Research Paper

Evaluation and Management of Health and Safety Risks of Chlorine Gas in Transportation Routes

Iraj Mohammadfam[1], Saeed Ghahremani Namain[2], Kamran Gholamizadeh[3], Hasti Borgheipour[2*]

1. Department of Ergonomics, Health Research Center in Accidents and Disasters, University of Rehabilitation Sciences and Social Health, Tehran, Iran.
2. Department of Environmental Engineering, Faculty of Civil& Earth Resources Engineering, Central Tehran Branch, Islamic Azad University, Tehran, Iran.
3. Department of Occupational Health Engineering, School of Health, Hamadan University of Medical Sciences, Hamadan, Iran.

Use your device to scan

Citation Mohammadfam I, Ghahremani Namain S, Gholamizadeh K, Borgheipour H. Evaluation and Management of Health and Safety Risks of Chlorine Gas in Transportation Routes. Health in Emergencies and Disasters Quarterly. 2023; 8(3):175-184. http://dx.doi.org/10.32598/hdq.8.3.466.1

doi: http://dx.doi.org/10.32598/hdq.8.3.466.1

Article info:
Received: 17 May 2022
Accepted: 22 Oct 2022
Available Online: 01 Apr 2023

ABSTRACT

Background: More than 90% of goods movement in Iran is done by road transport. A significant part of these materials is dangerous goods. Considering that chlorine gas is considered a toxic and oxidizing substance, predicting the way of release and mortality due to accidental leakage of chlorine gas can be a crucial tool in adopting preventive strategies. This study aims to evaluate the safety of chlorine gas transportation and analyze the consequences of its release.

Materials and Methods: This cross-sectional-analytical study was conducted in 2020 in Tehran. The transportation risk rating index was used to measure and evaluate the quantitative risk of transportation of hazardous materials. PHAST software was used to determine the consequence of possible accident scenarios on the transportation route. In the final stage, according to the amount of traffic, the time and manner of response to emergencies by the fire and emergency organization were simulated using Pathfinder software.

Results: In this evaluation, the chlorine risk rating was calculated as 192. The worst possible scenario was a catastrophic rupture of chlorine in the second half of 2021. As a result of the accident, up to a radius of 1800 m from the center of the leak, the dangerous concentration is equal to 20 ppm, that is, equal to the ERPG3 limit. The simulation results showed that the release of poisonous chlorine gas leads to the death of 10% of people up to a radius of 192 m around the scenario.

Conclusion: In the scenario of the sudden release of chlorine, in which people need to escape and move away from the accident site, it was found that it takes more than 24 minutes to leave the ERPG-3 area. Considering that the assumed average speed of 1.15 m/s is the average speed of people and naturally the speed of sensitive people is much lower in the conditions of an accident, it can be concluded that in the scenario of a sudden leak, a significant part of the people involved in the accident may suffer severe and irreparable damage.

Keywords:
Risk assessment, Accident, Chlorine

*** Corresponding Author:**
Hasti Borgheipour, PhD.
Address: *Department of Environmental Engineering, Faculty of civil& Earth Resources Engineering, Central Tehran Branch, Islamic Azad University, Tehran, Iran.*
E-mail: *hasti_bo@yahoo.com*

1. Introduction

Surveys show that more than 90% of goods movement in Iran is done by road transportation [1]. A significant part of these materials are considered to be dangerous goods, and due to their nature, their movement requires the adoption of special safety measures. Any negligence in applying the mentioned measures can have irreparable consequences for humans, the environment, and other assets [2]. Hazardous substances are substances that are harmful to the elements of the environment, including humans, animals, plants, water, air, etc. In most of the presented classifications, such goods are classified into nine groups, such as gases, toxic substances, oxidizing substances, etc. The statistics published by the United Nations (UN) show that about half of the loads that are transported belong to the group of dangerous substances because in most cases, the place of production and consumption of dangerous substances are not the same [3]. On the other hand, nowadays road accidents are one of the critical challenges of most developing countries, including Iran [4].

In total, 2.5% of the world's traffic accidents occur in Iran, which shows that the rate of this type of accident in Iran is 20 times higher than in other places [5]. In the same way, a significant part of the mentioned accidents is related to the accidents of the means of transportation of dangerous substances. Accidents that occur during the transportation of dangerous materials always have a high potential to become a disaster. The consequences of this type of accident can include the death and injury of people, severe damage to environmental elements, such as water, soil, air, etc. the evacuation of residents of an area, financial damages to government and private property and assets, traffic disorders, waste of time, etc. [6]. The cost of road accidents in the world has been estimated up to 3% of the gross national product of the countries that further emphasizes the importance of this issue [7].

Chlorine gas is one of the most widely used dangerous substances, a significant part of which is transported by road in the country. Chlorinated compounds are used to prepare bleaching materials and synthetic fibers, as well as disinfectants for drinking water, swimming pools, sewage, textile industries, paper industries, and aluminum extraction. During the release of chlorine gas or increase in concentration, poisoned people may become worried and restless with coughing accompanied by throat irritation, sneezing, and increased secretion of saliva. In larger amounts of chlorine, it is accompanied by vomiting, which depends on the duration of chlorine inhalation. In cases of heavy inhalation, difficulty in breathing can progress to the point of death. This substance is harmful and very toxic to aquatic life. Also, this substance is dangerous and harmful to the environment. Because chlorine is heavier than air, it collects in low and deep places [8].

