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Risk Matrix as a Tool for Risk Analysis in Underwater Operations in the Oil and Gas Industry

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Abstract

The study is a cross-sectional design assessment of the likelihood, frequency and severity of hazards associated with underwater operations in the Niger Delta. Five oil and gas companies were used for this study selected by a purposive method given that they had the highest number of workers involved in underwater operations. A sample size of 418 was computed to which the questionnaires were administered with response rate of 95.93%. Data analyses were carried out to cover descriptive statistics, analysis of variance and Pearsonal correlation coefficients. The 4 by 4 risk assessment matrix for the likelihood and consequences showed that 8 out of 20 underwater hazards were categorized as having very high risk according to their risk ratings. The eight hazards categorized based on their risk IDs were H01, H03, H04, H08, H10, H11, H12, and H15. The 4 by 4 risk matrix for frequency and consequences revealed that two hazards (Piracy & bandit attack/kidnapping (H01) and Other main vessels/heavy object dropping or falling load/collision (H08)) were identified to be of very high risk.

Keywords

Risk Matrix, Risk Analysis, Hazards, Risks, Underwater, Operations, Oil and Gas Industry

1. Introduction

The offshore oil and gas industry is a high-risk sector where workers face not only process hazards associated with the exploration, storage and processing of hydrocarbons on platforms but other forms of hazards related to the harsh working environment and transportation [1], piracy and bandit attack/kidnapping [2], poor visibility, heavy storms, strong wind, hyperbaric operations, rotating capstan, entrapment, capsizing, breakage or fatigue, uncontrolled inclinations, loss of buoyancy, pipeline failure, power failure, corrosion, poor installation and malfunction of the mechanical system. These high-risk operations present potential for accidents, injuries, and, in some cases, even death in the offshore environment. For the purpose of this study, the offshore operations can be used interchangeably with underwater oil and gas operations. One of the most critical and substantial concerns in the underwater oil and gas related operation is the safety of workers and the water environment. In order to improve safety during Uder Water Oil and Gas Related Operations (UWOGRO), safety personnel and other experts including legal and statutory authorities have adopted several rules and regulations since incidents and accidents in UWOGRO can cause fatal damages to human life and environment [3].

Globally, UWOGRO are very risky, dangerous and the environmental and economic impacts associated with the accidents that arise from the operations are usually massive and devastating. UWOGRO have been accounting for a higher injury incident rate than other domains in the petroleum industry [4] [5] [6] [7]. In the years 2007 to 2012, the occupational fatality rate of the oil and gas drilling industry was 2.5 times higher than the construction industry and 7 times higher than general industry [8]. Furthermore, there are many underlying risk factors involved in high rate of underwater oil and gas fatalities, critical accidents and life-threatening injuries [9] [10]. Underwater operations are carried out using a combination of several job tasks that comprise of logistics for offshore mobilization, diving, pulling, lowering, lifting, dragging, cutting, welding etc. and risk assessments must be carried out on these job tasks to either approve or disapprove the operation.

Risk assessment is an essential tool for the safety policy of a company [11]. It is the overall process of risk identification, risk analysis, and risk evaluation. Risks can be assessed at an organizational level or departmental level for projects, individual activities, or specific risks. Different tools and techniques may be appropriate in different contexts [12]. Risk assessment provides an understanding of risks, their causes, consequences, and probabilities. Risk assessment is a systematic use of available data to determine how often specific events may occur and the magnitude of their likely consequences. The risk assessment is the central part of the risk management process, which purposes to establish a proactive safety strategy by investigating potential risks [13] [14]. These risk assessments are usually carried out based on risk assessment matrix.

Risks are analyzed by combining estimates of severity and likelihood based on the control measures used. In general, magnitude or rating of any given risk is established using two-dimensional grid, with severity or consequence as one axis and likelihood as the other. This two-dimensional chart is known as Risk Assessment Matrix. The decision matrix risk-assessment (DMRA) technique is a systematic approach for estimating risks, which is consisting of measuring and categorizing risks on an informed judgment basis as to both probability and consequence and as to relative importance [15]. The combination of a consequence/severity and likelihood range, gives us an estimate of risk. According to [16] the National Patient Safety Agency (NPSA) (2008), a risk assessment matrix must be easy to use, provide reliable and consistent results when used by different workers in different positions, possess capacity to assess several kinds of risk in different areas and must be simple and assessable to health and safety agency in their country to understand and use.

