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# Optimizing safety performance through risk-based modeling in Nigeria's oil and gas sector

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**Mgbowaji Zacchaeus**
ORCID: https://orcid.org/0000-0001-8921-1135
World Bank African Centre for Excellence for Oil Field Chemicals Research, University of Port Harcourt, Choba, Rivers State, Nigeria
E-mail: mgbowaji@gmail.com
**John Nwenearizi Ugbebor**
ORCID: https://orcid.org/0009-0007-4122-1861
Centre for Occupational Health, Safety and Environment (COHSE), University of Port Harcourt, Choba, Rivers State, Nigeria
E-mail: john.ugbebor@uniport.edu.ng
**Ikechukwu Ozoemenam Agbagwa**
ORCID: https://orcid.org/0000-0001-6425-6273
World Bank African Centre for Excellence for Oil Field Chemicals Research, University of Port Harcourt, Choba, Rivers State, Nigeria
E-mail: ikechukwu.agbagwa@uniport.edu.ng
**Ochuko Felix Orikpete**
ORCID: https://orcid.org/0000-0001-8020-2195
Centre for Occupational Health, Safety and Environment (COHSE), University of Port Harcourt, Choba, Rivers State, Nigeria
E-mail: orikpeteochuko@gmail.com

**Abstract**
The Nigerian oil and gas sector is fraught with safety challenges that undermine operational integrity and worker welfare. Addressing these issues requires a nuanced risk-based intervention and modeling approach to improve safety performance. This study investigated the safety challenges in Nigeria's oil and gas sector, focusing on identifying and addressing hazards to enhance operational integrity and worker welfare. A semi-quantitative approach was used to develop a comprehensive hazard checklist, aligned with ISO standards and expert insights. Data on hazard likelihood and severity were gathered through questionnaires distributed among a diverse group of industry experts, workers, and stakeholders. The analysis highlighted key risks like inadequate infrastructure, valve and seal failures, security concerns, and oil spill risks, underscoring the need for targeted interventions to promote a safer working environment and reduce accident risks.
**Keywords:** Risk-based safety interventions, Nigerian oil and gas industry, hazard identification, semi-quantitative.

## 1. Introduction

The oil and gas industry plays a significant role in Nigeria's economy, accounting for over 95% of foreign export earnings and about 65% of the government's revenue (Uduji *et al.*, 2019; Ebimobowei, 2022). This industry is essential to Nigeria's economy, responsible for over 70% of the country's revenue from exported products (Akinwale, 2019). Nigeria is the largest oil producer in Africa (Awoyemi & Nwibe, 2022), and the sector accounts for a substantial portion of the country's GDP, foreign exchange earnings, and budgetary revenues (Gasu *et al.*, 2022).

The oil and gas sector is subject to various risks that can impact the success of construction projects and overall operations (Kassem *et al*., 2020). Although the industry holds economic importance, it is also linked to substantial safety hazards that can have severe repercussions for workers, the environment, and the communities it operates in. Between 2018 and 2022, the oil and gas industry in Nigeria witnessed the loss of approximately 412 lives (Jeremiah, 2023). The industry has encountered numerous incidents related to safety, resulting in loss of life, extensive environmental harm, and significant financial losses. Furthermore, the sector is plagued by occupational perils such as equipment malfunctions, pipeline sabotage, oil spills, fires, and explosions, all of which have resulted in catastrophic incidents. This situation requires immediate focus on the development of stronger risk management strategies, including risk-based interventions and modeling approaches. Enhancing safety performance is crucial for protecting human lives, preserving the environment, and promoting sustainable growth in the industry.

Several studies provide valuable insights into strategies and factors that can contribute to improving safety in the industry. Okezie *et al*. (2023) examined the influence of organizational factors on safety performance in oil and gas companies in the Niger Delta region of Nigeria, shedding light on the internal determinants that can impact safety outcomes. Additionally, Ajmal *et al*. (2022) highlighted the significant role of safety compliance in enhancing safety outcomes and reducing occupational accidents and injuries in the oil and gas industry, emphasizing the importance of regulatory adherence and safety management practices. Furthermore, Van Thuyet *et al*. (2007) discussed risk management strategies in oil and gas construction projects, providing insights into potential approaches that can be adapted to enhance safety in the industry. Additionally, Khalilzadeh *et al*. (2020) emphasized the importance of effective risk management strategies to improve project performance, which is pertinent to ensuring safety in oil and gas operations. These studies show that the effects of poor safety performance are far-reaching. Poor safety performance can result in substantial financial costs for the organization, negative publicity, and legal action for the organization and its management (Safetybank, 2019). Hence, poor safety culture and performance can represent a significant risk for organizations operating in Nigeria, especially the Niger Delta area and their management regarding financial and legal risks and the negative publicity of such accidents.

There is a paradigm shift occurring in occupational health and safety (OHS) practice today. This shift began about 17 years ago, when many thought leaders began to notice, among other things, that the number of serious injuries and fatalities (SIFs) was no longer decreasing, even in organizations with best-in-class OHS programs (Walaski, 2016). Recently, many large organizations started studying the trend and postulated that the flaws in most OHS programs included traditional or compliance-based approaches, e.g. the tendency to treat all incidents equally, leading to a failure to identify the subset that was more likely to have a significant outcome; the use of Heinrich's injury pyramid to advance the claim that reducing frequency also reduces severity; the predominant focus on after-the-fact approaches (e.g., incident investigations and lagging indicators to measure an organization's performance) instead of proactive activities that could prevent future incidents; and the use of low-level controls (e.g., PPE, training, and standard operating procedures) contingent on worker compliance to address high-severity risks (Walaski, 2016). This has prompted the promotion of a significantly different OHS strategy. It is crucial to switch from a compliance-based strategy to one that emphasizes risk and safety management systems.

