Disaster Management Strategies Based on Risk Assessment Modeling of Major Industrial Hazardous Gas Release in Cochin Using GIS

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Under the faculty of Environmental Studies

By

Anjana N. S.

(Reg. No. 4260)

School of Environmental Studies

Cochin University of Science and Technology

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Disaster Management Strategies Based on Risk Assessment Modeling of Major Industrial Hazardous Gas Release in Cochin Using GIS

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Author

Anjana N. S.
Research Scholar
School of Environmental Studies
Cochin University of Science and Technology
Kochi – 682 022
Kerala, India

Supervising Guide

Dr. M. V. Harindranathan Nair
Associate Professor (Retired)
School of Environmental Studies,
Cochin University of Science and Technology
Kochi – 682 022
Kerala, India

School of Environmental Studies
Cochin University of Science and Technology
Kochi, Kerala, India   682 022

May 2018

SCHOOL OF ENVIRONMENTAL STUDIES
COCHIN UNIVERSITY OF SCIENCE AND TECHNOLOGY
KOCHI - 682 022

Dr. M. V. Harindranathan Nair
Associate Professor (Retired)

Certificate

This is to certify that this thesis entitled **"Disaster Management Strategies Based on Risk Assessment Modeling of Major Industrial Hazardous Gas Release in Cochin Using GIS"** is an authentic record of the research work carried out by **Ms. Anjana N. S.** (Reg. No. 4260), under my guidance at the School of Environmental Studies, Cochin University of Science and Technology in partial fulfillment of the requirements for the award of the degree of Doctor of Philosophy in Environmental Sciences and no part of this work has previously formed the basis for the award of any other degree, diploma, associateship, fellowship or any other similar title or recognition. All the relevant corrections and modifications suggested by the audience during the pre-synopsis seminar and recommended by the Doctoral committee have been incorporated in the thesis.

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May 2018

Dr. M. V. Harindranathan Nair
(Supervising Guide)

Declaration

I do hereby declare that the work presented in the thesis entitled **"Disaster Management Strategies Based on Risk Assessment Modeling of Major Industrial Hazardous Gas Release in Cochin Using GIS"** is based on the authentic record of the original work done by me, for my Doctoral Degree under the guidance of **Dr. M. V. Harindranathan Nair**, Associate Professor (Retired), School of Environmental Studies, Cochin University of Science and Technology in partial fulfillment of the requirements for the award of the degree of Doctor of Philosophy in Environmental Sciences and no part of this work has previously formed the basis for the award of any other degree, diploma, associateship, fellowship or any other similar title or recognition.

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Preface

Industrial development is essential for commercial and economic growth of all nations, through which the standard of living can be raised. But now a days the growing frequencies of chemical disasters and its devastating effect on environment and population has become an important matter to be considered. After Bhopal Gas Tragedy in1983 much public concern was raised on hazardous material bulk storage at vulnerable locations. The locations of the industries in densely populated areas, lack of awareness among people to manage the emergency situations, and inadequacy in preparedness on the part of emergency management personnel, all make the situation highly vulnerable. Unlike other natural disasters that can be often predicted, occurrence of a chemical disaster is unanticipated.

Chemical accidents occurred in the past reveal that the causes of accidents in chemical plants are mainly due to human errors, improper training, manufacturing defects, and improper maintenance. Even adequate precautions taken to avoid such accidents reduce the risk of accidents in chemical plants, they do happen unexpectedly. As they are unanticipated incidents the only protection we can take is to be prepared to overcome the consequences. For an effective preparedness and management of such chemical disasters it is necessary to quantify the risks associated with these accidents.

Considering all the aforementioned aspects, the present study focuses on the risk assessment associated with the atmospheric release of hazardous chemicals and suggest preparedness measures for effective management of emergency situations. The application of two software programmes, ALOHA (Areal Locations of Hazardous Atmospheres) and GIS (Geographical Information System) are incorporated in this study to assess the risk and response to emergency situations. This study aims to

- Identify the possible spatial extent of chemical releases and their impacts.
- Estimate the vulnerable population coming under the impacted area
- Assess the resource availability for an effective preparedness and management of emergency situations.
- Suggest technical actions for chemical hazard management.

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Chapter 1

INTRODUCTION

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1.1 General Introduction

When some unforeseen causes damage the environment and puts people in danger, we call it a disaster (Adimola, 1999). Among various environmental disasters, accidental releases of large quantities hazardous chemicals during the storage, manufacturing and transportation have great potential to damage large areas and can result in the death and injury of large number of people inside and outside the industry. Industrial development is essential for commercial and economic growth of all countries, through which the standard of living can be raised. But, nowadays the growing frequencies of environmental disasters and their devastating effect on environment and population has become a matter of grave concern.

Hazardous materials are substances which cause serious injury, long lasting health effects, death and damage to environment when they are misused or accidently released into the atmosphere (GBRA, 2010). Wherever toxic and flammable chemicals are being manufactured, processed, stored and transported, there will always be a chance of an accident create a risky atmosphere. Even a release of small quantities of hazardous substance can damage the environment and cause harm to people. History reminds us that accidents do happen and when they happen they can be catastrophic.

The hazard may arise from several situations like equipment failure, leakage from valve, catastrophic infrastructure failure or at times, human error or negligence. The chemical hazard may be airborne, or spills and discharges depending on the physio-chemical characteristics of the chemical and nature of rupture. Many of the hazardous substances handled in chemical industries and transported are compressed gases and they form clouds heavier than air when they leak into the atmosphere.

Accidental release of hazardous materials may occur due to several reasons such as natural hazards (eg: earthquakes), human error, manufacturing defects etc. The past history of chemical accidents occurred in our country remind us that most of them happened as a result of human error. Five principal groups of factors governing the severity of the consequence of hazardous chemicals release are (Bennett et al., 1982)

1) Intrinsic properties: flammability, toxicity, and instability
2) Dispersive energy: Pressure, temperature and state of matter
3) Quantity present
4) Environmental factors: topology and weather
5) Population density in the vicinity and proximity to the hazard site.

The location of the industries in densely populated areas, lack of awareness among people and absence of preparedness from the part of people and emergency management authority, all make the situation more vulnerable. After the Bhopal Gas Tragedy in1983, much public concern has been raised on hazardous material bulk storage at vulnerable locations.

Accidental release of hazardous chemicals can result in severe consequences and give rise to a new class of problem because of the following reasons (Bourdeau & Green, 1998)

- In most cases, the hazardous chemicals are stored as a liquid, so that the volume of gas evolved is very large.
- The modes of release can vary widely from a ruptured pipe to a complete tank failure and the initial momentum may be significant. The site of the accident may not be a fixed location, in the case of transportation and pipeline accidents.
- Phase transformation from liquid to gas occurs when the chemicals are released into the atmosphere. In some cases, a chemical transformation also takes place as a result of reaction with water vapor in the ambient atmosphere.
- The physical properties of the chemicals usually result in the formation of a denser-than-air cloud and this negative buoyancy can have marked effect on the dispersion characteristics
- The release can occur over a short time-scale and this gives rise to the complication of predicting the impacted area of chemical dispersion.

Despite the horrifying death and destruction caused by the accidental releases of chemicals in Kerala in recent years, the absence of critical equipment and viable management plans still hampers the state's ability to handle such emergencies. In the worst incident of its kind, on December 31, 2009, seven people lost their lives when the gas transported in a tanker exploded at Karunagapally in Kollam. An LPG carrier had burst into flames at Chala in Kannur district on 27th, August 2012, killing 20 persons and injuring as many. Just two weeks after (11th September 2012) a blast at Chala, 18 tonnes of LPG released from a bullet tanker at the Indian Oil Corporation (IOC) bottling plant in Udayamperoor. Close to the heels of the incident on September 2012, a major LPG leakage incident occurred in the same plant on May 5th, 2014. 10 tonnes of gas were leaked in this incident (The New Indian Express, 2014). On January 7, 2014, a gas leak in an LPG tanker on the National Highway near Angamaly triggered panic among the local people (The Hindu, 2014). On march 30, 2014, panic gripped people in Kozhikodu, after gas leaked from an LPG tanker which overturned and fell on a stationary auto rickshaw killing its driver. A major tragedy was averted when an LPG tanker overturned at Mailaty in Kazargod on September 15th 2010. Recently on 20th May 2016, a barge carrying 96 tonnes of ammonia gas to the Ambalamugal FACT Cochin division was found leaking near Chambakara canal near Vyttila. A few persons complaining of eye irritation, and nausea were hospitalized in this incident. On 28th January 2018 another incident of ammonia leakage occurred from the storage tank of FACT on Willingdon Island caused physical discomfort to many including students of nearby school, and 14 persons hospitalised in the city.

All the aforementioned incidents highlight the need of an effective emergency management in Cochin City. Large part of the Cochin City is considered as vulnerable due to the hazards caused by the leakage of many hazardous gases. Considering this, through the present study, some useful information to formulate effective emergency management strategies are provided by assessing the risk and vulnerability to the population due to accidental releases of hazardous chemicals. To achieve this, the application of two software programs, ALOHA (Areal Locations of Hazardous Atmosphere) and GIS (Geographical information System), are incorporated in this study. The integration of these two software portrays quick information at a glance for an effective management of emergency situations.

1.2 Sources and Types of Industrial Hazards

Industrial hazards or chemical hazards are those caused by the potential of chemicals, chemical processes or operations to cause accidents that could damage or endanger human life, environment or property. The major outcomes of chemical hazards are fire, explosion, and toxic releases.

1.2.1 Fires

There are four different kinds of fires.

Jet fires: Jet fire is usually associated with compressed liquefied gases. Chemical release at high velocity through holes or apertures would entrain air and mix with it rapidly and dilute to below LEL (Lower Explosive Limit). Jet flames are characterized by high heat intensity and claim 100% fatalities within the direct flame zone. Beyond the flame zone, the radiation would diminish with distance.

Fireballs / BLEVE: Boiling Liquid Expanding Vapor Explosion (BLEVE) involves the violent rupture of hydrocarbon containers due to heat impingement. The material released from the container is thrown out and vaporizes or boils at the same time. BLEVE are considered the most dreaded of all LPG / Propane incidents. Though the fire balls of BLEVE are of very short duration, the heat radiation is so high that even a short exposure may cause major damage. The blast wave effect is also associated with BLEVE.

Vapor Cloud Explosion: These are the fires resulting from delayed ignition of flammable vapor evolving from a pool of volatile liquid or gases venting from a punctured or damaged container. The unignited vapor cloud moves in the downwind direction and when it encounters the condition of ignition, a wall of flame may flash back towards the source of the gas or vapor engulfing everything in its path.

Liquid Pool Fire: These are the fires evolving from liquid fuels spilled on the surface of land or water. The primary hazard associated with it is the thermal radiation and/or corrosive products of combustion. The terrain condition may aid the movement of the liquid fuel into the sewer, drains, surface water or other catchments spreading the fire and engulfing more combustible materials. If the storage tanks have dykes, the damage can be much confined.

1.2.2 Explosion

Explosion occurs because of the rapid equilibration of combustible gases in a confined volume due to rapid combustion flame or flame fronts of explosions travel very fast. There are two types of explosion

Thermal Explosion: The thermal explosion may happen because of ignition of flammable gases or vapors within a confined space. Virtually all substances handled under conditions of air-fuel mixtures within the explosive or flammable limits in an enclosed space have a high probability of exploding rather than simply burning upon ignition.

Non-Thermal Explosion: These generally occur due to over-pressurization of a container. The strength of this explosion is a function of the pressure at which the walls of the container burst and the nature of the walls (brittle or ductile).

1.2.3 Toxic Releases

Most chemicals are toxic effect on human body and it enter the body in different ways, namely oral, dermal, and inhalation. Toxic exposure is a function of the exposure level or concentration and the exposure duration. It is accepted that there are certain toxic threshold values, below which the toxic effect could be insignificant to warranty attention, even for highly toxic materials. The rate of exposure or dose for inhalation is a function of many parameters including the airborne concentration, rate of breathing, age of the victim, exposure duration, contaminant properties etc. Similarly, the effect of an ingestion or oral intake could be a function of the intake rate small doses over a time or a large dose at once.

1.3 Legislations and Regulatory Framework

In order to keep safety performance and minimize the chance of a major accident, today, most countries have regulations to comply with that control potentially hazardous industries, and operations. Some regulations try to ensure better risk management of potentially hazardous industries while others focus on setting up an adequate institutional framework at the administration level to enable proper decision making on issues related to emergency preparedness, response and mitigation. For better management of technological risks, a comprehensive regulatory system forms the cornerstone, especially in developing countries like India (Sengupta, 2007).

1.3.1 Regulatory Framework

A separate ministry, the MoEF (Ministry of Environment and Forest), was created in 1980 recognizing the need to mainstream environmental concerns in all developmental activities and was declared as the nodal ministry for the management of chemical disasters. After experiencing the world's most terrifying chemical disaster at Bhopal, in 1984, Government of India enforced the industrial legislation for the safety of public and environment. For ensuring safety, health and welfare at the workplace, the Factories Act was enacted in 1948. The regulatory framework on chemical safety can be traced to the Factories Act, 1948. Later the Environment (protection) Act, 1986 was enacted to deal with chemical management and safety. Based on 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, Manual on Emergency Preparedness for Chemical Hazards (1992), the Disaster Management Act, 2005. Based on the Environment Act 1989, guidelines to safe transport of hazardous chemicals (1995) were formulated, revised and amended over the intervening years. The rule 13 (1) of MSIHC Rules requires the occupier of any Major Accident Hazard (MAH) installation to prepare an On-site Emergency Plan and the rule 14 (1) of MSIHC Rules requires the District Authorities to prepare an Off-site Emergency Plan for the District.

Thereafter, a number of regulations covering safety, insurance, liability, transportation and compensations were enacted. The MoLE (Ministry of Labor and Employment) and its technical organ, the Directorate General Factory Advice Service and Labor Institutes (DGFASLI), amended the Factories Act, 1948, notifying 29 types of industrial activities as hazardous process. This amendment introduced special provision for hazardous process industries in its newly added chapter IV A. Preparation of emergency plans, notification of permissible exposure limits for harmful chemicals, framing safety policies etc. were introduced by these amendments.

1.3.2 Important Acts covering emergency plan issue: -

- The factories Act, 1948, as amend, 1976 and 1987
- The Environment (protection) Act, 1986
- The Public Liability Insurance Act, 1991 amend, 1992
- The National Environment Tribunal Act, 1995.

Rules: -

- Model rules under the Factories Act, 1948 amend, 1987
- The Manufacture, Storage and Import of Hazardous Chemicals Rules (MSIHC), 1989, amend.1994
- The Public Liability Insurance Rule, 1991 amend. 1992
- Chemical Accidents (Emergency, Preparedness, Planning and Response) Rule, 1996

1.3.2.1 Provisions in the Factories Act and Rules

The Factories Act, 1984 was conceived as a welfare Act. Only in 1987, the act was amended to introduce a chapter dealing with hazardous processes. Chapter IV A, Section 41 (B) of the Factories Act amended in 1987 requires the drawing up of an on-site emergency plan and detailed disaster control measures with the approval of the chief inspector. The provision applies to all hazardous process industries listed in the first schedule of the amended Act irrespective of hazardous chemical being handled or not.

1.3.2.2 Provision in the Manufacture, Storage and Import of Hazardous Chemicals (MSIHC) rules, 1989 under the Environment (Protection) Act, 1986.

The MSIHC rules are in effect industrial prevention and preparedness regulations. The rule 13 of these rules requires the occupier to prepare and keep up-to-date an on-site emergency plan for dealing with possible major accidents. This provision applies to hazardous chemical installations, which include both industrial processes and isolated storages, handling hazardous chemicals in quantities laid down in the rules and indicated as threshold planning quantities. Rule 14 of these rules, requires the District Emergency Authority or the District Collector in the state to prepare an off-site emergency plan for the district details made available by the hazardous installations and the transport authorities.

1.3.2.3 Provisions in the Public Liability Insurance Act, 1991 and Rules

As per this Act, every owner handling hazardous substance in quantities notified shall take out one or more insurance policies before starting his activity. The money provided under the act is an interim, and the ultimate liability to pay total compensation to the victims is that of the owner. This Act, apart from assuring financial assistance to the victim makes it obligatory on the part of the owner to prevent accidents and prepare for emergencies. This act thus, has given impetus to enhancement of safety.

1.3.2.4 Provision in Chemical Accidents (Emergency Planning, Preparedness and Response) Rule, 1996

The rules of emergency planning, preparedness and rules to chemical accidents complement the set of rules on accident prevention and preparedness notified under the Environment (Protection) Act, 1986 entitled "Manufacture, Storage, and import of Hazardous Chemicals rules" and envisage a four-tier crisis management set up at the local, District, State, and Central level.

These rules provide a statutory back-up for setting up of a Crisis group in districts and states which have a list of Major Accident Hazard (MAH) Installations and provide information to the public. As per the rules, the Government of India is to constitute a Central Crisis Group (CCG) for the management of chemical accidents and set up an alert system within 30 days of the notification. The Chief Secretaries of the area constitute State Crisis Group (SCG) to plan and respond to chemical accident in the State and notify the same in gazette within 45 days. The district collector shall not only constitute a District Crisis Group (DCG) but also constitute a Local Crisis Group (LCG) for every industrial pocket in the district within 60 days. The CCG shall be the apex body in the country to deal with and provide expert guidance for planning and handling of major chemical accidents in the country. The CCG shall continuously monitor the post-accident situation and suggest measures for prevention of reoccurrence of such accidents. It shall meet every six months and respond to inquiries from the SCG and DCG. The SCG will be chaired by the state Chief Secretary and shall be apex body in the state, consisting of Government officials, technical experts and industry representatives and will deliberate on planning, preparedness and mitigation of chemical accident within a view to reduce the extent of loss of life, property and ill-health.

The SCG will review the entire district off-site Emergency plan for its adequacy. The guidance for which is available in the amendments of October 1994 to Manufacture, Storage and Import of Hazardous Chemical Rules in Schedule-12. The district collector shall be the chairman of the DCG and the DCG will serve as the apex body at the district level and shall meet every 45 days. This group shall review all on-site Emergency plan prepared by the occupiers of the major accident hazard installations for preparation of a district Off-site Emergency Plan, which shall also include hazards due to the transportation of hazardous chemicals both by road and by pipeline. The district

Chairperson shall conduct at least one full scale mock-drill of the District Off-site Emergency plan each year.

1.4 Hazards, Risk and Vulnerability

The research and practices on disaster management often refers to a formula. i.e,

Risk = Hazard (vulnerability – resources)

(Dwyer et al., 2004; UCLA Centre for Public Health and Disasters, 2006)

where, 'Risk' is the expectation or likelihood of loss.

'Hazard' is a condition which posing the threat of harm.

'Vulnerability' is the extent to which persons or things are likely to be affected.

'Resources' are the assets in place that help to reduce the effects of hazards.

According to Alexander (2017), hazard may be regarded as the pre-disaster situation, in which some risk of disaster exists, principally because the human population has placed itself in a situation of vulnerability. According to him the sequence of states pertaining to disaster is as follows.

Hazard → Risk → Threat → Disaster (impact) → Aftermath

The hazard is based on the properties intrinsic to the material and the level and duration of exposure. The extent of exposure can be influenced by the nature and quantity of the substance, proximity to the point of release, and the circumstances of release such as weather condition, topography, mitigation measures etc. (US EPA, 1999).

Vulnerability is the condition determined by social, economic, physical and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards

According to WHO (WHO, 2007), risk is a function of the hazards to which a community is exposed and the vulnerabilities of that community. However, that risk is reduced by the level of the local preparedness of the community at risk.

Risk is proportional to Hazard × vulnerability / level of preparedness

In the field of chemical incident management, vulnerability assessment also known as Community Risk Assessment (CRA), is an assessment of the potential effects of a chemical incident in the local area. Vulnerability assessment comprises of four steps (Wisner, 2002).

- The identification of hazardous chemical sites
- The identification of possible incident scenario and its pathway of exposure
- The identification of vulnerable population and environment
- Estimation of the health impact and the requirement for health-care facilities.

1.5 Risk Assessment

Risk is a function of the hazards to which a population is exposed and the vulnerabilities of that community. Risk may be expressed in several forms like risk contour, average individual risk, societal risk, etc. (QUEST, 2009). The most important step in the risk management process may be the risk assessment. Risk assessment is a systematic process for describing and quantifying the risks associated with hazardous substances, processes, action, or event (Covello & Merkhofer, 1993). Risk Assessment process is a combination of various stages which are mentioned below (Desai, 2008; Sengupta, 2007).

Hazards Identification: In which a hazard source, types, and location etc are identified in the concerned locality. Chemical hazards in general may result from fire, explosion, toxic release or combination of all these (NDMG, 2007). The major chemicals hazards identified in the industries are

- Fire hazard due to petroleum products such as diesel, kerosene, petrol, benzene, styrene, etc.
- Explosion or BLEVE due to LPG, ethylene, Propylene, C2/C3, Ethylene/ Propylene Oxide etc.
- Toxic release of materials like ammonia, oleum, chlorine, pesticides etc.

Probability Analysis: In this stage likelihood of each identified events are evaluated.

Consequence Analysis: Consequence analysis is the evaluation of the consequences and impact associated with the occurrence of postulated accident scenarios in a process. The Offsite Consequence Analysis (OCA) is the centre piece of the risk assessment. It is an estimate of harm to people and the environment beyond the facility's fence line that can result from a chemical release. The OCA answers four basic questions needed to understand a chemical hazard (US EPA document, 1999).

- What hazardous substances could be released?
- How much of the substances could be released?
- How large is the hazard zone created by the release?
- How much people could be injured?

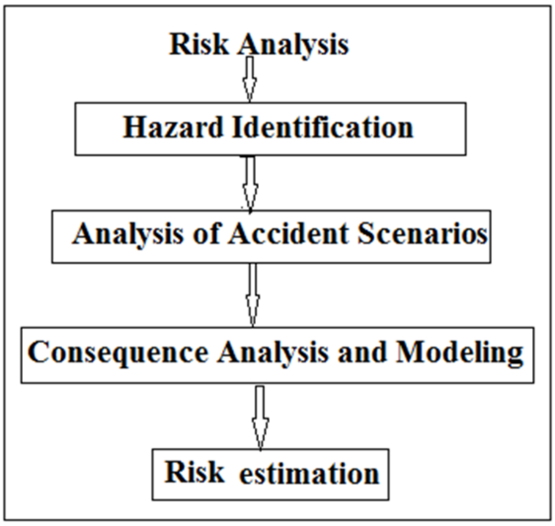

Figure 1.1. Process of Risk Analysis

Risk Analysis: In simple terms, it is a process for decision making under uncertainty. As part of the risk analysis the result of accident probability and consequence analysis are combined and overall risk associated with each event is calculated. The step by step process of risk analysis is given below in Figure 1.1.

In the case of hazardous industries, risk management is undertaken in an attempt to prevent incidents and to minimize their impact if they do occur. Its major link with emergency planning is in the treatment of risk (Emergency planning guidelines for hazardous industry, 1998).

