Original Article

Environmental Risk Assessment of Gas Wells Drilling Effluents: Integration of Environmental Failure Mode and Effects Analysis and Analytic Network Process Models

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Abstract

Background: Environmental risk assessment, the process of qualitative analysis of potential hazards and coefficients of potential risks in the project, as well as the vulnerability of a peripheral environment need to be taken into account. Accordingly, the purpose of this study was to identify and investigate the potential hazards and make practical suggestions in order to eliminate or reduce the environmental hazards related to gas wells drilling effluents and wastewater in southern cities.

Methods: This is an applied research using descriptive-analytical method. The required data were categorized into two groups including: a review of written sources and a field study of one of the oil and gas wells based on the available components and variables. Data analysis was done using EFMEA (Environmental Failure Mode and Effects Analysis) and the components and variables were analyzed using Analytic Network Process model (ANP). Analysis of variance and correlation coefficients were also used to investigate the relationship between the components. Finally, a strategy model was developed based on the studies conducted to determine the effectiveness of corrective and control measures.

Results: Research findings based on EFMEA environmental risk assessment of oil and gas drilling effluents and wastewater showed that 83.4% of the risk scores, in this case, were placed at the medium risk level and 16.6% at the low-risk level. The results of the network analysis model also showed that drilling effluents and wastewater caused by drilling wells of Oil and Gas had the highest impact (0.124) on the degradation of vegetation and also on the destruction of the natural habitats in this region.

Conclusion: Accordingly, some strategies such as integration of EFMEA and ANP Models which were developed to reduce the environmental crises in oil and gas drilling have been very useful and appropriate.

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Introduction

Recently, oil and gas drilling has been fast becoming one of the largest sources of pollution which is a problem in the oil industry.[1] Regarding energy demand growth, the heavy reliance of the Iranian economy on oil and the necessity of stabilizing Iranian share in OPEC, drilling processes are significantly vital.[2] The drilling industry is one of the main sections of the petroleum industry and it has been regarded as the most specialized industrial activity in the world.[3,4] This industry returns wastewater and effluents to the environment, like any other industrial activities, and if no proper planning, treatment, disposal, and filtration are considered, in the long run, and due to the climatic conditions, various adverse environmental impacts and harmful effects occur on the environment.[5]

Environmental risk assessment is defined as the process of qualitative and quantitative analysis of linear potentials and coefficients of potential risks in a project as well as sensitivity or vulnerability of the surrounding environment.[2, 6] Environmental pollution is a byproduct of various industrial activities which have threatened the environment enormously.[7] Recently, occurring environmental crises, moving towards sustainable development, removing non-tariff barriers to the economy, preventing the waste of the resources, and creating conditions for understanding tariffs and economic issues have resulted in the advent of the environmental management system.[8] In this view, the simultaneous promotion of quality, environmental safety, and health levels is a criterion to select the services and products in a civilized society.[9] Therefore, the environment management system works based on safety and keeps the environment safe and the quality of this system should be considered as a key element of any organization regarding the accurate understanding of the system.[2] Environmental risk assessment is the process of qualitative analysis of the potential hazards and coefficients of potential project risks as well as the sensitivity or vulnerability of the peripheral environment.[8, 10] Therefore, in addition to examining and analyzing different aspects of the risk with high knowledge about the environment of the area, the degree of the environmental sensitivity and the environmental values of the area are important in risk analysis.[8, 11] The main purpose of the risk analysis and evaluation is to determine the uncertainty and cost of the system under the study, provide solutions to reduce it, and measure the cost of the related solution.[12, 13] Data analysis showed the failure mode and effects analysis on the environment which is a qualitative method of environmental impact assessment aiming at providing a tool to facilitate the work of companies so that the production development is accompanied by the environmental considerations.[14] The process of risk assessment generally involves identification and determination of the risk, risk assessment, risk analysis, responses to risk, and risk response control.[15] Regarding the risk assessment process and since a variety of wastewater and effluents are usually left in a drilling process, the risk of these contaminants in the environment needs to be assessed.[16] The pollution resulting from drilling has existed from the beginning of operations to the excavation phase of the gas wells, and those who are working in the drilling area are directly in contact with these pollutions.[17, 18] Therefore, it is necessary to assess the environmental impacts through conducting different studies and using techniques in order to reduce and control pollution which may result in damages.[19, 20] According to excavations that have been carried out by Oil and Gas Company, most of the effluents resulting from these activities, either intentionally or unintentionally, lead to the environmental damages which necessitate the assessment of the power and potential risks.[21, 22] The purpose of this study was to identify and evaluate the potential hazards and provide practical suggestions to eliminate or reduce the environmental hazards associated with gas wells drilling effluent pits.

