
Thermal Desorption	5th	6th	6th
Bio-venting	4th	4th	5th

7.2.7 Outcome of the Sustainability Assessment

The simple qualitative sustainability assessment carried out as detailed in Section 7.2.6 and Tables 7.3, 7.4, 7.5, 7.6 and 7.7 identified Enhanced *In-situ* Bioremediation as the most sustainable remediation option for the treatment of the site. The assessment indicates that enhanced *in-situ* bioremediation will present better sustainability outcomes for the agreed sustainability indicators in all three dimensions of environment, social and economic as well as from the three scenario perspectives of ideal, environment and economics. The assessment equally revealed that the application of enhanced *in-situ* bioremediation has low sustainability score for the following parameter.

- In the ease of verification of the efficacy of the remediation activities, this is a general problem associated with the application of biological *in-situ* techniques;
- Easily lend to community protests and work stoppage basically as the activities are *in-situ* within the community land, as would other on-site options and
- May not be easily adapted to changing situations especially in soil structure and discovery of other contaminants. Not all contaminants are treatable using biological techniques and the technique is only effective in the near surface hence deeper contamination cannot be treatable.

Chapter 8 Findings and Discussions

This chapter discusses the results of the risk assessment, remediation options appraisal and sustainability assessment.

8.1 The Case study

The AIREGIN site was simulated based on literature and the experience of the researcher (Chapter 5).

8.2 Regulations

There are basically two agencies/institutions that regulate the management of petroleum-contaminated sites in Nigeria (Section 2.1). Both agencies and their respective regulatory frameworks support a voluntary application of Risk Based Contaminated Land Management, in line with the ASTM Risk Based Corrective Action (RBCA) Model (Sections 2.1.1 & 2.1.3). The industry best practice guidelines for the petroleum industry also support the risk-based approach to the management of petroleum-contaminated sites (Sections 2.1.4 & 2.1.5). This is a substantial starting point for the adoption of sustainable remediation, which is the application of sustainable development to risk-based contaminated land management and according to Bardos et al (2011) has an objective of achieving risk-based contaminated land management (Section 3.3.2). The application of the risk-based approach is voluntary and has not been effective (Section 7.1) as most remediation strategies are built on the remediation goals prescribed in EGASPIN (2002) without considering the risk and site specificities. Though the application of the risk-based contaminated land management approach will need to be reinforced and made mandatory but it's availability in the Nigerian regulations provides a strong point for the incorporation and implementation of sustainable remediation in Nigeria.

There is no legal policy, guideline or framework advocating the application of sustainability concepts in the management of contaminated lands in

Nigeria (Section 7.1). The existing laws, regulations, guidelines and standards have no requirements for the inclusion of sustainability assessment in the choice of a remediation strategy. Though, there are some provisions on the sustainability assessment for the remediation of petroleum contaminated lands in the best practice guideline published by IPIECA (Section 3.3.5) but this is not applied in Nigeria. This lack of regulatory framework on the concept of sustainable remediation is obviously not limited to Nigeria as it is a general challenge in the promotion and adoption of sustainable remediation (Section 3.3.10). There is therefore the need for Nigerian regulatory agencies to review extant laws and regulations related to the management of contaminated land to include mandatory requirements for detailed risk and sustainability assessments.

There is no agreement amongst practitioners (regulators, operators and consultants) as to the objective of remediation of a petroleum-contaminated soil as defined in EGASPIN (2002) (Section 2.1.1). EGASPIN (2002) for example defined two values, namely target and intervention values as 50mg/kg and 5000mg/kg respectively for Total Petroleum Hydrocarbon (TPH). This has brought confusion amongst regulators, industry experts and proponents of remediation as to the actual values for TPH that could be adjudged as having met the remediation objectives. SPDC has set remedial objectives at 3000mg/kg, claiming that this value is more stringent than the intervention value advocated by EGASPIN (2002) (Section 2.1.1) but the DPR claims that all remediation sites must target to bring the TPH to <50mg/kg. There is no empirical support for these values neither are there a clear means by which either the intervention or the target values were derived. This confusion also exists between the two principal government agencies regulating the remediation of petroleum-contaminated land in Nigeria, NOSDRA and DPR. UNEP (2011) stated that the two principal regulators DPR and NOSDRA have differing interpretations of these values and of EGASPIN (Section 2.1.1). This lack of consensus on the remedial objective is accentuated by the unavailability of National and/or regional background values for the various contaminants (Edet, 2014), hence UNEP (2011) stated that this situation has enabled operators to close remediation projects before achieving environmental quality with good functionality for human, animal and plant life (Section 2.1.1). In this situation, the availability of a well-researched and scientifically determined background values for the contaminants of concern would have helped resolved the differences. According to DEA-RSA (2010) consideration of natural background values is important in the derivation of site-specific remediation criteria.

With respect to EGASPIN standards, the target limits for the contaminants of concern are higher than international standards (Section 2.1.1) as identified by IUCN-NDP (2013) and there is generally lack of benchmarking in delivery of remediation in Nigeria against international best practices even amongst the IOCs. Furthermore, the guidelines and best practice guidelines provided by IOGP and IPIECA are not used to benchmark the practice in Nigeria.

Furthermore, there is generally insufficient transparency and enforcement in the regulatory regime in several areas that impact on the management of contaminated land. The IUCN-NDP (2013) noted that in certain sites, which were claimed to have been remediated and signed off by the Nigerian authorities for a clean bill of health, the CoSC levels were far higher than the standards prescribed in EGASPIN (2002). This underpins the insufficiency in enforcement of the regulatory regime and calls for higher commitment from the operators and increased monitoring of the local contractors engaged to implement the remediation projects. Ja'Afaru (2014) also found that the federal government is complacent because of the joint venture contract with the operators and are seen to be protective of its shares by taking sides with the operators at the detriment of host communities.

