Asian Journal of Advanced Research and Reports

Volume 18, Issue 6, Page 252-265, 2024; Article no.AJARR.117176
ISSN: 2582-3248

Improving Safety Performance in Nigeria's Oil and Gas Industry: A Comparative Risk Model Analysis

Mgbowaji Zacchaeus [a*], John Nwenearizi Ugbebor [b], Ikechukwu Ozoemenam Agbagwa [a] and Unyeawaji Brownson Ntesat [c]

[a] World Bank Africa Centre of Excellence in Oilfield Chemicals Research, University of C
[b] Centre for Occupational Health, Safety and Environment (COHSE), University of Port Harcourt, Choba, Rivers State, Nigeria.
[c] Department of Agricultural and Environmental Engineering, Rivers State University, Nkpolu-Oroworukwo, PMB 5080, Port Harcourt, Nigeria.

Authors' contributions

This work was carried out in collaboration among all authors. Authors MZ, JNU, UBN and IOA conceptualized the study, analyzed and interpreted the data. Authors MZ and UBN drafted the manuscript. Authors JNU and IOA revised the manuscript with critical and intellectual content. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/ajarr/2024/v18i6669

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/117176

Original Research Article

Received: 05/03/2024
Accepted: 09/05/2024
Published: 14/05/2024

ABSTRACT

This study examined a risk-based model for the enhancement of safety performance in Nigeria's oil

---

**Corresponding author: Email: mgbowaji@gmail.com;*

***Cite as:** Zacchaeus, M., Ugbebor, J. N., Agbagwa, I. O., & Ntesat, U. B. (2024). Improving Safety Performance in Nigeria's Oil and Gas Industry: A Comparative Risk Model Analysis. Asian Journal of Advanced Research and Reports, 18(6), 252–265. https://doi.org/10.9734/ajarr/2024/v18i6669*

and gas sector. A non-probabilistic convenience sampling method was adopted to consider the selected five oil and gas companies in operations within this study area. A quantitative approach was employed using a comprehensive hazard checklist developed based on industry standards and expert insights, utilizing a structured questionnaire to collect data from industry experts, workers, and stakeholders on hazard likelihood and severity. The 392-sample size used was selected purposively to represent the total population of oil and gas workers in these companies. 392 copies of the questionnaire were administered, and 357 copies were used for the study, with a response rate of 91.07%. The analysis revealed key risk factors for oil and gas offshore operations, such as structural failure due to poor design, valve and seal failures, security threats, fire/ explosions, blowouts, and oil spills. Modelling the risk score against the likelihood showed a good model fit (R^2 = 0.831), indicating that the model explains 83.1% of the variance, and the likelihood coefficient was positive and significant. Modelling the risk score against the severity also showed a reasonably good fit (R^2 = 0.676), with the severity coefficient being positive and significant. However, modelling the risk score against both likelihood and severity showed excellent fit (R^2 = 0.994), explaining 99.4% of the variance. The likelihood and severity coefficients were positive and highly significant; this indicated that an increase in either factor would lead to an increase in the risk score. These models provide a quantitative way to assess risk in the oil and gas industry based on the key factors of likelihood and severity of potential hazards. This study bridged theoretical risk management concepts with practical applications and provided actionable recommendations for policymakers, significantly enhancing safety performance in a crucial economic sector.

Keywords: Questionnaire; assessment; hazardous; likelihood; severity; modelling risk management.

1. INTRODUCTION

Owing to its substantial contribution to GDP and status as the principal generator of export revenue, the oil and gas sector has historically occupied a critical position within Nigeria's economic sphere [1,2]. The sector holds significant importance for the Nigerian economy, contributing over 70% of the country's revenue through product exports [3]. According to [4], Nigeria is among the continent's leading oil and gas producers. Oil also accounts for much of the nation's GDP, foreign exchange earnings, and budgetary revenues [5]. Several safety concerns, including worker accidents, equipment malfunctions, pipeline sabotage, and oil spills, beset the country’s oil and gas sector. These incidents' consequences illustrate the gravity of the issues from fatalities, extensive environmental damage, and substantial financial losses [6].

From 2018 to 2022, approximately 412 people were killed because of negligence in the storage and distribution of petroleum products. These deaths were primarily attributed to fires at fuel retail stations and tanker accidents, highlighting the sector's lack of adequate health, safety, and environmental practices [7]. The tugboat, Jascon-4, capsized in May 2013 while performing towing operations for Chevron Offshore Escravos, killing 12 crew members. This incident could have been avoided if proper safety precautions, such as upgraded safety jackets and others [8].
More than two millennia ago, the Athenians displayed proficiency in risk assessment [9]. However, risk assessment and management as a scientific discipline is relatively new, having emerged within the last thirty to forty years. This is the era of the first academic journals, conferences, and publications that discuss the fundamental ideas and concepts of risk assessment and management. These fundamental concepts and ideas, which still influence the field today, are the source of risk assessment and management procedures that have been in use since the 1970s and 1980s. Nevertheless, since then, the field has made tremendous strides. Thanks to many new and improved analytical tools, risk analysis is used in almost every aspect of society [10]. Numerous industries, including finance, insurance, healthcare, oil and gas, safety engineering, environmental studies, and project management, rely heavily on the idea of risk and how to evaluate it [11].

