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# Comparison of environmental risks of drilling operations of cluster and single ring models

**Soheil Zamanzadeh**[1], **Sanaz Khoramipour**[*2], **Fatemeh Razavian**[2]

[1]*Department of Environmental science and engineering, West Tehran Branch, Islamic Azad University, Tehran, Iran*

[2]*Department of Environmental Science and Engineering, West Tehran Branch, Islamic Azad University, Tehran, Iran*

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## ABSTRACT

The purpose of this study is to compare the environmental risks arising from two models of drilling operations of single-ring and clustered wells in the land area, and finally, to select the most appropriate drilling operations to reduce environmental risks. For this purpose, after identifying the most important drilling activities of oil and gas wells and collecting the opinions of the statistical community, the risks arising from the activities in this field for both drilling models were identified and evaluated using the failure modes and effects analysis (FMEA) method. Then, the best option was selected using the hierarchical analysis process technique, which is useful in prioritizing and selecting the best option. The location of drilling risks in the high and medium risk matrix was determined using the FMEA method for both models with 1<RPN<30. And using the analytic hierarchy process (AHP) technique in the range of zero and one and between the single ring and cluster prioritized the techniques, and the best drilling technique for oil and gas wells, namely cluster drilling, was selected.

## 1. Introduction

Over the past decades, risk analysis has become an important tool for the oil industry. Various methods of risk analysis have been used to evaluate exploration and development projects, as well as investment decisions. In addition, the use of risk analysis methods for economic and engineering applications is widely accepted [1]. Risk analysis is defined as the process of describing, managing, and informing others about the existence, nature, size, prevalence, contributing factors, and uncertainty of potential losses [2,3]. Qualitative techniques are used to identify risk and the stages of risk analysis: FMEA [4], experimental analysis [5,6], and process-performance modeling [7]. Among the risk assessment techniques, the FMEA method is the only analytical method that can better assess the potential risks and also identify the causes and related effects. Ranking the benefits of this method can be appropriate for quantitative risk assessment and its reliability to

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*Corresponding author. Tel: +989125621438
E-mail: Khorami.sanaz@wtiau.ac.ir
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predict problems and identify the most effective risk prevention solution [8,9]. FMEA is one of the environmental risk assessment procedures to identify and prioritize the environmental impacts of a project [10]. Braglia [11] developed a multi-criteria analysis model of FMEA based on hierarchical analysis that considers risk parameters as decision criteria, probable causes of failure as decision-making options, and prioritization of failure as the goal of decision making. Following the AHP method, all possible causes of failure are evaluated and ranked. Referring to Braglia [11], Chang [12] proposed a method that combines the FMEA multi-criteria analysis model and the 2-tuple representation to assess and prioritize risk. Carmignani [13] introduced a priority-cost-based FMEA approach based on a new interpretation of the risk priority number (RPN), the AHP method, and a new profitability variable in which AHP is used to determine the different weights of risk parameters. Environmental risk assessment became significantly important for all industries due to legal regulations, global warming, industrialization, and competition. Companies use different types of environmental risk assessment methods to prevent and reduce the harmful effects of their activities [14]. Environmental pollution and health care should be one of the criteria for a sustainable environment [15]. Therefore, environmental risk assessment is of considerable importance [16]. The drilling industry is one of the riskiest sectors of the oil industry due to its special nature. Major and minor accidents in this industry cause human and financial losses. The first step in reducing accidents and damages in this industry is identifying and evaluating the observed risks. Risks can then be prioritized in terms of their importance, and then appropriate long-term strategies can be identified and implemented to reduce accidents [17]. In oil and gas drilling engineering, high-risk investment characteristics are especially important when drilling in deep and complex formations or offshore [18-21]. The uncertainty of drilling geological parameters, measurement error, and inaccuracy of the calculation model will lead to uncertainty in the formation pressure calculation [22-24]. Uncertainty about the pressure of the formation can lead to an irrational plan that poses drilling risks. Drilling risk prediction is an important tool for ensuring safe drilling [25]. Oil and gas wells are separated according to the relative amounts of hydrocarbon liquid and steam produced using the cumulative ratio of gas to oil. Oil wells produce crude oil and associated gas after the initial separation. After the initial separation, gas wellsproduce gas and condensate gas (non-separate). Gas from both types of wells is typically processed ashore to produce waste gas (mostly methane) and natural gas liquids consisting of ethane, propane, butane, and natural gasoline [26]. Wells are often classified as clusters on a pad (these clusters or groups may contain only one well). After drilling wells in one cluster, the drilling rig is transferred to the next cluster [27]. Predicting the production of an oilfield well is an important step in analyzing data during oilfield development [28]. Factors affecting the production of single wells include parameters such as formation energy, water content, water injection, etc. [28]. The risk assessment approach is one of the main focuses in establishing and using management systems in organizations. By establishing management systems (safety management, environmental management, quality management, etc.) in organizations and estimating the requirements needed to implement the error prevention approach and estimates, the organization's goals are achieved. According to previous research, the assessment of various environmental risks of drilling, especially in the offshore sector, is very outdated. Much work has been done, but so far, a comparison of environmental risks in single-ring and cluster well drilling methods for onshore development wells has not been done. Therefore, this study examines this important issue.

## 2. Material and methods

### *2.1. Yaran and South Azadegan oil fields*

The Azadegan field is an oil fields located in the Azadegan plain region, 100 km west of Ahvaz, Iran. This 20 by 75 kilometer field was discovered in 1997 by the Exploration Department of the National Iranian Oil Company. From the North, the Azadegan field is located in the vicinity of the Majnoon field in Iraq. The field's crude oil reserves are estimated at 33 billion barrels. The Yaran oil field is located 130 km southwest of Ahvaz, and to the west of the South Azadegan field in the border strip of Iraq; most of this field is located in Iraq. The dimensions of the area agreed for the development of this field is about 3 x 18 km. This field is located near the South Azadegan field, close to the Jufair and Yadavaran fields.

