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Research article

# Risk analysis of gas leakage in gas pressure reduction station and its consequences: A case study for Zahedan

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ABSTRACT

Industrial accidents have increased the importance of dealing with the risks of toxic exposure, fire and explosion. Despite the measures taken in the chemical industry to prevent accidents, the accidents occur often due to human error or process faults during repairs. Although several studies have been conducted on the accidents in the process industry, no research has modeled the risks caused by the leakage of toxic substances in the gas pressure reduction station. The consequences of gas leak and fire in Zahedan's gas pressure reduction station were investigated in Iran. This research aims to determine the safe range of the station and observe the safety measures required for the gas pressure reduction station in Zahedan. For modelling gas leak and fire, the ALOHA software was used to display the threat zone. In this research, with respect to the environmental data, the desired scenario was modeled. The results, based on two scenarios of gas leak and fire in both hot and cold seasons, indicate that the gas leak scenario in hot seasons and the fire scenario in cold seasons influence a larger region.

## 1. Introduction

Pipelines are considered as the best ways to transport oil and gas products in terms of safety and economic concerns. However, risks and sudden damage to people's lives are disadvantages of this type of transport (Gupta et al., 2018). The failure of the pipeline network has consequences such as loss of resources, environmental impact, and public safety. To eliminate or reduce these outcomes, it is essential to identify and control the factors causing accidents (Hopkins et al., 2009; Veritas 2010; Abbasi et al., 2020; Gharouni Jafari et al., 2020).

Today, safety is one of the most important topics (Noorzai and Golabchi, 2020; Gharouni Jafari et al., 2014), especially in the chemical processes. The toxic chemicals have caused concern for workers, people and environment. The past accidents have been associated with many economic losses and damages. One of these accidents was the leak of hydrogen fluoride from the South Korea's Solvent Liquid Products Company on September 27, 2012 (Zhang et al., 2018). The study of catastrophic accidents indicates that companies with long safety records can be affected by adverse accidents (Gharouni Jafari et al., 2021). Similar to recent examples, the accidents in the Macondo Prospect in the Gulf of Mexico were associated with explosion of the horizontal diaphragm (DWH). In addition to many damages to the environment, this accident led to the death of 11 people and injury of 17 people. Two other cases were the Fukushima Nuclear Power Plant (NPP) accident in Japan that caused the widespread radioactive contamination and the Floating Production Storage & Offloading (FPSO) accident in Brazil where nine workers died (Silva 2017). The hazardous chemical leak specifications are being unexpected, severe effects, and large effect range. The high-density gases expand on the earth's surface for being heavier than air. These leaks cause safety threats and secondary accidents for those working in industry and the environment (He et al., 2011; Li et al., 2014). The two parameters of density and exposure time to hazardous substances play an important role in determining the hazard level to human beings against the process accidents. The higher the density and the longer the exposure time, the more severe the hazards. The most effective method to rescue and evacuate the residents is to predict the area affected by the mathematical model (Liu and Wei 2017).

Zahedan is a city that has recently been connected to the national gas network. In Zahedan, because of the urban structural density, the layout of the gas pressure reduction station has become very important. The proximity of the gas pressure reduction stations to the residential homes makes the risk assessment and hazardous areas classification necessary. Figure 1 shows a schematic diagram of the gas pressure reduction station. This research is carried out for modeling the gas leak and fire scenarios in

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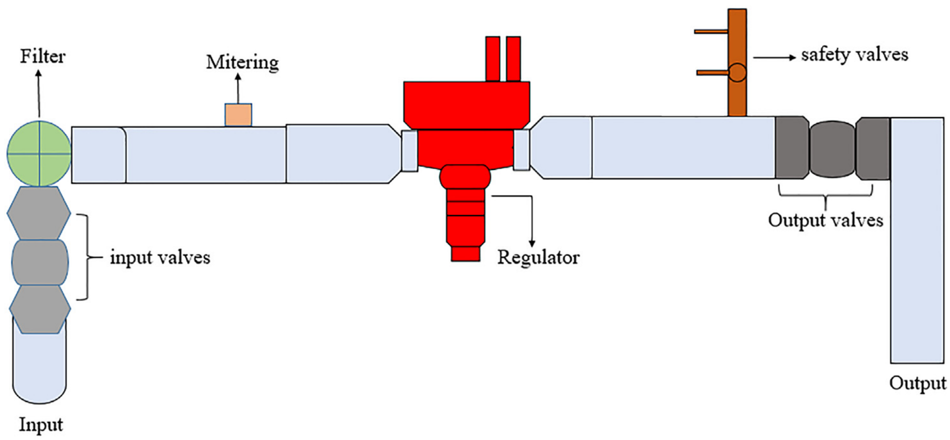


**Figure 1.** Schematic image of gas pressure reducing station.

the gas pressure reduction station. Zahedan is one of the cities of Sistan and Baluchestan province that is located in southeastern Iran. Zahedan, with an area of 55.7 $km^2$, is located on a semi-flat plain with a gentle southern slope. This city has a warm and temperate climate with an average annual temperature of 18.3 degrees Celsius. The highest and lowest temperatures in Zahedan are 42.5 and 12.6 degrees Celsius, respectively (RadFard et al., 2018).