Lockhart et al., [12] define risk as the combination of the probability of an event happening and its consequences, which can be either beneficial or detrimental. As determined by [13], risk encompasses any potential hazard that can adversely affect organizations, economies, or societies. Per the [14] definition, safety is devoid of unfavourable consequences, such as accidents and incidents. Safety can be classified as a characteristic or quality that is essential and sufficient to ensure that events that can cause harm to humans and the environment are maintained at a sufficiently low level. [15] define safety as effectively controlling unintentional damage to the environment, resources, and individuals to maximize benefits. According to [16], workers in the oil and gas industry are exposed to various safety hazards. They risk sustaining injuries such as slips, trips, falls, fire explosions, and being trapped in confined spaces, as shown in Fig. 1.

Risk can also be defined as the likelihood of losing something of value, which can be physical (such as health or property), financial, or intangible (such as reputation). It refers to the effects of uncertainty on objectives, which may have positive or negative consequences or both [18],[19]. Risk is often defined by sources, events, outcomes, and likelihoods. Risk can come from inherent variability or uncertainties related to human behaviour, organizational structures, or societal influences that make it hard to predict any event. Thus, risk cannot always be quantified as events, consequences, and likelihoods [20]. [21] define risk as the product of the probability of harm occurring and the severity of the harm itself. The difference between risk is, in fact, a factor in the comprehensive evaluation of risk scenarios and possibilities. Risk is generally distinguished from hazard by the probability that an individual will sustain harm due to exposure to the hazard. [22] defines a hazard as an occurrence that can potentially induce a negative consequence regardless of the circumstances. On the other hand, risk typically signifies the likelihood that an adverse effect will occur in actual or plausible situations while also considering the substance's potency and the level of exposure to it. [17] categorized the risks in the oil and gas industry into two distinct classifications. The initial category encompasses safety hazards and potential harm, as illustrated in Fig. 1. The second category encompasses health hazards and the potential for illness.

Furthermore, [23] asserted that motor vehicle accidents are a widespread hazard to safety and injury in the industry, as illustrated in Fig. 1. These accidents usually occur when travelling on dangerous routes or covering extensive distances. Fig. 1 demonstrates that workers in oil and gas industries are susceptible to contact injuries, predominantly caused by tools and machinery. [24] reported that fire and explosion pose significant health and safety hazards in the oil and gas industry because of the abundance of highly flammable and other potential ignition sources. [[25,26] highlighted the inherent biological hazards faced by workers in the oil and gas sector. It was also observed that workers commonly suffer from viral, parasitic, and bacterial infections. In addition, there have been reports of psychological hazards among these workers [27].

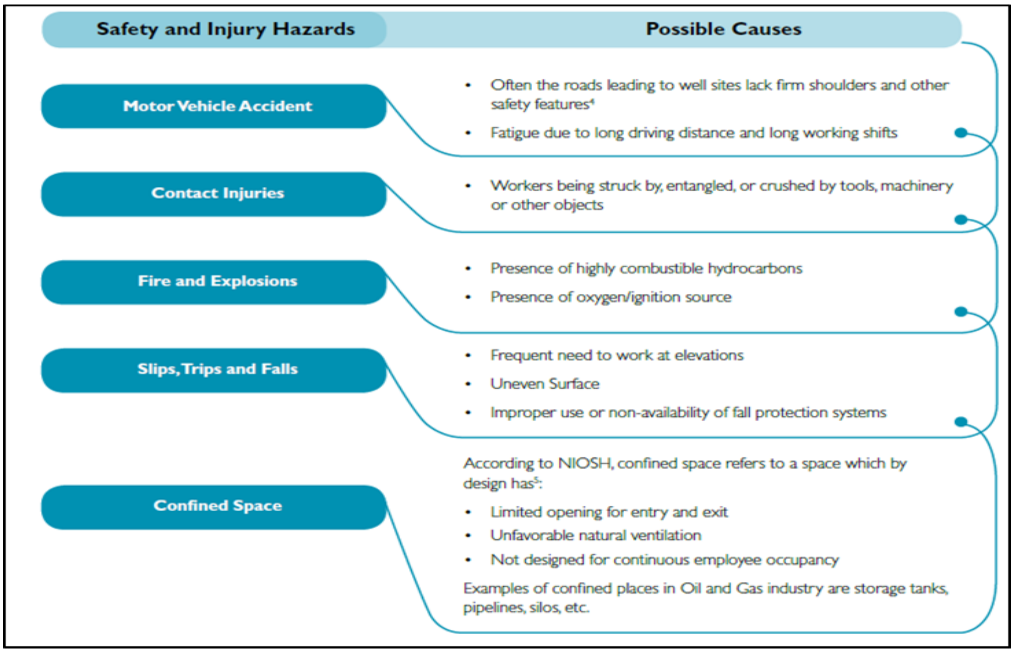

Fig. 1. Safety and Health Injuries in the Oil and Gas Sector [17]

Risk assessment entails identifying risks, analyzing them, and using the insights gained to evaluate risk by drawing conclusions about their relative significance in relation to the organization's objectives and performance thresholds. This process helps to inform decisions about whether treatment is required, treatment priorities, and risk-reduction actions [20].

According to [24,28], risk is defined as the effect of uncertainty on goals or objectives. This impact can manifest as beneficial, detrimental, or a departure from the anticipated outcome. The aim of this study is to identify and characterize the critical risk factors contributing to Nigeria's oil and gas industry safety incidents and to develop a risk-based intervention model tailored to the identified risk factors.

