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Research article

Toxic hazards of ammonia release and population vulnerability assessment using geographical information system

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ABSTRACT

Today, chemical industries manufacture, store and transport evermore hazardous substances and hence the risk of accidental releases of these chemicals can become more and more catastrophic in the context of increasing population and their requirements. The damage potential is proportional to the population characteristics of the location as well as various meteorological factors and geographical features. For the risk assessment of ammonia toxicity, the storage facility at Eloor industrial area is taken as a sample. Pollutant dispersion model - Areal Locations of Hazardous Atmosphere (ALOHA) is utilized to predict the toxicity impacted distance of ammonia. The model estimates the vulnerable areas, which may be affected toxically by an Ammonia release by integrating information about chemical properties of the substance, weather conditions prevalent in the area and release conditions. Risk assessment is done for four different atmospheric conditions, typical to the prevailing seasons and affected area is estimated in each scenario. To determine the affected population, the areal interpolation method in GIS database is also employed in this study, which illustrates the toxically impacted areas and the population in need of immediate help and evacuation. Such studies can serve as an effective tool for decision makers to prepare an emergency plan in case of accidental releases.

1. Introduction

Responding to concerns raised by the Bhopal Gas tragedy, more and more public attention has been paid to chemical emergency prevention and planning. As an aftermath, in order to prevent such disasters from recurring, UNEP initiated a worldwide program, Awareness and Preparedness for Emergencies at Local Level (APELL), in 1988 (Jover and Pavia, 1991). Realizing the importance of industrial legislation for safety of workers as well as the nearby population outside the industry, Government of India enforced a comprehensive legislation framework of Environment (Protection) Act 1986, administered through Ministry of Environment and Forest. Under this Act, a number of rules have been formulated related to the major hazardous industries namely Manufacture, Storage and Import of Hazardous Chemical (MSIHC) Rules, 1989, the Chemical Accident (Emergency Planning, Preparedness, and Response) Rules, 1996, the Disaster management Act, 2005, etc. (Gupta, 2006). As a result of the strict implementation of formulated rules, the risks haves gone down significantly. But nowadays with the increased number of chemical industries and their handling of large quantities of hazardous chemicals, occurrences of chemical accidents have increased. In spite of 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. Hence, this study is intended to assess the risk associated with leakage of ammonia from a storage plant, which is located at Eloor industrial area, Ernakulam, Kerala, India. A case study of ammonia storage facility carried out by Roy indicates that in case of accidental release of ammonia, its impact would permeate far beyond the plant (Prasun et al., 2011) Che Hassan et al. (Rosmani et al., 2009) shows that ammonia gases disperses fairly large distance with significant levels of toxic concentrations before the process of dilution to a less harmful concentration.

For any kind of disaster, the major element at risk is the population in the affected area. The risk can be assessed in several ways

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(Erkut and Veter, 1998). In this study, risk is considered as injury, illness, or death of population (Jianjun et al., 2000). The ammonia storage facility in Eloor is surrounded by a densely populated area. 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 ammonia release from a storage facility, two software applications, ALOHA (Areal Locations of Hazardous Atmosphere) and GIS, are integrated in this study. ALOHA is one of the widely accepted model used for simulating dispersion of hazardous gases and a number of studies successfully incorporated the applications of ALOHA for risk assessment purpose (Shah et al., 2014; Bahareh and Berrin, 2015). Renjith (Renjth and Madhu, 2010) carried out a dispersion modeling of ammonia and other gases using ALOHA and estimated the individual and societal risk. Many studies using this software for the dispersion modeling of other hazardous chemicals (LPG, Chlorine, etc) reveal its usefulness in risk assessment studies (Nilambar et al., 2016; Praveen and Nagendra, 2015; Lucyna, 2016). Many studies proved that the integrated applications of ALOHA and GIS is an yet more powerful tool of population vulnerability assessment (Chakraborty and Armstrong, 2001; Neumann et al., 1998; Veter and Kara, 2001; Chakrabarti and Jigisha, 2011).

It has been seen that most of the studies use homogeneously distributed pattern of population density for assessing the vulnerable population. In such cases it is assumed that the population is evenly distributed, even in uninhabited areas. However, Chakraborty and Armstrong, (Chakraborty and Armstrong, 1996), overcomes some of these limitations by incorporating chemical dispersion model with GIS database. This study modified the method proposed by Chakraborty and Armstrong, 1995, by avoiding the uninhabited area within the threat zone of ammonia leakage to estimate the vulnerable population by applying areal interpolations method. Dasymetric mapping method provide a clear estimated of the population distribution pattern. The result of this study answers a number of questions associated with accidental release of ammonia such as:-

- How much area or how much distance will the toxic vapour clouds of ammonia disperse in a given weather condition if it is accidently leaked through a pipe hole?
- How the atmosphere influences the dispersion of toxic clouds?, and
- How much population are likely to be impacted in case of an accident?

The results depicted in the form of a map can be a powerful tool for emergency management personnels to know at a glance, which area need immediate evacuation and how much population should be evacuated.

2. Study area

Eloor, an island of 13.23 km^2 formed between two tributaries of river Periyar in the suburbs of Kochi is a municipality in the Paravur Taluk of Ernakulam District in the southern Indian state of Kerala. It is an industrial area north of Cochin in the largest industrial belt of Kerala and is one of the world's 'top toxic hot spots' (Eloor is one of the world's most toxic spots, 2013). Though this region is an industrial area, it has a unique ecosystem with a large number of people residing in the surroundings. The ammonia storage facility is located in $10.067{,}99^0$ N latitude and $76.294{,}31^0$ E longitude in Eloor Municipality. In case of an accidental release of ammonia from this storage facility, it may affect the nearby Panchayaths also which are densely populated. Hence, to assess the population under threat, Eloor Municipality and the surrounding areas are taken in to account. The whole study area, including the location of ammonia storage facility and surrounding area, is given in Map 1.

3. Materials and methodology

Ammonia is one of the widely used hazardous chemical which have bulk storages in many chemical industries. The flammable limits of ammonia are 16–25% by volume in the air with an ignition temperature of 651 °C (US EPA, 2001). Probability of ignition of such mixture is very less under normal atmospheric temperature and pressure, therefore ammonia installations are not regarded as significant fire hazards (ILO and Geneva, 1993). But ammonia is a highly toxic material which has severe adverse effects even at large distances from the source of release (Boppana et al., 1996).

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 ammonia leakage and estimated vulnerable population. The methodology adopted in this study constituted in the following three steps.

3.1 Primary and secondary data collection
3.2 Consequence analysis of toxic impact of ammonia using ALOHA
3.3 Assessment of vulnerable population due to the toxic impact of ammonia using GIS

3.1. Primary and secondary data collection

The usefulness of integrated applications of ALOHA and GIS depends on the accuracy of information provided as an input. For this purpose, both primary and secondary data were collected form concerned departments and is given in the following Table 1.

3.2. Consequence analysis of toxic impact of ammonia using ALOHA

The widely used heavy gas dispersion modeling software ALOHA is used in this study to assess the risk posed by ammonia 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

Table 1
Primary and secondary data.

	data	Source
Primary data	Location of ammonia storage facility	Using GPS (in terms of latitude and longitude)
	Resources at 2 LISS 4 satellite imagery	NRSC, Hyderabad
	Toposheet	Survey of India.
Secondary data	Meteorological data	Indian Meteorological Department
	Administrative boundaries (including ward boundaries)	Concerned Panchayaths and Municipalities
	Census data (including ward wise population)	Concerned Panchayaths and Municipalities
	Information about ammonia storage	From the industry which have the storage of ammonia