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Integrating Multi-Criteria Decision Method for Improved Oil Spill Management

***[1,2]Ucheoma Uju Chinyere, [1]Abdullahi Mohammed Evuti, [1]Yetunde Meriam Aladeitan,**
***[1]Abdulwasiu Abdurrahman, [3]Kamiludeen Olanrewaju and [3]Abdullahi Zakari**

[1]Department of Chemical Engineering, University of Abuja, Nigeria.
[2]National Oil Spill Detection and Response Agency (NOSDRA) Abuja, Nigeria.
[3]Department of Nuclear Engineering, University of Abuja, Nigeria.

*Corresponding authors' email: ucheomauju@gmail.com Phone: +2347033199424

ABSTRACT

Environmental project decision-making is often complex due to trade-offs among socio-political, ecological, environmental, and economic factors. In oil spill management and contaminated site remediation, these decisions are further complicated by regulatory frameworks and additional criteria such as; cost-benefit distribution, safety, ecological risks, and human values. This study applied Multi-Criteria Decision Analysis (MCDA) to optimize oil spill management in Delta State, Nigeria. Stakeholders were surveyed, and both offshore and onshore oil facilities were identified. Criteria and alternatives were developed and integrated into matrices scored from 0 to 100% across key factors, including environmental, technological, economic, and socio-political dimensions. Using Intelligent Decision System software, weights were assigned to reflect the relative importance of each criterion. Results showed a 68% preference for dispersant use in deep offshore areas, 73% for containment and recovery near sensitive shorelines, and 63% for similar methods farther from shore. For tier 3 oil spills, dispersant use was rated highest at 81%. This approach decomposed a complex problem into analyzable units and produced a stakeholder-informed decision template for oil spill response in Delta State. The template serves as a data-driven tool for policymakers and regulators, supports community awareness, and provides cost-saving opportunities for oil operators through pre-positioning of response equipment. This research broadens the practical use of MCDA in environmental management and offers a scalable model that can be replicated in other oil-producing states. With refinement, it holds the potential to contribute to a national oil spill response reference manual for Nigeria.

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INTRODUCTION

Oil continues to play a central role in Nigeria's economy, fueling the ongoing extraction of petroleum resources (Fagbohun, 2012). However, this reliance has led to serious environmental harm, public health concerns, and socio-economic issues, especially when resource management lacks sustainability. The negative impacts are often associated with ecosystem disruption, gas flaring, waste discharge, and frequent oil spills. Although petroleum operations occur across the country, the Niger Delta remains the most affected due to its rich oil deposits and fragile ecological balance (National Oil Spill Detection & Response Agency, 2013).

Since oil production began in Nigeria over fifty years ago, the Niger Delta has experienced significant pollution, environmental degradation, health challenges, and related social and economic problems (UNEP, 2011). Among these issues, oil spills pose the greatest risk. These spills affect both land and water environments and may contaminate underground water sources. They are caused by equipment failure, operational errors, well blowouts, human mistakes, deliberate vandalism, and sabotage (National Oil Spill Detection & Response Agency, 2013).

The severity of oil spills depends on the type of oil, the nature of the organisms and habitats exposed, and the duration and method of exposure (Fagbohun, 2012). Managing such spills effectively requires a rapid and coordinated response, supported by a decision-making tool that can address multiple objectives, conflicting priorities, and complex tradeoffs (Bello-Dambatta et al., 2009).

Decision making in complicated situations typically falls into four categories (Frazao et al., 2018). These are choosing the best option, classifying actions based on standards, ranking alternatives by preference, and explaining choices and their outcomes. Multi Criteria Decision Analysis, or MCDA, supports such decisions under uncertainty by considering several often-opposing criteria and involving the interests of various stakeholders (Bello-Dambatta et al., 2009). It is used in sectors such as healthcare (Frazao et al., 2018), engineering (Jato-Espino et al., 2014), public policy, mining, and environmental planning (Garfi et al., 2009; Hanan et al., 2013; Sorvari & Seppala, 2010; Soltani et al., 2014; Department for Communities and Local Government, 2009; Sitorus et al., 2019). MCDA helps ensure decisions are credible, less biased, and aligned with established goals (Frazao et al., 2018).

The MCDA process usually begins with defining the problem and identifying stakeholders. Next, the problem is structured by listing alternatives and selecting relevant criteria. Alternatives are then evaluated through direct measurements, approximations, or constructed indicators. Stakeholder preferences are considered by assigning weights to different criteria. A mathematical model then compares tradeoffs to determine performance, followed by a sensitivity analysis to test result reliability. The process may involve several rounds to fine tune outcomes (Saarikoski et al., 2016).

Different MCDA methods suit different types of problems (Mendoza et al., 2002). The Analytic Hierarchy Process (AHP) is widely used and involves pairwise comparisons and a tiered structure to assign weights and rank options (Sharifi et al., 2003; Rauscher et al., 2000). While it is easy to apply, it may lead to inconsistent judgments. Multi Attribute Utility Theory (MAUT) needs detailed information but handles uncertainty well, especially in economic and agricultural contexts (McDaniels, 1995; Mardle & Pascoe, 1999). The Simple Multi Attribute Rating Technique (SMART) is flexible and easy to implement, though less precise. Fuzzy Set Theory (FST) is useful in handling ambiguity, especially in engineering, but often involves complex calculations (Nigeria Galleria, 2020; Hamalainen, 1995). Goal Programming (GP) works for large scale problems and can be combined with other techniques for better results. Preference Ranking Organization METHod for Enrichment Evaluation (PROMETHEE) and Elimination Et Choix Traduisant la Realite (ELECTRE) manage uncertainty effectively, with PROMETHEE being more user friendly and ELECTRE being more complex (Vaillancourt & Waaub,2002; Belton & Stewart, 2002; Rogers & Bruen, 1998; Al-Rashdan et al., 1999). Case Based Reasoning (CBR) uses historical cases for decision making but depends on the quality of available records. Data Envelopment Analysis (DEA) assesses efficiency based on multiple inputs and outputs, requiring high quality data. Methods like Technique for Order Preferences by Similarity to Ideal Solution (TOPSIS) and Simple Additive Weighting (SAW) are often used in business and water resource management because of their simplicity, though they may overlook certain complexities (Mendoza et al., 2002; Sharifi et al., 2003). MCDA is especially valuable in environmental decision making, where tradeoffs involve ecological preservation, economic feasibility, and social fairness. Geographic Information Systems are often combined with MCDA for tasks such as land assessment, emergency response planning, and site selection (Mabin & Beattie, 2006).

Practical uses of MCDA include its adoption by the United States Army for military land evaluations, by Dutch authorities for park zoning, and in landfill location decisions (Siddiqui et al., 1996). In Canada, PROMETHEE supports waste planning, and in Switzerland, ELECTRE combined with GIS is used in housing assessments. MAUT has been used in the United States for park boundaries, in Finland for water use regulation, and in the European Union for nuclear preparedness. SMART has helped the United States Army Corps clean contaminated sites, while MAUT aided river planning in Missouri (Diakoulaki & Grafakos, 2004; Mendoza et al., 2002; Sharifi et al. 2003; Ramanathan, 2001). India has applied AHP in environmental assessments, Ireland has used ELECTRE, and Finland has integrated AHP, MAUT, and SMART for water projects. Other applications include park planning and pest control in North America, and marine resource management in Tobago (Rogers & Bruen, 1998; Ramanathan, 2001; Kangas et al., 2001; Brown et al., 2001).

