Areal location of hazardous atmospheres simulation on toxic chemical release: A scenario-based case study from Ray, Iran

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Abstract

Background and aim: Chemical accidents cause significant danger for residents living close to chemical facilities. For this reason, this study assessed the impacts of a simulated chemical accident on surrounding residents in the city of Ray, Iran.
Methods: In this scenario-based case study in 2015, the Areal Location of Hazardous Atmospheres (ALOHA) model was applied to simulate a toxic chemical release from a chlorine warehouse in Shourabad, Ray, Iran. The population of the area was calculated based on the latest census in Iran, 2011. The atmospheric variables included were wind speed, air temperature, and relative humidity. We also included data on pollution source such as diameter, length and volume, and condition of chemicals. The simulation was repeated for each seasonal period. The simulated threat zones were mapped using Geographical Information System. The percentage of residents sustaining injuries and death was calculated using probit.
Results: The maximum and minimum simulated threat zones by chlorine release are during summer and winter at 8.8 and 6.4 kilometers respectively. The total affected population was estimated at approximately 30,000 people. The greater percent of injuries and death was estimated to occur in the winter and autumn, compared to summer and spring, because of greater climatic instability. The number of individuals affected by chlorine release in the spring, summer, autumn and winter at 8.3, 8.8, 7.6 and 6.4 kilometers, are estimated at 22,500, 25,000, 28,100 and 27,500, respectively. Populations located in hot and warm zones of toxic chemical releases should have access to medical resources.
Conclusions: The results showed that relevant factors impact human vulnerability, and these should be examined to mitigate the harmful consequences of chemical accidents. Establishing a multi-level Emergency Response Program is also recommended in the area under study.
Keywords: Chemical hazard, Residential environment, Emergency response

1. Introduction

Iran, the 18th largest country in the world, is located in the Middle East and has a workforce population of around 25 million (1). The pace of industrialization has speeded up over past decades in Iran, and is expected to increase (2).

This process meant that chemicals are produced, transported and stockpiled near residential areas, increasing concerns over public safety associated with explosions, leakages, and release of chemicals (3-4). Chemical accidents can occur in varying conditions with different intensities. In Iran in 2014, over 230 people were hospitalized after inhaling toxic gas in the city of Zahedan, south of Iran (5). In 2001, the accidental chlorine release in the water treatment station of Tehran killed 2 and injured 50 people (6). Leakage of chlorine during transportation in the north of Iran in 1995 killed 3, and 200 residents had to receive medical assistance (7). These types of chemical accidents are of concern in other countries. Chemical accidents in Seveso (Italy), Flixborough (United Kingdom) and Bhopal (India) killed and injured thousands of people, and caused serious health hazards and irreversible environmental damage (8-10). Tehran is an industrial province with more than 17 industrial parks, and it is highly likely to witness chemical accidents (11). One of its industrial zones is Shourabad, which is located in the city of Ray in Tehran province, and has a population of about 4000 people. It contains more than 200 chemical manufacturing plants and warehouses that stock various types of chemicals such as chlorine, ammonia, petroleum, and acids. Moreover, these plants are situated in the vicinity of residential areas. In all of these and other cases, a proactive approach to disaster mitigation and risk management is needed to prevent and mitigate potential harmful consequences (12-14). Various types of risk assessment studies such as scenarios simulation methods or measuring risk tolerance play a major role in emergency management, and may be carried out in connection with such a proactive approach. Information produced in risk assessment studies can be applied in decision making in real-time during an emergency (15). The extent to which chemical plants could forecast the scale of their threat zones in cases of explosions or chemical releases, enables them to better estimate and minimize the risks involved. These relevant studies have facilitated disaster mitigation and response preparations in these threatened areas up to now, and have perhaps lessened the degree of impact of toxic gas on residents (16). Thus, the rationale for this study is to simulate, in an Iranian context, the scale of threat zones in the event of chlorine release, and estimate the percentage of injuries or deaths in the study area. We hope to estimate the magnitude and severity of the chemical hazard in this study in the hope of convincing the decision makers to allocate the necessary resources in the understudy area.