Tixier et al. (2002), reviewed 62 risk analysis methodologies of industrial plants and suggested that there is not only one general method to deal with the problems of industrial risk. Though the interesting perspective of GIS had been examined for the risk assessment of natural hazards (Navarro et al., 1994; Gunes and Kovel, 2000; Zerger, 2002; Chen et al., 2003;), only a few numbers of works (Chang et al., 1997; Zerger and Smith, 2003; Cova et al., 2010; Ajay et al., 2014) identified the importance of GIS in the emergency management of chemical hazards. In contrast to the other works carried out in the past on risk assessment of chemical hazards in and around the country, this study makes use of the applications of GIS in risk assessment and in emergency management with the chemical dispersion model.

1.6 Properties of Liquefied Gases

Liquefied gases are gases that become liquid at normal temperatures when they are pressurized. Depending on the characteristics, the gases are introduced into the container under high pressure. The container is initially filled as a liquid. The liquid then evaporates to a gas and saturates the head space above the liquid through which it maintains liquid-vapor equilibrium. Ammonia, Chlorine, and LPG are stored as liquefied gases (Environment health and Safety).

Refrigerated liquefied gases, also known as cryogenic liquid, are kept in their liquid state at very low temperature and are extremely cold with boiling point below-1500^{0}C. The gases and vapor released from refrigerated liquefied gases can be extremely cold and may cause frost bites and blisters. When released from a container, even a small amount of refrigerated liquefied gases can expand into very large volume.

To liquefy a gas, it is necessary to cool the gas below its critical temperature and apply an appropriate pressure. The lower the temperature is below the critical temperature, the less the pressure required to liquefy the gases. Consideration must be given to the safety of both the site and the environment during the filling, storage and transport of compressed gases (Mathisen and Turkdogan, 2011). The main danger associated with the compressed gases arises from their pressure and their toxic or flammable properties.

The important problem related to liquefied gases is their behaviour on spillage deserve special treatment because their manufacturing and handling range from millions to hundreds of millions of metric tons on a world scale annually and make that much threat to life and properties. The liquefied gases may be toxic or flammable, although some of these gases have both the properties. Under adiabatic conditions the partial vaporization of these chemicals rapidly occur and the vaporization is accompanied by a decrease in temperature. Thereafter the rate of vaporization is determined by the rate of heat input from the surroundings and by the rate at which the vapour mixes with the ambient air (Gary et al., 1982). The diffusion of some heavy gases mainly depends on the ambient atmospheric conditions particularly the roughness of the surface and the mean wind speed (Eidsvik, 1980). The temperature structure of the atmosphere is the basis for ultimately determining the mixing characteristics of the atmosphere (Schnelle & Dey, 2000)

1.6.1 Reasons for the Gases becoming heavier than Air

There are several reasons for the gases becoming heavier than air like the high molecular weight (chlorine), low release temperature (liquefied natural gas), high storage pressure (failure of the container of ammonia and subsequent formation of aerosol) or chemical reaction of the released substance with water vapour in the atmosphere (the polymerization of hydrogen fluoride) (Markiewicz, 2006). Gases which are less dense than air can spread at low level when cold (e.g. release of ammonia refrigerant) (Carson, 2002).

1.6.2 Hazards of Liquefied Gases

The gases which become airborne must be considered more hazardous than handling of chemicals in liquid and solid forms because of some unique properties of these gases mentioned below (Carson & Mumford, 1994).

- Hazardous gases are often stored at high pressure, either under refrigerated conditions, or at ambient temperature. These liquefied gases are highly dangerous because of the potential source of high energy, low boiling point of the contents, ease of diffusion of the escaping gas, low flashpoint of highly flammable materials and the absence of visual and / or odour detection of leaking materials.

- Low boiling point materials can cause frostbite on contact with living tissue.
- these gases form clouds heavier than air and get suspended in the lower atmosphere for a long time causing dangerously toxic or anesthetic effects, asphyxiation, and rapid formation of explosive concentration.
- the flash point of a flammable gas under pressure is always lower than ambient temperature, and leaking gas can therefore rapidly form an explosive mixture with air.

All liquefied gas cylinders are hazardous in nature because of the high pressure inside the cylinder.

Liquefied gases can have more than one hazard properties. They are classified as below

- Corrosive reactions to human tissue and equipment
- Acutely toxic intermediated (poison) and Generation of flammable gas
- Oxidizing reaction
- Developing an asphyxiating environment

The leaked gas displaces oxygen in the air also, causing fire and suffocation, cause depletion of oxygen and also fumes generated by the fire may contain toxic gases.

1.7 Heavy Gas Dispersion Modeling

Many information systems useful to emergency planners and responders have been developed after the most serious disaster occurred in India, the Methyl Isocynate (MIC) release in vapour and liquid from the Union Carbon Plant in Bhopal. The manual methods used for modeling the dispersion of heavy gases is complicated, time consuming and difficult to predict the accurate concentration at different time and space. It can be clearly concluded that, if there were a proper method available to predict the dispersion of gas of Bhopal gas tragedy, the number of causalities could have been minimized. Fidler & Wennersten (2007) argues that the possible accidents should not be assessed using statistical methods. Commonly used consequence estimation methods involve simple assimilation of losses (without considering all the consequence factors) and time-consuming complex mathematical models, which leads to the deterioration of quality of estimated risk value (Arunraj & Maiti, 2009). Thus, dispersion models, especially developed for studying the dispersion of dense gases, are required to manage emergency situation (Nand & Olmos, 1996). Hence, there is an urgent need of heavy gas dispersion models, which can accurately predict the impacted area immediately after the gas release occur. CAMEO developed by National Safety Council, USA, CHEMSAFE of Germany, BATEX of France, and AUSTOX of Australia are some of them (Ross & Koutsenko, 1995). Number of other tools such as HGSYSTEM, ALOHA, SCIPUF, PHASTw, SLAB, and TRACEw are used to determine short-term acute effects on people (Witlox & Holt, 1999; NOAA & EPA, 19992; Sykes et al., 2004; Ermak, 1990; SAFER Systems, 1996). However, the basic formulation of the logarithmic wind profile such as variability of wind speed with height and the atmospheric stability correlations, used in these models, is identical to the traditional Gaussian models used for the dispersion of neutral or buoyant gases to obtain long term average concentration (Dharmavaram & Hanna, 20007).

Of these information systems, CAMEO provide desired types of information about hazardous substances, air dispersion modeling, mapping, and emergency planning information and computational capabilities (Wang et al., 2000).

To describe the heavy gas cloud dispersion in the atmosphere, some special models have been developed which are known as heavy gas dispersion models or dense gas dispersion models (Lees, 2012). These models include empirical, intermediate, and fluid dynamic models. The empirical and intermediate models used in software like PHAST, ALOHA etc are important components of emergency response system and risk assessment studies (Kashi et al., 2010). The modeling of dangerous substance dispersion by standard methods does not fully represent the behaviour or toxic or flammable clouds in obstructed areas such as street canyons. Therefore, the prediction from common software packages as ALOHA or other modeling software should be augmented (Bernatik et al., 2008). The heavy gas dispersion calculations used in ALOHA are derived from DEGADIS model (Jayajit & Marc, 1996; Spicer & Havens, 1989).

1.8 Emergency Planning and Preparedness

After Bhopal gas tragedy, the government felt an immediate need to be more cautious about handling of hazardous chemicals in different states of India. Immediately after the incident, the state governments in India started improving the emergency preparedness to control and mitigate the chemical disasters. Chemical emergency preparedness and planning is designated to minimize hazard to human health and the resulting environment from the unexpected release of hazardous materials. Preparedness is defined as measures and activities taken in advance of an event to ensure effective management to the impact of hazards (WHO Expert Consultation, 2007). Emergency Plan describes the emergency procedures that shall be followed by emergency management personnel when hazardous material is released.

Although many emergencies are often unexpectedly happening incidents, much can be done to reduce their effect by strengthening the response capacity. The health impact of chemical emergencies can be substantially reduced if the local emergency management authority and communities in high risk areas are well prepared. To achieve this there is a need of documented information in the form of emergency plan (Guidelines for On-Site and Off-Site Emergency Plans for Factories/ Industries in Himachal Pradesh, 2012).

The main objectives of an emergency plan are

a) to control the accident and if possible, eliminate it.
b) to minimize the effect of the accident on person and environment.

Knegtering et al. (2009) mentioned that chemical accidents are low probability incidents having high consequences. An incident that has the potential to cause injury and/or death beyond the factory boundary is often referred as an "Off-site emergency" (Off-site emergency Plan, 2006). To tackle any emergency due to hazardous chemicals, a systematic approach is required to plan and prepare the authorities and concerned agencies. Prediction of hazardous cloud dispersion in and around the industry is essential in the planning, preparedness, emergency evacuation, and provide an effective road map for the approach of the rescue teams to the accident site when chemical emergency occurs (Alhajraf et al., 2005).

For developing an emergency response plan, all the participants and departments should be identified and their roles, activities, resources, capabilities etc. should be established. All the members in the organization should be trained to deal with the emergency situation effectively. For the development of emergency response, the factors considered by the organization are

- Identification of resource person (as emergency controller at Emergency Control Centre (ECC))
- Identification of resource person (as incident controller at site)
- Resource person responsible for effective communication.
- Allocation of resources to mitigate the consequences
- Types of protective action like evacuation or shelter
- Consequence assessment report
- Responsible person for recovery action.

1.8.1 Essential Elements of the Emergency Management plan

- Identification of Hazardous chemicals.
- Release scenarios and its consequences in terms of heat radiation, over pressure, and intoxication.

- Preparation of plot and site plan incorporating the damage contours
- Identification of the vulnerable zone.
- Identification of important facilities in the vulnerable zone.
- Requirement of various departments for managing the emergency situation etc. (Ramabrahmam & Swaminathan, 2000).

1.9 Perspectives Related to Accidents

Countless industrial accidents involving hazardous chemicals had happened all over the world and they are occurring or may occur everywhere. The gathering of data from past accidents is very important to understand the consequences of such accidents and it helps the investigators to give reasons of why accidents occur. The list of chemical accident (Banerjee, 2003; NDMG, 2007) that had happened in India and other Countries in the recent past mentioned below provided an outline of the nature and types of chemical accidents we have encountered in the past.

- In Philips - Duphar, Netherlands (1963) less than 0.2 kg of TCDD (2,3,7,8, Tetrachlorodibenzoparadioxin) released at a pharmaceutical manufacturing company resulted in the death of 4 people.
- Flixborough (UK) explosion in 1974 took the lives of 28 people and 89 injured. And it damaged building and properties.
- Explosion and fire at Beek (the Netherlands) (1975) propylene release killed 14 people and caused significant damage.
- The Explosion occurred at a chemical plant in Seveso, Italy, 1976, released highly toxic TCDD (2,3,7,8, Tetrachloro

dibenzoparadioxin) to the atmosphere causing contamination to a wide area with health implications for the surrounding populace.

- The gas storage plant catastrophe near Mexio City at San Juan Ixhuatepec (1984) in which about 500 people perished and extensive damage occurred.
- The 1984 Bhopal gas tragedy in India is considered the world's worst industrial disaster. Over 500,000 people were exposed to methyl isocynate (MIC) gas and other chemicals and about 3400 were killed.
- The chemical spill at Basel (Switzerland) in 1986 severely contaminated the Rhine.
- At least 22 people were killed and many others injured following an explosion in the LPG storage area in HPCL refinery at Vishakapattanam. The explosion was a result of LPG pipeline leak.
- The 2000 EI Paso Natural Gas Pipeline explosion near Carlsbad, near Mexico that caused a death of 12 people.
- The accident of a train that took place on 6th January 2005 in Graniteville, South Carolina, in which 54 tons of chlorine released from ruptured tank cars, was one of the biggest chlorine transportation disaster.
- Chlorine gas leakage in GACL, Vadodara, Gujarat on 5th September 2002 killed 4 persons and injured more than 20 persons.

- On 20th December 2002 in IPCL, Gandhar, Gujarat chlorine release affected 18 workers and more than 300 villagers.
- Chlorine gas leakage from Orient Paper Mill, Madhya Pradesh affected more than 88 persons on 13th October 2003.
- More than 27 persons were badly injured by the chlorine leakage from Chemplast, Tamil Nadu on18th july 2004.
- Ammonia leak in Coromandel Fertilizer Ltd. Andhra Pradesh on 22.07.2005 caused injury to more than 55 persons.
- 6 persons were killed and more than 23 persons were injured during chlorine leakage from Kanoria Chemicals Industrial Ltd. Uttar Pradesh on 29th March 2006.

In addition of the above-mentioned incidents, numerous releases and accidents of lesser magnitude have been occurring in and around the country. Even though the catastrophic failure of the tank is not an unreal or remote possibility, this study emphasizes that the past history of chemical accidents, were due to accidental leaks.

1.10 Application of GIS in Chemical Emergency Management

Computerized expert software systems can provide the utilization of many types of spatial data and analysis, which in turn help to respond effectively to emergencies (Walker, 1985). Nowadays GIS is successfully used in some natural disaster monitoring, evaluation, and response system. In the case of chemical emergency, time is critical, as the chemicals are dispersed in the atmosphere very fast. In such a condition, an expert system can provide much information such as spatial location of the industry, spatial extent of chemical release in the given atmospheric condition, the population which needs evacuation etc. The Decision Support System (DSS) developed by Chang (1997), specifically illustrate the use of geographical information system (GIS) for the management of chemical emergency events in an urban environment and its technical focus is on integrating relevant spatial data with useful multi-scale models under a user-friendly interface in a GIS environment. GIS is an essential tool for rapid decision making in disaster management (Gobel et al., 2005).

CAMEO is one of the well-known hazardous models in use by HAZMAT teams in the USA (Cartwright, 1990). The chemical dispersion model provides a clear estimate of the dispersed area of the chemical. In order to spatially demonstrate this dispersed area on the surrounding environment, the spatial analytical functions of GIS can be used. The model output can be easily integrated into GIS as a different spatial layer. Using the spatial coordinate, the modeling result of chemical dispersion such as fire, explosion, and toxic results can be easily overlaid on the base map of GIS. Much essential geographical information such as nearby roads, streets, railways, waterways, sensitive areas, etc. must be included in the base map and through this geographical demonstration, emergency managers or responders can rapidly identify the risk area at a glance.

Another area of emergency management strategy where GIS has received much attention is evacuation planning. The assessment of vulnerable population using GIS will be very useful in estimating the extent of evacuation required during emergency. In contrast to natural hazard studies, the chemical hazard studies using GIS generally focus the vulnerability of human population, where the hazard is either implicit or primitively modeled (Cova, 1999). With the growing application of GIS, the development of new method for spatial population distribution modeling is given high importance (Reibel, 2007).

Li et al. (2010) proposed a GIS methodology for mapping human vulnerability to chemical accidents in the vicinity of chemical industry park. While representing population density data in choropleth maps, a main drawback is that the uninhabited area become misrepresented since the aggregation of census data results in the construction of statistical surfaces for inhabited areas only. In order to generate a more realistic model of population data, spatial database should be integrated with census data (Bajat et al., 2013). Eicher & Brewer (2001) stated that Dasymetric mapping depicts quantitative areal data using boundaries that divide the mapped area into zones of relative homogeneity with the purpose of best portraying the underlying statistical surfaces. In order to produce a finer distribution of population, Mennis (2003) defines dasymetric mapping as a kind of areal interpolation that uses additional / auxillary data to aid in the areal interpolation process. Dunn (1992) has analysed the role of GIS in generating alternative evacuation routes. To support the evacuation contingency plans around nuclear facilities, Silva et al. (1993) have developed and integrated an evacuation simulation model into GIS. For revealing potential evacuation difficulties in advance of disaster, Cova & Church (1997) describe a GIS-based method.

GIS aided expert system can also include large amount of many other geographical information using its spatial analytical capabilities. For instance, when a fire happen due to the chemical accident, responders need to know where fire hydrants are most closely located, which way is the shortest and more convenient for fire fighters to reach, etc. These kinds of function can be accomplished by means of GIS network analysis. All phases of emergency depend on data from a variety of sources. GIS provides a mechanism to centralize and visually display critical information during an emergency (Johnson, 2000).

1.11 Motivation behind the Research Work

All the chemical storage facilities in Cochin City come under suspicion that it poses a serious threat to the local community by its storage. In case of an accidental release of any of these chemicals in an uncontrollable level, it would lead to a disastrous and devastating consequence of annihilating all living beings in the city of Kochi. Among various hazardous chemical handling facilities in different parts of Cochin City, the chemical which become airborne have drawn special attention in chemical hazard history (U.S DHS & NIST, 2011). This is because, when they are released from a pressurized storage, it carries high energy and disperses in the air according to the prevailing atmospheric condition for a long distance causing damage to people and environment.

The airborne chemicals which are usually making hazardous situation are LPG, ammonia, and chlorine. These chemicals have larger volume of storage in the industries of Cochin City and small scale accident releases have been reported many times. Though considerable precautions and care have been made to prevent such accidents, accidents are still happening unexpectedly and at any time it may become a dreadful disaster scenario that can turn the Cochin City to another Bhopal. Thus, in addition to the preventive measures, specific emergency management system is also required to minimize the damaging effect of chemical accidents from the storage facility.

Dangers of chemical accidents cannot be predicted and it is situation specific. So, merely common emergency management plan cannot provide all the information needed to solve the evolving emergency. To strengthen the emergency management coordination of different agencies, various spatialy related data are essential. Only GIS can provide such information. Besides, a system that is capable of predicting air dispersion of hazardous chemicals must, above all, enable quick evaluation from the impact range of emitted hazardous substance and it can be used as a key tool for supporting decision makers in their rescue operation in case of emergency (Quaranta et al., 2002). Thus, by incorporating two software programmes, a method is demonstrated through this study for risk assessment and emergency management.

Study shows how GIS's analysis application can be useful in chemical disaster management and also show how chemical dispersion model can be integrated with GIS applications to estimate the risk associated with accidental release of hazardous chemical. It is expected that the methods used in this study will be very beneficial for the emergency responders for dealing with accidents in the limited time.

Selection of study area: This study is concentrated on the impact of release of some air borne chemicals, such as LPG, Ammonia and Chlorine. Four Industrial areas in Cochin City have identified with large quantities of LPG, ammonia, and chlorine storage facilities. Hence the study area classified in to four. As it is an airborne chemical, when it enters into the atmosphere, the area of diffusion is depending on various factors such as concentration of chemical released, prevailing atmospheric condition, land topology and wind speed and direction. As it is unpredictable the wind characteristics and atmospheric conditions prevailing at the time of accident, the area likely to be impacted (location of chemical handling unit and surrounding panchayath) by the chemical release has taken into account in vulnerability study and based on this the study area classified. The details of classification have given in chapter 2.

1.12 Objectives of the Study

The major objective of this study is to provide management strategies through risk assessment and vulnerability analysis using GIS. Specifically, the study aims to

- Identify the possible spatial extent of chemical release and its impacts.
- Estimate the vulnerable population coming under the impacted area
- Assess the resource availability for an effective preparedness and management of emergency situation
- Suggest technical actions for chemical hazard management

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Chapter 2

STUDY AREA AND METHODOLOGY DESCRIPTION

Contents

2.1 Study Area

2.1.1 Industrial Areas in Cochin City

In and around Kochi, there are a number of small, medium and large-scale industries. Medium scale industries in Kochi are concentrated along the foreshore areas and small-scale industries are spread all over the area. Large-scale industries are concentrated at the north-eastern and south-eastern areas, about 10-15 km off the central business district, in Eloor- Kalamassery belt and Ambalamugal- Karimugal belt. With the establishment of Goshree Bridge, which connects the western island to the mainland, large-scale industries with capital investment worth more than ₹ 15,000 crores are at various stages of implementation at Vallarpadam-Puthuvyppu area (The Island north of Kochi). The Kakkanad regions of the City is concentrated with IT industries (CDP, 2012).

2.1.2 Chemical Hazard Vulnerability in the Cochin City

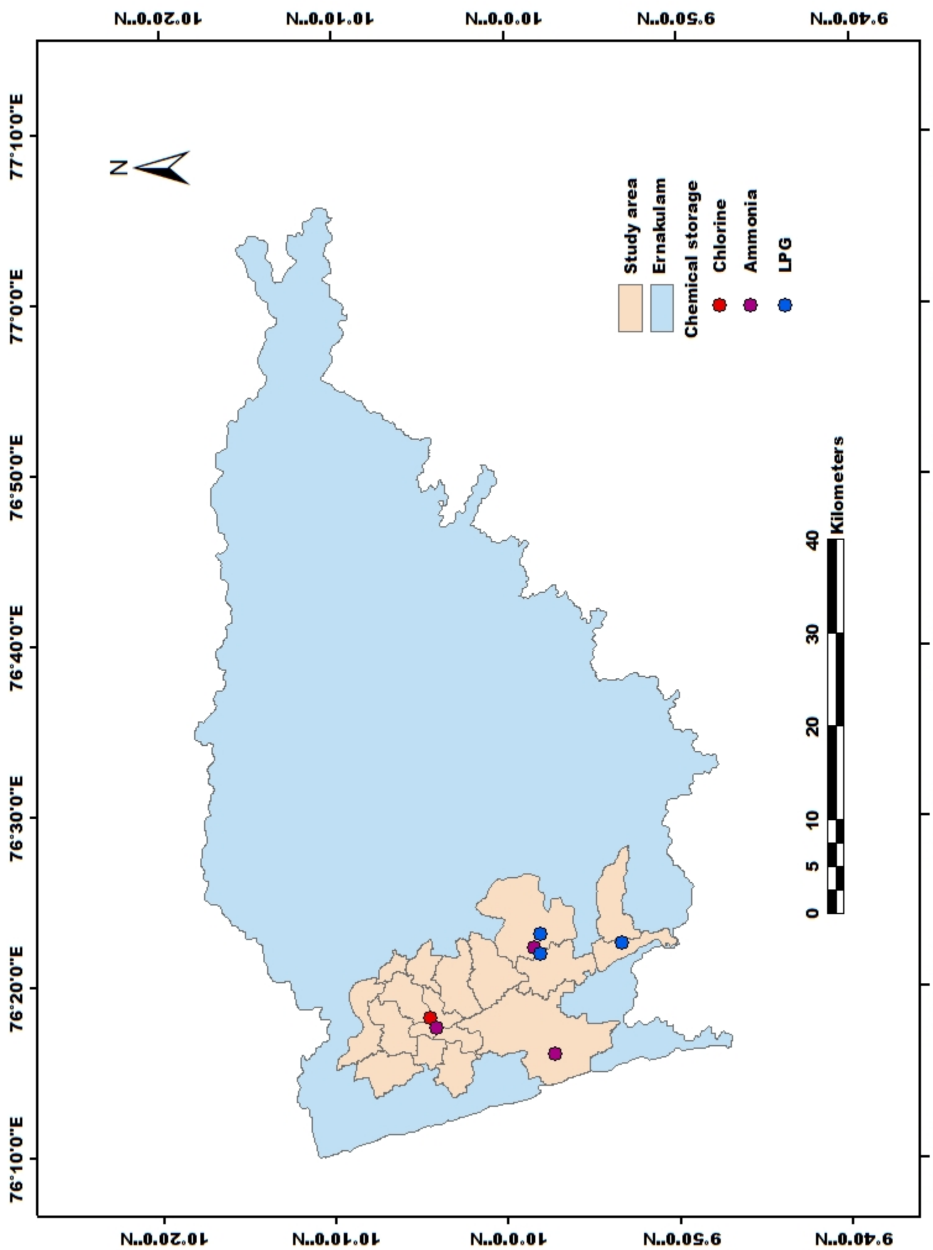
The potentiality of creating a vulnerable situation associated with the accidental release of hazardous chemical is greatest in urban area where population density, transportation and economic activities are very high. Kochi is considered as the commercial capital of Kerala and it is growing very fast with a major concentration of chemical and petrochemical industries and oil refineries. In Ernakulam District, Cochin City and nearby areas have a prominent chemical industrial component and is a highly industrialized area supporting a wide range of chemical, mechanical, electrical and other sectors of industries.