### *2.2. Research variables, criteria and alternatives*

Independent variables: single-ring and cluster drilling operations for oil and gas wells

Dependent variables: indicators related to risk assessment based on FMEA

Criteria: air pollution extent (P1), air volume (P2), soil area (P3), soil volume (P4), water area (P5), water volume (P6), number of habitats (P7), animal species (P8), plant species (P9), Groundwater volume: (P10)

Alternatives: drilling offshore single-ring oil and gas wells (C1) and drilling offshore cluster oil and gas wells (C2)

### *2.3. Method*

First, information was collected through library studies; then, field visits of oil and gas well drilling operations in the two fields of Yaran and South Azadegan of the West Karun field complex were taken. After collecting questionnaires prepared by experts to determine the relevant indicators related to risk assessment based on the FMEA model and environmental impact criteria according to ISO 14001, the information was analyzed. Then, the environmental risks arising from the activities of different parts of the drilling process were identified based on the FMEA model, including 12 major activities; risk assessment was performed for both the single-ring and cluster wells.

#### *2.3.1. Risk assessment of both models based on the FMEA method*

The FMEA risk assessment is an analytical method that tries to identify and rank as much as possible the potential risks in the area where the risk assessment is performed, as well as the related causes and effects. Predictable and unpredictable emergencies are becoming more prevalent with changes in technology and the environment. The FMEA can help risk managers assess and review failures and thus, reduce the impact of unavoidable events. It can also provide information for risk management decisions [29-31].

The steps for conducting an FMEA risk assessment are as follows:

1. Collecting information related to the process
2. Determining potential environmental hazards
3. Examining the aspects of each environmental hazard
4. Determining the causes of danger
5. Checking control processes
6. Determining the rate of deterioration
7. Probability of occurrence
8. Probability rate (frequency) of risk detection
9. Calculate RPN
10. Analysis of two drilling models and conclusion

#### *2.3.2. Comparison of risk assessment models using hierarchical analysis*

To quantitatively compare both drilling models, AHP is selected, and the decision matrix is prepared based on the criteria used in the FMEA method. Finally, both selected alternatives are compared with each other based on the specified criteria, and the final score represents the superior option. AHP is a semi-quantitative decision-making value approach that serves decision-making goals [32-34]. This method allows group decision-makers for planners. Planners can use their experience and knowledge to divide a problem into a hierarchical structure and solve it by AHP [34-36]. This method also facilitates the weight normalization of control agents. This process was developed by Satty [32] to calculate the required weighting factors using the priority matrix, where all relevant criteria are compared with reproducible preference factors (Table 4) [32,33,35,37]. AHP selects the best alternatives taking into account objective and subjective factors. In the present study, AHP was used to compare drilling wells and single-ring wells. Figure 1 indicates the work process.

