Assessment of risks and developing their handling options for hydraulic fracturing in Iranian oil and gas reservoirs

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Hydraulic Fracturing (HF) is the most applicable technique for increasing productivity in reservoirs with medium to high permeability. Iranian oil and gas reservoirs with such permeability can benefit from this technology. Nowadays, this is not a very common technique in Iran. Because of various risks and related factors in Iran, the HF operation elements (e.g., designing, execution, evaluation, management and etc.) have not had a considerable success and expansion. Correspondingly, an appropriate risk assessment and management can help the National Iranian Oil Company (NIOC) for developing this technology in their reservoirs. The aim of this work is to assess the HF risks and to determine an effective handling plan for this operation in Iran. The proposed methodology includes literature review, face-to-face interview with the respected experts, and evaluation of the gathered data. We hope the advised handling options are properly applied as a guideline for a successful HF in Iran.

keywords: *Hydraulic Fracturing (HF), Risk assessment, Iranian oil and gas reservoirs.*

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NOMENCLATURE

AER Alberta energy regulator.
AGL Australian gas light.
API American petroleum institute.
BOP Setting of blowout preventer.
CAPP Canadian association of petroleum producers.
HF Hydraulic fracturing.
HHERA Human health and ecological risk assessment.
HSE Health, safety and environment.
MSDS Material safety data sheets.
NIDC National Iranian drilling company.
NIOC National Iranian oil company.
NPC National petroleum council.
PEDEC Petroleum engineering and development company.
POGIDC Persia oil & gas industry development company.
PRAM Preliminary risk assessment method.
R&D Research and development.
WSI Wells services of Iran.

1. INTRODUCTION

Risk and uncertainty lie at the very heart of our life, business, and projects. So, the need for risk analysis and management has been widely recognized. The science of risk management was developed back in the sixteenth century during the Renaissance, a period of discovery [1]. According to PRAM guide (Preliminary Risk Assessment Method) [2], the risk is defined as "an unverifiable occasion or condition that, if it happens, has a positive or negative impact on project goals". Project risk management is the art and science of identifying, classifying, examining and reacting to hazard variables during the life of a project and in the greatest advantage of undertaking destinations [3]. The risk management methodologies include often four substantial stages: risk identification, risk analysis, risk handling, and risk monitoring.

Risk identification (or risk diagnosis) is the process of identifying risks, and documenting their characteristics [4]. It is notable that the objective of risk identification is to identify all possible risks, not to eliminate risks from consideration or to develop solutions for mitigating risks; those functions are carried out during the risk analysis and risk handling [5]. During this stage, risk factors need to be identified too. A risk factor (also called risk cause or risk source) is an event or situation that increases the probability of occurrence of a risk, e.g. smoking cigarette is a risk factor to the risk of heart attack. As another example, Haimes [6] believes that four sources of risks are organizational, human, software and hardware factors. According to Hillson and Simon [7], many people confuse causes of risk with risks themselves. The cause, however, describes existing conditions that might give rise to risks. For example, there is no uncertainty about the statement "We have never done a project like this before", so it cannot be a risk. But this statement could result in a number of risks that must be identified and managed.

Risk analysis (or risk evaluation) is the process of prioritizing individual risks by assessing their probability of occurrence (sometimes is known as likelihood of event) and impact (sometimes is called severity of occurrence of risk or effect on goals [8]) as well as other characteristics [4]. The key benefit of this stage is that it focuses efforts on high-priority risks. Assessment of every risk's significance and need for consideration is commonly directed utilizing a turn upward chart namely probability impact matrix. Such a matrix determines mixes of probability and impact that prompt rating the risks as low, moderate, or high priority [9]. It should be mentioned that risk identification and risk analysis are known as risk assessment altogether.

