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Modeling Offshore Environmental Risk Assessment: a Case Study of Installing Tripod Bases in a Deep Sea Mining Structure

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Abstract

Environmental degradation, particularly in marine ecosystems, has become a critical issue, due to industrial activities. Offshore areas are significantly impacted by the deep sea mining operations, leading to pollution and ecological imbalances. The existing environmental risk assessment models often fail to integrate the qualitative and quantitative data effectively, highlighting a significant research work gap. This work aims to address this gap by developing a comprehensive framework using the Bayesian Networks (BN), and the NETICA software to evaluate the risks associated with the installation of three-legged deep sea mining structures. The major goals are to systematically identify and prioritize the risks, and to develop effective mitigation strategies. The novelty of this work lies in its innovative use of the Bayesian modeling to combine the expert knowledge with the empirical data, providing a detailed categorization of risks into the low, medium, and high levels. The output parameters focus on the severity, likelihood, and detectability of risks. The results indicate that 40% of the habitat destruction risks are low, 46% fall within the ALARP region, and 14% are high, while the species destruction risks are 31% low, 50% ALARP, and 19% high. These findings guide the targeted mitigation measures to ensure effective protection of the offshore marine environment. Also, the work concludes with a set of recommendations aimed at mitigating identified risks, and minimizing the environmental impacts. These include the implementation of advanced monitoring technologies, adoption of best management practices, and enforcement of stricter regulatory frameworks.

1. Introduction

In the recent years, various factors such as the population growth, urban development, industrial expansion, improper utilization of natural resources, and other elements have led to a severe environmental pollution [1]. This work employs a comprehensive risk assessment methodology, utilizing the data from various governmental and non-governmental sources including environmental impact assessments, peer-reviewed journals, and direct field observations. The key data sources include the Environmental Protection Agency's reports, maritime industry publications, and the field data was collected during the site visits.

Over the past fifty years, the exploitation of non-renewable resources in response to the global demand for energy has significantly increased. Alongside this extraction surge, environmental pollution stemming from maritime structures has also escalated [2]. The construction of numerous complexes related to maritime industries, shipping transportation, as well as infrastructure development by the offshore companies has resulted in the emergence of industrial wastewater (chemical), accumulation of waste materials and debris, noise pollution, incineration of segregated gases, and overall water pollution. This has challenged the environment and ecosystem of the region. These processes can be a source of pollutants and ecological changes in the region.

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The destruction of marine ecosystems and aquatic habitats has caused an irreparable or a hardly reversible damage to the environment. Today, due to the unsustainable exploitation of the sea, and the high rate of discharge of pollutants, the resilience and ability to restore marine ecosystems have been reduced, and it is difficult for the sea to neutralize these pollutants [3]. The installation of aquatic structures, despite its significant role in the economic independence, improving living conditions, and creating job opportunities entails numerous challenges and risks. The environmental impacts of these activities, aside from any incidents resulting from normal operations warrant reflection. The assessment and modeling of the environmental risks involve a systematic process to identify the environmental hazards, analyze the probability and severity of the potential consequences, and manage the risk levels. The need for assessing and modeling the environmental risks is strongly felt in this era, where a wide spectrum of the human activities and natural events occur, and it is essential that the results inform decision-making in the relevant domains [4]. One of the fundamental solutions to address the issues arising from maritime pollution is to conduct assessment studies to identify the consequences and ecological aspects. Assessment can serve as a planning tool accessible to the planners, managers, and decision-makers, enabling them to identify the potential environmental impacts resulting from the implementation of construction and development projects. Consequently, they can select logical options to mitigate and reduce these impacts [5]. Risk management is one of the pillars of project management. Therefore, appropriate measures are taken to deal with the risks that have negative impacts on the project objectives (such as increased time and cost, and reduced quality. At every stage of its lifecycle, a project faces various risks, which are the result of the complex and the dynamic nature of the project. Therefore, risk management should be considered important in the projects regardless of their size to ensure the achievement of the pre-defined objectives. Risk is an uncertain event that, if it occurs, affects at least one of the project's objectives (quality, time, cost, and scope). Project risk management aims to increase the probability and impact of positive events and mitigate the probability and impact of the negative events. Assessment of environmental risks typically falls within one of two domains: human health and environmental health, and in the HSE management system [6], [7], [8], and [9]. In the recent years, significant advancements have been made in the experience and evaluation of risk assessment methods. For example, MerveTunali et al. investigated the effects of microplastics in soil [10]. Stoelting et al. developed and implemented the 21st-century chemical risk assessment in Europe [11] Li Tang et al. studied the drivers and environmental hazards of microplastics in marine environments [12], and Halim Topaldemir et al. examined the potential hazardous elements in the sediments in the Milic Marsh, Samsun, Turkey [13] using the environmental risk assessment methods. In the risk control and assessment process, the first step is identifying the risks, predicting, eliminating, or reducing the likelihood of risk occurrence. Raian et al. [14], Taheri et al. [15], and Dodd et al. [16] each mentioned the importance and the method of risk control in their articles. Elbisy investigated the environmental management of a water structure along with transmission pipelines in the Mediterranean Sea, and evaluated the environmental aspects and the pollution caused by it, and also pointed out that resource extraction and production operations depend on the level of the process, nature and sensitivity of the environment. Surroundings and production of the technology have a lot of potential to influence the environment [17]. Beyer et al., in investigating the environmental effects of the discharge of coastal waters produced as a result of the extraction of coastal resources by water structures, stated that these activities cause water pollution. These discharged waters mainly contain dispersed crude oil compounds and polycyclic aromatic hydrocarbons [18]. In a research work, Kirin et al. compared the experimental, numerical, and analytical risk of welded pipes in the drilling industry based on the failure mechanics parameters. They used the Failure Assessment (FA) chart to measure the probability of pipe failure. The results of his research work showed that analytical evaluation has a higher score [19]. Dimaio et al. developed a multi-objective Bayesian Network (BN) to model and calculate the destruction of safety barriers in risk assessment in industry, and the results showed that the multi-objective BN model can have the required efficiency [20]. Kleiv et al., during a review work, presented a framework for deep sea mining as a bibliometric analysis [21]. Also studied in the field of the environmental quality assessment; it is also of interest to the environmental researchers in the discussion of the Fuzzy and Uncertain, and Vagueness conditions [22] and [23]. Despite the increasing attention on the environmental impacts of offshore installations, there is a notable lack of comprehensive methodologies that integrate both the qualitative expert opinions and the quantitative data for environmental risk assessment. The existing models often fail to consider the full complexity of the interactions between different environmental variables, and the uncertainty inherent in these assessments. This gap highlights the need for the advanced modeling techniques that can provide more accurate and reliable risk assessments. To address this gap, the primary goals of this research work are to develop a comprehensive risk assessment model that combines the qualitative and quantitative methods to evaluate; the environmental risks associated with the installation of filtration bases in the deep sea mining structures. Specifically, the research work aims to utilize the BN modeling and the Netica software to integrate the expert knowledge and the empirical data, enhancing the accuracy and reliability of risk predictions. Additionally, it seeks to systematically identify and categorize the potential environmental impacts on the marine habitats and species, providing a clear basis for the mitigation strategies. The outputs of the model will be used to inform and prioritize the mitigation measures, ensuring that the environmental risks are managed effectively and sustainably. The novelty of this work lies in several key aspects. First, the innovative use of the BN modeling to combine the qualitative expert opinions with the quantitative data, a more nuanced and accurate risk assessment. Secondly, the detailed categorization of risks into the low, mediumheand high levels based on the severity, likelihood, and detectability is a novel approach in environmental risk assessments for offshore installations. Thirdly, the specific application to the installation of filtration bases in deep sea mining structures, a relatively underexplored area, highlights the study's unique contribution to environmental risk management in this context. Lastly, the emphasis on the need for continuous updating and validation of the risk model with the new data, as well as the development of adaptive management strategies reflects a forward-thinking approach that addresses the dynamic nature of the environmental risks.