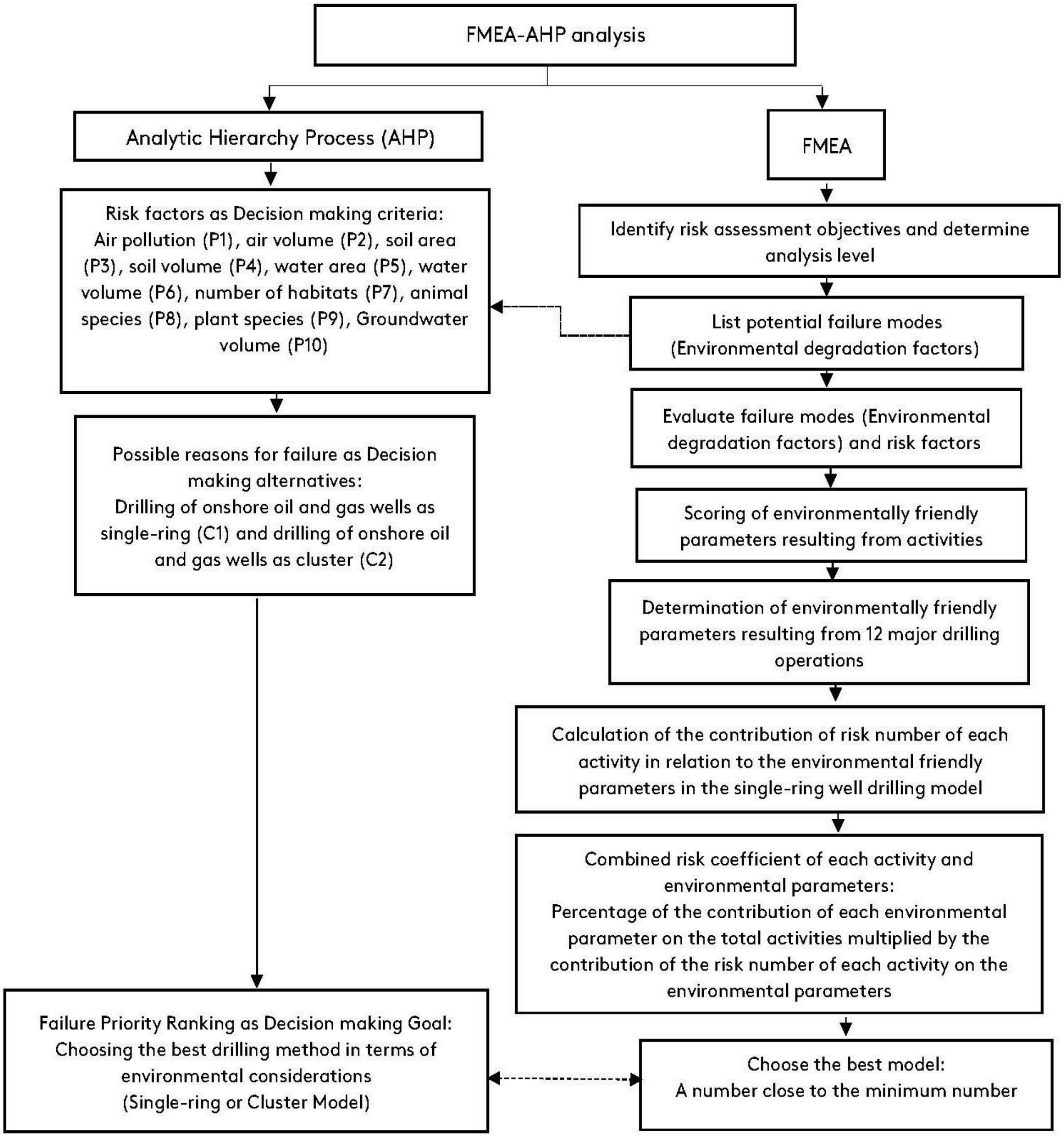

**Fig. 1.** Diagram of the work process.

## 3. Results and discussion

### *3.1. Comparison of environmental impact parameters in two drilling models using the experience of experts*

The most important environmental risks in this study were low and medium level (Tables 1 and 2). The highest degree of risk in this study is related to harvesting and leveling the land and adding soil from another land (medium risk) in drilling single-ring wells.

**Table 1.** Environmental risk assessment of single-ring wells drilling.

| Aspects of the environment | Consequences - Damage to the environment | Severity | Probability | Risk degree | Risk level |
|---|---|---|---|---|---|
| Dust release | Air Pollution | 3 | 6 | 18 | High |
| Degradation of land areas including pastures, forests, habitats, streams, lakes, deserts, rivers, etc. | Destruction of the natural structure of the environment, such as destruction of mountains, deserts, plains, forests, pastures, lakes, rivers, streams, animal habitats, the vegetation of the region, etc. | 3 | 6 | 18 | High |
| Explosion and fire | Destruction of the natural structure of the environment, such as destruction of mountains, deserts, plains, forests, pastures, lakes, rivers, streams, animal habitats, the vegetation of the region, etc. | 5 | 4 | 20 | High |
| Radiation of radioactive materials | Destruction of the natural structure of the environment, such as destruction of mountains, deserts, plains, forests, pastures, lakes, rivers, streams, animal habitats, the vegetation of the region, etc. | 4 | 4 | 16 | Medium |
| Discharge of industrial effluents to groundwater or surface water | Soil /water pollution | 4 | 6 | 24 | High |
| Wastewater discharge of waste into the soil | Soil /water pollution | 4 | 6 | 24 | High |
| Sanitary wastewater discharge to groundwater or surface water | Soil /water pollution | 4 | 6 | 24 | High |
| Atomic and radioactive waste | Soil /water pollution | 4 | 6 | 24 | High |
| Sanitary and infectious waste | Soil /water pollution | 4 | 6 | 24 | High |
| Noise from devices and machines | Noise Pollution | 3 | 6 | 18 | High |
| Waste (plastic, cans, barrels, etc.) | Soil pollution | 4 | 5 | 20 | High |
| Fume from welding and cutting | Air pollution | 3 | 6 | 18 | High |
| Emission of suspended particles | Air pollution | 3 | 6 | 18 | High |
| Gas emission of heating equipment stack and burners of facilities | Air pollution | 3 | 6 | 18 | High |
| Harvesting and levelling the land and adding soil from another land | Destruction of the natural structure of the environment, such as destruction of mountains, deserts, plains, forests, pastures, lakes, rivers, streams, animal habitats, the vegetation of the region, etc. | 5 | 6 | 30 | High |
| Water consumption | Reduce resources and energy | 3 | 6 | 18 | High |
| Electricity consumption | Reduce resources and energy | 3 | 6 | 18 | High |
| Paper consumption | Reduce resources and energy | 3 | 6 | 18 | High |
| Consumption of various petroleum derivatives | Reduce resources and energy | 3 | 6 | 18 | High |
| Gas consumption | Reduce resources and energy | 3 | 6 | 18 | High |
| Consumption of energy species | Reduce resources and energy | 3 | 6 | 18 | High |
| Leakage of various oils and petroleum products into the soil | Soil pollution | 3 | 6 | 18 | High |

| Aspects of the environment | Consequences - Damage to the environment | Severity | Probability | Risk degree | Risk level |
|---|---|---|---|---|---|
| Leakage of various chemicals into the soil | Soil pollution | 3 | 6 | 18 | High |
| Diesel and gasoline leaks | Soil pollution | 3 | 6 | 18 | High |
| Emission of chemical and volatile organic compounds vapours | Air pollution | 3 | 6 | 18 | High |