Materials and Methods

For data collection, a checklist was designed by the researcher in order to evaluate the environmental degradation coefficient by using Failure mode and effects analysis (FMEA) on the environment. This checklist examined various variables including process identification, amount of effluent (environmental aspects), potential effects of the effluents (consequences), potential causes of effluent disposal, initial assessment of the environmental aspects (severity, occurrence, extent of pollution or recyclability, risk priority number, risk level), controlling measures and secondary assessment of the environmental (severity, occurrence, range of pollution or recyclability, risk priority number, risk level) were assessed as the environmental aspects.[2, 23] The checklist benefited from content validity after consulting with some occupational health specialists, Health, Safety and Environment (HSE) specialists, mechanical and electrical engineers, and then wastewater and effluents disposal processes were examined.[2, 24] After collecting the data, the environmental degradation coefficient was evaluated by failure mode and effects analysis on the environment. Accordingly, the risk priority number was calculated by multiplying three parameters including severity, occurrence, and extent of pollution or recyclability. For the scoring, the severity parameter was scored between 1 to 10. Consequently, in the most severe case, it was scored 10 and in the least severe case, it was scored 1. The same scoring method was taken into account for the other parameters, too. However, the degree of risk-taking or risk priority was calculated by using the frequency distribution method.[2, 24]

Risk Priority Number (RPN)

Risk Priority Number (RPN) is a measure used

when assessing the risks to identify critical failure modes associated with the design or process. The FMEA RPN is commonly used in the automotive industry and it is somewhat similar to the criticality numbers used in Mil-Std-1629A.[25] The EFMEA tables were first completed by assessing the environmental impacts of the drilling effluent pit in assessing safety and environmental hazards. Using these tables containing columns, we found S (severity), O (occurrence) and D (detection) are related to the extent of pollution or recyclability. The RPN values for all units were calculated from the sum of these three parameters. Thereafter, the confidence level or risk index was obtained through statistical calculations and according to the risk index, some risks were neglected, but corrective measures were suggested for a group of risks.[2, 7, 26]
Severity×occurrence×Detection=Safety risk factor
The extent of pollution×Occurrence×Severity=Environ mental degradation factor

In fact, the standard number or degree of risk is the degree to which we can accept or take risks.

RPN Determination Method

First, the arithmetic mean was measured:

$$\bar{x} = \frac{1}{N}\sum_{i=1}^{N} x_i = \frac{x_1 + x_2 + \cdots + x_N}{N}$$

Then, using the following formula, the standard deviation of the data was calculated:

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \bar{x})^2}.$$

Afterward, the standard deviation was added to the arithmetic mean of the upper limit of the risk, and the lower risk level was measured through subtracting the two obtained numbers. The numeric risk priority number was scored between 1 and 100. For high-risk numbers, a workshop should be held in order to reduce this number through corrective action.

Is the Correction Necessary?

In this step, the risks were rated based on the risk priority number and an RPN limit regarding the FMEA system was set. For example, for the 90% confidence level, the limit was obtained as follows:

The risks that showed RPNs above 100 and actually needed correction were determined.

Note: Corrective action should also be taken into account for the risks that showed at least one 10.

Results

The two graphic below show the factors that make up the RPN and how it is calculated for each failure mode (Table 1).

According to the above calculations, the arithmetic mean of the risk scores was measured 164 and their standard deviation was measured 43. As a result, risks with high-risk scores above 205 were considered as high-risk levels, 119 and 205 as medium risk levels, and below 119 were considered as low-risk levels (Figure 1).

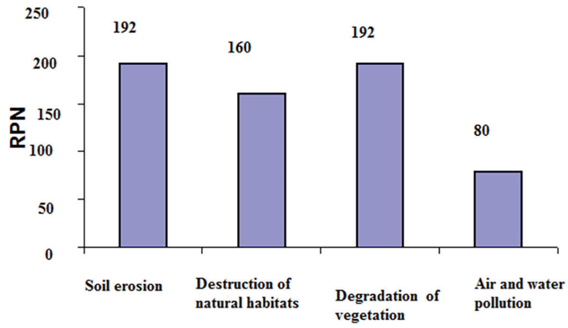

Figure 1: EFMEA Environmental Risk Assessment Figure

Regarding oil and gas drilling effluents and wastewater, the findings of this study showed that 83.4% of the risk scores, in this case, were placed at the medium risk level and 16.6% at the low-risk level. Therefore, in order to protect the environment from the hazards of oil and gas drilling mud in this area, extensive planning is required.