8.3 Risk Assessment and Conceptual Site Model

Risk based corrective action is advocated by the regulators (Sections 2.1.1 & 2.1.3) but no risk assessment protocol and matrix is provided. The adoption of a risk-based approach is voluntary and therefore not applied in most of the remediation projects (Section 7.1).

The use of conceptual site models for petroleum-contaminated sites in Nigeria is very minimal with low knowledge of its applications. Conceptual site models, which the researcher had the opportunity to review in the remediation action plan submitted by some of the operators, were merely generic and fall short of international practices.

The principal receptor identified by the desktop conceptual site model is the community farmers (Section 5.12), who use the contaminated land for subsistence agriculture (Section 5.2). This finding agrees with UNEP (2011) that farmers can suffer direct exposure to contaminated soil in their day-to-day work at crude oil spill sites in the Niger Delta of Nigeria.

8.4 Remediation Options Appraisal

The questionnaire survey identified that the most applied remediation strategies in Nigeria were biological and thermal treatments (Section 6.1.2 & Table 6.1). Experience of the researcher indicates that there are no empirical reasons for the choice except that they are generally available and easily implementable. Equally, EGASPIN (2002) supports the use of biological methods as primary remediation strategy for biodegradable waste (Figure 2.1) and the options appraisal carried out in this research supported biological and thermal methods (Section 6.2 & Table 6.4).

The importation of new remediation technologies into Nigeria is a rigorous, time consuming and expensive process (Section 3.1.8). This has led to restricted use of available technologies/variants (mainly biological and thermal) without exploring more innovative techniques/variants that has proven effective in other areas. The questionnaire identified mainly biological and physical methods as importable with only one chemical option (Section 6.1.3), presumably because of the rigors involved in validating the use of chemical reagents in Nigeria. Though, the research found that the implementation of sustainable remediation would encourage the easy importation of expertise and more innovative remediation technologies into the country, as part of the overall benefits (Section 7.1).

8.5 Sustainable Remediation

The research found that there is lack of understanding (Section 7.1) of the emerging concept of sustainable remediation in amongst the interviewee both within the industry and government agencies and by extrapolation in Nigeria. The concept of sustainable remediation is an emerging concept and this has not been adopted in Nigeria. There is no awareness of this concept. Sustainable development, a more common terminology and the concept is viewed more the perspective of societal engineering (Section 7.1).

In executing the sustainability assessment for the site, it was found that clear project objectives and boundaries are critical to the success of the exercise as well as the clear definition of the scope and nature of each sustainability indicator. This finding aligns with the conclusions of Smith and Kerrison (2013). The lack of consensus on the overall objective of a remediation project in Nigeria (Section 8.2) is as critical as the lack of knowledge of the sustainability process.

The general lack of consensus by the advocates and proponents of the concept of sustainable remediation on the indicators and assessment criteria (Section 3.3.10) was brought to fore during the simulated workshop, as members were engaged more in a general guess work before streamlining the indicators as identified in Section 7.2.5 of this research work. This lack of consensus was accentuated in the case of Nigeria by the lack of knowledge of the principles of sustainability assessment for contaminated land.

The implication of sustainability assessment in the remediation of a contaminated site may bring with it additional costs in the early stages of the project (Section 3.3.10). These may include cost implications of the assessment, engagement workshops and expertise in the assessment process. This initial cost may be a disincentive to adopting sustainability assessments in the management of contaminated lands in Nigeria and in most developing countries (Section 7.1). This is because most operators and the partners see remediation projects as cash drain especially as most of the contaminated lands are created by oil spill incidents resulting from acts of sabotage, illegal bunkering activities and artisanal/illegal refineries (Section 7.1).

Work experience of the researcher and engagements during the research also indicated that the Nigerian regulators lack the requisite expertise to oversee the implementation of sustainable remediation in Nigeria. The operators, whose personnel have better exposures to international trainings, workshops and conferences; and invariably more experienced than their government counterparts, drive the current practice. This finding agrees with UNEP (2011) that the Nigerian Government agencies lack qualified technical experts.

There is complete lack of literature and case studies on the subject matter of sustainable remediation in Nigeria (Section 7.1). This research is most likely the first academic work focusing mainly on the sustainability assessment of a remediation project in Nigeria and may therefore trigger further studies on the subject matter.

The adoption and implementation of sustainable remediation in Nigeria will be of significant benefit to the country (Section 3.3.4 & Section 7.1). The benefits accruable will include all those identified by CL:AIRE (2010b) (Section 3.3.4), which can be gained as defined in Table 8.1; and more specifically help in reinforcing risk-based contaminated land management, encourage early and continual stakeholders' engagement especially local communities, improve transparency in remediation projects, eliminate cosmetic remediation activities and invariably providing better return on investment in remediation projects and encourage the importation of more innovative technologies already established elsewhere. Early engagement of stakeholders will also make the process transparent and acceptable.