Each method has its strengths and weaknesses. AHP is simple but may lack consistency. MAUT is reliable but data intensive. SMART is adaptable but less rigorous. ELECTRE and PROMETHEE manage uncertainty well but vary in complexity. DEA and CBR depend heavily on data quality. The best choice depends on the decision context, data availability, and stakeholder needs.

In Nigeria, various tools support oil spill response, such as sensitivity maps, tide charts, and national and corporate response plans (National Oil Spill Detection & Response Agency, 2013). However, these tools are often applied in isolation, leading to slow and uncoordinated responses. This is worsened by poor inter-agency coordination, unpredictable spill behavior, competing interests, and political challenges linked to old spill sites. Therefore, a more integrated, transparent, and structured system is essential. MCDA provides a practical framework for combining ecological, technical, economic, and social factors. This research aims to apply MCDA to create a tailored and effective oil spill response strategy for Delta State, reflecting its specific challenges and realities.

MATERIALS AND METHODS

Study Area

Delta State, located in the South-South geopolitical zone of Nigeria and part of the Niger Delta region (Figure 1a), consists of 25 local government areas (Figure 1b). It is both an oil- and agriculture-producing state; while agriculture supports the rural economy with products such as rubber, timber, palm oil, and palm kernels for local use and export, petroleum remains the major economic driver, creating significant environmental challenges from oil production, processing, and transportation. The state is Nigeria’s second-largest petroleum producer after Rivers State, supplying about 35% of the country’s crude oil and notable quantities of natural gas. Warri hosts the nation’s second-largest refinery and a petrochemical plant (UNDP, 2020). In addition to oil, the state possesses under-utilized solid minerals including industrial clay, silica, lignite, kaolin, tar sand, decorative rocks, and limestone, which serve as raw materials for industries. Existing industries include natural gas, plastics, glass, textiles, rubber, plywood, boatbuilding, sawmilling, steel, and furniture production.

Delta State has a population of approximately 4,112,445 (2006 census) (Delta State Government, 2020) and covers a land area of 17,698 km² with a landmass of 18,050 km². Its capital is Asaba in the north, while Warri in the south serves as the economic hub (Delta State Government, 2020). Geographically, it lies between Longitude 5°00′–6°.45′E and Latitude 5°00′–6°.30′N, bordered by Edo State (north), Ondo State (northwest), Anambra, Imo, and Rivers States (east), Bayelsa State (southeast), and the Atlantic Ocean’s Bight of Benin (south) (Nigeria Galleria, 2020).

The state has a tropical climate, humid in the south and sub-humid in the northeast, with rainfall heaviest in July. Average rainfall is about 266.5 mm in the coastal areas and 1,905 mm in the far north (Ndebumog, 2020). The River Niger drains its eastern flank, discharging into the Atlantic through distributaries such as Forcados, Escravos, and Warri rivers, while the Jamieson and Ethiope rivers flow from the north and northeast to form the Benin River (Ndebumog, 2020). With a 160 km coastline along the River Niger, the state has a low-lying coastal belt interlaced with rivulets and streams, featuring mangrove swamps and rainforest vegetation (Delta State Integrated Development Program, 2011).

Figure 1a: Map of Niger Delta (Udotong et al., 2017)

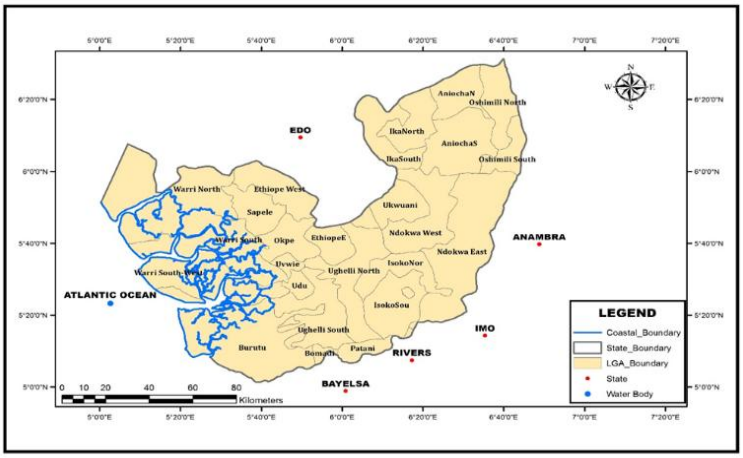


Figure 1b: Map of Delta State (Geospatial Analysis Mapping and Environmental Research Solutions, 2018)

Materials

The primary material for this research is secondary data, sourced from a variety of relevant databases and documents. These include the list of oil facilities in Delta State obtained from the Nigerian Upstream Petroleum Regulatory Commission (NUPRC) formerly (Department of Petroleum Resources) and the Gas Flare Tracker of the National Oil Spill Detection and Response Agency (NOSDRA); the Environmental Sensitivity Index Map, which provides information on access routes, natural and industrial resources, shorelines, environmental features, amenities, industries, water depths, key species, and local knowledge; Environmental Impact Assessment (EIA) reports for the study area; oil spill contingency plans from operators; data from the Oil Spill Monitor database; expert opinions to reduce bias in scoring and weighting; international sources on best practices; and applicable government regulations.

Methodology

Data were collected and collated through questionnaires distributed to stakeholders. A pilot trial of 400 questionnaires was conducted via email, personal contact, and forms. Feedback from the pilot refined the main survey to stakeholders with a proper understanding of the requirements. The main questionnaires covered all 34 known oil blocks operated by 19 oil companies, with four stakeholder groups participating: Delta State Ministry of Environment, oil operators, NOSDRA, and host communities.

The distribution was as follows: 19 companies × 3 contacts = 57; the remaining 3 groups × 3 contacts = 9; then 9 × 34 known blocks = 306. Thus, 306 + 57 operators + 10 extra = 373 questionnaires were distributed, but only 105 copies were returned (see Annex 1). Some responses were group-based, reducing the number of returned copies but enriching the information through collective discussions, which improved scoring reliability and minimized deviations. Responses were integrated into matrices using scatter plots and best-fit lines. Validity was cross-checked with existing documents and databanks. The study covered both onshore and offshore facilities.

MCDA Framework for Onshore Oil Spill Response

The process begins by defining the decision problem, followed by site identification and risk characterization. If multiple sites present unacceptable risks, prioritization is required. Decision attributes are then identified, performances measured, alternatives scored, scores normalized, and attributes weighted. Weighted attributes are aggregated to calculate total scores, enabling the selection of the site with the greatest risk.

MCDA Framework for Offshore Oil Spill Response

The process also starts with defining the decision problem, site identification, and risk assessment. Attributes for decision-making are then identified, performance measured, alternatives scored, and scores normalized. Attribute weights are assigned, and combined weighted scores are calculated to determine the best response strategy using Intelligent Decision System (IDS) Multi-criteria Assessor.

i. Decision-Problem definition: This specifies what the objective of the MCDA is or the set goal and identifies stakeholders in the decision-making. The decision context in this case is timely and cost-effective response for offshore facilities and prioritization of spill impacted sites for remediation.

ii. Site identification: The sites were identified from Gas Flare Tracker (Figure 2), Oil Spill Monitor of NOSDRA and DPR's data bank and compared with the ones collated by stakeholders such that all the locations were enumerated and the site-specific risks assessed through some of the sources listed in 3.1 and from field experience of the stakeholders. The list of the oil blocks and their fields in Delta State are presented in Appendix A