2. MATERIALS AND METHODS

2.1Study Area

The study was carried out in the southern region (Niger Delta) of Nigeria. One of the largest in the world, this wetland is renowned for its rich biodiversity and is interconnected with the Niger River via an intricate network of creeks, rivers, and tributaries. Roughly 70,000 km³ (27,000 sq mi) or 7.5% of Nigeria's total land area is made up of the Niger Delta [29]. The region, home to over 30 million people, is between latitudes $4^0$16’48’’ and 7^o51’36’’ and longitudes 4^o16’12’’ and 9^o24’. Abia, Akwa Ibom, Bayelsa, Cross River, Delta, Edo, Imo, Ondo, and Rivers are among its nine states. The production and exploration of oil and gas, which significantly boosts Nigeria's economy and the world's oil supply, depends on the Niger Delta. Human activity and the environment coexist in a delicate balance within the infrastructure, pipelines, wells, and oil fields.

2.2 Research Design

A quantitative research design approach was used in this study. With an emphasis on the Niger Delta, the research design was chosen to create a comprehensive risk-based solution for the oil and gas sector in Nigeria. To understand the risk environment of the industry, several thorough techniques were used, such as risk-based models, fault tree analysis, hazard checklists, qualitative risk assessments and questionnaires. A comprehensive hazard checklist was developed to identify hazards utilizing industry standards (ISO 17776) and professional expertise. The industry's common hazards were methodically identified and recorded using the checklist. After the hazards were identified, stakeholders, workers, and industry professionals in the Niger Delta's oil and gas sector were given a structured questionnaire which was validated, checked using content validity (test and retest with 6 months interval and high correlation) and HSE industry experts ensuring that the questions measuring the risks in oil and gas industry were valid and captured what it was intended to measure. The purpose of the questionnaires was to collect professional opinions and ratings regarding the likelihood and gravity of various risks associated with the oil and gas sector. The mean, mode, standard deviation, minimum, and maximum values of the hazard ratings derived from the questionnaires

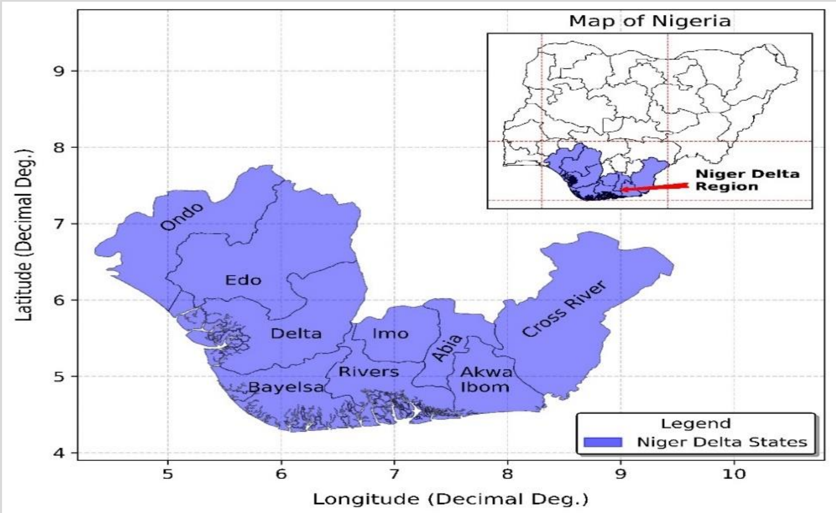

Fig. 2. Map of the study area

were all computed as descriptive statistics. The quantitative analysis yielded significant insights into the perceived risk landscape of the industry. To identify patterns and trends in risk perceptions, comparative analyses were also conducted with respect to differences in hazard ratings among various categories, such as types of hazards and job roles. Additionally, quantitative information from checklists and questionnaires was used in qualitative risk assessment techniques. The risks connected to the identified hazards were thoroughly assessed using a qualitative approach. Each identified risk was evaluated for possible impact and likelihood of occurrence using expert opinions and industry-specific knowledge. A safer working environment in Nigeria's oil and gas industry can be developed by integrating quantitative and qualitative findings in targeted risk-based interventions.

2.3 Exclusion Criteria, Study Population, Sampling Size and Technique

The study focused on workers who are employed by specific oil and gas companies in the Niger Delta region of Nigeria. These workers include male and female drivers, cleaners, and security personnel between 18 and 60. The sample size for this study was meticulously chosen to guarantee robust statistical analysis and dependable results. The study utilizes diverse sampling techniques to guarantee that the sample precisely reflects the population. Oil and gas companies were selected using a non-probabilistic method, specifically convenience sampling. The selection of this method was based on pragmatic factors such as the ease of access to the facility and the willingness of the company to participate. Only companies that permitted the collection of employee names and email addresses within their premises were deemed eligible and this gave rise to the selection of five businesses within the local area. Purposive sampling was used to select individual survey respondents. Individuals with previous experience in risk assessment, specifically in the oil and gas industry were deliberately selected for their expertise and applicability.

2.3.1 Exclusion criteria

i. Interns were not allowed to participate in the survey.

ii. National Youth Service Corps members were not allowed to participate in the survey.

The staff members' names and email addresses from the chosen companies were arranged in a Microsoft Excel spreadsheet. Eligible workers were invited to participate in the survey by receiving the questionnaire via an online platform (Google Forms).