Table 8.1 Means of Gaining the Benefits of SR Identified by CL:AIRE (2010b) in Nigeria

S/No	Benefits of SR (CL:AIRE, 2010b)	How the implementation SR may help Nigeria gain the Benefits
1.	Maximizing the value delivered by remediation works, by optimizing the overall benefit to cost ratio;	Elimination/reduction of cosmetic remediation activities (Section 7.1).
2.	Cost savings through avoidance of unnecessary or unsustainable remediation;	Reduction in cosmetic remediation (Section 7.1) and adopting effective remediation strategy (Section 8.4; IUCN-NDP, 2013).
3.	Effective management of risks to human health and the environment associated with soil and/or water contamination;	Reinforcing the use of RBCA for contaminated lands (Section 7.1) and adoption of more sustainable strategies.
4.	Minimizing the impact of remediation works on the environment and surrounding communities;	Eliminating/Reducing unnecessary intrusion on the ecosystem by eliminating cosmetic remediation (Section 7.1) and the application of sustainable strategies.
5.	Demonstrable commitment to sustainable development in remediation works;	Protecting the ecosystem and conserving natural resources (Section 7.1)
6.	Public impact on reputation and public relations, demonstrating corporate environmental and social responsibility;	Improving transparency in remediation process (Sections 3.3.7 & 7.1)
7.	Improving the robustness of remediation decision-making; and	Involving all stakeholders in the remediation process from beginning to end (Sections 3.2.1; 3.3.7, 3.3.8 & 7.1)

8.	Contributing to sustainable development, which now forms a cornerstone of many government and corporate policies.	Promoting sustainable solutions and legislations that will promote sustainable development.

A major challenge to the implementation of an effective sustainable remediation project in Nigeria is the incessant recontamination of sites by the activities of vandals, oil/facility thieves and illegal crude oil refineries (Section 7.1). This fact was echoed by UNEP (2011) in their recommendation that all sources of ongoing contamination including the artisanal (illegal) refining must be brought to a swift end before the clean-up of the Ogoni environment can begin. Other major challenges identified by this research are;

- The lack of regulatory backing and information base (Section 7.1);
- Lack of knowledge and expertise on the subject of sustainable remediation (Section 7.1);
- Funding support for the process of adopting and implementing sustainable remediation (Section 3.3.10 & Section 7.1);
- The usual human resistance to change (Section 7.1) and according to Rao and Rao (1999), one aspect of mankind that has remained more or less constant is his innate resistance to change; and
- The continuous demand from communities for remediation to be carried at sites where contaminant concentrations are not elevated and do not pose risk to any known receptor leading to a number of remediation projects that usually should not be carried out (Section 7.1). The consequences of these cosmetic remediation activities include costs without returns, disturbance of the ecosystem and other risks associated with the remedial works.

Other challenges that may impact the implementation of sustainable remediation in Nigeria are as generally discussed in Section 3.3.10.

There is an associated initial cost (Section 3.3.10) in the implementation of sustainable remediation but in the long run costs saving benefits accrue through the avoidance of unnecessary or unsustainable remediation (Section 3.3.4) and the competitive advantage that organizations gain by implementing sustainable remediation (Section 3.3.10 & The Horinko Group, 2014).

The availability of excellent SR frameworks, IPIECA Guideline and the ISO document (3.3.5) on SR are important footprints that will encourage the adoption of SR in Nigeria.

8.6 Local Community Engagement

The involvement and engagement of local communities is either not done or is very low (Section 3.3.7). Most time local community involvement is to gain access into the land and in the supply of local labour and materials. The local community is rarely involved in the process of risk assessment and options selection. Inevitably the operator sees remediation of petroleum-contaminated sites, which most often result from third party interferences, as compensation to communities and CSR. The IUCN-NDP (2013) found that during field investigations the community stakeholders were eager to be part of remediation activities and felt that it was unacceptable that they were excluded from decisions of such importance that had far reaching implications on their environment and communities. This was a general view amongst the three communities visited by the IUCN-NDP team. IUCN-NDP (2013) therefore recommended the need to support sustainability of remediation at the community level by the evolution of a socio-environmental strategy. This thought was further emphasized by Ja'Afaru (2014), when he concluded that it is imperative for the Nigerian government and operators to accept host communities as partners and begin to operate in an open and transparent manner.

Chapter 9 Conclusions: Scope of Sustainable Remediation in Nigeria

This chapter establishes the scope of sustainable remediation in Nigeria by drawing conclusions on the impact of the implementation of sustainable remediation in Nigeria and providing recommendations for the remediation sector.

9.1 Impact on Nigeria

The aim of this study is to evaluate the applicability of the sustainable remediation in Nigeria.

The findings of this work have revealed several opportunities and challenges for the adoption of sustainable remediation in Nigeria. The availability of a risk-based contaminated land management framework, though voluntary provides a positive point for the institutionalisation of SR in Nigeria (Section 8.2). Other encouraging findings include the availability of established SR frameworks, IPIECA Industry Guide and ISO/DIS 18504 (Sections 3.3.5 & 8.5), which could provide a background for establishing Nigerian framework and guides; the limited use of CSM (Section 8.3) indicative of basic knowledge in the global practice of contaminated land management; the possibility of importation of remediation technologies into Nigeria (Sections 3.1.8 & 8.4), which implies that innovative technologies/technology variants can be brought into the country despite the rigours; the substantial knowledge of sustainable development (Sections 7.1 and 8.5) and the identified benefits of the adoption of SR in Nigeria (Sections 7.1 & 8.5), especially the reduction in cosmetic remediation activities and the cost savings that may accrued and the possibility of gaining the benefits identified by CL:AIRE (2010b) (Table 8.1).