2. Methodology

This project was of an applied nature, and was implemented specifically in one of the phases of a marine structure in the Persian Gulf. The general flowchart of this research is depicted in the Figure 1.

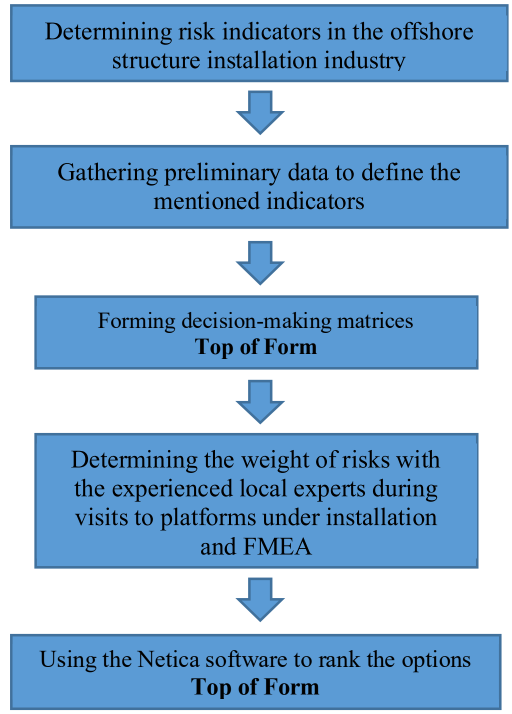

Figure 1. Flowchart of the research methodology.

2.1. Preparation of checklists and worksheets

The present scientific-applied research work, based on library studies, field visits to the installation of the tri-pod projects, evaluation team, and the prepared checklist. A sample of the checklist and worksheet used in this research work is provided in Tables 1 and 2 in the Appendix. To this end, a list of risks that may occur during the installation of the project was compiled using the opinions of the experts and the project managers at the project site, internet sources, and documents. Then the probability of risk occurrence and the severity of the environmental sensitivity for all risks were calculated. It is worth noting that the Persian Gulf and the Sea of Oman have been declared special marine regions according to the requirements of the MARPOL convention, where the accumulation and presence of hazardous substances for extended periods are possible, and the ecological conditions of the region indicate the necessity of protecting and preserving the living ecosystems and habitats.