2. Material and Methods

This study conducted a scenario based in Shourabad, Ray city, Tehran province in 2015. First, the area under study was examined due to its high density of chemical manufacturing plants and warehouses and also because of the kind of chemicals that were involved. The population of the area was calculated from the 2011 Iran census. More specifically, the chlorine warehouse in Shourabad was chosen as the subject of simulation in view of the accidents involving the release of chlorine elsewhere in Iran, as well as the widespread use of chlorine in different industrial procedures.

2.1. Areal Locations of Hazardous Atmosphere (ALOHA) simulation

Second, a probable scenario during nighttime hours was simulated in the study area so as to obtain the threat zone's toxic vapor dispersion, using the ALOHA 5.4.4 model. (This model is capable of simulating the dispersion of chemical vapor for over 900 chemicals). Moreover, rather than daytime, the model is used during the nighttime which has more atmospheric instability, and more regions are affected by chemical releases.

2.2. Characteristics of ALOHA simulation

The ALOHA model was chosen for simulation because the required data is not extensive even though the accuracy of predictions is appropriate (17). The ALOHA model is suitable for rapid deployment by emergency responders that may be pressed for time (18). The official Iran meteorological organization provided the values of required meteorological parameters for ALOHA modeling for the different seasons of a year. The registered data were available from January 1951 to December 2012 in monthly mean values. The input data were entered manually into the ALOHA software in two sections. The model selected the best fit for stability class from the information inputted.

2.2.1. Atmospheric data

Atmospheric data included wind speed and direction, wind measurement height, ground roughness, cloud cover, air temperature and relative humidity. The yearly mean values were calculated and used for wind speed, air temperature, and relative humidity.

2.2.2. Source data

A chlorine tank, as a contamination source, was selected based on the scenario in this study. Tank characteristics were its diameter, length and volume, the state of the chemical, ambient temperature, and the shape and diameter of the opening through which the pollutant could exit.

2.3. Determining Acute Guideline Exposure Levels (AEGLs)

After determining the physical scale of threat zones, the outputs of ALOHA are mapped using a Geographical Information System (GIS) with access to the best possible information from the hazard areas (AEGLs). The simulated threat zones are each divided into 3 zones, so as to help first responders to chemical accidents. ALOHA uses AEGLs as the default level for chlorine.

2.3.1. Acute Guideline Exposure Level 3

AEGL-3 (Red zone) is the airborne concentration of a substance, above which, it could have life-threatening health effects or death.

2.3.2. Acute Guideline Exposure Level 2

AEGL-2 (Orange zone) is the airborne concentration of a substance for which the prediction is that the general population, including susceptible individuals, could experience irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape.

2.3.3. Acute Guideline Exposure Level 1

AEGL-1 (Yellow zone) is the airborne concentration of a substance, above which, the general population, including susceptible individuals, could experience notable discomfort, irritation, or certain asymptomatic nonsensory effects which are transient and reversible upon cessation of exposure.

2.4. Estimating fatalities in the understudied area

The percentage of injuries or death in the threat zones was estimated using probit equations (19). The concentration of chlorine gas, corresponding to a percentage of fatalities in the exposed population is calculated via probit.

2.5. Ethical Consideration

The information of investigated documents, companies and warehouses were kept secret by the authors.