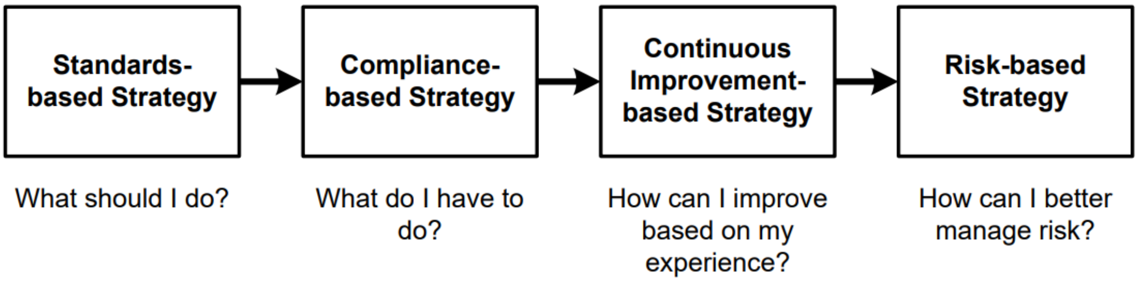


**Figure 1 - Evolution of strategies for preventing accidents and losses in the oil and gas industry (Source: Center for Chemical Process Safety, 2010)**

The oil and gas industry, with its inherent risks, has witnessed some of the world's most devastating accidents, including the Piper Alpha disaster in the North Sea and the Macondo blowout in the Gulf of Mexico. These tragic events led to numerous fatalities, extensive property damage, and a myriad of legal battles (Mandal & Agarwal, 2023). Risk is a combination of both the probability and severity of undesired events (Aalabaf-Sabaghi, 2023). Inadequate risk management in the offshore oil and gas industry has been a primary factor in numerous major accidents. These incidents have not only resulted in the loss of hundreds of lives but have also led to severe environmental damage and significant financial setbacks (Hosseinnia Davatgar *et al*., 2021). Hence, risk-based strategies concentrate on both diminishing the likelihood of an adverse event occurring and lessening the severity should the event transpire. The risk-based approach to safety is a systematic and proactive method that focuses on identifying, assessing, and managing risks to prevent accidents and promote safety in various industries, including the oil and gas sector (Naji *et al*., 2021). This approach involves analyzing potential hazards, evaluating their likelihood and consequences, and implementing appropriate control measures to mitigate risks. In the context of the oil and gas industry, the risk-based approach to safety is crucial due to the inherent hazards and risks associated with the extraction, production, and transportation of oil and gas. Organizational factors play a significant role in determining safety performance in this industry (Okezie *et al*., 2023). Risk-based safety studies aim to assess and manage the potential risks of accidental events that may lead to accidents, asset damage, and environmental pollution (Paik & Paik, 2020). Companies face a huge responsibility to ensure the safety of their employees; therefore, a risk-based approach serves to preclude or minimize the occurrence of catastrophic accidents or fatalities. In addition, by implementing a risk-based approach, adverse events can be filtered – thus, improving safety performance (Stefana *et al*., 2022).

The aim of this study is to construct an advanced risk-based safety framework tailored to the unique operational challenges of the Nigerian oil and gas industry, with an emphasis on significantly enhancing workplace safety performance. This paper sets out to systematically identify the prevalent hazards within this sector and to formulate an array of strategic interventions. Employing a comprehensive quantitative research design, the study will utilize a detailed hazard checklist, meticulously crafted in accordance with international safety standards and enriched with the nuanced insights of local industry experts. Through the deployment of structured questionnaires, we will capture a diverse range of data from a spectrum of industry operatives, from seasoned field experts to frontline equipment handlers. The intention is to distill a granular understanding of the perceived risks and to overlay this empirical data with a qualitative examination of the potential impacts on people and assets. The culmination of these efforts is aimed at proposing a robust, evidence-based intervention strategy that not only mitigates risks but also fosters a culture of sustained safety excellence in the Nigerian oil and gas industry's workplace.

## 2. Methods

*2.1 Research design*

The research design adopted for this study was a quantitative design approach. The research design was used to design a comprehensively risk-based solution for the Nigerian oil and gas industry, particularly focusing on the Niger Delta region. A number of multi-faceted methodology encompassing questionnaires, hazard checklists, qualitative risk assessments, and fault tree analysis and risk-based models was used to gain understanding of the industry's risk landscape.

For hazard identification, a comprehensive hazard checklist was developed based on industry standards (ISO 17776) and expert insights. The checklist was utilized to systematically identify and document common hazards inherent in the industry. After the hazard identification, structured questionnaires were administered to industry experts, workers, and stakeholders working in the oil and gas industry in the Niger Delta region. The questionnaires were designed to elicit expert opinions and ratings regarding the likelihood and severity of various hazards in the oil and gas sector. A purposive sampling technique was utilized in selecting industry experts, workers, and stakeholders that have been involved in any form of risk assessment.

Upon data collection, data analysis was conducted. Descriptive statistics was computed, encompassing mean, mode, standard deviation, minimum, and maximum values of hazard ratings obtained from the questionnaires. This semi-quantitative analysis provided invaluable insights into the industry's perceived risk landscape. Comparative analyses were also explored in term of variations in hazard ratings across different categories such as types of hazards and job roles, revealing patterns and trends in risk perceptions. Also, quantitative data obtained from questionnaires and checklists was employed in semi-quantitative risk assessment methods. The semi-quantitative approach involved in-depth evaluations of risks associated with identified hazards. Expert opinions and industry-specific knowledge was also harnessed to assess the potential impact and likelihood of occurrence for each identified risk. The use of semi-quantitative findings will form the basis for developing targeted risk-based interventions, fostering a safer working environment in the Nigerian oil and gas industry.

*2.2 Study area*

The research was conducted in the Niger Delta, located in the southern region of Nigeria. The Niger Delta region is a vast and ecologically diverse area characterized by a network of rivers, creeks, and wetlands. It covers approximately 7.5% of Nigeria's total land mass and is inhabited by over 25 million people across 186 Local Government Areas in nine southern states of Nigeria (Chinedu & Chukwuemeka, 2018). The region is one of the largest deltas in the world, covering an estimated land mass of 109,582 square kilometres (Brisibe, 2022). The Niger Delta is renowned for its rich biodiversity, including mangrove forests, which play a crucial role in the region's ecosystem (Nwobi *et al*., 2020; Nababa *et al*., 2020).

It is situated between latitude 4$^o$16’48’’ to 7$^o$51’36’’ and longitude 4$^o$16’12’’ to 9$^o$24’ (see Figure 3). The Niger Delta serves as a vital hub for oil and gas exploration and production, significantly contributing to Nigeria's revenue and global oil supply. Amidst the oil fields, wells, pipelines, and infrastructure, a delicate balance exists between human activities and the natural environment (Ugbomeh & Atubi, 2010). This study specifically targets the oil and gas companies operating within the Niger Delta. These companies are the backbone of the region's economy, engaging in exploration, extraction, transportation, and processing of hydrocarbon resources.