Risk handling (or risk response/risk treatment) is the process of developing response actions, selecting strategies, and agreeing on actions to address risks [4]. The key benefit of this process is that it identifies appropriate ways to address risks. This process also allocates resources and inserts activities into documents and the management plan as needed. In general, five alternative strategies may be considered for dealing with threats, which are [4] "avoid" (acting to eliminate the risk or protect the project from its impact), "transfer" (shifting ownership of a threat to a third party to manage it and to bear the risk impact if it occurs), "mitigate" (taking actions to reduce the impact of a threat), "accept" (acknowledging the existence of a risk and choosing not to resolve, transfer or mitigate), and "escalate" (resolving risk at the upper level or other relevant part of the organization, and not on the project level).

Risk monitoring (or risk control) is the process of monitoring the implementation of agreed-upon risk handling plan, tracking the identified risks, identifying and analyzing new risks. The key benefit of this stage is that it enables decisions to be based on valid and updated information about risks and handling options [4].

There are many tools and techniques to perform risk management stages. Several techniques (e.g., Brain storming, Brain writing, DELPHI, Nominal Group Technique, Decision conference, Crawford slip method, Questionnaire, Interview, and Workshop) belong to a wide and applicable approach namely "expert judgment". Expert judgment is defined as judgment provided based upon expertise in an application area, Knowledge Area, discipline, industry, etc., as appropriate for the activity being performed. Such expertise may be provided by any group or person with specialized education, knowledge, skill, experience, or training [4]. Additionally, according to [5], main guidelines to use expert judgment are: (1) The full team should be actively involved, (2) Potential risks/handling options should be identified by all members of the team, (3) No criticism of any suggestion is permitted, (4) Any potential risk/handling option identified by anyone should be recorded, regardless of whether other members of the team consider it to be significant, and (5) All potential risks/handling options should be documented and followed up.

Hydraulic Fracturing (HF) (also known as fracking or hydrofracking) is the process of injecting water into the formation with a pressure higher than formation breakdown pressure to fracture the rock in order to improve productivity index of production wells and release trapped hydrocarbons [10]. At first, a well is drilled and the casing is cemented. Target zones are sealed with packers because of isolating from other zones. Then special tools are run to perforate this interval. HF fluid containing water, chemical agent and sand is then pumped through perforation at relatively high pressure so that it can crack the formation rock [11, 12]. The solid materials in the HF fluid, which are typically sand or man-made ceramic fluid, are known as "proppant". The purpose of proppant is to keep an induced hydraulic fracture open, during or after a HF treatment. Before commencing a fracture operation, the length, height, and orientation of the fractures are evaluated by computer models and help the engineers to design the process as accurate as possible [13]. In 1948, HF process was introduced for the first time by STANOLIND Oil and Gas company (now Pan American Petroleum Corporation) for increasing productivity of wells by HF. Unfortunately the result of experiment was not very acceptable and the well performance did not improve remarkable. In 1949, the first commercial HF treatments were performed by Halliburton Company in Stephens County, Archer County, Texas and Oklahoma [14, 15]. Generally, most of oil and gas wells do not produce at their optimum level. Theoretically, all wells can benefit from HF. However, this is a common treatment mostly in medium to low permeability formations. In fact, the technique of HF the rock combined with horizontal drilling is the dominant mechanism of production, due to the technological advances that allow extracting natural gas from so-called unconventional reservoirs. Shale oil and gas, tight gas, coal bed methane, methane hydrates and heavy oil/tar sand are some kinds of unconventional reservoirs, which have moderate to low permeability [16]. HF in high permeability formations can be economically attractive option for productivity improvement and damage bypassing. In such formation, HF reduces skin factor due to drilling, completion or production operations which causes near wellbore damage. Furthermore, HF creates a large flow area. Considering this, some damages related to high velocities or large pressure gradient such as non-Darcy flow, fines movement and scale deposition can be bypassed [17]. A properly designed and executed HF can change flow from radial to nearly linear (Fig. 1), which leads to financially viable production rates at higher bottom hole flowing pressure and consequently higher productivity [18]. HF techniques have also other applications which are not related to oil and gas production, including ground water remediation, tunnel and dam development and construction, carbon sequestration, square block mining, rock burst alleviation and water well advancement [19]. Nevertheless, HF has been rarely used in Iran. All of attempts to apply HF in Iran do not go further four, and all were practiced on the Bangestan reservoir. The first three of them were chosen for acid fracturing while prop-fracturing was conducted for the last one [20].