These opportunities, may be hampered in Nigeria by the continuous recontamination of sites due to illegal activities if not checked (Section 8.5); insufficient transparency in the enforcement of the existing legal framework (Section 8.2) and the conflicting interpretation of the extant intervention and target values (Sections 8.2 & 8.5); and the lack of legal framework for mandatory risk assessment and regulatory backing for implementation of SR (Sections 8.2 & 8.5) and general lack of expertise on the subject matter (Section 8.5).

The impact of these identified opportunities and challenges in the adoption SR in Nigeria are discussed in four dimensions below.

9.1.1 Legal Dimension

The lack of a legal policy, regulatory framework and guidance manuals for the implementation of sustainable remediation in Nigeria (Section 8.2) indicate the need for a change in the extant regulatory policies, frameworks, guidance and standards related to the management of contaminated lands in Nigeria. The Nigerian regulatory agencies would have to provide clear guidelines for integrating sustainable remediation into the existing regulatory framework.

This implies that DPR and NOSDRA would have to organize workshops involving all relevant stakeholders (government, industry, consultants/experts, community, NGOs, CBOs, general public) on SR in order to develop Nigerian specific guidance under the umbrella of the DIS ISO 18504 thereby providing framework for incorporating sustainability assessment in remediation projects. This is an onerous task remembering that the EGASPIN was issued as a stop gap interim guidelines and standards since 1991 (Section 2.1.1) but has now becomes a permanent guideline as it has not been updated to provide a more permanent guideline with empirical justification for the limits prescribed.

Equally, due to the inconsistency in the interpretation of the target and intervention values defined in EGASPIN (2002) and lack of background levels for contaminants of concern (Sections 2.1.1; 2.1.4 and 8.2), it would be necessary that an in-depth study is carried out on the background levels of the various contaminants of concern and target limits established after the rigors of a detailed exposure risk assessment and toxicological studies. This has a huge implication (Section 8.2) if sustainable remediation must be implemented in Nigeria.

9.1.2 Economic Dimension

Having established that there is a knowledge gap amongst regulators on the concept of sustainable remediation (Section 8.5) which requires government regulatory agencies to **train their personnel** on the principles of contaminated land risk assessment, options appraisal and sustainability assessment processes for contaminated land management, there is therefore the attendant cost implication for the actualization of the trainings. The cost is further accentuated by the lack of the **necessary expertise and information base** (Section 8.5) on SR in-country and personnel would therefore be trained outside the shores of Nigeria, making the cost quite unappealing especially with the ongoing economic recessions. If Nigeria would adopt and implement the concept of sustainable remediation, there must be sacrifices in terms of **financial commitment** to build the required expertise and knowledge base amongst the government regulatory agencies. Furthermore, there will be substantial cost in engagement proceedings, in the evaluations and studies of implementation of the concept and in the awareness campaigns that would be necessary to bring the society on track. These costs would compete with other needs of the society.

However, there is evidence that the cost of carrying out remediation projects will not be raised significantly by adopting sustainable remediation rather costs savings accrue in the long-run (Section 8.5). Furthermore, the reduction in cosmetic remediation activities will mean savings for the operators and partners.

9.1.3 Social Dimension

The implication of adopting a new policy generally means a change in the way things are done and this might generally **impact on the extant historical and cultural values**. The general initial **innate resistance to change by humans** (Section 8.5 & Rao and Rao, 1999) will be a big challenge to the institutionalization of the concept of sustainable remediation in Nigeria. The adoption of the new concept would require all stakeholders to change the ways things are done presently in line with the new concept and this could possibly lead to a period of misjudgment and poor values.

Another social implication results from general lack of awareness of the concept (Section 8.5), which will require mobilization efforts to **create awareness** amongst the stakeholders and the general public. In a country with a high population and serious security challenges (BOKO HARAM, Niger Delta Militants, etc.) like Nigeria, awareness campaigns will be time consuming and expensive. Illegal activities, which result into recontamination of sites (Section 8.5) must be halted if the application of SR will be beneficial to Nigeria (Section 8.5 & UNEP, 2011). This will imply partnering with the security agencies in Nigeria to define a roadmap for the control of these illegal activities with its cost implications.

There is general acceptability of the concept of sustainability and demand for more sustainable practices (Section 3.3.3 & Section 3.3.10); hence people will generally be pleased with the concept as it is an acceptable principle that **more sustainable options are far more rewarding and advantageous to human race** (Section 3.3.1). This will provide a good opportunity for acceptance amongst the people. The encouragement for early engagement of local community by the concept of sustainable remediation (Section 3.3.7 and Section 8.6) will enhance the social permit to operate in these communities, thereby improving relationship between communities and proponents of remediation projects. It also makes the remediation process transparent and more acceptable.

9.1.4 Environment Dimension

Some of the remediation projects usually embarked on in Nigeria for social and cosmetic reasons will be eliminated by the implementation of sustainable remediation (Section 8.5). This will imply that at such sites no active remediation activities may be carried out, thereby saving cost and avoiding unnecessary intrusion into and protecting the ecosystem (Section 8.5) but operators may hide under the concept of risk and sustainability to do nothing at contaminated sites (Section 7.1) thereby making all remediation projects some version of natural attenuation. This would lead to acceptance problems amongst regulators and other stakeholders, especially in instances where the outcome of the risk and sustainability assessment decisions support a near do nothing approach. Again, risk and sustainable remediation strategy conflicts with societal demand for the total removal of contamination despite the intrusiveness of the strategy. In the positive direction, the adoption of a risk based and sustainable remediation strategy will be environmentally more rewarding as it takes cognizance of the protection of the overall environment while bringing risk to acceptable levels.

