TECHNIUM
SOCIAL SCIENCES JOURNAL

Vol. 15, 2021

A new decade for social changes

www.techniumscience.com

ISSN 2668-7798

Technium Social Sciences Journal
Vol. 15, 587-601, January, 2021
ISSN: 2668-7798
www.techniumscience.com

Risk mapping of Chlorine gas dispersion from a storage plant in a dense urban area of Lahore

Rafaqat Warda[1], Muhammad M. Shafique[1], Gill Kaif[3], Ashraf Nasir[3], Chuanli Huang[1], Shabbir Salman[2], Aqeel Suliman[4], Weiguo Song[1]

[1]State Key Laboratory of Fire Science, University of Science and Technology of China, Jinzhai Road 96, Hefei, Anhui, People's Republic of China, [2]Punjab Information Technology Board, Lahore, Punjab Pakistan, [3]University of The Punjab, Lahore, Punjab, Pakistan, [4]Punjab Emergency Service, Lahore Pakistan

warda@mail.ustc.edu.cn[1]

Abstract. In recent times, with the increasing population in urban areas, the adverse events happening due to explosion and dispersion of toxic chemicals has increased. Events like toxic gas dispersion can cause severe environmental issues that endanger human safety and health. Consequence hazard modeling and vulnerable population assessment are critical to predict and minimize the losses. Chlorine is not only utilized in water treatment plants as a disinfectant, but it ca n also lead to some serious concerns to human health. In this paper, the modeling of chlorine release has been investigated for chlorine storage plant by using Heavy gas dispersion model. The modeling results showed that the cloud of chlorine is about 1.9 miles across just downwind of the release for accidental release of chlorine in the summer; however, the probability of fatality is 100 % in a whole year in a distance of 0.36 miles from the Storage Place. As a significant result, the land around the chlorination unit covering a range of approximately 1.9 miles is vulnerable in all wind directions and in the case of South-West direction of the wind, vulnerable population is highly dense, risk prevention in that region should be accounted for. Affected Population and areas at risk are calculated, which illustrates the toxically impacted areas and the population in need of immediate help and evacuation. Such studies can serve as a useful tool for decision-makers to prepare an emergency plan in case of accidental releases.

Keywords. dispersion, toxic chemicals, safety, hazard modeling, Vulnerable Population

1. Introduction:

With the rapid growth in economy and population in metropolitan cities [1]use of hazardous materials has been increasing [2]Lahore, Pakistan is among the cities which are growing, every year population is rising, the current population of Lahore in 2019 is 12,188,000, a 3.83% increase from 2018 [3]. It also leads to the concerns of safety during transportation of hazardous chemicals to minimize risk, such as chlorine gas dispersion accident Lahore happened in January 1997 in which 32 persons died and 900 injured and approximately 1000 people were evacuated from the affected area [4]From that day till today a lot has been written about environmental protection of the city, and concerns like smog [5]and the population at risk due to other natural disasters but no study has been carried out in the field of toxic chemicals release. Nowadays, with the increased number of chemical industries and their handling of large quantities of hazardous chemicals, occurrences of chemical accidents have increased. Despite proper legislations and strict implementation, chemical accidents still are happening because of human error, improper training, manufacturing defects, and improper plant and/or storage maintenance. As they are unexpected incidents, the only solution is to be prepared to minimize the anticipated impact. For an effective preparedness and management of such disasters, it is necessary to assess the risk associated with a chemical disaster [6][7]. In Lahore city with an increase of population, consumption of water has increased; hence the number of water tube wells has become in a large number [8]All the extracted water is disinfected using Chlorination method, in each tube well [9]

Chlorine used for the disinfection of water is stored in a storage location of Water and Sanitation agency. This storage plant and the transporting vehicle can cause a serious threat to the surrounding dense area. Hence, this study is intended to assess the risk associated with accidental leakage of Chlorine gas from the storage location. A case study of Accidental Release of Chlorine from a Storage Facility and an On-Site Emergency Mock Drill carried out by Ambalathumpara Raman Soman and Gopalswamy Sundararaj, indicates that in case of accidental release of Chlorine, its impact would permeate far beyond the storage [10]. Dev D. Jani, David Reed, Charles E. Feigley, and Erik R. Svendsen show that Chlorine gases disperse relatively large distance with significant levels of toxic concentrations [11][12]. For any kind of disaster, the primary element at risk is the population in the affected area. The risk can be assessed in several ways [13]. In this study, the risk is considered as injury, illness, or death of population [14]. WASA Storage location is present in a highly dense urban area of Lahore and much near to the old city as well. Hence, it is necessary to identify the potential hazard associated with its storage and assess the vulnerable population. To assess the population under threat due to the consequential effect of Chlorine release from a storage facility, two software applications, ALOHA (Areal Locations of Hazardous Atmosphere) and GIS, are integrated into this study. ALOHA is one of the widely accepted models used for simulating the dispersion of hazardous gases and a number of studies successfully incorporated the applications of ALOHA for risk assessment purpose [15]. Renjith carried out a dispersion modeling of ammonia and other gases using ALOHA and estimated the individual and societal risk [16]Many studies using this software for the dispersion modeling of other hazardous chemicals (LPG, Chlorine, etc.) reveal its usefulness in risk assessment studies .Many studies proved that the integrated applications of ALOHA and GIS are a yet more powerful tool of population vulnerability assessment.

In this study, the extent of the hazardous area as well as the population under threat, in terms of important locations such as Educational and Hospital locations falling under threat zones being assessed, which help building the risk map of the surrounding area. This study generates basic four types of information first hazard map of the area, Vulnerable Population calculation and finding important vulnerable location points, risk map of the surrounding area, and evacuation route for the vulnerable population [17][18].

The results depicted in the form of a risk map can be a powerful tool for emergency management personnel to know at a glance that which areas need immediate evacuation and how much population should be evacuated.[19]Also, a route map is generated that can provide the quick evacuation guide, and a risk map can be used for planning and management of the nearby city.

2. **Study Area**:

Lahore is the biggest metropolitan city of Pakistan present near the Ravi River. Lahore is the country's second-most populous city. Figure 1 shows a map of the study area. The population of the city, according to 2017 census data, is 11,126,285, and according to Landscan data, the population is 10,591,636, and the area is 1,772 km^2 (684 sq mi). Figure 2 shows the population density.

Water and sanitation agency Lahore hydrological directorate office is located (31°34'18.9"N, 74°17'27.8"E) in a densely populated area of Lahore, which is considered as Storage location of chlorine being transferred to all tube wells in Lahore.

