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Analytic network process in petroleum hydrocarbon decontamination management in Nigeria

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This study examined the application of the Analytic Network Process (ANP), a multi-criteria decision analysis tool, in the selection of the best bioremediation technique for the remediation of a hydrocarbon-polluted site at Kwawa (4°36'29.26''N, 7°28'55.70''E) in Ogoniland, Niger Delta province, Nigeria. The decision-making problem involved four bioremediation techniques (that is, landfarming, field biopiles, thermal desorption, and phytoremediation) as well as four selection criteria (that is, health and safety, technical feasibility, regulatory requirements, and site-specific characteristics) and their twelve selection sub-criteria. The ANP evaluation involved pairwise comparisons of the remediation alternatives, selection criteria, and selection sub-criteria. Judgement matrices including unweighted supermatrix, weighted supermatrix, and a limit matrix were developed. The alternative with the highest priority vector at convergence was selected as the best. Result showed that phytoremediation with the highest priority vector of 0.1054 was the most appropriate remediation alternative for the study site. Additionally, site-specific characteristics with highest priority vector of 0.1636 was the most important selection criteria while type of soil with highest priority vector of 0.0625 was the most influential selection sub-criterion for the study site. This suggests that the ANP promises to be a veritable decision-support tool for the selection of the most appropriate bioremediation method for petroleum-contaminated sites in the Niger Delta province, Nigeria.

Key words: Multi-criteria decision analysis, land contamination, bioremediation.

INTRODUCTION

The spill of petroleum products, including crude oil or its derivatives (that is, liquid hydrocarbon) into the environment, whether deliberate or accidental have negative effects on the environment if not cleaned up on time. The negative effects of oil spill on the environment have been widely reported in the open literatures (Adedokun and Ataga, 2006; Daka and Ekweozor, 2004; Jack et al., 2005; Adeyinka, 2011).The practice of ameliorating these negative impacts on the environment is termed remediation; and one of the processes involved is bioremediation, which is a process of transforming or degrading contaminants in environmental media into less

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harmful substances by microbial metabolism (Azubuike et al., 2016; Zabbey et al., 2017). The need for remediation of oil-polluted soils, according to Nathanail et al. (2011), is hinged on one or more of the following four reasons: (i) to remove risks to sensitive ecological receptors; (ii) to enable redevelopment of the land; (iii) to repair failed corrective actions; and (iv) to maximise sale value of the land without regulatory involvement.

In most parts of the developing world, managing crude oil-polluted soil is an uphill task because of lack of knowledge of what methods to deploy from a spectrum of methods (Isheke, 2015). The problem also has been compounded by the lack of a system to quickly ascertain the nature, scope, degree of pollution, and associated risks to ecological health, as well as paucity of information to enable the formulation of a remediation management plan (Das and Chandran, 2010). A remediation management plan is a framework for the assessment of associated risks to ecological health with the end use of the land in view. It helps to ensure that a sustainable remediation method is deployed in the restoration process, considering relevant regulatory requirements in terms of achieving remediation target (National Oil Spill Detection and Response Agency (NOSDRA), 2011). The selected remediation method should match the soil type, duration of spill, size of impacted area, and the depth of impacted soil. To arrive at the appropriate remediation method that will meet these criteria is very complicated and requires a systematic and rational thinking process since all the variables involved cannot be reduced into monetary values (Bello- Dambatta, 2009) as cited by Isheke (2015).

Hence, using a multi-criteria decision analysis (MCDA) tool will give a science-based approach and a lucid thinking process. This is because MCDA tools have been used to simplify complex problems such as contractor selection process for projects (Cheng and Li, 2004) and finding the best location for a restaurant (Tzeng et al., 2002); just to mention a few. There are numerous MCDA tools currently available including (among others) the Analytical Hierarchy Process (AHP), the Fuzzy logic model, Monte Carlo model, Bayesian Theorem, and Analytic Network Process (ANP). The use of ANP method for decision making involving multiple criteria problems has been quite successful in other fields. For instance, Meade and Priestly (2002) used the ANP model in a study to select the most appropriate research and development (R&D) project to undertake. The R&D project selection involved the apportioning of funds to a class of competing project proposals. They used the ANP model to select the project most worthy of the research grant. Wolfslehner et al. (2005) applied the ANP model in multi-criteria analysis of sustainable forest management. In the study, four different management options with six criteria and forty-three indicators were compared and the best management option was chosen from among the four using the ANP. Ozden (2006) in a study also proposed the use of the model in taking right decisions when choosing a vendor from amongst so many. His work was successful in evaluating supplier selection process as a support base for managers. He showed that the ANP model can be used as a good tool to solve multi-criteria supplier selection problems in which such criteria are interdependent. In the same vein, Gencer and Gurpinar (2007) used the ANP to evaluate and choose the best supplier of raw materials. They used the ANP to develop a system that was used successfully to select the best supplier in an electronic firm. Furthermore, the ANP model was applied in a research to establish weights in order to re-accredit a programme of a University in Colombia (Lesmes et al., 2009). For the first time, the ANP model was used in the selection of the best facility layout plan considering the dependencies of criteria using professional judgements and fundamental equations. A network format was built of all clusters and criteria as well as the dependencies amongst them, leading to the selection of the most effective layout plan (Al-Hawari et al., 2014).