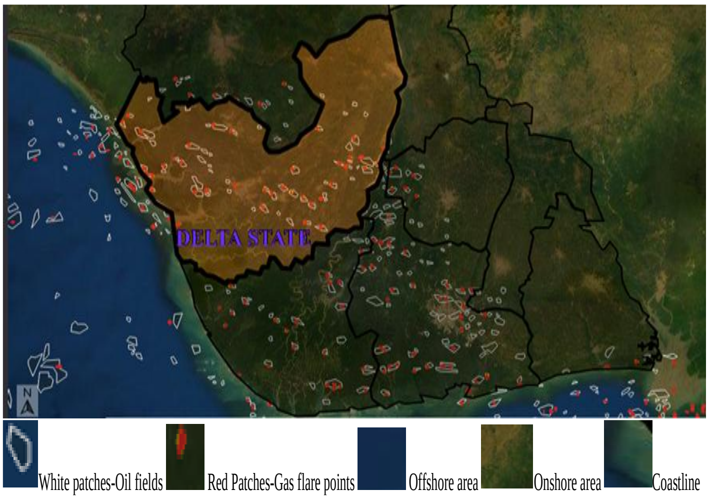


Figure 2: Map showing Oil Fields in Delta State (NOSDRA, 2014)

iii. Identification of attributes: There was full involvement of the key players to ascertain what criteria would be used to evaluate the options and what will distinguish between a good choice and a bad one. The set goal, site identification and risk assessment gave a clue of what Criteria to be identified. If there were so many identified criteria, too large to be handled; there would have been need for grouping or structuring of value tree but that is not the case here so there was no grouping. It was also ascertained that the criteria captured all the key aspects of the objectives (checking for completeness) and that there were no criteria identified, which are not necessary (checking for redundancy) (Department for Communities and Local Government, 2009).

iv. Measuring performance and scoring alternatives: To measure the level of performance of attributes with respect to available alternatives a performance matrix or consequence table was set up and numerical scales assigned to the criteria, corresponding to any two (interval scale) reference points on the scale. The scale used is pair-wise comparison scale as stated below which is also in accordance with Analytic Hierarchy Process.

Table 1: Pair-Wise Comparison Scale, Used: 0 to 9

Numerical Rating	Judgements of Preferences
9	Extremely preferred
8	Very Strongly to extremely
7	Very Strongly preferred
6	Strongly to very strongly
5	Strongly preferred
4	Moderately to strongly
3	Moderately preferred
2	Equally to moderately
1	Equally preferred
0	Not recommended

The Performance Matrix Format Created, with Stakeholders' Involvement is Presented in Tables 2 and 3

Table 2: Sample of Matrix for Offshore Facilities

	CRITERIA / ATTRIBUTE														
OPTIONS/ ALTERNATIVES	**Good access**	**Poor access**	**Water depth**	**High wind speed**	**Low wind speed**	**Equipment / Material stockpile proximity**	**Equipment / Material Availability**	**High Tide**	**Low Tide**	**1st tier oil spill**	**2nd tier oil spill**	**3rd tier oil spill**	**Environmental Sensitivity Indices Consideration**	**Coastline Distance Consideration**	**No Secondary pollution**
Dispersants use															
Containment & Recovery (Boom & Skimmers)															
Containment & Diversion															
Sorbents use															
Do nothing but monitor															
In-situ burning															

The Goal is to Optimize Response Time and Protect the Environment

Note, Tier 1 oil spill: 0-25 bbl to inland waters or 0-250 bbl to land or coastal/offshore waters. Tier 2: 25-250 bbl. to inland waters or 250-2500 bbl to land or coastal/offshore waters Tier 3: Greater than 250 bbl to inland waters or above 2500 bbl to land or coastal/offshore waters (National Oil Spill Detection & Response Agency, 2013).

Table 3: Sample of Matrix for Onshore Facilities

	CRITERIA/ ATTRIBUTES					
OPTION	**Accessibility**	**Proximity to people**	**Proximity to water body for domestic use**	**Negative impacts on livelihood of the people**	**Other Environmental Sensitivity indices**	**Human population consideration**
Site 1						
Site 2						
Site 3						
Site 4 etc.						

NB: Goal: Site Prioritization for On-shore Facilities

v. Score normalization and Attributes weighting: score normalization was done to provide a common numerical scale; Weight selection is done arbitrarily based on stakeholders' preference to reflect their relative importance to the decision (Belton & Stewart, 2002). Equal weighting was the choice in this particular case and thus there was no need for sensitivity analysis.

vi. Combining weights and calculating total score: AHP weighting method of the Intelligent Decision System (IDS) Multicriteria Assessor software was chosen, in combining these two components to give an overall assessment of each option being appraised.

The overall preference score for each option is simply the weighted average of its scores on all the criteria. Letting the preference score for option i on criterion j be represented by Sij and the weight for each criterion by Wj, then for n criteria the overall score for each option, Si, is given by:

$$S_i = W_1 S_{i1} + W_2 S_{i2} + \cdots + W_n S_{in} = \sum_{j=1}^{n} W_t S_{it} \quad \text{..(equ.1)}$$

That was processed by the software. IDS was chosen because it is different from most other MCDM software packages in that it works on the basis of Evidential Reasoning and so can handle different types of uncertainties, such as randomness, ambiguity and ignorance in an integrated framework with little or no limitation. Its major characteristics is the use of pair-wise comparisons as in AHP to both compare the alternatives with respect to the various criteria and estimate criteria weights after which the best decision is taken based on maximum weight. It is to be noted that the terms Alternatives and options were used interchangeably in this work as well as Attributes and Criteria.