Prioritization of Important Factors Affecting the Environmental Degradation by Using ANP Model

The purpose of this study was to identify the factors affecting environmental degradation based on oil and gas drilling effluents. Different criteria and indicators have been considered in relation to the impact of drilling wastewater and effluents on the environment.[27-29] In this regard, the effects of each element in reducing environmental degradation were determined by establishing intra- and inter-group relationships between the elements and indicators (Figure 2).

In this study, the criteria were divided into four clusters including soil erosion, destruction of natural habitats of animals, degradation of vegetation, and air and water pollution, containing a number of influential elements. There was also a correlation between the clusters.

The "pairwise comparison principle" consists of giving a rate to each cluster. The comparisons are made on a 1 to 9-point scale.[30] The numerical judgments established at each level of the hierarchy were made using paired matrices. It is worth noting that pairwise comparisons were made for all criteria and options. Table 2 presents the results of the

Table 1: Environmental risk assessment by EFMEA method

N	Activity. Equipment . Material	Environmental aspect	Em/ Ab /Nr	Aspect Direct	Aspect indirect	Consequences	Present actions	(S)	(O)	(R)	RPN	Controls and suggested actions
1	Drilling mud pit	Topographical soil deformation	NR		✓	1.Soil erosion	No action	8	8	3	192	1.Planting trees around the mud pit 2. Soil stabilizer (corrective) 3.Pit placement in a manner that minimizes damage to the habitat of animals. 4.Cultivation of dominant plant species in the r egion. 5.Vegetation restoration
						2.Conservation of the natural habitat of animals	No action	8	5	4	160	
						3.degradation of vegetation	No action	8	8	3	192	
2	Road to access MUD PIT	Topographical soil deformation	NR		✓	1.Conservation of the natural habitat of animals	No action	8	8	3	192	1.Construction of access roads in a way that minimizes damage to vegetation and animals in the area. 2.Restoration of vegetation around the access road 3.Appropriate road infrastructure access.
						2.degradation of vegetation		8	5	4	160	
						3. Air pollution due to road traffic, road construction, and other vehicles	No action	5	4	4	80	

Table 2: The matrix of paired comparison and weight of clusters

Item	Soil erosion	Destruction of natural habitats	Degradation of vegetation	Air and water pollution	Relative weight	Final weight
Soil erosion	1	1.38	3	2	0.637	0.184
Destruction of natural habitats	3	1	0.81	0.95	0.748	0.131
Degradation of vegetation	3	1.41	1	2	0.804	0.217
Air and water pollution	0.034	0.46	3	1	0.412	0.103

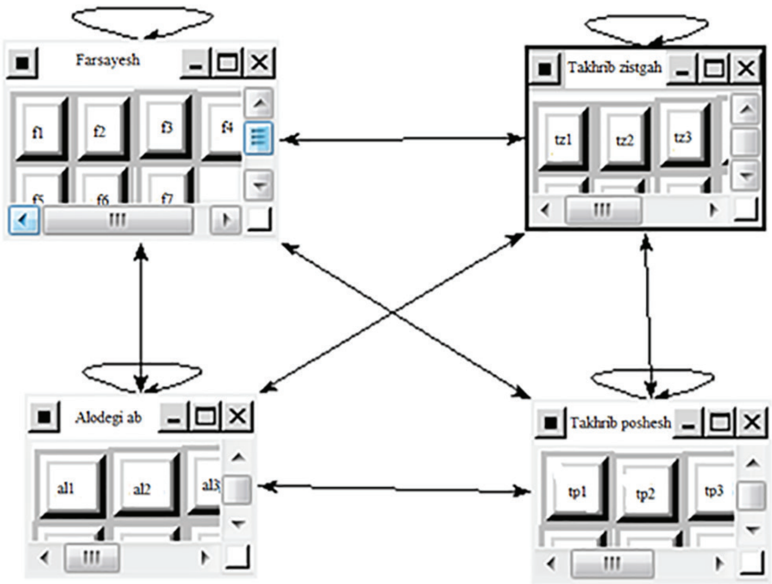

Figure 2: Relationship between clusters of drilling effluents impact on the environment