Despite the widespread application of ANP in other fields, only a limited number of studies can be found in the open access literature on the application of ANP in the evaluation of petroleum contaminated site remedial countermeasures (Promentilla et al., 2006; Yang et al., 2010; Banar et al., 2015; Li et al., 2016). In Nigeria, there is no method currently adopted to tackle the challenge of petroleum contaminated site management. In most cases, personnel engaged to carry out remediation projects either deploy the cheapest and the most familiar method without considering its appropriateness or merely adopt the method specified by the international oil companies (IOCs), which is usually insitu remediation by enhanced natural attenuation (RENA) (e.g., Ebuehi et al., 2005). Even though the adoption of RENA as a remedial countermeasure in Nigeria has been strongly disapproved because of its ineffectiveness (UNEP, 2011; Orji et al., 2012; Zabbey, et al., 2017), contaminated sites across the country are remediated and certified by government agencies with such sites still remaining non-vegetated and unusable years after such certification (UNEP, 2011). Therefore, there is a need now more than ever before to evolve a method of evaluating the most appropriate remedial countermeasure for the management of soil contamination problems in Nigeria. This is because of the recent search by the Federal Government of Nigeria for appropriate remedial countermeasures for the hydrocarbon pollution restoration project (HYPREP) in Ogoniland in the Niger Delta province of Nigeria.

This study was aimed at evolving a technical approach for the selection of the most appropriate bioremediation technique for petroleum-contaminated land in the Niger Delta province of Nigeria. To do this, the ANP model was used to select the most appropriate technique from four remedial countermeasures, including landfarming, phytoremediation, field biopiles, and thermal desorption using a petroleum-contaminated site in Ogoniland in the Niger Delta province, Nigeria as a case study. The choice of ANP over other MCDAs was because, according to literature (Ishizaka and Nemery, 2013), it takes into account the dependencies that exist among the selection criteria and sub-criteria.

MATERIALS AND METHODS

Study area

Figure 1 shows the study site, which is a historical petroleum-contaminated land at Kwawa (4°36'29.26"N, 7°28'55.70"E) in Ogoniland in the Niger Delta province, Nigeria. It is an area marked as a legacy site by the Shell Petroleum Development Company (SPDC) and one of the sites studied by UNEP during the environmental assessment of Ogoniland. The site lies in the heart of the Niger Delta region, which has the third largest wetlands covering a stretch of 70,000 km^2 (Niger Delta Environmental Survey, 1995), and situated in the Southern part of Nigeria. This contaminated site is a typical example of several other impacted sites in the Niger Delta region. Further details of the oil spill incident as well as the characteristics of the site as sourced from the UNEP (2011) Environmental Assessment Report Site-Specific Fact Sheet number QC-016-001 are shown in Table 1.

Analytic Network Process (ANP)

Problem structuring

The first step in the ANP was to set up the structure of the problem by defining the principal objective, which involved identifying the goal, selection criteria and associated sub-criteria, the remediation alternatives or options of choice, and putting them into clusters. After the clustering, the dependencies that exist among the different elements in the structure were identified. In this study, the goal of the decision making is to select the most appropriate remediation technique from among four remediation alternatives. Thus, the goal constituted one cluster with node G while the remediation alternatives (RA) (that is, the chosen remediation methods) made up another cluster with four nodes, namely; landfarming (LDF), field biopiles (FBS), thermal desorption (TDU), and phytoremediation (PHY) as shown in Figure 2. From a number of open access literatures on bioremediation we were able to access (e.g., Linkov et al., 2005; Oduolisaeme, 2012; Frutos et al., 2012; Smith et al., 2015; Li et al., 2016; Azubuike et al., 2016), the remaining four clusters (selection criteria) – health and safety (HS), site-specific characteristics (SC), regulatory requirements (RR), and technical feasibility (TF) – and their sub-criteria (or elements) shown in Figure 2 were considered. As can be seen in Figure 2, RA was taken as the dependent variable while the independent variables were HS, SC, RR, and TF as well as their sub-criteria. For instance, the sub-criteria for HS are impact on human health (IHH), impact on soil organisms (ISO), and impact on both surface and groundwater (ISG) (Figure 2).

Pairwise comparisons- formation of judgement matrices and convergence

To construct the unweighted supermatrix, which is a square matrix of all elements in the decision-making problem containing local priorities, pairwise comparison was carried out. At the node level, pairwise comparison was carried out using the elements of the selection criteria with respect to the remediation alternatives and with respect to each other. At the cluster level, pairwise comparison was also carried out using the clusters with respect to each cluster. The purpose of the pairwise comparison was to enable a trade-off of the many selection criteria by expressing the qualitative judgement made in numerical values. Saaty (2006) has developed a 9-point priority scale of measurement (Table 2), with a score of 1 representing equal importance of the two compared elements and 9 being extreme dominance of one element (row element) over another element (column element). According to Saaty (2006), when there is extreme dominance of a column element over a row element, a score of 1/9 is given. To do this, verbal judgement were first given by experts in line with the Saaty (2006) scale and then a numerical value was allotted to that judgement. The pairwise comparison led to the development of a series of judgement matrices.

In developing the comparison matrix, two sets of axioms-transitivity and reciprocity-were followed in order to have a consistent matrix (Harker and Vargas, 1987). The size of the matrix depends on the number of selection criteria, sub-criteria, and alternatives to be considered in any particular case. A judgement is consistent when the transitivity and reciprocity axioms are fulfilled as shown in Equations 1 and 2, where Equation 1 is for the transitivity and Equation 2 is for the reciprocity (Ishizaka and Nemery, 2013).

$$d_{ij} = d_{ik} \times d_{kj} \tag{1}$$

Where, $j > k > i$

$$d_{ij} = 1/d_{ji} \tag{2}$$

The element d_{ij} compares the ith and jth terms on the column and row of a given matrix.