Furthermore, the adoption of sustainable remediation will encourage the importation of more innovative technologies/technology variants and expertise already developed in other areas (Section 8.4 and Section 8.5) and also help conserving natural resources (section 8.5) by encouraging the use of less environmentally intrusive technologies. The possibility for the importation of more innovative technologies will help resolve the concerns raised by UNEP (2011) and IUCN-NDP (2013) on the effectiveness of the biological methods adopted in the Niger Delta.

9.2 Conclusions

This research was based on desktop sustainability assessment of AIREGIN site and review of relevant literature on the practice of remediation in Nigeria and how the emerging concept of sustainable remediation would impact on Nigeria. Taking considerations of the findings and impact of sustainable remediation as elucidated in Section 8.1, this research concludes that **sustainable remediation is implementable in Nigeria but needs;**

- Changes in the extant laws, regulations and guidelines to reflect international best practice with regards to target limits, risk assessment models, sustainability assessment requirements etc.
- Training of the principal stakeholders (government regulatory agencies, proponents/operators and consultants)

- Creation of awareness amongst other stakeholders (local communities, NGOs, CBOs etc) and the general public
- Funding support for the creation of the enabling environment for the implementation of the concept.

9.3 Limitations of this Research

Due to the methodology adopted using simulated site and simulation of stakeholders, using team members at work the research suffered the following limitations.

- The site was created by the researcher and may not represent the sophistication of a truly petroleum-contaminated site in the Niger Delta of Nigeria.
- The choice of criteria for the remediation options appraisal were done by the researcher and may only reflect the opinion and experience of the researcher and not represent the general practice in Nigeria.
- The use of team members to simulate stakeholders;
    - May have provided the researcher an advantage to muscle through his opinion in the choice of sustainability indicators bearing in mind that the team members do not have adequate knowledge of the concept of sustainable remediation;
    - Pose some difficulty in getting into the mind set of third parties like regulators and the local community; and
    - Subjected to the internal hierarchical dynamics of the organization.

9.4 Recommendations

From the activities and finding of this research, the following recommendations are essential for the implementation and institutionalization of the concept of risk based contaminated land management and sustainable remediation in Nigeria. The recommendations are made in four categories as follows.

9.4.1 All Stakeholders

All stakeholders must be involved for a successful institutionalization of the sustainable remediation strategy in Nigeria. Key recommendations for all stakeholders in Nigeria are;

- Nigeria will need to establish a working group on sustainable remediation to review the practices in the international environment and the activities of the Sustainable Remediation Forum(s). This will enable the establishment of standard frameworks for the application of sustainable remediation in Nigeria. The working group should have persons from the industry, government, remediation consultants, NGOs and possibly international community (UNEP, IUCN etc). The working group may have to set up a SURF-NG for the institutionalization of sustainable remediation in Nigerian and link with other SuRF Chapters and ICCL. It is the opinion of the researcher that this will provide a new impetus to drive the update of existing regulations and the implementation of risk-based contaminated land management.
- The principal stakeholders should clearly define the involvement and engagement of local communities in the process of remediation; and be transparent in the engagement with the local communities as it relates to choice and implementation of remediation strategies in their lands.
- To set up a funding structure for the development of a road map for the adoption and implementation of sustainable remediation in Nigeria.
- Partner to carry out studies to establish national/regional background levels for major contaminants of concern, especially in the Niger Delta.
- All stakeholders must come up with a security road map to end the senseless vandalism of oil installations that has contributed immensely to contamination of the Niger Delta of Nigeria.

9.4.2 Government and Regulatory Agencies

For the government and regulatory agencies, it is recommended that;

- The existing legal and regulatory regime for the management of contaminated land in Nigeria should be reviewed incorporating mandatory risk-based contaminated land management and sustainability assessment in the selection of remedial strategies.
- DPR should urgently clarify the concepts of target and intervention values as used in EGASPIN (2002). In the interim, DPR should issue a clarification circular to define the trigger and closure limits for remediation of petroleum-contaminated sites.
- Government and regulatory agencies should provide proper trainings for their personnel on the subject matters of contaminated land risk assessment, options appraisal and sustainable remediation.

9.4.3 IOCs

The IOCs should;

- Immediately commence the application of risk-based approach to the management of petroleum-contaminated sites in Nigeria in line with EGASPIN (2002) and the IPIECA (2014) guide.
- Provide more support to communities in understanding and appreciating the objectives of remediation and involve them in the entire process of the project.
- Provide funding support for the development of more innovative remediation technologies and for research and development of sustainable remediation in Nigeria.

9.4.4 Consultants

Remediation service providers and consultants should;

- Show more transparency in the execution and validation of remediation projects.
- Continually train and retrain their personnel on emerging concepts in the management of contaminated land.

9.5 Areas of Further Research

Presently, there are no researches relating to sustainable remediation in Nigeria, therefore research into the following areas will be of immense value to the remediation sector in Nigeria.

- **Review of available sustainability indicators and development of indicators for sustainability assessment in Nigeria.** The frameworks (Section 3.3.5) available have identified key indicator categories but are based on the needs and development of the countries that have developed and accepted them, hence for developing countries like Nigeria there is the need to domesticate the concept by developing indicators that take consideration of the more important peculiarities and priorities of the country.
- **Sustainability assessment of a petroleum-contaminated land in Nigeria.** This work has relied on simulations without involving actual parties and real site. It would be beneficial to carry out full-scale sustainability assessment of petroleum-contaminated site involving the relevant parties in the assessment process. This will provide factual responses from the relevant stakeholders as well as lead to better appreciation of SR.