Cochran's (1978) sample size formula for proportions was used to determine the appropriate and representative sample size. Equation (1) provides the formula for calculating sample size, considering an estimated population size of approximately 18,712 oil and gas employees in Nigeria, according to [30], with a 95% confidence level and a 5% margin of error:

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

Where,

$n_o n_o$ = sample size
e = margin of error = 5%
p = estimated proportion of an attribute that is present in the population,
q = 1-p
Z = abscissa of the normal curve that cuts off an area α at the tails (1 - α equals the desired confidence level, i.e., 95%) = 1.96

2.4 Sample Size Calculation

$$n_o n_o = \frac{1.96^2(0.63)(0.37)}{0.05^2}$$
$$\frac{(1.96)^2(0.185)(1-0.185)}{(0.05)^2}$$
$n_o n_o$ = 350 copies of questionnaire.

A 10% allowance is provided to account for those who do not participate but subsequently drop out (non-response rate and incomplete responses). The study requires a minimum sample size of 392 individuals who meet the inclusion criteria [31].

2.5 Nature/ Sources of Data

Both primary and secondary data were used in the research project. Primary data were collected directly, as opposed to secondary data, which the researcher acquired indirectly. Copies of a structured questionnaire were given to a subset of Niger Delta oil and gas industry workers to gather primary data. These workers were selected from the sampled companies' workforces and instructed to assess their perceptions of hazards that were acknowledged using a 4-point Likert scale. The acquisition of secondary data involved conducting an extensive literature review on risk and risk assessment, risk management and controls, previous oil and gas industry incidents, safety management systems, and accident causation theories.

2.6 Methods of Data Analysis

This study employed a thorough methodology to extract significant insights from the collected data. This included quantitative and qualitative methodologies. The following were used:

2.6.1 Descriptive statistics

The data collected from the questionnaire was analyzed using descriptive statistics. The mean likelihood and severity ratings were calculated specifically. The statistical method provided a precise understanding of the participants' average opinions on the probability and seriousness of recognized hazards.

2.6.2 Qualitative risk assessment using the risk matrix

A qualitative risk assessment was carried out with the aid of a risk matrix. This technique made it possible to categorize the hazards that were found according to their likelihood and severity ratings. Based on their ratings on a risk matrix, hazards were categorized as low, moderate, high, or critical. This qualitative evaluation highlighted areas of urgent concern and provided a visual representation of the entire risk landscape (see Tables 1-4).

Table 1. Prevalent Risk Events in the Oil and Gas Industry in Nigeria [32]

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 2. Risk analysis of hazard from structural failure [32]

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 3. Risk analysis of hazard from gas leak [32]

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

Table 4. Risk analysis of hazard from security threats [32]

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

2.7 Risk-Based Model Development

This study leveraged a comprehensive database compiled from Nigeria’s oil and gas operations, encompassing January 2010 to December 2020. The database consists of operational, safety, and incident records for 5 major oil and gas companies operating within Nigeria during this timeframe. These companies represent a cross-section of the industry, including upstream exploration and production companies, midstream pipeline operators, and downstream refining and distribution firms. Operations encompassed within the dataset range from offshore deep-water drilling to onshore pipeline maintenance and refinery operations, providing a holistic view of the sector's safety landscape. Operational data critical for the analysis were obtained from a range of sources to ensure a comprehensive understanding of the sector’s risk profile such as the annual safety and operational reports from the Nigerian National Petroleum Corporation (NNPC) and the Nigerian Upstream Regulatory Commission (NUPRC); Incident and accident databases maintained by international oil and gas safety organizations; The selection of companies and the corresponding dataset were determined in collaboration with the Nigerian National Petroleum Corporation (NNPC) and the Nigerian Upstream Regulatory Commission (NUPRC), ensuring a comprehensive representation of the industry. Specific company names and sensitive information have been anonymized to maintain confidentiality and comply with data-sharing agreements. The analysis herein focuses on aggregated trends and systemic issues rather than individual company practices. This approach ensures the protection of confidential information while allowing for a thorough examination of the sector's safety performance and risk factors. To develop a risk-based model, a regression analysis was used to establish the relationship between the risk score, which served as the dependent variable, and the likelihood and severity of the hazards occurring, which served as the independent variables in the oil. The first risk-based model developed showed the relationship between the risk score and the likelihood of the hazard occurring. The second risk-based model developed showed the relationship between the risk score and the severity of the hazard occurring. The third risk-based model developed was a multiple linear regression showing the relationship between the risk score, which was the dependent variable, and the severity and likelihood of hazards as the independent variables. After the risk assessment, the risk score, the likelihood of the hazard occurring, and the severity of the hazard occurring were obtained. Equations 2 and 3 show the model equation form for the linear regression, while Equation 4 shows the multiple linear regression form [33], [34].

$$\text{Risk Score} = \beta_0 + \beta_1 * \text{Likelihood} \quad (2)$$

$$\text{Risk Score} = \beta_0 + \beta_1 * \text{Severity} \quad (3)$$

$$\text{Risk Score} = \beta_0 + \beta_1 * \text{Severity} + \beta_2 * \text{Likelihood} \quad (4)$$

where β_0 is the intercept, β_1 and β_2 is the regression coefficient.

Various goodness of fit indicators were used to assess the model's goodness of fit. The goodness of fit indicators and what they measure are described below:

2.7.1 Coefficient of determination (R^2)

Calculated to assess the proportion of the variance in the risk score that can be explained by the likelihood of hazards.

2.7.2 Adjusted R^2

Calculated to provide a reliable indicator of model fit while considering the number of predictors.

2.7.3 Mean square error (MSE)

Used to quantify the average deviation between the predicted and observed risk scores, indicating the model's accuracy.

2.7.4 Root mean square error (RMSE)

Derived from MSE, it represents the standard deviation of the residuals, reflecting the model's predictive performance.