Table 3: ANP Network Incompatibility Rate

Indexes	Soil erosion	Destruction of natural habitat	Degradation of vegetation	Air and water pollution	Incompatibility rate mean
Incompatibility rate	0.0535	0.0228	0.03710	0.01067	0.03101

pairwise comparisons in the network analysis model for the impact of drilling effluents on the environment. Table 3 shows the incompatibility rate of the judgment which is scored 0.03101,while the incompatibility value should not exceed 1.[31, 32]

The error rate given a large number of judgments and errors is acceptable by polling (Table 3).

Table 4 shows the relative weight of the clusters obtained by comparing the paired matrix. In the paired matrix, the *aij* score indicated the relative importance of the component in row *i* with respect to *j* column; in other words, *aij=wi/wj*, while 1 represented the importance of two components and 9 represented the significance of component *i* over the component *j*. Then, the elements within each cluster were compared by using the same method as the network analysis process. In the next step, the relative weights of the matrix elements were calculated and, finally, the table elements were normalized. Since some elements within the clusters may depend on the elements of the other clusters, a pairwise comparison matrix was formed according to the matrix control criteria, the matrix elements were compared one by one and the matrix weight was obtained. The result entered the primary super-matrix. The supermatrix resulting from the combination of different matrices was the primary supermatrix with more than one element in each column of the supermatrix.[31, 32]

In the next step, the supermatrix was normalized and the resulting supermatrix was the weight matrix (Table 5). Finally, for the convergence of the weighted supermatrix and the elements in the criteria were large enough to converge. As shown in Table 5, the weight of the clusters and the super-matrix of the general weight limit and the final weight of the criteria were calculated. In this step, the supermatrix table of the general weight limit was not mentioned in terms of the number of elements in the rows and only the number in Table 5 was expressed in terms of the final weight.

The results of the network analysis model showed that drilling effluents caused by drilling wells of Oil and Gas Company had the highest impact (0.124) on the degradation of vegetation in the region. In the second stage, it showed the destruction of the region's natural habitats; both of these seriously threaten the environment and necessitate planning and preserving the environment in line with sustainable development goals. Besides, in order to meet the needs, it is important to maintain and strengthen the region's environment along with optimal exploitation of the region's oil and gas.

Discussion

Regarding the findings of the study, the arithmetic mean of risk and standard deviation were scored 164 and 43, respectively. Moreover, a risk score above 205 was considered as the high risk levels, between 119 and 205 the medium-risk levels and below 119 was regarded as the low risk levels.[2, 7] Thus, in oil and gas drilling effluents and waste water, 83.4% of the risk scores were at the medium risk level and 16.6% at the low risk level. In this regard, Rezaian et al., in a study to assess the environmental risk of drilling projects, concluded that 3 out of 12 identified risks were recognized unacceptable. The shortlisted risks were prioritized at the final step using a technique for ordering the preference by similarity to the ideal solution. "Habitat fragmentation" with a weight of 0.3002, "water pollution" with a weight of 0.295, and "impacts on aquatics" with a weight of 0.293 were identified as three top priority flooding risks.[33]

The results of the network analysis model showed that drilling effluents caused by drilling wells of Oil and Gas Company had the highest impact (0.124) on the degradation of vegetation in the region. Next, it affected the destruction of the natural habitats, endangering the surrounding environment. The results of structural modeling of the components of the effects of oil and gas drilling effluents on the environment of this region showed that drilling effluents had a direct effect (8.10) on the destruction of natural habitats of animals. It directly affected air pollution (8.08) and showed direct effects on the destruction of vegetation in the area (7.48) as well as on the reduction of the economic and social benefits of the residents of the area (7.18).