In the current study, a general process of risk identification, risk analysis and risk handling of HF treatment is implemented by a comprehensive literature review together with expert elicitation. This study will help the NIOC to reduce their threats associated with the HF operation and will motivate this company to apply the related handling options on their reservoirs more than before.

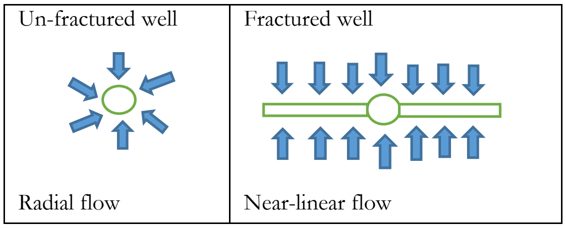

Fig. 1. Flow regime in fractured and un-fractured well [17].

2. METHODOLOGY

This research is started with a literature review related to HF. The review aims at providing knowledge regarding relevant methods and their advantages and disadvantages, and helping to formulate meaningful research questions. In the current study, an extensive literature review is conducted on the HF instruction of different international oil and gas companies such as:

- Australian gas light (AGL) [21],
- National petroleum council (NPC) of north America [22],
- ExxonMobil [23],
- American petroleum institute (API) [24], and
- ConocoPhillips [25].

This review was necessary because of this fact that there is not enough experience on HF treatment in Iran. Anyway, an adopted risk classification has been extracted based on the above sources. After that, the research questions on risk identification, determining the probability levels, determining the impact levels, and specifying risk handling options were made. A series of structured interviews were performed as face to face with various experts from different oil companies, to gather information on the research questions. A structured interview (also known as a standardized/formal interview) is a conversation where an interviewer asks all interviewees a set of predetermined questions in a standardized order. Asking the same uniform questions helps interviewers have similar forms of information. This process has several advantages, such as: easy to quantify, easy to test, fairly quick to conduct which means that many interviews can take place within a short duration of time, the results are less likely to be biased, and the responses are easy to compare. In addition, the interview experiences are more productive as questions are designed in advance to collect the most fundamental and respected information.

There was an opportunity for the authors to take part in a technical panel of well services and HF. This panel contained many experts from 18 well-known operational and professional Iranian contractors such as:

- Petroleum engineering and development company (PEDEC),
- Petro-pars,
- Mehran engineering & well services company,
- Wells services of Iran (WSI),
- National Iranian drilling company (NIDC),
- Sarvak Kish engineering and drilling services company,
- Persia oil & gas industry development company (POGIDC),
- Sea-land engineering and well services company.

In the panel, a number of experts with more than 12 years experiences of working in the well services (e.g., acidizing, drilling, perforation, well completion, and well test) provided their assistance and expertise in identification and analysis of risks, and determination of handling options. The min and max age of the experts were 33 and 64 years old. The min and max average years' experience were 12 and 20. A variety of certain objective sources such as standards, regulatory initiatives, and valid documents, developed by some industry or technical organizations, were available to assist the experts who wanted to extract ideas on e.g. identifying objective handling options on risks. In fact, the experts could choose any idea from a variety of regulatory instruments to achieve the desired outcomes. The most important sources were:

- AGL code of practice for HF,
- Queensland gas company well simulation plan and management,
- Alberta Energy Regulator (AER) mitigating risk of HF,
- Canadian association of petroleum producers (CAPP) records,
- API records,
- British columbia oil and gas commission records, and
- New Brunswick: energy and mines.

After collection the data, they were systematically analyzed and interpreted to answer the research questions. It should be noted that Table 1 and Table 2 were used to determine the level of risk probability and risk impact. In addition, Table 3 is utilized to show the identified risks, and their types.