3. Results

The ALOHA model is employed to simulate a chlorine release in Shourabad. A 1-ton cylinder of chlorine is assumed damaged during incorrect handling, causing the release of its content into the air at nighttime. Nighttime is the period from 1 hour before sunset to 1 hour after sunrise. The simulation computed the range of toxic vapor, assuming the release in one hour of the contents from the damaged cylinder. Table 1-2 and Figures 1-4 show the environmental configurations and outputs of ALOHA simulation. Figures 1-4 demonstrate the implementation of ALOHA simulated threat zones in a GIS presentation. The result showed that seven villages and two cities were affected by the chemical release, based on the scenario selected. The number of individuals affected by chlorine release in the spring, summer, autumn and winter at 8.3, 8.8, 7.6 and 6.4 kilometers, are estimated at 22,500, 25,000, 28,100 and 27,500, respectively. The maximum and minimum concentrations of chlorine gas in the red zone (Immediately Dangerous to Life or Health (IDLH) or AGEL-3), orange zone (AGEL-2) and yellow zone (AGEL-1) and the percentage of injuries and death, are calculated using the ALOHA diagrams and equations (1, 2).
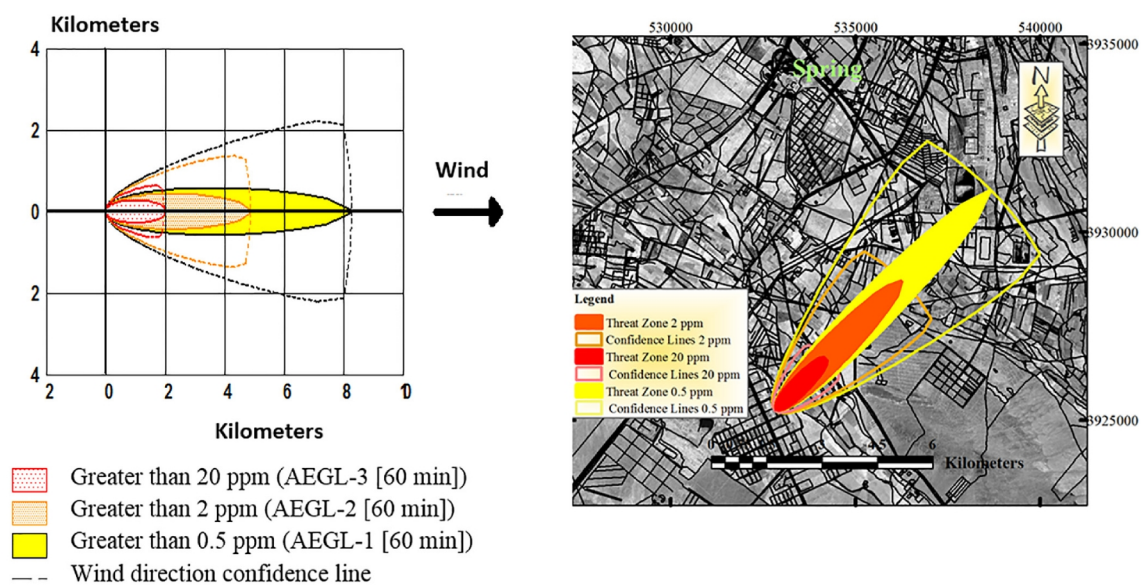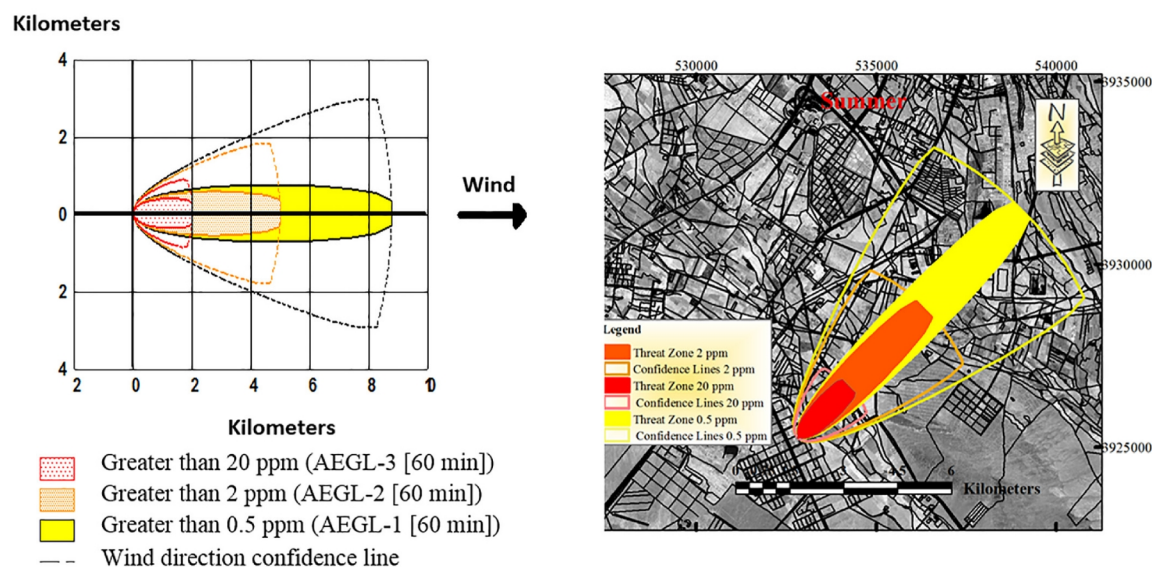
Table 1. Configurations of the release scenario for the seasonal simulation