The chemical hazard potential in Cochin City is based on the MAH (Major Accident Hazards) units. The main clusters of MAH units in Cochin City and nearby areas are Willingdon Island cluster, Kakkanad Irumpanm Cluster, Udayamproor, Ambalamugal cluster, Udyogamandal, Kalamassery cluster, Puthu Vypin cluster.

Though there are number of industrial clusters in Cochin City and different hazardous chemicals are handled in the industries, this study is concentrated on the hazards related to LPG, Ammonia and Chlorine. The industries which handle these chemicals are mainly distributed among four major places in Cochin. So, based on the location of the industries and area likely to be impacted, the study area is classified into four. They are,

Study area-I: Eloor and adjoining area
Study area- II: Willingdon Island and adjoining area (Cochin Corporation)
Study area- III: Ambalamugal and adjoining area
Study area- IV: Udayamperoor and adjoining area

More details of each study area are described in chapter 4. The Map 2.1 given below shows the whole study area and locations of chemical storage facilities.



Map 2.1. Location of Composite Study Area

2.2 Methodology

2.2.1 Data Collection

This disaster management study is mainly based on the integrated application of spatial and non-spatial data. So, both primary and secondary data were collected from the concerned departments. The collected data were in the following aspects.

a) Meteorological Data

Meteorological data regarding humidity, temperature and wind were collected from Indian Meteorological Department (IMD).

b) Panchayaths and Ward Boundaries

Panchayath wise population and ward boundaries relevant to the study locations were collected from concerned panchayaths as well as municipal offices of Cochin City. The data collection covered 5 Municipalities (Eloor, Kalamassery, Trikkakara, Aluva, and Tripinithura), 9 Panchayats (Kadungalloor, Cheranallur, Varappuzha, Kadamakkudy, Alangad, Choornikkara, Vadavucode-Puthencruz, Udayamperoor, and Mulanthuruthy) and Cochin Corporation.

c) Information from MAH Units

Information related to handling of hazardous chemicals, their storage conditions, quantities, safety measures, etc. were collected during the site visits of all MAH units.

d) Resource Data

The resources for management of chemical emergency such as police stations, fire stations, government and private hospitals in the vicinity of the chemical industries were identified and necessary information were collected from them.

e) Collection of Spatial Data

Spatial data in terms of latitude and longitude were collected for all the MAH industries and other resources using GPS.

2.2.2 Risk Assessment and Emergency Management

This risk assessment and emergency management study mainly involves the following three steps.

1) Hazard Identification and Consequence Analysis
2) Vulnerability Analysis
3) Emergency Preparedness and Planning

Each of the above three steps are organized as each chapter. The methods adopted to achieve each step are summarized below.

2.2.2.1 Hazard Identification and Consequence Analysis

Hazard identification is carried out by adopting the checklist method including field visit and interviewing the experts in the industries. During the field visit all the available data regarding the hazard possibilities and hazardous nature of LPG, Ammonia, and Chlorine storage facilities were collected.

After gathering the required information, consequence analysis of these hazardous chemicals was carried out using the air dispersion model ALOHA (details of ALOHA are described below). Consequence analysis, which include the performance of air dispersion modeling of identified accidental release scenarios of hazardous chemicals into the atmosphere is essential to assess the severity of risk (Spellman, 1997), and it is one of the vital part of determining the magnitude of Emergency Response Plan.

The performance of the consequence analysis and its results depend upon the accuracy of the information provided as input. For this purpose, various data, regarding handling of hazardous chemicals, their storage condition, quantities, dimensions of the storage tank, etc., were collected from the concerned departments.

Consequence analysis was carried out for all identified hazards associated with LPG, Ammonia, and Chlorine. The major hazards modeled for LPG are its impact area developed following the release and BLEVE (Boiling Liquid Expanding Vapor Explosion) effect (complete explosion of the tank). The hazard modeled for Ammonia and Chlorine are its toxicity impacted area when it is released from a storage container.

Atmosphere largely influences the dispersion of released chemicals. As it is not able to predict when the accident will occur and what the atmospheric conditions will be in the area at the time of accident, it is necessary to prepare separate scenarios for different types of hazardous chemical substances in different time period. Even a change in one variable may alter the impact zone. Bubbio & Mazzarotta (2007) identified a number of hazardous scenarios by varying the value of important atmospheric parameters such as ambient temperature, wind velocity, Pasquill stability class, release rate etc and indicate that no generally applicable rule can be given for the influence of the basic input parameters on toxic gas dispersion in the atmosphere. As it is difficult to model the consequences considering all the changing atmospheric conditions, atmospheric situations at four different time periods of a day are taken into consideration and analysis done by using the varying value of atmospheric parameters respective to the time of a day. The predominant weather conditions prevailing in the study area at these four different time periods was chosen from the IMD (Indian Meteorological Department) weather data for consequence analysis. Each of the four time period is considered as the four different scenarios. Thus, four scenarios were modeled for each of the identified hazard associated with LPG, ammonia, and chlorine and difference in the impacted distance is assessed. From the result of modeling, the scenario which shows the largest impacted distance is taken as the worst-case scenario.

a). ALOHA (Areal Locations of Hazardous Atmospheres)

ALOHA is the air hazard program in the CAMEO software suite. It was developed and supported by the Emergency Response Division (ERD), a division within the National Oceanic and Atmospheric Administration (NOAA) in collaboration with the office of Emergency Management of the Environmental Protection Agency (EPA). ALOHA is widely used to simulate airborne release of hazardous chemicals. It is accepted for off-site consequence analysis and responds to chemical emergencies in California, Delaware, New Jersey and Nevada. ALOHA deals specifically with human health hazards associated with inhalation of toxic chemical vapor, thermal vapor, thermal radiation from chemical fires, and the effect of the pressure wave from vapor cloud explosions. Based on information about a chemical release, ALOHA source strength models estimate how quickly the chemical will escape from a tank, puddle, or gas pipeline and from a hazardous gas cloud. It also estimates how release rate change over time (Jones et al., 2013)

ALOHA's database includes a chemical library about the physical properties of approximately 1,000 common hazardous chemicals. The result may be displayed graphically using an ESRI-based extension, called ALOHA Conversion Analysis and Summary (ACAS), designed to integrate the plume-modeling results directly with ArcGIS (Gobel et al., 2005).

b). Dispersion Model in ALOHA: ALOHA incorporate two air dispersion models: Gaussian dispersion model and heavy gas dispersion model. The Gaussian dispersion model of ALOHA predict how gases that are about as buoyant as air will disperse in the atmosphere. The neutrally buoyant gases have about the same density as air. According to this model, forces that move the molecules of a released gas through the air are wind and atmospheric turbulence, so as an escaped cloud is blown downwind, "turbulent mixing" causes it to spread out in the crosswind and upward directions.

The Heavy Gas model is appropriate for pollutant clouds with densities greater than the ambient air and are affected in a significant way by gravity. When gases heavier than air are released into the atmosphere, it behaves very differently than neutrally buoyant gases. Heavy gas first slump or sink after release, and then its gravity spreads when it travels in downwind direction. So, it moves slightly upwind than the release sources and after travelling at certain distance, the gas starts to dilute. When its concentration reaches below 1 percentage than the surrounding air, the released gas behaves like a buoyant gas. This depends on the amount of gas release. Higher the amount of gas release, greater will be diluted (Jones et al., 2013). In ALOHA, the Heavy Gas dispersion calculations are based on the DEGADIS model (Spicer & Havens, 1989) because of its general acceptance and the extensive testing that was carried out by its authors.

The model is able to calculate the outcome of an accidental release of a chemical in the air and depict the impacted area on maps in order to have a better understanding of the situation and the spatial extent of the impacted area. The model can keep the track of a chemical release from vapor cloud formation in the air, through flammable area and finally fire and explosion.

ALOHA shows the result (area affected by chemical release) in the form of threat zones. The size and shape of the threat zone is represented either in the form of a circle or approximated to a triangle. The size and shape of the area affected by a sudden explosion of chemical will approximate to a circle. The shape and orientation of the area affected by a toxic release will be governed by the wind speed and direction. The wind will produce a roughly triangular shape. The higher the wind speed, the smaller the apex angle. There does not seem at present to be any simple law which will relate the area affected to an exponential function of the mass of material spilled (Gray et al., 1982).

Limitations of ALOHA: The model does not incorporate the effect of chemical reactions, particulate, chemical mixture, and hazardous fragments. ALOHA is limited in its ability to account for the effects associated with terrain and building. The wind field used in ALOHA does not vary with time of horizontal position but does vary with elevation. It does not resolve steering effects from features in the terrain or buildings. It does not consider very low wind speeds or calm conditions, only applicable where the wind speed is greater than 1 meter per second (at 10 meters height).

2.2.2.2 Vulnerability Analysis

The vulnerability analysis is carried out in the 4th chapter, which mainly focuses on the human vulnerability in the vicinity of hazardous chemical storage facility. Population vulnerability in an area due to chemical release depends upon various factors such as, population density around the plant, hazardous nature of the released chemical, spatial extent and direction of the chemical released, and availability of emergency management measures. Spatial extent of impacted zones of accidental release of LPG, ammonia, and chlorine under the given four scenarios were estimated (chapter 3) and is used to assess the vulnerable population. Of the four scenarios modeled for each hazardous outcome of the chemical, only the worst case (scenario which shows largest impacted distance) was taken into account to assess the vulnerable population.

Many of the past studies uses merely the population density in an area to assess the vulnerable population. This kind of assessment do not give a clear idea about the exact location of the densely populated areas in an impact zone. And when it is depicted through a map, even the uninhabited area may be highlighted as an inhabited area. This may mislead the emergency management personnel during emergency management measures. Therefore, more specific population distribution in an area is important. To solve this problem, this study adopted a more realistic depiction of population distribution method; called Dasymetric mapping method. The dasymetric mapping method gives a clear estimation of population distribution pattern in an area (more details are given in chapter 4). The output of dasymetric mapping calculate the population for each Landuse-landcover cell.

To implement dasymetric mapping method in ArcGIS, various layers were prepared as an input information, such as vector and raster layers of Landuse-Landcover (LULC) and ward boundaries of each administrative area. The attribute data of population of each ward were also incorporated with it. After preparing all the input information, to calculate the population for each LULC cell (pixel), a modified equation of Holloway et al. (1997) was used.

$$P = ((RA* (PA/PA))* N/E) / AT$$

Where,

'P' is the population of the cell,

'RA' is the relative density of a cell within LULC type A,

'PA' is the proportion of LULC type A in the ward

'N' is the actual population of ward

'E' is the expected population of ward calculated using relative densities.

'E' equals the sum of the products of relative density and the proportion of each LULC type in each ward.

AT is the total number of cells in the ward.

PA / PA, which cancels each other out, is to calculate the unit area in the grid-based dasymetric mapping. The output population estimated was not for each mapping unit (LULC type), but for each cell. The size of the cell was obtained from ArcMap and divide the area of the ward by cell size to get the value of AT.

The analysis to calculate population distribution is carried by using various analytical tools available in the tool box of Arc map. The Spatial Analyst tool includes Reclass, Zonal, Map algebra etc. are used as various analysis functions as a part of dasymetric mapping. In conversion tool, vector to raster conversion and in analyst tool, extract, overlay, and proximity, all were the unavoidable analytical tools in dasymetric mapping.

After preparing population distribution maps, the threat zones (Chemical release impacted area) of worst case scenario is integrated with Arc map and overlaid on population distribution. Then using the areal interpolation method, vulnerable population (population within the impacted area of chemical release) was calculated. Areal interpolation is a kind of re-aggregation of data from one set of polygons (the source polygon) to another set of polygons (the target polygons). Area weighted interpolation, a simplest type of areal interpolation, is used here to calculate the vulnerable population (details given in chapter 4).

2.2.2.3 Emergency Preparedness and Planning

The uniform structure and varying content of the emergency management and planning were studied from the guidelines prepared by Ministry of Environment and Forest (MoEF), Government of India.

Reviewing of Off-site Emergency Plan of Ernakulam District, 2006, provided an insight of roles and responsibilities of various agencies involved in chemical disaster management.

This third section of this study describes the following areas.

A. Responsibilities of various Agencies for Chemical Emergency Management

Duties and responsibilities of the following persons or agencies are given in detail in this section

B. Mapping of Facilities or Resources available in the City for Effective Hazard Management

This section describes the emergency resources available near the study area for taking an immediate action in case of an accident. The resources needed for the management of chemical emergency is identified, mapped and details about the facilities are provided. To achieve this, ground truthing survey was carried out throughout the study area using GPS. Also collected were various information regarding the chemical emergency management from the concerned government officials.

C. Identification of people to be evacuated

The factors considered to decide about evacuation are amount of released material(s), health hazards, dispersion pattern, wind direction, rate of release, and potential duration of release. The outcomes of chapter 3 and 4 are utilized here to identify the area which needs immediate evacuation. Applications of Arc map tools also used here for mapping various locations, tracing the road networks, displaying vulnerable area etc.

D. Emergency Response Guidelines for LPG, Ammonia, and Chlorine Releases.

This section describes the First-aid measures, Fire-fighting measures and modes, leaks and Emergency Measures for LPG, Ammonia, and Chlorine. Some precautionary measures are also suggested here.

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Chapter 3

RISK ASSESSMENT - IDENTIFICATION AND CONSEQUENCE ANALYSIS USING ALOHA

Contents

3.1 Introduction

During the last few decades the hazards and risks associated with the chemical industries are often catching up with their rapid growth and development. The hazardous nature of chemicals differs, some may be flammable, explosive, toxic or corrosive depending on their inherent properties. Hazard is an intrinsic property of the chemical, whereas risk is an extensive property, which depends on the quantity of chemical released and the resulting exposure (Mackay et al., 2001). Looking back to the history of chemical accidents, most of them have limited effect, but infrequently some of them lead to a disaster like the one in Bhopal, in 1984, which affected lakhs of people, 1997 LPG explosion in Vizag refinery which claimed the death of 56 people, and LPG tanker explosion occurred at Kerala, in 2012, made victim of 41 people (Nair, 2005; Rodante, 2003; Pramod, 2013). Therefore, risk assessment of accident scenarios that harm people and the environment is necessary to take the precautionary measures and to minimize the impact.

Risk assessment and prediction of large scale chemical accidents are not easy to accomplish, due to the uncertainty of the kind and the amount of hazardous materials present at a certain time and place (ILO, 1990). It should include the description of the location and extent of hazard that affect the jurisdiction (American Health Care Association). Since risk assessment is a probabilistic approach, different scenarios have to be modeled varying the value of some of the most important input parameters which affect the dispersion of the chemical. The higher the number of scenarios modeled, the higher the accuracy of result (Bubbio & Mazzarotta, 2007). The target of risk assessment is to identify potential accidents, analyse the causation and evaluate the effects of the risk reduction measures (Selvan & Siddqui, 2015). In order to determine the magnitude of any Emergency Response Plan, it is necessary to simulate a large scale gas release (Gas dispersion, 2010).

As a first stage of emergency management study, this chapter aims to identify the hazard associated with the storage of LPG, Ammonia, and Chlorine in different MAH (Major Accidental Hazard) units in different locations of Cochin City and analysed different hazard scenarios using the air dispersion model ALOHA.

There are several studies focusing on the consequences of accidental release of LPG using ALOHA [Renjith and Madhu, 2010; Ramprasad et al., 2014]. This software is designed to respond in short time and give accurate results by checking the user's input errors (Mehdi et al., 2017). The model has been used in numerous studies to analyze the downwind concentration of various hazardous chemicals such as

Ammonia, LPG, Chlorine, Benzene etc (Inanloo and Tansel, 2015, Angela et al., 2010, TSENG et al., 2012, Renjith, 2010) reveals its advantages in consequence modeling

3.2 Identification of Major Hazards associated with LPG, Ammonia, and Chlorine.

In risk assessment studies the first key step is hazard identification. The hazard identification study is conducted with appropriate checklists which cover all hazard information. It was based mostly on interviews, documentation reviews, and field inspections from which the hazard source, types, and locations were identified. During the site visits, discussions with the plant operators and managers helped to understand information such as storage condition of chemicals, quantity of storage, and other physical and chemical characteristics of chemical. The hazard identification study also identified the possible fire, explosion and toxic release scenario associated with LPG, Ammonia, and Chlorine. The results are described below.

3.2.1 Properties and Hazardous Nature of LPG

3.2.1.1 Physical and Chemical properties of LPG

LPG is handled in liquefied form under pressure. LPG is a mixture of commercial butane (C3H8) and commercial propane (C4H10). At atmospheric pressure and temperature LPG is a gas and is 1.5 to 2.0 times heavier than air. Under moderate pressure it gets readily liquefied. Properties of LPG are given in table 3.1 (ELGAS)

Table 3.1. Properties of LPG (Propane)

Physical state	Gas at ambient condition (Liquid under pressure)
Appearance	Colorless & odorless (smell due to mercaptan dosing)
Boiling point	-42°C
Melting-Freezing point	-188°C
Molecular weight	44.097kg/kmole
Specific gravity of the liquid LPG	0.495 (25°C)
Gaseous density	1.898kg/m^3
Energy content	25mJ/L
Gaseous expansion	1L(liquid)=0.27 M^3(gas)
Flame temperature	1967°C
Limit of flammability	2.15% to 9.6% LPG/air
Auto ignition temperature	470°C

3.2.1.2 LPG Storage

LPG's storage options include both spherical LPG pressure vessels and cylindrical vessels, also called bullet tanks. Of the identified three locations of LPG storage Industries, two are having spherical storage (Kochi Refinery and Hindustan Organic Chemicals Limited)) and one has bullet tanks (Indian Oil Corporation Limited). While LPG has the threshold storage quantity of 15 MT, 1400 MT of LPG is stored in Kochi Refinery and HOC stores 1540 MT. Out of the 10 bullet tanks installed in IOC LPG bottling plant, three stores 100 MT each and seven have a capacity 150 MT each. The consequence analysis is carried out for each of these three storage capacity in varied atmospheric conditions.

The LPG storage tanks are neither insulated nor refrigerated, so the tank contents are at ambient temperature. Since the ambient temperature is significantly above propane's boiling point, the chemical is highly pressurized. Whenever a liquid is confined in a closed vessel at a temperature greater than its boiling point, there will be a measurable pressure against the confining walls. The saturated vapor pressure of LPG is determined by temperature. As temperature rises, the pressure in vessels containing LPG increases sharply. The design pressure for such vessels therefore, is close to the gas pressure at maximum possible ambient temperature. At temperature differences up to 40°C, the maximum degree of filling of LPG pressure reservoirs with liquid phase is 85% and at higher temperature differences, it is even lower.

3.2.1.3 Hazardous Properties of LPG

LPG is a highly flammable gas which may result in fire and explosion in case of leaks from the storage container. Since LPG vapor is heavier than air, it would normally settle down at ground level when it is released into the atmosphere and can spread for long distances along the ground. LPG has an explosive range considerably narrower (LEL 1.8% UEL 9.5 % volume of gas in the air), than other common gaseous fuels (Matheson Gas, 2013; Sanjay et al., 2016) indicating potential hazard of LPG vapor if accumulated in low-lying areas. LPG will not ignite on its own at normal temperature because the auto-ignition temperature of LPG is around 410-580 °C.

Under atmospheric pressure and at low concentrations, petroleum gases are not toxic to humans. However, at high concentrations, hydrocarbons displace oxygen and act as an asphyxiant. Another effect of LPG is that it causes cold burn to the skin owing to its rapid vaporization. As LPG is a highly flammable gas, there are many possibilities of hazards like vapor cloud explosion (VCE), BLEVE (Boiling Liquid Expanding Vapor Explosion), and fire (Sandeep & Rajiv, 2015). Number of case studies have reported the fire and explosion hazards of LPG (Bariha et al., 2013; Bubbico & Marchini, 2008; Elatabani, 2010). In the nearest past (2012 and 2014) LPG leaks were detected two times at Udayamperoor plant but major disasters were averted (The Hindu, 2012; Madhyamam, 2014). It is reported that in both the cases the leaks were detected through the pressure valve, while the fuel was being transferred from the bullet tanker to the storage tanker.

Fire Hazard of LPG: If LPG escapes from a tank and does not immediately burn, a flammable vapor cloud will form in the atmosphere. Potential hazard from LPG which is not burning as it leaks from a tank are downwind vapor cloud flash fire, and overpressure (blast force) from vapor cloud explosion. The flammable area is assessed in between two threshold values defined by the Lower Explosive Limit (LEL) and the Upper Explosive Limit (UEL) of the chemical. The vapor cloud disperses in the atmosphere as it travels downwind and parts of the cloud where the concentration is within the flammable range (between the LEL and UEL) will burn when it encounters an ignition source. If vapor concentrations in the air are within this range (LEL- UEL), the area is considered as a flammable area, but burning / explosion starts only if the vapor comes in contact with an ignition source. Beyond these limits the ignition will not happen because below the LEL the concentration of the chemical is too small to start fire and above the UEL the amount of oxygen needed to assist the ignition will not be enough to begin a fire. Potential hazard associated with a rapid burning of flammable cloud include thermal radiation, smoke, and toxic byproducts from the fire.

Explosion Hazard of LPG (BLEVE): Boiling Liquid Expanding Vapor Explosion (BLEVE) is a physical explosion of a tank containment and can affect any liquid contained in a closed vessel at a temperature significantly higher than its boiling point at atmospheric pressure (AIChe/ CCPS, 2000; Salla et al., 2006). The BLEVE-Fireball model in ALOHA is a solid flame model and is based on studies of fireballs resulting from BLEVEs involving flammable gases liquefied under pressure and stored at ambient temperature (AIChe, 1994).

BLEVE occurs if the metal is struck by an object. The vapor tries to leak through the opening when the tank structure collapses, resulting in a decrease of pressure inside the tank. Due to the drastic lowering of pressure the chemical inside the tank boils rapidly and the vapor formation increases. The escaping vapor carries high pressure and in the presence of fire source it leads to explosion and produce shock waves. This results in complete destruction of the tanks structure and surrounding areas.