Node level pairwise comparison is used for the formation of the comparison matrix as illustrated in Figure 3. In this illustration, computation of the comparison matrix (Figure 3a) is done using the three elements of the selection criterion – Health and Safety – shown in Figure 2. To compare the elements IHH, ISO, and ISG with respect to the goal (G), positive values of 1 in line with the Saaty's scale (Table 2) are placed diagonally in the comparison matrix (Figure 3a) since the elements are assumed equally important. However, if IHH for example is assumed more important than ISO when comparing their relative importance to the goal, IHH is assigned a higher value (2 say) than ISO; and the reciprocal of 2 is assigned to ISO. The value 2 is placed in cell (ISO, IHH) while the reciprocal of 2 (that is, 0.5) is placed in cell (IHH, ISO) as shown in Figure 3a. Then, the remaining cells are filled the same way. The values of the comparison matrix are normalized to sum up to 1.0 or 100%. To do this, first, the columns of the comparison matrix are summed as shown in Figure 3a. Then, the column is normalized by dividing the values of each column of the comparison matrix by the related column total (Figure 3b). The eigenvector is then calculated by averaging the values of each row of the normalized matrix to get the local priorities or relative weights, which is used to form the unweighted supermatrix (Figure 3c).

Cluster level pairwise comparison is used to convert the unweighted supermatrix to weighted supermatrix. In this step, just as we did at the node level pairwise comparison, two clusters are compared with respect to the goal. The weighted supermatrix is obtained by multiplying the result obtained from the cluster comparison by the unweighted supermatrix; and column stochastic is achieved by ensuring that each column of the weighted supermatrix summed up to 1. The weighted supermatrix obtained is then multiplied by itself until convergence is reached (Cheng and Li, 2004). The supermatrix obtained at convergence is the limit

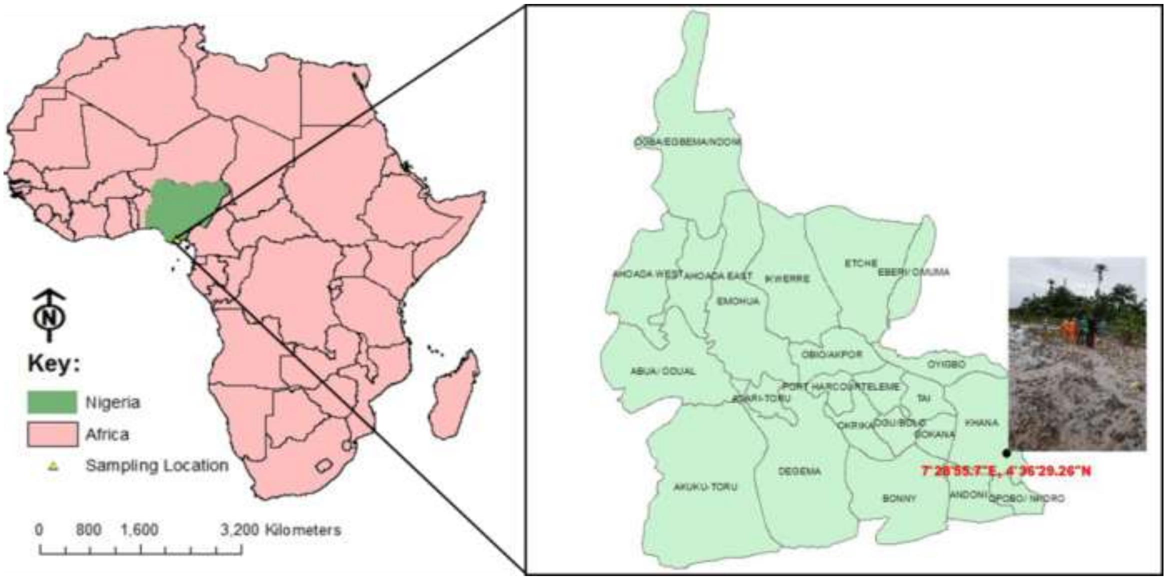

Figure 1. The study site at Kwawa in Ogoniland in the Niger Delta region, Nigeria (Datum and Projection: GCS WGS 1984. Africa shape files source: ESRI®, CA, USA).

Table 1. Summary of oil spill incident and environmental assessment report of the study site at Kwawa in Ogoniland in the Niger Delta region, Nigeria.

Site/spill characteristics[a]	Outcome of investigation[a]	Intervention value[b]	Target value[b]
Type of pollutant	Hydrocarbon	NA	NA
Site use	Pipeline right of way, adjoining vegetation used for farming activities	NA	NA
Type of oil infrastructure	Yorla Well 004 (abandoned), Yorla Well 005 (suspended), 8" Yorla Flow Station to Bomu Tie-in-Manifold Delivery Line, and 16" Yorla to Bomu Trunkline (disused)	NA	NA
Spill history	The spills occurred on these dates: 23rd October, 1992, 9th December, 1992, 14th January, 1993 and 6th May, 1993	NA	NA
Coordinates	4°36'29.26"N, 7°28'55.70"E	NA	NA
Impacted media	Soil (localized) and ground water (widespread)	NA	NA
Area	654,600 m^2	NA	NA
TPH in soil	8,820 mg/kg	5,000 mg/kg	50 mg/kg
TPH in groundwater	77,000 μgl^{-1}	600 μgl^{-1}	50 μgl^{-1}
Depth	0.2 m	NA	NA
Soil type	Clay-loam	NA	NA

TPH, Total Petroleum Hydrocarbon; NA, Not applicable.
[a]Data from UNEP (2011)
[b]Data from DPR (2002).

supermatrix. The alternative or the bioremediation technique with the largest relative weight at convergence is the most appropriate method.