2.2. Methods

FMEA, an analytical and law-based technique, is used for the proactive prevention by identifying the potential failure factors. One of the reasons for using this method is the success of FMEA during its execution. This technique is designed to be a "preventive action" rather than a "reactive exercise." In other words, one of the fundamental differences between FMEA and other techniques is that FMEA is a proactive action rather than a reactive one. The purpose of implementing FMEA in this project is to search for all the potential factors that could lead to failure or, in this case, environmental contamination during the installation of the structure, before the structure is installed and causes contamination. One of the most challenging stages of risk management planning is the assessment phase, and one of the most difficult aspects of risk assessment is determining the probabilities of the risks occurring. Since the consequences of risk occurrence can be negative (threats) or positive (opportunities), or uncertain (uncertainty), organizations intending to operationalize a risk management plan are better off defining appropriate definitions for the probability levels and consequences of each risk, considering the various types of consequences it may entail. The presence and impact of risks are defined. Based on this, the identification of the aspects, effect analysis, and evaluation of the consequences arising from the installation of the tri-pod in the marine environment were identified. The variables such as operational identification, potential failure mode (environmental aspects), potential effects of failure (consequences), potential causes, and initial assessment of environmental aspects (severity, occurrence, extent of pollution, priority number, and risk level) were examined. After collecting the necessary data, the environmental degradation coefficient was evaluated using the failure mode, and the effect analysis method and its effects on the environment. Accordingly, the priority number of the target risk was calculated by multiplying two parameters: the severity of the impact (consequences) and the probability of occurrence, considering the sensitivity of the marine environment. The scoring method was such that the severity parameter was assigned the numerical values from 1 to 5, where the most severe cases received a score of 5, and the least severe cases received a score of 1. Similarly, for the "probability of occurrence, " thenumerical values between 1 and 5 were applied to the parameter. In the highest and lowest likelihood cases, scores of 5 to 1 were respectively assigned. The step-by-step process of carrying out the above procedure is illustrated in Figures 2 and 3.

After completing the standard worksheets for all the activities and identified hazards, quantitative risk assessments were conducted through expert consultation and using tables of severity and probability values for the environmental factors. Scores were assigned based on the severity, probability of occurrence, and environmental factors, and the Risk Priority Number (RPN) was calculated according to the following formula. The calculated RPN values were then entered into the prepared worksheets for quantification.

$$RPN = Severity \times Occurrence \times Detection \quad (1)$$

After determining the risk priority number (RPN) using tables and expert consultation, the obtained values were transferred to the priority determination table to identify the type and priority of each risk. The tables 1 to 6 to outline the necessary items for assessing environmental events during the installation of the structure.

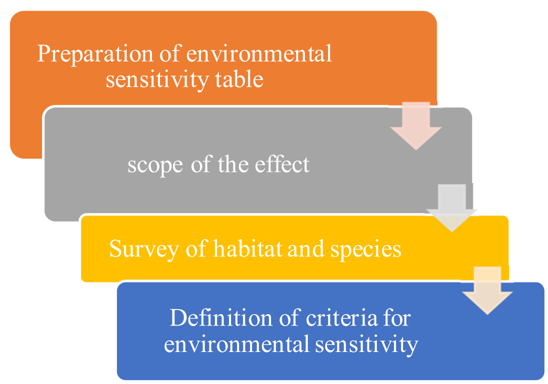

Figure 2. Step-by-step steps of the environmental sensitivity process.

Figure 3. Step-by-step steps of doing the activity.

According to Table 5; this table provides a quantitative and descriptive assessment framework for evaluating the environmental risks, assigning scores based on severity, likelihood of occurrence, and detectability.

Also in Table 6, this decision table categorizes risk status into three levels: low risk (below 5.5), middle risk (6-17), and high risk (18 and above), guiding the priority for action and intervention.

Table 1. Criteria for the intensity of the environmental sensitivity assessment process

Measure of Activity Intensity	Environmental sensitivity criterion	
	habitat	Kind
repetition	coral	Being in high heat
breadth	Sea grass	Presence in pollution
Period		Presence of noise pollution

Table 2. Sub-sections of selection criteria for habitat and species.

Habitat criteria (coral, sea grass)	Species criteria
Uniqueness	Uniqueness
Rarity	Rarity
Critical habitat	Spawning or Breeding
Dependency	Vulnerability
Representativeness	Diversity
Diversity	-
Productivity	-
Spawning or spawning areas	-
Naturalness	-
Integrity	-
Vulnerability	-
Bio-geographic importance	-

Table 3. The severity of the risk of biological events.

Assessment	Consequence description	Rank
Very strong and extensive effect	Severe, serious, and continuous environmental damage.	5
Intensely impactful	Severe and serious damage to the environment of the region There is a requirement for the company to measure and carry out extensive investigations in order to repair the damages Long-term entry of pollutant into the environment and causing extensive damage.	4
Moderate impact	Entry and discharge into the environment, and causing damage to more distant distances significant impact on the environment (species and habitat)/violation of recommended regulations or restrictions.	3
Partial effect	Limited and perceptible pollution (or discharge into the environment and causing damage).	2
Negligible effect	It has a negligible impact on the environment within the premises.	1
Ineffectual	It has no enviromental impact.	0

Table 4. Environmental risk probability table.

Conditions	Description of likelihood of occurrence	Rank
High	Has a history of multiple occurrences per year at the location.	5
Moderate	Has a history of occurrence in the past five years.	4
Low	Has a history of occurrence in the distant years (repeats every few years).	3
Very low	Has a very low occurrence history (but rare).	2
Impossible	Has no history of occurrence.	1

Table 4. It explains the table related to the likelihood of the environmental risks occurring.