Regardless of the importance of a risk assessment matrix being recorded in literature for different job tasks and industries, there is scarcity of information on the risk assessment matrix that will differentiate relative risks to facilitate consistent and improved decision-making for underwater operations in the oil and gas industry. There is need to develop a decision-making risk assessment matrix for these UWOGRO which would help to rank the hazards involved in these operations. The HSE officers and other workers will have a consistent risk assessment procedure for assessing the risk involved in any underwater activity such as construction, diving, operations and maintenance based on the ranking of the hazards involved. This would help new and inexperienced personnel carry out appropriate risk assessments and put in place fit for purpose control measures.

2. Materials and Methods

2.1. Study Area

Niger Delta occupies the Gulf of Guinea continental margin in equatorial West Africa, between latitudes 4˚N and 6˚N and longitudes 5˚E and 8˚E [17] as show in **Figure 1**. The region shares boundary with Ogun, Osun, Ekiti, Kogi, Anambra, Enugu and Ebonyi states. The Niger Delta is host to Nigeria's huge deposits of oil and gas. This well-endowed ecosystem, which contains high concentrations of biodiversity on the planet, in addition to supporting the abundant flora and fauna, arable terrain that can sustain a wide variety of crops and economic trees, has more species of freshwater fish than any ecosystem in West Africa. Nigeria oil & gas reserves are situated in the region, contributing to 90% of government revenue.

2.2. Research Design

This study utilized a cross-sectional research design. The reason is because findings from cross-sectional studies are representative and can be generalized. Cross-sectional study design is a type of observational study design where the investigator measures the cause and effect in a study population at the same time [18]. It collects data to make inferences about a population of interest at one point in time. This design is relevant as it involved collecting data from respondents and presenting them without manipulation. Consequently, quantitative method was employed to assess and investigate the likelihood of hazard occurrence, the frequency level, the level of severity and the consequences.

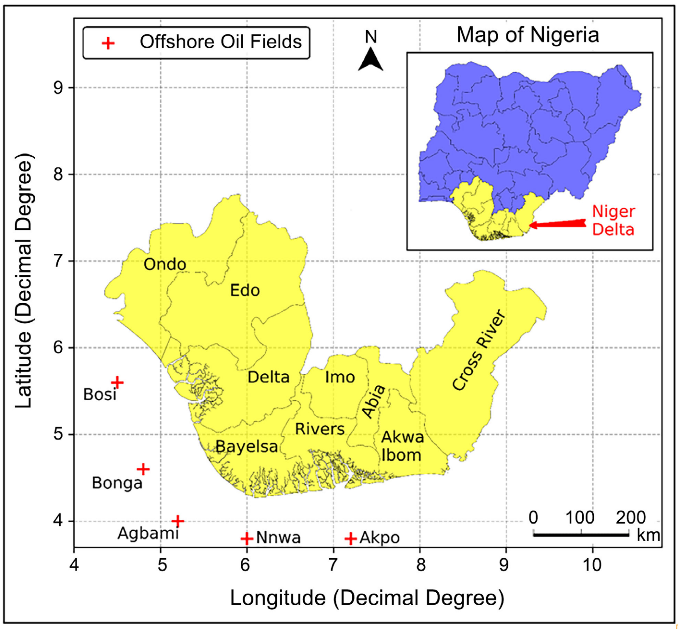

Figure 1. Map of study area showing some offshore oilfields.

2.3. Population of the Study

The population of the study is comprised of an estimated number of 7500 employees in the five (5) selected oil and gas companies that are involved in offshore or underwater oil and gas operations in the Niger Delta. For the underwater workers whose daily work activities expose them to hazards and risks of which they need to carry out a risk assessment before undertaking their underwater duties. The five selected companies were major oil and gas companies involved in underwater operations in the Niger Delta. Three of these companies were EU owned and two others were America-owned. This indicates that this study covers majorly the oil multinational companies and also presumes that underwater hazards across these companies are the same.