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Appendices

Appendix 1: Target and Intervention Values for Micro pollutants for a standard soil (EGASPIN, 2002)

Substance	Soil/Sediment (mg/kg dry material)		Groundwater (µg/l)	
	Target value	**Intervention value**	**Target value**	**Intervent ion value**
A. Aromatic Compounds				
Benzene	0.05(dt)	1	0.2	30
Ethyl Benzene	0.05(dt)	50	0.2	150
Phenol	0.05 (dt)	40	0.2	2000
Toluene	0.05 (dt)	130	0.2	1000
Xylene	0.05(dt)	25	0.2	70
B. Metals				
Arsenic	29	55	10	60
Barium	200	625	50	625
Cadmium	0.8	12	0.4	6
Chromium	100	380	1	3
Cobalt	20	240	20	100
Copper	36	190	15	75
Mercury	0.3	10	0.05	0.3
Lead	85	530	15	75
Nickel	35	210	15	75
Zinc	140	720	65	800
C. Chlorinated Hydrocarbon				
1,2-dichloro ethane	-	4	0.01(dt)	400
D. Polycyclic Aromatic Hydrocarbon (PAHs)				
PAH (Total of 10)*	1	40	0.1	70
Napthalene	-	-	0.02	5
Anthracene	-	-	0.02	5
Phenathrene	-	-	0.005	1
Fluoranthracene	-	-	0.002	0.5
Benzo(a)anthrancene	-	-	-	-
E. Other Pollutants Mineral Oil	50	5000	50	600

dt.= Detection threshold

* = Total of 10, include the five listed above and the following: Chrysene, benzo (a) pyrene, benzo (ghi) pryrelene, benzo (k) fluoranthene and indeno (1,2,3- cd) pyrene

Appendix 2: Table E-1: Remediation Technologies for Hydrocarbons (IOGP, 2008)

Media	Type	Technology	Description	Time[a]	Relative Cost	Applicability
Soil	*In situ*	Passive (Natural) Remediation	Allowing the natural processes of dilution, adsorption and degradation to mitigate the risks generated by hydrocarbon contamination. Normally considered when contaminant migration and the associated risks to groundwater are low	Long	Low	Often considered where contaminant concentrations are below cleanup criteria values or where remedial action may cause more negative impacts than 'no action' (e.g., access to remote locations). Low cost, minimum surface disturbance. Cleanup criteria may not be met. May require long term monitoring.
Soil	*In situ*	Bioremediation	Involves the use of naturally occurring micro-organisms to biodegrade the hydrocarbons. This process can be enhanced by the addition of water, nutrients and by controlling the soil pH to promote bacterial action.	Short – medium	Low – Moderate	Soil and groundwater can be treated in one operation. Applies only to soil contaminated to depth of aeration. Treatability studies may be required. Not suitable for low permeability soils.

Media	Type	Technology	Description	Time[a]	Relative Cost	Applicability
Soil	*In-situ*	Solidification/ Stabilisation	The processes produce dry solids where contaminants are immobilized by mixing with cement or pozzolanic agents (e.g., fly ash). Metals are rendered immobile by the high pH of the cement mixture. Hydrocarbons are physically rather than chemical bound within the matrix. These approaches use either deep soil mixing machines or rakes and ploughs where shallow wastes (pit solids) are being treated.	Short	Moderate – High	Proven technology, limited to loose, friable soils. High concentrations of hydrocarbons and/or salts may interfere with the curing process. May require special equipment and is labour and chemical intensive.
Soil	*In situ*	Soil Vapour Extraction	This is used primarily for soils containing volatile compounds. Light hydrocarbons are stripped from the soil by creating a negative pressure in the subsoils via a series of extraction wells. Off-gases are then vented to atmosphere or treated as required.	Medium – Long	Moderate	Not suitable for low permeability soils. Effects on local residents are possible.
Soil	*In situ*	Isolation/ Containment	Subsurface barriers such as cement grouting or sheet piling can be used to isolate contamination from the receiving environment. These barriers are typically installed in conjunction with surface covers and drainage systems designed to control water flow into and/or around the structure.	Short	Moderate	Isolates contamination source from a sensitive receptor; liabilities remain on site; usually requires long-term monitoring.

Media	Type	Technology	Description	Time[a]	Relative Cost	Applicability
Soil	*Ex situ*	Land Spreading	The treatment processes involved in land spreading are similar to those in land treatment. However, land spreading refers to the one-time application of contaminated soil to a site at comparatively low contaminant application rates. Volatilization, dilution and biodegradation are processes limiting hydrocarbon concentration in the soil. Biodegradation may be enhanced by nutrient addition and periodic tillage. Care must be taken to limit application volumes and to minimize surface run-off.	Short	Low	Contaminants can be treated on-site. End product (soil) can be reused. Can treat a range of hydrocarbons. Treatability studies may be required. Need to limit run-off. May not be suitable where metal contents are high. Requires large land area.
Soil	*Ex situ*	Land Treatment	Contaminated soils are spread in layers 20 to 30cm thick and mixed into the upper soil zone. Nutrients and moisture are optimized and the soils tilled to provide mixing and oxygen transfer. Land treatment usually involves repeated applications of biodegradable waste to a site. Therefore soil containing significant levels of available heavy metals, persistent toxic compounds or low specific activity (LSA) scale may not be suitable. Land	Medium	Low - Moderate	Contamination can be treated on-site. End product (soil) can be reused. Can treat a range of hydrocarbons. Metals, chlorinated organics, salts cannot be treated. Need to monitor soil and groundwater. Can require substantial land area.