**Table 2.** Environmental risk assessment of cluster wells drilling.

| Aspects of the environment | Risk level | Risk degree | Severity | Probability | Consequences - Damage to the environment |
|---|---|---|---|---|---|
| Dust release | Medium | 12 | 3 | 4 | Air Pollution |
| Degradation of land areas including pastures, forests, habitats, streams, lakes, deserts, rivers, etc. | Medium | 12 | 3 | 4 | Destruction of the natural structure of the environment, such as destruction of mountains, deserts, plains, forests, pastures, lakes, rivers, streams, animal habitats, the vegetation of the region, etc. |
| Explosion and fire | Medium | 12 | 3 | 4 | Destruction of the natural structure of the environment, such as destruction of mountains, deserts, plains, forests, pastures, lakes, rivers, streams, animal habitats, the vegetation of the region, etc. |
| Radiation of radioactive materials | Medium | 12 | 3 | 4 | Destruction of the natural structure of the environment, such as destruction of mountains, deserts, plains, forests, pastures, lakes, rivers, streams, animal habitats, the vegetation of the region, etc. |
| Discharge of industrial wastewater to groundwater or surface water | Medium | 12 | 3 | 4 | Soil /water pollution |
| Wastewater discharge of waste into the soil | Medium | 12 | 3 | 4 | Soil /water pollution |
| Sanitary wastewater discharge to groundwater or surface water | Medium | 12 | 3 | 4 | Soil /water pollution |
| Atomic and radioactive waste | Medium | 12 | 3 | 4 | Soil /water pollution |
| Sanitary and infectious waste | Medium | 12 | 3 | 4 | Soil /water pollution |
| Noise from devices and machines | Medium | 12 | 3 | 4 | Noise Pollution |
| Waste (plastic, cans, barrels, etc.) | Medium | 12 | 3 | 4 | Soil pollution |
| Fume from welding and cutting | Medium | 12 | 3 | 4 | Air pollution |
| Emission of suspended particles | Medium | 12 | 3 | 4 | Air pollution |
| Gas emission of heating equipment stack and burners of facilities | Medium | 12 | 3 | 4 | Air pollution |
| Harvesting and levelling the land and adding soil from another land | Medium | 12 | 3 | 4 | Destruction of the natural structure of the environment, such as destruction of mountains, deserts, plains, forests, pastures, lakes, rivers, streams, animal habitats, the vegetation of the region, etc. |

| Aspects of the environment | Risk level | Risk degree | Severity | Probability | Consequences - Damage to the environment |
|---|---|---|---|---|---|
| Water consumption | Medium | 12 | 3 | 4 | Reduce resources and energy |
| Electricity consumption | Medium | 12 | 3 | 4 | Reduce resources and energy |
| Paper consumption | Medium | 12 | 3 | 4 | Reduce resources and energy |
| Consumption of various petroleum derivatives | Medium | 12 | 3 | 4 | Reduce resources and energy |
| Gas consumption | Medium | 12 | 3 | 4 | Reduce resources and energy |
| Consumption of energy species | Medium | 12 | 3 | 4 | Reduce resources and energy |
| Leakage of various oils and petroleum products into the soil | Medium | 12 | 3 | 4 | Soil pollution |

First, the environmental impact parameters of the activities were scored using risk assessment and the experiences of experts. Environmental impact parameters resulting from 12 major drilling operations activities were recorded and calculated according to the results of questionnaires obtained from experts in both drilling models. The contribution of the risk number of each activity concerning the parameters in the single-ring well drilling model was calculated and recorded. The combined risk factor of each of the activities and parameters is specified in Table 1. As in the single-ring model, the average risk numbers for the cluster model were extracted from the risk assessment table, and the contribution of risk number of each activity concerning the parameters in this drilling model was calculated and recorded. Then, the combined risk factor of each activity and parameter was determined in the cluster model. In Table 3, the effective environmental parameters resulting from the 12 major activities of drilling operations have been recorded and calculated according to the results of the questionnaires obtained from experts in both drilling models.

**Table 3.** Effective environmental parameters resulting from activities.

| Activities | Effective environmental parameters resulting from activities | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total | P10 - Groundwater | P9- Plant species | P8- Animal species | P7- Number of habitats | P6- Water volume | P5- Water area | P4- Soil volume | P3- Soil area | P2- Air volume | P1- Extent of air pollution |
| Drilling sites, roads and camp-A1 | 100% | 5% | 10% | 5% | 10% | 10% | 10% | 15% | 15% | 15% | 5% |
| Drilling supplies, materials and equipment-A2 | 100% | 10% | 10% | 5% | 5% | 10% | 10% | 10% | 15% | 15% | 10% |
| Operations inside and outside the well-A3 | 100% | 10% | 5% | 5% | 5% | 10% | 5% | 15% | 15% | 15% | 15% |
| Drilling rig replacement - A4 | 100% | 5% | 15% | 15% | 15% | 5% | 5% | 10% | 10% | 10% | 10% |
| Drilling wastewater and wastes - A5 | 100% | 5% | 10% | 5% | 10% | 15% | 15% | 15% | 15% | 5% | 5% |
| Maintenance sites - A6 | 100% | 5% | 10% | 5% | 10% | 10% | 10% | 15% | 15% | 10% | 10% |
| Roads - Car routes - A7 | 100% | 5% | 10% | 5% | 10% | 10% | 10% | 15% | 15% | 15% | 5% |
| Yard - Power Distribution System - A8 | 100% | 0% | 15% | 10% | 15% | 5% | 5% | 20% | 20% | 5% | 5% |
| Rig repository-A9 | 100% | 5% | 10% | 5% | 10% | 10% | 10% | 15% | 15% | 15% | 5% |
| Conex-WC-A10 | 100% | 15% | 10% | 5% | 10% | 15% | 15% | 10% | 10% | 5% | 5% |
| Drinking water storage tanks - A11 | 100% | 10% | 5% | 5% | 10% | 20% | 15% | 10% | 15% | 5% | 5% |
| Diesel generator and fuel tank-A12 | 100% | 10% | 10% | 5% | 10% | 5% | 5% | 10% | 15% | 15% | 15% |
| | | 85% | 120% | 75% | 120% | 125% | 115% | 160% | 175% | 130% | 95% |