3. FINDINGS: RISK FACTORS

As a fundamental platform to identify the risks, firstly risk factors were investigated and addressed. We concentrated on risk factors of the three major parts of the HF operation: design, execution, and management & human resources.

A. Risk factors of design activity

Design is the first phase and one of the most important parts of the operation. Unfortunately, this stage in Iran has not been taken into account seriously due to various reasons which are:

- Lack of down hole data archive and lack of sufficient data as well as lack of precision data,
- Using common version of stimulation for all of the wells and lack of attention to specific down hole information for each well,
- Lack of quantitative indicators and targets for stimulation wells by the owner, according to characteristics of the well and the it's situation in the field,
- No universality of risk analysis and alternative handling options at the design stage,
- Lack of systematic records and weakness in the use of lessons learned, and
- Excessive attention to the operation than design.

B. Risk factors of execution activity

Execution is the most important part of the operation that is the interest point of both owners and contractors. There are a lot of problems (as follows) in terms of equipment and technology, engineering, procedures, instructions and HSE (Health, Safety and Environment) in execution section.

Table 1. Probability of occurrence [4]

Scale	Meaning	Symbol
Frequent	Occurred frequently.	1
	Will be ceaselessly experienced unless a handling option is made.	
Likely	Occurred some times.	2
	The occasion anticipated that would happen 50-99% of the time.	
	Will happen frequently if occasions take after ordinary examples of procedure.	
	The occasion is repeatable and less sporadic.	
Occasional	Occurred rarely.	3
	An occasion happens rarely, or unpredictably, or 25-50% of the time.	
	Occasions are sporadic in nature.	
Seldom	Unlikely to happen	4
	Not known it has happened.	
	An occasion that happens discontinuously or 1-25% of the time.	
Improbable	A remote probability, being practically unfathomable that occasion will happen.	5

Table 2. Impact of occurrence [4]

Scale	Meaning	Symbol
Catastrophic	Equipment crushed.	A
	Multiple deaths.	
	System-wide shut down and negative income effect.	
	Extensive environmental impact.	
	Loss or breakdown of whole system or a sub-system.	
	Persistent infringement of any safety regulation that could bring about genuine damage or death.	
	Potential for an uncontrollable public relations event.	
Critical	An expansive reduction in safety margins, physical trouble and/or workload such that operators cannot perform their tasks precisely or completely.	B
	Serious injury or death.	
	Accident incident with injuries and/or moderate to major equipment damage.	
	Possible criminal punishment.	
	Medium environmental effect.	
	Hazardous spill into the environment.	
	An operational debasement.	
	A security finding requiring quick remedial activity before proceeded with operation.	
	An employee injury/broken bone.	
	Moderate enterprise risk including official administration inclusion.	
	Very large public relations effect requiring resources to manage information.	
	Potential misfortune or breakdown of whole sub-system or divisional operations.	
	Production errors containing administrative infringement resulting in shutdown of a larger operation.	
Moderate	Mishap or incident with minor harm.	C
	Non-life debilitating worker harm, with recording of lost time injury.	
	Small environmental effect.	
	Security issues in the way that it requires a corrective action plan.	
	Production component errors that might posture indirect consequences to the operation.	
	Potential to bring about supported unpredictable operations until issue is determined.	
	Complete shutdown of smaller operations or divisions.	
	Additional public relations efforts and resources required.	
Minor	No regulatory action anticipated.	D
	No environmental impact anticipated.	
	No evident security threat affected.	
	Minor errors in completed company policy procedures.	
	Production errors containing quality system and/or opportunities for improvement.	
	No equipment damage or slight damage.	
	No public relations impact.	
Negligible	No regulatory violation.	E
	No environmental impact.	
	No security element affected.	
	No public relations impact.	