2.4. Sample and Sampling Technique

This study adopted a purposive sampling technique. A purposive sample is a type of non-probability sampling method where the sample is taken from a group of people easy to contact or to reach. The sample size of 380 was selected using [19] sample size determination from the total population of 7500 workers. For this study, 418 copies of questionnaire were distributed after calculation of the attrition rate. This was done to ensure that the minimum sample size which will give a good representation of the population will be achieved, as some of the questionnaires will not be fit for usage.

2.5. Data Collection and Quality Control

Data were collected via a questionnaire and checklist. The template and structure of the questionnaire and checklist were adopted from ISO 19900, ISO 19901-2, ISO 19904, ISO 19905-1 and industry Hazards Identification and Risk Assessment (HIRA) level 2. Before undertaking the data collection process, an official letter was addressed to respective management in the various studied facility seeking their consent. The managements were assured of treating the information from respondents/participants confidentially. The questionnaire has three (3) sections namely; sections A, B, and C. Section A contained information on socio-demographic data/occupational history. Section B contained items on the likelihood of underwater hazards, frequency or occurrence of hazards, and severity of hazards. Section C contained information on the consequences of hazards. These sections were in a 4-point Likert scale with ratings as 4, 3, 2 and 1; respectively. The criterion mean rating of 2.5 (criterion mean) was adopted for decision. Response mean less than the criterion mean of 2.5 indicates not agree/no sign of occurrence or likelihood while response means greater than 2.5 indicates agree/sign of occurrence or likelihood.

Questionnaire was computed and administered to 418 underwater workers. The workers were informed that the collected data was just for the purpose of conducting a scientific study and they could discontinue participation in the study whenever they wished. Out of the 418 questionnaires distributed, 401 were considered fit to be used for the study, representing a response rate of 95.93%.

2.6. Data Analysis

Data from the questionnaire received from respondents were transcribed into Excel sheet and then transferred to XLSTAT version 17. Data were analyzed using descriptive statistics such as mean, mode, standard deviation, and a ranking system based on the mean response was used to evaluate hazards that are more likely to occur. Qualitative risk assessment was employed in evaluating the risks associated with underwater operations. The evaluation of risk was done using the risk assessment matrix which is a method under qualitative risk assessment. The risk assessment matrix is widely used in the Petroleum industry and it is considered the best practice. Evaluation of risk using the risk matrix is based on the combined effect of the likelihood of a hazard occurring and the associated consequence/severity of that hazard. After obtaining the combined effect, the risk is rated as low, moderate, high, or very high according to its position on the risk assessment matrix.

3. Results

3.1. Demographic Distribution of Underwater Workers

Table 1 showed that majority of offshore workers were predominantly men. About 365 respondents that took part in the survey were men which accounted for 91.02% of the total respondents and 36 respondents were female, which accounted for 8.98% of the total respondents. The figure further showed that majority of the workers are between the ages of 40 to 44 years. A total of 151 respondents that took part in the survey indicated that they were between the ages of 40 to 44 years which accounted for 37.66% of the total respondents. Also, 383 out of 401 respondents indicated that they attended tertiary institution, that is, 95.51% of the total respondents and 162 (40.40%) respondents with more than 15 years of working experience took part in the survey.

3.2. Likelihood, Frequency, and Severity of Hazards and Risks

The result in Table 2 showed that though adverse weather and sea condition was likely to occur at a very frequent rate, the severity of this hazard does not rank first, indicating that adverse weather and sea conditions might not result to fatality of underwater workers. Also, strong current/wind which came 2^{nd} is most likely hazard to occur at a frequent rate is ranked 7^{th} on the severity indicating that its effects might not lead to the fatality of workers. Piracy & bandit attack/kidnapping which is ranked 3^{rd} likely hazard to occur at a fairly frequent rate had serious consequence if it occurs.

3.3. Consequences of Hazards

The result for the impact of consequences of hazards on personnel, properties and others is presented in Table 3. The result shows that the impact of the hazards was more pronounced on personnel, is ranked the first with 3.38 ± 0.76. Most of the respondents suggested that the consequence of the hazards on personnel was very high. Health effect/injury and damage to equipment/property were reported to be the second and third consequences with 3.29 ± 0.73 and 3.22 ± 0.78, respectively.

Table 1. Demography of underwater workers.