In classifications of chemical substances, chlorine gas is included in the group of toxic gases. In Iran, thousands of people are at risk of exposure to chlorine in chlorine production factories, transportation, and industries that use it in some way, including water treatment plants. This substance is known as dangerous based on (OSHA Standard Communication Hazard 1200) CFR1910 29. Iran's occupational exposure limit standard has determined the ceiling value of this substance as ppm 0.4. This limit is a concentration of a chemical substance that more occupational exposure, even for a moment, is not allowed [9].

Occupational exposure limits, authors' group, fifth edition, Ministry of Health, Treatment and Medical Education, 2021.

In normal conditions, if 10 tons of chlorine is released into the air, it will create a concentration of 140 ppm in 2 km from the source and 15 ppm in 5 km, which is due to the use of chlorine in urban areas and population density in large cities, the depth of the disaster is clear [10]. The incident of chlorine gas leakage from a 50-ton cylinder in Astara City, Iran, during the transportation of the cylinder, which caused the death of several people and injured hundreds of people, is one of the incidents related to this dangerous substance [10].

As mentioned, one of the main centers of chlorine consumption is water treatment plants. Water treatment plants are located in dense urban centers and due to their proximity to important institutional, academic, administrative, and residential commercial centers, they have a high potential for harm. Chlorine gas leakage can seriously threaten the health of the employees of the treatment plants and the residents around them. Since in the matter of crisis management, the first and critical priority is to save lives and preserve human health, therefore, predicting the manner of release and mortality due to chlorine gas leakage can be one of the crucial tools in management decisions and adopting preventive strategies in reducing the harmful consequences of accidental leakage [11].

The main background for conducting the present study can be attributed to the high probability of chlorine leakage in Tehran. In Iran, the hazardous material transport fleet is worn out [12]. In addition, the intra-urban transfer of chlorine in sensitive and vital areas of Tehran, the capital of Iran, was one of the other reasons for the importance of this research. Therefore, the present study aimed to evaluate and manage truck chlorine leakage's health and safety consequences.

2. Materials and Methods

This cross-sectional study was conducted in 2020 in Tehran. To carry out the work, first through field studies, reviewing documents, and unstructured interviews, necessary data, such as chlorine gas transportation routes from the origin (chlorine production plant in Semnan industrial town) to the destination (Shahid Fatemi water treatment plant), the capacity of vehicles carrying chlorine gas, weather conditions of the region, traffic safety guidelines, distance and proximity to residential and critical areas on the transportation route, the number of accidents, safety guidelines, and standards were collected.

In this study, to evaluate the safety of transportation route variables, surrounding residential areas, proximity to urban infrastructures, public places, and strategic buildings are considered. In the next step, according to the available information, the transportation risk rating index was used to measure and evaluate the quantitative risk of transporting dangerous substances [13].

Then, by determining the weighted average risk rating index using the NFPA704 code, the distance factor from the residential place (D), the molecular weight or the distribution factor (MW/DF), and the quantity factor of the transported chemical substance and using the evaluation method of transportation risk rating index (TRRI), the risk of chemical transport was determined from the product of four criteria as follows [14].

Calculation of the weighted average risk rating index of chemical substances: To estimate this factor, the weighted average of each of the ratings presented in the risk rhombus of the National Fire Protection Association of America (NFPA) as follows:

$$Wi = \frac{\text{value of rhombus specialization rating of risk}}{\text{Total degrees of all risks}}$$

WARRI=Σ (rhombus specialization rating of risk)×Wi

1. The amount of cargo carried by the tanker: This factor is subject to variables, such as temperature and pressure, and is classified from 0 to 4 in the form of less than 10 kg (grade zero), 10 to 99 kg (grade 1), 100 to 999 kg (grade 2), 1000 to 5000 kg (grade 3), and more than 5000 kg (grade 4).

2. The distance of residential areas: The shorter the distance of the chemical tankers from the first residential area, the greater the risk to the people living in that area. This factor is divided from 0 to 4 as more than 10000 m (grade zero), 5001 to 10000 (grade 1), 1 501 to 5000 m (grade 2), 500 to 1500 (grade 3), and less than 500 m (grade 4).

3. Molecular weight or distribution factor: The amount of vapor emission is indirectly a function of density, which is also a function of the molecular weight of the substance; therefore, the higher the molecular weight of the material, the higher the risk level of transporting the material. This factor is classified from 0 to 4 in the form of less than 15 g/mol (grade zero), 15 to 22 g/mol (grade 1), 23 to 33 g/mol (grade 2), 34 to 45 (grade 3), and more than 45 g/mol (grade 4). Finally, the dangerous transport risk index was classified into four levels, low (0 to 64), medium (65 to 128), dangerous (129 to 192), and very dangerous (193 to 256).