Fire near tanks is another reason for BLEVE. When a container is exposed to sustained heat – say from the heat radiation emanating from a nearby fire, the tank is thermally stressed and the internal pressure rises. If the pressure relief valve fails to adequately relieve the pressure, the tank explodes from the combination of heat and pressure. If the chemical inside the tank is above its boiling point when the tank structure collapse, the chemical completely vaporizes and forms gas clouds in the atmosphere. Much of the fuel, in the form of both liquid droplets and gas, is thrown into the air and ignites. The fire burns at the surface where sufficient air can mix with the fuel resulting in the formation of fireball burns for tens of seconds and often lifts into the air. The expansion process provides the energy for propulsion of the container.

The study modeled the two hazardous outcomes of LPG: -

a) Flammable Area of Vapor Cloud, and
b) Boiling Liquid Expanding Vapor Explosion (BLEVE)

3.2.2 Properties and Hazardous Nature of Ammonia

3.2.2.1 Physical and Chemical Properties of Ammonia

Anhyrous ammonia (compound of nitrogen and hydrogen) is a clear colorless gas with pungent odor, which is used in a variety of industrial processes and in agriculture. It is a gas at normal temperature and pressure but it can be liquefied by application of modest pressure or by cooling to low temperature (240^0 K) (Bennett et al., 1982). Properties of Ammonia is given in table 3.2 below

Table 3.2. Properties of Ammonia

Chemmical Formula	NH_3
Physical state	Gas at ambient condition
Appearance	Colorless gas
Odor	Strong pungent odor
Boiling point	-33.34°C
Melting-Freezing point	-77.73°C
Molecular weight	17.031g/mol
Vapor pressure	857.3 kPa
Gaseous density	0.769 kg/ m^3 (STP) (0.589 times lighter than air)
Solubility in water	31% W/W (at 25°C)
Gaseous expansion	Liquid ammonia expands 850 times when evaporating
Limit of flammability	15%- 25%
Auto ignition temperature	651°C

3.2.2.2 Ammonia Storage

Ammonia is commonly stored in three ways, they are (a) stored at ambient temperature and equivalent pressure in cylindrical vessels, (b) stored under pressure, (c) stored at atmospheric pressure under cryogenic conditions (Major hazard control, 1993). In the identified three locations of ammonia storage facilities in the City [FACT-WI (Willingdon Island), FACT-CD (Ambalamugal), FACT-PD (Eloor)], ammonia is stored as a liquid under cryogenic condition (low temperature) in a refrigerated system by reducing the temperature -33.4°C. The cylindrical storage tank is flat bottomed and double walled with storage capacity 10000 MT (Willingdon Island) and 5000MT (Ambalamugal and Eloor).

3.2.2.3 Potential Hazardous Properties of Ammonia

When evaporating from liquid form, ammonia expands by 850 times its own volume and spread to larger areas including the atmosphere. Though it is lighter than air, because of its tremendous affinity to water, it reacts immediately with humidity in the air and may remain close to the ground. Moreover, chemicals released from a cryogenic state can form heavy gas clouds (Zohuri, 2017).

Anhydrous ammonia is classified by the Dept. of Transportation as nonflammable, since its auto-ignition temperature is 651°C but ammonia vapor in high concentration, 16 to 25 percent volume in air will burn if it comes into contact with an ignition source (OSHA, 2016; Ramabrahmam et al., 1996). Outside conditions that would support these vapor concentrations are rare, but if it occurs in a confined space, it may result in an explosion. As the probability of such event is low, ammonia installations are not regarded as significant fire hazard (Prasun, 2011).

Fire hazard of ammonia will increase in the presence of oil or other combustible materials. The low IDLH (300 ppm) and TLV-TWA (25 ppm) values of ammonia indicates that it is highly hazardous in nature (Lewis, 1996). Ammonia is not a poison, but it is a toxic substance since, when ammonia contacts moist surface, it forms ammonium hydroxide and produce heat. Because of its hygroscopic character, ammonia readily migrates to moist areas of the body such as eye, nose, throat, and moist skin area and can result in immediate damage (severe irritation and burns) (USEPA, 2001; National Research Council, 2008). The odor threshold of ammonia is between 5-50 parts per million (ppm) and permissible exposure is 50 ppm averaged over an 8-hour period (USEPA, 2001; OSHA, 1992). The exposure levels and effect on human body of ammonia is detailed in table 3.3.

Table 3.3. Ammonia Exposure Levels and the Human Body

Exposure (ppm)	Effect on the body	Permissible Exposure
50 ppm	Detected by most people	No injury from prolonged or repeated exposure
134 ppm	Irritation of nose and through	Eight hours maximum exposure
700 ppm	Coughing, sever eye irritation, may lead to loss of sight	One-hour maximum exposure
1700 ppm	Serious lung damage, death unless treated	No exposure permissible
2,000 ppm	Skin blisters and burns within seconds	No exposure permissible
5, 000 ppm	Suffocation within minutes	No exposure permissible

(Source: Nowatzki, 2011).

In recent past, January 2018, a leakage was detected in Willingdon Island Kochi, while the liquefied ammonia was being transferred from the tanker and fourteen persons suffered breathing difficulties following the leakage (The Hindu). The incident in Kochi occurred after a slightly bigger ammonia leak was detected in Goa on January 19, 2018, when a gas tanker turned upside down. Another leakage was reported in Kochi, on May 2016, while ammonia was transported in a barge, causing hospitalization of a large number of people (Mathrubhumi, 2016). All these incidents remind us the toxic hazardous potential of ammonia.

Considering the toxic hazard potential of ammonia, the study modeled the toxicity impacted area of ammonia for three locations in Kochi.

3.2.3 Properties and Hazardous Nature of Chlorine

3.2.3.1 Physical and Chemical Properties of Chlorine

Chlorine, a yellow green gas, is easily recognizable with an intense pungent smell in its natural state and with a molecular weight of 70.9 making it more than twice as heavy as air (Watt, 2002). Chlorine has a normal boiling point of -34°C and is therefore a gas, but it is frequently handled as liquid gas under pressure (Mannan, 2005). Chlorine is slightly soluble in water, approximately 1 percent at 9.4°C. Above this, its solubility decreases with rise in temperature up to the boiling point of water at which it is completely insoluble (Indian standard, 1997). Chemical and Physical properties of chlorine is given in table 3.4.

Table 3.4. Properties of Chlorine

Chemical Formula	Cl_2
Physical state	Gas at ambient condition
Appearance	Gas is greenish yellow and liquid is clear amber
Odor	Penetrating and irritating smell
Boiling point	-34.05°C
Melting point	-101°C
Molecular weight	70.9g/mol
Gaseous density	3.213 kg/m^3(About two and half times as dense as air)
Solubility in water	Slightly soluble in water
Expansion Ratio (liquid to gas)	450-500
Limit of flammability	Not flammable
Auto ignition temperature	Not flammable

3.2.3.2 Chlorine Storage

Travancore Cochin Chemicals (TCC), located in Eloor is a public-sector undertaking owned by the Government of Kerala, engaged in the manufacture and marketing of Caustic Soda, Chlorine and allied chemicals. This is the only industry identified in the City, which handles bulk storage of chlorine. The plant stores 50 MT of chlorine while its threshold quantity of 10 MT. Chlorine is liquefied and stored in a horizontal cylindrical tank with 7.31 m length and 2.8 m diameter. A partial pressure of 3kg/cm^2 and temperature of -5°C are maintained in the storage tank.

3.2.3.3 Hazardous Properties of Chlorine

Chlorine is a highly reactive chemical, which is the reason that chlorine is so important to industry, being used in the manufacturing of wide variety of chemicals and materials. Though chlorine is neither explosive nor flammable, it is almost as efficient an oxidizer as oxygen. Therefore, any ordinary combustible or very flammable materials may become explosive when mixed with chlorine (Routley, 1991).

The significant hazard associated with chlorine is its inhalation by person or animals. Therefore, emergency handling must be focused on this hazard (Bennett et al., 1982). Chlorine is classified as both toxic and poisonous. Chlorine gas poisoning is illness resulting from the effects of exposure to chlorine beyond the threshold limit value. The threshold limit value (TLV) of chlorine is 1ppm and 35 ppm for a short period is considered to be dangerous. Chlorine can be smelt at concentration of about 1/2 ppm or less so that persons exposed normally try to escape (Ruj & Chatterjee, 2012). Its long term occupational exposure standard is 0.5 ppm. Many organic materials react with chlorine explosively and at higher temperatures many metals will burn in chlorine (Mannan, 2005). The extent of injury following chlorine exposure depends upon concentration and duration of exposure as well as the water content of the tissue involved. Chlorine exposure threshold and effect on human is given in table 3.5 (OXY Occidental Chemical Corporation, 2014).

Table 3.5. Chlorine Exposure Threshold and Effect on Humans

Exposure Level (ppm)	Effect on Humans
0.2-0.4 ppm	Odor detection (some tolerance develops)
1-3 ppm	Mild mucous membrane irritation (can be tolerated 1 hour)
5-15 ppm	Moderate irritation of upper respiratory tract
30 ppm	Immediate chest pain, vomiting, dyspnea, cough
40-60 ppm	Toxic pneumonitis and pulmonary edema
430 ppm	Lethal over 30 minutes
1000 ppm	Fatal within a few minutes

The most serious hazard associated with chlorine is that of a large-scale release in a short duration from which escape is not possible. Liquid chlorine in a ruptured tank during an accident is expected to volatilize rapidly, forming a greenish-yellow cloud of chlorine gas, which remains in the lower atmosphere, as it is heavier than air. This gas cloud can be carried several miles away from the source of release. Since chlorine immediately reacts with both organic and inorganic materials, it is not expected to remain in the environment very long after it is released.

Once used in World War-I as a chemical weapon, chlorine gas has long been known for its toxic hazard properties. In recent years, one of the worst chlorine accidents occurred in Graniteville, South Carolina in 2005, and a chlorine leak on Mumbai Port Trust's yard in 2010, all revealing the hazardous potential of chlorine (Jones et al., 2010; Sharma et al., 2010). Various case studies have been reported the release of chlorine from storage facilities (Yu et al., 2009; Gangopadhyay et al., 2005; Tseng et al., 2008). Present study modeled the toxic impact of chlorine release from a storage facility at Eloor.

The identified major hazardous outcomes of LPG, Ammonia & Chlorine are given below in table 3.6.

Table 3.6. Major Hazards Associated with LPG, Ammonia and Chlorine

LPG	Flammable area, and. BLEVE
Ammonia	Toxic inhalation hazard
Chlorine	Toxic inhalation hazard

3.3 Consequence Analysis using ALOHA

Consequence analysis represents one of the fundamental steps in the comprehensive methodology of Risk assessment. ALOHA is intended to be used for predicting the extent of area downwind of a chemical accident where people may be at risk of exposure to hazardous effect of chemicals (Renjith & Madhu, 2010). The consequences of an accidental release of a chemical depend on the conditions of the release as well as in situ conditions at the time of the release. To model the accidental release of chemicals, ALOHA incorporate all these conditions as input information: Data on local atmospheric conditions, the identity of the chemical, and details about the spill scenario. Besides, the model also takes into account other information such as location information, Date and time, Ground roughness, and building type. All the information provided are detailed below.

3.3.1 Ground Roughness (Terrain)

ALOHA takes into account ground roughness, as the wind profile is affected by the irregularities on the surface of ground over which the pollutants move. The model provides three roughness classes or terrain conditions (open country, urban forest, open water). As the industrial areas of Cochin City has many frictions generating roughness elements like trees and buildings, the choice of 'urban forest' is selected indicating the high ground roughness.

3.3.2 Building Type

For a toxic gas dispersion scenario, ALOHA estimates the indoor air concentration of chemical by 'building types' taken into account. The type of building that is most common in the present study area is 'double storied building'. The model assumed that the chemical conditions build up faster within single–stories rather than double storied buildings. To estimate indoor pollutant concentration, ALOHA first estimate the building's air exchange rate. The model accounts for the effect of wind speed and temperature to compute air exchange rates. The higher a building's air exchange rate, the faster the concentration of a toxic gas is predicted to rise within the building. This computation is not applicable for fire and explosion scenario.

3.3.3 Chemical Information

ALOHA includes data files with physical, chemical and toxicological properties for hundreds of chemicals. To characterize a chemical substance the first required information in ALOHA is the chemical name and its properties. The following properties of a chemical are available in the data file: Molecular weight, critical temperature, critical pressure, critical volume, freezing point, normal boiling point, vapor pressure, liquid density, heat of vaporization, heat of combustion, vapor heat capacity, and liquid heat capacity. The data requirement for analysis based on the modeling (source strength modeling, heavy gas dispersion modeling, modeling of fire and explosion, Gaussian dispersion modeling, etc.) selected for the study. The chemical selected in the study, LPG, Ammonia, and Chlorine, are included in the chemical library of ALOHA and can be directly availed.

3.3.4 Atmospheric Data

The accidental release of airborne chemicals has drawn more attention by its hazardous nature as the atmospheric conditions prevailing at the time of accident plays a major role in its dispersion and affected area. Atmospheric conditions such as wind speed and stability largely influence the affected area of toxic, flammable, and explosive gas clouds (Canepa et al., 2000). Stability is a concept used to characterize the property of the low-lying atmosphere that governs the vertical movement of air. The core factor in ALOHA's dispersion model is the stability classification. Since turbulence intensity cannot be measured directly, correlations are sought to indicate stability class as a function of readily measurable variables (Woodward, 1998). As it is difficult to measure the stability, Pasquill (1961) proposed a scheme in order to estimate the stability classes, which are dependent on wind speed and solar insolation during the day and cloud cover during the night. Pasquill classifies the atmospheric conditions from stable to unstable. Paquill-Gifford's stability classes include six classes decided by the wind speed, solar radiation and cloud cover as described below in the table 3.7.

Table 3.7. Pasquill Stability Classes

Classes	Stability Condition
A	Very unstable
B	Unstable
C	Slightly unstable
D	Neutral
E	Stable
F	Very stable

A, B, C are typical daytime stability classes and start increasing significantly around 0700 hours in the morning and stop decreasing fast at around 1700 hrs. The classes E and F only occur at night time. The neutral class D can occur during the day or night according to wind conditions or transform times of dawn and dusk (Magidi, 2013). Night refers to the period from 1 hour before sunset to 1 hour after sunrise (Turner, 1994).

As it is impossible to predict when the accident can occur, in the present study, four hypothetical scenarios are selected - Scenario I, Scenario II, Scenario III and Scenario IV representing the Night, Morning, Afternoon and Evening respectively. The prevailing weather conditions at the time of accident are also as unpredictable as the time of the accident. Hence, to obtain the ambient atmospheric conditions, the atmospheric variables taken into consideration are temperature, wind speed, humidity at the above-mentioned times, characteristic to the geographical location of Kochi. The average value of each of these variables, respective to time, were taken by referring the site meteorological data collected from the weather monitoring stations operating in the City under Indian Meteorological Department (IMD). ALOHA itself determine the stability classes corresponding to the given weather conditions, where solar insolation and wind speed are the primary determining factor. Information on date, time, location, and cloud cover is used to determine the solar insolation in ALOHA (NOAA and U. S EPA, 2007). The values of atmospheric variables and stability class used in the modeling are given in table 3.8.

Table 3.8. Atmospheric Variables used in Modeling.

Atmospheric Variables	Time of day			
	Scenario I Night (00.00)	**Scenario II Morning (06.00)**	**Scenario III Afternoon (12.00)**	**Scenario IV Evening (05.30)**
Temperature	24°C	27°C	32°C	29°C
Humidity	85%	68%	60%	76%
Wind speed	1 m/s	1.5 m/s	3.6 m/s	3.3 m/s
Stability class	E	D	B	C

3.3.5 Source Information

The source is the vessel or pool from which a hazardous chemical is released into the atmosphere. ALOHA links source strength model to air dispersion model to estimate the spatial extent of toxic, flammable, and explosive vapor clouds. Source strength or release rate is the rate at which the chemical escapes into the atmosphere or burn rate. Using the source strength model, it estimates the rate at which the chemical is released from containment and enters the atmosphere, by taking into account the tank shape, size, volume of liquid, size of the hole through which the chemical is released into the atmosphere and nature of the rupture (the tank shape, size and volume are mentioned above). If the chemical escapes into the atmosphere very quickly, the source strength will be high, and if released slowly over a long period of time, the source strength will be low. ALOHA predicts release rate from a tank as a series of hundreds of brief time steps. These values are averaged into fewer steps so that calculations can be completed quickly.

ALOHA use only the averaged release rate(s) to make its threat zone estimation. When ALOHA calculates a source strength (release rate) for a scenario modeled, it estimates it for more than 1 hour after a release begins. The reason for the 1-hour duration limit is that the wind changes speed and direction frequently. The maximum averaged release rate is the highest of these averaged release rates.

In the present study, there are some assumptions taken for the nature of rupture and size of the hole through which chemical is released. It is assumed that chemicals are leaking through a short pipe or valve of a storage tank which is used to transfer the chemical from the tank. In the case of selection of size of valve, through which a chemical is released into the atmosphere, different methodologies were used in different studies. Regardless of pipe size, some analysts uses 2 inches and 4 inches diameter and in some studies it ranges from too small (0.2 inches) to large (6 inches) (AIChe/CCPS, 2000). In this study to understand the probability of risk of chemical release the assumption taken is that the chemicals are released through 2-inch diameter pipe connections. The valve opening is assumed beneath the liquid level. In a liquefied gas vessel, open valve beneath the liquid level is potentially more serious than if it is placed in the gas space, as the mass flow rate is greater (Carson, 2002).

3.4 Result and Discussion

3.4.1 LPG Release and its Consequences

ALOHA can graphically represent the result of modeling of various accident scenarios. It depicts the impacted area as threat zones and the area within the threat zone is the region where the ground level concentration of chemical exceeds the limit or threshold concentration at some time after the release begins. The concentration of pollutant in each threat zone is a function of both time and location. The model predicts that concentration of chemical will be highest near the release point and along the centerline of pollutant cloud and will drop off smoothly and gradually in the downwind direction. Though the dispersing vapor cloud generally moves in a downwind direction, it also spreads in a direction perpendicular to the wind, as well as vertically depending on the atmospheric condition.

The two hazardous outcomes of LPG, 'Flammable area of vapor cloud' and 'BLEVE', modeled for the above mentioned three locations in the study area with varied storage capacities of 150 MT, 1540 MT, and 1400 MT. The modeling results are detailed below.

3.4.1.1 Flammable Area of LPG

Figure 3.1 shows the graphical representation of flammable area of LPG under different atmospheric conditions (Scenarios I, II, III and IV), when the release is from a 150 MT storage tank. In figure 3.1, the red and yellow colors are the threat zones representing the impacted area. The red zone represents the worst hazardous area which is critically dangerous, as it is nearer to the release point. The yellow threat zones represent areas of decreasing hazard, as the chemicals are dispersed and have diluted the concentration. The outer line (black dotted line) of the footprint reflects uncertainty in the wind direction. The wind direction usually will not remain constant, and it may vary along with the wind speed. As it shifts direction, it carries the released chemical in a new direction. The “uncertainty line” around the Yellow threat zone encloses the region within which, the chemical cloud is expected to remain. The lower the wind speed, the more likely the wind change its direction. Therefore, when the wind speed decreases, the uncertainty line become farther apart and forms a circle.

ALOHA employs Levels of Concern (LOCs) to indicate the impact of toxic air plumes, fires, and explosion hazards. For flammable chemicals, the LOCs are based on the Lower Explosive Limit (LEL). ALOHA uses LEL as the LOC to determine the areas in which a fire might occur. When a flammable vapor cloud is released and disperses in the air, the concentration of the chemical is not uniform in all parts. There will be an area where the concentration is higher than the average and yet another area where the concentration is lower than the average. This is called concentration patchiness. The concentration levels estimated are time-averaged concentration. The model uses 60% and 10% LEL as the limits for the identification of flammable area. The LOCs to determine the flammable area of LPG is given in table 3.9

Table 3.9. LOCs taken for modeling Flammable Area of Vapor Cloud of LPG

Hazard Identified	Threat modeled	Threat Zones	Chemical Concentration	Impact
Leaking tank, Chemical is not burning as it escapes into the atmosphere	Flammable area	Red	12600 ppm	60% LEL
		Yellow	2100 ppm	10% LEL

In figure 3.1 ALOHA’s threat zone plot shows two flammable threat zones: red threat zone and yellow threat zone. The red and yellow zones both indicating areas where the fuel-air concentration is likely to exceed the LOC at some time after the release of chemical and if the concentration of chemical in the air above the LOC (threshold concentration of fuel) a flammable hazard may occur.

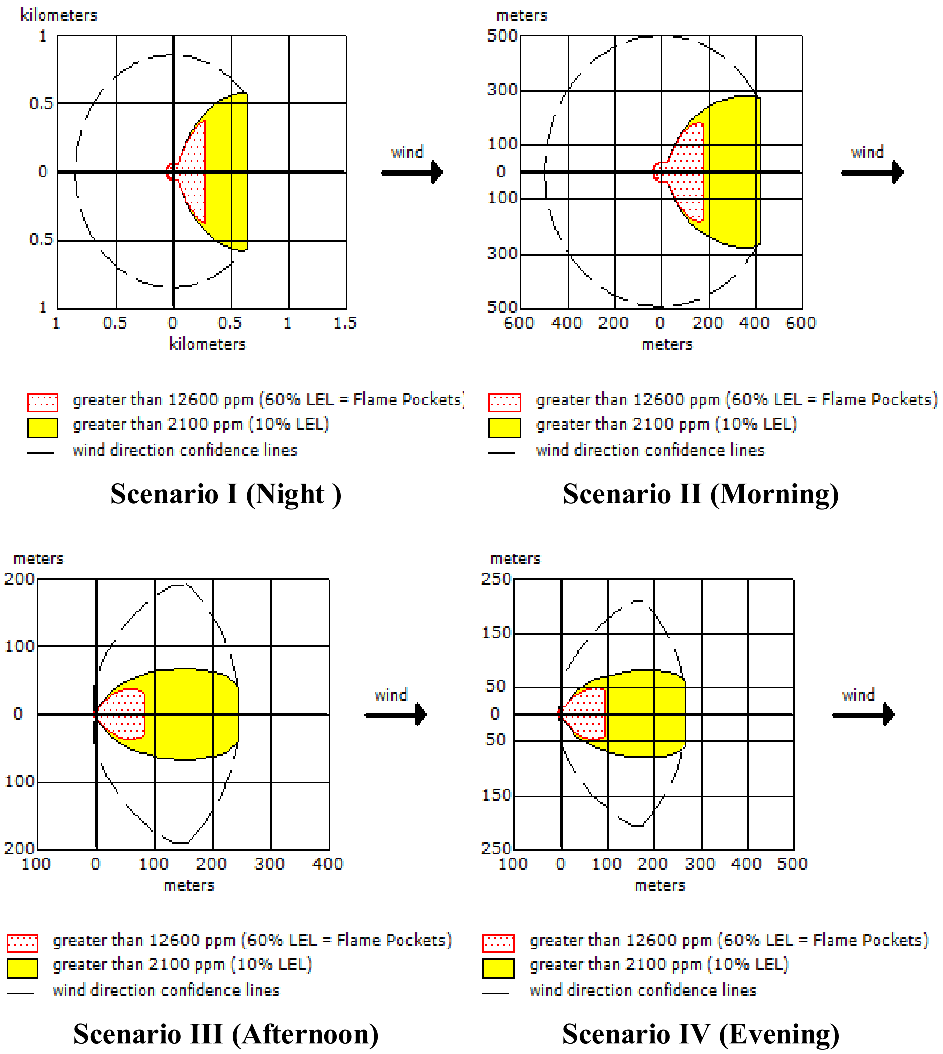


Figure 3.1. Scenario Analysis for Flammable Area of LPG Release from 150 MT Bullet Tank.