Likelihood Level	Score	Description
Impossible	0	0% probability of occurrence-it does not happen.
Very low	1	1-24% probability of occurrence-it may happen but is unlikely/rare.
Low	2	25-49% probability of occurrence-it can happen occasionally but is exceptional/uncommon.
Moderate	3	50-74% probability of occurrence-it may happen sometimes/quite likely.
High	4	75-99% probability of occurrence-it will happen in most cases/highly likely.
Certain	5	100% probability of occurrence-we expect it to happen in most cases.

Table 5. Quantitave and descriptive.

Risk score	Risk quality
Below 5.5 (Low risk)	Low risk
Numbers 6 to 17 (Middle risk)	Middle risk
18 and above (High Risk)	High Risk

Table 6. Decision table for the risk status.

		Probability					
		Impossible	Very Low	Low	Moderate	High	certain
Severity	Severity Visibility	0	0	0	0	0	0
	Minor/Low	0	1	2	3	4	5
	Moderate	0	2	4	6	8	10
	Major	0	3	6	9	12	15
	Very high	0	4	8	12	15	20
	Intolerable	0	5	10	15	20	25

According to Table 5, this table provides a detailed quantitative and descriptive analysis of the identified risks. Each risk is assessed based on its probability of occurrence and the potential severity of its impact. This comprehensive analysis helps in prioritizing risks and determining the most effective mitigation strategies.

Table 6 categorizes the risks based on their calculated scores into three risk levels: low, medium, and high. This categorization is crucial for the decision-makers to allocate the resources effectively, and implement appropriate risk management measures. For example, the risks with scores above 18 are considered high, and require immediate action to mitigate their impact.

Based on the severity, likelihood of occurrence, and detectability of the hazard, the risk level is determined using a risk level calculation formula. With the calculated risk level and assigned scores, the priority for action and intervention to reduce, limit, or eliminate the risk is determined. Table 7 illustrates the main activities in the installation of the tri-pod structure.

2.3. Use of Bayesian reasoning and Netica

In order to model the environmental effects of offshore projects, the BN tools, which are based on the probabilities, have been utilized. For this purpose, the environmental risks in the process of installing of offshore deep sea mining structures in the mentioned phase were scored as a case study. In this research work, and based on the assigned scores, the environmental impact index was calculated. After determining the most influential parameters on the environmental status of the region, the region model was designed using the BN method, and entered into the Netica software. The Netica software is a powerful, easy-to-use, comprehensive program for working with reliable networks and diagrams. It has a user interface for designing the networks, and the relationships between variables can be entered as individual probability in the form of equations or inferred from the data files. When a network is created, the knowledge contained in it can be transferred to other networks by cutting and pasting, or storing it in the modular form by creating a library of nodes for other networks. Netica can use the networks to perform various inferences using fast and modern algorithms [24].

$$P(A|B) = P\{A + B\}/P\{B\} \quad (2)$$

Assume that $B1, \dots, Bk$ form a partition of the sample space S such that for each j = 1, …, k. we have $P(Bj) > 0$. Let A be an event with $P(A) > 0$. Then for $i = 1, \dots k$, we have:

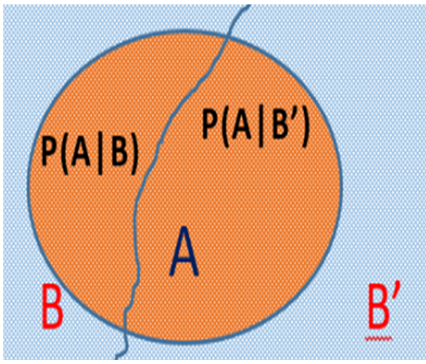

Figure 4. A partition for the sample space S.

From here, we can write:

$$P(A) = \sum_{i=1}^{n} P(A \cap Bi) = \sum_{i=1}^{n} P(A\,|Bi)\, P(Bi) \qquad (3)$$

$$P(Bi|\, A) = \frac{P(A|Bi)\, P(Bi)}{\sum_{j=1}^{k} P(A|Bj)\, P(Bj)} \qquad (4)$$

The analysis, modeling, and simulation were then performed using the Netica software. This software provides a visual interface for the users to design networks, define relationships between variables as probability distributions, and generate output from data files. When a network is created, the knowledge within it can be transferred to other networks by creating a library of nodes in a modular form. The nodes in the modular form Netica are described as Table 8.

$$P(A|B) = \frac{P(A \cap B)}{P(B)} \qquad (5)$$

Since a point in A must either belong to both A and B, or belong to A and not B, we know that $A \cap B$ and $A \cap B'$ are mutually exclusive. Therefore, we can write:

$$A = (A \cap B) \cup (A \cap B) \qquad (6)$$

Table 7. The primary activities in installing the tripod structure.

Installation of the structure	**Noise pollution**	• Disruption in feeding, breeding, nursing, communication, sensitivity, vital behaviors. • Alteration in marine bio-diversity, and balance. • Cerebral hemorrhage or other tissue damage. • Hearing loss or permanent/temporary impairment. • Injury to the internal organs. • Changes in the aquatic habitat presence and migration to the new areas. • Mortality resulting from hemorrhage.
	Change in marine regime	• Alteration in water flow.
	Anchoring	• Oil and gas pipelines (national and international economy).
		• Fiber optic cables (national and international economy).
		• Loss of plant cover on the seabed due to anchoring.
	Oil pollution	• Mortality
	Concrete pouring	• Mortality
	Other pollution related to the project	• -

Table 8. Nodes and qualitative definitions and values for offshore maritime activities.