RESULTS AND DISCUSSION

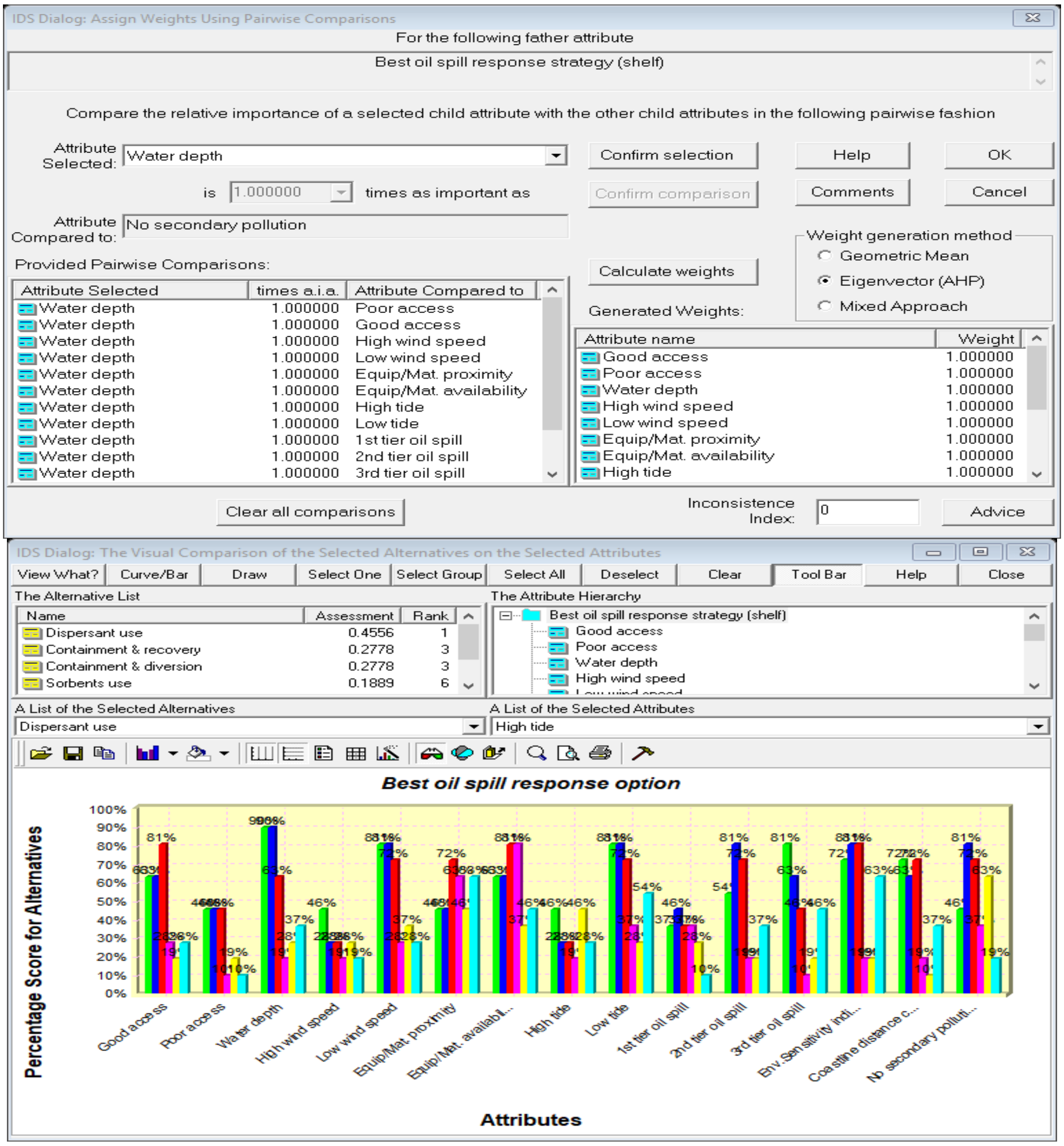
Site Identification

As outlined in Figure 2, the various oil fields in Delta State are identified and the list of fields, presented in appendix A. The decision context is timely and cost-effective oil spill response for offshore facilities and prioritization of spill impacted sites for remediation. The stakeholders are NOSDRA, Delta State Ministry of Environment, Host communities, Oil field operators. This can be achieved through identification of oil wells in Delta state and sorting of the wells according to terrain (locations). A total of 34 oil blocks covering a total area of 34,938Km^2 were identified as shown in Appendix A; where the land area of the blocks covers 17,842Km^2 having in mind that some of the blocks traversed areas in neighboring states, continental shelf area is

8,496Km^2 and Deep Offshore blocks cover area of 8,600Km^2. The blocks selected in this study for deep offshore are traced from the head and tail of the Delta State map to the blue zone (ocean) in order to create a boundary even though the effect of oil spill in deep offshore anywhere outside the chosen blocks would still have effect on the study area depending on the oil spill distance and trajectory.

Analysis of Results

This section involves defining criteria, developing alternatives with respect to the objective function, scoring by the stakeholders through questionnaires and analysis of the data collected, using Intelligent Decision System software (IDS50StudentVersion_000.rar (evaluation copy)); its interface is shown in Figure 3. Using IDS for multi-criteria decision problem analysis includes four major tasks which are Modeling, Data input, Result reporting and Sensitivity analysis. To model the problem, the IDS multi criteria assessor Application was started; the Attribute hierarchy was built by inserting Attributes, defining top and other higher-level attributes, bottom attribute, then defining qualitative attribute (in this case) and completing the rest of the model as instructed. Attribute grades were converted; relating the qualitative attribute to its father attribute by either rule-based approach or utility approach. Weights were assigned, which can be done in any of the following ways; visual scoring, pairwise comparison or combination of the two. In this case equal weightings were assigned, after which Alternatives were added, defined and assessment information for the qualitative attributes inputted. Once assessment information for all bottom level attributes was collected, the overall performance and the performance for higher level attributes were then calculated by IDS Multicriteria Assessor using the Evidential Reasoning (ER) approach automatically (IDS Limited, 2007) then the results were viewed on graphic interface. It should be noted that since equal weightings were assigned, sensitivity analysis was not required. All the results viewed on graphic interface were extracted, aggregated and presented as templates.



IDS Dialog: Assign Weights Using Pairwise Comparisons

For the following father attribute

Best oil spill response strategy (shelf)

Compare the relative importance of a selected child attribute with the other child attributes in the following pairwise fashion

Attribute Selected: Water depth

is 1.000000 times as important as

Attribute Compared to: No secondary pollution

Weight generation method
○ Geometric Mean
● Eigenvector (AHP)
○ Mixed Approach

Provided Pairwise Comparisons:

Attribute Selected	times a.i.a.	Attribute Compared to
Water depth	1.000000	Poor access
Water depth	1.000000	Good access
Water depth	1.000000	High wind speed
Water depth	1.000000	Low wind speed
Water depth	1.000000	Equip/Mat. proximity
Water depth	1.000000	Equip/Mat. availability
Water depth	1.000000	High tide
Water depth	1.000000	Low tide
Water depth	1.000000	1st tier oil spill
Water depth	1.000000	2nd tier oil spill
Water depth	1.000000	3rd tier oil spill

Generated Weights:

Attribute name	Weight
Good access	1.000000
Poor access	1.000000
Water depth	1.000000
High wind speed	1.000000
Low wind speed	1.000000
Equip/Mat. proximity	1.000000
Equip/Mat. availability	1.000000
High tide	1.000000

Inconsistence Index: 0

IDS Dialog: The Visual Comparison of the Selected Alternatives on the Selected Attributes

The Alternative List

Name	Assessment	Rank
Dispersant use	0.4556	1
Containment & recovery	0.2778	3
Containment & diversion	0.2778	3
Sorbents use	0.1889	6

The Attribute Hierarchy

Best oil spill response strategy (shelf)
- Good access
- Poor access
- Water depth
- High wind speed

A List of the Selected Alternatives: Dispersant use

A List of the Selected Attributes: High tide

Figure 3: Software Interface (IDS Limited, 2007)

Optimization of Response Time and to Protect the Environment Using Best Oil Spill Response Strategy for Deep-Offshore

Table 4 represents the performance matrix for 4 different deep offshore oil blocks with the same scores, the attributes were inserted in the software, taking note of the father attribute which is 'best oil spill response option for deep offshore' as the first entry, followed by the child attributes from Good access to No secondary pollution. The Alternatives were inserted, attribute type specified as 'qualitative', assessment grades specified as 0 to 9 and evaluation grades well defined on the basis of pairwise comparison (see Table 1). The weighting (AHP weighting option) of the attributes was equal and assessment of each selected alternatives on the attributes were done and completed for all, providing all the grades with the same belief degree. The overall performance and the performance for the individual attributes were automatically calculated by the software using Evidential Reasoning (ER) approach, the results were viewed on the graph interface as shown in Figures 4 & 5. Figure 4 represents the general performance, showing both the performance of father attribute and child attributes Figure 5 shows the best response options when considering the volume of spilled oil at the upper part of the graph, the lower part brings out the objective function (goal) which is the father attribute on which the other attributes branched out from. Figure 4 can be likened to the universal set whereas Figure 5 is its subset.