In the next step, PHAST software was used for modeling to determine the outcome of possible accident scenarios in the transportation route [15, 16]. In this regard, the possible scenarios (road accidents) of each of the routes were specified by determining different information to the simulator software, such as different weather conditions, whether it is night or day when the accident occurs, determining leakage, explosion, or fire, different outcomes of possible accidents of chlorine gas transportation were determined. The result of simulating the outcome using PHAST software determined the outcome of human injuries due to chlorine gas emission in different radii based on threshold limit value (TLV), emergency response planning guidelines (ERPG), and resulting human injuries. In the final stage, according to the amount of traffic, the time and manner of response to emergencies by the fire and emergency organization were simulated using Pathfinder software [17, 18].

3. Results

In this section, firstly, the results of the risk assessment related to the transportation of chemicals using the transportation risk index (TRI) method are described, and in the next step, the analysis of possible scenarios with high risks for the chemical chlorine is described, and finally, the time of action by the relief and rescue groups by software Pathfinder simulation software is determined.

Table 1. Determining chlorine gas transportation risk

Risk Factor	Chlorine
Weighted average risk rating index (WARRI)	4
Distance factor from a residential place (D)	4
Molecular weight or distribution factor (MW/DF)	4
The quantity factor of transported material (Q)	3
Chemical transportation risk index (TRI)	192

Health in Emergencies and Disasters Quarterly

Transportation risk index (TRI)

As stated, the information in Table 1 is needed to determine the risk rating of carriers of dangerous chemicals.

In Table 1, in determining the factor of the amount of transported material, in addition to the weight of the material, the pressure and temperature of its storage are also crucial. Regarding chlorine gas, due to preserving at a pressure of 8.654 bar, despite transporting chlorine gas with tanks of one cubic meter and filling 80% of the capacity, the quantity factor of the transported material was determined as 3. As can be seen in Table 1, the risk rating of chlorine is equal to 192, which is placed in the dangerous category. Therefore, according to the traffic of trucks carrying chlorine gas tanks in Tehran City, to provide water purification services as well as urban services (car fuel supply), it is necessary to determine the possible outcomes in case of accidents for the carriers of dangerous chemicals.

Outcome assessment

The simulation method with PHAST software was used to evaluate the risk outcome. In this method, firstly, the weather parameters related to the year 2018 in Tehran City were investigated, and in the next part, for 4 points in Tehran City in the second half of 2018, the possible scenarios of the tankers carrying chlorine gas were investigated, and the total of the investigated scenarios was 4.

To simulate scenarios in PHAST software, it is necessary to determine some data. These data are effective parameters on how to discharge and distribute materials. These cases include the conditions of the tankers carrying toxic substances (volume of the stored substance, pressure, temperature, and dimensions of the tanker), the geographical conditions of the place where the scenarios took place, and the weather conditions of the place of the accident or the desired scenario (temperature, atmospheric pressure, wind speed and direction, humidity, and atmosphere stability) (Table 2).

The information in Table 2 was collected through field surveys of contractors and also the standard of construction of storage tanks.

In this study, the two main scenarios investigated were:

Destruction and catastrophic rupture of the tank due to accident and overturning

Chlorine leakage from line rapture due to accident

The locations of the scenarios were chosen on the path of transferring gas cylinders to the refinery and based on criteria, such as proximity to densely populated cen-

Table 2. Specifications of tankers carrying dangerous chemicals (chlorine)

Chemicals	Scenario	Amount of Chemical Substance (m^3)	Tanker Capacity (m^3)	Leak Height (m)	Tanker Pressure (Barge)	Storage Temperature (°C)	Amount of Leakage (Inches)
Chlorine gas	Catastrophic rupture	1	1.5	1.5	8.654	Ambient temperature	-------
	Leak	1	4	1.5	8.654	Ambient temperature	2

Health in Emergencies and Disasters Quarterly

Table 3. Summary of selected Scenario analysis results

Catastrophic Rupture						
	The Weather of the 1st Half of the Year			The Weather of the 2nd Half of the Year		
Outcome	1st level (1 ppm)	2nd sevel (3 ppm)	3rd level (20 ppm)	1st level (1 ppm)	2nd level (3 ppm)	3rd level (20 ppm)
Toxic gas release	2425 m	1575 m	755 m	10290 m	5690 m	1800 m
Possible loss percentage	0.1% 340 m	1% 264 m	10% 185 m	0.1% 517 m	1% 327 m	10% 192 m
Outcome	1st level (1 ppm)	2nd level (3 ppm)	3rd level (20 ppm)	1st level (1 ppm)	2nd level (3 ppm)	3rd level (20 ppm)
Toxic gas release	1050 m	592 m	221 m	5799 m	2927 m	896 m
Possible loss percentage	0.1% 154 m	1% 113 m	10% 75 m	0.1% 584 m	1% 389 m	10% 217 m

ters, such as schools, universities, special centers, such as hospitals, kindergartens, hotels, sensitive government centers, such as ministries, etc. The initial probable scenarios following the accidents in the tankers carrying chlorine chemicals included catastrophic rupture and leakage from the pipes leading to gas release, which were modeled with the help of PHAST software. It should be noted that all the leakage sizes are determined according to the existing standards appropriate to the conditions of the scenarios.