Parameters	Season			
	Spring	Summer	Autumn	Winter
Air temperature ($^\circ$C)	16.5	29.5	18.5	4.8
Relative humidity (%)	40	26	37	61
Wind speed (knots)	6.8	5.6	4.4	4.1
Wind direction	SW*	SW	SW	SW
Elevation of wind speed measurement (m)	10	10	10	10
Ground roughness	Open country	Open country	Open country	Open country
Atmospheric stability class	D	D	F	E
Cloud cover (0-10)	5	0	5	7
Total volume released (kg)	1000	1000	1000	1000
Model of release	Heavy gas	Heavy gas	Heavy gas	Heavy gas
Total duration (min)	60	60	60	60

*South West

Table 2. Threat zones, concentration, percent of injuries and deaths of toxic substance release in Shourabad, Ray city, Iran

Season	Threat zones	Distance (km)	Concentration (Min-Max(ppm)	Injury, Death (Min-Max (%)
Spring	AGEL-3 (IDLH)	1.9	21-30000	4-38
	AGEL-2	4.8	3.5-20	0-3.7
	AGEL-1	8.3	<0.5	0
Summer	AGEL-3 (IDLH)	2	22-150000	4.2-45.2
	AGEL-2	5	2.1-21	0-4
	AGEL-1	8.8	<0.5	0
Autumn	AGEL-3 (IDLH)	1.7	35-150000	6.3-45.2
	AGEL-2	4.4	2.1-34	0-6.2
	AGEL-1	7.6	<0.4	0
Winter	AGEL-3 (IDLH)	1.5	20-800000	3.7-53
	AGEL-2	3.7	2.1-19	0-3.5
	AGEL-1	6.4	<0.5	0

Greater than 20 ppm (AEGL-3 [60 min])
Greater than 2 ppm (AEGL-2 [60 min])
Greater than 0.5 ppm (AEGL-1 [60 min])
— — Wind direction confidence line

Figure 1. Chlorine release scenario; Spring

Greater than 20 ppm (AEGL-3 [60 min])
Greater than 2 ppm (AEGL-2 [60 min])
Greater than 0.5 ppm (AEGL-1 [60 min])
— — Wind direction confidence line