Access to the required data and visiting the gas pressure reduction station were the limitations of this research. After this research, many topics and questions were raised about the hazards of the station. Among the most important topics that were expressed as questions and theories, the following cases can be mentioned:

Does the fire scenario in winter have more consequences for the study area and what are the most important measures to prevent excessive damage to the study area? The fire and gas leak scenarios in the summer affect the larger areas. Consequences of toxic and flammable substance leak cause damage to the study area up to a radius of a few meter. By examining and investigating the published statistics on the process industry accidents, it can be found that the process accident causes very heavy and irreparable damage. Accordingly, it is essential to discuss the simulation of the toxic substance leak and fire. By defining the radius affected by toxic substances and fire, the required safety measures can be taken for reducing the damage. It should be noted that all information, including the characteristics of the chemical, the study area, and the gas pressure reduction station, are considered based on the real gas used by the public.

## 2. Literature review

Bernoulli (1954) provides one of the first definitions of risk assessment with geometry that is the reduced risk size with spread potential in independent accidents. According to this definition, the risk values are measured with two combined variables of accident frequency and outcomes. Companies divide macro risks into two categories based on the complexity and magnitude of the risks they are dealing with. The first risk is the static risk that only causes damage. The features of this risk are the negative and unpredictable effects under the insurance policy. The second risk is the potential or dynamic risk that causes damage and creates an income opportunity (Verbano and Venturini 2013). The risk management topics of chemical industry, petrochemical industry, and process safety have widely been discussed (Yoo and Lee 2019). Although the gas industry has been successful, but hundreds of accidents have occurred in the natural gas industry, because of the flammability and high toxicity of raw natural gases, which were accompanied by severe losses (Nolan 2014). The hazards followed by accidents have made safety a major issue in the natural gas industry. The main objective of safety management system is to prevent the accidents through active identification, assessment, prediction, elimination, and control of safety risks at an acceptable level (Noorzai et al., 2020; Rathnayaka et al., 2012). Increased safety depends on the correct and systematic identification of safety risks with an objective to analyze and identify potential risks in a system related to an activity, introduction of risk control measures to eliminate or reduce the potential damage to people, environment or other assets (Noorzai, 2021). The risk management is a preventive and systematic approach to define the best course of action during uncertainty, which includes taking risk for different stakeholders (Rausand 2013; Golabchi and Noorzai 2013). The risk analysis is based on the risks and threats of the studied goal in regard of its performance. The risks are somehow relevant to the energy resources, so they are of great importance Abbasi and Noorzai, 2021. A general list of hazards, threats, and energy sources is a valuable tool for recognizing the potentially hazardous accidents. The risk control and risk reduction is a major necessity in such circumstances. There are two main types of risk reduction measures: 1) Preventive measures to reduce the frequency of one or more hazardous accidents that are known as frequency reduction measures; 2) Preventive measures to reduce the consequences of a potentially hazardous accident that are known as reaction or consequence reduction measures (Rausand 2013).

There are certain concepts and phrases in safety planning and design; such as the term "hazard", which Brauer (2016) defines as follows: the intrinsic or potential specifications of an activity, conditions or environments, which are capable of causing harmful consequences. OHSAS 18001 (2007) cited that the possibility of hazard is the probability of certain conditions in a given situation or work environment. They also believe that severity of a hazard is a classified description of the level of hazards based on their true or observed potential for causing injury, damage, and harm. OHSAS 18001 (2007) defines an accident as an incident that leads to injury, illness, or death. Brauer (2016) defines safety as the relative relief from harm, hazard, injury, or loss. A few studies associated with the present article have been conducted in the recent years and Table 1 examines the similarities and differences between these studies and the present article.

A small number of studies have focused on the gas pressure reduction station especially in terms of risk assessment. For example, in similar studies, Shao and Duan (2012) investigated the analysis of substance leak from a natural power plant, which was based on three types of leak conditions and subsequent measures. Tseng et al. (2012) compared the simulation of toxic materials in three chemical companies of chlorine, epichlorohydrin, and phosgene with respect to two leak criteria that are hazardous for human life and health. Liu and Wei (2017) conducted a research on the simulation of dense gas leak for emergency response, in which the simulation of distribution and gas concentration was investigated for emergency programs taking into account five different times.

**Table 1.** Review of related research.

| Criteria | Zhang et al. (2018) | Liu and Wei (2017) | Shao and Duan (2012) | Tseng et al. (2012) | Baalisampang et al. (2019) |
|---|---|---|---|---|---|
| Studying various times for simulation | * | | | * | |
| Performing analysis using ALOHA | | | * | * | |
| Simulating gas dispersion | * | * | * | | * |
| Studying various leakage conditions | | | * | | |
| Considering emergency reaction plan | | * | | * | |
| Employing complementary methods | * | * | | | |
| Predicting gas emission focus field | * | | | | |
| Applying calculation methods | | | | | * |

Asterisks in Table 1 show that the studies listed in the first row had the criteria listed in the first column.

Zhang et al. (2018) studied the risk assessment of process facilities and examined the gas emissions.