Node	Definitions and values
Transferring the structure from land to the site	• Structure falling into the sea, water equilibrium.
Acoustic pollution	• The sound of ship engines and propellers.
Maritime conditions	• Change in acidity and temperature.
Geographical extent	• Geographical range (in nautical miles).
Water equilibrium	• Entry of alien species into the specified area.
Marine fish	• Cumulative geographical effects and activity levels.
Anchoring	• Destruction of the seabed, the risk of pipeline, fiber optic cable breakage.
Maritime transportation	• Internal transportation along the Persian Gulf and the Gulf of Oman. • Emerging international commercial, oil transportation.
Impact on the population	• The cumulative effects of indicators considering the likelihood of negative, neutral, and positive outcomes on the local and offshore populations.
Development of oil and gas	• Cumulative effects of the geographical extent (spatial) and intensity (type) of activities.
Change of habitat	• Integration of the effects of seasonal conditions, marine conditions, and fishing activities.
Other	• Transferring cement into the sea.

3. Data Analysis

3.1. Based on the available information from the installation operations,

The potential failure mode and its effects were analyzed based on two factors. The first factor was the severity of the environmental risk, considering resilience and restoration power as well as the habitat sensitivity and species. The second factor was the likelihood of the environmental risk occurrence. In this technique, the product of the two values of the probability of occurrence and severity of risk was determined as the risk score. Patterns of failure with the highest scores were prioritized. Additionally, it is worth noting that if the severity of the risk is classified as 4 or 5, regardless of the RPN, it should be investigated promptly. As a result, the risks with an RPN value exceeding 20% were recognized as the priority risks (information related to all marine pollutants and all marine pollutants related to the installation of the tripod installation project (habitat and species) is provided in two tables, labeled Table 3 and Table 4, in the appendix of the article.

Table 9. Completed risk checklist during structure installation.

Type of Activity/Hazard that may arise in the project	Type of hazard explanation		
	Safety	***Health***	***Environmental***
Oil leakage	❉	❉	❉
Collision	❉	❉	❉
Man overboard	❉	❉	
Working at heights	❉		
Welding	❉	❉	❉
Cutting	❉		❉
Strapping and packaging	❉		❉
Painting	❉	❉	❉
Work on the water surface	❉		
Diving	❉		❉
Electrical cable laying	❉		
H_2S gas leak	❉	❉	❉
refueling	❉	❉	❉
Radiography		❉	❉
Destructive and non-destructive testing		❉	
Ergonomic hazards		❉	
Psychological risks		❉	
Loading		❉	
Anchoring	❉		
Transporting the structure by barge	❉		❉
Heavy lifting	❉		❉
Helicopter operations	❉		❉
Noise	❉		
Fishing	❉		❉

3.2. Findings of environmental risk assessment.

Based on the findings of the research work, the total number of significant environmental risks identified in the installation project was 31, with 15 related to the habitats, and the remaining 16 related to the species. Among the important risks concerning habitats, 6 were classified as the low risk, 7 as the moderate risk, and 2 as the high risk (intolerable). Regarding the species, 5 was classified as the low risk, 8 as the moderate risk, and 3 as high risk. Table 10 provides the number of risks and their percentage relative to the total risks calculated and documented.

Table 10. Table of identified risks count and percentage.

Risk classification	Number of habitat risks	Percent	Number of species risks	Percent
Low risk	6	40%	5	31%
Moderate risk	7	46%	8	50%
High risk	2	14%	3	19%
Total	15	100%	16	100%

Table 11. Risks, causes, and consequences related to the habitat.

Risk potential			Consequences	Threats (causes)	Hazard and sources
R	S	P			
4	2	2	Sedimentation on the seabed pollution.	Mooring rope wrapping	Mooring line and oil drum falling into the sea Mooring line dropping.
8	2	4	Sedimentation on the seabed pollution.	Welding	Dropping welding wire into the sea.
10	5	2	Sea surface pollution	Fuel transfer.	Oil leak.
8	4	2	Sea surface pollution	by person	Plastic bottle falling into the sea
3	3	1	Sea surface pollution.	Painting the structure	Entering dyes and solvents into the sea.
3	1	3	Rippling of the diving area.	Diving	Changing the marine regime Speedboat traffic.
5	1	5	Waving of the traffic area.	Traffic high-speed boats and floaters	
2	2	1	Sedimentation on the seabed Seabed pollution.	Loading on the water level with a crane.	Entry of objects into the sea.
20	4	5	Destruction of sea floor vegetation.	Anchoring	Environmental hazard.
15	3	5	Waving of the traffic area	Transfer of structure with barge	Change in marine regime and discharge of materials ship permit.
10	2	5	Changing the sea regime around the structure.	Heavy leaf and installation.	Changing the marine regime.
10	2	5	Changes in the sea floor/bed.	Hammering	Noise
3	1	3	Very little impact.	Helicopter operations	Helicopter operations
20	4	5	Sea surface pollution.	Cement (grout) woman	Cement injection inside the piles
8	4	2	Decomposition of hydrogen sulfide in seawater under different ratios of dissolved oxygen/hydrogen sulfide. varies	Well-leak	H_2S gas leak.