Consistency of the judgement matrices

To get the consistency of the judgement matrices, Equation 3 was used.

$$C.R. = \frac{C.I.}{R.I.} \quad (3)$$

Where, C.R. = Consistency ratio, C.I. = Consistency index, and R.I. = Random index. C.I. is defined by Equation 4.

$$C.I. = \frac{(\lambda_{max} - n)}{n - 1} \quad (4)$$

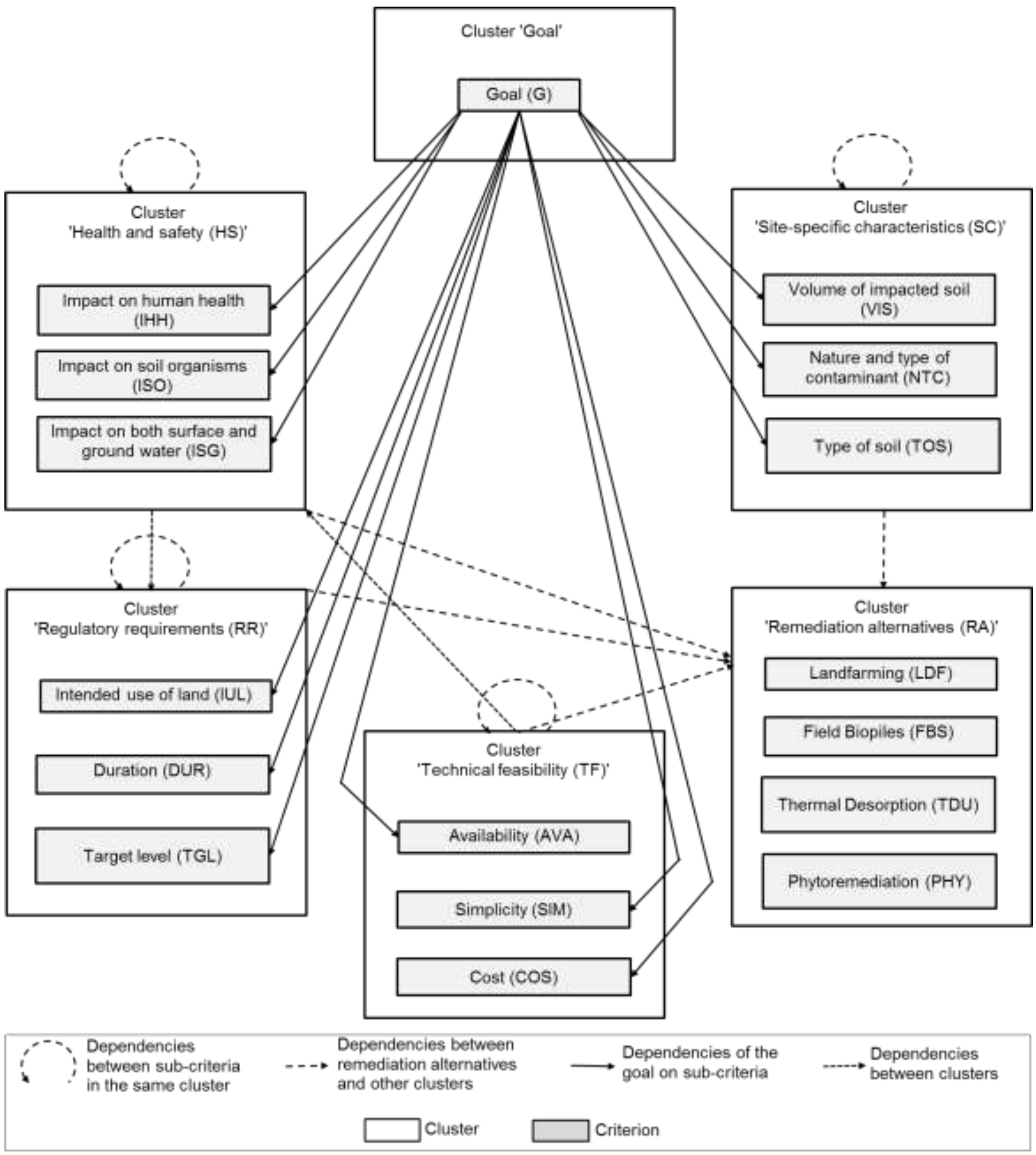

Figure 2. Simplified ANP network structure of the decision-making problem for selection of most appropriate bioremediation technique for studied petroleum-contaminated site in the Niger Delta region, Nigeria. (Due to the complexity of the figure, dotted arcs relating dependencies of remediation alternatives on sub-criteria and vice versa as well as dashed arcs between sub-criteria in different clusters are not shown, but those dependencies do exist).

Where, λ_{max} is the maximum eigenvector. The R.I. is based on the order or size of the matrix, n. The random C.I. is shown in Table 3 (Saaty, 2006). R.I. was computed for n ≤ 10 for very expansive samples and was used to generate at random reciprocal matrices based on Saaty's scale of 1/9, 1/8…1/2, 1, 2…8, 9 and the average of their eigenvalues was deduced. It has been strongly advised in the literatures that C.R. is less than 0.1 since a C.R. higher than 0.1 shows there is inconsistency and the decision cannot be relied upon. It is acceptable for the inconsistency to be one order of magnitude less. On a scale of 0 to 10, it should be around 10 % (Isheke, 2015).

RESULTS

In this study, because of the number of selection criteria and sub-criteria involved in the decision making process

G	IHH	ISO	ISG
IHH	1	0.5	0.5
ISO	2	1	0.5
ISG	2	2	1
Column totals	5	3.5	2

(a)

0.2	0.14	0.25
0.4	0.29	0.25
0.4	0.57	0.5

(b)

0.59
0.94
1.47

(c)

Figure 3. Node level pairwise comparisons shown here as illustration with: (a) Comparison matrix shaded in grey colour; (b) Normalized matrix; and (c) Unweighted supermatrix. (G, Goal; IHH, Impact on human health; ISO, Impact on soil organisms; ISG, Impact on both surface and groundwater).

Table 2. Saaty's fundamental scale of preference.