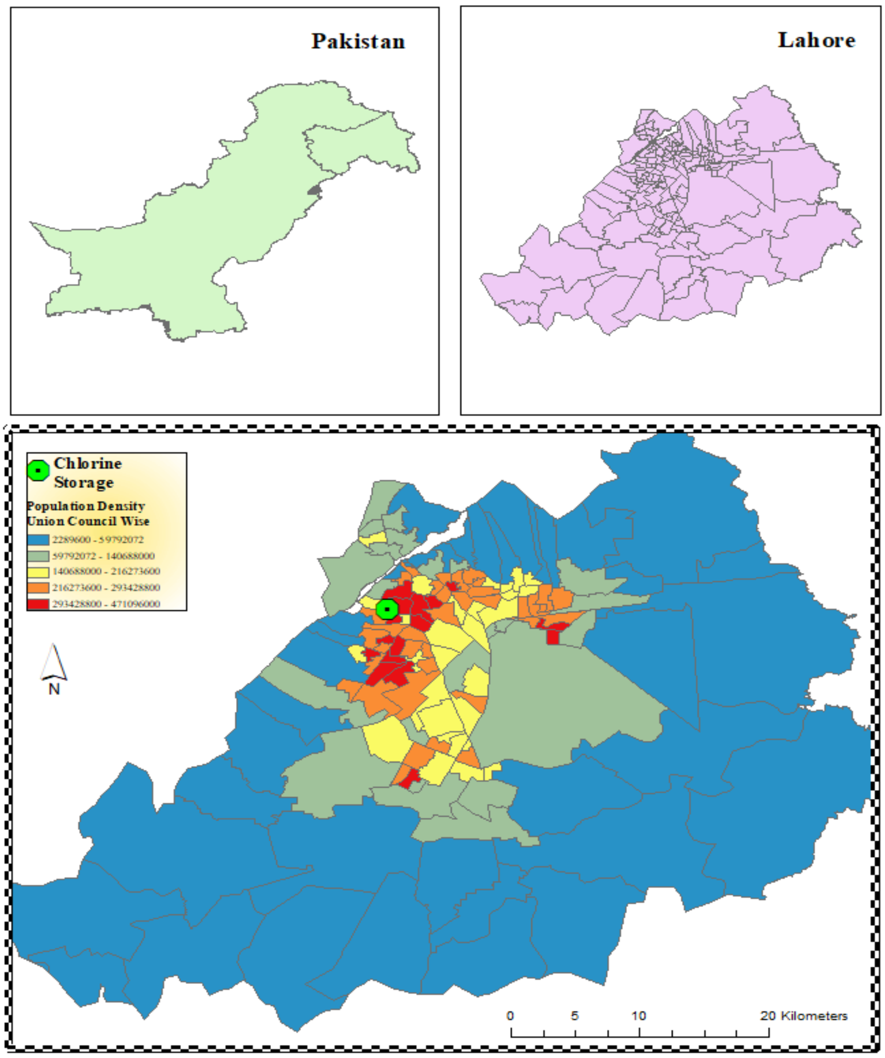


Figure 1: Study Area

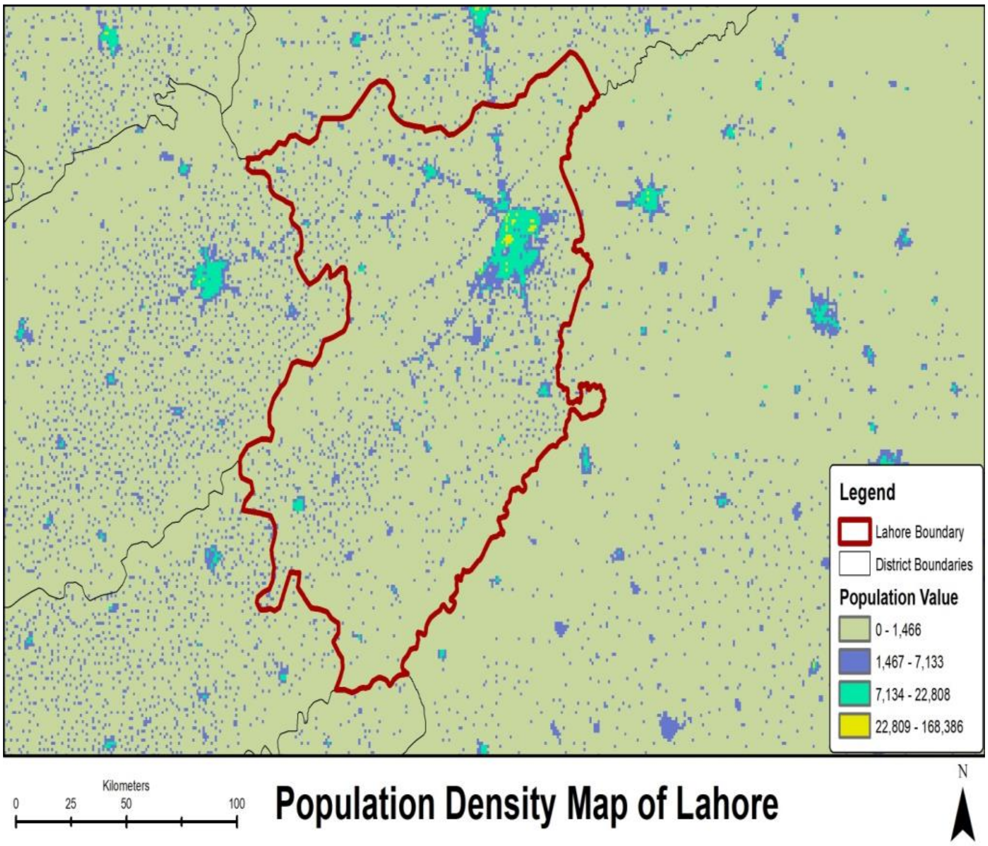


Figure 2: Lahore population density map

3. Materials and Methodology:

Gaseous chlorine is poisonous and classified as a pulmonary irritant. It has intermediate water solubility with the capability of causing acute damage to the upper and lower respiratory tract. Chlorine gas has many industrial uses, but it was also once used as a chemical weapon in World War I. Today, most incidents of chlorine exposure are through accidental industrial or household exposures. As for industrial exposures, there have been several instances of train accidents carrying liquid chlorine that caused the release of chlorine gas to the surrounding environment. At home, a mixture of chlorine bleach with other household products that contain acid or ammonia is a common source of exposure to chlorine gas.