Table 12. Risks, causes, and consequences related to the species.

Risk potential			Consequences	Threats (causes)	Hazard and sources
R	S	P			
4	2	2	Sedimentation on the seabed Seabed pollution.	Mooring rope wrapping.	Mooring line and oil drum falling into the sea Mooring line dropping.
8	2	4	Sedimentation on the seabed Seabed pollution.	Welding	Dropping welding wire into the sea.
10	5	2	Sea surface pollution	Fuel transfer	Oil leak
8	4	2	Sea surface pollution	by person	Plastic bottle falling into the sea.
3	3	1	Sea surface pollution	Painting the structure	Entering dyes and solvents into the sea.
3	1	3	Rippling of the diving area	Diving	Changing the marine regime speedboat traffic.
5	1	5	Waving of the traffic area	Traffic high-speed boats and floaters.	
2	2	1	Sedimentation on the seabed seabed pollution.	Loading on the water level with a crane	Entry of objects into the sea.
20	4	5	Destruction of sea floor vegetation.	Anchoring	Environmental hazard.
15	3	5	Waving of the traffic area.	Transfer of structure with barge.	Change in the marine regime, and discharge of materials (ship permit)
10	2	5	Changing the sea regime around the structure.	Heavy leaf and installation	Changing the marine regime
10	2	5	Changes in the sea floor/bed.	hammering	Noise
3	1	3	Very little impact.	Helicopter operations	Helicopter operations
20	4	5	Sea surface pollution	Cement (grout) woman	Cement injection inside the piles
8	4	2	Decomposition of hydrogen sulfide in seawater under different ratios of dissolved oxygen/hydrogen sulfide varies.	Well-leak	H_2S gas leak.

After extracting information from the identification of hazards and assessing environmental risks, the data was summarized and classified statistically. To provide a better and more comprehensive overview, graphical methods were used to visually represent the level of hazards (Figures 5 and 6).

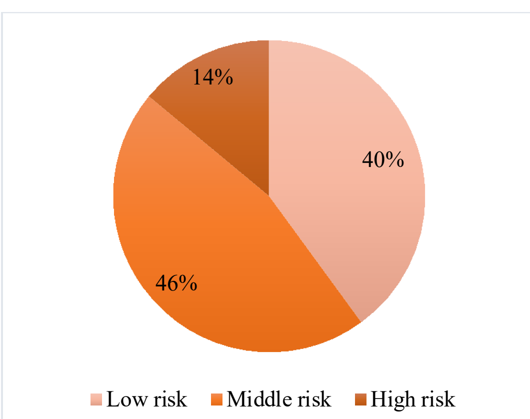

Figure 5. Pie Chart of the percentage of Identified risks by habitat.

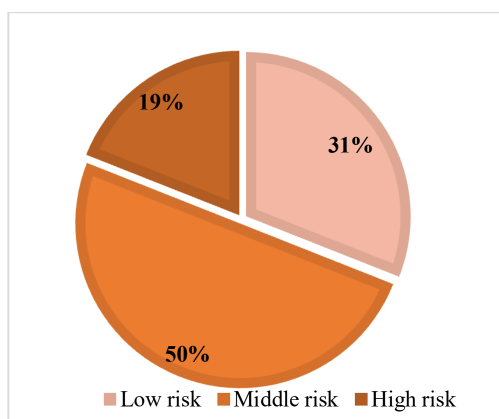

Figure 6. Percentage of identified risks categorized by the species.

Based on the statistical analyses conducted and the results of risk assessment matrices, the most important environmental risks of installing the three-legged offshore platform are presented in Table 13, along with the risk numbers.

Table 13. Important environmental risks identified in the installation project in order of importance and priority number.

Risk	Ecological consequence	Risk number
Anchoring	Changes in the seabed/damage to the sea floor.	20
Grouting	Surface pollution of the sea.	20
Barge transportation	Change in the marine regime, waste influx.	15
Risk	**Species consequence**	**Risk number**
Hammering	Environmental pollution.	22
Grouting	Oil spill into the sea, and environmental pollution.	20
Transferring structures with barges	Collision of terrestrial species with the ship's propeller, eating garbage.	20
Installation of the structure	Abrasion inside the lines due to the presence of sand and pipe. corrosion and oil leakage.	15
anchoring	Collision of the anchor with the species of the bottom, and the collision of the tow wire with the species of the surface.	15
Speedboat traffic	Changing the pattern of being in the water and migrating to newer places.	15
H2S leak	Mortality, disorder.	15

3.3. Modeling risks with Netica

For modeling, Netica software and Bayesian networks were used. These networks provide a specific framework for integrating experimental data. Using this method makes it easy to

Understand the cause-and-effect relationships between variables, and its diagrammatic and schematic nature provides a framework for top-level managers and experts to aggregate and organize their thoughts and make necessary managerial decisions. According to expert opinions, the relationships between risks and activities were connected as parent and child nodes to each other, and the probability of the occurrence of a node was changed based on the number of occurrences defined in the probability table. These figure7to9 represent how the probability of each scenario occurring is estimated based on expert opinions and its percentage.