Media	Type	Technology	Description	Time[a]	Relative Cost	Applicability
			treatment areas may require a liner and/or groundwater monitoring wells.			
Soil	*Ex situ*	Composting/ Biopiles	Composting is similar to land treatment in that biodegradation rates are enhanced by improving porosity, aeration, moisture content and operating temperatures. Contaminated soil is mixed with bulking agents (e.g., wood chips, straw, rich hulls or husks). Manure or agricultural wastes may be added to improve the water holding capacity. Fertilizer is also added. Compost piles may be small enough (less than 1m deep) to be tilled, or placed in containers or on platforms to allowed forced aeration of the pile.	Medium	Moderate	Can affect treatment using less space and more rapidly than land treatment. Availability of suitable bulking agents may be limited. Metals and chlorinated organics cannot be treated. Requires special provisions should salt removal be necessary. Need to monitor soils and groundwater.
Soil	*Ex situ*	Solidification/ Stabilisation	Contaminated soil is solidified using chemical and physical processes at a central processing facility. Stabilized wastes can be used for construction or placed in a landfill	Short	Moderate – High	Labour intensive. High concentrations of hydrocarbons and/or salts may interfere with the curing process. Requires treatability testing.
Soil	*Ex situ*	Road Application	Some oily sludges such as tank bottoms may be spread on gravel road surfaces for road surfacing or dust suppression. In general the sludges should not	Short	Low	Dependent on the availability of acceptable raods. Run-off needs to be managed.

Media	Type	Technology	Description	Time[a]	Relative Cost	Applicability
			contain halogenated hydrocarbons, hazardous chemicals or deleterious substances such as filters and vegetation. Flare pit sludges are generally not suitable for disposal in this manner. Soil soils can be used for road base material.			
Soil	*Ex situ*	Asphalt Incorporation	Paving materials produced at hot-mix asphalt plants consist of 95% aggregate (sand, gravel) and roughly 5% asphalt. Oil contaminated soil may be added to hot-mix asphalt during the aggregate preparation process. Because the soil particle are size affects the strength and durability of the asphalt mix, the clay and silt content of the soil feed is usually limited to 20%. In cold mix asphalt a surfactant produces an emulsion of asphalt, cement and water. The liquid asphalt is then combined with aggregate. Oil contaminated soil may be blended into the liquid asphalt along with the aggregate feed. Soils with a high clay content or high capacity for water	Short	Moderate	Dependent on the availability of asphalt plants and acceptable roads. Requires monitoring of plant operations.

Media	Type	Technology	Description	Time[a]	Relative Cost	Applicability
			retention are not suitable for asphalt incorporation because they interfere with adherence of the asphalt to the aggregate.			
Soil	*Ex situ*	Landfill	Engineered landfills may be specially constructed and monitored containment cells designed to ensure long-term containment. They may contain an impermeable lining to prevent seepage depending on the risk to groundwater. Liners may be constructed of clay, synthetic materials and/or multi-layer lining. Groundwater monitoring wells or leachate collection systems may also be installed as monitoring/containment provisions.	Short	Moderate	Fast, effective method of removing contamination. Liabilities remain and typically require long-term monitoring. There may be a lack of suitable sites in remote or developing areas.
Soil	*Ex situ*	Thermal treatments	There are a variety of thermal treatments available. These include low temperature and high temperature desorption systems. Thermal desorption is dependent on volatilization; light hydrocarbons (BTEX, C1-C6 alkanes) are easily removed while PAHs are more difficult to treat. Desorption typically produces secondary wastes	Short	High	May permanently reduce the volume, toxicity and mobility of contaminants. air emission equipment and permitting requirements can be substantial. Does not address salts or most metals.

Media	Type	Technology	Description	Time[a]	Relative Cost	Applicability
			such as solids, water condensate and air emissions. Mobile rotary kilns or cement kiln (where available) can be used for incineration of oil contaminated soil. Ash resulting from incineration needs to be properly handled and disposed of. Air pollution controls may also be required.			
Groundwater	*In situ*	Passive (Natural) Bioremediation	Natural dilution, adsorption and biodegradation occurs in aquifers as microbial populations become acclimatized to the contaminant.	Long	Low	Sites where likely impact is acceptable may require long-term monitoring, but need for monitoring could be determined (by modeling) in advance.
Groundwater	*In situ*	Enhanced Bioremediation	Degradation rates can be modified by the use of various withdrawal, injection and recirculation pumping systems to mix the contaminant with nutrients and an oxygen source.	Short – Mid	Moderate	Applicable to a wide range of hydrocarbon contaminants. not suitable on soils with low permeabilities. Requires power and long-term maintenance of equipment.
Groundwater	*In situ*	Air Sparging	Involves the injection of air into the aquifer to create a bubbling effect. Soil vapour extraction can be used to	mid	Moderate	Needs soil vapour extraction systems; suitable for volatile compounds only.