Numerical value	Judgement	Explanation
1	Equal placement	The two elements have equal importance on the parent element
3	Slight placement of one over another	One decision element is slightly of more importance than the other on the parent element
5	Strong placement for one over another	One decision element has strong influence on the parent element than the other
7	Very strong placement for one over another	One decision element has a very strong influence on the parent element than the other
9	Utmost placement for one over another	One element is of utmost importance to the parent element than the other
2, 4, 6, 8	Intermediate placement depicts close likeness	Intermediate values between the equal, slight, strong, very strong and utmost

(Source: Saaty, 2006). According to Saaty, reciprocal numbers are used for inverse comparison.

Table 3. Random Index corresponding to the size of a matrix.

Order, n	Random Index [a]
1	0
2	0
3	0.52
4	0.89
5	1.11
6	1.25
7	1.35
8	1.40
9	1.45
10	1.49

[a] Data from Saaty (2006).

(Figure 2), a total of twenty-six judgement matrices were developed. For obvious reasons, we are unable to show all of them here. All the same, we show the comparison matrix of the clusters, unweighted supermatrix, weighted

Table 4. Unweighted supermatrix.

	LDF	FBS	TDU	PHY	IHH	ISO	ISG	AVA	SIM	COS	IUL	DUR	TGL	VIS	NTC	TOS
LDF	1	0	0	0	0.42	0.29	0.09	0,48	0.47	0.47	0.11	0.21	0.11	0.17	0.25	0.29
FBS	0	1	0	0	0.27	0.16	0.15	0.27	0.28	0.28	0.11	0.21	0.11	0.28	0.25	0.29
TDU	0	0	1	0	0.12	0.06	0.52	0.09	0.1	0.07	0.3	0.5	0.48	0.11	0.25	0.14
PHY	0	0	0	1	0.19	0.49	0.27	0.16	0.16	0.17	0.48	0.09	0.3	0.45	0.25	0.29
IHH	0	0	0	0	0.29	0.16	0.12	0.33	0.5	0.5	0	0.33	0	0	0	0
ISO	0	0	0	0	0.14	0,54	0.32	0.33	0.25	0.25	0	0.33	0	0	0	0
ISG	0	0	0	0	0.57	0.3	0.56	0.33	0.25	0.25	0	0.33	0	0	0	0
AVA	0	0	0	0	0.25	0	0	0.5	0.25	0.25	0.2	0	0	0	0	0
SIM	0	0	0	0	0.5	0	0	0.25	0.5	0.25	0.2	0	0	0	0	0
COS	0	0	0	0	0.25	0	0	0.25	0.25	0.5	0.6	0	0	0	0	0
IUL	0	0	0	0	0.16	0.16	0.25	0	0	0.14	0.24	0.33	0.33	0	0	0
DUR	0	0	0	0	0.3	0.3	0.25	0	0	0.43	0.14	0.33	0.33	0	0	0
TGL	0	0	0	0	0.54	0.54	0.5	0	0	0.43	0.62	0.33	0.33	0	0	0
VIS	0	0	0	0	0.2	0.2	0.3	0.16	0	0.4	0	0.54	0	0.32	0.2	0
NTC	0	0	0	0	0.6	0.6	0.4	0.3	0	0.2	0	0.3	0	0.12	0.4	0
TOS	0	0	0	0	0.2	0.2	0.4	0.54	0	0.4	0	0.16	0	0.55	0.4	0

AVA, Availability; COS, Cost; DUR, Duration; FBS, Field biopiles; IHH, Impact on human health; ISG, Impact on surface and ground water; ISO, Impact on soil organisms; IUL, Intended use of land; LDF, Land farming; NTC, Nature and type of contaminant; PHY, Phytoremediation; SIM, Simplicity; TDU, Thermal desorption; TGL, Target level; TOS, Type of soil; VIS, Volume of impacted soil.

Table 5. Cluster matrix.

	RA	HS	TF	RR	SC
RA	1.000	0.064	0.061	0.079	0.167
HS	0.000	0.379	0.180	0.237	0.000
TF	0.000	0.117	0.380	0.152	0.000
RR	0.000	0.184	0.135	0.380	0.000
SC	0.000	0.255	0.245	0.152	0.833

RA, Remediation alternative; HS, Health and safety; TF, Technical feasibility; RR, Regulatory requirements; SC, Site-specific characteristics.

supermatrix, and limit matrix.

Unweighted supermatrix and cluster matrix

The unweighted supermatrix, which is the outcome of the node level pairwise comparison, is shown in Table 4; while the eigenvectors obtained from the comparison of the clusters, indicating the cluster weights is shown in Table 5.

Weighted supermatrix and limit matrix

The weighted supermatrix, resulting from the cluster level pairwise comparison, is shown in Table 6 in which the sum of each column is equal to 1. As stated, this was obtained by multiplying the unweighted supermatrix in Table 4 by the cluster matrix in Table 5. The limit matrix is shown in Table 7. From Table 7, the final global priority vectors were derived.

DISCUSSION

Synthesized priorities for the remediation alternatives

As can be seen in Table 6, the synthesized priorities for the remediation alternatives (LDF, FBS, TDU, and PHY) appear very close to one another. However, the differences become easily apparent when the synthesized priorities for the remediation alternatives are isolated and plotted separately using a different scale on the priority axis as shown in Figure 4. The synthesized priority for the alternatives in Figure 4 showed that phytoremediation with the highest priority vector is the most appropriate remediation method for the impacted

Table 6. The weighted supermatrix.