The first step in developing strategies to mitigate the environmental threats from the oil and gas drilling in the studied well is to identify the dimensions and variables affecting the extent of these crises.[34, 35] For this reason, the strengths, weaknesses, opportunities, and threats in the region were studied by using previous chapters and indicators. Strengths and weaknesses contain internal factors, while opportunities and threats contain external factors, and others that go beyond

Table 4: Weighted supermatrix derived from criteria and elements within clusters

		Soil erosion							**destruction of natural habitats**					
		$_1$f	$_2$f	$_3$f	$_4$f	$_5$f	$_6$f	$_7$f	$_1$tz	$_2$tz	$_3$tz	$_4$tz	$_5$tz	$_6$tz
Soil erosion	$_1$f	00.0	35.0	15.0	00.0	15.0	93.0	12.0	01.0	45.0	83.0	03.0	81.0	67.0
	$_2$f	38.0	00.0	72.0	47.0	08.0	72.0	24.0	53.0	15.0	28.0	29.0	27.0	27.0
	$_3$f	14.0	21.0	00.0	43.0	51.0	48.0	45.0	16.0	91.0	00.0	00.0	23.0	38.0
	$_4$f	25.0	54.0	61.0	00.0	21.0	21.0	00.0	08.0	63.0	07.0	37.0	00.0	00.0
	$_5$f	00.0	22.0	01.0	36.0	00.0	47.0	00.0	00.0	00.0	01.0	00.0	42.0	00.0
	$_6$f	01.0	00.0	08.0	82.0	36.0	00.0	21.0	54.0	00.0	41.0	45.0	00.0	32.0
	$_7$f	11.0	00.0	00.0	10.0	91.0	16.0	00.0	11.0	37.0	00.0	00.0	52.0	00.0
Destruction of natural habitats	$_1$tz	00.0	23.0	46.0	52.0	31.0	00.0	33.0	00.0	18.0	43.0	12.0	00.0	21.0
	$_2$tz	18.0	31.0	00.0	13.0	54.0	46.0	73.0	41.0	00.0	00.0	82.0	34.0	00.0
	$_3$tz	31.0	00.0	36.0	21.0	00.0	12.0	00.0	00.0	53.0	000.0	25.0	47.0	41.0
	$_4$tz	00.0	00.0	00.0	00.0	42.0	44.0	36.0	12.0	00.0	48.0	00.0	41.0	83.0
	$_5$tz	12.0	16.0	00.0	36.0	00.0	00.0	00.0	00.0	00.0	46.0	71.0	00.0	82.0
	$_6$tz	00.0	23.0	00.0	00.0	00.0	00.0	00.0	67.0	00.0	42.0	00.0	00.0	00.0
Degradation of vegetation	$_1$tp	00.0	00.0	00.0	37.0	00.0	00.0	05.0	10.0	82.0	63.0	72.0	27.0	42.0
	$_2$tp	21.0	23.0	61.0	43.0	06.0	42.0	23.0	00.0	00.0	51.0	39.0	09.0	31.0
	$_3$tp	13.0	64.0	083.0	06.0	23.0	34.0	73.0	25.0	09.0	07.0	72.0	61.0	24.0
	$_4$tp	00.0	51.0	00.0	09.0	00.0	01.0	18.0	41.0	41.0	00.0	38.0	00.0	32.0
	$_5$tp	14.0	62.0	35.0	00.0	36.0	20.0	00.0	00.0	34.0	31.0	00.0	38.0	00.0
	$_6$tp	73.0	00.0	71.0	41.0	51.0	61.0	00.0	23.0	09.0	42.0	12.0	17.0	45.0
	$_7$tp	16.0	00.0	000.0	12.0	80.0	07.0	00.0	00.0	00.0	00.0	31.0	00.0	000.0
Air and water pollution	$_1$a	11.0	32.0	28.0	00.0	37.0	35.0	01.0	07.0	42.0	51.0	08.0	56.0	19.0
	$_2$a	00.0	85.0	09.0	66.0	19.0	71.0	51.0	43.0	71.0	36.0	21.0	00.0	07.0
	$_3$a	21.0	64.0	00.0	08.0	00.0	00.0	00.0	27.0	00.0	19.0	52.0	39.0	33.0
	$_4$a	04.0	09.0	37.0	01.0	31.0	00.0	48.0	00.0	17.0	00.0	00.0	27.0	00.0
	$_5$a	06.0	00.0	23.0	00.0	06.0	31.0	00.0	57.0	00.0	13.0	78.0	00.0	54.0