Media	Type	Technology	Description	Time[a]	Relative Cost	Applicability
			reduce subsurface air pressure and to remove the volatilized compounds from the vadose zone.			Not suitable for low permeability soils.
Groundwater	*In situ*	LNAPL[b] Recovery	Involves a product pump downhole floating on the water table. This can either be a passive system or an active system which employs a skimmer pump. Trenches can be used if groundwater is shallow.	Short – Medium	Low – Moderate	Passive system uses simple technology. Product may be recovered to a reusable grade. Requires monitorin. Recovers free product only; does not remediate dissolved phase in groundwater.
Groundwater	*Ex situ*	Oil/Water Separation	Oil/water separation is often used in conjunction with other technologies as a primary remediation technique with supplementary technologies used for polishing. The treatments vary from simple gravity separation to the use of coalescing plates and filters within the separator units.	Short – Mid	Moderate	Oil/water separation is typically applied to heavier hydrocarbon compounds that cannot be readily volatilized. Often needs supplementary technologies to complete cleanup. Requires ongoing monitoring, power supply.
Groundwater	*Ex situ*	Air Stripping	This process involves pumping contaminated water from the ground then down a column while a countercurrent of air flows from the bottom of the column. This promotes volatilization and contaminants move	Short – Mid	Moderate	Suitable for volatile compounds only. Not suitable for low permeability soils. Requires ongoing monitoring, power supply.

Media	Type	Technology	Description	Time[a]	Relative Cost	Applicability
			from dissolved phase to the gaseous phase. Off-gases are then release to atmosphere or treated as required. Remediated waters are then re-injected or disposed of in another approved manner. Re-injection has been proven beneficial for speeding up remediation by serving to flush contaminants towards recovery wells and by injecting oxygen-rich water into the aquifer.			

[a] Short: <1 year, Medium: 1-5 years, Long: >5 years
[b] LNAPL: Light nonaqueous phase liquids are hydrocarbons that exist as a separate, immiscible phase when in contact with water.

Appendix 3: Questionnaire on Availability of Petroleum Contaminated Soil Remediation Technologies in Nigeria

RESPONDENTS DETAILS

Provide email address if you would like a copy of the results:……………………………………………………………

ORGANIZATION CATEGORY:

☐ PETROLEUM INDUSTRY
☐ REMEDIATION CONTRACTOR
☐ REGULATORY AGENCY

1. Are you involved in remediation of petroleum contaminated soil in your organization?

☐ Yes
☐ No

2. Which of the following remediation technologies have you used or being involved with and how frequently have you used or been involved with them?

Remediation Technology	Number of Sites
☐Monitored Natural Attenuation	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
☐Bio venting	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
☐Enhanced *In-situ* Bioremediation	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
☐Phytoremediation	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
☐Electrokinetic Separation	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
☐Fracturing	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
☐Soil Flushing	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
☐Soil Vapor Extraction (SVE)	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
☐Solidification/Stabilization	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
☐Thermally Enhanced SVE	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
☐Bio-piles	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
☐Composting	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
☐Land Farming	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
☐Slurry Phase Biological Treatment	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
☐Chemical Extraction	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
☐Chemical Reduction/Oxidation	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
☐Soil Washing	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
☐Solidification/Stabilization	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
☐Incineration	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
☐Pyrolysis	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
☐Thermal Desorption	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
☐Landfill Cap	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
☐Excavation, Retrieval and Offsite Disposal	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

KEY
0 - 0 Not appl
1 – 1 Project
2 – 2-3 Projec
3 – 4 Projects
4 – 5 Projects
5 – >5 Projec

3. Which of the following remediation technologies not available in Nigeria but can be easily accessed/imported?

Remediation Technology

☐Bioventing	☐ *Enhanced In-situ* Bioremediation
☐Phytoremediatin	☐ Electrokinetic Separation
☐Fracturing	☐ Soil Flushing
☐Soil Vapour Extraction (SVE)	☐ Solidification/Stabilization
☐Thermally Enhanced SVE	☐ Biopiles
☐Composting	☐ Land farming
☐Slurry Phase Biological Treatment	☐ Chemical Extraction
☐Chemical Reduction/Oxidation	☐ Soil washing
☐Solidification/Stabilization	☐ Incineration
☐Pyrolysis	☐ Thermal Desorption
☐ Landfill Cap	☐ Excavation, Retrieval and Offsite Disposal

4. Have you used, tested or been involved with other remediation technologies, not listed above?
   ☐ Yes
   ☐ No
   If Yes, List in the box below.

5. Are you aware of any case studies of petroleum contaminated soil remediation in Nigeria?
   ☐ Yes
   ☐ No
   If Yes, kindly email EITHER a web address or a PDF of any publicly available information to lgxnma@nottingham.ac.uk

6. Are you willing to share any of your project activities with the researcher?
   ☐ Yes
   ☐ No
   If Yes kindly email reports, photographs etc to lgxnma@nottingham.ac.uk

7. On a scale of 5, how confident are you with the answers provided in this questionnaire
   ☐ 1 Not Confident
   ☐ 2 Moderately confident
   ☐ 3 Confident
   ☐ 4 Very Confident
   ☐5 Extremely Confident

Appendix 4: List of Interviewees

S/NO.	NAMES	Category	ORGANIZATION/DESIGNATION
1.	Ejiro UFONDU	Regulator	DPR/ Head, Health, Safety and Environment
2.	Abiodun ABDULRAHAMAN	Regulator	DPR/Environnent Manager, PHC Zone
3.	Philip SHEKWOLO	Industry	SPDC/Head, Remediation Governance
4.	Sigismund IHEAGWAM	Industry	TOTAL/Oil Spill Preparedness and Response Coordinator
5.	Julius BROWN	Industry	ADDAX PETROLEUM/Head, Environment
6.	Gumsuri MOHAMMED	Regulator	NOSDRA/Environment Scientist
7.	Olisa CHUKWURA	Contractor	PRIME SOURCES/Consultant
8	Sunny IBEH	Contractor	EMCO/Consultant
9.	Prince EBURUE	Industry	PANOCEAN/Environment Engineer
10.	Chuks EZEIGWE	Contractor	AMCHEZ/Consultant