Demographic Criteria	Parameters	Number of Respondents	Percentage
Gender	Female	36	8.98%
	Male	365	91.02%
Age	24 years and less	3	0.75%
	“25 - 29 years”	1	0.25%
	“30 - 34 years”	41	10.22%
	“35 - 39 years”	86	21.45%
	“40 - 44 years”	151	37.66%
	“45 - 49 years”	59	14.71%
	50 years and above	60	14.96%
Education	Secondary	18	4.49%
	Tertiary	383	95.51%
Years of Work Experience	“1 - 5 years”	17	4.24%
	“6 - 10 years”	92	22.94%
	“11 - 15 years”	130	32.42%
	>15 years	162	40.40%

Table 2. Mean response and ranking of likelihood, frequency and severity of underwater hazards.

Hazard ID	Hazards	Likelihood		Frequency		Consequence	
		Mean	Rank	Mean	Rank	Mean	Rank
H01	Piracy & bandit attack/kidnapping	3.3	3	2.82	5	3.40	1
H02	Shallow waterway/poor visibility	3.27	4	3.08	3	2.93	18
H03	Adverse weather and sea condition/heavy storms	3.48	1	3.15	1	3.21	6
H04	Strong current/wind	3.43	2	3.13	2	3.13	7
H05	Hyperbaric operations/falling overboard	3	9	2.48	13	2.95	16
H06	Rotating capstan/winch	2.73	20	2.41	15	2.71	20
H07	Entrapment/entanglement of personnel	2.88	14	2.46	14	2.98	15
H08	Other main vessels/heavy object dropping or falling load/collision	2.93	11	2.58	11	3.07	8
H09	Embarking and disembarking from SPM	3.03	8	2.74	6	2.76	19
H10	Fire/explosion	3.06	6	2.42	16	3.39	2
H11	Blowout/release of fluid or gas	2.87	16	2.43	18	3.34	3
H12	Capsizing/overturning/toppling	2.82	15	2.23	20	3.22	4
H13	Breakage or fatigue	3.13	6	2.83	8	2.96	10
H14	Uncontrolled inclination/ leakage into hull	2.79	17	2.38	17	2.88	17
H15	Loss of buoyancy or sinking/adrift	2.78	18	2.25	19	3.15	5
H16	Valve system/pump/pipeline failure	2.97	12	2.66	9	2.95	11
H17	Remote operation/power/cooling/gauging system failure	2.9	13	2.66	10	2.93	14
H18	Corrosion/debris accumulation	3.16	5	2.93	4	3.02	9
H19	Malfunction of instrumentation or mechanical system	3.08	10	2.83	6	3.01	12
H20	Poor installation	2.78	19	2.54	12	2.99	13

Table 3. Mean response for consequences of hazard.

Consequences of Hazard	Mean	Mode	Std. Deviation	Rank
Damage to equipment/asset or property	3.22	3.00	0.78	3rd
Effect on personnel	3.38	4.00	0.76	1st
Community (s) affected	2.77	2.00	0.95	8th
The environment affected	3.13	3.00	0.79	6th
Project delay/down time	3.12	3.00	0.71	7th
Health effect/injury	3.29	4.00	0.73	2nd
Fatalities/drowning	3.21	4.00	0.96	4th
Economy	3.16	3.00	0.72	5th

3.4. Risk Assessment Matrix

The result of the risk assessment is presented in form of a risk assessment matrix. Table 4 shows the modal value used in calculating the risk score which were utilized in developing the risk assessment matrix. The risk assessment matrix for the likelihood and consequences of hazards is shown in Figure 2. The risk rating showed that 8 out of 20 offshore hazards were categorized as very high risk. The eight hazards so categorized based on their hazard IDs were H01, H03, H04, H08, H10, H11, H12, and H15. These eight hazards are rated very high due to the fact that if they occur on offshore sites would lead to detrimental effects on personnel and properties. The result from the risk assessment matrix also shows that twelve underwater hazards identified were rated to be high. The twelve hazards based on their hazard IDs are H02, H05, H06, H07, H09, H13, H14, H16, H17, H18, H19, and H20. All the offshore hazard risks identified were either rated as very high or high, which indicated that offshore hazards are detrimental to the personnel and the facility. Therefore, high safety measures must be put in place to control these risks. The risk-ranking results for likelihood and severity showing the hazards, risk ID, risk score, L-indices, outcome, and risk rating are presented in Table 5.