Figure 2. Chlorine release scenario; Summer

Greater than 20 ppm (AEGL-3 [60 min])
Greater than 2 ppm (AEGL-2 [60 min])
Greater than 0.5 ppm (AEGL-1 [60 min])
Wind direction confidence line
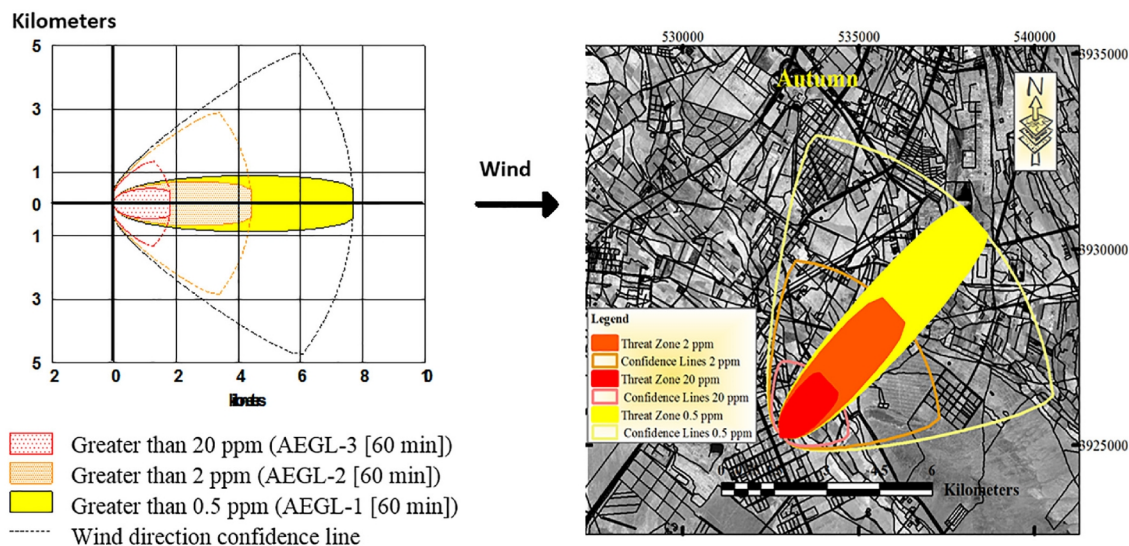
Figure 3. Chlorine release scenario; Autumn

Greater than 20 ppm (AEGL-3 [60 min])
Greater than 2 ppm (AEGL-2 [60 min])
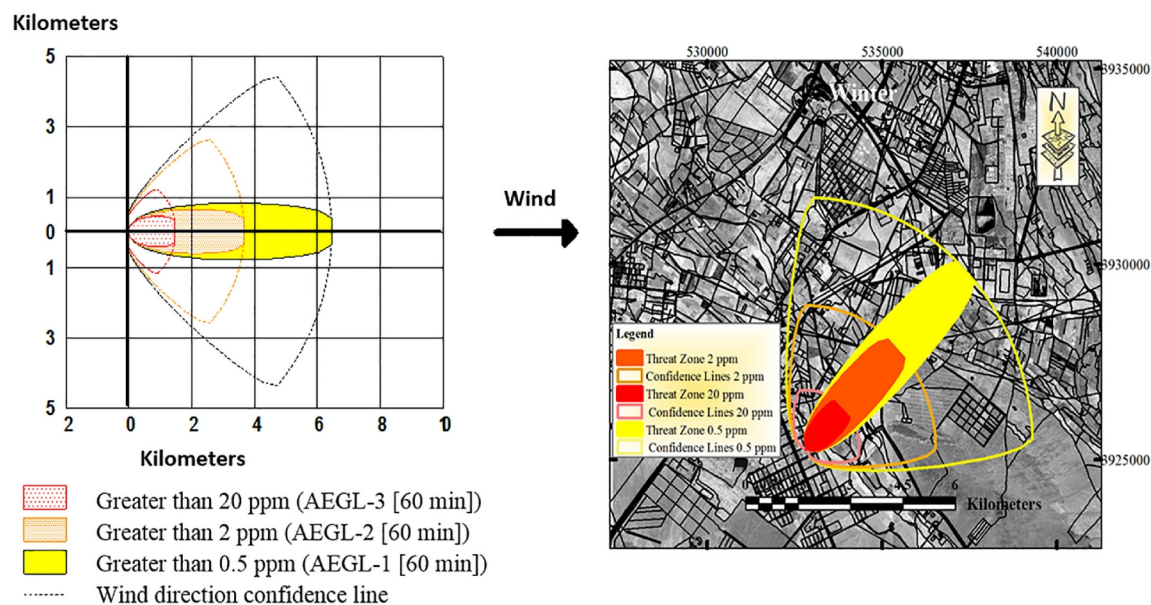Greater than 0.5 ppm (AEGL-1 [60 min])
Wind direction confidence line