Baalisampang et al. (2019) investigated the random gas emissions in the process unit and analyzed the gas leak scenarios. In this paper, the risk assessment was done by ALOHA software. First, the gas leak scenario was performed in cold and hot seasons and then the radius affected by the gas leak scenario was simulated. Then, the second scenario of fire was simulated in hot and cold seasons and the radius affected by this scenario was determined. The most important scenario can be considered as gas leak, because the next accidents will be caused by gas leak. Hence, in this scenario, two states were investigated, and finally the necessary safety measures were provided to prevent and avoid the consequences of hazards.

Yang et al. (2018) clarified the concept of operational risk assessment in the oil and gas industry by performing a structural review that includes operational risk assessment, dynamic risk assessment and real-time risk assessment. They ignored the application of quantitative methods, the gap that the current study attempts to fill.

Rajeev et al. (2019) examined the human vulnerability map of the chemical accidents in the major and important Kerala Industries in India. In this study, the individual hazards and social risks were identified using Arc Gis software. After investigating and determining the population vulnerability map, a comprehensive procedure was identified. One of the weak points of this research was not using the research chart.

Sanchez et al. (2018) simulated the scenarios using the local vulnerability index and analyzed the technical hazards. The potential impacts of a technical accident are estimated by risk assessment. Considering this issue, the hidden or potential situation can be identified and declined. The research method includes the toxic threat zone simulated by ALOHA software and sociological classification layer of the damaged population. Failure to express the research background can be considered as one of the weak points of this research.

Anjana et al. (2018) used ALOHA software to examine the ammonia emission and population vulnerability assessment by the pollutant dispersion model. This model estimates the vulnerable areas that could be affected by an ammonia emission, integrated information on the chemical properties of substance, climate conditions of outbreak in the region, and emission conditions. This research had weak points, such as the lack of topics related to the definitions and background of the research.

Orozco et al. (2019) described and investigated the impacts of ammonia emission from the existing reservoirs in the Matanzas industrial zone on the population and surrounding environment. Three of the predictions are as follows: toxic steam cloud, flammable area, and steam cloud explosion. The more hazardous scenario is the ammonia steam

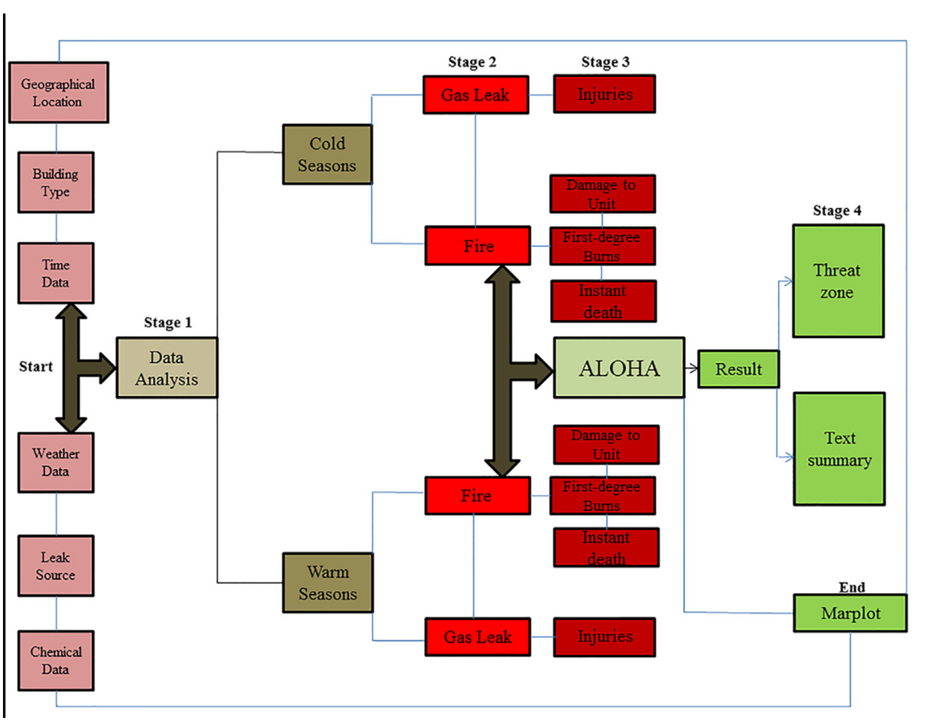


**Figure 2.** Research workflow.

**Table 2.** Different ERPG levels.

| ERPG levels | Consequences |
|---|---|
| ERPG-1 | The maximum density of the chemical in the air that all people can be exposed to for an hour, without disturbing them or having an unpleasant odor. |
| ERPG-2 | The maximum density of the chemical in the air that all people can be exposed to for an hour, without being seriously or irreparably damaged or being unable to take safety precautions. |
| ERPG-3 | The maximum density of the chemical in the air that all people can be exposed to for an hour without threatening their lives. |

**Table 3.** Effects of different levels of thermal radiation.

| Intensity of thermal radiation | Consequences |
|---|---|
| 37.5 | Causing damage to process units and equipment, as well as instant death for those exposed to it |
| 20 | Serious injuries to the exposed people can result in death if the rescue team does not arrive in time |
| 12.5 | Minimum energy required to ignite wood pilots and melt plastics |
| 4.5 | Causing pain in people who are exposed to it for at least 20 s (First-degree Burns) |
| 1.6 | Causing relatively mild side effects with prolonged contact |
| 0.7 | Sun radiation |

cloud, which is located in a large area with a dense population that causes damage to the environment. Two weak points of this research were the lack of definitions and background of the research.