Table 4. Modal responses for risk matrix parameters.

Hazard ID	Hazards	Likelihood	Frequency	Severity
H01	Piracy & bandit attack/kidnapping	4.00	3.00	4.00
H02	Shallow waterway/poor visibility	3.00	3.00	3.00
H03	Adverse weather and sea condition/heavy storms	4.00	3.00	3.00
H04	Strong current/wind	4.00	3.00	3.00
H05	Hyperbaric operations/falling overboard	3.00	2.00	3.00
H06	Rotating capstan/winch	3.00	2.00	3.00
H07	Entrapment/entanglement of personnel	3.00	3.00	3.00
H08	Other main vessels/heavy object dropping or falling load/collision	3.00	3.00	4.00
H09	Embarking and disembarking from SPM	3.00	3.00	3.00
H10	Fire/explosion	3.00	2.00	4.00
H11	Blowout/release of fluid or gas	3.00	2.00	4.00
H12	Capsizing/overturning/toppling	3.00	2.00	4.00
H13	Breakage or fatigue	3.00	3.00	3.00
H14	Uncontrolled inclination/ leakage into hull	3.00	2.00	3.00
H15	Loss of buoyancy or sinking/adrift	3.00	2.00	4.00
H16	Valve system/pump/pipeline failure	3.00	3.00	3.00
H17	Remote operation/power/cooling/gauging system failure	3.00	3.00	3.00
H18	Corrosion/debris accumulation	3.00	3.00	3.00
H19	Malfunction of instrumentation or mechanical system	3.00	3.00	3.00
H20	Poor installation	3.00	3.00	3.00

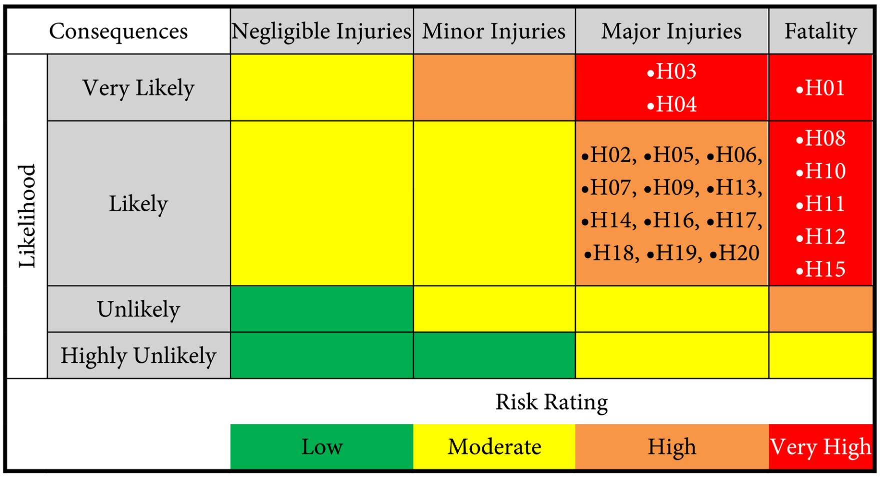

Figure 2. Risk Assessment Matrix of the likelihood and severity of underwater hazards.

Table 5. Risk-Ranking results for likelihood and severity.

Hazards	Risk ID	Risk score	L-indices	Severity/Outcome	Risk rating
Piracy & Bandit attack/Kidnapping	H01	4 × 4 = 16	Very likely	Fatality	Very High
Adverse weather/Heavy storm, Strong current/wind	H03, H04	4 × 3 = 12	Very Likely	Major injuries	Very High
Other main vessels/heavy object dropping or falling load/collision, Fire/explosion, Blowout/release of fluid or gas, Capsizing/overturning/toppling, Loss of buoyancy or sinking/adrift	H08, H10, H11, H12, H15	3 × 4 = 12	Likely	Fatality	Very High
Shallow waterway/poor visibility, Hyperbaric operations/falling overboard, Rotating capstan/winch, Entrapment/entanglement of personnel, Embarking and disembarking from SPM, Breakage or fatigue, Uncontrolled inclination/ leakage into hull, Valve system/pump/pipeline failure, Remote operation/power/cooling/gauging system failure, Corrosion/debris accumulation, Malfunction of instrumentation or mechanical system, Poor installation	H02, H05, H06, H07, H09, H13, H14, H16, H17, H18, H19, H20	3 × 3 = 9	Likely	Major injuries	High