Also, all the transportation routes of dangerous chemicals in the studied city from loading to unloading were investigated and based on the parameters of urban service centers (hospitals, hotels, schools, government offices, military organizations, etc.), buildings, population concentration, and the response time of the firefighting centers to the incidents, the locations of the investigated scenarios were determined. The place of loading and unloading of chlorine gas was respectively Semnan industrial town and Water and Sewerage Company located on Dr. Fatemi Street and the important places identified on the route, including the Ministry of Interior building, the Ministry of Interior Pension Fund building, the Jihad Agriculture building, the Central Water and Sewerage Department, the parking lot, Jihad Metro, Laleh Hotel, banks, private companies, and residential buildings. The distance from the scenario location to the fire station was determined to be 2 100 m.

Figure 1 shows the critical places and buildings in the vicinity of the scenario:

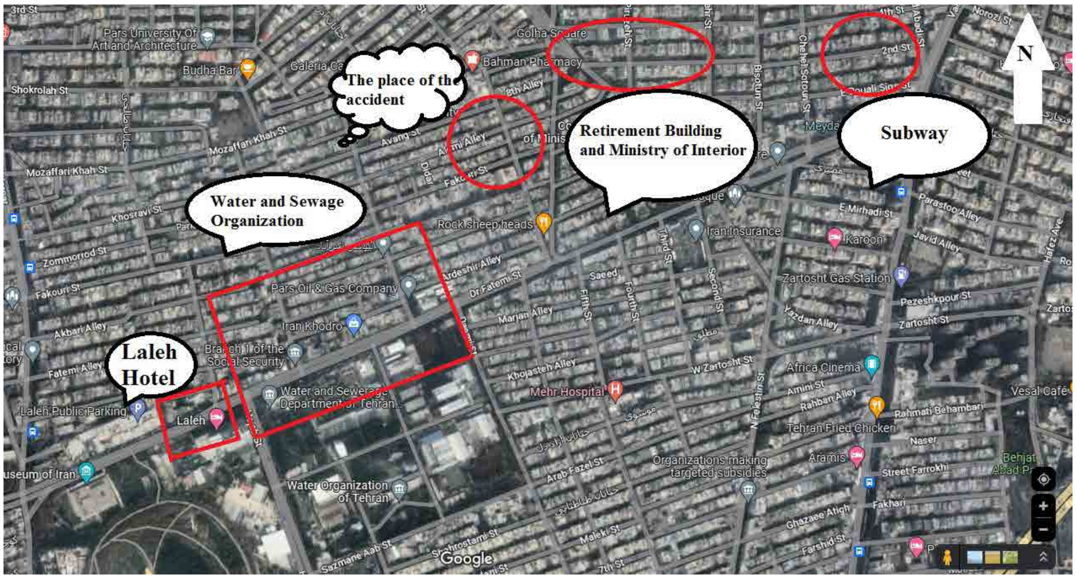

Figure 1. Critical places and buildings in the vicinity of the scenario

Table 4. Escape simulation results of the selected Scenario with Pathfinder Software

Toxic Release						
Outcome	Occurrence Time	Intervals and Time	Mean of Scape Speed (m/s)	Chlorine Gas Concentration		
				1	2	3
Catastrophic rupture	The 1st half of the year	Emission radius (m)	1.15	2425	1575	755
		Calculated mean escape time (s)		200	1300	640
	The 2nd half of the year	Emission radius (m)		10290	5690	1800
		Calculated mean escape time (s)		8498	4699	1487
Leak	The 1st half of the year	Emission radius (m)		1050	592	221
		Calculated mean escape time (s)		794	390	167
	The 2nd half of the year	Emission radius (m)		5799	2927	896
		Calculated mean escape time (s)		4382	2212	677

Health in Emergencies and Disasters Quarterly

Table 3 presents the results of the analysis of the scenario of catastrophic rupture and leakage of chlorine gas in two halves of the year.

The results of Table 3 show that the worst possible scenario is a catastrophic rupture in the second half of the year. Due to the occurrence of such an incident, the dangerous concentration of 20 ppm, i.e. ERPG3 limit, has spread up to a radius of 1800 m, which can expose the building of the entire country's pension, the building of the Agricultural Jihad, banks and private companies around Jihad Square and residential buildings in addition to central buildings of the Ministry of Interior according to the wind direction changes. According to the definition of ERPG3, to prevent the effects of chlorine toxicity, the rescue teams should evacuate the people from the buildings within one hour and safety measures should be considered for these parts.

The simulation results showed that the release of poisonous chlorine gas leads to the death of 10% of people up to a radius of 192 m around the scenario. Figure 2 shows the distribution of chlorine gas emission levels and the percentage of human casualties in the emission areas after the mentioned scenario:

Tehran fire organization has determined the operational areas of each of its stations, according to the information on the site of the fire department and safety services of Tehran municipality, providing emergency services on Dr. Fatemi Street, Jihad Square, as well as the administrative and government building located there is the responsibility of fire station No. 40 (Laleh Park), therefore, the approximate distance estimated from fire station No. 40 to the selected scenario is about 1.2 to 2.3 km, which during the investigations carried out during the week and the day, the average speed of rescue vehicles from fire station No. 40 was estimated to be around 20-25 km/h, and at this speed, it takes about 5 to 7 minutes to reach the scene, hence, all measures required starts at the place where the scenario occurs after the mentioned time has passed.