Vairo et al. (2021) examined the risk assessment aspect of natural gas lines. By investigating historical accidents in NG pipelines in the United States, Canada and the European Union, they concluded that the critical factors causing these accidents included the failure mode, immediate and root cause, evolving scenario, degree of confinement produced by the surroundings and ignition timing. Focusing on a refined Event Tree framework, they failed to assess it against real cases.

Willey et al. (2020) conducted a research at the university level to analyze chemical safety process risks. The aim of this study was to help university graduates understand the dangers associated with chemical processes. They employed checklist and bowtie analysis methods along with HAZOP (hazard and operability study). Major weakness of this study was the lack of practical safety recommendations.

Not providing information on chemicals, study area, research background, and research chart were the weakness of the similar research on the risk assessment of the oil and gas industry; the items that the current study attempts to address. In this research, the risk assessment was conducted for two scenarios of gas leak and fire using ALOHA in the gas pressure reduction station. The risk range was modeled and determined in both hot and cold seasons. Then, the safety suggestions were given with respect to the conditions of each scenario and environmental conditions.

## 3. Research methodology

Accident outcome modeling refers to the use of mathematical models to predict the effects and consequences of a substance that is distributed in environment. The main consequences are the emission of flammable substances into the environment, fire, explosion, and distribution of toxic substances. The goal of accident outcome modeling in the industrial units is to determine the impact range of accidents on the process equipment and individuals (personnel in the industrial unit and people outside the

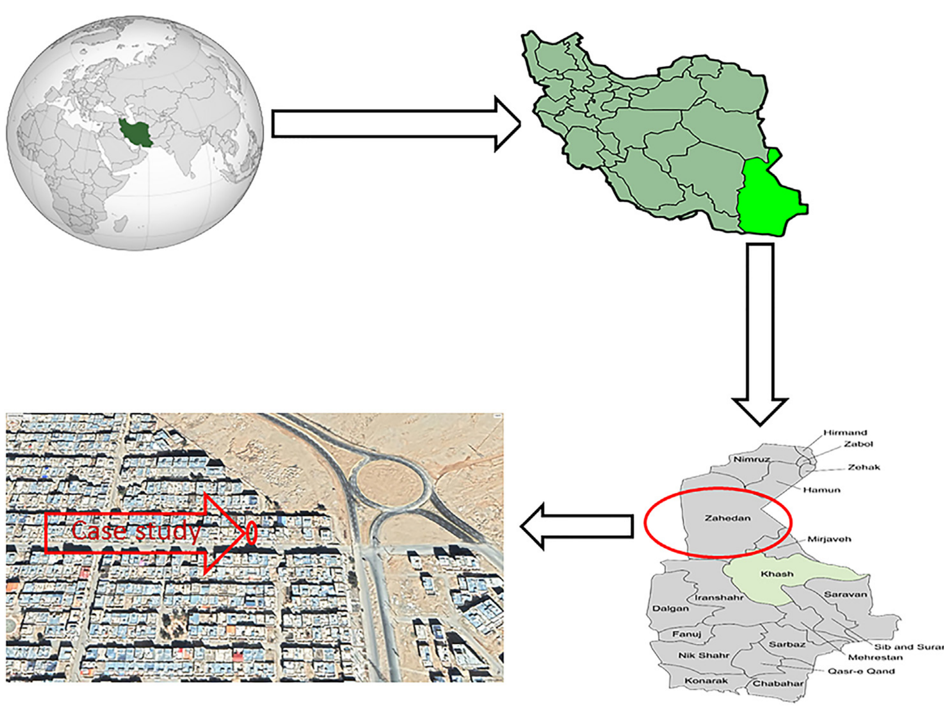


**Figure 3.** Geographical map of the study area.

**Table 4.** Location information.

| Location | Longitude | Latitude | Height above sea level |
|---|---|---|---|
| Zahedan | 60.51° E | 29.30° N | 1378 m |

**Table 5.** Chemical properties.

| Name | Molecular Weight | LEL | UEL | Boiling point |
|---|---|---|---|---|
| Methane | 16.04 g/mol | 50000 ppm | 150000 ppm | -258.7°c |

**Table 6.** Weather information.

| Parameter | Amount | Explanation |
|---|---|---|
| Wind Speed | 4 m/s | Average in cold seasons |
| | 3.6 m/s | Average in warm seasons |
| Wind Direction | 180 deg. | Dominant wind direction in cold seasons (South) |
| | 360 deg. | Dominant wind direction in warm seasons (North) |
| Environment Temperature | 8 °C | Average in cold seasons |
| | 30 °C | Average in warm seasons |
| Humidity Level | 40% | Average in cold seasons |
| | 15% | Average in warm seasons |

**Table 7.** Characteristics of gas pressure reduction station.

| Gas Temperature | Diameter of pipe | Gas Pressure | Pipe Surface |
|---|---|---|---|
| Cold seasons (25 °C) | Input (5 in.) | Input (250 psia) | Flat |
| Warm seasons (35 °C) | Output (8 in.) | Output (60 psia) | Flat |

unit). The gas leak outcome modeling in the gas pressure reduction station is proposed in four stages as follows:

1. Scenario selection: The desired scenario of gas leak or fire is selected in hot or cold seasons. First, the gas leak scenario and then the fire scenario in cold and hot seasons are simulated and examined.
2. Condition analysis: Variable conditions such as the weather conditions and emission of the substance from the container are investigated in this stage. Variable conditions and scenario study in both cold and hot seasons play a major role in the final results.
3. Accident modeling: In this stage, the scenario is modeled by ALOHA to determine the maps for the impact of material toxicity and fire. The two scenarios of gas leak and fire are modeled separately in hot and cold seasons and the results are analyzed individually.
4. Damage assessment: Based on the output results of the modeling, the damage assessment and eventually the safety suggestions are provided. Damage assessment varies based on variable conditions and modeling in both cold and hot seasons. In Figure 2, the research chart containing consequences and type of damage to individuals is specified.

All of the items examined in this study are a subset of HSE. The release of toxic substances will have consequences of damage to people and surrounding area of station. In this research, two scenarios of toxic substance leak and fire have been investigated. The toxic substance leak scenario causes damage to people and threatens their lives and the fire scenario is also associated with consequences of damage to the process unit, burns and instant death.

The criterion used to evaluate the toxicity of substances is the emergency response planning guideline (ERPG) showing at three levels (See Table 2). At the first level, the maximum concentration is examined for not causing discomfort or an unpleasant odor for an hour. At the second level, the focus is on a maximum concentration of toxic substances that does not cause serious or irreparable damage to people for an hour. At the final level, the maximum concentration is expressed, which people can be exposed to for an hour that does not threaten their lives. In Table 3, the radiation intensity of various fire levels has been shown along with their consequences.

The criterion used to investigate the fire scenario is the thermal radiation criterion (Kw). This criterion is defined in 6 levels based on thermal radiation intensity. At the first level, the maximum thermal radiation intensity of 37.5 causes damage to process equipment and instant death of individuals. At the next two levels, the thermal radiation intensity of 20 and 12.5 lead to outcomes of serious damage to the exposed individuals and minimum energy required to create the spark, respectively. First-degree burns are the surface outcome with a thermal radiation intensity of 4.5. The thermal radiation of 1.6 has mild side effects. The last thermal radiation level of 0.7 has a solar radiation outcome. This research aimed to model the hazards of gas pressure reduction station in 2019. This study has been conducted using ALOHA to determine the range affected by gas leak and fire scenarios. The target population of this research was the residents around the station due to the exposure to risk. The gas pressure reduction station is located at the end of the Zahedan Villa Street. The most important task of this station is to reduce the gas pressure from 250 psi to 60 psi. The subsystems of the gas pressure reduction station are the filter, regulator, counter, shut-off valve, and safety valve. Figure 3 shows the geographical area of study.

### 3.1. Steps of the ALOHA software application

ALOHA is a free software program based on Gaussian distribution made of continuous and floating air pollution leaks. This software is used to evaluate the threat zones of toxic cloud that is capable of modeling and predicting the leak process to a better response against the accidents caused by the accidental release of chemicals. ALOHA is provided by national oceanic and atmospheric administration (NOAA) and environmental protection agency (EPA) for the modeling of accidents caused by the release of toxic, explosive, and flammable materials and their outcomes. ALOHA has an information bank with 1000 chemicals and a simple environment to prevent the user errors (Jones et al., 2013; Tseng et al., 2012). This software can also be used to investigate an emergency response plan.

First, the following steps should be taken to enter the information into the ALOHA software:

1. Identifying the city (location) where the chemicals were released along with its time and date: Table 4 shows the location information.
2. Selecting the relevant chemical from the software's chemical information library: Table 5 shows the properties of the relevant chemical.
3. Entering information about weather conditions: Table 6 shows the weather information.
4. Explaining how the chemical came out of its container: Table 7 describes the characteristics of the pressure reducing station.
5. ALOHA is required to display the threat zone of toxic substances, ignition, thermal flux and increased pressure (LOCs = Levels of Concerns). If three LOCs are selected, ALOHA shows three hazard zones in red, orange, and yellow, in which the red zone represents the most dangerous state, followed by orange and then yellow as less hazardous areas.

### 3.2. Research phases

a) *Scenario Selection:* In the first stage, the scenarios or incidents with important outcomes are selected. The most important step in evaluating the outcome is to choose a scenario, because choosing the most important scenarios among the large number of options would reduce the time and volume of calculations. The goal of choosing scenarios is two criteria of probability and severe outcomes of that scenario. The

**Table 8.** The result of the gas leak scenario in both hot and cold seasons.

| Scenario | Season | Emission Data | | Risk Area of Toxic Chemical Leakage | | |
|---|---|---|---|---|---|---|
| | | Maximum average of emission | Total amount of emission | ERPG-3 | ERPG-2 | ERPG-1 |
| 1 | Warm | 2.580 lb./min | 154.701 lb. | 71(m). | 92(m). | 177(m). |
| 2 | Cold | 2.620 lb./min | 157.264 lb. | 66(m). | 86(m). | 164(m). |

validity of scenarios is determined based on experience, knowledge, and history of similar accidents in the past. Prior to choosing a scenario, it is necessary to collect information on the process, type and amount of processed or stored chemicals, physical state of the materials, operating conditions, and storage of materials such as temperature and pressure.