2.7.5 Durbin-watson statistic (DW)

Examined to detect any autocorrelation in the residuals, as a violation of the assumption of independence can affect model validity.

2.7.6 Analysis of variance (ANOVA)

Conducted to evaluate the overall significance of the model, applying F-statistic and p-value to assess the strength of the predictors. The risk-based model developed provides a quantitative approach to assess and predict the risk scores associated with different hazards in the oil and gas industry. It assists in identifying high-risk hazards and supports decision-making processes related to risk mitigation strategies, resource allocation, and safety enhancement.

3. RESULTS AND DISCUSSION

3.1 Risk-based Modelling

The result of the modelling is presented in this section. The model developed related the risk score obtained from the risk analysis to the likelihood and severity of the hazard occurring in the oil and gas industry.

3.2 Modelling the Risk Score against the Likelihood of Hazards occurring

Table 5 presents the goodness of fit for the mode. The result from the goodness of fit showed good model fit as indicated by the coefficient of determination (R^2). The R^2 stands at 0.831, signifying that the model explains approximately 83.1% of the variance in the data. The adjusted R^2, considering the number of predictors, is 0.826, indicating a robust fit. The mean square error (MSE) and root mean square error (RMSE) are 1.164 and 1.079, respectively, providing insights into the average deviation of observed values from predicted values. The Durbin-Watson statistic (DW) is 1.856, suggesting a lack of autocorrelation in the residuals.

Table 6 presents the result from the analysis of variance which unveils the model's significant effect. The model F-statistic is 157.321, with an extremely low p-value (< 0.0001), indicating a strong influence of the predictors. Table 7 provides details on the model parameters. The Likelihood coefficient is 4.536, with a standard error of 0.362, demonstrating a highly significant positive impact on the risk score ($p < 0.0001$). The result showed that as the likelihood of the hazard increases, there is a corresponding increase in the risk score and vice versa. Therefore, to reduce the risk of hazard occurring in the oil and gas sector, the likelihood of the hazard occurring should be reduced to the barest minimum.

Table 5. Goodness of fit of the model

Observations	**34.000**
Sum of weights	34.000
DF	32.000
R^2	0.831
Adjusted R^2	0.826
MSE	1.164
RMSE	1.079
DW	1.856

3.3 Modelling the Risk Score against the Severity of the Hazards

Table 8 outlines the goodness of fit for the model, presenting key metrics that evaluate its performance. The coefficient of determination (R^2) is 0.676, indicating that the model explains approximately 67.6% of the variance in the data. The adjusted R^2, considering the number of predictors, is 0.666, suggesting a reasonably robust fit. The mean square error (MSE) and root mean square error (RMSE) are 2.229 and 1.493, respectively, offering insights into the average deviation of observed values from predicted values. The Durbin-Watson statistic (DW) is 1.956, suggesting a lack of autocorrelation in the residuals. Table 5 shows the analysis of variance, which reveals a significant effect of the model. The model F-statistic is 66.881, with an extremely low p-value (< 0.0001), indicating a strong influence of the predictors. Table 10 provides details on the model parameters. The Severity coefficient is 5.574, with a standard error of 0.682, demonstrating a highly significant positive impact on the risk score (p < 0.0001). The result suggests that as the severity of the hazard increases, there is a corresponding increase in the risk score, highlighting the importance of addressing and mitigating severe hazards to reduce overall risk in the oil and gas sector.

Table 6. Analysis of variance

Source	DF	Sum of squares	Mean squares	F	Pr > F
Model	1	183.169	183.169	157.321	< 0.0001
Error	32	37.258	1.164		
Corrected Total	33	220.427			

Computed against model Y=Mean(Y)

Table 7. Model parameters

Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
Intercept	-3.619	1.170	-3.093	0.004	-6.003	-1.236
Likelihood	4.536	0.362	12.543	< 0.0001	3.799	5.272

*Risk score = -3.619 + 4.536 * likelihood*

Table 8. Goodness of fit of the model

Observations	34.000
Sum of weights	34.000
DF	32.000
R^2	0.676
Adjusted R^2	0.666
MSE	2.229
RMSE	1.493
DW	1.956

Table 9. Analysis of variance

Source	DF	Sum of squares	Mean squares	F	Pr > F
Model	1	149.092	149.092	66.881	< 0.0001
Error	32	71.335	2.229		
Corrected Total	33	220.427			

Computed against model Y=Mean(Y)

Table 10. Model parameters

Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
Intercept	-7.934	2.314	-3.429	0.002	-12.647	-3.221
Severity	5.574	0.682	8.178	< 0.0001	4.186	6.962

*Risk score = -7.934 + 5.574 * severity*

Table 11. Goodness of fit of the model

Observations	34.000
Sum of weights	34.000
DF	31.000
R^2	0.994

Adjusted R^2	0.994
MSE	0.040
RMSE	0.200
DW	1.902

Table 12. Analysis of variance

Source	DF	Sum of squares	Mean squares	F	Pr > F
Model	2	219.184	109.592	2733.635	< 0.0001
Error	31	1.243	0.040		
Corrected Total	33	220.427			

Computed against model Y=Mean(Y)

Table 13. Model parameters

Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
Intercept	-10.516	0.316	-33.239	< 0.0001	-11.162	-9.871
Likelihood	3.296	0.079	41.813	< 0.0001	3.135	3.457
Severity	3.218	0.107	29.972	< 0.0001	2.999	3.437