The estimated time is effective in the amount of damage to the buildings and people around the place of the scenario. In this regard, the time to calculate the escape of the people around the place of the accident was simulated by the Phatfinder software according to the effects of the outcome of the scenario. The software considers the average speed of each adult as 1.19 m per s, but the actual speed of people is a function of gender, the interference of fleeing people, and the obstacles ahead, such as cars and traffic obstacles. In this regard, 3 people with the characteristics of a young person with a running speed of 3 m/s, an old man with a running speed of 1 m/s, and a middle-aged woman with a running speed of 1.5 m/s were considered. In the emergency escape simulator environment, the approximate time of these people moving away from the location of the accident was estimated at 1.15 m/s. In the situation of sudden destruction and leakage of the chlorine gas tanker in the chlorine gas re-

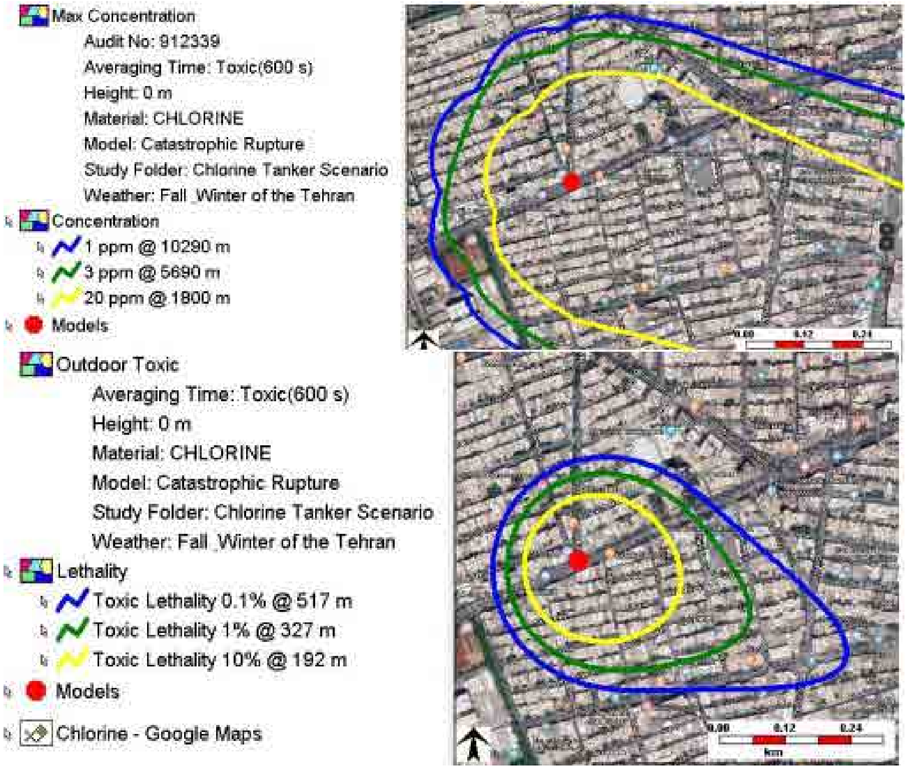

Figure 2. Distribution of emission levels and percentage of human casualties in chlorine gas emission areas after a catastrophic rupture in the second half of the year

lease scenario in the first and second half of the year, the results of Table 4 were estimated.

According to the field investigations, the minimum time for the rescue team to reach the accident site is about 6 minutes, and according to Table 4, in the studied scenario, in the sudden destruction of the second half, the chlorine gas emission radius is at its maximum (about 1800 m) that the time of moving people away in case of response as soon as possible is about 25 minutes, and in case of contact for more than an hour, this gas will have irreversible effects for people in this area.

4. Discussion

In this study, chlorine was investigated as a dangerous substance. Examining the published data shows that the road transportation of hazardous materials in the world has an increasing trend [19]. According to the data published in America in 2007, the transportation of hazardous materials in 2002 reached 18.7 billion tons to 111 billion tons in 2007, which shows an increase of 92.7 billion tons in 5 years. In addition, the average transportation distance of hazardous materials for each shipment was 1366 km this year [20]. Along with the increase in the volume of transportation of hazardous materials, public concern has increased, especially with road transportation due to passing through densely populated and enclosed places. When an accident related to the transportation of hazardous materials occurs, many passengers and vehicles may be trapped in the traffic resulting from this accident and spread the outcome of the accident. Also, traffic congestion may delay the arrival of emergency service teams at the scene of the accident and prevent the timely evacuation of curious passers-by from around the place [21]. Although the probability of accidents caused by the transportation of hazardous materials is considered as a low probability event, these types of events are classified as low probability high consequence (LPHC), which practically increases the risk of recent accidents to an unacceptable level. What makes the management of these types of events more complicated is the general public's understanding of the low risk of accidents. Field observations of incidents in recent years in the country, such as the Neishabor train accident, show that people's understanding of low risk prevents the implementation of the vital step of incident management, i.e. securing the scene.