b) *Status Analysis:* At this stage, all the physical conditions affecting the accident are identified. For example, if the studied scenario is about the chemical leak from a tube containing toxic substances, the density of the released material to air, diffusion temperature, ambient temperature, as well as release rate are the effective factors. Examining these factors would help choosing the proper model to simulate the accident in the next stage.

c) *Modelling Incident:* At this stage, after considering all the effective factors on the accident, the accident is simulated. The results of this stage can be used to estimate the outcomes and damages. After selecting the logical scenarios, the most important factor in correct assessment of outcome is to select a right model that can simulate the accident close to the occurring situation.

d) *Damage Evaluation:* Based on the output results of the model and their measurement with the existing criteria, the severity of the accident is specified. If the studied scenario is about the release of a toxic substance into the environment, the concentration distribution of the released substance at different distances is compared with the toxicity threshold of that substance and the danger range is determined. This step is carried out with an aim to determine the area affected by the hazards and also the safe area around the station in the hot and cold seasons. ALOHA inputs are meteorological data and data related to the station and the released material, and the maps of the affected areas around the station are specified with software analysis. The results of the research can be used in preparing the emergency response plan, crisis headquarters, and future constructions in the surrounding residential areas.

e) *Data Analysis:* Process hazards are associated with irreversible outcomes. Therefore, the risk assessment and modeling of potential risks is important and necessary. In this research, the gas pressure reduction station hazards were modeled. Although the risk is low, it is important to consider the safety measures to avoid the losses. In all scenarios, the regional radius affected by the gas leak and fire is calculated per meter. The regulator of the gas pressure reduction station was considered as the most possible component for gas leakage, due to the structure consisting of flanges and fasteners.

## 4. Results

### 4.1. Results of scenario 1: gas leakage and the resulted toxic zone

In the first scenario, considering gas leak, TBS information, and atmospheric information, the outcomes of gas leak and emissions from TBS are modeled, and the results of the hot and cold seasons are shown in Table 8 and the results of gas leak scenario in cold season are shown in Figure 4.

In the gas leak scenario in cold season, the gas leak from the source at the ERPG-3 level with a concentration above PPM 40000 affects a distance of 66 (m) from the station in wind direction to the north of TBS, which is shown in red in the diagram. The leak in ERPG-2 with a concentration above 23000 PPM affects a distance of 86 (m) from the station in the wind direction toward the north of the TBS, which is shown in

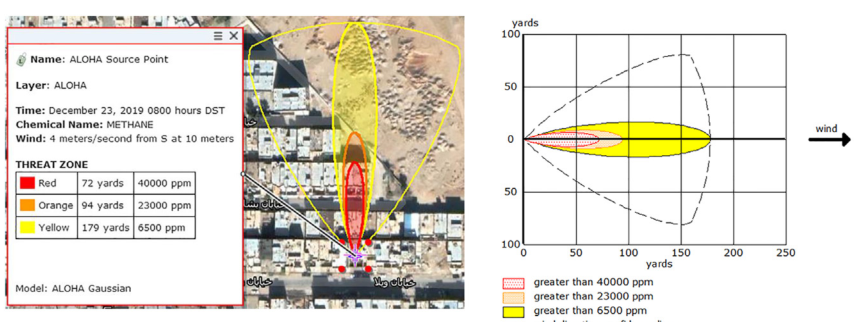


**Figure 4.** Results of gas leakage scenario in cold seasons.

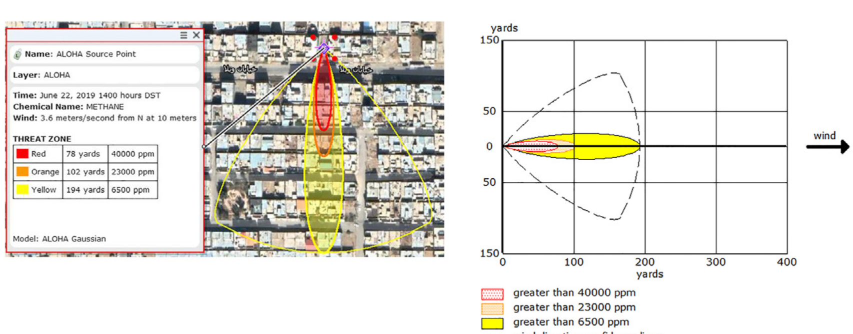


**Figure 5.** Results of gas leakage scenario in warm seasons.

**Table 9.** The result of the fire scenario in both hot and cold seasons.

| Scenario | Season | Emission Data | | | Risk Area of Thermal Radiation | | |
|---|---|---|---|---|---|---|---|
| | | Maximum flame length | Burning Speed | Total amount of burning | 37.5 kw | 12.5 kw | 4.5 kw |
| 1 | Cold | 13(m). | 4.660 lb./min | 157.276 lb. | 14(m). | 26(m). | 42(m). |
| 2 | Warm | 13(m). | 4.530 lb./min | 154.701 lb. | 13(m). | 25(m). | 42(m). |