Toxicity to chlorine gas depends on the dose and duration of exposure. At concentrations of 1 to 3 ppm chlorine gas acts as an eye and oral mucous membrane irritant, at 15 ppm there is an onset of pulmonary symptoms, and it can be fatal at 430 ppm within 30 minutes. [20]

For its strong odor, chlorine gas can be detected easily. Symptoms of chlorine gas exposure include the burning of the conjunctiva, throat, and the bronchial tree. Higher concentrations can produce bronchospasm, lower pulmonary injury, and delayed pulmonary edema.

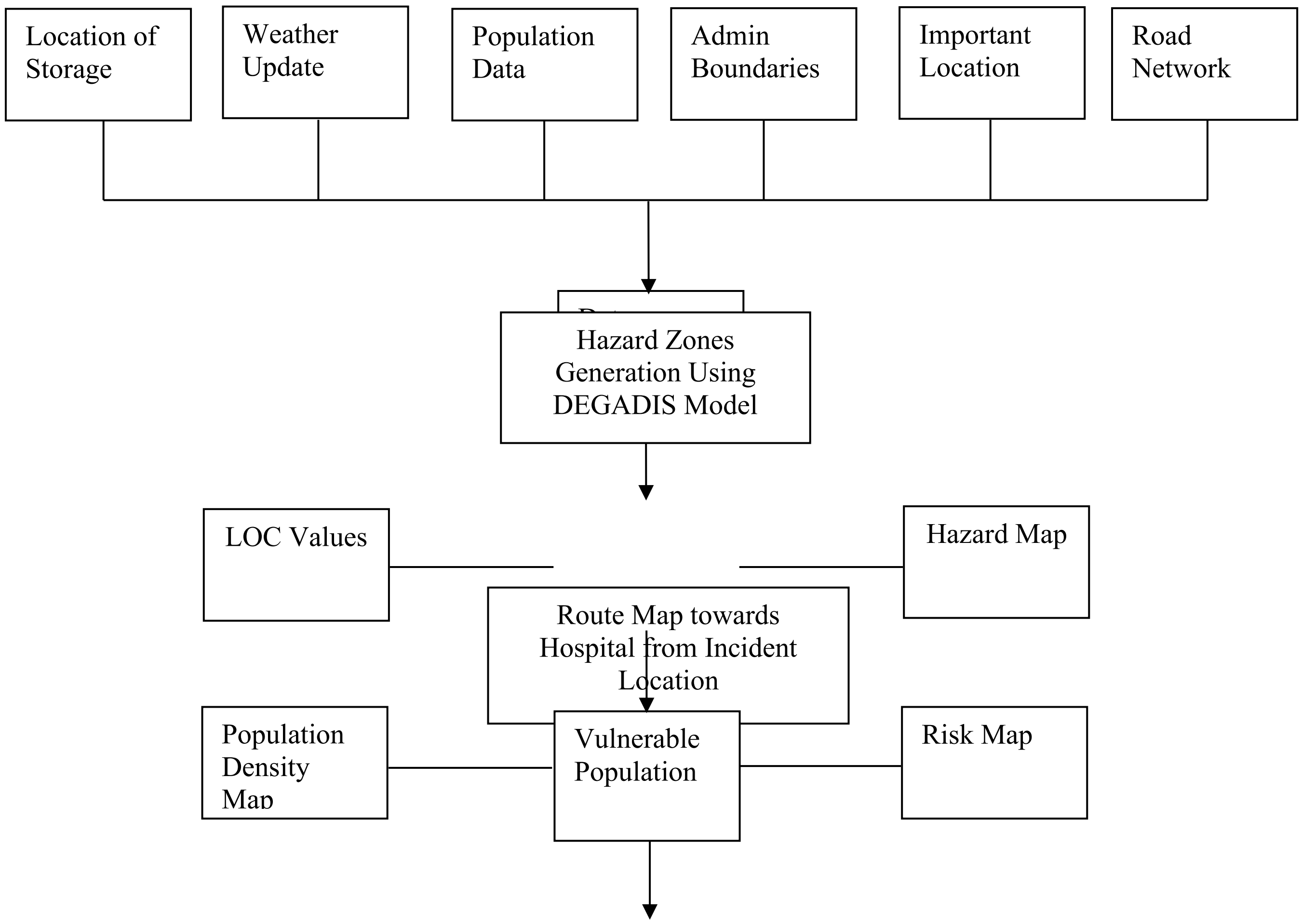
Two software programs, Areal Locations of Hazardous Atmospheres (ALOHA) and Geographical Information System (GIS), are incorporated in this study, to assess the risk posed by the toxic impact of Chlorine Dispersion, estimated vulnerable population, found important points under threat and route guide for the evacuation of injured persons.

The methodology adopted in this study constituted in the following four steps. The whole process is presented in Figure 3.

- Preparing Data
- Hazard Zones generation of the toxic impact of Chlorine using ALOHA

Technium Social Sciences Journal
Vol. 15, 587-601, January, 2021
ISSN: 2668-7798
www.techniumscience.com

- Assessment of vulnerable population and Finding Important location at risk due to the toxic impact of Chlorine using GIS
- Generating Route map for the injured population using the road network and nearby hospital information



I. **Preparing Data:**

The usefulness of integrated applications of ALOHA and GIS depends on the accuracy of information provided as an input. For this, data was collected through the google map and validated through a ground survey. Data used for the purpose is mentioned below. Table1.

Data	**Type**	**Source**
Location of Storage	Point	Google Map
Weather Update	Average Weather Lahore	Weather spark https://weatherspark.com/[20]
Population Data	Raster (1X1)km2	Landscan 2017
Admin Boundaries	Polygon	Alahsan Systems Private Limited[21]
Important Locations	Point	Alahsan Systems Private Limited
Road Network	Polyline	Google Map

Hospitals	Point	Punjab Emergency Service

Table 1: Input Data

II.Hazard zones generation of toxic impact of Chlorine using ALOHA:

The widely used heavy gas dispersion modeling software ALOHA is used in this study to assess the risk posed by chlorine leakage from a storage facility. The software is developed and supported by the National Oceanic and Atmospheric Administration (NOAA) in collaboration with the office of Emergency Management of the Environmental Protection Agency (EPA) to provide emergency response personnel the estimates of the spatial extent of chemical hazards. ALOHA is a component of CAMEO (Computer-Aided Management of Emergency Operations), a comprehensive computer software program developed by the US Government and the chemical database of ALOHA are the subset of those found in CAMEO chemicals, a database of hazardous chemicals. This model is chosen for this study due to its very advanced ability to model the dispersion of heavy gases which form clouds heavier than air and spread by gravitational forces as they are dispersed by downwind and turbulence. It is one of the most widely accepted models for emergency management, and its tools allow integration of the results with ArcMap. The information that is provided by the integrated application of ALOHA and GIS is functional in real-time emergency management. Compared to other software programs, ALOHA is very easy to run and gives a fast estimation of the impacted area, so that responders can use ALOHA as a responsible tool during a spill event.
ALOHA uses two types of computation for the dispersion of gas clouds in the atmosphere, Gaussian air dispersion and heavy gas dispersion. Based on the information about the properties of the chemical and the amount of chemical released, it chooses whether to make Gaussian or heavy gas dispersion computation. A gas which has higher molecular weight than air, ALOHA considers it as a heavy gas. When a lighter gas such as chlorine is released into the atmosphere from pressurized and refrigerated storage tanks, in the presence of moisture (such as high relative humidity) form vapors that are heavier than air and get suspended in the lower atmosphere. In such cases, ALOHA considers the gas to be heavy. Heavy gas dispersion calculation used in ALOHA is based on the DEGADIS model (Dense Gas Dispersion model) [21]To estimate the rate at which the chemical is released in the atmosphere, the model evaluates various factors such as phase released (liquid, gas, or mixed phase), the driving pressure, and the nature of the rapture of the tank.
The potentiality of risk scenario of the hazardous chemical can vary widely, based on a number of factors, such as the properties of the chemical involved in the accident, storage condition, nature of the release, and the ambient atmospheric conditions at the time of the accident [22]. Considering all these, ALOHA incorporates various data on chemical characteristics, location information, meteorological conditions, and source strength to estimate the spatial extent of the chemical dispersal. To assess the toxic impact of ammonia, ALOHA estimates the spatial extent of chemical release representing graphically in the form of threat zones, specifically on human health hazard grounds. The data summary required for ALOHA modeling is given below.

III. Chemical Data

Chemical properties are as follows:
Chemical Name: CHLORINE
CAS Number: 7782-50-5
Molecular Weight: 70.91 g/mol

TECHNIUM SOCIAL SCIENCES JOURNAL

Technium Social Sciences Journal
Vol. 15, 587-601, January, 2021
ISSN: 2668-7798
www.techniumscience.com

AEGL-1 (60 min): 0.5 ppm AEGL-2 (60 min): 2 ppm AEGL-3 (60 min): 20 ppm
IDLH: 10 ppm
Ambient Boiling Point: -29.3° F
Freezing Point: -149.9° F

IV.Weather Information

Atmospheric conditions prevailing at the time of accident affect the dispersion of toxic cloud. The factors significantly affecting the dispersion of gas clouds are the velocity and direction of the wind and atmospheric turbulence.
Weather information of Lahore city by weather spark.com is used for two seasons, summer and winter. Table 2.

Table 2: Weather Conditions

Atmospheric Parameters	Winter		Summer	
	1-Jan		1-Jun	
	12:00 AM	12:00 PM	12:00 AM	12:00 PM
	Scenario 1	Scenario2	Scenario3	Scenario4
Wind Speed	5.5 mph	5.8 mph	6 mph	6 mph
Temperature	52 F	64 F	88 F	101 F
Humidity	20%	20%	25%	21%
Stability	Neutral Stable	Slightly Unstable	Neutral Stable	Slightly Unstable

Topography
Urban or forest topography is selected as the tube well present in the city Centre.
Source Strength
Sodium hypochlorite presents at storage location is 275Kgs Active Chlorine Proportion is 16 percent of 275 kg approximately 44Kgs.

4. Area under Hazard Result

A Chlorine gas storage place (latitude 31°34'21.16"N longitude 74°17'25.21"E) at outfall road Sannat Nagar Lahore is the potential source of chlorine gas release in the atmosphere. If chlorine is accidentally released into the atmosphere, the immediate danger associated with it is the toxic inhalation hazard. Hazard modeling of chlorine gas dispersion is done for two weather conditions in day and night time, and the results are given below.

Table 3: Impacted distance of toxic hazard of Chlorine from the source of leakage

Toxic Level of Concerns	Concentration Level	Affected distance from the source of leakage			
		January		June	
		12:00 AM	12:00 PM	12:00 AM	12:00 PM
		Scenario 1	Scenario 2	Scenario 3	Scenario 4
AEGL-3 [60 min]	20PPM	0.43	0.36	0.43	0.37

AEGL-2 [60 min]	2PPM	1.1	0.9	1.1	1
AEGL-1 [60 min]	0.5PPM	1.8	1.6	1.9	1.7

ALOHA employs levels of concern (LOCs) to address the toxic inhalation hazards on the human population. LOCs are concentrations of airborne chemicals associated with adverse health effects, and it is specific to chemicals. AEGLs estimate the concentrations at which most people—including sensitive individuals such as old, sick, or very young people—will begin to experience health effects if they are exposed to a hazardous chemical for a specific length of time (duration). For a given exposure duration, a chemical may have up to three AEGL values, each of which corresponds to a specific tier of health effects. [23]Results are given with the value of the affected area in table 3.
By finding the results of four scenarios, the worst-case scenario is filtered out and considering four wind direction NW, NE, SW, SE vulnerable population is assessed. All results of different wind directions are graphically represented in Fig. 5.