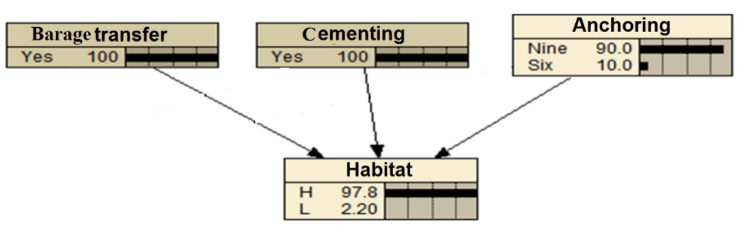

Figure 7. Interaction level of the major factors involved in the habitat destruction.

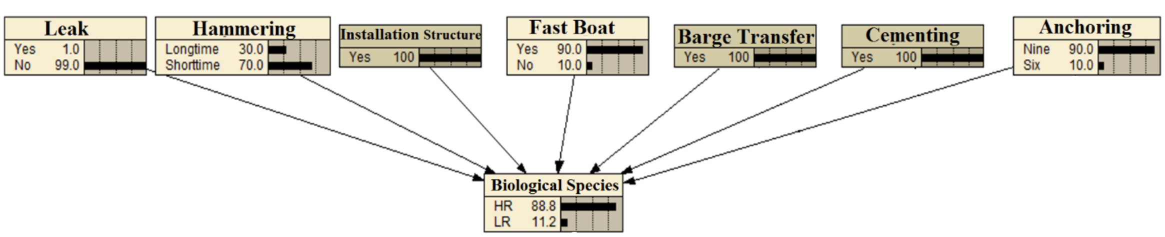

Figure 8. Interaction level of the major factors involved in the species destruction.

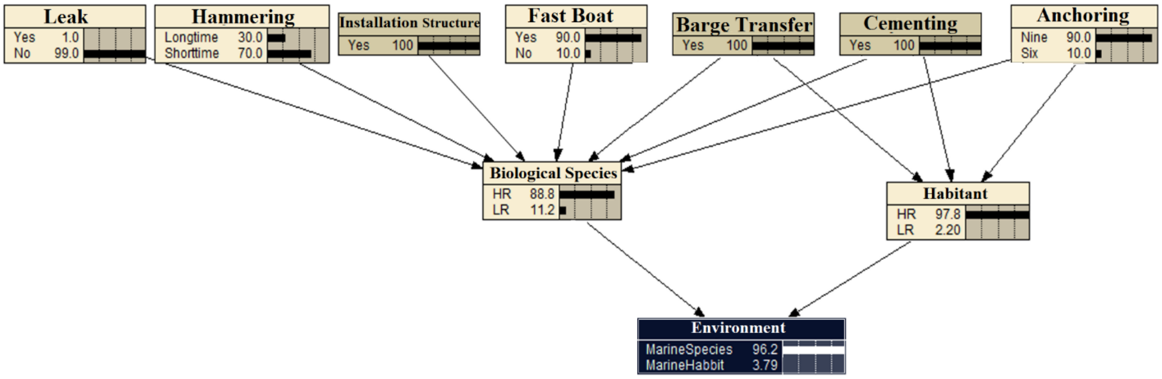

Figure 9. Interaction level of the major factors involved in the environmental destruction in the installation project.

3.4. Modeling findings

After completing the table related to the probability of node occurrences, the results obtained were examined in the sensitivity analysis section of the Netica guide, determining the impact of all the parameters on the habitat and the species-related risks in the studied area.

3.4.1. Habitat-dependent risks

The results of modeling the factors affecting the habitat-dependent risks indicate that the majority of risks are related to anchoring, structure transfer, and concreting. Through interactions, if the number of anchors thrown is reduced (from 9 to 3), the risk of damage decreases by 2.2%. However, 97.8% of the risks remain unchanged.

3.4.2. Risks associated with species dependence

The results of modeling the factors affecting the risks associated with species dependency indicate that if pile driving is performed in the short-term, fewer anchors are thrown, the boat has less frequent trips, and there is no leakage of H_2S gas; the risks decrease by 11.2%. However, 88.8% of the risks remain unchanged.

3.5. Risk reduction and environmental impact control

To address the identified environmental risks, the study proposes several mitigation strategies:

1. Implementing real-time monitoring systems to detect and respond to the environmental hazards promptly.

2. Utilizing less invasive installation techniques to reduce seabed disturbance.

3. Enhancing spill response protocols and preparedness to manage the potential oil and chemical spills effectively.

4. Enforcing stricter environmental regulations and ensuring compliance through regular inspections and audits.

4. Conclusions

The findings of the risk identification and the assessment process, indicating that:

1. 40% of the risks are within a low-risk tolerance for the habitat destruction.

2. 46% are in the ALARP (as low as reasonably practicable) region.

3. 14% are in the high-risk region for the habitat destruction.

4. For the species destruction, 31% are in the low-risk tolerance, 50% in the ALARP region, and 19% in the high-risk region.

These results underline the importance of targeted mitigation measures to manage the environmental risks effectively during offshore installations.