**Table 4.** Risk assessment of single-ring wells.

| Activities | Total | The contribution of risk number of each activity concerning the parameters | | | | | | | | | | Average risk number for each activity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Drilling sites, roads and camp-A1 | 24 | 1.2 | 2.4 | 1.2 | 2.4 | 2.4 | 2.4 | 3.6 | 3.6 | 3.6 | 1.2 | 24 |
| Drilling supplies, materials and equipment-A2 | 19 | 1.9 | 1.9 | 0.95 | 0.95 | 1.9 | 1.9 | 1.9 | 2.85 | 2.85 | 1.9 | 19 |
| Operations inside and outside the well-A3 | 19 | 1.9 | 0.95 | 0.95 | 0.95 | 1.9 | 0.95 | 2.85 | 2.85 | 2.85 | 2.85 | 19 |
| Drilling rig replacement - A4 | 18 | 0.9 | 2.7 | 2.7 | 2.7 | 0.9 | 0.9 | 1.8 | 1.8 | 1.8 | 1.8 | 18 |
| Drilling wastewater and wastes - A5 | 24 | 1.2 | 2.4 | 1.2 | 2.4 | 3.6 | 3.6 | 3.6 | 3.6 | 1.2 | 1.2 | 24 |
| Maintenance sites - A6 | 18 | 0.9 | 1.8 | 0.9 | 1.8 | 1.8 | 1.8 | 2.7 | 2.7 | 1.8 | 1.8 | 18 |
| Roads - Car routes - A7 | 27 | 1.35 | 2.7 | 1.35 | 2.7 | 2.7 | 2.7 | 4.05 | 4.05 | 4.05 | 1.35 | 27 |
| Yard - Power Distribution System - A8 | 30 | 0 | 4.5 | 3 | 4.5 | 1.5 | 1.5 | 6 | 6 | 1.5 | 1.5 | 30 |
| Rig repository-A9 | 18 | 0.9 | 1.8 | 0.9 | 1.8 | 1.8 | 1.8 | 2.7 | 2.7 | 2.7 | 0.9 | 18 |
| Conex-WC-A10 | 18 | 2.7 | 1.8 | 0.9 | 1.8 | 2.7 | 2.7 | 1.8 | 1.8 | 0.9 | 0.9 | 18 |
| Drinking water storage tanks - A11 | 18 | 1.8 | 0.9 | 0.9 | 1.8 | 3.6 | 2.7 | 1.8 | 2.7 | 0.9 | 0.9 | 18 |
| Diesel generator and fuel tank-A12 | 18 | 1.8 | 1.8 | 0.9 | 1.8 | 0.9 | 0.9 | 1.8 | 2.7 | 2.7 | 2.7 | 18 |

In Table 4, the contribution of the risk number of each activity concerning the parameters in the single-ring drilling model is calculated and recorded. Table 5 specifies the combined risk factor of each activity and parameter. Like the single-ring model, for the cluster model, the average risk numbers are extracted from the risk assessment table, and the contribution of risk number of each activity concerning the parameters in this drilling model is calculated and recorded in Table 6 and Table 8. Then, the combined risk factor of each activity and parameters in the cluster model was determined (Table 7). Figure 2 indicates risk factors of each activity. Then, according to the combined final numbers of the risk factors of each of the drilling models extracted from Tables 5 and 7, and for a better comparison and selection of a more appropriate method, the combined maximum and minimum risk factors are extracted according to Table 9 and compared in Table 10. And the number close to the minimum number, which is the same as the cluster drilling model, has been identified as the superior method.

**Table 5.** Combined risk factor of each activity and parameters in the single-ring model.

| Activities | Combined risk factor | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Drilling sites, roads and camp-A1 | 2.08 | 0.071 | 0.200 | 0.080 | 0.200 | 0.192 | 0.209 | 0.338 | 0.309 | 0.415 | 0.063 |
| Drilling supplies, materials and equipment-A2 | 1.69 | 0.224 | 0.158 | 0.063 | 0.040 | 0.152 | 0.165 | 0.119 | 0.244 | 0.329 | 0.200 |
| Operations inside and outside the well-A3 | 1.85 | 0.224 | 0.040 | 0.063 | 0.040 | 0.152 | 0.041 | 0.267 | 0.244 | 0.329 | 0.450 |
| Drilling rig replacement - A4 | 1.89 | 0.053 | 0.338 | 0.540 | 0.338 | 0.036 | 0.039 | 0.113 | 0.103 | 0.138 | 0.189 |
| Drilling wastewater and wastes - A5 | 2.21 | 0.071 | 0.200 | 0.080 | 0.200 | 0.432 | 0.470 | 0.338 | 0.309 | 0.046 | 0.063 |
| Maintenance sites - A6 | 1.53 | 0.053 | 0.150 | 0.060 | 0.150 | 0.144 | 0.157 | 0.253 | 0.231 | 0.138 | 0.189 |
| Roads - Car routes - A7 | 2.34 | 0.079 | 0.225 | 0.090 | 0.225 | 0.216 | 0.235 | 0.380 | 0.347 | 0.467 | 0.071 |
| Yard - Power Distribution System - A8 | 3.22 | 0.000 | 0.563 | 0.400 | 0.563 | 0.060 | 0.065 | 0.750 | 0.686 | 0.058 | 0.079 |
| Rig repository-A9 | 1.56 | 0.053 | 0.150 | 0.060 | 0.150 | 0.144 | 0.157 | 0.253 | 0.231 | 0.312 | 0.047 |
| Conex-WC-A10 | 1.81 | 0.476 | 0.150 | 0.060 | 0.150 | 0.324 | 0.352 | 0.113 | 0.103 | 0.035 | 0.047 |
| Drinking water storage tanks - A11 | 1.81 | 0.212 | 0.038 | 0.060 | 0.150 | 0.576 | 0.352 | 0.113 | 0.231 | 0.035 | 0.047 |
| Diesel generator and fuel tank-A12 | 1.73 | 0.212 | 0.150 | 0.060 | 0.150 | 0.036 | 0.039 | 0.113 | 0.231 | 0.312 | 0.426 |
| Drilling sites, roads and camp-A1 | 23.70618 | 1.73 | 2.36 | 1.62 | 2.35 | 2.46 | 2.28 | 3.15 | 3.27 | 2.61 | 1.874 |