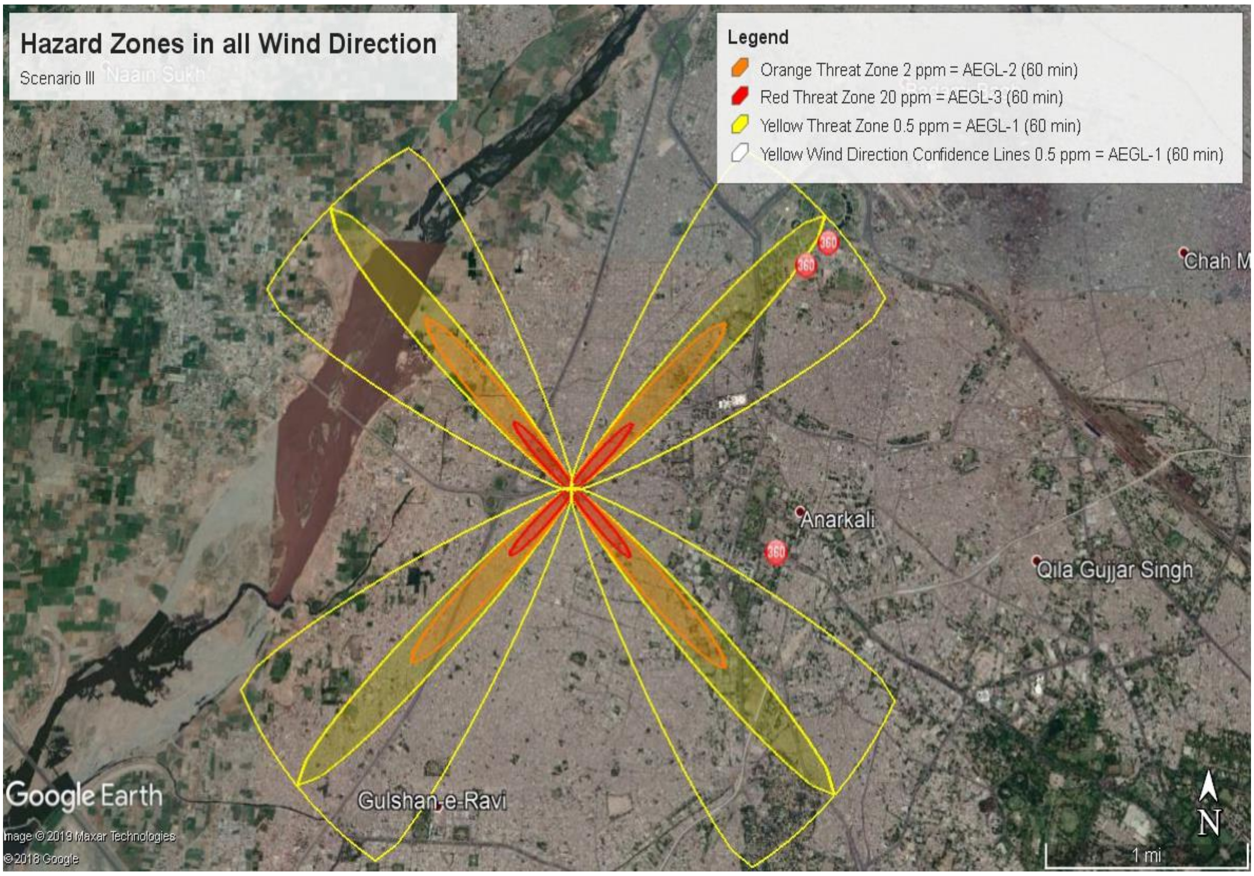


Fig. 3. Hazard Map of the city in case of an accidental spill of chlorine gas

In all the scenarios in Fig. 4, red, orange, and yellow represent the threat zones where the ground level concentration of chemical exceeds the LOCs at some time after the release occurs. Each threat zones indicates three levels of AEGL values, such as AEGL-3, AEGL-2, and AEGL-1, for a 60-minute exposure. AEGL-3 is the maximum airborne concentration, 20 ppm, considered as the worst-case level, above which there is a possibility of experiencing life-threatening health effects or death. The concentration of the chemical in the second level, AEGL-2, is taken as 2 ppm, above which it is predicted that the people may experience significant adverse health effects such as dizziness, severe eye or respiratory irritation, and muscular weakness. The

Technium Social Sciences Journal
Vol. 15, 587-601, January, 2021
ISSN: 2668-7798
www.techniumscience.com

AEGL-1 level identifies the concentration of 0.5 ppm, which is noticeable due to odor, discomfort, and irritation. Below the maximum airborne concentration level predicted in each zone (AEGL-1, AEGL -2, and AEGL -3), the people could be exposed for up to 1 h without experiencing any adverse health effects.

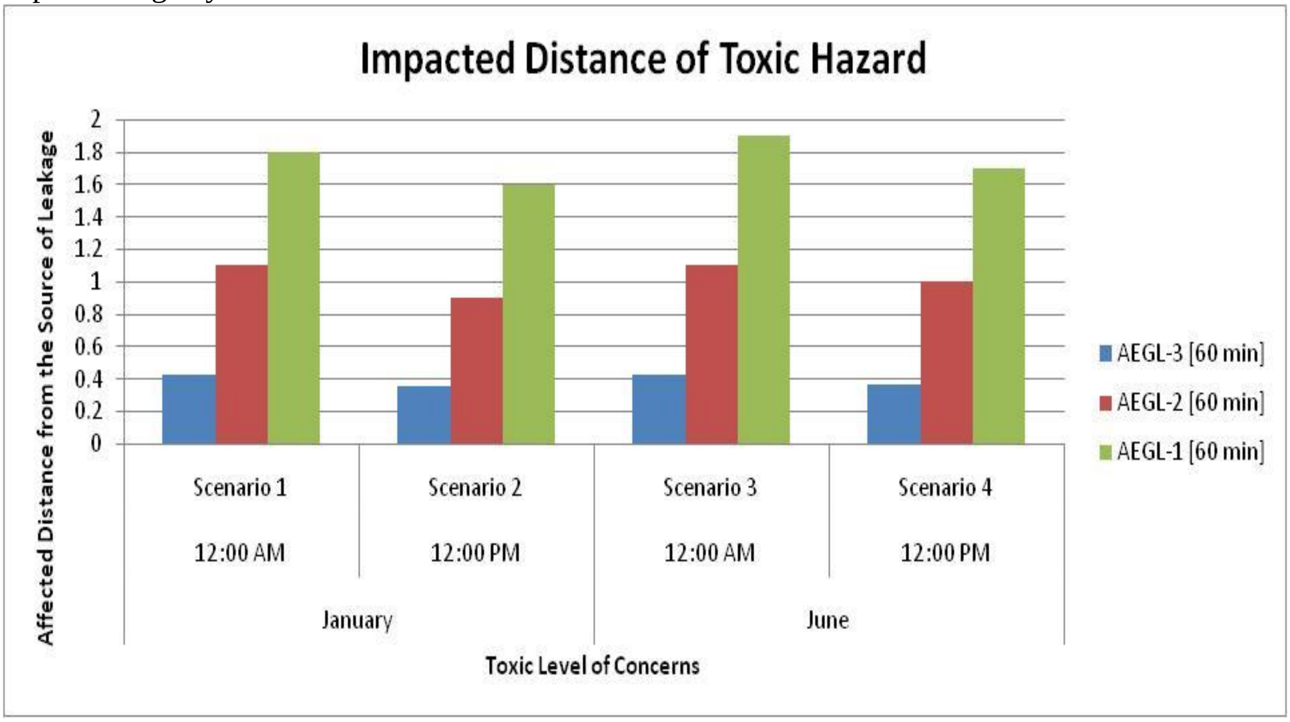


Figure 4:Impacted distance of Toxic Hazard

The dispersion of toxic clouds usually takes place by the diffusion of the chemical in the air. The chemical is transported mainly in the wind direction but also perpendicularly to the wind based on atmospheric turbulence. From the comparison of the result of ALOHA modeling of Chlorine leak in two different weather conditions, it can be understood that the affected area of hazard will depend upon the weather conditions prevailing in the area at the time of the accident. A variation can be seen in the affected distance as well as the plume width based on the weather conditions. Comparing two different seasons, the impacted distance is greater in summer than in winter. When the time of occurrence is taken into account, it is observed that the night time is more dangerous than the day time as it shows the larger impacted distance.
Of the four scenarios, the maximum impacted distance of AEGL-3 is observed in scenario-III and I, 4.3 miles from the source, based on weather conditions. In the case of Scenario II, IV, the impacted distance is 0.36 and 0.37 Miles. The risk associated with the impacted area of Chlorine is dependent upon the population, which is likely to come under the threat zone. Figure 4