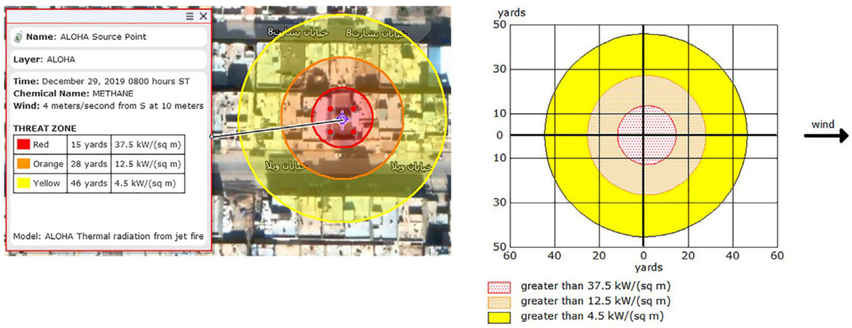


**Figure 6.** Results of fire scenario in cold seasons.

orange in the diagram. The yellow color in the diagram is related to ERPG-1 level with concentration above 6500 PPM, which the residents around the station up to radius of 164 (m) to the north can be exposed to for an hour without being disturbed and having unpleasant odor. In the following, the result of the gas leak scenario in the hot season is shown in Figure 5.

In the first scenario, the gas leak in the hot season from the source at the ERPG-3 level with concentration above 40000 PPM affects the distance of 71 (m) to the south of the gas pressure reduction station. The leak in ERPG-2 at a concentration above 23000 PPM affect the distance of 92 (m) from the station in the wind direction to the south of the pressure reduction station, which is shown in orange. The yellow color in the diagram shows the ERPG-1 level at a concentration above 6500 PPM, and this concentration can affect the areas up to 177 (m) to the south of TBS. In the study of the results of gas leak in both hot and cold seasons, the maximum average gas emission in the cold season is 40 pounds per minute higher than the hot season. The value related to the total methane released in the cold season is 2.563 pounds higher than the hot season. Finally, the gas leak in the hot season affects more areas than in the cold season. This difference is 5 (m) on the ERPG-3 level, 6 (m) on the ERPG-2 level, and 13 (m) on the last ERPG-1 level.

## *4.2. Results of scenario 2: gas leakage and the resulted fire*

In this scenario, considering the gas leak, TBS information, and atmospheric information, the consequences of gas leak and fire are modeled and the results of the scenario in cold and hot seasons are shown in Table 9.

The modeling of the software and the calculations made in this scenario in hot and cold seasons showed that the heat radiation zone in the fire scenario as jet fire in the cold season is associated with more consequences. The red zone in this diagram with radiation of 37.5 kW per square meter affects an area with a radius of 14 (m). The orange area in the diagram with radiation above 12.5 kW per square affect an area with a radius of 26 (m), which causes the minimum energy required for creating spark in wooden pilots and melting plastic materials. The last affected area with radiation above 4.5 kW per square meter causes damage and pain to those who are exposed to it for at least 20 s and affect an area with radius of 42 (m). In Figure 6, the results of fire scenario in the cold season are shown.

In Figure 7, the red zone with radiation above 37.5 kW per square meter affect an area with a radius of 13 (m) to the north, which leads to consequences for damage to process units and equipment and instant death for those exposed to it. The orange area in the diagram with radiation above 12.5 kW per square meter causes damage such as the minimum energy required for creating a spark in wooden pilots and melting plastic materials up to an area with radius of 25 (m). The last region with radiation above 4.5 kW per square affect a region with radius of 42 (m) to the north and is associated with pain in people who are exposed to it for at least 20 s. The overall results of the fire scenario in hot and cold seasons indicate that the flame length is the same in both seasons. Another difference in both hot and cold seasons of the fire scenario relates to the burn rate, which is 130 pounds per minute higher in the cold season. The difference in total burn rate was 2.575 pounds, which is higher in the cold season than in the hot season. The latest difference in the fire scenario in hot and cold seasons is the area affected by the fire;

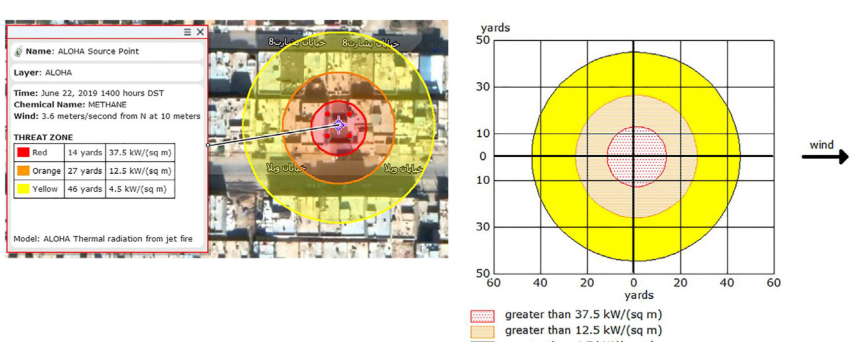


**Figure 7.** Results of fire scenario in warm seasons.

the difference in the cold season at two radiation levels of 37.5 and 12.5 kW per square meter is one meter higher than the hot season and is equal to 4.5 kW per square meter. The results of the fire scenario in the hot season are shown in Figure 7.