Table 3. Probability and impact matrix

Risk probability	Risk impact				
	Catastrophic A	Critical B	Moderate C	Minor D	Negligible E
1-Frequent	1A	1B	1C	1D	1E
2-Likely	2A	2B	2C	2D	2E
3-Occasional	3A	3B	3C	3D	3E
4-Seldom	4A	4B	4C	4D	4E
5-Improbable	5A	5B	5C	5D	5E
Red zone: High risk, Yellow zone: Medium risk, Green zone: Low risk					

- Lack of guaranteed access to high-quality equipment, new technologies and modern simulation tools,
- Lack of a documented system of maintenance, including: failure diagnosis, maintenance schedule of contractors, following mechanism of the maintenance schedule of contractor during the operation,
- Shortage in the international information and experiences and updated methods,
- Lack of Research and Development (R&D) and the use of new methods and techniques,
- No comprehensive registration and the use of lessons learned and improvements in the implementation,
- The absence of written instructions for the implementation and evaluate on of the operations,
- Lack of effective and timely inspections the relevant failures, which can help us to follow safety policy,
- Lack of sufficient funding for environmental protection,
- Weakness in the safety framework, and a systematic process to revise the relevant guidelines,
- Lack of universality in full compliance with safety instructions available from owner and contractor,
- Lack of professional training of the HSE technical staff,
- Lack of risk assessment and management, and
- Waste management problems.

C. Risk factors of management & human resources

The issues concerning management and human resources also play a very important role in the progress of the HF operation. Definitely, if the best design is conducted, but the perspective of management and the ability of human resources are not consistent with the goals of the operation, in all probability any success will not happen. Truly, a substantial factor for the success of the HF operation is professionals and experienced human resources. As a matter of fact, experts together with the right management and sufficient financial resources are the pillars of a successful treatment. Highly trained and experienced human resources are considered as one of the company's strengths. Therefore, quality of the HF operation is subject to shortage of human resources and lack of operational control. In contrast, good human resources bring good effects on well stimulation operation, data assessment, and the use of software and management team. In summary, the risk factors of management and human resources in Iranian well stimulation operation are as follow:

- No cost-benefit review and analysis, in arrival of new technologies,
- Operation stroke and non-optimal allocation resources in engineering, operation and training,
- Unbalanced expectations between owner and reality of operation, execution and economics,
- No comprehensive databases,
- Weak support to enter the new technologies by owners,
- Confidentiality of information especially by owners.
- Lack of standard specialized training centers,
- Lack of professional training for fresh employees,
- Shortage of skilled manpower in engineering and operations,
- Insufficient skill in usage of special software,
- Weakness in the knowledge transfer between individuals and firms, and
- The problems concerned with selecting and training of the owner supervisors.

4. FINDINGS: RISKS, TYPES AND HANDLING OPTIONS

This section reports the main output of the study. Herein, all the identified risks are presented along with their proposed handling options. The risks have been classified in six types: (1) Workplace health & safety, (2) Impact on water resources, (3) Air pollution, (4) Localized, temporary noise and vibration, (5) Loss of well integrity, and (6) Induced seismicity.

A. Workplace health & safety

The workplace health and safety policy has been affirmed to guarantee a protected and sound working environment for staff, equipment, and guests. This requires the progressing incorporation of security standards into the work practices. Everybody is in charge of their own security and health and in that of other labors. The level of obligation and responsibility of each person will rely on their authority and level of impact or control [26]. Some of actual cases in this type, which often occurs in Iranian oil and gas industry, are as follows. In the below list, the code in the parenthesis refers to the more likely location cell of each case in the probability and impact matrix as Table 3.

a) Fire of shaker screens on helideck (4B),
b) Cut finger during lifting mouse hole (2C),
c) Drinking rig wash (4D),
d) Ring finger of one of floor man gets injured as he was arranging shackles on shackle rack (3C),
e) Striking left tong tail to driller cabin glass (2D),
f) Tip of crane boom stroke to monkey board wall (4D),
g) Motorman's hand burned as checking oil level of crane gearbox (4D),
h) C/M's hand caught by hose reel of submersible pump (3C),
i) Two cranes collide to each other (4B),
j) Slipping on rig floor (2D),
k) Wellhead engineer slipped on main deck (3D), and
l) Fire in the cement unit while doing welding job and failure of fire extinguisher (4B).