The operations of these companies are diverse, providing employment opportunities and driving ancillary services, thus significantly impacting the region's economic landscape. The workforce within this sector includes technicians, engineers, and administrative staff, each contributing their expertise. Notably, the ecological sensitivity of the study area is paramount. The intricate ecosystem of the Niger Delta is intricately linked to the overall health of the region, making it a focal point of this research.

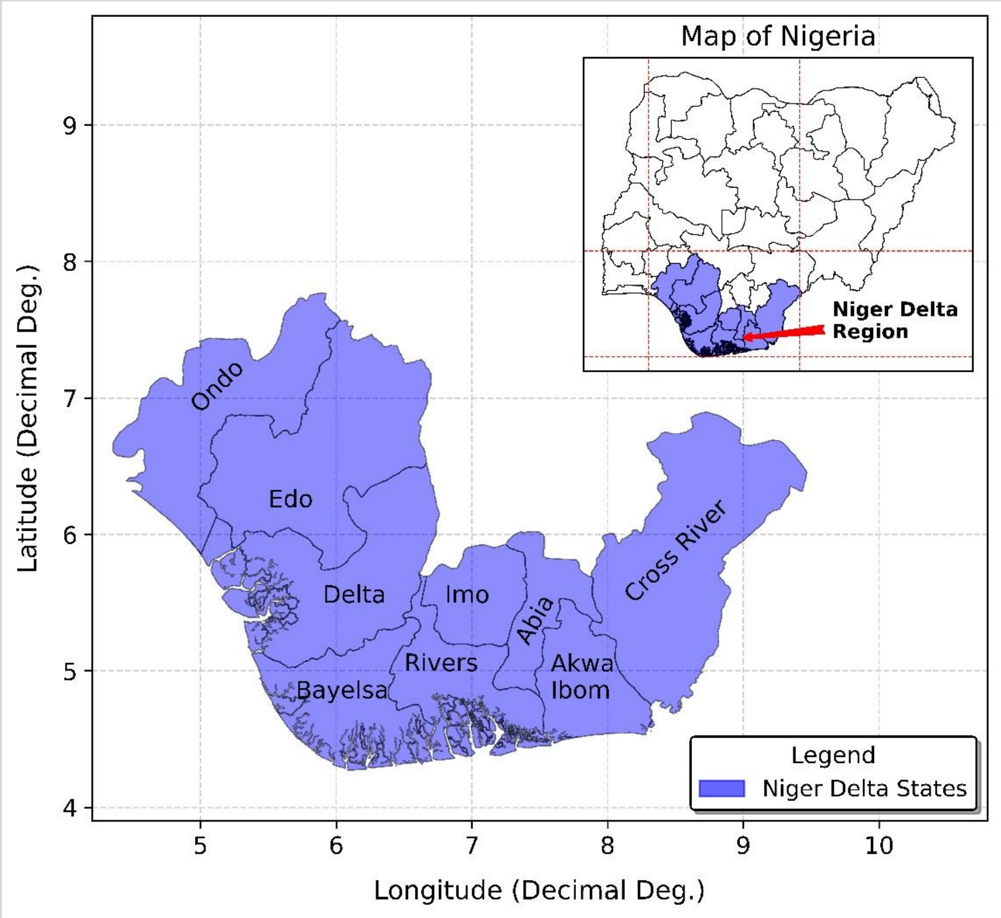


**Figure 2 - Map of study area (Source: Ikhumetse *et al*., 2022).**

*2.3 Population of the Study*

The study encompasses individuals with expertise in risk assessment working within the oil and gas companies in the Niger Delta region. This group includes both male and female employees, along with drivers, cleaners, and security personnel aged between >18 to <60 years. The study aims to survey this population, ensuring a response rate exceeding 75%. Any incomplete or ambiguous responses may require follow-up inquiries to ensure comprehensive data collection.

*2.4 Sample and sampling techniques*

The samples used for the study were the oil and gas companies and workers in the companies. The study employed a combination of sampling techniques to ensure a representative sample. For the selection of oil and gas companies, a non-probabilistic approach, specifically convenience sampling, was used. This method was chosen considering practical factors like accessibility to facilities and the companies' willingness to participate. Only companies allowing access to their facilities, enabling the collection of employees' names and email addresses, were eligible. Five companies were chosen from the available pool within the region.

Conversely, individual participants for the questionnaire survey were selected using a purposive sampling technique. Specifically, individuals with prior experience in risk assessment within the oil and gas industry were deliberately chosen, ensuring expertise and relevance. This targeted approach enhanced the depth and quality of the data collected for the study.

<u>Inclusion criteria</u>

i. Oil company workers must a minimum of six months working experience.

ii. They must have been involved in risk assessment

Exclusion criteria

i. Interns were not allowed to participate in the survey
ii. Members of the National Youth Service Corps were not allowed to participate in the survey

The names and email addresses of staffs from the selected companies were organized in a Microsoft Excel sheet. Workers who qualified to take part in the survey were invited to participate in the survey, receiving the questionnaire through an online platform (Google Forms).

Cochran (1978) sample size for proportion was used in obtaining the adequate sample size that would be representative. Cochran equation for sample size calculation is presented in Equation (1)

$$n_o = \frac{Z^2 pq}{e^2} \tag{1}$$

Where $n_0$ = sample size, e = margin of error, p = estimated proportion of an attribute that is present in the population, q = 1-p and Z = abscissa of the normal curve that cuts off an area α at the tails (1 – α) equals the desired confidence level, e.g., 95%).

$$n_o = \frac{1.96^2 (0.63)(0.37)}{0.05^2}$$

$n_o$ = 357 questionnaires

To make allowance for those who will not participate or participate but drop out (non-response rate and incomplete responses), a 10% allowance is given. Therefore, the minimum sample size of the study is 392 people who meet the inclusion criteria.

In order to collect data that will be a representative of the whole oil companies in the study area, companies will be randomly chosen from within Port Harcourt.

*2.5 Sources of data*

The study adopted two sources of data namely primary and secondary data. The primary data were directly collected by the researcher while the secondary data were collected indirectly. The primary data was obtained through the administration of structured questionnaires to selected employees in the sampled companies within the oil and gas sector in the Niger Delta region. The secondary data was acquired through a review of existing literature and company records.

Primary data collection for this study involved visiting various oil and gas company facilities in the Niger Delta region to assess potential hazards using a comprehensive checklist. Additionally, structured questionnaires of possible hazards faced during operation were administered to employees, aiming to gauge their rating regarding the likelihood and severity of identified hazards. Participants were encouraged to rate their perceptions of identified hazards using a Likert scale. Demographic questions were included to gather relevant information about the respondents.