The varied distance in flammable area for each scenario is given in table 3.10. Of the four scenarios, the largest fire hazard area is observed for scenario I, ie, in the night time and the smallest in the after noon time. In the case of largest flammable area obtained for scenario I, it is estimated that, the red threat zone extends 277 meters in the downwind direction where the chemical concentration is greater than 12600 ppm with 60% LEL. The yellow threat zone, where the estimated concentration of the chemical is greater than 2100 ppm with 10% LEL, extend up to 647 m from the source of release. Only a slight difference can be seen in the flammable area of Scenarios III and IV.

Table 3.10. Flammable Area of Vapor Cloud Distance of LPG (released from150 MT of LPG Bullet).

Threat Zone	**Impacted distance**			
	Scenario I (Night)	**Scenario II (Morning)**	**Scenario III (Afternoon)**	**Scenario IV (Evening)**
Red	277 m	180 m	83 m	95 m
Yellow	647 m	423 m	245 m	267 m

Figure 3.2 given below shows the graphical representation of flammable area of LPG under different atmospheric conditions (Scenarios I, II, III and IV) when released from 1400 MT and 1540 MT of LPG spherical tanks. As the factors which affect the release and dispersion of chemical such as shape of the tank, atmospheric condition and source information are same for both the 1400 MT and 1540 MT spherical tanks, notable change is not observed in the flammable area modeled by ALOHA in these two cases. Moreover, there is only a slight difference in the storage capacity. For both the cases, the flammable area modeled for

different atmospheric conditions gives the same result and its graphical representations are given below (figure 3.2).

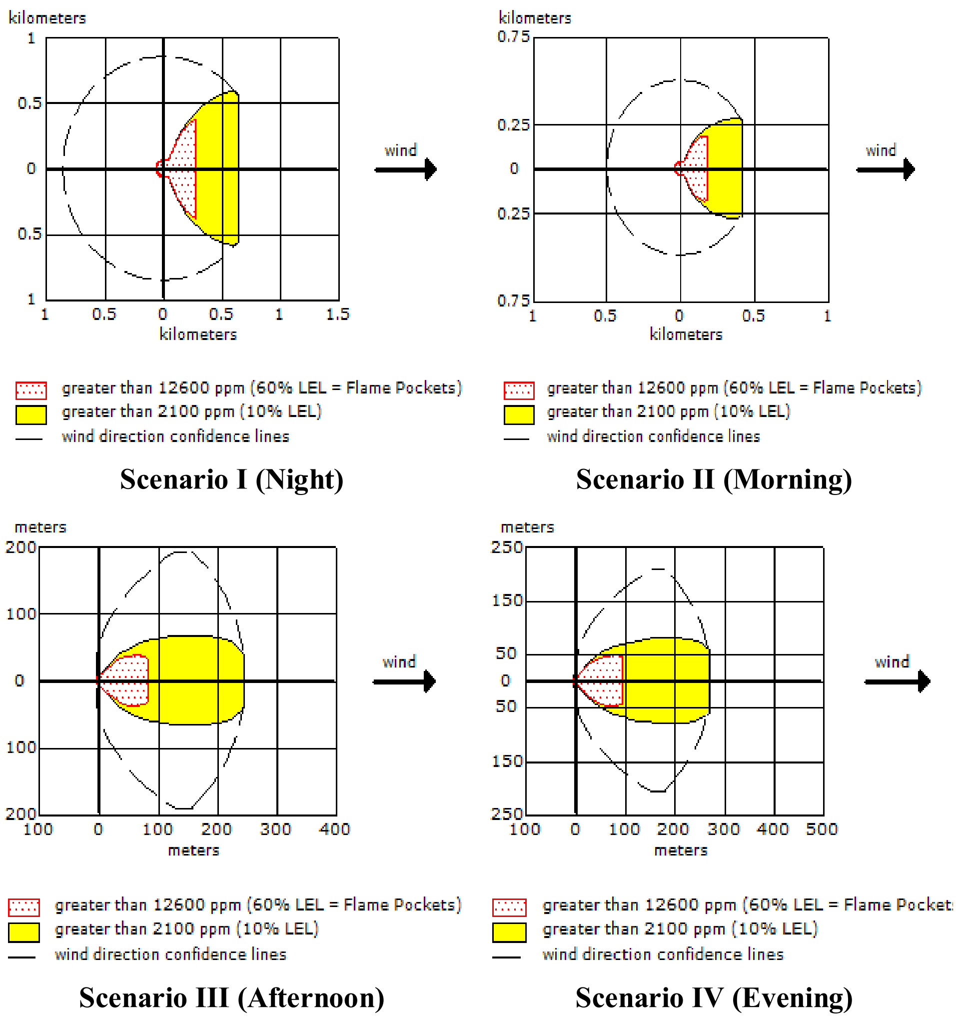


Figure 3.2. Scenario Analysis for Flammable Area of LPG Release from 1400 MT and 1540 MT Spherical Tanks.

Table 3.11 shows the varied distance of flammable area followed by LPG release from 1400 MT and 1540 MT spherical tanks. The largest impacted area observed is at the night time, 652 m from the source and smallest at the afternoon time, 246 m.

Table 3.11. Flammable Area of Vapor Cloud Distance of LPG (release from 1400 MT and 1540 MT of LPG spheres)

Threat Zone	Impacted Distance			
	Scenario I (Night)	**Scenario II (Morning)**	**Scenario III (Afternoon)**	**Scenario IV (Evening)**
Red	278 m	181 m	84 m	95 m
Yellow	652 m	425 m	246 m	269 m

Release Rate: When a liquefied gas escapes from a pressurized container, the release rate may drop very quickly as the pressure within the container drops. Once released into the atmosphere, the model averages the series of many release rates to make its threat zone. The Maximum Average Sustained Release rate is the highest of these averaged release rates. The release rate and the total amount of chemical released into the atmosphere during 1-hour duration under different atmospheric conditions are estimated by the model and is given in table 3.12. The model estimates the evaporation rate for not more than 1-hour duration after a release begins because the wind changes speed and direction frequently. This 1-hour limit represents the maximum possible release duration.

The table 3.12 indicates that the release rate of chemical is high at the afternoon time compared with other times of the day. It is less in the night, as the atmosphere is calm and at low temperatures.

Table 3.12. Release Rates and total amounts released during 1 hour

Release rate and amount released	Scenario I (Night)	Scenario II (Morning)	Scenario III (Afternoon)	Scenario IV (Evening)
Release Rate	859 kg/min	904 kg/min	980 kg/min	934 kg/min
Total amount released	51,467 kg	54,133 kg	58,671 kg	55,935 kg

Comparing the flammable areas, following an LPG release from 150 MT bullet tank with 1400 MT and 1540 MT spherical tanks, only a slight variation is observed in the impacted distance. However, the result indicates that the chemical released from a spherical tank disperses to a larger distance.

3.4.1.2 BLEVE of LPG

Potential BLEVE hazards include overpressure, hazardous fragments, smoke, and toxic byproducts from the fire. ALOHA focuses only on the thermal radiation effect of BLEVE, as it is the most significant threat of BLEVE and its impact is greater than the overpressure. The model estimates that the amount of chemical in the fireball is three times the amount of chemical that flash boils. People experiences thermal radiation effects depending upon the length of time they are exposed to a specific thermal radiation level. Even a lower thermal radiation level over a longer exposure time, can produce serious physiological effects on human body.

Levels of Concern (LOCs), the level above which a hazard may exist, for thermal radiation is its threshold level with associated health effects. ALOHA's thermal radiation values are based on a review of several widely accepted sources (AIChe, 1994; Handbook of Chemical

Hazard Analysis Procedures, 1988; Lees, 2001). In this study, to estimate the thermal radiation threat zones, three default thermal radiation values (consider as three LOCs) suggested by the model is used (given in table 3.13).

Table 3.13. LOCs taken for modeling thermal radiation effect of BLEVE of LPG

Hazard identified	Threat modeled	Threat zones	LOC for Thermal radiation	Impact on public (within 60 sec)
BLEVE	Thermal radiation	Red	10.0 kw/(sq m)	Potentially lethal
		Orange	5.0 kw/(sq m)	2nd degree burn
		Yellow	2.0 kw/(sq m)	Pain

Studies report that, it is difficult to say when the fire will start and when a BLEVE will occur after flame impingement on a container (Peterson, 2002). As BLEVE is a sudden explosion, the given atmospheric conditions in this study do not show any variation in the affected area. During BLEVE the tank containment fully explodes and its affected area depends on the quantity of chemical involved in a fire or (quantity of chemical stored in a container). ALOHA assumes a near-instantaneous rupture for a BLEVE scenario and defaults to an assumption that the entire contents of a tank contribute to the fireball. Based on the mass of fireball, the maximum diameter of the fireball is computed. The diameter of the fireball is a function of time and the maximum diameter is used in ALOHA to ensure that hazard zones are not underestimated.

The BLEVE affected area of LPG modeled for 150 MT of LPG bullet tank under different atmospheric conditions are given in table 3.14 shows that affected area for all scenarios modeled have same value. Its graphical extent is shown in figure 3.3.

Table 3.14. Thermal Radiation affected area of BLEVE (150 MT LPG Bullet)

Threat zone	Impacted distance			
	Scenario I (Night)	**Scenario II (Morning)**	**Scenario III (Afternoon)**	**Scenario IV (Evening)**
Red	643 m	643 m	643 m	643 m
Orange	908 m	908 m	908 m	908 m
Yellow	1.4 km	1.4 km	1.4 km	1.4 km

ALOHA's three threat zones are given below for thermal radiation effect of BLEVE (figure 3.3). It is estimated that the red threat zone, the worst hazard level, will extend to about 646 meters in all directions. This zone is considered as potentially lethal. The orange and yellow zones represent areas of decreasing hazard and it is estimated that it will extend 908 meters and 1.4 kilometers respectively from the source in all directions. The expected health hazard associated with orange threat zone is 2nd degree burn and with yellow zone is pain within 60 seconds.

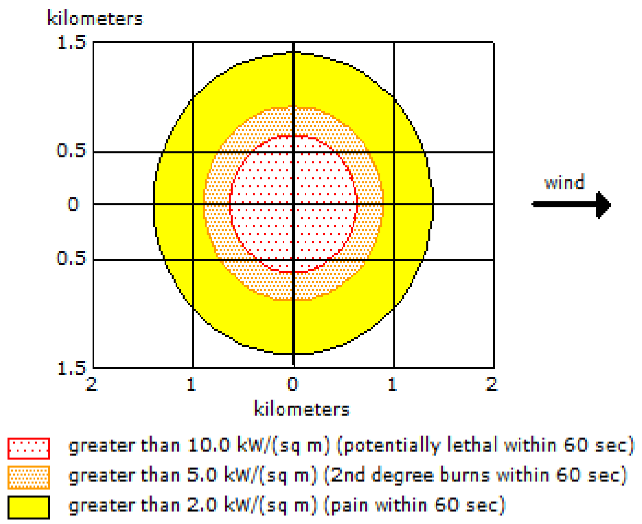
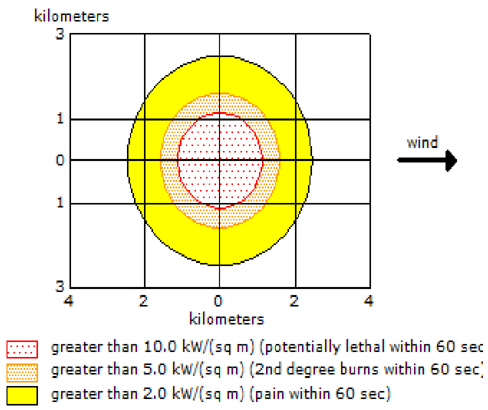


Figure 3.3. Thermal Radiation Effect of BLEVE (150 MT LPG Bullet Tank).

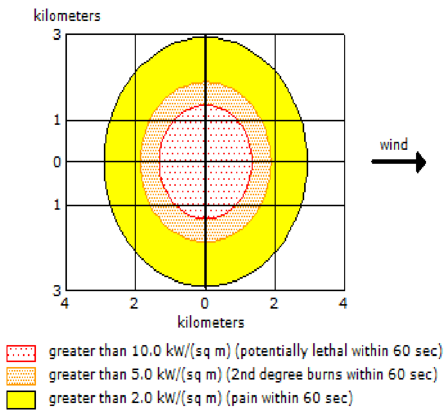
The BLEVE affected area of LPG modeled for 1400 MT and 1540 MT of LPG spheres under different atmospheric conditions are given in table 3.15. From the table it is clear that a notable difference is not observed in the impacted area under different atmospheric conditions. However, the impacted area of 1540 MT tank (2.9 km from the source) is greater than when 1400 MT tank explodes (2.5 km from the source). Graphical representation of BLEVE effect of 1400 MT and 1540 MT LPG sphere are given in figure 3.4.

Table 3.15. Thermal Radiation affected area of BLEVE (1400 MT and 1540 MT of LPG spheres)

Threat zone	Time							
	Scenario I (Night)		Scenario II (Morning)		Scenario III (Afternoon)		Scenario IV (Evening)	
	1400 MT	1540 MT	1400 MT	1540 MT	1400 MT	1540 MT	1400 MT	1540 MT
Red	1.1 km	1.3 km	1.1 km	1.3 km	1.1 km	1.3 km	1.1 km	1.3 km
Orange	1.6 km	1.9 km	1.6 km	1.9 km	1.6 km	1.9 km	1.6 km	1.9 km
Yellow	2.5 km	2.9 km	2.5 km	2.9 km	2.5 km	2.9 km	2.5 km	2.9 km



1400 MT LPG Sphere



1540 MT LPG Sphere

Figure 3.4. Thermal Radiation Effect of BLEVE (1400 MT & 1540 MT of LPG sphere)

The higher the storage quantity, the higher will be the impacted area. Figure 3.5 shows the comparison of BLEVE effect of LPG due to different quantities of storage tank.

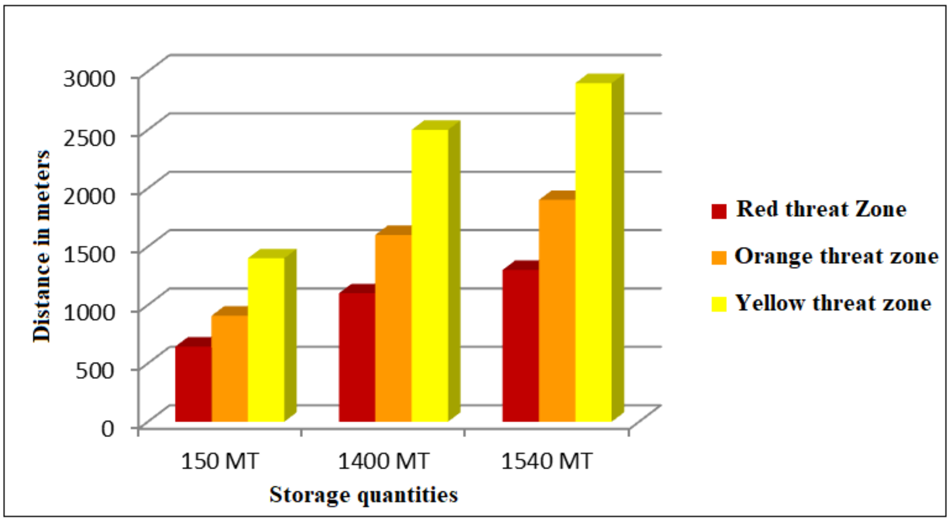


Figure 3.5. Comparison of BLEVE effect of LPG from different quantities of storage tanks

3.4.2 Ammonia Release and its Consequences

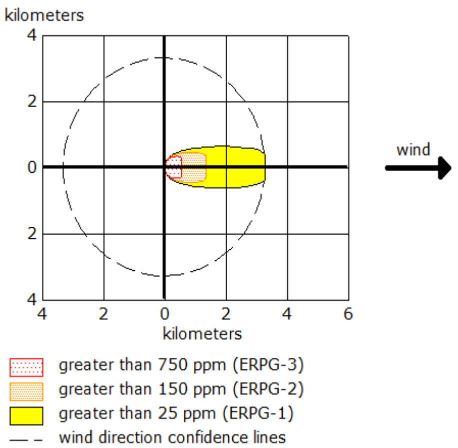
As mentioned above, the major hazard associated with the ammonia storage facilities in the three locations of Kochi City is its toxic inhalation hazard. Toxic threat zone is an impacted area where the ground-level pollutant concentration is predicted to exceed the Levels of Concern (LOC) at some time after a release begins. For inhalation hazards, ALOHA's LOCs are concentrations of chemicals associated with adverse health effects. For any point within the threat zone, ALOHA predicts that the LOC will exceed at some time after the release begin. In typical cases, this happens shortly after the cloud of pollutant gas reaches that point and not all points within the threat zone will exceed the LOC for the same length of time. Most commonly used kinds of toxic LOCs are public exposure guidelines which have an exposure duration associated with them and reflect the effects of a toxic agent on people. The exposure guidelines and standards have an exposure duration associated with them. In this study ERPGs (Emergency Response Planning Guidelines) is chosen as the toxic LOCs for modeling an ammonia release. ERPGs are developed by the Emergency Response Planning committee of the American Industrial Hygiene Association to assist the emergency response personnel in planning for hazardous chemical releases to the community (ERPG, 2007). ERPGs estimate the concentration of chemical at which most people (sensitive members such as old, sick, or very young people are not covered by these guidelines) will begin to experience health effects if they are exposed to a hazardous airborne chemical for 1 hour. Sensitive members may experience adverse effects at concentrations below the ERPG values.

ERPG-3 is a worst-case planning level. If there is possibility that the people are exposed to levels above ERPG-3, it will be lethal to some members of the community. Above ERPG-2 concentrations, some members of the community may experience significant adverse health effects such as dizziness, severe eye irritation and respiratory problems. The ERPG-1 level identifies the concentration that may be noticeable due to odor, discomfort, or irritation but does not pose a health risk (Cavender et al., 2008). The LOCs for toxic inhalation hazards of ammonia and associated health effect is given in table 3.16.

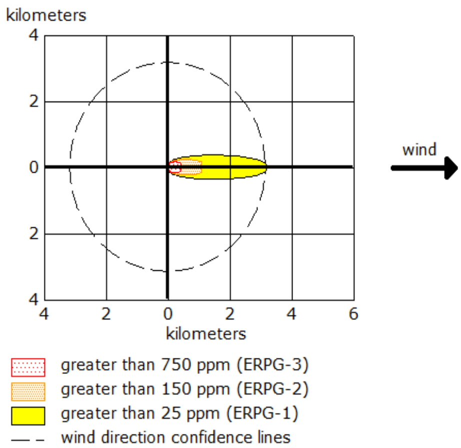
Table 3.16. LOCs taken for modeling the Toxic Inhalation Hazard affected area of Ammonia

Hazard identified	Threat modeled	Threat zones	Concentration of chemical	Effect on people
Toxic inhalation hazard	Toxicity affected area	Red (ERPG-3)	> 750 ppm	Life threatening health effect
		Orange (ERPG-2)	>150 ppm	Serious health effect
		Yellow (ERPG-3)	>25 ppm	Transient adverse health effect

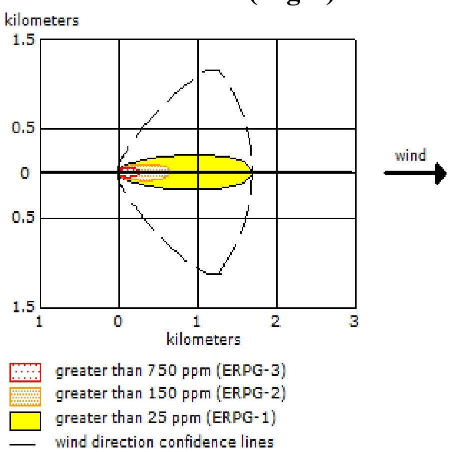
Though three storage locations of ammonia in the City have varied storage capacity (one having capacity of 10000 MT and the other two having the capacity of 5000 MT), the result of toxicity impacted area modeled by ALOHA shows the similar results, as all the information provided for modeling are same for each of these locations except the quantity of chemical. However, variations in the impacted area are observed under different atmospheric conditions (figure 3.6). Figure 3.6 is the graphical representation of the result of toxicity impact modeled for different scenarios (different atmospheric conditions).



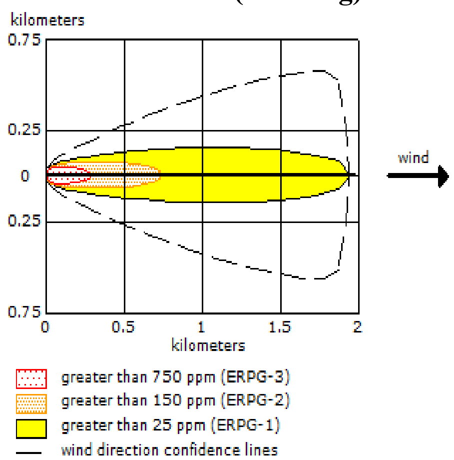
Scenario I (Night)



Scenario II (Morning)



Scenario III (Afternoon)



Scenario IV (Evening)

Figure 3.6. Toxic Inhalation Impact affected distance of Ammonia under different Atmospheric Conditions

From figure 3.6, it is clear that the largest impacted area is observed for scenario I, at night time and the smallest in the afternoon time. The extent of red, orange, and yellow threat zones in each scenario is given in table 3.17. In the case of largest impacted distance obtained for scenario I, it may affect up to 3.3 km from the source of release. The highly dangerous red threat zone extent up to 561 m and orange up to 1.4 km from the source in scenario I.

Comparing scenarios I and II, almost the same effect can be seen. In the case of scenarios III and IV noticeable difference is not seen in the total extent of impacted area (1.7 km and 1.9 km). But the extent of red and orange zone shows notable difference.

Table 3.17. Toxic Inhalation Hazard affected distance of Ammonia under different Atmospheric Conditions.