	LDF	FBS	TDU	PHY	IHH	ISO	ISG	AVA	SIM	COS	IUL	DUR	TGL	VIS	NTC	TOS
LDF	1	0	0	0	0.03	0.02	0.02	0.04	0.06	0.03	0.05	0.03	0.08	0.03	0.04	0.05
FBS	0	1	0	0	0.02	0.01	0.02	0.03	0.06	0.02	0.05	0.03	0.08	0.05	0.04	0.05
TDU	0	0	1	0	0.01	0	0.03	0.02	0.05	0	0.06	0.05	0.13	0.02	0.04	0.02
PHY	0	0	0	1	0.01	0.03	0.02	0.02	0.05	0.01	0.09	0.02	0.11	0.08	0.04	0.05
IHH	0	0	0	0	0.11	0.06	0.05	0.07	0.13	0.08	0	0.09	0	0	0	0
ISO	0	0	0	0	0.05	0.2	0.12	0.07	0.09	0.04	0	0.09	0	0	0	0
ISG	0	0	0	0	0.22	0.11	0.21	0.07	0.09	0.04	0	0.09	0	0	0	0
AVA	0	0	0	0	0.03	0	0	0.19	0.13	0.1	0.07	0	0	0	0	0
SIM	0	0	0	0	0.06	0	0	0.11	0.21	0.1	0.07	0	0	0	0	0
COS	0	0	0	0	0.03	0	0	0.11	0.13	0.19	0.12	0	0	0	0	0
IUL	0	0	0	0	0.03	0.03	0.05	0	0	0.02	0.12	0.14	0.2	0	0	0
DUR	0	0	0	0	0.05	0.05	0.05	0	0	0.06	0.09	0.14	0.2	0	0	0
TGL	0	0	0	0	0.1	0.1	0.09	0	0	0.06	0.28	0.14	0.2	0	0	0
VIS	0	0	0	0	0.05	0.05	0.05	0.05	0	0.1	0	0.09	0	0.26	0.18	0
NTC	0	0	0	0	0.15	0.15	0.1	0.14	0	0.05	0	0.06	0	0.1	0.33	0
TOS	0	0	0	0	0.05	0.05	0.1	0.08	0	0.1	0	0.03	0	0.46	0.33	0

AVA, Availability; COS, Cost; DUR, Duration; FBS, Field biopiles; IHH, Impact on human health; ISG, Impact on surface and ground water; ISO, Impact on soil organisms; IUL, Intended use of land; LDF, Land farming; NTC, Nature and type of contaminant; PHY, Phytoremediation; SIM, Simplicity; TDU, Thermal desorption; TGL, Target level; TOS, Type of soil; VIS, Volume of impacted soil.

site. Thermal desorption was the second most preferable method followed by field biopiles and land farming. The result suggests that phytoremediation method has an aggregated advantage over the others on all the selection criteria considered in this study. Phytoremediation, though not recommended for use in Nigeria by regulation, it is advantageous because, according to several literatures, it is environmentally friendly, cost-effective, easy to deploy, less energy demanding, maintains vegetative cover and helps in checking erosion, and suitable for shallow soil impact of less than 5 m depth. This result is similar to that of Banar et al (2015), who used a combination of ANP and ELECTRE (Elimination and Choice Expressing the Reality) to select the most appropriate remediation technology from six different techniques for a metal contaminated site in Eskisehir, Turkey and found that phytoremediation was the most appropriate.

Synthesized priorities for the sub-criteria

Figure 5 shows the synthesized priorities for all the sub-criteria. A look at the ranking of the sub-criteria as shown in Figure 5 shows that TOS weighed more than all others and hence had the most influence on the choice of a suitable remediation method for the impacted site than others. The others are: ISG > NTC > TGL > VIS > ISO > COS. Amongst the sub-criteria considered under health and safety, Figure 5 shows that ISG weighs more in ranking and was the most significant. This was followed in decreasing order of importance by ISO and lastly, IHH. This shows further that any method that has minimal negative effect on water and soil organisms is most safe on human health and is to be considered above others. In terms of technical feasibility, Figure 5 shows that COS weighed most in ranking and had most influence on decision makers than other sub-criteria. This was followed in decreasing order of influence by SIM and AVA. This result suggests further that if a particular method is simple to operate or use, it is likely to be readily available. On the other hand, a method may be available but may not be simple to operate. Overall, if the method being considered is simple to operate and available but not affordable, it is most likely to be ditched. Amongst the sub-criteria considered under regulatory requirements, Figure 5 shows that TGL weighed most in ranking and hence was most significant than others. DUR and IUL, which were equal in ranking followed in decreasing order of influence. The synthesized priorities of the sub-criteria considered under site-specific characteristics as shown in Figure 5 shows that the TOS weighed most in ranking and so had most influence on decision makers than other elements. This was followed by NTC and VIS in decreasing order of influence. The result further suggests that the TOS determines the depth of penetration and spread of contaminants within the soil.

Most important selection criteria

The synthesized priorities for the selection criteria in Figure 6 shows that site-specific characteristics weighs most in ranking and so was adjudged the most important

Table 7. Limit matrix.