A comprehensive literature review was conducted, encompassing academic articles, industry reports, regulatory documents, and other relevant resources. This review served as a foundation for understanding prevailing trends and theories in workplace safety, enhancing the study's context.

Secondary data was sourced from various documents, including ISO 17776 (Petroleum and natural gas industries Offshore production installations) standards, company hazard logs, incident rate sheets, and HSE 2001 records. These documents provided valuable insights into past hazards experienced, hazard management practices, and industry-specific safety guidelines.

*2.6 Methods of data collection*

In this study, two instruments were utilized: the Checklist and the Questionnaire.

Checklist

A hazard checklist, a fundamental tool in hazard identification, was employed. This written compilation of hazards and hazardous events derived from past experiences helps in systematically considering safety aspects related to the study object.

The objectives of a checklist analysis include:

- Identifying all relevant hazards during intended use, foreseeable misuse, and all interactions with the study object.
- Identifying necessary controls and safeguards to mitigate the identified hazards.

Several industry-specific checklists exist, tailored for different purposes. For instance, ISO 17776 provides a comprehensive checklist for the offshore oil and gas industry (Duijm, 2015). These checklists also provided invaluable tools to systematically identify potential problems and contribute to a more complete hazard identification process.

Structured self-administered questionnaires were used to rate the likelihood and severity of identified hazards. The questionnaire was meticulously designed with closed-ended questions, aligning with the study's objectives. Additionally, the questionnaire incorporated Likert scale responses, allowing participants to express their opinions on the likelihood and severity of hazards.

2.7 *Validity/reliability of instrument*

In this study, ensuring the reliability and validity of the instruments—namely, the Checklist and the Questionnaire—was of paramount importance to guarantee the accuracy and credibility of the collected data. Questionnaire's reliability was established through rigorous pilot testing. A sample group of participants answered the questionnaire, and the consistency of their responses was analyzed. Adjustments were made based on this feedback, ensuring the questions were clear and reliable in measuring the intended constructs.

Content validity was utilized in validating the instruments. For the checklist, content validity was achieved by ensuring the hazards identified were in line with established hazard reporting in the oil and gas industry such as the ISO 17776. Additionally, the questionnaire was reviewed by experts in the field to ensure its relevance and appropriateness for the study's objectives.

*2.8 Methods of data analysis*

In this study, a comprehensive approach to data analysis was employed to extract meaningful insights from the collected data. The analysis involved a multi-faceted process, incorporating both quantitative and qualitative techniques. The following methods were utilized:

Descriptive statistics were employed to analyze the data obtained from the questionnaire. Specifically, mean likelihood and severity ratings were calculated. This statistical approach provided a clear understanding of the average perceptions regarding the likelihood and severity of identified hazards among the participants.

A semi-quantitative risk assessment was conducted utilizing a risk matrix. This method allowed for the categorization of identified hazards based on their likelihood and severity ratings. By plotting these ratings on a risk matrix, hazards were classified into different risk levels, such as low, moderate, high, or critical. This semi-quantitative assessment provided a visual representation of the overall risk landscape, highlighting areas of immediate concern.

Risk-based modeling techniques were applied to assess and predict potential future risks within the studied context. By utilizing historical data and the insights gained from the risk matrix and fault tree analysis, predictive models were developed. These models allowed for the estimation of future risk scenarios based on different variables and factors. Risk-based modelling provided a forward-looking perspective, aiding in proactive risk mitigation strategies.

## 3. Results and Discussion

The data, as elucidated in the tables and figures, provide a detailed analysis of demographic characteristics, perceptions of hazards, and risk assessments. The response rate of 91.07% for completed and usable questionnaires (Table 1) indicates a high level of engagement among the participants, suggesting that the findings are representative of the industry's workforce. The demographic breakdown (Table 2) reveals a predominantly male workforce (77.04%) with a significant proportion of respondents holding Post Graduate Degrees (62.24%). This demographic composition is crucial for interpreting the survey results, particularly in terms of educational background influencing hazard perception.

The study identifies a range of hazards prevalent in the oil and gas industry, with storms and rough sea, oil spills, and gas leaks being the most acknowledged (Table 3). The use of a 4-point Likert scale to assess the likelihood and severity of hazards (Tables 4, 5, 7, 8, 10, etc.) provides a nuanced understanding of the risks. For instance, poor design or construction and valve failure are perceived as highly likely and severe hazards, as evidenced by their high risk scores (Tables 6, 9, 15, 18, 21, 24). The risk matrices (Figures 3, 4, etc.) visually summarize the combined impact of likelihood and severity, enabling a quick comprehension of the most critical hazards. The categorization of risks into 'Very High,' 'High,' 'Moderate,' and 'Low' allows for prioritized risk management strategies. The goodness of fit and model parameters (Tables 25, 26, 27) provide a statistical backbone to the survey findings. The model's adjusted $R^2$ of 0.896 indicates a high level of variance in risk scores explained by the factors of 'Likelihood' and 'Severity'. This statistical evidence strengthens the reliability of the risk assessment process.

While the study provides a thorough analysis, it has limitations. The demographic skew towards a predominantly male and highly educated workforce might influence hazard perception and may not reflect the views of a more diverse workforce. Additionally, cultural and organizational factors within the Nigerian oil and gas sector, which may influence hazard perception and risk assessment, have not been explicitly addressed.

**Table 1 - Responses to the distributed questionnaires to oil and gas workers**

| Survey Parameters | Oil and Gas Workers | |
|---|---|---|
| | No. of Questionnaires | Percentage |
| Total copies of questionnaire distributed | 392 | 100% |
| Unreturned copies of questionnaire | 10 | 2.60% |
| Incomplete copies of questionnaire | 25 | 6.49% |
| Completed and usable questionnaire | 357 | 91.07% |

**Table 2 - Demographic characteristics of all respondents to the questionnaire from the study alignments.**

| Demographic Criteria | Gender | Frequency | Percentage (%) | Cumulative Percentage (%) |
|---|---|---|---|---|
| Gender | Male | 302 | 77.04 | 77.04 |
| | Female | 90 | 22.96 | 100 |
| Highest Qualification | Secondary School | 0 | 0 | 0 |
| | Diploma | 0 | 0 | 0 |
| | Bachelor Degree | 148 | 37.76 | 37.76 |
| | Post Graduate Degree | 244 | 62.24 | 100 |
| Age | 18 to 30 years | 0 | 0 | 0 |
| | 31 to 40 years | 28 | 7.14 | 7.14 |
| | 41 to 50 years | 198 | 50.51 | 57.65 |
| | 51 to 60 years | 161 | 41.07 | 98.72 |
| | Above 60 | 5 | 1.28 | 100 |