*Risk score = -10.516 + 3.296 * likelihood + 3.218* severity*

3.4 Modelling the Risk Score against the Likelihood and Severity of the Hazards

Table 11 provides an overview of the goodness of fit for the model. The degrees of freedom (DF) are 31, R^2 is exceptionally high at 0.994, indicating that the model explains approximately 99.4% of the variance in the data. The adjusted R^2, accounted for the number of predictors, and this remained at 0.994, confirming an excellent fit. The mean square error (MSE) and root mean square error (RMSE) are 0.040 and 0.200, respectively, showcasing the minimal average deviation of observed values from predicted values. The Durbin-Watson statistic (DW) is 1.902, suggesting a lack of autocorrelation in the residuals. In Table 8, the analysis of variance demonstrated a highly significant effect of the model. The model F-statistic is 2733.635, with an extremely low p-value (< 0.0001), indicating a strong influence of the predictors. Table 13 presents the model parameters. The Likelihood coefficient is 3.296, with a standard error of 0.079, and the Severity coefficient is 3.218, with a standard error of 0.107. The model parameters for both likelihood and severity were positive, indicating that both the likelihood and severity of the hazard affect the risk score in a positive manner. An increase in both the likelihood and severity of the hazards would lead to an increase in risk.

3.5 Intervention for Structural Failure

Swedler [35] stated in their works that risks associated with structural failure in oil and gas sector provided important information that calls for focused interventions. Respondents reached a consensus on the high likelihood of poor design or construction issues, emphasizing the urgency of addressing these concerns. The severity assessment indicated that poor design or construction could have catastrophic consequences, making it a top priority for mitigation efforts. Accidents impacting the platform were perceived as moderately likely but could cause severe damage. Interventions should focus on raising awareness about load limits, ensuring proper weight distribution, and mandating dynamic load assessments during platform design and operation. [30,33,36,37] reported that poor safety culture may negate employee's safety behaviour at work, and this can consequently lead to injuries and accident even to third parties.

3.6 Intervention for Gas Leak

Respondents overwhelmingly identified valve failure as highly likely to occur, ranking it as the top hazard in terms of likelihood. This consensus underscores the urgency of addressing maintenance and inspection protocols related to valves. Seal failure, while slightly less likely, still poses a significant risk. Proactive seal maintenance, regular replacements, and careful material selection are imperative interventions to mitigate this risk effectively. Design flaws, although perceived as unlikely, can have severe consequences if overlooked. Inadequate consideration of stress points, material compatibility issues, and the use of inappropriate materials were identified as root causes. [38] established that strengthening design evaluation processes, ensuring material compatibility, and adherence to industry standards are essential steps in preventing design-related gas leaks. Addressing material compatibility and implementing protective measures against corrosion, such as coatings and inhibitors, are vital interventions to mitigate the risk of metal deterioration. Studies from [35] affirmed that safety management practices, a measure of organizational safety culture has an indirect and/or direct significant relationship on workers' behaviour in several high-risk companies in India. Also, studies from [6] reported that over 60% of participants acknowledged feeling pressured to put production first at the risk of their own lives and that of others.

3.7 Intervention for Security Threat

Respondents identified agitation by host communities as highly likely, indicating underlying socio-economic disparities and lack of community engagement. [39] Historical grievances and unresolved conflicts further exacerbate community agitation, emphasizing the need for community development initiatives and conflict resolution programs. Militant and kidnapper activities are driven by socio-economic challenges and perceived injustices, highlighting the importance of addressing root causes such as unemployment and environmental degradation [40,41,42,43]. Implementing vocational training programs, educational initiatives, and promoting sustainable development in local communities can mitigate the factors driving individuals towards militant activities. Pipeline vandalism can be reduced by bolstering law enforcement, putting community-based environmental initiatives into action, and improving transparency in the oil and gas industry.

3.8 Intervention for fire, explosion and Oil Spills

Implementing stringent safety guidelines for storage facilities, along with routine inspections and maintenance, can mitigate the risks. Implementing strict safety protocols, including fire watch personnel, flame arrestors, and using advanced welding technologies, can enhance the safety of hot work activities. For Corroded Pipelines, inadequate inspection and maintenance practices, exposure to corrosive environments, and aging infrastructure contribute to pipeline corrosion and potential oil spills. [44,45,46,47,48] Studies emphasize the importance of implementing regular inspections by utilizing advanced technologies such as intelligent pigging and cathodic protection systems. Incorporating corrosion-resistant materials during pipeline construction and ensuring prompt repairs for identified corrosion points can significantly mitigate the risks associated with corroded pipelines. Interventions should focus on implementing predictive maintenance strategies, incorporating condition monitoring techniques to identify worn-out seals in advance. Regular seal replacements based on predetermined intervals or condition-based assessments are essential [6]. Additionally, installing leak detection systems can promptly identify seal failures, allowing for immediate corrective actions.

4. CONCLUSION

In Nigeria's oil and gas sector, poor safety performance due to inadequate assessment and mitigation of the inherent risks is a leading cause of death and huge financial losses. Therefore, planning and implementing preventive actions through risk assessment and modelling pathways is critical to enhancing the sector's safety performance. By employing a semi-quantitative methodology, it successfully identifies key risks 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. Interventions for fire and explosion risks were addressed which included safety training, strict guidelines, predictive maintenance, effective ventilation, and advanced welding technologies. Oil spill risks required regular inspections, leak detection systems, certified welders, rigorous inspections, continuous training, and stress analysis during pipeline design.