The results of this type are depicted in Table 4.

B. Impact on water resources

This section investigates some potential hazards related to water resources including: (1) groundwater contamination due to well drilling and production; (2) water withdrawals; (3) truck movement and its effects on water quality; (4) wastewater management; (5) storm water management; and (6) surface spills and leaks [27]. Related risks to water resources are portrayed as Table 5.

C. Air pollution

During well stimulation treatment, pollutants are discharged from wellheads, flared gas, pipelines, tanks, pits and compressor stations. With reference to combustion byproducts, for example, diesel discharges are transmitted by equipment utilized for drilling, fracking, stimulation, transportation of materials and drying out gas. Volatilizing chemicals are released during drilling, HF and maintenance of well pads and equipment [28]. Table 6 shows related risks to air pollution.

D. Localized, temporary noise and vibration

Noise impact is also a significant issue. Drilling regularly happens 24 hours a day, and where drilling is near the residential locations, there is a critical risk of unsettling influence activating protests. This section describes the impacts associated with well stimulation treatments and also proposed some handling options [29]. The results are shown in Table 7.

E. Loss of well integrity

There are various definitions for well integrity. The most generally acknowledged definition is given by NORSOK D-010 (Norwegian standard in petroleum industry): "Use of specialized, operational and authoritative answers for diminishing risk of uncontrolled discharge of formation fluids for the duration of the life cycle of a well". Well integrity engineers need to cooperate continually with various disciplines to evaluate the status of well obstructions and well boundary envelopes at all times because well integrity is a multidisciplinary approach [30]. The related risk and handling options are shown in Table 8.

F. Induced seismicity

Induced micro seismicity is resulted from HF treatment associated with the new induced fractured and collaboration with pre-existing fractures. The magnitude depends on the hydraulic energy and site conditions. But usually, they cannot be recorded even by usage of very sensitive recorders near the proximity due to their small magnitude. In some reservoirs which have high stress level or when faults are activated, the risk (see Table 9) is more likely to happen. Actually, all the cases related to the