In a study conducted by Oggero et al. in 2006, 1932 accidents that occurred during road and rail transportation of hazardous materials from the beginning of the 20th century to July 2004 were examined. The obtained results showed an increase in the frequency of accidents during this period. More than half of the accidents (63%) were related to road transport. The highest frequency of accidents was related to the release of chemicals into the environment with a frequency of 78% [22]. In the study conducted by Mohammad Fam et al. [23-25] titled "assessment of health outcome caused by chemical accidents in road transport using a fuzzy approach", it was determined that the most severe exposures were in the sensitive group of society (children, the elderly, and people with underlying problems) with an intensity factor of 0.92 and adolescents and middle-aged people with an intensity factor of 0.767.

In the present study, the transportation risk rating index (TRRI) was used to measure and evaluate the quantitative risk of transporting hazardous materials. Based on the results, the risk of chlorine was determined 192 and equivalent to dangerous. Jahangiri et al. have used this approach to assess the risk of transporting chemicals on the routes leading to the cargo terminal in Shiraz [13]. The results of this study showed that the risk of transporting some dangerous chemicals in routes less than 500 m leading to the terminal is at a dangerous level. According to the index capabilities, researchers have recommended that this method can be used to assess the risk of transporting dangerous chemicals and determine control priorities in this field.

In this study, PHAST software was used to model the outcomes of chlorine release, during which two possible scenarios of catastrophic rupture and leakage from the tank and each in two halves of the year were investigated. Based on the comparison of the findings, the worst scenario is the catastrophic rupture of chlorine gas due to an accident leading to the rupture of the tanker or its overturning in the fall and winter seasons, which leads to a complete rapture. In this research, the worst possible scenario was a catastrophic rupture of chlorine in the second half of the year, as a result of which chlorine gas spreads to a radius of 1800 m with a dangerous concentration of 20 ppm, i.e. ERPG3 limit. According to the results, in this case, the gas release leads to 10% of deaths of people up to a radius of 192 m around the scenario. This finding is similar to the study conducted by Bagheri et al. In the mentioned study, the scenarios of the sudden release of chlorine gas in the Jalalieh water treatment plant of Tehran were modeled with software. The results of the study showed that the gas release in case of damage to the one-inch outlet valve of the tank may be fatal up to a radius of 2.4 km and effective up to a radius of 8.3 km and can be felt up to a radius of more than ten km. It was also found that in the first minute, the gas emission in the winter season is around 1080 ppm and in the summer season, it is around 339 ppm. The release of chlorine gas in the winter season is more than in the summer season due to the stability of the air caused by the inversion phenomenon, especially in recent years [26].

The high damage outcomes in the cold seasons of the year are similar to the findings of Bouafia et al. [27], Barjoee et al. [28], Yoon et al. [29], and Yarandi et al. [30]. The reason for this is the environmental changes, such as the temperature of the environment, which was one of the effective parameters in aggravating the outcomes of the accident.

Khorram in his study on modeling the outcome of chlorine gas emissions concluded that based on ERPG concentrations, chlorine gas has traveled a shorter distance between 6 and 10 AM to reach 2-3 ERPG values, in distances of 2811 and 1040 m, respectively, compared to other investigated periods. On the contrary, at night, these distances have the most risk privacy based on the values of the mentioned concentrations in the distances of 5212 and 1459 m, respectively [31].

Mortazavi et al. investigated the release of chlorine gas from storage tanks for the development of a response plan in emergencies in the petrochemical industry and concluded that the release of chlorine gas due to the catastrophic explosion of the tank and scrubber failure in the summer season is at emergency level 4 and in the winter season, it is at emergency level 3 [32].

In the scenario of the sudden release of chlorine, where the escape and moving away of people from the accident site is crucial, the simulation results with the Pathfinder software showed that leaving the ERPG-3 area in the first and second half of the year, respectively, 640 and 1487 s (more than 24 minutes) are required. The mentioned times for ERPG-2 are 1300 and 4699 s, respectively (more than 78 minutes). Considering the concept of ERPG-2, which is the maximum concentration of a chemical substance in the air that all people can be exposed to for one hour without suffering serious or irreparable harm or being unable to take safety measures, and also considering that the assumed average speed of 1.15 m/s is the average speed of people, and naturally, the speed of elderly people, pregnant women, children, people with underlying diseases, and similar people have a lower speed in the accident. It can be concluded that in the scenario of a sudden chlorine leak, severe and irreparable injury to a significant part of the people involved in the accident is possible.

It is worth mentioning that the use of Pathfinder software in simulating the escape of people in emergencies has been used in numerous studies and its usefulness has been emphasized [33-35].

The main strength of the current study was the use of three complementary methods to determine transportation risk, modeling results, and escape routes. The critical existing limitation was the weak cooperation of organizations related to the required data. To solve this limitation, a practical proposal is to approve the plan for the integrated management of national data and information in the Islamic Council and monitor its accurate and correct implementation [36].