Number of respondents = 395

**Table 3 - Prevalence Hazardous Event in the oil and gas industry in Nigeria.**

| Hazardous Event | Percentage Agreement | Ranks |
|---|---|---|
| Storms and Rough Sea | 98.65% | 1 |
| Oil Spills | 80.56 | 2 |
| Gas leak | 75.69 | 3 |
| Fire/Explosion | 74.25 | 4 |
| Structural Failures | 70.68 | 5 |
| Security Threat | 68.75 | 6 |
| Blowout | 65.25 | 7 |

**Table 4 - Mean response for likelihood of hazard (4-point Likert scale)**

| Index | Likelihood of Hazard | Mean | Mode | Std. Deviation | Rank |
|---|---|---|---|---|---|
| L1 | Poor design or construction | 3.56 | 4 | 0.86 | 1 |
| L2 | Excessive vibration | 2.99 | 3 | 0.61 | 3 |
| L3 | Accidents impact on the platform | 2.55 | 3 | 0.66 | 5 |
| L4 | Substandard material used | 3.28 | 4 | 0.17 | 2 |
| L5 | Overloading of the platform | 2.79 | 3 | 0.58 | 4 |

Likert Scale (VL-Very Likely, L-Likely, U-Unlikely, VU-Very Unlikely)

**Table 5 - Mean response for Severity of hazard (4-point Likert scale).**

| Index | Severity of Hazard | Mean | Mode | Std. Deviation | Rank |
|---|---|---|---|---|---|
| L1 | Poor design or construction | 3.69 | 4 | 0.86 | 1 |
| L2 | Excessive vibration | 2.78 | 3 | 0.61 | 5 |
| L3 | Accidents impact on the platform | 2.89 | 3 | 0.76 | 4 |
| L4 | Substandard material used | 3.25 | 4 | 0.97 | 3 |
| L5 | Overloading of the platform | 3.35 | 4 | 0.18 | 2 |

Likert Scale (C-Catastrophic, S-Severe, D-Damage, MD-Minor Damage)

**Table 6 - Risk analysis of hazard.**

| Index | Hazard | Likelihood | Severity | Risk Score | Rank Rating |
|---|---|---|---|---|---|
| L1 | Poor design or construction | 3.56 | 3.69 | 13.14 | Very High |
| L2 | Excessive vibration | 2.99 | 2.78 | 8.31 | High |
| L3 | Accidents impact on the platform | 2.55 | 2.89 | 7.37 | High |
| L4 | Substandard material used | 3.28 | 3.25 | 10.66 | High |
| L5 | Overloading of the platform | 2.79 | 3.35 | 9.35 | High |

Risk score = likelihood x severity

**Table 7 - Mean response for likelihood of hazard (4-point Likert scale).**

| Index | Likelihood of Hazard |
|---|---|
| L1 | Valve failure |
| L2 | Seal failure |
| L3 | Design flaws |
| L4 | Metal deterioration |

Likert Scale (VL-Very Likely, L-Likely, U-Unlikely, VU-Very Unlikely)

**Table 8 - Mean response for Severity of hazard (4-point Likert scale).**

| Index | Severity of Hazard |
|---|---|
| L1 | Valve failure |
| L2 | Seal failure |
| L3 | Design flaws |
| L4 | Metal deterioration |

Likert Scale (C-Catastrophic, S-Severe, D-Damage, MD-Minor Damage)

**Table 9 - Risk analysis of hazard.**

| Index | Hazard | Likelihood | Severity | Risk Score | Rank Rating |
|---|---|---|---|---|---|
| L1 | Valve failure | 3.78 | 3.89 | 14.70 | Very High |
| L2 | Seal failure | 3.68 | 3.78 | 13.91 | Very High |
| L3 | Design flaws | 2.56 | 3.56 | 9.11 | Very High |
| L4 | Metal deterioration | 3.21 | 3.89 | 12.49 | Very High |

Risk score = likelihood x severity

| **Consequences** | | Minor Damage | Damage | Severe | Catastrophic |
|---|---|---|---|---|---|
| **Likelihood** | Very Likely | | | | L1, L2, |
| | Likely | | | | L3, L4 |
| | Unlikely | | | | |
| | Highly Unlikely | | | | |
| | **Risk Rating** | Low | Moderate | High | Very High |

**Figure 3 - Risk matrix showing risk level for gas leak hazards.**

| **Consequences** | | Minor Damage | Damage | Severe | Catastrophic |
|---|---|---|---|---|---|
| **Likelihood** | Very Likely | | | | L1 |
| | Likely | | | L2, L3, L4, L5 | |
| | Unlikely | | | | |
| | Highly Unlikely | | | | |
| | **Risk Rating** | Low | Moderate | High | Very High |

**Figure 4 - Risk matrix showing risk level for structural failure hazards.**

**Table 10 - Mean response for likelihood of hazard (4-point Likert scale).**

| Index | Likelihood of Hazard | Mean | Mode | Std. Deviation | Rank |
|---|---|---|---|---|---|
| L1 | Agitation by host community | 3.56 | 4 | 0.78 | 2 |
| L2 | Militant and kidnapper | 3.17 | 3 | 0.68 | 3 |
| L3 | Piracy | 2.12 | 2 | 0.66 | 4 |
| L4 | Pipeline vandalism | 3.78 | 4 | 0.68 | 1 |
| L5 | lack of security personnel | 1.78 | 2 | 0.26 | 5 |

Likert Scale (VL-Very Likely, L-Likely, U-Unlikely, VU-Very Unlikely)

**Table 11 - Mean response for severity of hazard (4-point Likert scale).**

| Index | Severity of Hazard | Mean | Mode | Std. Deviation | Rank |
|---|---|---|---|---|---|
| L1 | Agitation by host community | 3.39 | 4 | 0.85 | 3 |
| L2 | Militant and kidnapper | 3.53 | 3 | 0.31 | 2 |
| L3 | Piracy | 3.12 | 4 | 0.66 | 4 |
| L4 | Pipeline vandalism | 3.65 | 4 | 0.48 | 1 |
| L5 | lack of security personnel | 2.75 | 3 | 0.63 | 5 |

Likert Scale (C-Catastrophic, S-Severe, D-Damage, MD-Minor Damage)