Likelihood: 4—Very likely (having a high probability of occurring more than once per year or more often), 3—Likely (expected to occur once (approx. once in 10 years), 2—Unlikely (not expected for at least 100 years), 1—Very Unlikely (Not expected to happen for at least 1000 years Severity: (Health Effects), 4—Fatality (Potential for one or fatalities), 3—Major injuries (Potential for one or more serious injuries; irreversible), 2—Minor injuries (Potential for one or more lost time injuries), 1—Negligible injuries (Potential for minor injuries or irritation).

Figure 3 shows the risk assessment matrix in terms of the frequency of occurrence of the risk. From Figure 3, two hazards were identified to be of very high risk. The two hazards identified were Piracy & bandit attack/kidnapping (H01) and Other main vessels/heavy object dropping or falling load/collision (H08).

Fifteen hazards were identified to be high risks while three hazards were identified to be low risks. The risk-ranking results for frequency and severity showing the hazards, risk ID, risk score, F-indix outcome, and risk rating is presented in Table 6.

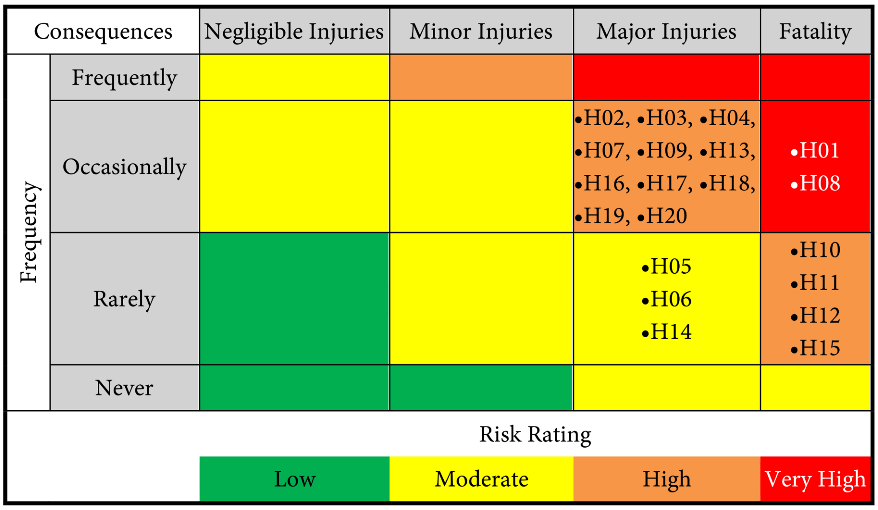

Figure 3. Risk Assessment Matrix of the frequency and severity of underwater hazards.

Table 6. Risk-Ranking results for frequency and severity.

Hazards	Risk ID	Risk score	F-indices	Severity/Outcome	Risk rating
Piracy & Bandit attack/Kidnapping, Other main vessels/heavy object dropping or falling load/collision	H01, H08	3 × 4 = 12	Occasionally	Fatality	Very High
Shallow waterway/poor visibility, Adverse weather/Heavy storm, Strong current/wind, Entrapment/entanglement of personnel, Embarking and disembarking from SPM, Breakage or fatigue, Valve system/pump/pipeline failure, Remote operation/power/cooling/gauging system failure, Corrosion/debris accumulation, Malfunction of instrumentation or mechanical system, Poor installation	H02, H03, H04, H07, H09, H13, H16, H17, H18, H19, H20	3 × 3 = 9	Occasionally	Major injuries	High
Fire/explosion, Blowout/release of fluid or gas, Capsizing/overturning/toppling, Loss of buoyancy or sinking/adrift	H10, H11, H12, H15	2 × 4 = 8	Rarely	Fatality	High
Hyperbaric operations/falling overboard, Rotating capstan/winch, Uncontrolled inclination/ leakage into hull	H05, H06, H14	2 × 3 = 6	Rarely	Major injuries	Moderate

Frequency: 4—Frequently (Happened a couple of times (once per year or more often), 3—Occasionally (Happened once (approx. once in 10 years), 2—Rarely (Almost happened, near miss (Approx. once in 100 years), 1—Never (Never happened, but is thinkable (Approx. once in 1000 years) Severity: (Health Effects) 4—Fatality (Potential for one or fatalities), 3—Major injuries (Potential for one or more serious injuries; irreversible), 2—Minor injuries (Potential for one or more lost time injuries),1—Negligible injuries (Potential for minor injuries or irritation).