ACKNOWLEDGEMENTS

The authors are grateful to the World Bank Africa Centre of Excellence in Oilfield Chemicals Research, University of Port Harcourt, Choba,

Rivers State, Nigeria and Centre for Occupational Health, Safety and Environment (COHSE), University of Port Harcourt, Choba, Rivers State, Nigeria.

COMPETING INTERESTS

The authors have declared that no competing interests exist.

REFERENCES

1. Uduji JI, Okolo-Obasi EN, Asongu SA. Corporate social responsibility and the role of rural women in sustainable agricultural development in sub-Saharan Africa: Evidence from the Niger Delta in Nigeria. Sustainable Development. 2019;27(4):692-703. Available:https://doi.org/10.1002/sd.1933.
2. Ebimobowei A. Oil revenue and economic growth of Nigeria: 1990–2019. African Journal of Economics and Sustainable Development. 2022;5(1):17-46. Available:https://doi.org/10.52589/ajesd-jwzxifnw.
3. Akinwale OE. Employee voice: Speaking up in organization as a correlate of employee productivity in oil and gas industry: An empirical investigation from Nigeria. Serbian Journal of Management. 2019;14(1):97-121. Available:https://doi.org/10.5937/sjm14-15308
4. Awoyemi OB, Nwibe DA. A causal assessment of Nigeria's crude oil revenue, health expenditure, and economic growth. International Journal of Energy Economics and Policy. 2022;12(5):420-424. Available:https://doi.org/10.32479/ijeep.13318
5. Gasu M, Gasu G, Olanrewaju S, Yakubu S. International and national policy responses to combating global warming and climate change in Nigeria. Town and Regional Planning. 2022;81:113-123. Available:https://doi.org/10.18820/2415-0495/trp81i1.9
6. Ehiaguina E, Moda H. Improving the safety performance of workers by assessing the impact of safety culture on workers' safety behavior in Nigeria oil and gas industry: A pilot study in the Niger Delta region. International Journal of Medical and Health Sciences. 2020;14(6):152-156.
7. Jeremiah K. 412 People Killed as Nigeria's Oil Sector Struggles with Safety. The Guardian. Available:https://guardian.ng/business-services/412-people-killed-as-nigerias-oil-sector-struggles-withsafety/#:~:text=Going%20by%20the%20rate%20of,become%20worse%20for%20such%20development. (2023, March 30)
8. Ismail K. Health, Safety Issues in Nigeria's Oil, Gas Sector. Foresight global oil and gas investment company ltd. Available:https://www.foresightglobaloilandgas.com/2019/04/12/health-safety-issues-in-nigerias-oil-gassector/#:~:text=Multinational%20oil%20companies%20operating%20in,during%20oil%20and%20gas%20operations. (2019, April 12)
9. Bernstein PL. Against the Gods: The remarkable story of risk. New York: John Wiley and Sons; 1996.
10. Aven T. Risk assessment and risk management: Review of recent advances on their foundation. European Journal of Operational Research. 2016;253(1):1-13. Available:https://doi.org/10.1016/j.ejor.2015.12.023
11. Althaus CE. A disciplinary perspective on the epistemological status of risk. Risk Analysis. 2005;25(3): 567–588. Available:https://doi.org/10.1111/j.1539-6924.2005.00625.x
12. Lockhart D, Yu J. How the upstream oil and gas industry can leverage interdisciplinary research to more effectively engage with Indigenous communities. The APPEA Journal. 2021; 61(2):417-421. Available:https://doi.org/10.1071/AJ20150
13. Matheus GDS, Correia JR, Morais TB, Vazzoler A. Asset integrity management in mature process plants. Process Safety Progress. 2023;42(1):33-49. Available:https://doi.org/10.1002/prs.12499
14. Hollnagel E. Safety-I and Safety-II: The Past and Future of Safety Management. Ashgate; 2014
15. Wilson L, McCutcheon D, Buchanan M. Industrial safety and risk management. University of Alberta Press; 2003.
16. Chauhan N. Safety and Health Management System in Oil and Gas Industry; 2013. Available:http://www.wipro.com/documents/safety-and-health-management-system-in-oil-and-gas-industry.pdf