		Degradation of vegetation							**Air and water pollution**				
		$_1$tp	$_2$tp	$_3$tp	$_4$tp	$_5$tp	$_6$tp	$_7$tp	$_1$a	$_2$a	$_3$a	$_4$a	$_5$a
Soil erosion	$_1$f	00.0	52.0	16.0	09.0	31.0	24.0	63.0	34.0	41.0	34.0	53.0	34.0
	$_2$f	12.0	00.0	31.0	12.0	00.0	00.0	08.0	17.0	00.0	21.0	00.0	23.0
	$_3$f	53.0	09.0	00.0	00.0	23.0	36.0	17.0	00.0	37.0	38.0	25.0	00.0
	$_4$f	42.0	24.0	27.0	24.0	07.0	72.0	54.0	41.0	52.0	00.0	32.0	56.0
	$_5$f	00.0	00.0	31.0	00.0	12.0	14.0	32.0	12.0	00.0	41.0	00.0	00.0
	$_6$f	37.0	63.0	00.0	42.0	53.0	00.0	12.0	34.0	61.0	32.0	41.0	00.0
	$_7$f	06.0	00.0	14.0	00.0	14.0	00.0	00.0	00.0	04.0	00.0	16.0	18.0
Destruction of natural habitats	$_1$tz	00.0	00.0	00.0	01.0	70.0	56.0	08.0	53.0	15.0	00.0	61.0	00.0
	$_2$tz	31.0	38.0	41.0	14.0	16.0	16.0	21.0	27.0	00.0	03.0	24.0	26.0
	$_3$tz	62.0	00.0	55.0	26.0	12.0	27.0	43.0	38.0	29.0	17.0	09.0	31.0
	$_4$tz	00.0	71.0	21.0	00.0	10.0	08.0	20.0	00.0	43.0	56.0	31.0	00.0
	$_5$tz	09.0	53.0	00.0	34.0	31.0	21.0	00.0	06.0	79.0	24.0	48.0	18.0
	$_6$tz	21.0	07.0	14.0	00.0	02.0	00.0	24.0	00.0	51.0	00.0	07.0	09.0
Degradation of vegetation	$_1$tp	00.0	09.0	23.0	61.0	03.0	61.0	25.0	57.0	00.0	00.0	00.0	33.0
	$_2$tp	07.0	00.0	00.0	37.0	34.0	00.0	00.0	00.0	27.0	67.0	42.0	08.0
	$_3$tp	42.0	23.0	00.0	00.0	52.0	17.0	37.0	36.0	16.0	00.0	44.0	00.0
	$_4$tp	03.0	00.0	42.0	00.0	00.0	00.0	00.0	00.0	34.0	37.0	31.0	37.0
	$_5$tp	61.0	13.0	00.0	48.0	00.0	43.0	14.0	27.0	00.0	26.0	23.0	07.0
	$_6$tp	32.0	34.0	05.0	17.0	09.0	00.0	00.0	31.0	43.0	00.0	00.0	52.0
	$_7$tp	00.0	09.0	27.0	52.0	29.0	57.0	00.0	00.0	00.0	14.0	00.0	00.0
Air and water pollution	$_1$a	08.0	53.0	15.0	12.0	16.0	61.0	51.0	00.0	03.0	27.0	15.0	20.0
	$_2$a	00.0	01.0	30.0	23.0	21.0	47.0	18.0	09.0	00.0	00.0	17.0	71.0
	$_3$a	18.0	25.0	13.0	14.0	00.0	02.0	00.0	50.0	21.0	00.0	00.0	00.0
	$_4$a	50.0	00.0	00.0	65.0	38.0	00.0	58.0	27.0	02.0	13.0	00.0	09.0
	$_5$a	00.0	31.0	37.0	05.0	03.0	03.0	64.0	23.0	34.0	08.0	00.0	00.0

Table 5: The final weight of the studied indices and the impact of drilling effluents on the environment

Indices	General Weight	Weight of clusters	Final weight
Destruction of natural habitats	633.0	184.0	116.0
Degradation of vegetation	95.0	131.0	124.0
Soil erosion	405.0	217.0	087.0
Air and water pollution	281.0	103.0	028.0

the potentials of the region should be taken into account.[36, 37]

Conclusion

Choosing a right site for disposal of the environmental effluents and wastewater from oil and gas drilling and transporting them to the new sites is economically reasonable. Minimizing the risk to the environmental components including soil, vegetation cover of animals and ultimately environmental and human health; establishing refineries to purify drilling mud and making it safe to the environment (soil improvement, vegetation enhancement) are important suggestions to reduce the environmental impact of drilling in the oil and gas industry. Accordingly, some strategies such as integration of EFMEA and ANP Models which have been developed to reduce the environmental crises in oil and gas drilling have been very useful and appropriate.

Conflict of Interest: None declared.

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