4. Discussion

From the study, eight hazards were rated very high based on their risk IDs as presented in the risk assessment matrix and they include Piracy & bandit attack/kidnapping, Adverse weather and sea condition/heavy storms, Strong current/wind, Other main vessels/heavy object dropping or falling load/collision, Fire/explosion, Blowout/release of fluid or gas, Capsizing/overturning/toppling, and Loss of buoyancy or sinking/adrift. These hazards are rated very high due to the fact that if they occur during underwater operations, and could lead to detrimental effects on personnel, properties, and the environment.

A risk matrix is a graphical presentation of the likelihood, or probability, of an outcome and the consequence should that outcome occur. The risk matrix as the name implies, tends to be focused on outcomes that could result in loss, rather than gain. The risk ranking result for likelihood and severity showed that piracy and bandit attack/kidnapping will very likely result to fatality. This could be as a result of the insecurities faced by Nigeria economic zones and which oftentimes leads to the death of the individual kidnapped if a ransom is not paid. Despite efforts by coastal countries, including Nigeria, as well as by external actors, the Gulf of Guinea (GoG) remains one of the most dangerous maritime areas in the world, with acts of piracy now extending from Ivory Coast to Congo-Brazzaville. Piracy and bandit attack/kidnapping needs immediate attention.

Furthermore, the risk matrix showed that adverse weather/heavy storm and strong current/wind will very likely result to major injuries when it occurs. This result is in line with [20]. Their study reported that such extreme operating conditions can disrupt the offshore infrastructure and cause major accidents, posing a great challenge to operators. Other main vessels/heavy object dropping or falling load/collision, Fire/explosion, Blowout/release of fluid or gas, Capsizing/overturning/toppling, and Loss of buoyancy or sinking/adrift will likely result to fatality as they occur. According to HSE (1996), fire and explosion will not only result in significant casualties and economic losses, but also cause serious pollution and damage to surrounding environment and coastal marine ecosystems.

Fire is adverse event with tangible costs to property and human life [21] [22]. Quantification of these cost provide a metric for understanding the social and economic impact of fire, which can be useful for assessing and influencing fire prevention and protection. In addition, fire also inflicts adverse consequences on the natural environment. These include contamination of the air via the fire plume and its subsequent diffusion, with deposition of particulate and other materials likely to contaminate soil and water. Contamination of soil and water from fire suppression runoff, which might contain toxic or hazardous materials, and direct exposure to soil and water from hazardous materials whose containers / containment systems may fail due to fire [21]. Hydrocarbon fires and explosions are extremely hazardous on offshore platforms [23].

According to [21], blowout is the most frequent cause of accidents in the offshore oil and gas. Blowouts can cause loss of life, environmental damage, and loss of resource [24]. Capsizing refers to a situation where in the vessel at sea list to one side to such an extent that is not able to regain its original position, leading to tipping over of the vessel in water and making it unsafe for both crew and machinery onboard. Capsizing of the vessel can lead to loss of life and vessel damage.

5. Conclusion

The study concluded that eight hazards categorized based on their risk IDs (H01, H03, H04, H08, H10, H11, H12, and H15) were rated very high due to the fact that if they occur on offshore sites, it would lead to detrimental effect on personnel and properties. The result from the risk assessment matrix also shows that twelve underwater hazards identified were rated to be high. The twelve hazards based on their risk IDs were H02, H05, H06, H07, H09, H13, H14, H16, H17, H18, H19, and H20 through a 4 by 4 risk matrix of likelihood and severity. Furthermore, Piracy & bandit attack/kidnapping (H01) and other main vessels/heavy object dropping or falling load/collision (H08) were the hazards identified to be of very high risk based on a 4 by 4 risk matrix of frequency and severity. All the offshore risks identified were either rated as very high or high, which indicated that offshore hazards are detrimental to the personnel and the facility. Therefore, high safety measures must be put in place to control these risks.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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