Table 4: Oil Spill Response Performance Matrix for Deep Offshore Oil Fields

CRITERIA / ATTRIBUTE
For Deep Offshore – OML 134, OML 120, OML133 & OML 125

OPTIONS/ ALTERNATIVES	**Good access**	**Poor access**	**Water depth**	**High wind speed**	**Low wind speed**	**Equipment / Material stockpile proximity**	**Equipment / Material Availability**	**High Tide**	**Low Tide**	**1st tier oil spill**	**2nd tier oil spill**	**3rd tier oil spill**	**Environmental Sensitivity Indices**	**No Secondary pollution**
Dispersants use	8	3	9	2	9	4	7	4	7	3	5	8	*	3
Containment & Recovery (Boom & Skimmers)	8	1	8	1	6	6	8	1	8	5	7	6	*	6
Containment & D Iversion	3	1	4	2	6	6	7	2	8	5	3	2	*	6
Sorbents use	3	1	0	1	2	8	8	1	3	3	1	0	*	2
Do nothing but monitor	6	4	3	2	5	4	4	6	2	1	3	4	*	7
In-situ burning	7	2	6	4	6	6	4	2	6	0	4	7	*	1

*The Locations have the Same Scores and the Environmental Sensitivities are the Same and Far Away from Shoreline Therefore, Environmental Sensitivity Indices were not Considered in the Performance Matrix

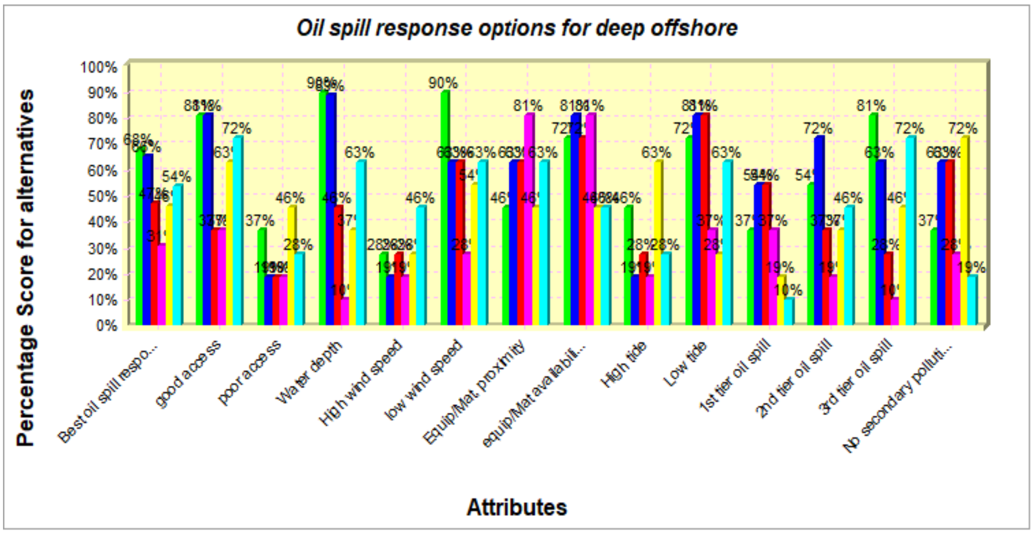


Figure 4: Performance Chart for Deep Offshore Oil Spill Response Options

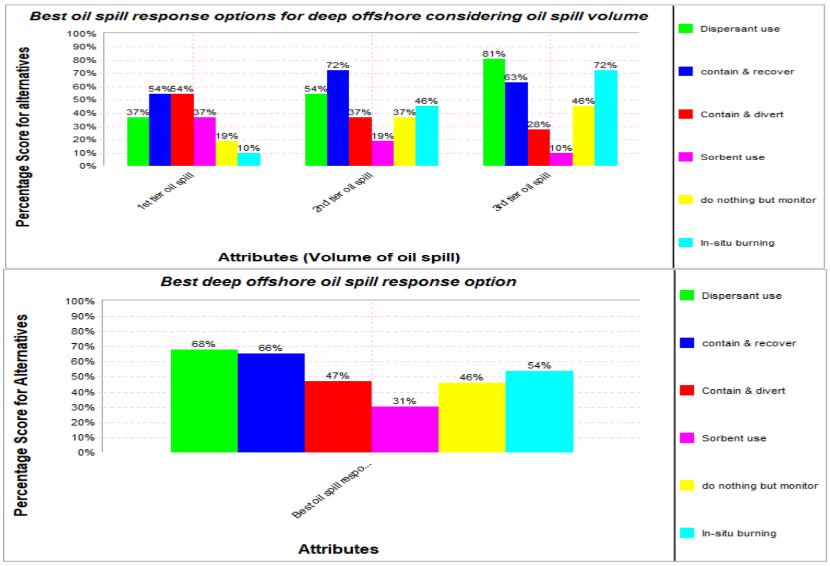


Figure 5: Best Deep-Offshore Oil Spill Response Option Chart (Overall Performance)

The result shows that generally, ‘dispersant use’ is the best oil spill response option for deep offshore, though not sacrosanct when oil spill volume is within the 1st and 2nd tier in which case the oil can be ‘contained and recovered’ as well as ‘contained and diverted’ but when massive volume as in tier 3 is involved, dispersant use is the best option (see Figure 5) for timely response to break up the oil fast enough to save the environment.

Optimization of Response Time and to Protect the Environment Using Best Oil Spill Response Strategy for Near-Shore Facilities

Table 5 is the performance matrix for 5 different blocks (OMLs 95, 227, 79, 90 & 109) in the continental shelf with the same scores, Table 6 shows 5 different blocks (OMLs 91, 89, 136, 108 & 110) with similar scores, all in the continental shelf. The procedure stated in paragraph 3.2.1 was followed and the charts viewed for each of the groups are represented in Figures 6 to 8. The Father attribute which is the objective function and the overall performance is part of the general performance chart though isolated and viewed separately as the software can only display maximum of 15 attributes at once.

Table 5: Oil Spill Response Performance Matrix for Continental Shelf OML (95, 227, 79, 90 &109)

	Continental shelf - OML 95					**CRITERIA / ATTRIBUTE**									
OPTIONS/ ALTERNATIVES	**Good access**	**Poor access**	**Water depth**	**High wind speed**	**Low wind speed**	**Equipment / Material stockpile proximity**	**Equipment / Material Availability**	**High Tide**	**Low Tide**	**1st tier oil spill**	**2nd tier oil spill**	**3rd tier oil spill**	**Environmental Sensitivity indices consideration**	**coastline distance consideration**	**No Secondary pollution**
Dispersants use	4	2	0	2	9	4	7	4	7	0	3	3	2	0	3
Containment & Recovery (Boom & Skimmers)	9	4	9	3	9	5	8	3	9	5	8	8	6	8	9
Containment & Diversion	9	4	9	3	9	5	8	3	9	5	8	5	7	9	7
Sorbents use	4	1	1	1	2	8	8	1	4	2	1	0	4	4	2
Do nothing but monitor	5	2	4	2	4	4	4	5	2	1	2	3	2	0	7
In-situ burning	3	1	2	1	6	5	3	2	5	0	3	4	1	3	1

Continental Shelf Scores for OML 227, OML 79, OML 90 and OML 109 are the Same with OML 95. Therefore the Above Performance Matrix is the Same with the Aforementioned Locations

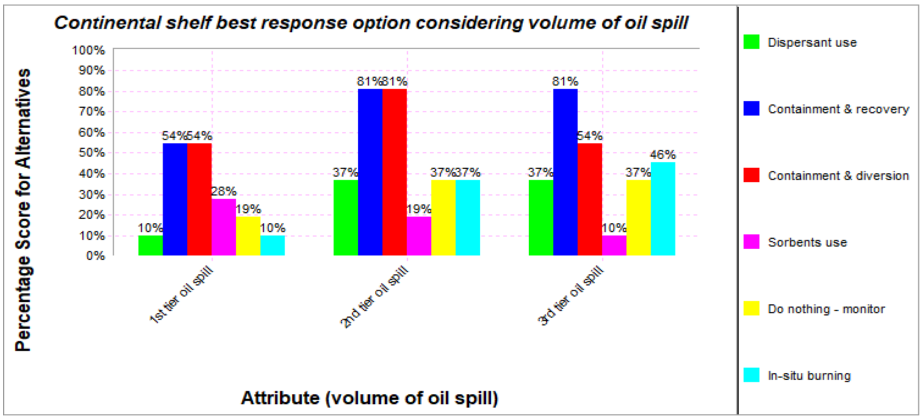


Figure 6: Performance Chart for Shelf (OML 95) Oil Spill Response Options in Terms of Spilled Volume