5. Conclusion

According to the strong black theory in which the possibility of any credible incident is not zero, the transportation of chlorine tanks with a large volume inside Tehran City regardless of the travel time and the pre-designed route, the location of water treatment stations in densely populated residential areas and inevitably, in the vicinity of vulnerable centers, such as schools, hospitals, hotels, etc. can have disastrous outcomes. The findings of this study emphasize the accurate timing of transporting chlorine tanks from the procurement centers to the treatment plants, the precise determination of safe routes, the complete training of drivers in the field of managing emergencies in the accidents and accidental leaks of tanks, periodic testing of tanks, and full supervision for its implementation.

Ethical Considerations

Compliance with ethical guidelines

The participants were informed about the purpose of the research and its procedure. They also made sure that their information was kept confidential.

Funding

This research did not receive any grant from funding agencies in the public, commercial, or non-profit sectors.

Authors' contributions

All authors equally contributed to preparing this article.

Conflict of interest

The authors declared no conflict of interests.

Acknowledgments

The authors appreciate and thank all the drivers who helped the researchers by spending time.

References

[1] Khodadad Kashi F, Nourani Azad S, Ghanbari B. [Impact of fleet renovation on the productivity of Iran's road transportation industry (Persian)]. Economic Modelling. 2018; 12(42):137-60. [Link]

[2] Mohammad Fam I, Azadeh A, Faridan M, Mahjub H. Safety behaviors assessment in the process industry: A case study in gas refinery. Journal of the Chinese Institute of Industrial Engineers. 2008; 25(4):298-305. [DOI:10.1080/10170660809509093]

[3] Rezazadeh MH, Aghaei AA. Risk factors in transportation of hazardous materials in Iran. Dilemas Contemporáneos: Educación, Política y Valore. 2018; 6(1). [Link]

[4] Ebrahimi H, Tadic M. Optimization of dangerous goods transport in urban zone. Decision Making: Applications in Management and Engineering. 2018; 1(2):131-52. [DOI:10.31181/dmame1802138e]

[5] Yadollahi M, Gholamzadeh S. Five-year forecasting deaths caused by traffic accidents in Fars Province of Iran. Bulletin of Emergency And Trauma. 2019; 7(4):373-80. [DOI:10.29252/beat-070406] [PMID] [PMCID]

[6] Mohammadfam I, Bastani S, Esaghi M, Golmohamadi R, Saee A. Evaluation of coordination of emergency response team through the social network analysis. Case study: Oil and gas refinery. Safety and Health at Work. 2015; 6(1):30-4. [DOI:10.1016/j.shaw.2014.09.004] [PMID] [PMCID]

[7] Khasawneh M, Al-Omari A, Ganam B. Forecasting traffic accidents in developing countries using time series analysis. Jordan Journal of Civil Engineering. 2022; 16(1):54-70. [Link]

[8] Hemati Alam N, Kashi E, Habibpour R. [Investigation of field experiments and mathematical models for heavy gas dispersion (Persian)]. Journal of Environmental Science and Technology. 2021; 23(8):169-84. [doi:10.30495/jest.2019.21912.3126]

[9] Tupper C, Swift CJ. OSHA chemical hazards and communication. Island: StatPearls Publishing; 2022. [PMID]

[10] Adl J, Mohammadfam I, Nezam Aldini ZAS. [Evaluation of chorine leakage hazards in chlorination stations of Tehran water purification system by FTA technique (Persian)]. Jundishapur Scientific Medical Journal. 2008; 6(4):461-8. [Link]

[11] Jayakumar C, Isac S, Prasad DMR. Emergency response plan for methane and chlorine with dispersion modelling using CAMEO. International Journal of Occupational Safety

and Ergonomics. 2022; 28(3):1802-10. [DOI:10.1080/10803548.2021.1942658] [PMID]

[12] Mohammadfam I, Abdullah MN, Gholamizadeh K. Developing a comprehensive technique for investigating hazmat transport accidents. Journal of Failure Analysis and Prevention. 2021; 21(4):1362-73. [Link]

[13] Jahangiri M, Jamshidi HR. [Chemical transportation risk assessment in the pass leading to Amirkabir Terminal at Shiraz city (Persian)]. Iran Occupational Health. 2016; 13(4):23-30. [Link]

[14] Rao KR, Rao SV, Chary V. Estimation of risk indices of chemicals during transportation. Process Safety Progress. 2004; 23(2):149-54.[DOI:10.1002/prs.10012]

[15] Baser B, Behnam B. An emergency response plan for cascading post-earthquake fires in fuel storage facilities. Journal of Loss Prevention in the Process Industries. 2020; 65:104155. [DOI:10.1016/j.jlp.2020.104155]

[16] Zarei E, Mohammadfam I, Azadeh A, Khakzad N, Mirzai M. [Dynamic risk assessment of chemical process systems using Bayesian Network (Persian)]. Iran Occupational Health. 2018; 15(3):103-17. [Link]

[17] Pan H, Zhang J, Ma W. Simulation of pedestrian flow mixed with wheelchair users in funnel-shaped bottlenecks based on Pathfinder. RSVT '20: Proceedings of the 2020 2nd International Conference on Robotics Systems and Vehicle Technology. 2020; 83-8. [DOI:10.1145/3450292.3450306]