**Table 6.** Average numbers of risk extracted from the risk assessment table of cluster wells.

| Activities | Total | The contribution of risk number of each activity concerning the parameters | | | | | | | | | | Average risk number for each activity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Drilling sites, roads and camp-A1 | 12 | 0.6 | 1.2 | 0.6 | 1.2 | 1.2 | 1.2 | 1.8 | 1.8 | 1.8 | 0.6 | 12 |
| Drilling supplies, materials and equipment-A2 | 12 | 1.2 | 1.2 | 0.6 | 0.6 | 1.2 | 1.2 | 1.2 | 1.8 | 1.8 | 1.2 | 12 |
| Operations inside and outside the well-A3 | 12 | 1.2 | 0.6 | 0.6 | 0.6 | 1.2 | 0.6 | 1.8 | 1.8 | 1.8 | 1.8 | 12 |
| Drilling rig replacement - A4 | 12 | 0.6 | 1.8 | 1.8 | 1.8 | 0.6 | 0.6 | 1.2 | 1.2 | 1.2 | 1.2 | 12 |
| Drilling wastewater and wastes - A5 | 12 | 0.6 | 1.2 | 0.6 | 1.2 | 1.8 | 1.8 | 1.8 | 1.8 | 0.6 | 0.6 | 12 |
| Maintenance sites - A6 | 12 | 0.6 | 1.2 | 0.6 | 1.2 | 1.2 | 1.2 | 1.8 | 1.8 | 1.2 | 1.2 | 12 |
| Roads - Car routes - A7 | 12 | 0.6 | 1.2 | 0.6 | 1.2 | 1.2 | 1.2 | 1.8 | 1.8 | 1.8 | 0.6 | 12 |
| Yard - Power Distribution System - A8 | 9 | 0 | 1.35 | 0.9 | 1.35 | 0.45 | 0.45 | 1.8 | 1.8 | 0.45 | 0.45 | 9 |
| Rig repository-A9 | 12 | 0.6 | 1.2 | 0.6 | 1.2 | 1.2 | 1.2 | 1.8 | 1.8 | 1.8 | 0.6 | 12 |
| Conex-WC-A10 | 12 | 1.8 | 1.2 | 0.6 | 1.2 | 1.8 | 1.8 | 1.2 | 1.2 | 0.6 | 0.6 | 12 |
| Drinking water storage tanks - A11 | 12 | 1.2 | 0.6 | 0.6 | 1.2 | 2.4 | 1.8 | 1.2 | 1.8 | 0.6 | 0.6 | 12 |
| Diesel generator and fuel tank-A12 | 12 | 1.2 | 1.2 | 0.6 | 1.2 | 0.6 | 0.6 | 1.2 | 1.8 | 1.8 | 1.8 | 12 |

**Table 7.** Combined risk factor of each activity and parameters in the cluster model.

| **Activities** | **Combined risk factor** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Drilling sites, roads and camp-A1 | 1.04 | 0.035 | 0.100 | 0.040 | 0.100 | 0.096 | 0.104 | 0.169 | 0.154 | 0.208 | 0.032 |
| Drilling supplies, materials and equipment-A2 | 1.07 | 0.141 | 0.100 | 0.040 | 0.025 | 0.096 | 0.104 | 0.075 | 0.154 | 0.208 | 0.126 |
| Operations inside and outside the well-A3 | 1.17 | 0.141 | 0.025 | 0.040 | 0.025 | 0.096 | 0.026 | 0.169 | 0.154 | 0.208 | 0.284 |
| Drilling rig replacement - A4 | 1.26 | 0.035 | 0.225 | 0.360 | 0.225 | 0.024 | 0.026 | 0.075 | 0.069 | 0.092 | 0.126 |
| Drilling wastewater and wastes - A5 | 1.10 | 0.035 | 0.100 | 0.040 | 0.100 | 0.216 | 0.235 | 0.169 | 0.154 | 0.023 | 0.032 |
| Maintenance sites - A6 | 1.02 | 0.035 | 0.100 | 0.040 | 0.100 | 0.096 | 0.104 | 0.169 | 0.154 | 0.092 | 0.126 |
| Roads - Car routes - A7 | 1.04 | 0.035 | 0.100 | 0.040 | 0.100 | 0.096 | 0.104 | 0.169 | 0.154 | 0.208 | 0.032 |
| Yard - Power Distribution System - A8 | 0.97 | 0.000 | 0.169 | 0.120 | 0.169 | 0.018 | 0.020 | 0.225 | 0.206 | 0.017 | 0.024 |
| Rig repository-A9 | 1.04 | 0.035 | 0.100 | 0.040 | 0.100 | 0.096 | 0.104 | 0.169 | 0.154 | 0.208 | 0.032 |
| Conex-WC-A10 | 1.21 | 0.318 | 0.100 | 0.040 | 0.100 | 0.216 | 0.235 | 0.075 | 0.069 | 0.023 | 0.032 |
| Drinking water storage tanks - A11 | 1.21 | 0.141 | 0.025 | 0.040 | 0.100 | 0.384 | 0.235 | 0.075 | 0.154 | 0.023 | 0.032 |
| Diesel generator and fuel tank-A12 | 1.15 | 0.141 | 0.100 | 0.040 | 0.100 | 0.024 | 0.026 | 0.075 | 0.154 | 0.208 | 0.284 |
| Drilling sites, roads and camp-A1 | 13.26529 | 1.09 | 1.24 | 0.88 | 1.24 | 1.46 | 1.32 | 1.61 | 1.73 | 1.52 | 1.161 |