Table 4. Workplace health & safety risks and handling options

Risk	Level	Handling options
Accident due to heavy vehicle movement (for related vehicle or other road users)	Green	Using drivers that are completely assessed and appropriately licensed.
		Strategy of obligatory should be established for a long journey.
	Yellow	Evaluation of chosen travel course prior to mobilization of heavy vehicles movements.
		Construction of a traffic arrangements plan.
		Vehicles should support records and routine checks according to the journey management plans, which include identification of the travel route.
	Red	Exerting vehicle management systems, including a live tracking system.
		Escort vehicles in front of caravan.
Equipment damage during rig up	Green & Yellow	Only authorized personnel can be on site.
		Site should managed by a suitable schedule to ensure orderly movements.
	Red	Reversing any of equipment requires land guide.
		Wellhead must be barricaded to prevent reversing.
Injury to onsite personnel due to equipment set up	Green	Only authorized personnel can be on site.
		Personnel must wear appropriate safety and protective gear at all the times.
		Controlling equipment movement during rig up.
	Yellow	Contractual workers must conduct site visit and planning workshop preceding establishment.
		Pre-rig up meeting must be held prior to starting the work.
		Employing a health team consisting of nurses, first-aid workers, evacuation means, medicines, and so on.
	Red	Site management must be established which includes but not limited to, land guides, site directions, access limitations, signage, and permit to work system.
Uncontrolled pressure release and causing injury to onsite personnel	Green & Yellow	Controlling primary pressure safety control and electronic pump cut outs in equipment.
		Employing annual third party certification of all pressure equipment.
		Implementing signage and exclusion zones
	Red	Establishment of remote and local equipment kill-switches.
		Secondary pressure relief valves must exist to enable pressure release.
		Continuous pressure monitoring must be done.
Flow back line release causing injury to personnel	Green & Yellow	Flow back lines should be pressure rated.
		Fixed bean choke must be used to control flow back.
		Maintaining zones.
	Red	Locating the open top flow back tank 25 meters away from well with diffuser for more control of fluid flow back
		Pipes must be braced in order to reduce movement and vibration and avoiding fatigue failure
Fire and related injuries	Green	Construction of appropriate diesel storage areas.
		Pre-job inspections must be taken.
		Different firefighting techniques must be trained to the relevant personnel.
		Fire extinguishing equipment need to be provided on site and regularly serviced and on the ground ready for use.
		Rural/Local fire service contact details require to be existed on site and should be debriefed prior to any activities.
	Yellow & Red	HF equipment must equipped with rig savers/ mechanical or electrical emergency shutdown controls.
		Emergency fire drills should be conducted.
Chemical mishandling or inadvertent contact with chemical hazards	Green & Yellow	Visual inspections of stored chemicals.
		Personnel should be given adequate training in chemical handling.
		Storage of all chemicals in bounded areas.
		Providing exclusion zones around chemical areas.
		Chemical segregated by class and generating a load sheets for better identifying specification and locations.
		Appropriate personal protective equipment must be provided for the chemicals being handled.
		Establishment of safety showers, first aid kits and eye wash bays on site.
	Red	All Material Safety Data Sheets (MSDS) must be available on site.
		Human Health and Ecological Risk Assessment (HHERA) must be completed for all chemicals.
		Continuous monitoring of chemical injection into fluid is required.
Equipment sabotaging by illegal entrants	Green	Making use of appropriate security firms and fencing.
		Resorting to signage to inform general public (called site is "restricted").
	Yellow & Red	Ceaselessly working with the local police services.
		Site security needs to be checked, especially every morning and night.

induced seismicity have been reported in Oklahoma, United Kingdom, and British Columbia [31].

5. CONCLUSION

In this work, an inclusive risk assessment and the proposed risk handling options for NIOC was prepared with the use of the respected literature as well as the expert's opinions. A user-friend technique for identification of the risks and determination of probabilities and impacts has been used. The results are the three lists of risk factors, the six sets of identified risks and the relevant several handling plans. We conclude that accurately following the results of this study can led the NIOC to reduce their damages into the personnel, environment and equipment and have a successful treatment with minimum unforeseen incidents.

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Table 5. Impact on water resources risks and handling options

Risk	Level	Handling options
Risk of source water spill	Green	Making use of sluice gates.
		Retaining walls or dikes around tanks.
	Yellow & Red	Vacuum truck must be available on site.
		Booms in water basins should be adjoined to the facility.
		Absorbent pads are necessary.
Flow back water spill due to incorrectly transportation, capturing and/or removing	Green & Yellow	Flow back water must be stored in designed tanks or other above ground holding tanks, which are fully contained.
		Visual inspection of pipes that is utilized to transport flow back water to over the ground holding tanks.
		Visual inspections must be led on all tanks preceding the storage of any fluids.
		Visual investigations additionally should be directed a few times each day during HF operations to guarantee no overflow or leaks.
		Bounding of water tanks in order to containing liquid when a leakage occurs.
		Wells must be supervised during flow back operations.
	Red	Vacuum truck must be available on site.
		Utilizing fixed transport tankers to expel flow back water from site or holding dams to an endorsed facility.
		Keeping surplus water tanks nearby so that if a hole was to happen in a tank the substance of the tank could be pumped into the spare storage tank.
		Pipes must be pressure tested during commissioning and before use.
Connectivity and cross sullying between target formation and advantageous aquifers (i.e., sway on water quality attributes, changes in groundwater characteristics, and changes in surface water levels)	Green & Yellow	Pressure monitoring (at individual) during fracture stimulation.
		Starting job execution from the most profound zone and advance up the well because of gathering additional data before drawing nearer the useful aquifers.
		Checking the flow back chemistry changes.
		Groundwater checking programs must be led to give baseline information preceding HF treatment in this way permitting patterns or changes in shallow water chemistry to be recognized.
		Water testing and investigation of these water sources prior and then afterward job treatment.
		Well integrity tests should be run in order to guarantee the isolation of aquifers.
		Flow back water must be recovered in a lined evaporation pond, with vacuum truck available on location.
		Use of above-ground tanks in lieu of pits.
		Use of leak finding systems and line pits.