17. Fakhru'l-Razi A, Pendashteh A, Abdullah L, Biak D, Madaeni S, Abidin Z. Review of technologies for oil and gas produced water treatment. Journal of Hazardous Materials. 2009;170(2-3):530-551. Available:https://doi.org/10.1016/j.jhazmat.2009.05.044
18. International Organization for Standardization. Risk Management – Guidelines (ISO Standard No. 31000: 2018); 2018. Available:https://www.iso.org/standard/63787.html
19. International Organization for Standardization. Risk Management – Risk assessment techniques (ISO Standard No. IEC 31010:2019); 2019. Available:https://www.iso.org/standard/72140
20. International Labour Organization (ILO). Safety and health at work'; 2017. Available:http://www.ilo.org/global/topics/safety-and-health-at-work/lang-en/index.html
21. Guneri AF, Gul M, Ozgurler S. A fuzzy AHP methodology for selection of risk assessment methods in occupational safety. International Journal of Risk Assessment and Management. 2015;18(3/4):319-335. Available:http://dx.doi.org/10.1504/IJRAM.2015.071222
22. Asante-Duah K. Principles and Concepts in Risk Assessment. Public Health Risk Assessment for Human Exposure to Chemicals, 75-100. Kluwer Academic Publishers; 2017. Available:https://doi.org/10.1007/978-94-024-1039-6_4'.
23. Niven K, McLeod R. Offshore industry: Management of health hazards in the upstream petroleum industry. Occupational Medicine. 2009;59(5):304-309. Available:https://psycnet.apa.org/doi/10.1093/occmed/kqp076
24. Trones NK, Rusten NFK. Opportunities and challenges for exploration companies on the Norwegian Continental Shelf (Master Thesis); 2010.
25. 25. Boxall P, Chan W, McMillan M. The impact of oil and natural gas facilities on rural residential property values: A spatial hedonic analysis. Resource and Energy Economics. 2005;27(3): 248-269. Available:http://dx.doi.org/10.1016/j.reseneeco.2004.11.003
26. Azadeh A, Raoofi Z, Zarrin M. A multi-objective fuzzy linear programming model for optimization of natural gas supply chain through a greenhouse gas reduction approach. Journal of Natural Gas Science and Engineering. 2015;26:702-710. Available:https://doi.org/10.1016/j.jngse.2015.05.039
27. Osborn S, Vengosh A, Warner N, Jackson R. Reply to Saba and Orzechowski and Schon: Methane contamination of drinking water accompanying gas-well drilling and hydraulic fracturing. Proceedings of the National Academy of Sciences. 2011; 108(37):665-666. Available:https://doi.org/10.1073/pnas.1109270108
28. Cai T, Fang J, Daida S, Lou HH. Review of synergy between machine learning and first principles models for asset integrity management. Frontiers in Chemical Engineering. 2023;5:138-283. Available:https://doi.org/10.3389/fceng.2023.1138283
29. Otoabasi A. The Niger Delta Question and the peace plan. Spectrum Books; 2011.
30. Lu CS, Tsai CL. The effect of safety climate on seafarers' safety behaviours in container shipping. Accident Analysis and Prevention. 2010;42(6):1999-2006.
31. International Centre for Investigative Reporting. Women make up just 18% of employees in Nigeria's oil and gas sector, men constitute 82%. 2022. https://www.icirnigeria.org/women-make-up-just-18-of-employees-in-nigerias-oil-and-gas-sector-men-constitute-82/
32. Zacchaeus M, Ugbebor J, Agbagwa I, Orikpete OF. Optimizing safety performance through risk-based modeling in Nigeria's oil and gas sector. The Journal of Engineering and Exact Sciences. 2023;9(10):17799.
33. Edwards JR, Davey J, Armstrong K. Returning to the roots of culture: A review and re-conceptualization of safety culture. Safety Science. 2013;55:70-80.
34. Uyanik GK, Guler N. A Study on Multiple Linear Regression Analysis. 2013;106: 234-240.
35. Swedler DI, Verma SK, Huang YH, Lombardi DA, Chang WR, Brennan M, et al. A structural equation modelling approach examining the pathways between safety climate, behaviour performance and workplace slipping. Occup Environ Med, 2015;72(7): 476-481. DOI: doi.org/10.1136/oemed-2014-102496

36. Nordlof H, Wiitavaara B, Winblad U, Wijk K, Westerling R. Safety culture and reasons for risk-taking at a large steel-manufacturing company: Investigating the worker perspective. Safety Science. 2015; 73:126-135.
37. Zahoor H, Chan AP, Gao R, Utama WP. The factors contributing to construction accidents in Pakistan: Their prioritization using the Delphi technique. Engineering, Construction and Architectural Management, 2017;24(3):463-485. DOI: doi.org/10.1108/ECAM-01-2016-0027
38. Okoye PU, Okolie KC. Assessment of Human Environment Interactions on Health and Safety Behaviour of Construction Workers. International Journal of Neuroscience and Behavioral Science. 2017;5:27–43. DOI: doi.org/10.1155/2017/8496258
39. Boughaba A, Hassane C, Roukia O. Safety culture assessment in petrochemical industry: A comparative study of two Algerian plants. Safety and Health at Work. 2014;5:60–65. DOI: doi.org/10.1016/j.shaw.2014.03.005
40. Agumba J, Pretorius J, Haupt T. Employee Involvement and Empowerment in Health and Safety: A Perception of Small and Medium Contractors in South Africa; 2013.
41. Avnet M. A Network-Based Approach to Organizational Culture and Learning in System Safety. Procedia Computer Science. 2015;588-598.
42. Hawash B, Abuzawayda YI, Mokhtar UMI, Yusof Z, Mukred M. Digital transformation in the oil and gas sector during COVID-19 pandemic. International Journal of Management. 2020;11:725-735. DOI: 10.34218/IJM.11.12.2020.067
43. Hussain SSH, Ariff ASM, Sham ASA, Jasni MN. Implementation of safety performance using safety culture in the oil and gas industry during COVID-19 pandemic. Journal of administrative Science. 2022;19(1):189-209.
44. Gunduz MHL. Construction safety risk assessment with introduced control levels. Journal of Civil Engineering and Management. 2018;20-25.
45. Xia NQX. Antecedents of safety behavior in construction: A literature review and an integrated conceptual framework. Elsevier. 2020;12-24.
46. Morrow SGK. Exploring the relationship between safety culture and safety performance in U.S. nuclear power operations. Safety Science. 2014;37-47.
47. Naji GMA, Isha ASN, Alzoraiki M, Al-Mekhlafi AA, Sharafaddin O, Saleem MS. Impact of safety culture and psychosocial hazard on safety performance among upstream employees in Malaysia at oil and gas industry. Solid State Technology. 2020;63(6).
48. Ebrahimi MMA. Effects of Administrative Interventions on improvement of safety and health in workplace: A case study in an oil company in Iran (2011-2015). Journal of Engineering and Applied Sciences, 2016; 346-351.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/117176