Figure 4. Chlorine release scenario; Winter

4. Discussion

The results showed that in the case of the release of chlorine gas, large areas, and many people were in danger. Based on the results of dispersion simulation for a scenario of a toxic chemical accident, the leak of chlorine during the summer, had the greatest threat zone, followed by the release of chlorine during the spring. The maximum and minimum number of people exposed to health risks by chlorine release, estimated in the autumn and spring, is 25,400, and 24,100 people at 6.5, and 8.8 kilometers, respectively. Despite slower wind speed in the autumn, because of greater climatic instability in comparison to spring, a larger number of regions tended to be affected by the chemical in their surroundings, leading to an increased number of affected people. The highest percentage of injuries and death, 6.3 to 45.2, were also calculated for autumn. This estimation depends on the concentration of chlorine in the air and also in the distance to the source of the contamination. Population locating in AGEL-3 (IDLH) and AGEL1-2 zones, encounter death or severe health problems most frequently, and must receive medical assistance as soon as possible. In all seasons, sustainable injuries and death for AGEL-1 zone have been estimated at 0% in this study. Horng et al. found that residents without enough time to escape should shelter in places in the areas with a maximum concentration of chlorine up to 3 ppm at AEGL-1 (20). Another study recommended that the areas

in which chlorine concentration is greater than 3 ppm at AEGL-2 and AEGL3 should be equipped with evacuation plans (21). In the area of study at present, there are no safe places that can act as shelters. Nor is there an evacuation plan in case of chemical accidents. Risk communication and evacuation routes to populations living in these areas are essential. They should have information about hazards in the vicinity and the protective actions that they can take if a chemical incident occurs (22-23). For instance, many lives would have been saved in the Bhopal accident, if people had been aware of the simple safety measure to stay in an enclosed space with wet cloths on their faces (24). The results of these studies should be combined with an Emergency Response Planning (ERP) for dealing with accidents for which there is limited response time (25). Strong reporting and analysis of chemical accidents will help to establish a national chemical database (26). This surveillance system should be able to identify high-risk locations, provide early detection of significant events, as well as planning ERP that is the distinction between chemical incidents and natural disasters such as earthquakes (27-29). Based on the threat zones and their numerous harmful impacts, ERP could be adjusted at several levels with each of them requiring a separate set of guidelines for activation at the time of crisis (30). As a basic element for understanding the risk of chemical disasters, knowing the level of exposure is not the only critical factor. Calculating the degree of vulnerability is also a key issue for research on emergency management (31). In addition to having an appropriate ERP, it is necessary to consider human vulnerability factors such as old age or illnesses, and match the available capacities with the criteria in further studies.

5. Conclusions
At the initial stage of risk assessment, simulating the pattern of toxic vapor dispersion using the ALOHA model, was essential in this study. The statistics from the simulation based on AGELs and using the probit equations, not only served as a useful reference for disaster management, but also were the basis for notifying residents in the affected areas to take necessary safety precautions to ensure the safety of their lives and properties. Preparing multi-level ERP, according to threat zones in the field under study, is vital. On the other hand, determining the presence and extent of human vulnerability factors could mitigate the potential chemical harms for residents living in proximity to industrial installations and complete the risk assessment process.

Conflict of Interest:
There is no conflict of interest to be declared.

Authors' contributions:
All authors contributed to this project and article equally. All authors read and approved the final manuscript.

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