	LDF	FBS	TDU	PHY	IHH	ISO	ISG	AVA	SIM	COS	IUL	DUR	TGL	VIS	NTC	TOS
LDF	0.1038	0.1038	0.1038	0.1038	0.1038	0.1038	0.1038	0.1038	0.1038	0.1038	0.1038	0.1038	0.1038	0.1038	0.1038	0.1038
FBS	0.1042	0.1042	0.1042	0.1042	0.1042	0.1042	0.1042	0.1042	0.1042	0.1042	0.1042	0.1042	0.1042	0.1042	0.1042	0.1042
TDU	0.1046	0.1046	0.1046	0.1046	0.1046	0.1046	0.1046	0.1046	0.1046	0.1046	0.1046	0.1046	0.1046	0.1046	0.1046	0.1046
PHY	0.1054	0.1054	0.1054	0.1054	0.1054	0.1054	0.1054	0.1054	0.1054	0.1054	0.1054	0.1054	0.1054	0.1054	0.1054	0.1054
IHH	0.0438	0.0438	0.0438	0.0438	0.0438	0.0438	0.0438	0.0438	0.0438	0.0438	0.0438	0.0438	0.0438	0.0438	0.0438	0.0438
ISO	0.0453	0.0453	0.0453	0.0453	0.0453	0.0453	0.0453	0.0453	0.0453	0.0453	0.0453	0.0453	0.0453	0.0453	0.0453	0.0453
ISG	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053
AVA	0.0446	0.0446	0.0446	0.0446	0.0446	0.0446	0.0446	0.0446	0.0446	0.0446	0.0446	0.0446	0.0446	0.0446	0.0446	0.0446
SIM	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045
COS	0.0453	0.0453	0.0453	0.0453	0.0453	0.0453	0.0453	0.0453	0.0453	0.0453	0.0453	0.0453	0.0453	0.0453	0.0453	0.0453
IUL	0.0452	0.0452	0.0452	0.0452	0.0452	0.0452	0.0452	0.0452	0.0452	0.0452	0.0452	0.0452	0.0452	0.0452	0.0452	0.0452
DUR	0.0452	0.0452	0.0452	0.0452	0.0452	0.0452	0.0452	0.0452	0.0452	0.0452	0.0452	0.0452	0.0452	0.0452	0.0452	0.0452
TGL	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051
VIS	0.0488	0.0488	0.0488	0.0488	0.0488	0.0488	0.0488	0.0488	0.0488	0.0488	0.0488	0.0488	0.0488	0.0488	0.0488	0.0488
NTC	0.0523	0.0523	0.0523	0.0523	0.0523	0.0523	0.0523	0.0523	0.0523	0.0523	0.0523	0.0523	0.0523	0.0523	0.0523	0.0523
TOS	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625

AVA, Availability; COS, Cost; DUR, Duration; FBS, Field biopiles; IHH, Impact on human health; ISG, Impact on surface and ground water; ISO, Impact on soil organisms; IUL, Intended use of land; LDF, Land farming; NTC, Nature and type of contaminant; PHY, Phytoremediation; SIM, Simplicity; TDU, Thermal desorption; TGL, Target level; TOS, Type of soil; VIS, Volume of impacted soil.

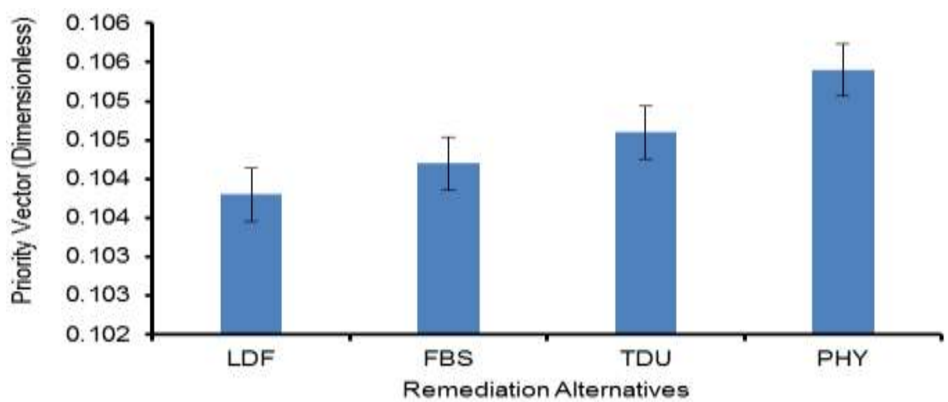

Figure 4. Synthesized priorities for the remediation alternatives (Chart shows error bars with standard error). LDF, Landfarming; FBS, Field biopiles; TDU, Thermal desorption; PHY, Phytoremediation