5. Assessment of vulnerable population and Finding Important location at risk due to the toxic impact of Chlorine using GIS

For an effective risk assessment and emergency preparedness, GIS plays a vital role by providing a wide variety of information such as synoptic view of the release location Population density under threat zone, and the vulnerable location susceptible to damages. To estimate the vulnerable population, the population likely to come under the threat zone of Chlorine toxicity, a number of GIS database layers were prepared.

Technium Social Sciences Journal
Vol. 15, 587-601, January, 2021
ISSN: 2668-7798
www.techniumscience.com

The layers prepared are, Union Council Boundaries Source AL Hasan Systems Private Limited [24]and population distribution pattern of each Union Council and the layer of threat zone as created by simulation method of Chlorine Gas dispersion using Aloha. Population Density maps of each UC provide solid ground for finding risk areas.
Table 3. shows a total number of Union Councils falling in each zone of the Hazard Area as well as their names. Based on the Population density of each Union Council, Risk zones have been calculated and divided into different levels, from red to yellow Table 4.

Table 4: Hazard area

Hazard Area		
Zone	**UC fall number**	**Ucs Name**
Red	4	Chohan Park, Jinnah Hall, Sanda Kallan, Sanda Khurd
Orange	5	Abu Bakar Siddique Colony, Sham Nagar, Kareem Park, Bilal Ganj
Yellow	5	Kot Begum, Bahawalpur House, Androon Bhatti Gate, Riwaz Garden, Sham Nagar

Table 5: Risk Area

Risk Area	**UC fall number**	**Ucs Name**
Red	2	Jinnah Hal, Sanda Khurd
Orange	2	Bilal Ganj, ,Sanda Kallan
Yellow	3	Sham Nagar, Riwaz garden, Chohan Park
Green	5	Androon Bhatti Gate, Bahawalpur House, Rizwan Park, Kareem Park

Table 6: Important POIs falling under hazard area

Red Zone of	**Number of Hospitals**	**Number of Colleges**	**Number of Schools**	**Number of Universities**
Hazard	13	9	109	2
Risk	12	9	78	2

TECHNIUM SOCIAL SCIENCES JOURNAL

Technium Social Sciences Journal
Vol. 15, 587-601, January, 2021
ISSN: 2668-7798
www.techniumscience.com

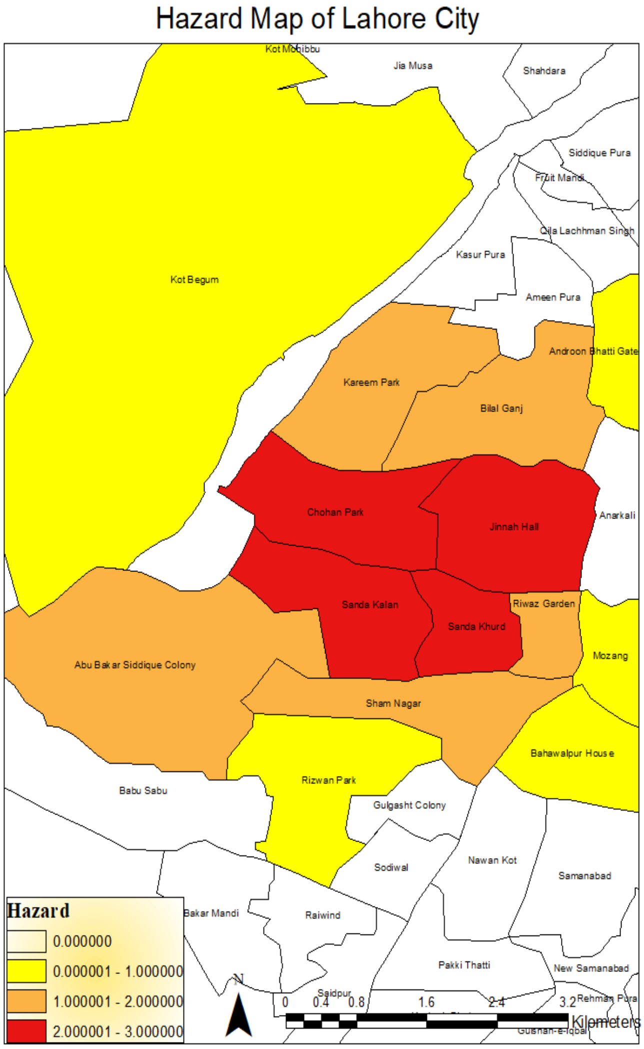


Figure 5: Hazard Map of the City in case of accidental Chlorine Gas Dispersion from Storage Location

Technium Social Sciences Journal
Vol. 15, 587-601, January, 2021
ISSN: 2668-7798
www.techniumscience.com