To address the identified environmental risks, the work proposes several mitigation strategies:

1. Implementing real-time monitoring systems to detect and respond to the environmental hazards promptly.

2. Utilizing less invasive installation techniques to reduce seabed disturbance.

3. Enhancing spill response protocols, and preparedness to manage the potential oil and chemical spills effectively.

4. Enforcing stricter environmental regulations and ensuring compliance through regular inspections and audits.

As was told before, the environmental risk assessment for the installation of offshore structures reveals that a significant proportion of the risks fall into the medium and high-risk categories, specifically, 40% of the risks pertain to habitat destruction, while 31% involve the species destruction. These findings underscore the urgent need for the targeted risk mitigation strategies.

To mitigate these risks, it is essential to adopt a multi-faceted approach that includes an advanced monitoring systems, less invasive construction techniques, and stringent regulatory enforcement. By implementing these measures, we can significantly reduce the environmental impact of offshore installations, and promote sustainable maritime operations.

The work acknowledges limitations including the reliance on expert opinions for the probability assessments, which may introduce subjective biases. Additionally, the modeling does not fully account for all the potential environmental variables and their complex interactions, suggesting the need for a continuous updating and validation with the new data.

The future work should focus on improving the precision of risk models by incorporating more comprehensive empirical data, and exploring advanced modeling techniques. There is also a need to enhance real-time monitoring capabilities, and develop adaptive management strategies to respond to emerging environmental risks dynamically.

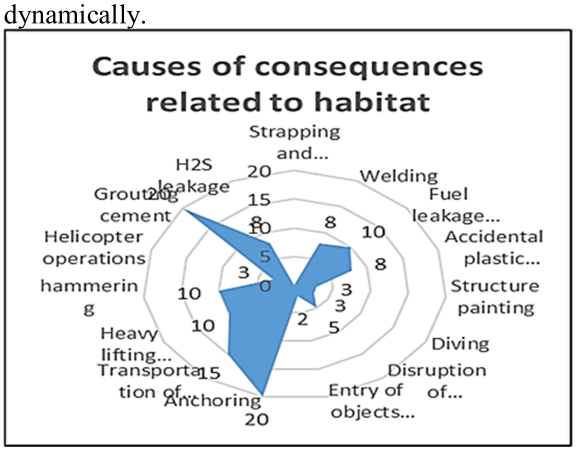

Figure 10. Causes of consequences related to the habitat. Figure depicts the interaction levels of the major factors involved in the environmental destruction during the installation project, showing the probability, and impact of different activities on the habitat and the species destruction based on the expert opinions and BN modeling.

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مدل‌سازی ارزیابی ریسک محیطی فراساحلی: مطالعه موردی نصب سازه سه پایه برای استخراج در اعماق دریا

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چکیده:

تخریب محیط زیست، به‌ویژه در اکوسیستم‌های دریایی، به دلیل فعالیت‌های صنعتی به یک مسئله بحرانی تبدیل شده است. مناطق فراساحلی به‌شدت تحت تأثیر عملیات استخراج معدن در اعماق دریا قرار می‌گیرند که منجر به آلودگی و عدم تعادل‌های زیست‌محیطی می‌شود. مدل‌های ارزیابی ریسک محیطی موجود غالباً در ادغام مؤثر داده‌های کیفی و کمی ناکام هستند و این امر خلأ قابل‌توجهی را در پژوهش‌ها نمایان می‌سازد. این پژوهش با هدف رفع این خلأ، چارچوب جامعی با استفاده از شبکه‌های بیزین (BN) و نرم‌افزار NETICA برای ارزیابی ریسک‌های مرتبط با نصب سازه‌های سه‌پایه در اعماق دریا توسعه می‌دهد. اهداف اصلی شامل شناسایی و اولویت‌بندی نظام‌مند ریسک‌ها و توسعه راهبردهای مؤثر کاهش ریسک است. نوآوری این کار در استفاده ابتکاری از مدل‌سازی با روش بیزین برای ترکیب دانش کارشناسی با داده‌های تجربی است که دسته‌بندی دقیقی از ریسک‌ها را به سطوح کم، متوسط و زیاد فراهم می‌کند. پارامترهای خروجی بر شدت، احتمال وقوع و قابلیت تشخیص ریسک‌ها تمرکز دارند. نتایج نشان می‌دهد که ۴۰ درصد از ریسک‌های تخریب زیستگاه در سطح کم، ۴۶ درصد در ناحیه قابل تحمل و ۱۴ درصد زیاد هستند، در حالی که ریسک‌های تخریب گونه‌ها به ترتیب ۳۱ درصد کم، ۵۰ درصد قابل تحمل و ۱۹ درصد زیاد برآورد شده‌اند. این یافته‌ها راهنمایی برای اقدامات هدفمند کاهش ریسک در جهت حفاظت مؤثر از محیط زیست دریایی فراساحلی فراهم می‌کند. همچنین، پژوهش با ارائه مجموعه‌ای از توصیه‌ها برای کاهش ریسک‌های شناسایی‌شده و به حداقل رساندن اثرات زیست‌محیطی به پایان می‌رسد. این توصیه‌ها شامل اجرای فناوری‌های پیشرفته پایش، اتخاذ بهترین شیوه‌های مدیریتی و تقویت چارچوب‌های قانونی سخت‌گیرانه است.

کلمات کلیدی: ارزیابی ریسک، فراساحلی، سه پایه، FMEA، روش بیزین.