## 5. Discussion

The first scenario is gas leak in cold season. This scenario affects a smaller area at north of the station compared to the gas leak scenario in the hot season. At the ERPG-3 level, the gas leak of the cold season affects up to 66 (m) at the north of the station to the Besharat 8 Street. At the ERPG-2 level, the gas leak in the cold season involves 86 (m) from the orange range until Besharat 6 Street. At the ERPG-1 level, the gas leak affects 164 (m) toward the north of the station. This yellow range that involves the barren lands at the north of the station poses the lowest risk to residents. The gas leak in the hot season affects a larger area than in the cold season. At the ERPG-3 level, the gas leak affects 71 (m) to the south of the station. This level affects up to two rows of houses toward the south of the station. At the ERPG-2 level, the gas leak affects 92 (m) of the orange range, which affects up to three rows of houses to the south of the station. At the ERPG-1 level, at the length of 177 (m), the maximum range to the south of the station is affected. The highest risks in the gas leak scenario, due to the leakage of toxic substances, are related to the ERPG-3 level in the hot and cold seasons that affects all areas, residential houses and streets. At the ERPG-2 level, the highest risk is the gas leak scenario in the hot season to the south of the station, because the whole affected region is located in the residential area. At the same level, in the cold season, the final part of the orange area affects the Bayer land. The highest risk at the ERPG-1 level is related to the hot season scenario toward the south of the station, because all affected regions are residential areas. In the gas leak scenario, most of the affected regions in the cold season are the Bayer lands at the north of the station.

The fire scenario in the cold season with thermal radiation of 37.5 kW per square meter affects 14 (m) of the areas around the gas pressure reduction station. The highest risk in the red range involves houses located at the east, west, and north of the station. The thermal radiation intensity of 12.5 kW per square meter marked by the orange color affects 26 (m) around the station. In addition to the residential areas, the thermal radiation intensity affects the Villa Street adjacent to the gas pressure reduction station. The latest heat radiation intensity is 4.5 kW per square meter that affects a larger area with length of 42 (m). The yellow radiation also affects the houses in front of the station. In the hot season, a fire scenario with radiation intensity of 37.5 kW per square meter affects 13 (m) from the area around the gas pressure reduction station. This red range has the most hazardous outcomes for homes adjacent to the station. The thermal radiation intensity of 12.5 kW per square meter marked by orange affects 25 (m) around the station. This level of thermal radiation affects more areas up to Besharat 8 Street. The latest thermal radiation of 4.5 kW per square meter affects a larger region up to Besharat 8 Street and residential houses in front of the station. The highest risks of the fire scenario, given the consequences of thermal radiation intensity, are related to the thermal radiation intensity of 37.5 kW per square meter. The affected area at this level of thermal radiation intensity in the cold season is one meter higher than in the hot season. The thermal radiation intensity of 12.5 kWh per square meter in the cold and hot seasons is associated with highest risks of fire scenario, respectively. The risks and areas affected by the thermal radiation intensity of 4.5 kW per square meter are the same in both cold and hot seasons.

## 6. Conclusion

The main objective of this research was to determine the areas affected by gas leak and fire in both hot and cold seasons. The methane gas emission is associated with many consequences in environment and safety. Among the advantages of reducing methane gas emissions, as the main component of NG gas, the economic and environmental benefits can be pointed out (Farzaneh-Gord et al., 2018). The gas leak scenario in the hot season affects more areas than the cold season. On the other hand, in the hot season, all affected regions are residential areas and there is a need for more attention and safety measures compared to the gas leak in the cold season. In the fire scenario, there is no considerable difference between the affected areas in the hot and cold seasons. In the fire scenario in both seasons, the residential areas and the Villas Street adjacent to the gas pressure reduction station are affected. It can be concluded that the gas leak scenario, due to the affected outcomes and regions, is more hazardous than the fire scenario. In the gas leak scenario, the hot seasons are associated with more outcomes than the cold seasons due to the affected residential areas. The most important safety measures to prevent damage to the area are as follows:

- Necessary training for workers at the gas pressure reduction station and a codified program for periodic inspection of the gas pressure reduction station components
- Establishing fast communication equipment with the nearest fire station and other relief centers to have the fastest response in case of an accident.
- Determining safe shelters for the barren lands at the north of the station and creating special conditions for construction at the north of the station.
- Inserting warning signs in the Villa Street, Besharat Street, railway station, and railways at the north and east of the station to take the necessary safety measures in case of an accident.

For future research, given that one of the effective measures to reduce human casualties during the emission of toxic and hazardous gases is the timely notification at the time of leakage and effective measures in the evacuation and relocation of manpower. Therefore, preparing an emergency response plan in this research will play an effective role in limiting the adverse effects of the release of toxic and hazardous substances. Adding an explosion scenario and modeling scenarios at the same time is one of the things that can be done for further research.

## Declarations

### *Author contribution statement*

Peiman Dadkani: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Esmatullah Noorzai: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

AmirHossein Ghanbari & Ali Gharib: Performed the experiments.

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The authors declare no conflict of interest.

### Additional information

No additional information is available for this paper.

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