**Table 12 - Risk analysis of hazard.**

| Index | Hazard | Likelihood | Severity | Risk Score | Rank Rating |
|---|---|---|---|---|---|
| L1 | Agitation by host community | 3.56 | 3.39 | 12.07 | Very High |
| L2 | Militant and kidnapper | 3.17 | 3.53 | 11.19 | Very High |
| L3 | Piracy | 2.12 | 3.12 | 6.61 | Moderate |
| L4 | Pipeline vandalism | 3.78 | 3.65 | 13.80 | Very High |
| L5 | lack of security personnel | 1.78 | 3.05 | 5.43 | Moderate |

Risk score = likelihood x severity

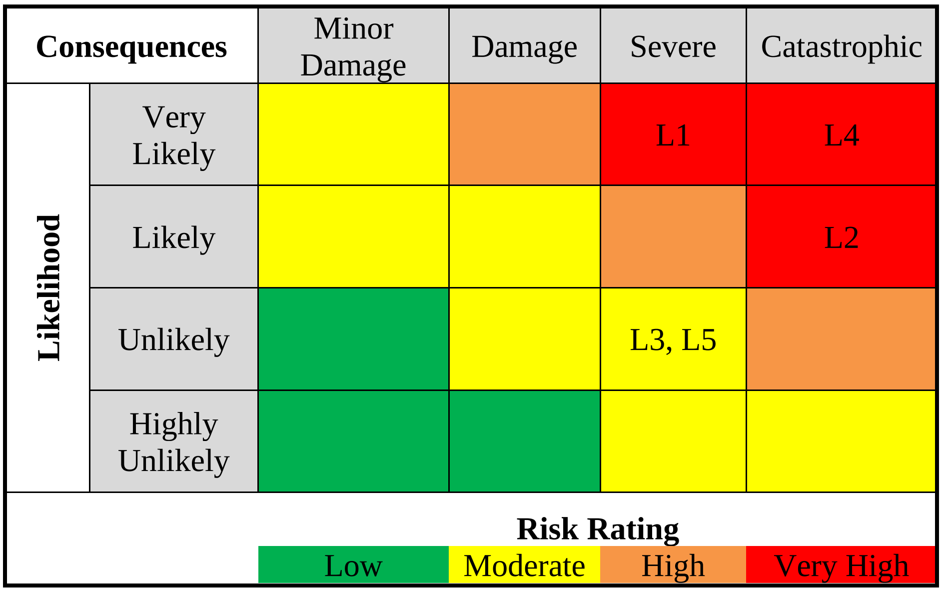


**Figure 5 - Risk matrix showing risk level for security threat hazards.**

**Table 13 - Mean response for likelihood of hazard (4-point Likert scale).**

| Index | Likelihood of Hazard | Mean | Mode | Std. Deviation | Rank |
|---|---|---|---|---|---|
| L1 | Improper storage of inflammable substance | 3.42 | 3 | 0.72 | 2 |
| L2 | Poor electrical design or connection | 2.75 | 3 | 0.25 | 5 |
| L3 | Failure of valves | 3.22 | 3 | 0.89 | 4 |
| L4 | hot work activities | 3.33 | 3 | 0.63 | 3 |
| L5 | Gas accumulation in confined space | 3.86 | 4 | 0.56 | 1 |

Likert Scale (VL-Very Likely, L-Likely, U-Unlikely, VU-Very Unlikely)

**Table 14 - Mean response for severity of hazard (4-point Likert scale).**

| Index | Severity of Hazard | Mean | Mode | Std. Deviation | Rank |
|---|---|---|---|---|---|
| L1 | Improper storage of inflammable substance | 3.82 | 4 | 0.26 | 2 |
| L2 | Poor electrical design or connection | 3.57 | 3 | 0.36 | 3 |
| L3 | Failure of valves | 3.18 | 3 | 0.38 | 5 |
| L4 | hot work activities | 3.23 | 3 | 0.43 | 4 |
| L5 | Gas accumulation in confined space | 3.98 | 4 | 0.66 | 1 |

Likert Scale (C-Catastrophic, S-Severe, D-Damage, MD-Minor Damage)

**Table 15 - Risk analysis of hazard**

| Index | Hazard | Likelihood | Severity | Risk Score | Rank Rating |
|---|---|---|---|---|---|
| L1 | Improper storage of inflammable substance | 3.42 | 3.82 | 13.06 | Very High |
| L2 | Poor electrical design or connection | 2.75 | 3.57 | 9.54 | Very High |
| L3 | Failure of valves | 3.22 | 3.18 | 10.24 | High |
| L4 | hot work activities | 3.33 | 3.23 | 10.76 | High |
| L5 | Gas accumulation in confined space | 3.86 | 3.98 | 15.36 | Very High |

Risk score = likelihood x severity

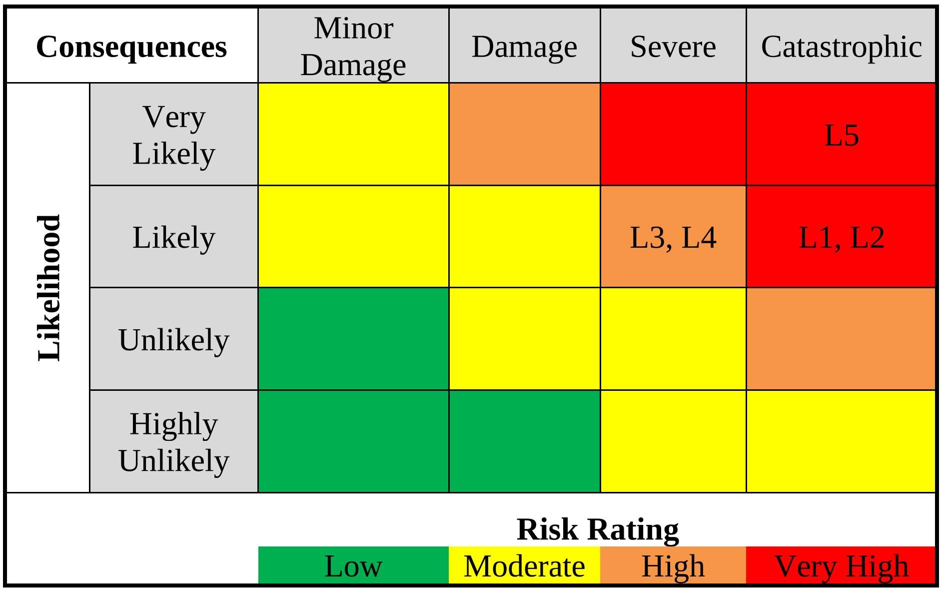


**Figure 6 - Risk matrix showing risk level for fire and explosion hazards.**

**Table 16 - Mean response for likelihood of hazard (4-point Likert scale).**

| Index | Likelihood of Hazard | Mean | Mode | Std. Deviation | Rank |
|---|---|---|---|---|---|
| L1 | Corroded pipeline | 3.78 | 4 | 0.76 | 2 |
| L2 | Worn-out seal | 3.17 | 3 | 0.71 | 3 |
| L3 | Improper welding | 2.48 | 2 | 0.66 | 5 |
| L4 | Malfunctioning of valve | 3.13 | 3 | 0.67 | 4 |
| L5 | Crack and leakage | 3.88 | 4 | 0.68 | 1 |