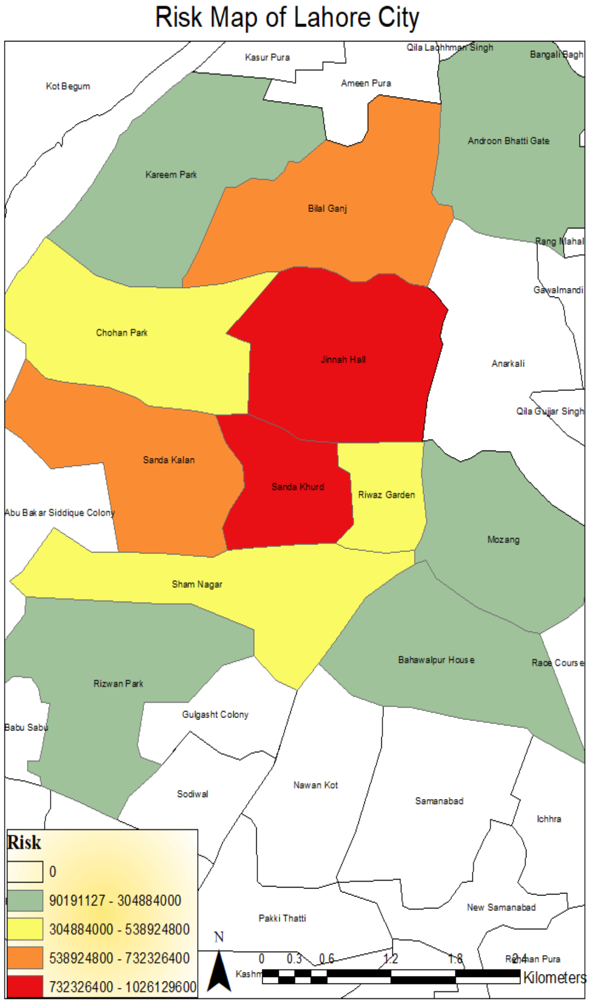


Figure 6: Risk Map of the City in case of accidental Chlorine Gas Dispersion from Storage Location

Figure 6. Hazard Map is basically a combination of falling UCs in Each Threat Zone. The red color in the map shows Union councils such as Chohan Park, Jinnah Hall, Sanda Kallan, Sanda Khurd, which are mainly affected by hazard, orange colors show the union councils from where the people of the need to move to the hospital. Figure 7 In risk Map, the Union Councils consider at high risk are based on the population density of each UC as well as Important points such as a number of hospitals, universities, and colleges falling in hazard area are also being considered as Described in Table 6.

6. Generating Route map for the injured population using the road network and nearby Hospital information:

Once our risk maps have been prepared, and the basic area under threat in the case of chlorine Gas Dispersion has been assessed. We prepared the Road Data of the city considering all turns, using Google map and hospital locations of ten major hospitals in the city as shared by 1122, the rescue department of the city. [25] GIS network analysis is used, where the population in a

Technium Social Sciences Journal
Vol. 15, 587-601, January, 2021
ISSN: 2668-7798
www.techniumscience.com

network is allocated to the nearest facility locations. Site suitability analysis is the third GIS function that identifies sites according to their suitability for the location of the facility under a set of certain conditions. Based on the Nearest Available facility, and the Shortest path is chosen, the Hospital is decided to move injured. Chosen the high-risk area and the nearby accessible hospital through ArcGIS the route map is given. Basic hospitals used by 1122 the main existing rescue team by the government of Punjab shared the list of 10 major hospitals that are usually considered by them for movement of injured in any case of emergency. Recent times of Covid it has been witnessed the lack of hospitals, and especially related to ventilators and respiratory machines has been discussed in detail. [26] so a better and before time planning is really need of the hour for city safety.

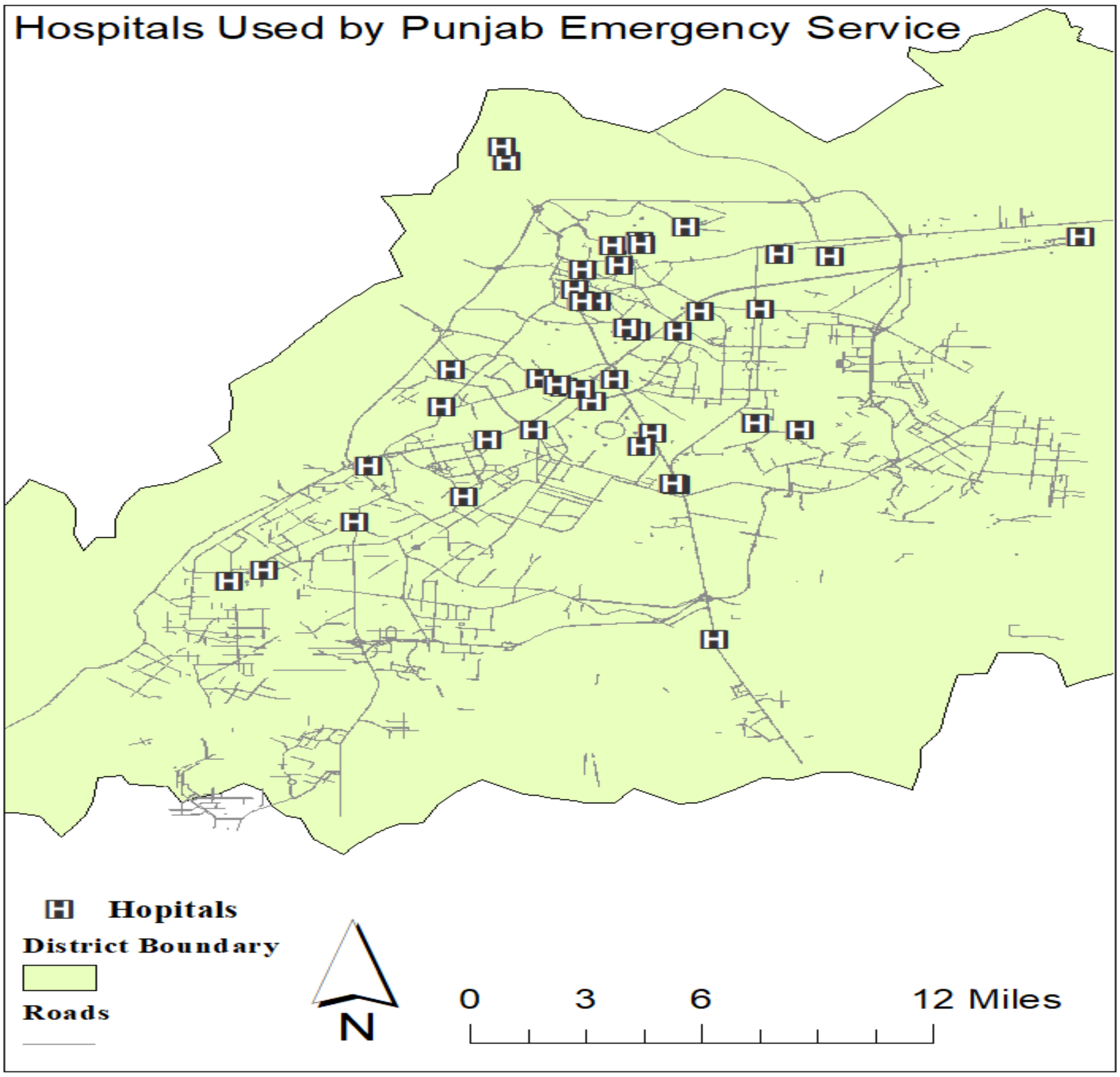


Figure 7: Hospitals Dedicated by Rescue Office

Technium Social Sciences Journal
Vol. 15, 587-601, January, 2021
ISSN: 2668-7798
www.techniumscience.com