Table 6. Air pollution risks and handling options

Risk	Level	Handling options
Excessive exhaust emissions and surface dust generation from road movements due to trucks, vehicles, operational equipment operating during activities, air emanations further to the utilization of fixed and mobile diesel motors	Green & Yellow	Employing signposted travelling speeds to reduce dust generation from traffic movements.
		Engines must be stopped when not necessary.
		Consistent maintenance of all vehicles, also fixed and mobile motors for improving combustion.
		Use of well-maintained vehicles.
		Using smaller, more powerful engines.
	Red	Routine dust suppression where generation has been observed on roads and appropriate gravel must be used to surface roads where required to minimize from road movements.
		Limiting and reducing the vehicle use.
		Setting source water close to the well site, introducing provisional pipelines and Water reusing because of lessen truck movement.
		All fracture stimulation activities must be done greater than 200 meters from residences.

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Table 7. Localized, temporary noise and vibration risks and options

Risk	Level	Handling options
Localized, provisional visual and noise effects due to heavy vehicles, operational equipment and flow back operations	Green & Yellow	Fracture stimulation pumping, work over, rig operations and heavy vehicle movements must be restricted to 7 am to 7 pm Monday to Friday and 8:00 am-1:00 pm Saturday. Outside of these hours, activities should be limited to light vehicle access, rigging up, rigging down, equipment maintenance and pilot testing.
		Utilizing the required individual security equipment.
		Making use of motor covers.
		Pleasing the team far from loud sources (under 50 dB).
		Safety training and awareness of the crew.
		Directing noise-generating equipment away from receptors.
		Setting of tanks, topsoil stockpiles, trailers or feed bundles between the clamor sources and receptors.
		Utilization of clamor diminished equipment, for example, doctor’s facility suppressors, ventilation systems or other high-grade baffling.
		Pointing of high-pressure release pipes far from noise receptors and expansion of noise divider or noise obstructions.
	Red	Community consultation must be occurred with neighbors prior to commencement of activities.
		Noise logging onsite and at nearby receivers must be provided to identify any problematic areas.
		Employing a health team consisting of nurses, first-aid workers, evacuation means, medicines, and so on.
		Surrounding noise level test requiring consistent noise observing for 24 to 72 hours before works initiating to pick up substantial background noise estimation.

Table 8. Loss of well integrity risks and handling options

Risk	Level	Handling options
Loss of well control or blowout during work over operations	Any zone	Applying safety margins incorporated into fracture stimulation design.
		Using the API certified casing and wellhead.
		Bridge plugs needs to apply to isolate each treated zone.
		Perforation of selected zones only.
		Making use of cement bond logs to be run on all wells.
		Casing should be pressure tested prior to perforating.
		Setting of Blowout Preventer (BOPs) in wells.
		Utilization of H2S portable sensors.
		Trace of activities and continues preservation of installations.
		Respecting responsibilities and instructions in case of incident.
		Generation of an emergency contingency plan.

Table 9. Induced seismicity risks and handling options

Risk	Level	Handling options
Induce seismicity that can occur due to fracture stimulation activities; for example, disrupt a nearby fault	Green & Yellow	Monitoring of injection rates.
		Investigation of injection wells.
	Red	Drilling and logging records must be performed to identify faults.
		Seismic mapping to identify faults.
		Avoiding activity near big faults.
		Petro-physical qualities of reservoir must be beforehand calculated to guarantee that micro-fractures are restricted.
		Estimation of the height’s HF propagation utilizing temperature log to guarantee that it doesn’t surpass the points of confinement of the target reservoir level.

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