Likert Scale (VL-Very Likely, L-Likely, U-Unlikely, VU-Very Unlikely)

**Table 17 - Mean response for severity of hazard (4-point Likert scale).**

| Index | Severity of Hazard | Mean | Mode | Std. Deviation | Rank |
|---|---|---|---|---|---|
| L1 | Corroded pipeline | 3.22 | 3 | 0.76 | 3 |
| L2 | Worn-out seal | 3.18 | 3 | 0.71 | 5 |
| L3 | Improper welding | 3.20 | 3 | 0.66 | 4 |
| L4 | Malfunctioning of valve | 3.25 | 3 | 0.67 | 2 |
| L5 | Crack and leakage | 3.45 | 3 | 0.68 | 1 |

Likert Scale (C-Catastrophic, S-Severe, D-Damage, MD-Minor Damage)

**Table 18 - Risk analysis of hazard.**

| Index | Hazard | Likelihood | Severity | Risk Score | Rank Rating |
|---|---|---|---|---|---|
| L1 | Corroded pipeline | 3.78 | 3.22 | 12.17 | Very High |
| L2 | Worn-out seal | 3.17 | 3.18 | 10.08 | High |
| L3 | Improper welding | 2.48 | 3.20 | 7.94 | Moderate |
| L4 | Malfunctioning of valve | 3.13 | 3.25 | 10.17 | High |
| L5 | Crack and leakage | 3.88 | 3.45 | 13.39 | Very High |

Risk score = likelihood x severity

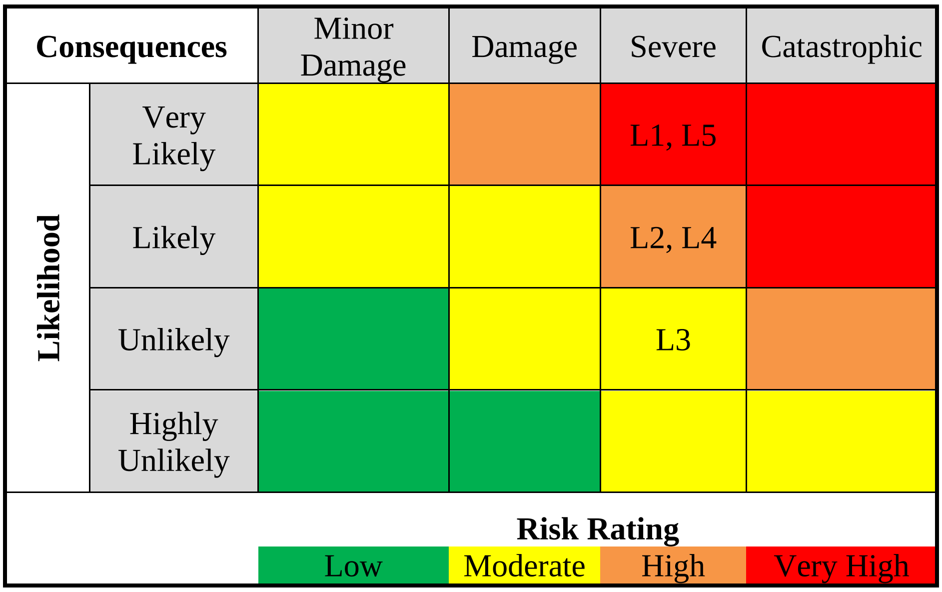


**Figure 7 - Risk matrix showing risk level for oil spill hazards.**

**Table 19 - Mean response for likelihood of hazard (4-point Likert scale).**

| Index | Likelihood of Hazard | Mean | Mode | Std. Deviation | Rank |
|---|---|---|---|---|---|
| L1 | Gas influx into the wellbore | 3.40 | 3 | 0.33 | 2 |
| L2 | loss of well control | 3.65 | 4 | 0.45 | 1 |
| L3 | fluid ingestion into the well | 3.28 | 3 | 0.86 | 4 |
| L4 | Elevated formation pressure | 3.33 | 3 | 0.17 | 3 |
| L5 | malfunction of safety system | 2.88 | 3 | 0.89 | 5 |

Likert Scale (VL-Very Likely, L-Likely, U-Unlikely, VU-Very Unlikely)

**Table 20 - Mean response for severity of hazard (4-point Likert scale).**

| Index | Severity of Hazard | Mean | Mode | Std. Deviation | Rank |
|---|---|---|---|---|---|
| L1 | Gas influx into the wellbore | 3.45 | 4 | 0.36 | 3 |
| L2 | loss of well control | 3.89 | 3 | 0.51 | 1 |
| L3 | fluid ingestion into the well | 3.38 | 4 | 0.78 | 4 |
| L4 | Elevated formation pressure | 3.67 | 4 | 0.29 | 2 |
| L5 | malfunction of safety system | 3.25 | 3 | 0.88 | 5 |

Likert Scale (C-Catastrophic, S-Severe, D-Damage, MD-Minor Damage)

**Table 21 - Risk analysis of hazard.**

| Index | Hazard | Likelihood | Severity | Risk Score | Rank Rating |
|---|---|---|---|---|---|
| L1 | Gas influx into the wellbore | 3.40 | 3.45 | 11.73 | High |
| L2 | loss of well control | 3.65 | 3.89 | 14.20 | Very High |
| L3 | fluid ingestion into the well | 3.28 | 3.38 | 11.09 | High |
| L4 | Elevated formation pressure | 3.33 | 3.67 | 12.22 | Very High |
| L5 | malfunction of safety system | 2.88 | 3.25 | 9.36 | High |