Threatzone	Scenario I (Night)	Scenario II (Morning)	Scenario III (After noon)	Scenario IV (Evening)
Red	561m	400 m	268 m	291 m
Orange	1.4km	1.1 km	659 m	737 m
Yellow	3.3 km	3.2 km	1.7 km	1.9 km

Release rate of ammonia estimated is 140kg/min and 8,377 kg of chemical released in to the atmosphere during 1 hour.

3.4.3 Chlorine Release and its Consequences

As mentioned earlier, during the survey only one chlorine storage facility beyond the threshold quantity have been identified. Same as ammonia the major impact associated with chlorine is its toxic inhalation hazard. LOCs for toxic inhalation hazards are specific to chemicals. LOCs for chlorine is given in table 3.18.

Table 3.18. LOCs taken for modeling the Toxic Inhalation Hazard affected area of Chlorine

Hazard identified	Threat modeled	Threat zones	Concentration of chemical	Effect on people
Toxic inhalation hazard	Toxicity affected area	Red (ERPG-3)	>20 ppm	Life threatening health effect
		Orange (ERPG-2)	>3 ppm	Serious health effect
		Yellow (ERPG-3)	>1 ppm	Transient adverse health effect

The most serious hazard associated with chlorine is that of a large scale release in a short duration from which escape is not possible (Ruj & Chatterjee, 2012). Figure 3.7 shows the graphical representation of modeling of toxic inhalation hazard of chlorine.

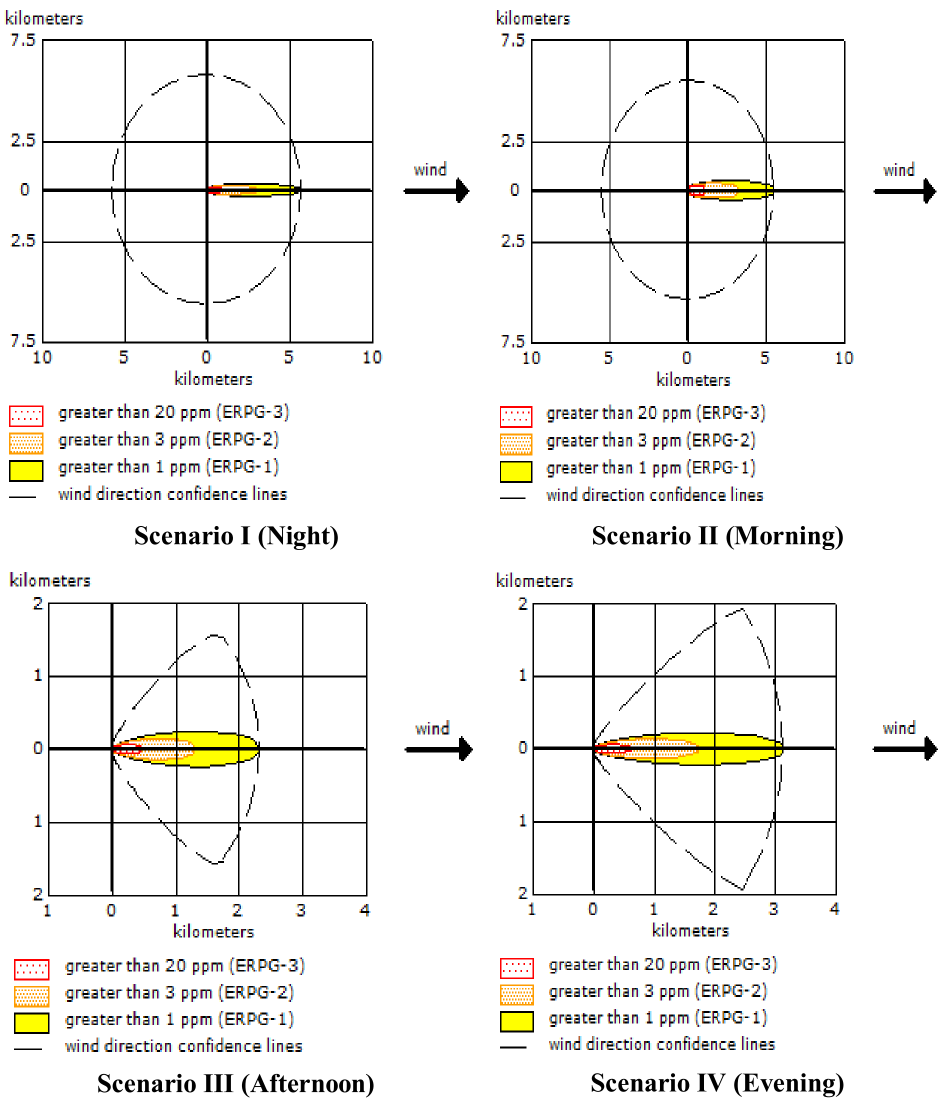


Figure 3.7. Toxic Inhalation Impact affected distance of Chlorine under different Atmospheric Conditions

Same as LPG and ammonia, the result indicates that the atmospheric conditions prevailing in the night time cause the vapor cloud to spread in larger area than in the other times of a day.

Toxic inhalation hazard affected distance or the extent of threat zones in each scenario is given in table 3.19. The largest dispersed extent, 5.8 km from the source is observed for scenario I and its red, orange, and yellow zones distance are 1.1 km, 3.2 km and 5.8 km respectively. Comparing the four scenarios, a high difference in the impacted distance is observed revealing the influence of atmosphere in the dispersion of Chlorine. The minimum impacted distance is observed for scenario III in the afternoon. Release rate of chemical estimated is 41 kg/ min and the amount of chemical released during one hour is 2,454 kg.

Table 3.19. Toxic Inhalation Hazard affected distance of Chlorine under different Atmospheric Conditions.

Threat zone	Scenario I (Night)	Scenario II (Morning)	Scenario III (After noon)	Scenario IV (Evening)
Red	1.1km	908 m	481m	642m
orange	3.2 km	3.2 km	1.3km	1.8km
yellow	5.8 km	5.5 km	2.3km	3.1km

Comparing the toxic inhalation hazard of ammonia and chlorine, chlorine shows larger impacted area as it diffuses in the atmosphere faster than ammonia. Figure 3.8 shows the difference of toxicity affected area of ammonia and chlorine.

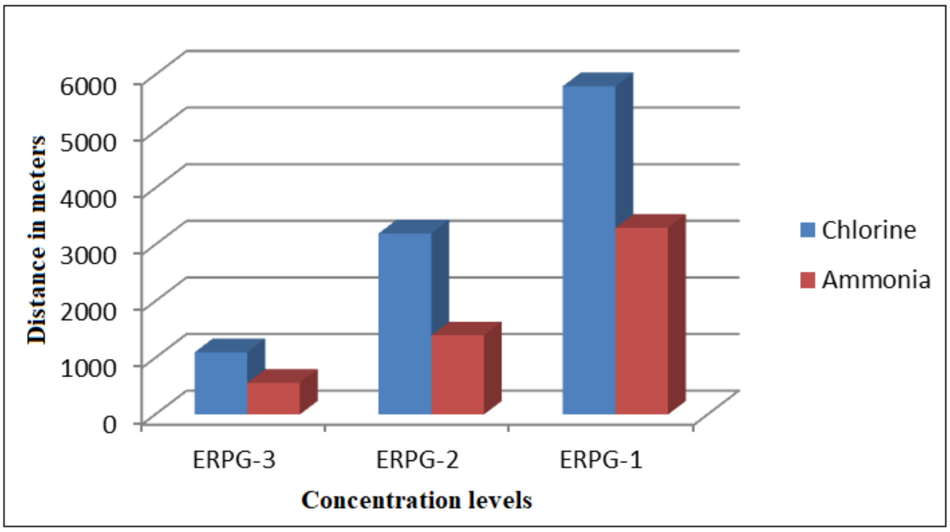


Figure 3.8. Difference of Toxicity Affected Distance of Ammonia and chlorine

3.4.5 Comparison of affected area of LPG, Ammonia and Chlorine.

From the result of modeling of release scenario of three chemicals on different atmospheric conditions, it is evident that atmospheric conditions have a major impact on the rate of dispersion of a pollutant cloud except in the case of BLEVE. It is also clear that in the same atmospheric conditions different chemicals show different distance of impacted area depending on their chemical and physical characteristics. Of the two hazardous outcomes (flammable area of vapor cloud and BLEVE) modeled for LPG, BLEVE is considered to be the most dangerous as it has the power to damage larger area within minutes by releasing high heat energy. Comparing the impacted areas of three chemicals (LPG, Ammonia, and chlorine), the largest is observed for the chlorine toxicity.

It is observed that, of the four scenarios modeled, considering different atmospheric conditions, the night time conditions take the hazardous gas clouds to a larger distance than the other times of a day. The shortest hazardous distance is observed during the mid-day in the case of all three chemicals. Meteorological conditions such as wind speed and stability, representing the amount of atmospheric turbulence, are likely to have definite influence on the overall hazardous distances. If the air is more turbulent, it causes quick dilution of toxic clouds. Stability class is at its peak during mid-day due to larger solar radiation. Under this condition (unstable conditions), because the pollutants are soon diluted, the hazardous gas clouds will not travel to larger distance as far as it is expected under stable condition. The largest impacted area estimated under night time conditions (scenario I) is considered as the worst-case scenario and further analysis in this study is based on this worst-case scenario. The impacted area of worst case scenario of LPG, ammonia and chlorine and other details are given in table 3.20.

Table 3.20. Worst case scenario of LPG, Ammonia and Chlorine.

<table>
<tr><th>Chemical</th><th colspan="2">Scenario Modeled</th><th>Release rate</th><th>Total amount of chemical released during 1 hour</th><th>Maximum impacted area</th></tr>
<tr><td rowspan="4">LPG</td><td colspan="2">Flammable area of vapor cloud</td><td>859 kg/min</td><td>51,467 kg</td><td>652 m</td></tr>
<tr><td rowspan="3">BLEVE</td><td>150 MT</td><td rowspan="3">Not applicable</td><td>150 MT</td><td>1.4 km</td></tr>
<tr><td>1400 MT</td><td>1400 MT</td><td>2.5 km</td></tr>
<tr><td>1540 MT</td><td>1540 MT</td><td>2.9 km</td></tr>
<tr><td>Ammonia</td><td colspan="2">Toxic inhalation hazard</td><td>140 kg/min</td><td>8,377kg</td><td>3.3km</td></tr>
<tr><td>Chlorine</td><td colspan="2">Toxic inhalation hazard</td><td>41 kg/min</td><td>2,454kg</td><td>5.8 km</td></tr>
</table>

3.5 Conclusion

An attempt has been made in this chapter to estimate the atmospheric dispersion of LPG, ammonia and chlorine. Local meteorological conditions are more relevant in air dispersion modeling. Therefore, different atmospheric parameters on different times of the day is taken into account and the impact is modeled using ALOHA air dispersion model. The study shows that varying atmospheric conditions largely influence the dispersion of hazardous gas clouds in the atmosphere. It can be seen that the higher wind speed leads to the shorter vapor cloud distance for any chemical. This may be because the concentration of the cloud is diluted continuously when the wind pushes the vapor clouds to disperse forward to the downwind direction. Not only the atmosphere, but also the characteristics of the chemical, its storage condition, and nature of leakage, all influences the dispersed area of hazardous chemicals in the atmosphere. The study shows that chlorine can disperse to larger distances in a short time than the LPG and ammonia. But LPG is a highly flammable chemical and no one can predict when the LPG leakage leads to BLEVE, the most dangerous effect associated with it. A very stable atmosphere allows the gas clouds to move large distance and impact larger population. This is what happened in the Bhopal gas tragedy and lack of preparedness made the situation worse. But the only precaution we can take is to anticipate the impact and be more prepared to reduce the effect when it happens. No generally applicable rule can be applied to understand the influence of atmosphere on gas dispersion because the intensity of the variables changes not only with the time, but also with the season. From the result of modeling of different scenarios of LPG, ammonia, and chlorine, the worst-case scenario has been identified and is further analysed in the next chapter to assess the vulnerability.

A prior knowledge of effect of different atmospheric conditions on the dispersion of denser gas clouds might be of great help for taking immediate management strategies in case of hazardous chemical leaks in the storage facilities. A good insight can be provided by these types of studies to the decision makers to identify the possible threat zone, formed from chemical hazards like fire, explosion and toxic release. The study reveals that air dispersion model ALOHA will be a very useful tool for such studies and help the emergency management personnel to prepare an effective management plan.

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Chapter 4

MAPPING AND ASSESSMENT OF VULNERABLE POPULATION USING DASYMETRIC MAPPING AND AREAL INTERPOLATION METHOD

Contents

4.1 Introduction

Vulnerability is defined as “the extent to which a community, structure, service, or geographical area is likely to be damaged or disrupted by the impact of a particular hazard, on account of their nature, construction and proximity to a hazardous terrain or disaster prone area” (District disaster management plan - New Delhi, 2014). Vulnerability has been defined in various ways such as the threat of exposure, the capacity to suffer human and the degree to which different social groups are at risk (Cutter et al., 2000; Renjith, 2010). In this study, vulnerability is assessed by the population which is at risk during a hazardous chemical release. Human vulnerability is defined as the factors that make people working in the chemical installation or living in the proximity of such places vulnerable to harm and injuries (Li et al., 2010). For any type of hazard, either industrial or natural, one of the major element at risk is the population in the hazard site. For reducing the injuries, causalities and death, it is necessary to assess the human vulnerability of the residents of industrial area (Fatemi et al., 2017). Factors affecting the human vulnerability are population density, quantity of chemical released, shelter, the access into and out of the site, and people's awareness of risks and response measures, etc.

For responding and mitigating to many social, political, economic and environmental problems, the knowledge of the size and distribution of human population in an area is essential (Liu, 2003). As chemical hazards are unpredictable and are often devastating, conceptual framework and methods must be developed to help decision makers and emergency personal to identify areas which are likely to be affected by a chemical hazard, as well as the characteristics of population residing in the area. Identification of vulnerable population due to chemical hazards helps the emergency planners to focus on that particular population in order to facilitate evacuation.

In the present study, the impacted population is identified as the population at risk due to the presence of several hazardous storage facilities in Cochin City. Though the degree to which population are vulnerable to hazards depend upon the individual's character (health, age) and social factors (wealth, housing characteristics etc.) (Cutter et al., 2000). This study gives more priority to geographical proximity of population to the potential source of hazard. So, all the individuals coming within the hazardous zone is given equal priority. Population group which have risk of high exposure include workers of the facility and the residents near the source of release. The vulnerability of the population changes with the type of hazard, nature of chemical and density of population. The result of dispersion modeling, carried out in the previous chapter, is used as an input data for vulnerability assessment.

GIS as an integrating technology: Geographic Information System (GIS) provides a framework for gathering, storing, managing, analysing, and displaying data. It can be used as tool in both problem solving and decision making processes, as well as for visualization of data in a spatial environment. The primary benefit of GIS is the ability to interrelate multiple types of information assembled from a range of sources. The role of GIS has flooded almost every field in the engineering, natural and social sciences for collecting, viewing and analyzing spatial data. The uses of GIS, GPS, and RS technologies, either individually or in combination, span a broad range of applications and degrees of complexity.

This chapter also demonstrates how GIS can be integrated with chemical dispersion model and how its analytical applications can be used for exploring population vulnerability. With the advantages of GIS, the shape and size of the affected area can be represented more effectively. Dasymetric mapping and Areal interpolation method using GIS is adopted in this study to assess the vulnerable population. The details of mapping process is explained below.

4.2 Study Area

Chlorine, ammonia and LPG storage facilities in Cochin City are spread over a number of industrial clusters as mentioned in the second chapter. Based on the location of storage of these chemicals and their likely impacted distances, the entire study area is classified into six. Each location is mentioned in the table 4.1 below.

Table 4.1. Chemical Storages in the Study Area

Location	Place	Chemical storage	Position of chemical storage tank (Latitude and longitude)
Study area-I	Eloor and adjoining area	Ammonia	10°04’08” N, 76°17’35” E
		chlorine	10°04’29” N, 76°18’12” E
Study area-II	Willingdon Island and adjoining area	Ammonia	9°57’13” N, 76°16’03” E
Study area-III	Ambalamugal and adjoining area	Ammonia	9°58’26” N, 76°22’17” E
		LPG (1400 MT)	9°58’04” N, 76°23’05” E
		LPG (1540 MT)	9°58’07” N, 76°21’54” E
Study area- IV	Udayamperoor and adjoining area	LPG (150 MT)	9°53’23” N, 76°22’34” E

4.3 Dasymetric Mapping and Areal Interpolation Method

Methodology used to estimate demographic composition of a population which can be affected by accidental releases of hazardous chemicals are an important element in the evaluation of consequences of serious accidents (Brzozowska, 2016). A modified method suitable to the study area of Dasymetric mapping and Areal interpolation method (Chakraborty & Armstrong, 1996) is used in this study to estimate the vulnerable population. A dasymetric map depict quantitative areal data using boundaries that divide the mapped area into zones of relative homogeneity and portraying the underlying statistical surface (Eicher &. Brewer, 2001). The term areal interpolation means transferring information from one set of boundaries to another (Goodchild & Lam, 1980; Lam, 1983) or from one set of spatial units to another.

Choropleth map of population density usually represent a homogeneously distributed pattern of population even at the place that are uninhabited. Dasymetric mapping resolve this problem by incorporating population data with Landuse- landcover as ancillary data. The mapping method used in this study displays population distribution characteristics of the study area as well as illustrates the vulnerable population estimates in each hazard zones. The dasymetric map also provides an overview for easily understanding the population distribution pattern of the incident location.

Several GIS database layers are required to assess the community vulnerability including census data of each wards, ward boundaries and landuse-landcover (LULC) characteristics of the area. The ancillary information of LULC is extracted from Google earth image. Land use maps were prepared from Google earth high resolution imageries. Different land use classes were identified and prepared through digital process. Spatial accuracy for google earth images were verified using Garmin eTrex H handheld GPS, having better than 10m accuracy. Latitude and longitude of known positions were collected and overlaid on Google earth image to validate the spatial accuracy.

The digitised polygon features are converted form KML to layer in ArcGIS software. Chances of topological errors were eliminated using topology correction (validate topology) process in ArcGIS for all digitized land use layers. The ward boundary maps of Panchayaths and Municipal areas were used for the identification of the wards within each study area.

After building the required layers, the spatial analytical capabilities of GIS tool such as overlay, extraction, zonal applications, reclassification, raster calculation etc. helped to generate a population distribution map. Based on the methodology given by Holloway et al. (1997) and Mennis (2003), initially LULC database were prepared and classified it into five different classes such as built up, industrial area, vegetation, vacant land and water body. These classes were reclassified by giving values to each, based on the occurrence of population. Built up and industrial area is considered as highly populated, vegetation and vacant land is very less populated and water body is considered as uninhabited area in this reclassification. Population counts were correlated with these reclassified LULC classes to generate population distribution raster surfaces for four different locations. The resulting raster surfaces and their attributes were then used to estimate vulnerable population.

The result of modeling of hazardous gases by ALOHA (as given in the previous chapter), in the form of plume footprint, could be integrated directly with ArcGIS and plume analysis were also done as part of estimating vulnerable population. When the plume footprints were overlaid on the GIS data base layers, the shape of the footprint did not coincide with ward boundaries and LULC boundaries. In such cases, the areal interpolation method helps to compute the population within plume footprint. The areal-weighting method is a straight forward algorithm for performing areal interpolation (Goodchild & Lam, 1980). To determine the number of people affected by the chemical release, areal weightage is given to inhabited area (built up area) of each ward. The population within each threat zone plume footprint can be expressed as:

$$\textbf{Pop} = \sum_{i=0}^{n} Pi + \sum_{j=0}^{m} (Pj * aj' / aj)$$

Where,

n : number of wards entirely enclosed by the footprint (whose boundaries may not coincide with the impact zone boundary)

Pi : population of a ward entirely enclosed by the footprint.

i = 0,1,2,3…………., n

m : number of wards partially contained within the footprint (whose geographical boundaries do not exactly coincide with the footprint boundary)

Pj : population of the ward partially contained the footprint; j = 0,1,2,….., m

aj : total area of populated region of partially contained wards (calculated from the GIS laduse classification layer)

aj' : area of populated region of partially contained wards that is enclosed within the footprint;

The methodology used to estimate population characteristics of affected area, summarized in the form of flow chart (Figure. 4.1), consist of two major components: a chemical dispersion model and a GIS database.

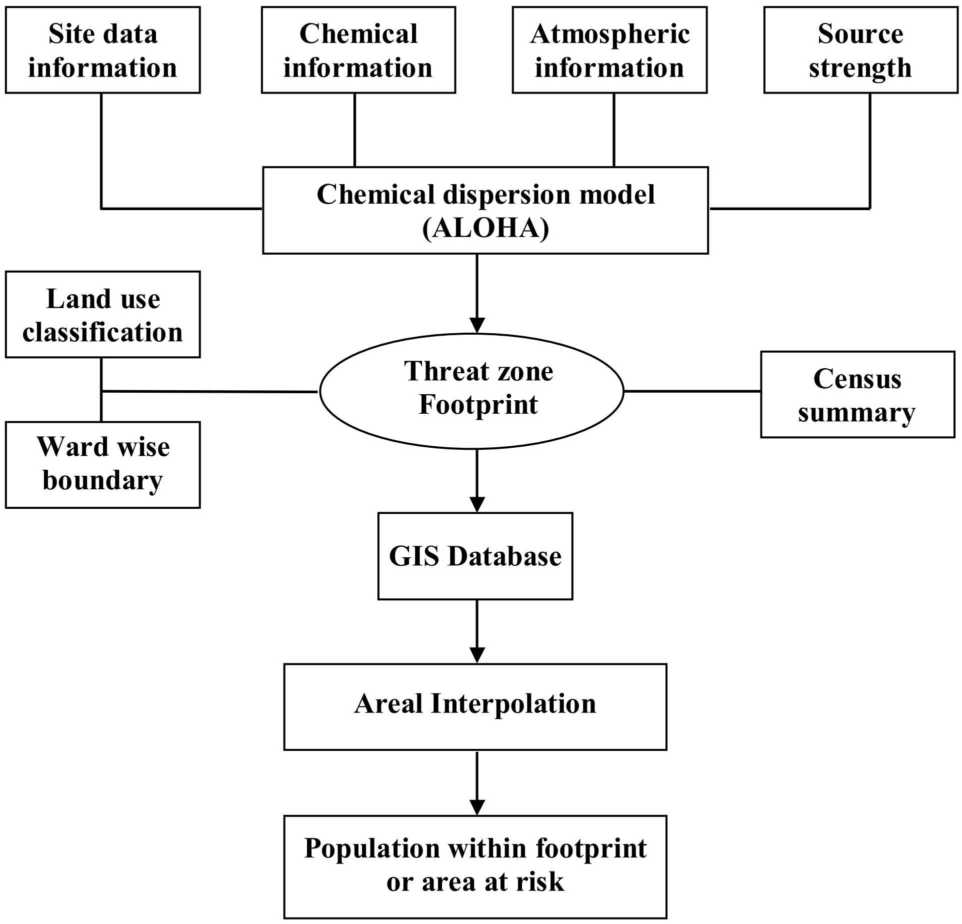


Figure 4.1. Methodological Framework for estimating Population Characteristics of Affected Areas

In the case of dispersion of chemicals, it is necessary to take into account the atmospheric conditions, which may change with time and influence the behavior of dispersion of heavy gas cloud. The wind carries the heavy gas cloud in its direction. As it is not possible to foresee the wind direction when an accident occurs, for the population vulnerability assessment, the maximum impacted distance around the plant is take into consideration. Regardless of plume width, for assessing the population likely to be impacted, the four directions as a whole (NE, SE, SW, NW) is taken into account. Affected population in each direction is estimated separately so that the emergency management personals can get a clear outlook of population mass in particular direction.