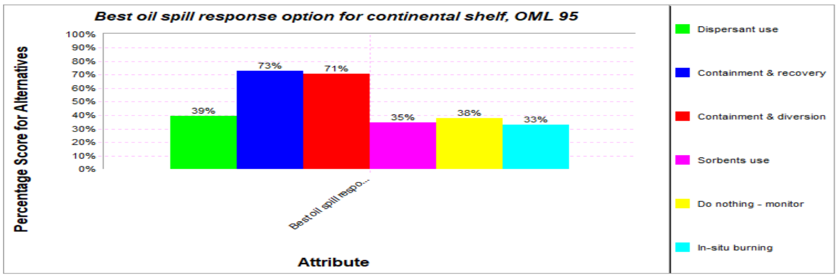


Figure 7: Best shelf (OML 95) Oil Spill Response Option Chart (Overall Performance)

The result shows that the best oil spill response option for these blocks within the continental shelf is ‘containment and recovery’ even when huge volumes (3^{rd} tier) are involved. It is good to note that these blocks are not only in shallow waters but very close to highly sensitive shoreline, this validates the attributed scores. For 1^{st} & 2^{nd} tier spill on these sites, ‘containment & recovery’ is not the only option, ‘containment & diversion’ is also an option; this is to channel oil spill away from the most vulnerable part.

Table 6: Oil Spill Response Performance Matrix for Continental Shelf OMLs (91, 89, 136, 108 & 110)

	OML 91, OML 89, OML 136, 108 & 110 (continental shelf) CRITERIA / ATTRIBUTES													
OPTION/ ALTERNATIVES	**Good access**	**Poor access**	**Water depth**	**High wind speed**	**Low wind speed**	**Equipment / Material stockpile proximity**	**Equipment / Material Availability**	**High Tide**	**Low Tide**	**1^{st} tier oil spill**	**2^{nd} tier oil spill**	**3^{rd} tier oil spill**	**Environmental sensitivity indices consideration**	**Coastline distance consideration**	**Non-Secondary pollution**
Dispersants use	6	4	9	2	8	4	6	4	8	3	5	8	7	5	3
Containment & Recovery (Boom & Skimmers)	8	3	6	1	7	7	8	2	8	4	6	5	8	6	9
Containment & Diversion	8	4	6	2	7	7	8	2	7	3	7	4	8	7	7
Sorbents use	2	0	1	1	2	6	7	1	3	3	1	0	1	1	3
Do nothing but monitor	1	1	2	2	3	4	3	4	2	2	1	1	1	0	6
In-situ burning	2	0	3	1	2	6	4	2	5	0	3	4	6	1	1

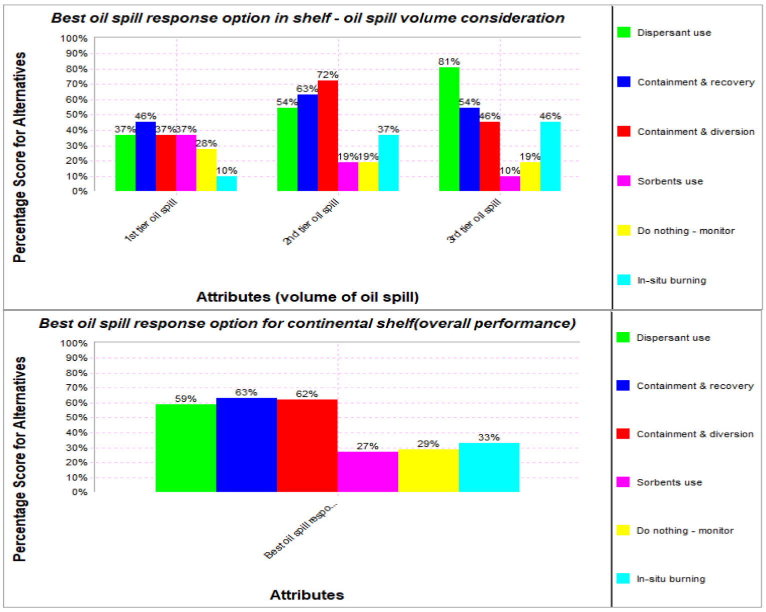


Figure 8: Best Shelf (OML 91, 89, 136, 108 & 110) Oil Spill Response Option Chart (Overall Performance)

The result shows that ‘containment and recovery’ remains the best response option for the blocks in continental shelf; dispersants can as well be used for a 3rd tier oil spill. These blocks are not too close to the shoreline even though within the continental shelf.

As seen in the site identification log (Appendix A), the available information shows that OML 110 has a depth of 20meters, OML108 has a depth of 30 – 213meters and 15miles distance away from shoreline which is equivalent to 13.03 nautical miles. The standard for dispersant use is: spill site not less than 10 nautical miles away from shoreline and water depth not less than 20 meters, these criteria are seen to have been met by the oil blocks and therefore validates the scores as presented by stakeholders.

The aggregation of results from the performance charts in Figures 4 to 8 is presented in Table 8 as a reference template.

Prioritization of on-shore Oil Spill Sites for Clean-up/remediation

Table 7 is the performance matrix for onshore oil spill sites prioritization, the father attribute is the site prioritization and the child attributes are from Accessibility to Human population consideration which is all qualitative. The alternatives in this case are the oil blocks to be prioritized. Figures 9 and 10 are the performance charts based on the Attributes; Figure 11 is the overall performance chart on onshore oil spill site prioritization. From the performance charts, the bars with high percentages denote high risk evaluation therefore the bar is shortest where the risk appraisal is smallest. The aggregation of results from the performance charts is presented in table 9 as a reference template.

Table 7: Performance Matrix for Onshore Oil Spill Sites Prioritization

Goal: Site Prioritization for On-shore Facilities

	CRITERIA/ ATTRIBUTES					
OPTION	**Accessibility**	**Proximity to people**	**Proximity to water body for domestic use**	**Negative impacts on livelihood of the people**	**Other Environmental Sensitivity indices**	**Human population consideration**
OML 40	8	5	4	5	4	3
OML 41	6	1	3	2	4	1
OML 49	4	5	7	6	4	5
OML 38	5	6	5	4	5	6
OML 56	5	6	6	5	6	6
OML 43	6	5	7	4	4	5
OML 28	7	5	7	6	7	4
OML 42	3	5	6	5	4	5
OML 45	6	5	7	4	4	6
OML143/39	4	5	6	5	3	4
OML 61	6	6	7	3	2	5
OML 65	5	1	4	2	3	1
OML 62	3	1	7	2	4	1
OML 57	5	1	5	2	4	1
OML 26	9	6	3	3	6	5