7. Conclusion:

In this study, the main focus was on assessing the extent of hazard areas in case of accidental release of Chlorine under different atmospheric conditions and an assessment of likely-to-be affected population and the safe evacuation. From these modeling results, it can be concluded that the climate conditions, including wind speed, humidity, atmospheric stability, etc. play a decisive role in deciding the areas more prone to hazardous impacts. Based on the dispersion behavior of the chlorine vapors, the risk maps were generated, and the union council level risk of the city is being found. The Analytical capabilities of GIS provide an overview of how much population need to be evacuated from the area in case of an emergency and what will be the route. As the wind changes its direction with time, it is necessary to pre-estimate the vulnerable population around different directions of the hazardous material storage facility for effective preparedness and timely evacuation after an accident. This study shows the validity of this data and methodology of analysis to effectively understand the repercussions of an accident. An extension of this study using more frequent weather parameters and other necessary details can be used as an appropriate and ready to refer manual for decision-makers to take immediate actions in case of an emergency.

Acknowledgements

This research was supported by National Key R&D Program of China (2018YFC0807000); the Fundamental Research Funds for the Central Universities (Grant No.WK2320000040). Special Thanks to Punjab Emrgency services for providing us data and State Key Lab of Fire Sciences for giving us resources to carry the study.

References

[1] “The World’s Cities in 2018.”
[2] “Environmental indicator report 2018 - In support to the monitoring of the 7th Environment Action Programme — European Environment Agency.” .
[3] “Lahore, Pakistan Metro Area Population 1950-2020 | MacroTrends.” .
[4] “Appendix 12.2 Historical Chlorine Incident Records Records from MHIDAS database (extract from EIA report ‘North East New Territories New Development Areas’, AEIAR-175/2013).”
[5] “(4) (PDF) Smog; A potential threat in Lahore Pakistan.” .
[6] J. R. Bhardwaj, R. Chawla, and R. K. Sharma, “Chemical disaster management: Current status and perspectives,” J. Sci. Ind. Res. (India)., vol. 66, no. 2, pp. 110–119, 2007.
[7] “(No Title).”
[8] “THE ISLAMIC REPUBLIC OF PAKISTAN LAHORE DEVELOPMENT AUTHORITY (LDA) WATER AND SANITATION AGENCY LAHORE (WASA LAHORE) PREPARATORY SURVEY REPORT ON THE PROJECT FOR ENERGY SAVING IN WATER SUPPLY SYSTEM IN LAHORE,” 2014.
[9] “Frequently Asked Questions | WASA, Lahore.” .
[10] A. R. Patel, F. Patra, N. P. Shah, and D. Shukla, “Biological control of mycotoxins by probiotic lactic acid bacteria,” Dynamism dairy Ind. Consum. demands, vol. 2015, no. February, pp. 2–4, 2017, doi: 10.1155/2015.
[11] “(PDF) Dispersion Modeling of Accidental Release of Chlorine Gas.” .
[12] S. S. and S. Gupta, Anil K, Nair, “Chemical Disaster Management,” Proceeding Vol. Natl. Work. Prep. Natl. Action Plan, pp. 2–76, 2009.
[13] E. Erkut and V. Verter, “Modeling of transport risk for hazardous materials,” Oper. Res., vol. 46, no. 5, pp. 625–642, 1998, doi: 10.1287/opre.46.5.625.

[14] S. Schneiderbauer and D. Ehrlich, “Risk, hazard and people’s vulnerability to natural hazards: A review of definitions, concepts and data,” Eur. Comm. Jt. Res. Centre. EUR, 21410, vol. 40, no. January, 2004, doi: 10.1007/978-3-540-75162-5_7.
[15] N. S. Anjana, A. Amarnath, and M. V. Harindranathan Nair, “Toxic hazards of ammonia release and population vulnerability assessment using geographical information system,” J. Environ. Manage., vol. 210, pp. 201–209, 2018, doi: 10.1016/j.jenvman.2018.01.021.
[16] “Individual and societal risk analysis and mapping of human vulnerability to chemical accidents in the vicinity of an industrial area | Request PDF.” .
[17] S. Yasuhiro, “Hazard Mapping and Geography: Why Hazard Mapping Projects are Now Strongly Promoted,” Geogr. Rev. Japan, Ser. A, vol. 76, no. 12, pp. 924–930, 2003, doi: 10.4157/grj.76.12_924.
[18] P. Tran, R. Shaw, G. Chantry, and J. Norton, “GIS and local knowledge in disaster management: A case study of flood risk mapping in Viet Nam,” Disasters, vol. 33, no. 1, pp. 152–169, 2009, doi: 10.1111/j.1467-7717.2008.01067.x.
[19] W. Rafaqat, W. Song, and M. A. Niaz, “Hazard Mapping and Vulnerable Population Estimation of Chlorine Gas Dispersion,” in 2019 9th International Conference on Fire Science and Fire Protection Engineering, ICFSFPE 2019, 2019, doi: 10.1109/ICFSFPE48751.2019.9055797.
[20] S. Chauhan et al., “Chemical warfare agents,” Environmental Toxicology and Pharmacology, vol. 26, no. 2. Environ Toxicol Pharmacol, pp. 113–122, Sep-2008, doi: 10.1016/j.etap.2008.03.003.
[21] T. Spicer, J. Havens, and D. Guinnup, “User’s guide for the DEGADIS 2.1 dense gas dispersion model,” 1989.
[22] I. Roefliana and A. Puspitasari, “Alternatif Transportasi Sehat,” 2007.
[23] “Acute Exposure Guideline Levels (AEGLs) | response.restoration.noaa.gov.” .
[24] “Alahsan Systems Private Limited - Google Search.” .
[25]: :: “Rescue 1122 Official Website :::” [Online]. Available: http://www.rescue.gov.pk/Performance.aspx. [Accessed: 04-Apr-2020].
[26]: Rafaqat Warda, Weiguo Song, Gill Kaif, Chuanli Huang, Shabbir Salman, & Ashraf Nasir. (2020). Covid-19 spread prediction and its correlation with social distancing, available health facilities using GIS mapping data models in Lahore, Pakistan. Technium Social Sciences Journal, 10(1), 21-38. https://doi.org/10.47577/tssj.v10i1.1291