**Table 8.** The contribution of risk number of each activity concerning the parameters.

| Activities | The contribution of risk number of each activity concerning the parameters | | | | | | | | | Average risk number for each activity | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Drilling sites, roads and camp-A1 | 1.2 | 2.4 | 1.2 | 2.4 | 2.4 | 2.4 | 3.6 | 3.6 | 3.6 | 1.2 | 24 | 24 |
| Drilling supplies, materials and equipment-A2 | 2 | 2 | 1 | 1 | 2 | 2 | 2 | 3 | 3 | 2 | 20 | 20 |
| Operations inside and outside the well-A3 | 3 | 1.5 | 1.5 | 1.5 | 3 | 1.5 | 4.5 | 4.5 | 4.5 | 4.5 | 30 | 30 |
| Drilling rig replacement - A4 | 1 | 3 | 3 | 3 | 1 | 1 | 2 | 2 | 2 | 2 | 20 | 20 |
| Drilling wastewater and wastes - A5 | 1.5 | 3 | 1.5 | 3 | 4.5 | 4.5 | 4.5 | 4.5 | 1.5 | 1.5 | 30 | 30 |
| Maintenance sites - A6 | 1 | 2 | 1 | 2 | 2 | 2 | 3 | 3 | 2 | 2 | 20 | 20 |
| Roads - Car routes - A7 | 1.5 | 3 | 1.5 | 3 | 3 | 3 | 4.5 | 4.5 | 4.5 | 1.5 | 30 | 30 |
| Yard - Power Distribution System - A8 | 0 | 3 | 2 | 3 | 1 | 1 | 4 | 4 | 1 | 1 | 20 | 20 |
| Rig repository-A9 | 1.5 | 3 | 1.5 | 3 | 3 | 3 | 4.5 | 4.5 | 4.5 | 1.5 | 30 | 30 |
| Conex-WC-A10 | 3 | 2 | 1 | 2 | 3 | 3 | 2 | 2 | 1 | 1 | 20 | 20 |
| Drinking water storage tanks - A11 | 3 | 1.5 | 1.5 | 3 | 6 | 4.5 | 3 | 4.5 | 1.5 | 1.5 | 30 | 30 |
| Diesel generator and fuel tank-A12 | 2 | 2 | 1 | 2 | 1 | 1 | 2 | 3 | 3 | 3 | 20 | 20 |

**Table 9.** Maximum and minimum risks.

| Activities | Minimum risk number for each activity | Maximum risk number for each activity |
|---|---|---|
| Drilling sites, roads and camp-A1 | 1 | 30 |
| Drilling supplies, materials and equipment-A2 | 1 | 30 |
| Operations inside and outside the well-A3 | 1 | 30 |
| Drilling rig replacement - A4 | 1 | 30 |
| Drilling wastewater and wastes - A5 | 1 | 30 |
| Maintenance sites - A6 | 1 | 30 |
| Roads - Car routes - A7 | 1 | 30 |
| Yard - Power Distribution System - A8 | 1 | 30 |
| Rig repository-A9 | 1 | 30 |
| Conex-WC-A10 | 1 | 30 |
| Drinking water storage tanks - A11 | 1 | 30 |
| Diesel generator and fuel tank-A12 | 1 | 30 |

**Table 10.** Comparison of the number of risks in drilling single-ring wells and cluster wells.

| The minimum combined number of risk factors of each activity and parameters | The combined final number of risk factors of each activity and parameters in the cluster model | The combined final number of risk factors of each activity and parameters in the single-ring model | The maximum combined number of risk factors of each activity and parameters |
|---|---|---|---|
| 1.223859649 | 18.35789474 | 29.37263158 | 36.71578947 |