[18] Lee HS, Mun HL, Lee SK. Evacuation time at Jong-no 3ga subway station considering electric train delays and congestion. Journal of Transportation Security. 2018; 11(3):137-50. [DOI:10.1007/s12198-018-0198-9]

[19] Paltrinieri N, Landucci G, Molag M, Bonvicini S, Spadoni G, Cozzani V. Risk reduction in road and rail LPG transportation by passive fire protection. Journal of Hazardous Materials. 2009; 167(1-3):332-44. [DOI:10.1016/j.jhazmat.2008.12.122] [PMID]

[20] Xie Y, Lu W, Wang W, Quadrifoglio L. A multimodal location and routing model for hazardous materials transportation. Journal of Hazardous Materials. 2012; 227-228:135-41. [DOI:10.1016/j.jhazmat.2012.05.028] [PMID]

[21] Lozano A, Muñoz Á, Macías L, Antún JP. Hazardous materials transportation in Mexico City: Chlorine and gasoline cases. Transportation Research Part C: Emerging Technologies. 2011; 19(5):779-89. [DOI:10.1016/j.trc.2010.09.001]

[22] Oggero A, Darbra R, Munoz M, Planas E, Casal J. A survey of accidents occurring during the transport of hazardous substances by road and rail. Journal of Hazardous Materials. 2006; 133(1-3):1-7. [DOI:10.1016/j.jhazmat.2005.05.053] [PMID]

[23] Mohammadfam I, Kalatpour O, Gholamizadeh K. Quantitative assessment of safety and health risks in HAZMAT road transport using a hybrid approach: A case study in Tehran. ACS Chemical Health & Safety. 2020; 27(4):240-50. [Link]

[24] Mohammadfam I, Kalatpour O, Gholamizadeh K. [Evaluation of health consequences in chemicals road transport accidents using a fuzzy approach (Persian)]. Journal of Occupational Hygiene Engineering. 2019; 6(3):1-8. [Link]

[25] Mohammadfam I, Zarei E, Yazdi M, Gholamizadeh K. Quantitative risk analysis on rail transportation of hazardous materials. Mathematical Problems in Engineering. 2022; 2022. [DOI:10.1155/2022/6162829]

[26] Bagheri H, Fatemi F, Bakhtyari N. [An investigation of the sudden release of chlorine gas in Jalalieh water treatment plant through ALOHA (Persian)]. Journal of Crisis and Emergency Management. 2020; 12(38):31-59. [Link]

[27] Bouafia A, Bougofa M, Rouainia M, Medjram MS. Safety risk analysis and accidents modeling of a major gasoline release in petrochemical plant. Journal of Failure Analysis and Prevention. 2020; 20(2):358-69. [DOI:10.1007/s11668-020-00845-6]

[28] Barjoee SS, Elmi MR, Varaoon VT, Keykhosravi SS, Karimi F. Hazards of toluene storage tanks in a petrochemical plant: Modeling effects, consequence analysis, and comparison of two modeling programs. Environmental Science and Pollution Research. 2022; 29(3):4587-615. [DOI:10.1007/s11356-021-15864-5] [PMID]

[29] Yoon S, Yun J, Han J, Jung S. Risk analysis of transporting hazardous substances in harbor using modeling program. Journal of Ocean Engineering and Technology. 2018; 32(4):272-8. [DOI:10.26748/KSOE.2018.6.32.4.272]

[30] Yarandi MS, Karimi A. [Evaluation of consequence modeling of fire and explosion on methane storage tanks in a CNG refueling station (Persian)]. Journal of Safety Promotion and Injury Prevention. 2018; 6(4):237-46. [Link]

[31] Khorram R. [Modeling the outcome of chlorine emission based on emergency response planning values over 24 hours using the PHAST software (case study: Bushehr nuclear power plant) (Persian)]. Journal of Military Medicine. 2020; 22(5):492-501. [Link]

[32] Mortazavi SB, Parsarad M, Mahabadi H, Khavanin A. [Evaluation of chlorine dispersion from storage unit in a petrochemical complex to providing an emergency response program (Persian)]. Iran Occupational Health. 2011; 8(3):68-77. [Link]

[33] Khan RM, Bhuiyan SAM, Haque FM, Wasi M, Rahman MA. Effects of unsafe workplace practices on the fire safety performance of ready-made garments (RMG) buildings. Safety Science. 2021; 144:105470. [DOI:10.1016/j.ssci.2021.105470]

[34] Jia H, Taheri B. Model identification of solid oxide fuel cell using hybrid Elman Neural Network/Quantum Pathfinder algorithm. Energy Reports. 2021; 7:3328-37. [DOI:10.1016/j.egyr.2021.05.070]

[35] Mei Y, Ye Y, Deng X. A paradigm of intelligent evacuation route decision for metro station emergence based on social media. International Journal of Performability Engineering. 2020; 16(9):1416-23. [DOI:10.23940/ijpe.20.09.p10.14161423]

[36] Azadeh MA, Keramati A, Mohammadfam I, Jamshidnedjad B. Enhancing the availability and reliability of power plants through macroergonomics approach. Journal of Scientific and Industrial Research. 2006; 65:873-8. [Link]