OPL 135 now OML 149	3	1	4	4	5	1
OML 35	3	1	4	3	5	1
OML 30	9	8	7	7	5	9
OML 60	5	6	5	4	4	5
OML 34	9	9	6	6	7	9

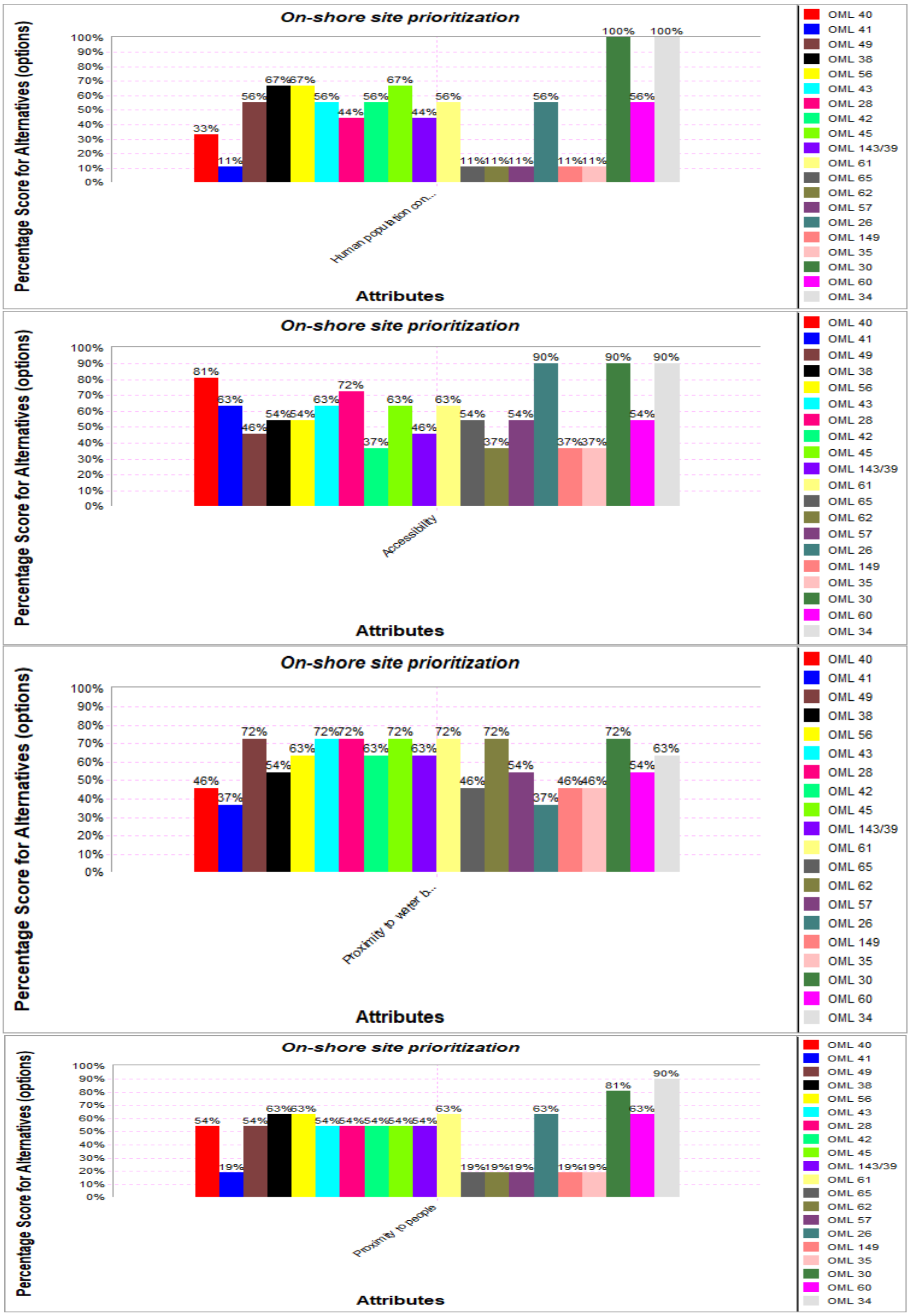


Figure 9: Onshore Oil Spill Sites Prioritization Chart Based on Human Population Consideration, Accessibility, Proximity to Water body for Domestic Use & Proximity to People

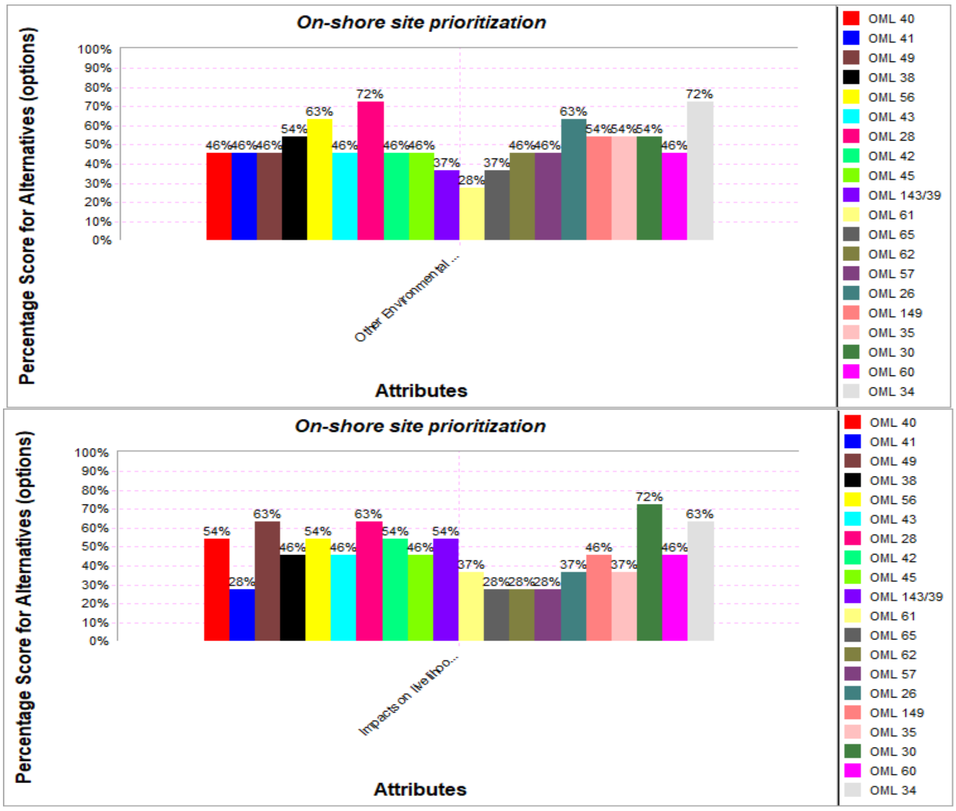


Figure 10: Performance Chart for Onshore Oil Spill Site Prioritization Based on Other Environmental Sensitivity Indices & Impacts on Livelihood of the People

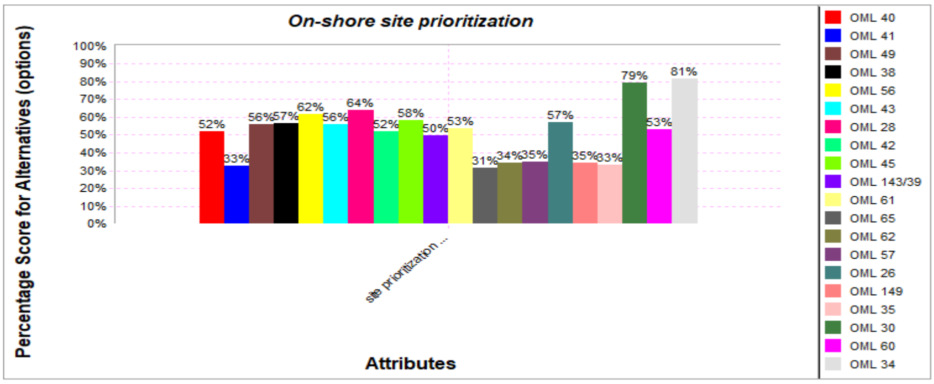


Figure 11: Overall Performance Chart on Onshore Oil Spill Sites Prioritization

The overall risk-based prioritization shows that some of the sites have almost similar risks and for that reason, other criteria can be used to prioritize them for clean-up/remediation, which is the reason for the individual criterion-based prioritization in figures 9 to 10

Relevance of the Chosen Attributes

Accessibility plays a big role in oil spill response as you can only respond when you gain access to the site, visibility when using aircraft to respond comes under accessibility in this context.