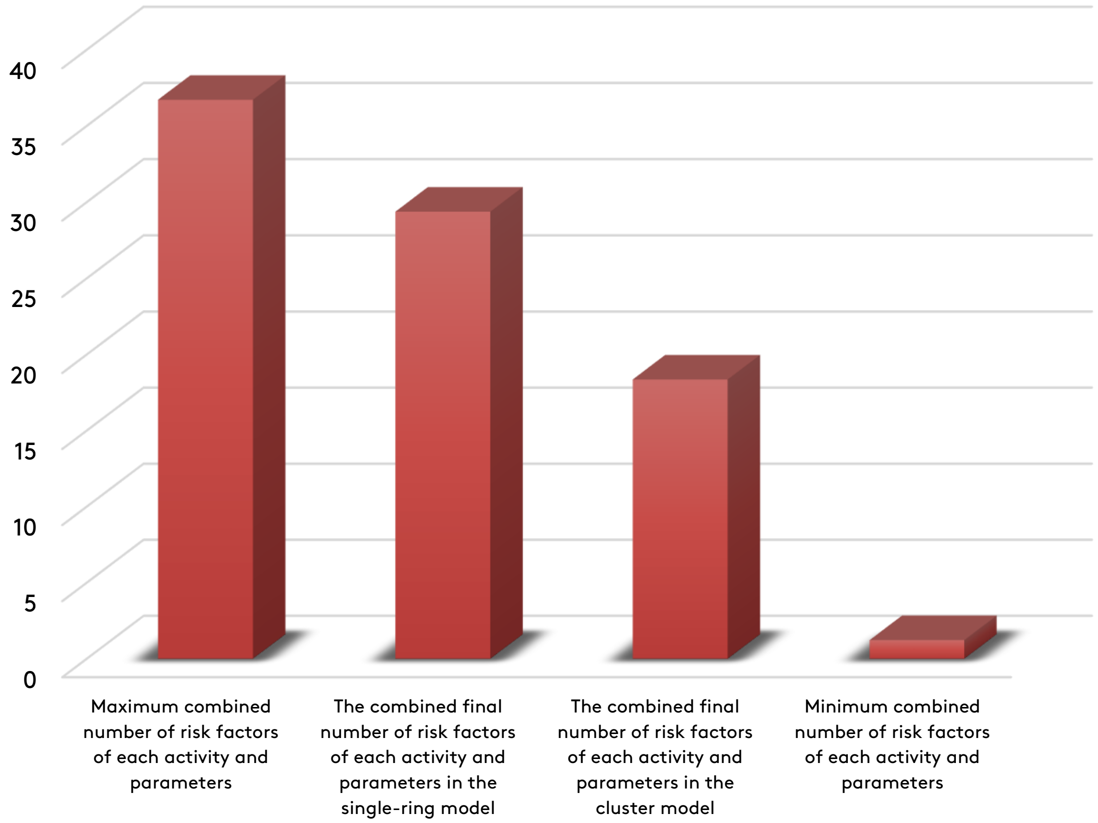

**Fig. 2.** Risk factors of each activity.

### *3.2. Selection of superior drilling method using AHP method*

The FMEA multi-criteria analysis model considers risk parameters as decision criteria, possible reasons for failure as decision alternatives, and failure priority ranking as the goal of decision-making based on the hierarchical analysis method. Following the AHP method, all possible causes of failure are evaluated and ranked. In Table 11, the alternatives and criteria according to the AHP technique are compared with each other after performing all the calculation steps. And the final score of 0.8 is obtained in the range between zero and one, which indicates the superior model of drilling, i.e., cluster drilling. In this study, environmental risks were identified in two parts: the risk of drilling single-ring wells and drilling cluster wells by the FMEA method. The following include aspects of the studied environment: dust emissions; destruction of the natural structure of the environment such as destruction of mountains, deserts, plains, forests, pastures, lakes, rivers, streams, animal habitats, vegetation of the region, etc.; explosions and fires; radiation of radioactive materials; discharge of industrial wastewater into groundwater or surface water; wastewater discharge of waste into the soil; sanitary wastewater discharge to groundwater or surface water; atomic and radioactive waste; sanitary and infectious waste; noise from devices and machines; waste (plastic, cans, barrels, etc.); fume from welding and cutting; emission of suspended particles; gas emission of heating equipment stack and burners of facilities; harvesting and leveling the land and adding soil from another land; water consumption; electricity consumption; paper consumption; consumption of various petroleum derivatives; gas consumption; consumption of energy species; leakage of various oils and petroleum products into the soil; leakage of various chemicals into the soil; diesel and gasoline leaks; and emission of chemical and volatile organic compounds vapors. Based on the research results, it appears that cluster drilling has fewer environmental risks than single-ring drilling. Via descriptive comparisons (quantitative and qualitative), it is shown that the cluster model has less environmental risks than the single-ring model. In this study, these two models are compared and there is a significant difference between single-ring drilling and cluster well drilling. The most important environmental risks of drilling seem to be water and soil pollution. Bakke et al. [38] concluded that water formation with hydrocarbons (produced water) and rock cuts from drilling are the main sources of pollutants that enter the sea from regular operations. Before discharge, The drilling waste and water produced are cleaned with various physical devices; also, regulations set strict limits on the levels of pollutants that can be discharged into the sea. Operational discharge of produced water and drilling cuts from offshore oil and gas rigs is a continuous source of pollutants to continental shelf ecosystems. The greatest concern about the biological effects of such discharges on the Norwegian continental shelf is related to the effects of water produced. Gharibi et al. [39] mentioned minimizing the risk for environmental parameters, such as soil, vegetation, and animals, by establishing refineries to treat drilling mud and making the environment safer by improving the soil and increasing vegetation. These are important suggestions for reducing the environmental impacts of drilling in the oil and gas industry. Since the drilling industry of oil and gas wells is mainly related to water and soil more than other environmental parameters, the identification and evaluation of the set of environmental activities in both drilling models indicate that the RPN of water and soil is higher than other environmental parameters. Also, based on the comparison of the two models, it is obvious that the single-ring model significantly increases this ratio of soil and water pollution compared to the cluster model.

**Table 11.** The final score of study alternatives.

| Alternatives | P1 | P2 | P3 | P4 | P5 | P6 | P7 | P8 | P9 | P10 | Final score |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C1 | 0.25 | 0.25 | 0.33 | 0.13 | 0.17 | 0.17 | 0.13 | 0.25 | 0.17 | 0.25 | 0.20 |
| C2 | 0.75 | 0.75 | 0.67 | 0.88 | 0.83 | 0.83 | 0.88 | 0.75 | 0.83 | 0.75 | 0.80 |

## 4. Conclusions

The hierarchical analysis method prioritizes the conditions that cause environmental degradation in the drilling process. Thus, after investigating the factors of environmental degradation, the best model of drilling oil and gas wells were identified. Then, the FMEA method analyzed the environmental risk, calculated the combined risk factor, compared the minimum and maximum combined factor, selected a number close to the minimum, and chose the best method of drilling oil and gas wells. Choosing the best drilling model with the least damage to the environment from two paths of risk analysis helped to make a better and more effective choice. Therefore, this new approach increases the accuracy of selecting the drilling model with the least environmental impact in the field of risk assessment.

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