4.4 Result and Discussion

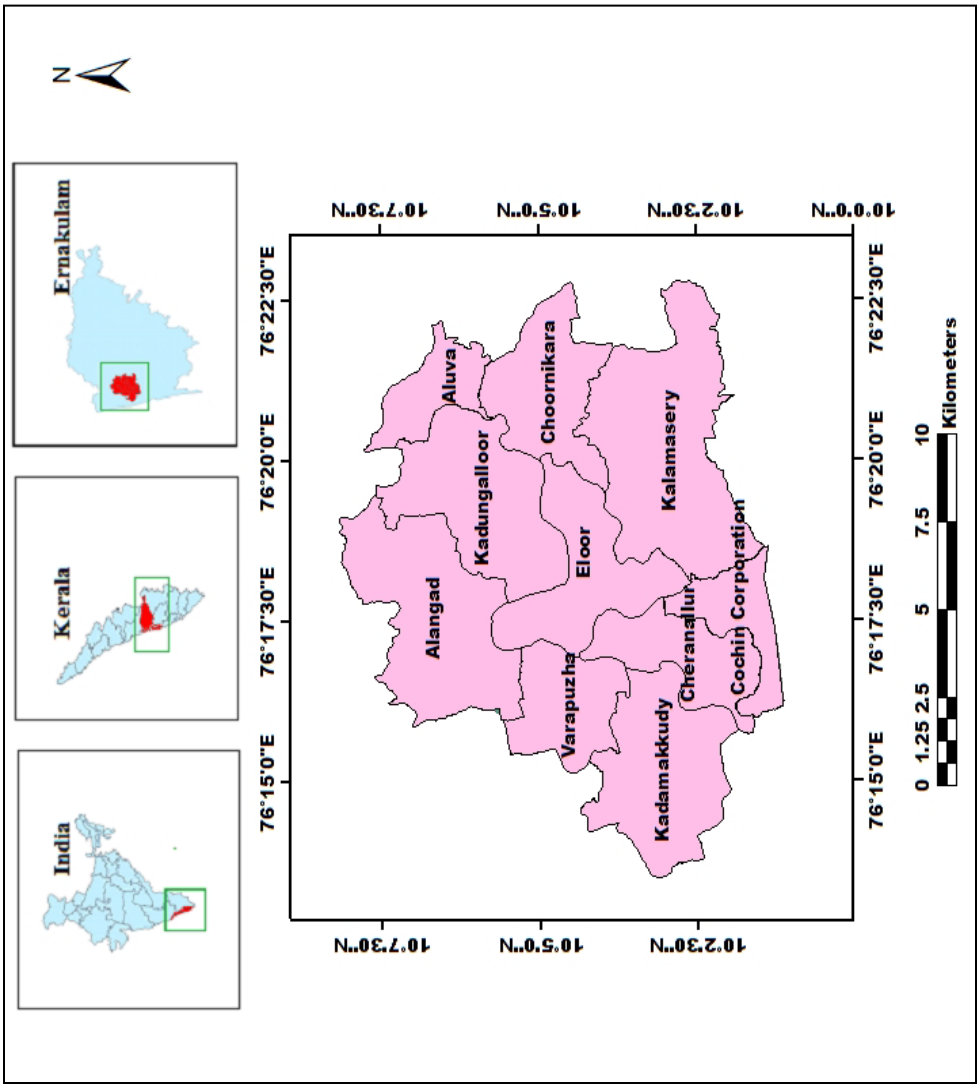
4.4.1 Study Area-I (Eloor and adjoining area): Ammonia and Chlorine release

In location one, ammonia and chlorine storage facilities were identified. The ammonia storage facility is located at 10^{0}04'08" N latitude and 76^{0}17'35" E longitude and the position of chlorine storage facility is 10^{0}04'29" N latitude and 76^{0}18'12" E longitude of Eloor Municipality. Based on the area likely to be affected by the release of ammonia and chlorine, Eloor municipality and adjoining areas were taken into account and considered as study area I. The adjoining areas to Eloor municipality are Kalamassery municipality, Kadungalloor Panchayath, Choornikkara Panchayath, Cheranallur Panchayath, Varapuzha Panchayath, Kadamakkudy Panchayath, Alangad panchayath, Aluva Municipality and Cochin

Corporation. Though Cochin Corporation is one of the adjoining administrative area of Eloor Municipality, only a small portion of it is included in study area-I. This is because the major part of the corporation is far away from Eloor industrial area and it is assumed that the chemical release may not affect that much distance.

Eloor is a suburb of Kochi and a municipality in Paravur Taluk, Ernakulam District in the Kerala State. It is an industrial area north of Cochin and an island of 13.23 km^2 formed between two tributaries of river Periyar. It is the largest industrial belt in Kerala. According to the international environmental group Greenpeace (2003), the industrial belt of Eloor in Kerala is one of the world's "top toxic hot spots". Though this region is an industrial area, it has a unique ecosystem and large number of people are residing in the surroundings of the industries.

Though the installation is located in Eloor municipal area, in case of a chemical disaster, depending on the weather condition and other influencing factors of gas leak, the chemical may spread into the neighbouring area depending on the wind direction. Map 4.1 shows the location of study area-I including Eloor Municipality and adjoining areas.



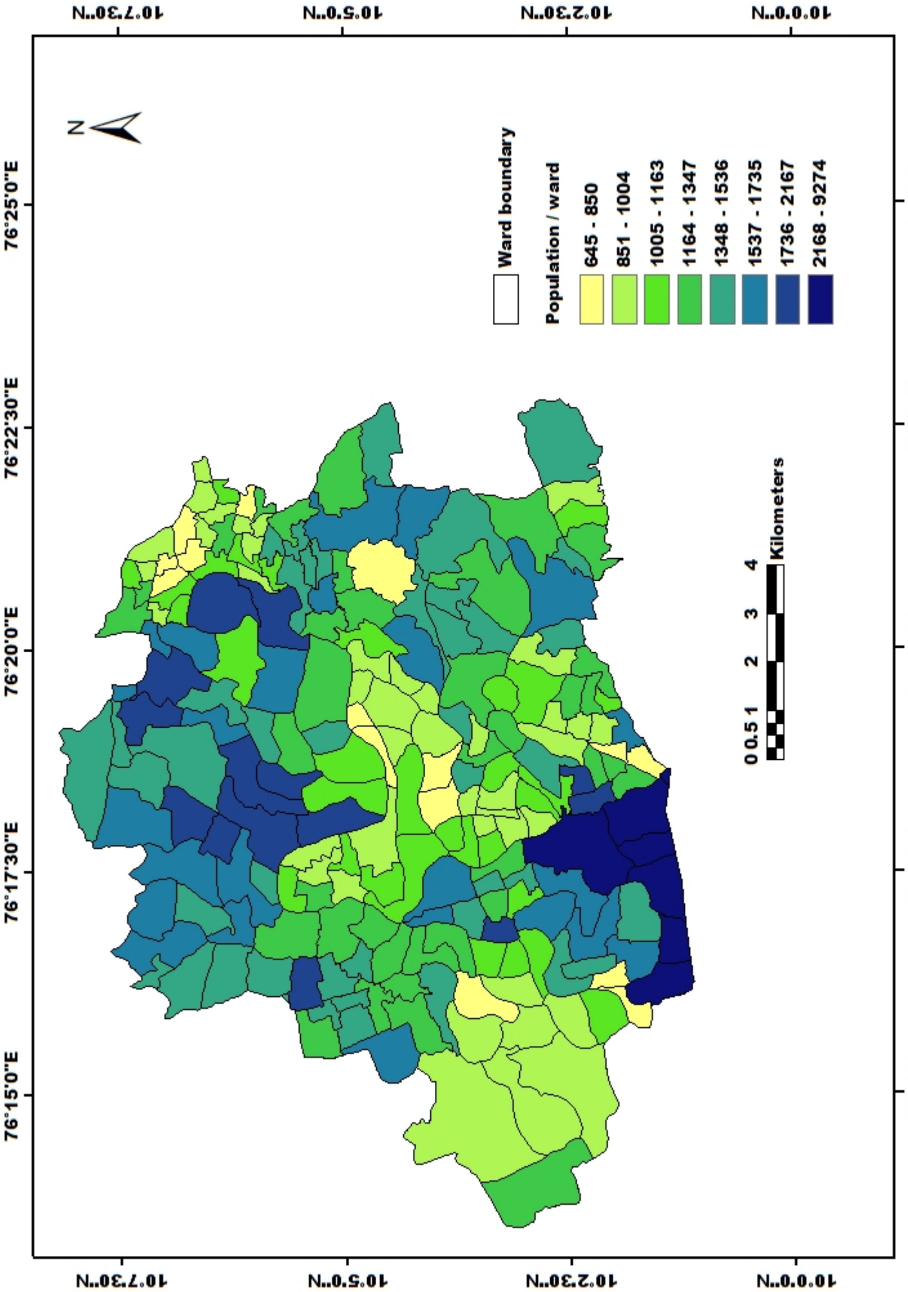
Map 4.1. Location Map of Study Area-I

4.4.1.1 Demographic Details

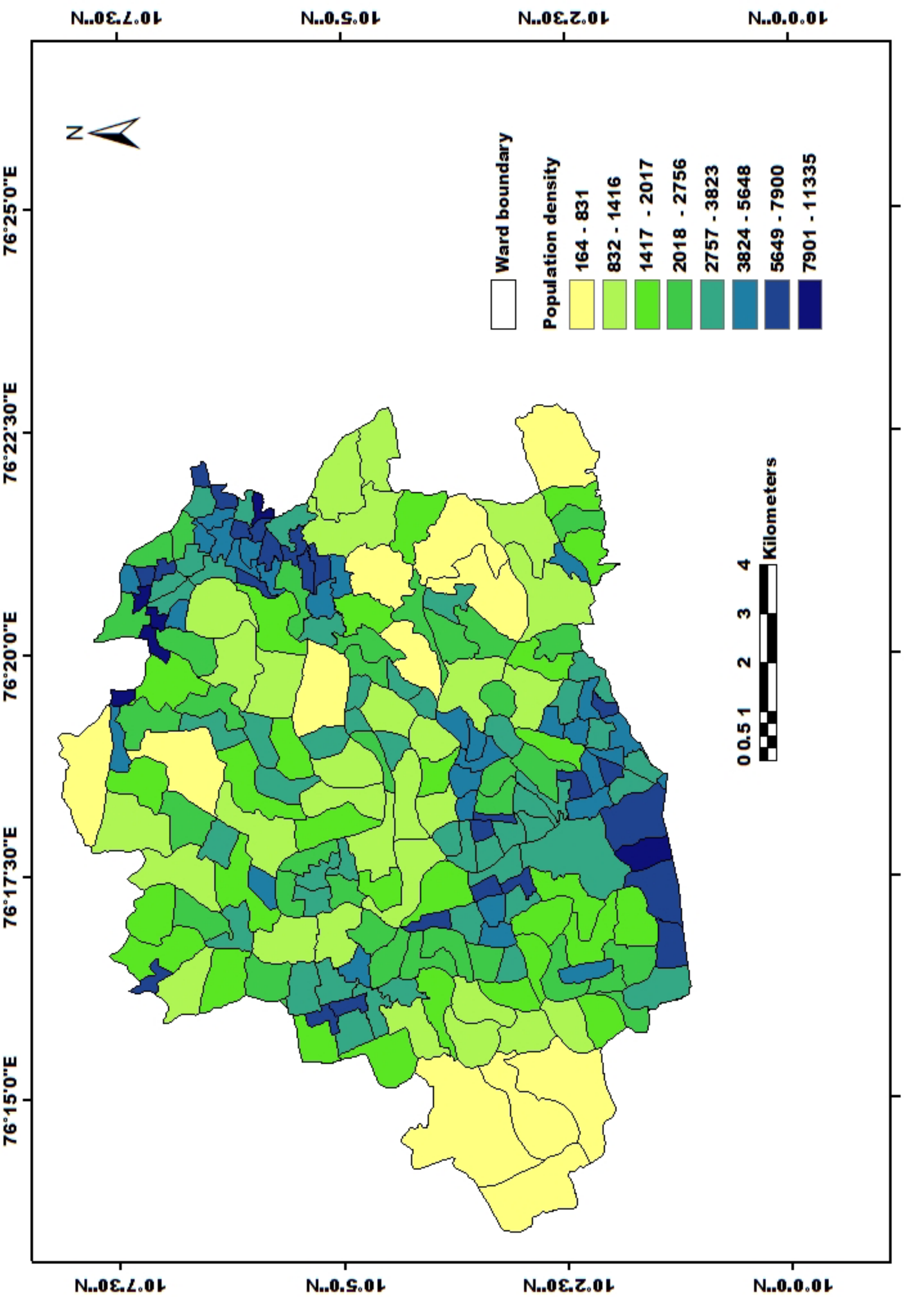
The demographical details of the Study Area-I are given in table 4.2. It shows that, in total around 322121 people are residing in and around the Eloor industrial area and the Cochin Corporation along with contributing 601,574 people. The area covers 197 wards and the population number in wards is ranging from 645 to 9274. Population range in each wards of study area-I is shown in Map 4.2 and its density is given in Map 4.3.

Table 4.2. Demographic Details of Study Area-I

Nearby areas of ammonia storage at Location-1	Total Area (km^2)	Total Population
Eloor	13.23	35,573
Kalamassery	25.23	70,776
Kadungalloor	17.14	39,666
Choornikkara	11.92	37,998
Cheranallur	9.12	26,330
Varappuzha	9.05	24,516
Kadamakkudy	16.73	15,823
Alangad	20.10	47,329
Cochin Corporation	4.05	601,574
Aluva	7.93	24,110
Total geographic area	134.5	



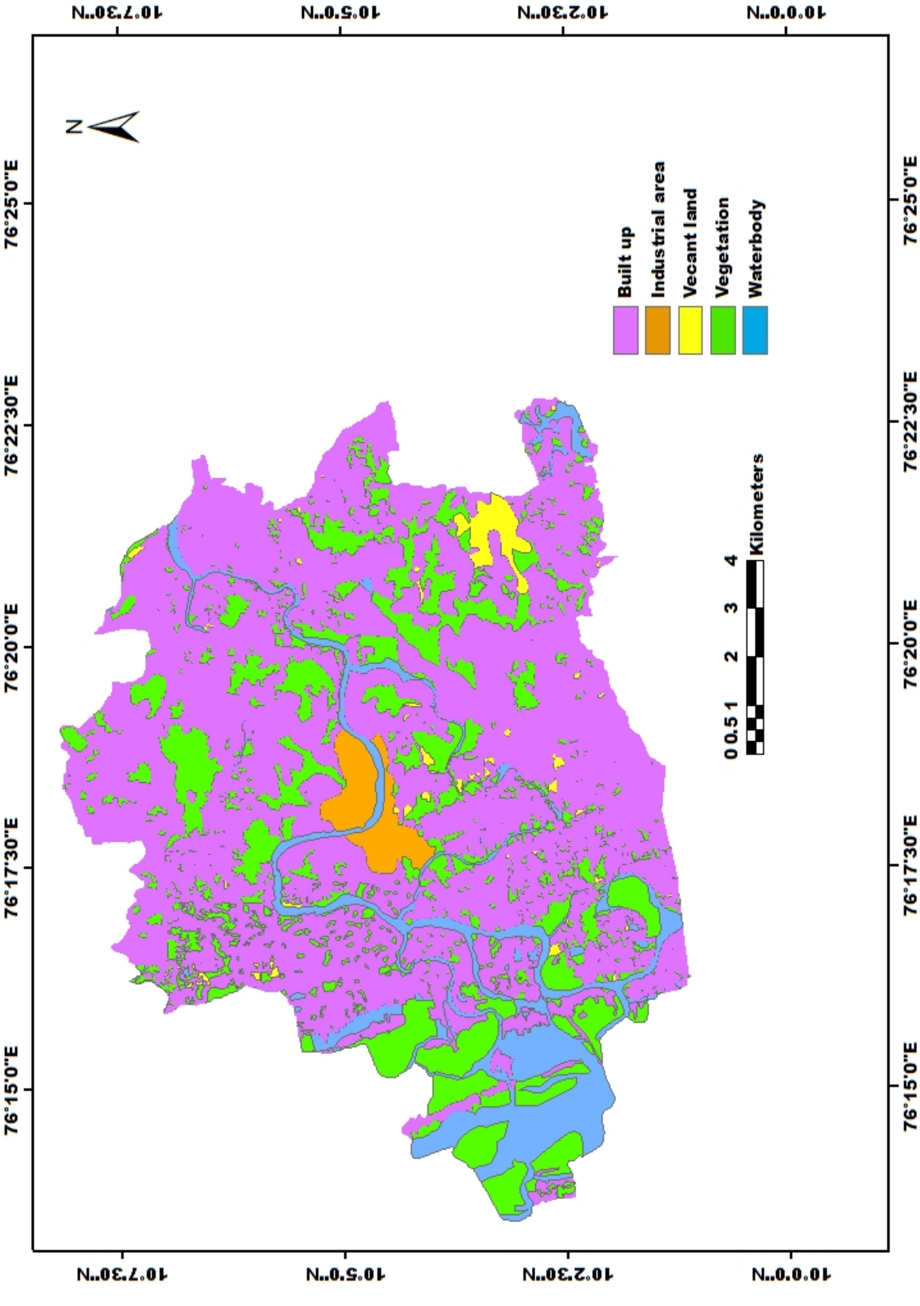
Map 4.2. Population of each Ward in the Study Area-I



Map 4.3. Population density in the Study Area-I

4.4.1.2 LULC Classification

The LULC classification of the study area –I is given in Map 4.3 which gives a clear idea of the land use pattern near the chemical installation of Ammonia and Chlorine. The proportion of each class is represented as a pie chart in figure 4.2.



Map 4.4. LULC Classification of Study Area-I

The classification shows that 64% of the land is covered by human residence and other buildings. Both of these together is considered as populated area. When only populated area (built up area) is taken into account, the population density in the area may be about 2465 people / km^2. Industries are located at only 2% of the total area. Water resources are available in 9 % of the total land and the remaining are vegetation (23%). Vacant land covers only 2%. The actual area covered by each land class is given in the table 4.3.

Table 4.3. Area Covered by Each LULC Classes of Study Area-I

SI No	LULC Classes	Area (km^2)	Proportion of classes
1	Water body	13.25	10%
2	Vegetation	30.29	22%
3	Built up	85.34	64%
4	Vacant Land	2.24	2%
5	Industrial Area	3.10	2%
Total area		134.22	

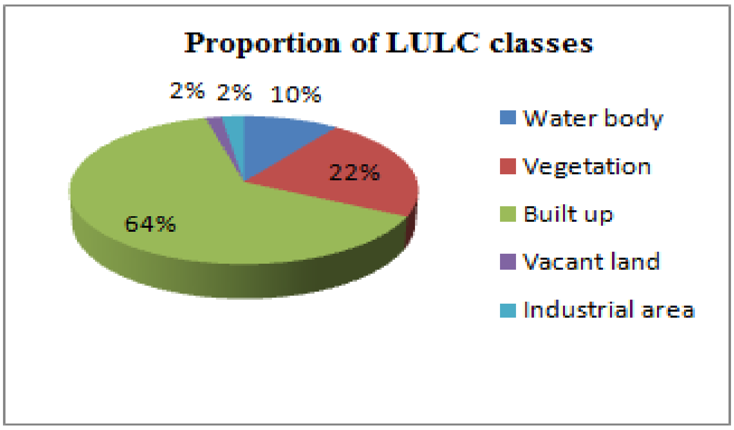
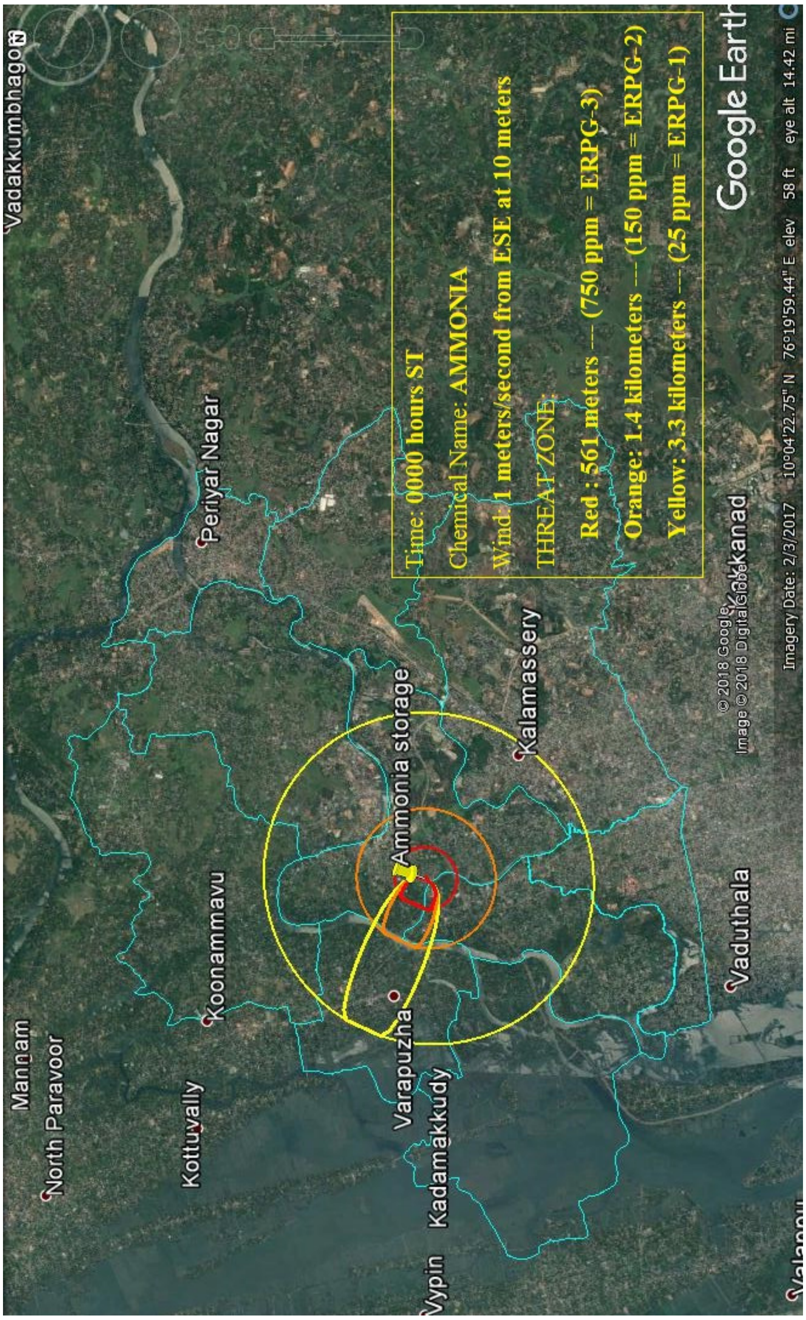