Tides originate in the oceans and progress towards the coastlines where they appear as the regular rise and fall of the sea surface (National Oceanic and Atmospheric Administration, 2020), this definitely affects the trajectory of oil slick on ocean surface. Wind speed, ocean tide and the resultant ocean current affect accessibility and response options; for instance, when the oceans are turbulent, mechanical response proves abortive, booms and skimmers cannot be launched and of course moving in for the response generally becomes problematic.

Coastline distance is considered because most of the environmental sensitive indices are domiciled at the coastline/shoreline; booming and diversion option is most often than not to redirect the slick away from the sensitive parts. Nigeria national dispersant use policy is also dependent on the distance of the oil spill from shoreline which must be above 10 nautical miles away and the ocean depth must not be less than 20 meters provided no shallow water is less than one meter away from spill point.

The different tiers of oil spill considered as attributes are representing the volumes of oil spill that can be handled by the different response options.

In all the options, any one that has the tendency of secondary emissions/pollutions in the course of use is scored low and defeats the objective of the MCDA which is to protect the environment. Considering in-situ burning, although it can be effective in some situations, it is rarely used on marine spills because of widespread concern over atmospheric emissions and uncertainty about its impacts on human and environmental health. The major issues for in-situ burning of oil spills are proximity to human populations (burning must take place at least three miles away from population at risk (NOSDRA, 2014).

For onshore oil fields, the accessibility criterion depicts ease of entrance into the facilities, which relates to time factor. Contaminant spread in the soil in vaporized, residual or absorbed phases, free phase and dissolved phase (Mohammed et al., 2020), so Human Population criterion is based on the number of people living within 2Km of the facility that are likely to be exposed to the negative effects of oil spill, some are even closer than others still within the 2km which is the reason for the criterion ‘proximity to people”. Proximity to water body for domestic use is a very sensitive criterion because apart from direct health impact from use, oil spill seepage into water bodies poses danger to aquatic animals and consequently impacts negatively to the economy of the host communities especially when they are predominantly fishermen and farmers. These with other factors affect the livelihood of the people. Other environmental sensitivity indices criterion refers to other likely receptors of the impact of oil spill outside the attributes already stated e.g., biological resources (economic trees, farm crops & different species of animals) and human-use resources.

Presentation of Templates (Aggregation of all Results from the Performance Charts)

Table 8: Summary of Offshore Results

OML	Terrain	Overall site-specific Oil spill response option	Best response option for tier 1 oil spill (0 – 250 barrels)	Best response option for tier 2 oil spill (250 – 2500)	Best response option for tier 3 oil spill (above 2500 barrels)
134	Deep Offshore	Dispersant use	Containment & recovery/Containment & diversion	Containment & Recovery	Dispersant Use
120	Deep Offshore	Dispersant use	“	“	“
133	Deep Offshore	Dispersant use	“	“	“
125	Deep Offshore	Dispersant use	“	“	“
95	Shelf	Containment & recovery	Containment & recovery/Containment & diversion	Containment & recovery/Containment & diversion	Containment & recovery
227	Shelf	“	“	“	“
79	Shelf	“	“	“	“
90	Shelf	“	“	“	“
109	Shelf	“	“	“	“
91	Shelf	Containment & recovery	Containment & recovery	Containment & diversion	Dispersant use
89	Shelf	“	“	“	“
136	Shelf	“	“	“	“
108	Shelf	Containment & recovery	Containment & recovery	Containment & recovery	Dispersant Use
110	Shelf				

🟧 Dispersant Use 🟦 Containment & Recovery 🟥 Containment & Diversion 🟪 Containment & Recovery/Containment & Diversion

Table 9: Summary of Onshore Results in Descending Order of Priority

Overall risk-based site prioritization ↓	Site Accessibility prioritization ↓	Proximity to water body for domestic use ↓	Livelihood impact prioritization ↓	Human population-based prioritization ↓	Prioritization based on site Proximity to people ↓	Prioritization based on other Environmental Sensitivity Indices ↓
OML 34	OMLs (34, 30 & 26)	OMLs (49, 43, 28, 45, 61, 62 & 30)	OML 30	OML 34 & OML 30	OML 34	OML 34 & OML 28
OML 30	OML 40	OMLs (56, 42, 143/39 & 34)	OMLs (49, 28 & 34)	OMLs (38, 56 & 45)	OML 30	OML 26 & OML 56
OML 28	OML 28	OMLs (38, 57 & 60)	OMLs (40, 56, 42 & 143/39)	OMLs (60, 26, 61, 42, 43 & 49)	OMLs (26, 61, 56, 38 & 60)	OMLs (38, 149, 35 & 30)
OML 56	OMLs (41, 43, 45 & 61)	OMLs (40, 65, 149 & 35)	OMLs (38, 43, 45, 149 & 60)	OML 28 & OML143/39	OMLs (40, 49, 43, 28, 42, 45 & 143/39)	OMLs (40, 41, 49, 43, 45, 42, 62, 57 & 60)
OML 45	OMLs (38, 56, 65, 57 & 60)	OML 41 & OML 26	OMLs (61, 26, & 30)	OML 40	OMLs (41, 65, 62, 57, 149 & 35)	OML 143/39 & OML 65

Overall risk-based site prioritization	**Site Accessibility prioritization**	**Proximity to water body for domestic use**	**Livelihood impact prioritization**	**Human population-based prioritization**	**Prioritization based on site Proximity to people**	**Prioritization based on other Environmental Sensitivity Indices**
OML 38 & OML 26	OML 49 & OML 143/39		OMLs (41, 65, 62 & 57)	OMLs (41, 65, 62, 57, 149 & 35)		OML 61
OML 49 & OML 43	OMLs (42, 62, 149 & 35)					
OML 61 & OML 60						
OML 40 & OML 42						
OML143/39						
OML 57 & OML 149						
OML 62						
OML 41 & OML 35						
OML 65						

CONCLUSION

This study demonstrates the effectiveness of Multi-Criteria Decision Analysis (MCDA) as a structured decision-making tool for optimizing oil spill management strategies in Delta State, Nigeria. By integrating stakeholder input and evaluating alternatives across environmental, ecological, socio-political, technological, and economic criteria, the analysis yielded clear, data-driven outcomes: dispersant use was most suitable for deep offshore spills with a 68% preference weight, while containment and recovery was favored in continental shelf areas near sensitive shorelines at 73%, and further offshore at 63%. Additionally, dispersant use in a tier 3 oil spill scenario was rated at 81%, highlighting its effectiveness in large-scale incidents. These quantified insights helped decompose the complex decision landscape into manageable, weighted criteria, resulting in a replicable template for pre-spill planning, site-specific response, and cost-effective remediation prioritization. The study provides a practical reference for policymakers, regulators, and operators, and lays the groundwork for a national oil spill response manual adaptable to other oil-producing regions in Nigeria.

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