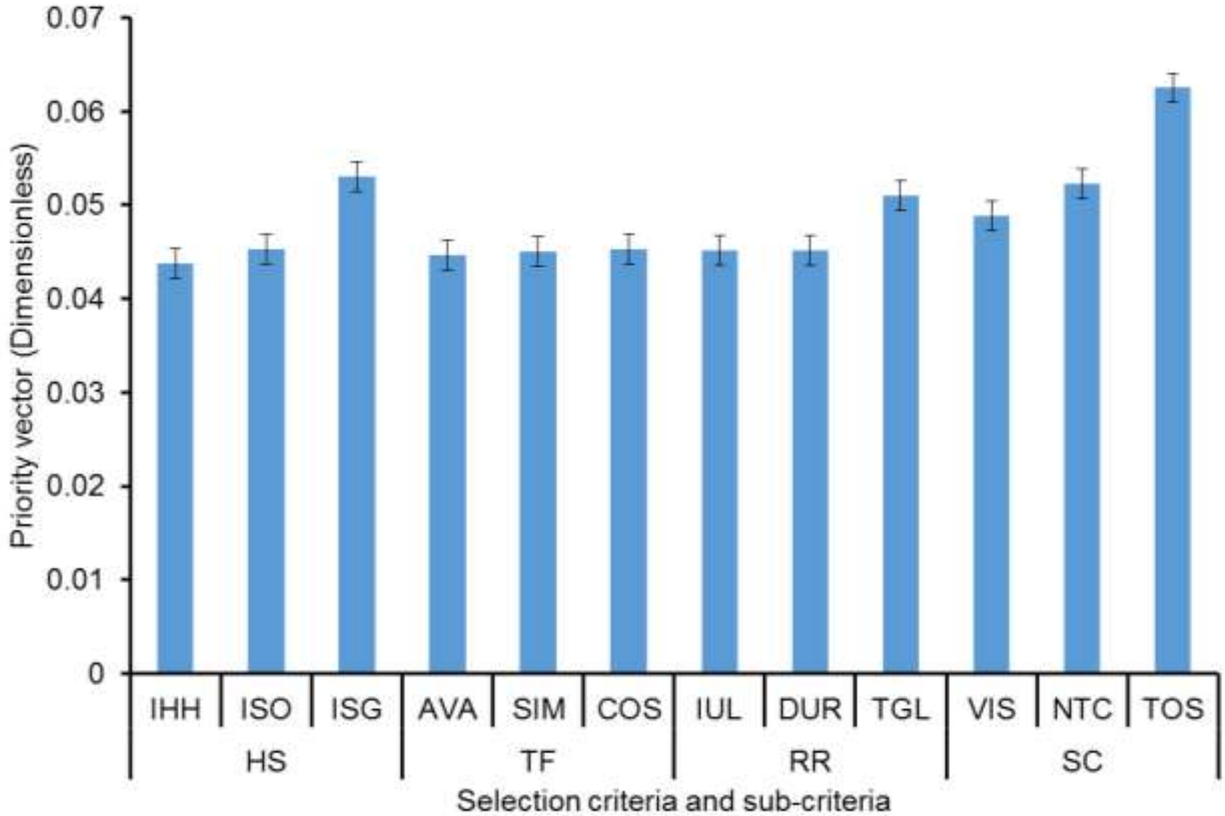

Figure 5. Synthesized priorities for the sub-criteria (chart shows error bars with standard error). AVA, Availability; COS, Cost; DUR, Duration; FBS, Field biopiles; HS, Health and safety; IHH, Impact on human health; ISG, Impact on surface and ground water; ISO, Impact on soil organisms; IUL, Intended land use; LDF, Land farming; NTC, Nature and type of contaminant; PHY, Phytoremediation; RR, Regulatory requirements; SC, Site-specific characteristics; SIM, Simplicity; TDU, Thermal desorption; TF, Technical feasibility; TGL, Target level; TOS, Type of soil; VIS, Volume of impacted soil.

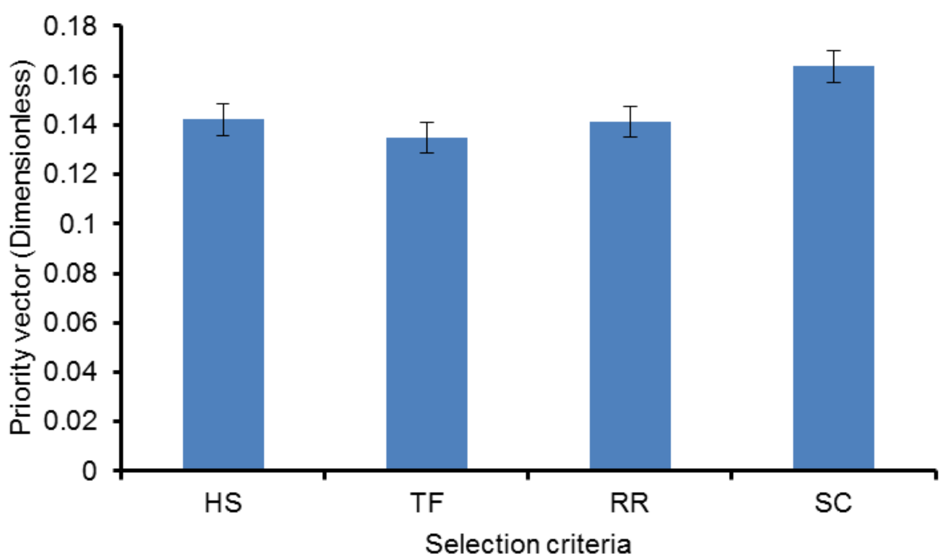

Figure 6. Synthesized priorities for the selection criteria (chart shows error bars with standard error). HS, Health and safety; TF, Technical feasibility; RR, Regulatory requirements; SC, Site-specific characteristics.

criteria when selecting a suitable remediation method. This was followed in order of decreasing effect by health and safety considerations, regulatory requirements, and technological feasibility.

Conclusions

This study applied the ANP as a multi-criteria decision-support tool in the selection of the most appropriate bioremediation method for the sustainable management of petroleum-contaminated land in the Niger Delta province, Nigeria. Four bioremediation alternatives (land farming, field biopiles, thermal desorption, and phytoremediation) and four selection criteria (site-specific characteristics, regulatory requirements, health and safety, and technical feasibility) were considered. Each of the selection criteria had three sub-criteria, making a total of twelve sub-criteria that were considered. After pairwise comparisons, results obtained show that phytoremediation (priority vector = 0.1054) was the most appropriate remediation method for the study site. Additionally, site-specific characteristics (priority vector = 0.1636) were the most important selection criteria for the study site. Of the three sub-criteria considered under site-specific characteristics, type of soil (priority vector = 0.0625) was the most influential sub-criterion for the study site. These show that the ANP is a promising multi-criteria decision-support tool for selecting the most appropriate bioremediation method to the satisfaction of all environmental stakeholders in order to deal with the problem of land contamination in the Niger Delta province, Nigeria.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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ABBREVIATIONS

AVA, Availability; **ANP,** Analytic Network Process; **COS,** Cost; **DPR,** Department of Petroleum Resources; **DUR,** Duration; **ELECTRE,** Elimination and Choice Expressing the Reality; **FBS,** Field biopiles; **HS,** Health and safety; **HYPREP,** Hydrocarbon Pollution Restoration Project; **IHH,** Impact on human health; **ISG,** Impact on surface and ground water; **ISO,** Impact on soil organisms; **IUL,** Intended land use; **LDF,** Land farming; **MCDA,** Multi-criteria decision analysis; **NTC,** Nature and type of contaminant; **NOSDRA,** National Oil Spill Detection and Response Agency; **PHY,** Phytoremediation; **RR,** Regulatory requirements; **SC,** Site-specific characteristics; **SIM,** Simplicity; **TDU,** Thermal desorption; **TF,** Technical feasibility; **TGL,** Target level; **TOS,** Type of soil; **UNEP,** United Nations Environment Programme; **VIS,** Volume of impacted soil

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