Risk score = likelihood x severity

| Likelihood | Consequences | Minor Damage | Damage | Severe | Catastrophic |
|---|---|---|---|---|---|
| | Very Likely | | | | L2 |
| | Likely | | | L1, L3, L5 | L4 |
| | Unlikely | | | | |
| | Highly Unlikely | | | | |

**Risk Rating**

Low | Moderate | High | Very High

**Figure 8 - Risk matrix showing risk level for blowout hazards.**

**Table 22 - Mean response for likelihood of hazard (4-point Likert scale).**

| Index | Likelihood of Hazard | Mean | Mode | Std. Deviation | Rank |
|---|---|---|---|---|---|
| L1 | Strong wind | 3.35 | 3 | 0.76 | 3 |
| L2 | Heavy rainfall | 3.42 | 3 | 0.71 | 2 |
| L3 | Storm surges | 3.89 | 4 | 0.66 | 1 |
| L4 | Lightning strikes | 2.45 | 2 | 0.67 | 5 |
| L5 | Turbulent water | 3.15 | 3 | 0.68 | 4 |

Likert Scale (VL-Very Likely, L-Likely, U-Unlikely, VU-Very Unlikely)

**Table 23 - Mean response for severity of hazard (4-point Likert scale).**

| Index | Severity of Hazard | Mean | Mode | Std. Deviation | Rank |
|---|---|---|---|---|---|
| L1 | Strong wind | 3.32 | 3 | 0.26 | 2 |
| L2 | Heavy rainfall | 2.45 | 3 | 0.91 | 4 |
| L3 | Storm surges | 3.78 | 4 | 0.36 | 1 |
| L4 | Lightning strikes | 2.43 | 2 | 0.27 | 5 |
| L5 | Turbulent water | 3.20 | 3 | 0.68 | 3 |

Likert Scale (C-Catastrophic, S-Severe, D-Damage, MD-Minor Damage)

**Table 24 - Risk analysis of hazard.**

| Index | Hazard | Likelihood | Severity | Risk Score | Rank Rating |
|---|---|---|---|---|---|
| L1 | Strong wind | 3.35 | 3.32 | 11.12 | High |
| L2 | Heavy rainfall | 3.42 | 2.45 | 8.38 | Moderate |
| L3 | Storm surges | 3.89 | 3.78 | 14.70 | Very High |
| L4 | Lightning strikes | 2.45 | 2.43 | 5.95 | Moderate |
| L5 | Turbulent water | 3.15 | 3.20 | 10.08 | High |

Risk score = likelihood x severity

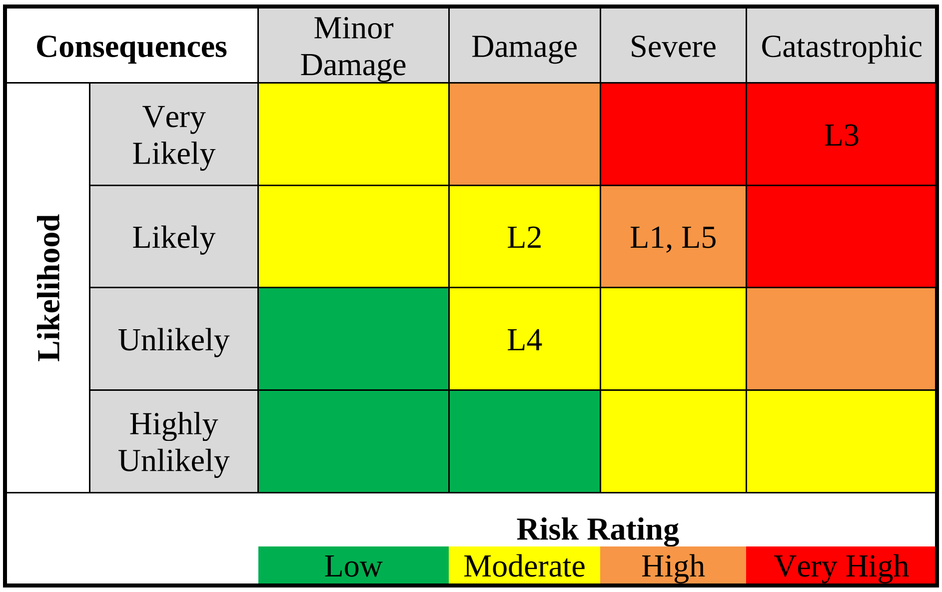


**Figure 9 - Risk matrix showing risk level for Storms and Rough Sea hazards.**

**Table 25 - Goodness of fit.**

| | |
|---|---|
| Observations | 401 |
| Sum of weights | 401 |
| DF | 398 |
| $R^2$ | 0.300 |
| Adjusted $R^2$ | 0.896 |
| MSE | 0.842 |
| RMSE | 0.492 |
| MAPE | 14.259 |
| DW | 1.769 |
| Cp | 3.000 |
| AIC | -565.391 |
| SBC | -553.409 |
| PC | 0.711 |

**Table 26 - Analysis of variance.**

| Source | DF | Sum of squares | Mean squares | F | Pr > F |
|---|---|---|---|---|---|
| Model | 2 | 41.331 | 20.666 | 85.275 | **<0.0001** |
| Error | 398 | 96.452 | 0.242 | | |
| Corrected Total | 400 | 137.783 | | | |

*Computed against model Y=Mean(Y)*

**Table 27 - Model parameters.**

| Source | Value | Standard error | t | Pr > \|t\| | Lower bound (95%) | Upper bound (95%) |
|---|---|---|---|---|---|---|
| Intercept | 1.439 | 0.171 | 8.430 | **<0.0001** | 1.103 | 1.775 |
| Likelihood | -0.047 | 0.057 | -0.823 | 0.411 | -0.158 | 0.065 |
| Severity | 0.607 | 0.051 | 11.925 | **<0.0001** | 0.507 | 0.707 |

Model Equation
Risk score = 1.4390521745-4.6523787824E-02*Likelihood+0.60712232429*Severity

## 4. Conclusion

In conclusion, this study sheds light on the significant safety challenges within Nigeria's oil and gas industry. By employing a semi-quantitative methodology, it successfully identifies key hazards and underscores the necessity for specific interventions to bolster safety. The findings reveal critical areas such as infrastructure inadequacies, valve and seal failures, security concerns, and oil spill risks. Addressing these issues is crucial for enhancing the safety performance in the industry, ensuring the wellbeing of workers, and maintaining operational integrity. This research provides a foundational step towards a more secure and sustainable future in the oil and gas sector in Nigeria.

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