Figure 4.2. Proportion of LULC Classes in the Study Area-I

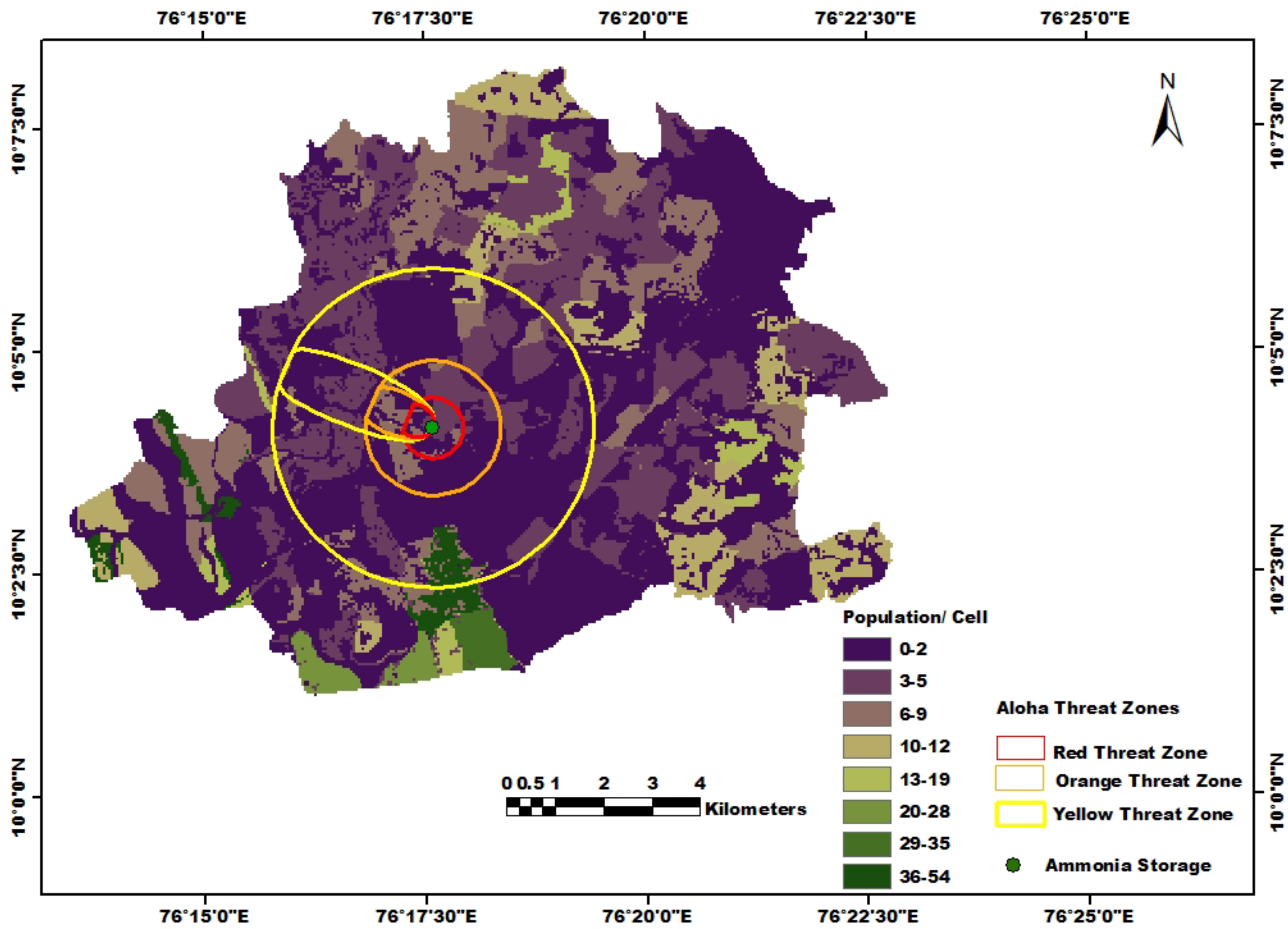
4.4.1.3 Population Vulnerability of Ammonia Release at Study Area- I

From the four different scenarios modeled for ammonia release, only the worst-case scenario (night time) is considered for population vulnerability assessment, as it shows the largest impacted area. Map 4.5 shows the position of Ammonia Storage Tank and threat zone of worst case scenario overlaid on Google Earth image. Map also shows the administrative boundaries and the area which is likely to be impacted by ammonia release. In the map, the threat zones are directed to North West (NW), as it was assumed that the wind is from ESE. As the wind changes its direction with time, the threat zones may change accordingly. Therefore, the wind direction confidence line of red, orange, and yellow threat zones is also shown in the map (represented as round figure).

Using the dasymetric mapping method, population distribution map of study area-I was prepared (map 4.6), which shows the overlaid threat zones also. This map gives a valid representation of population within ward and its attributes help to calculate the vulnerable population within the threat zone.



Map 4.5. Location of Ammonia Storage at Study Area-I and Threat Zones of Ammonia Overlaid on Google Earth Image.



Map 4.6. Population Distribution Map of Study Area-I and Threat Zones of Ammonia Release

The wind direction may change with time. Therefore, population vulnerability is assessed in all directions separately and the result is given in table 4.4.

Table 4.4. Number of People likely to be affected in different directions of Storage Facility at Study Area-I. Eloor (Ammonia Toxicity)

Threat Zone	Population likely to be affected in different directions around the Storage Facility				Expected Impact on People
	NE	SE	SW	NW	
Red	Workers of the industry	50	200	161	Life threatening health effect
Orange	925	5160	4825	3550	Serious health effect
Yellow	16114	21364	22486	24701	Transient adverse health effect

Note: NE- North East; SE- South East; SW-South West; NW- North West

The result of population vulnerability assessment in Study Area-I (Table 4.4) indicate that if the total population is considered, among the four directions, large number of people are likely to be impacted in the NW direction of the ammonia release. But, if the red threat zone (the most dangerous one) is considered, largest number of people are observed in the SW direction. The north east direction is comparatively less populated, but the people working in the industry can be badly injured. If an immediate evacuation of the people coming under this zone is not performed, death may happen.

The orange threat zone indicates the concentration of ammonia with irreversible or other serious, long lasting adverse health effects or an impaired ability to escape. Compared to all directions, the orange zone is more prevalent in the SE direction. Population structure in each direction is depicted in Figures 4.3. Based on the estimated population vulnerability of ammonia release (table 4.4.), map 4.7 shows the population vulnerability zones.

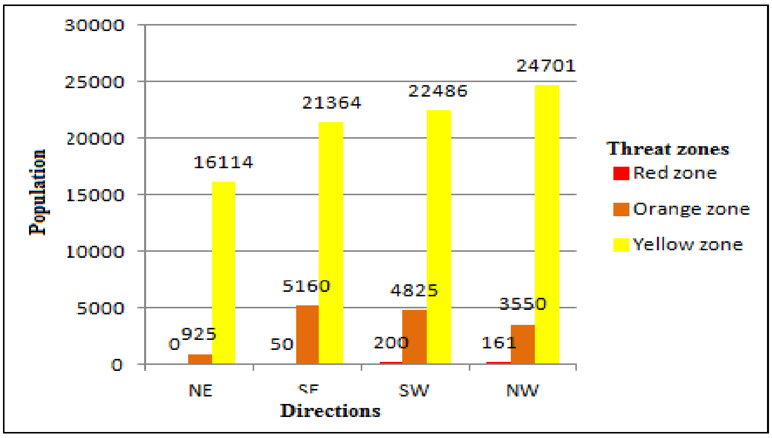
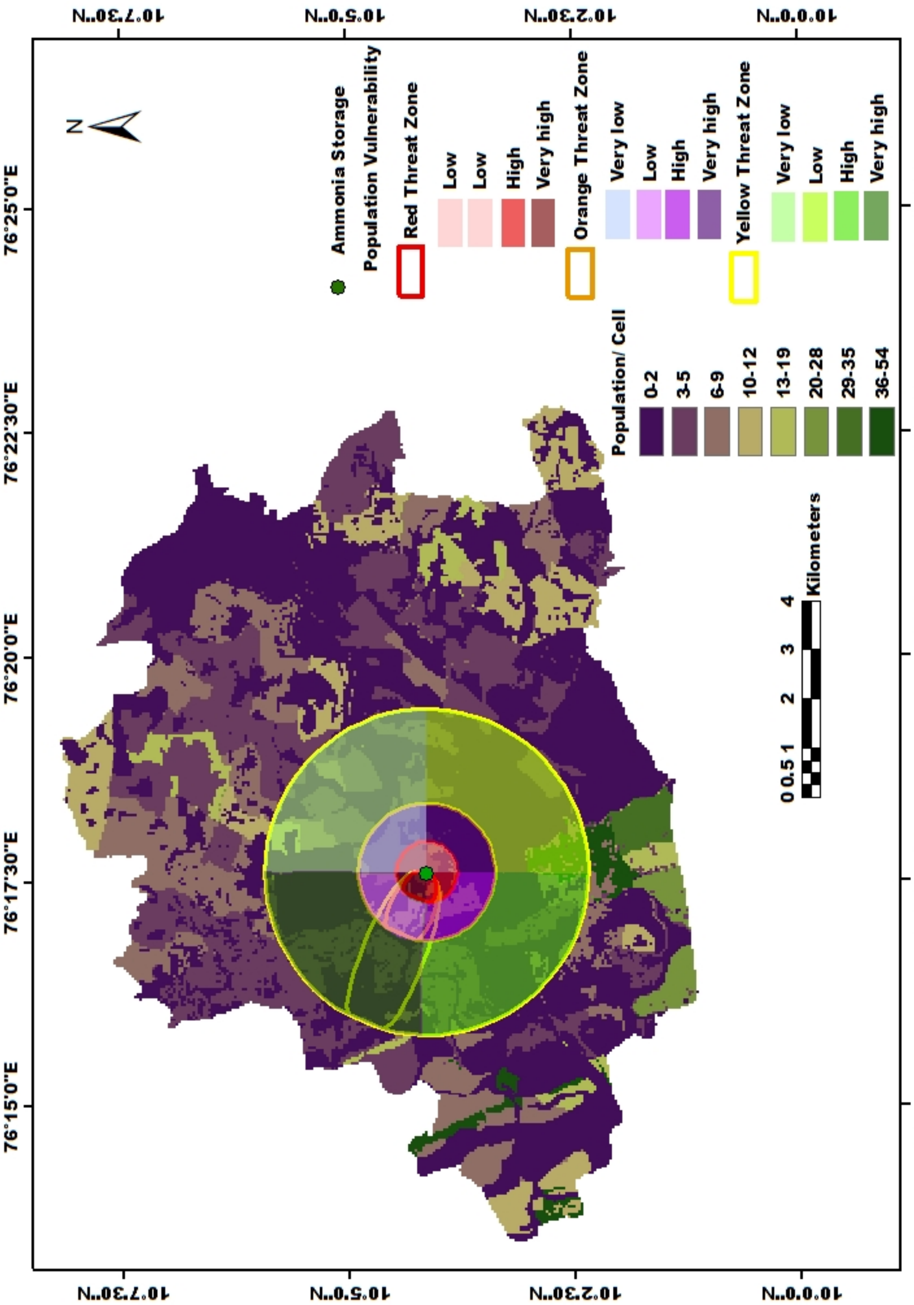


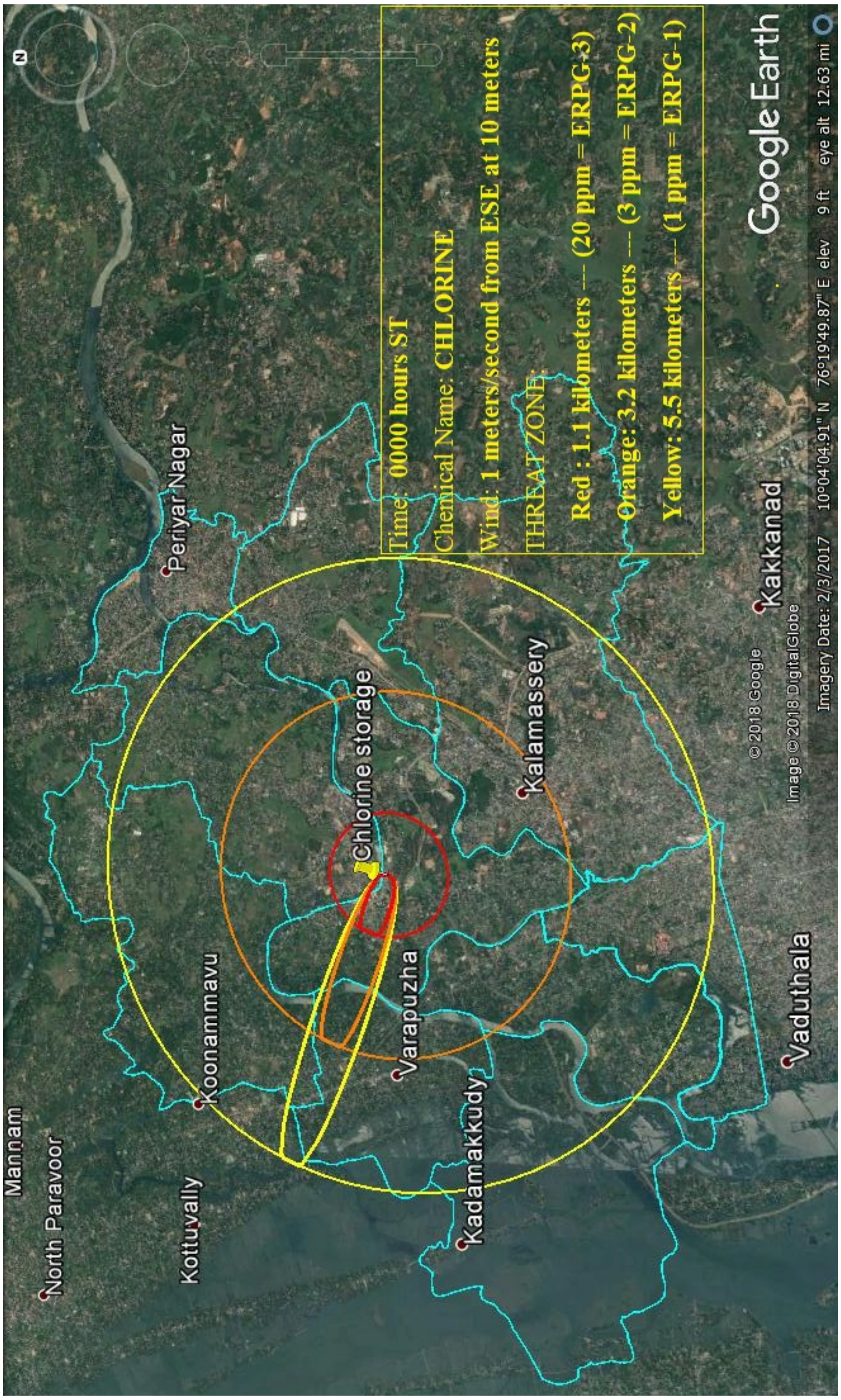
Figure 4.3. Population under the Threat Zone around (four directions) the Storage Facility of Ammonia



Map 4.7. Population Vulnerability within the Threat Zones of Ammonia Release

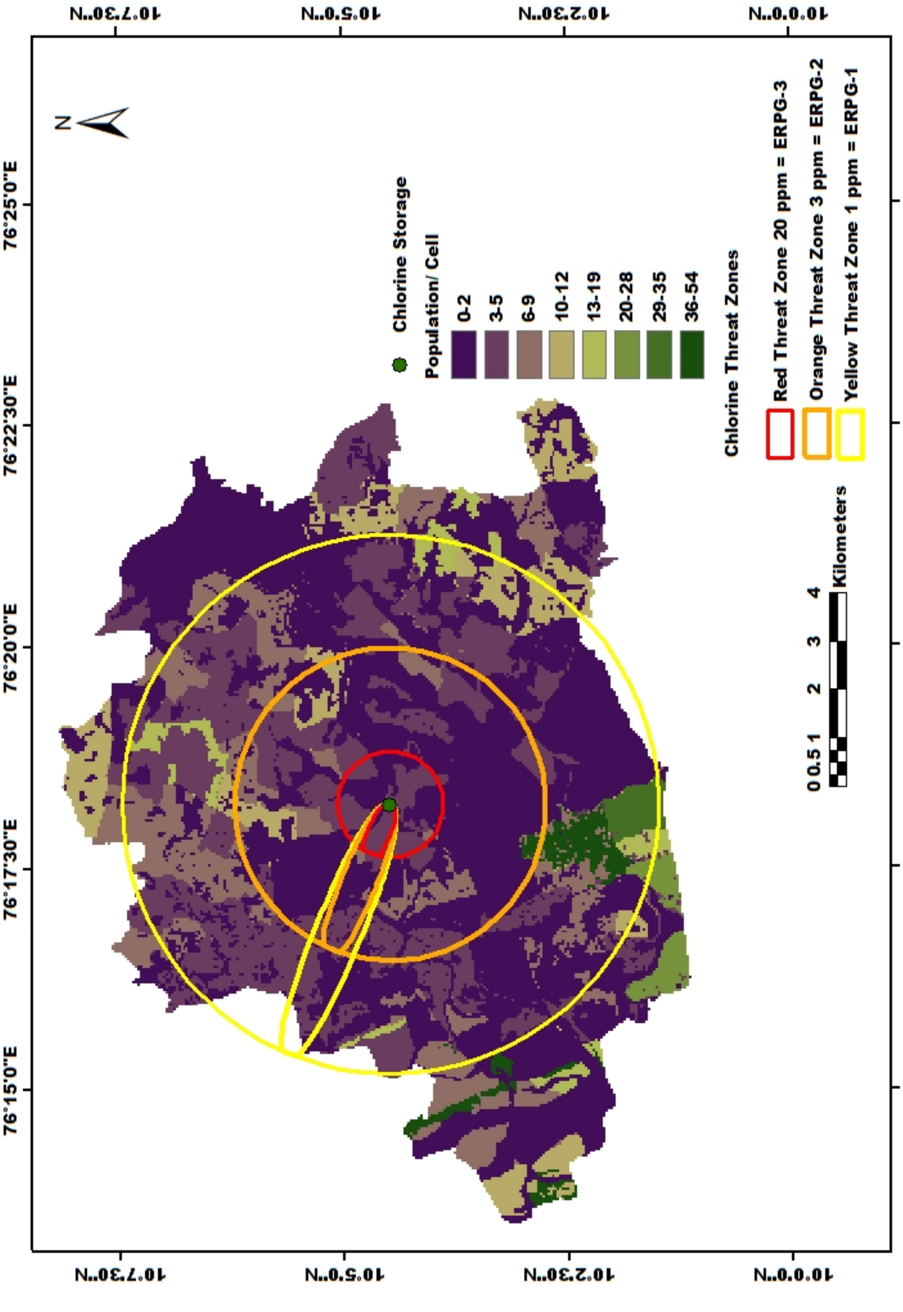
4.4.1.4 Population Vulnerability of Chlorine Release at Study Area-I

Map 4.8 shows the threat zones of chlorine release overlaid on the actual location in Google Earth. As mentioned earlier in chapter 3, the modeling result indicate that in the worst case scenario, the most hazardous concentration of chlorine as indicated by the red threat zone may extend up to a distance of 1.1 km from the source depending on the release conditions. The lesser hazard concentration zones, orange and yellow, may extend up to a distance of 3.2 km and 5.5 km from the source of release. The map also shows the administrative area (showing boundaries) coming under the threat zone. The red, orange and yellow circles indicate the wind confidence line, as the wind changes its direction. As the modeling is done by considering the wind direction from ESE, the threat zone direction in the map is in NW direction.



Map 4.8. Location of Chlorine Storage at Study Area-I and Threat Zones of Chlorine overlaid on Google Earth Image.

Map 4.9 shows the population distribution in study area-I with overlaid threat zones of chlorine release. Population vulnerability assessment indicates that (table 4.5) within the most dangerous red zone, in the NE and NW direction there is no public population. As this zone is covered by industrial area, the workers of the industries need to take immediate protective measures. But this red zone is vulnerable in SE and SW directions, which includes nearly 1200 and 360 people respectively. But, a large number of people comes within the orange and yellow threat zones.



Map 4.9. Population Distribution Map of Study Area-I and Threat Zones of Chlorine Release

Table 4.5. Number of People likely to be affected in different directions of Storage Facility based on the Wind Direction at Location-1. (Eloor Chlorine Release)

Threat Zone	**Population likely to be affected in different directions around the Storage Facility**				**Expected impact on people**
	NE	**SE**	**SW**	**NW**	
Red	Workers of the industry	1200	360	Workers of the industry	Life threatening health effect
Orange	15221	11332	12804	14294	Serious health effect
Yellow	23522	18793	32338	22053	Transient adverse health effect

Note: NE- North East; SE- South East; SW-South West; NW- North West

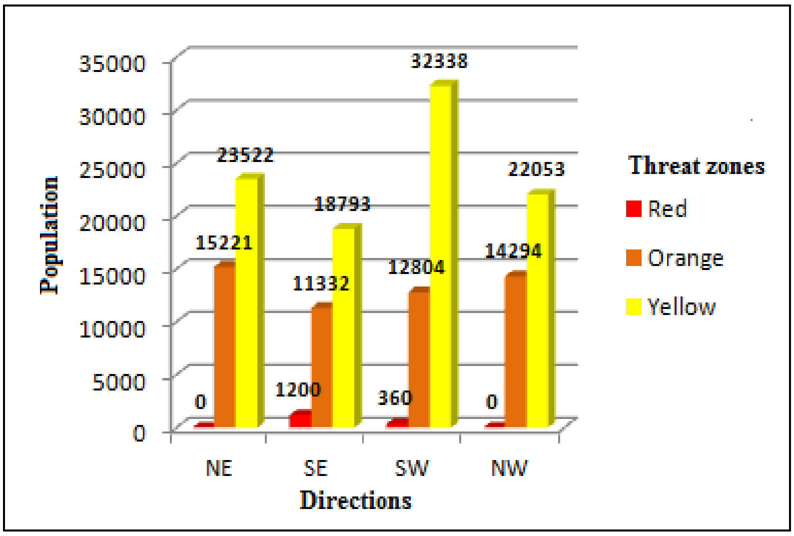
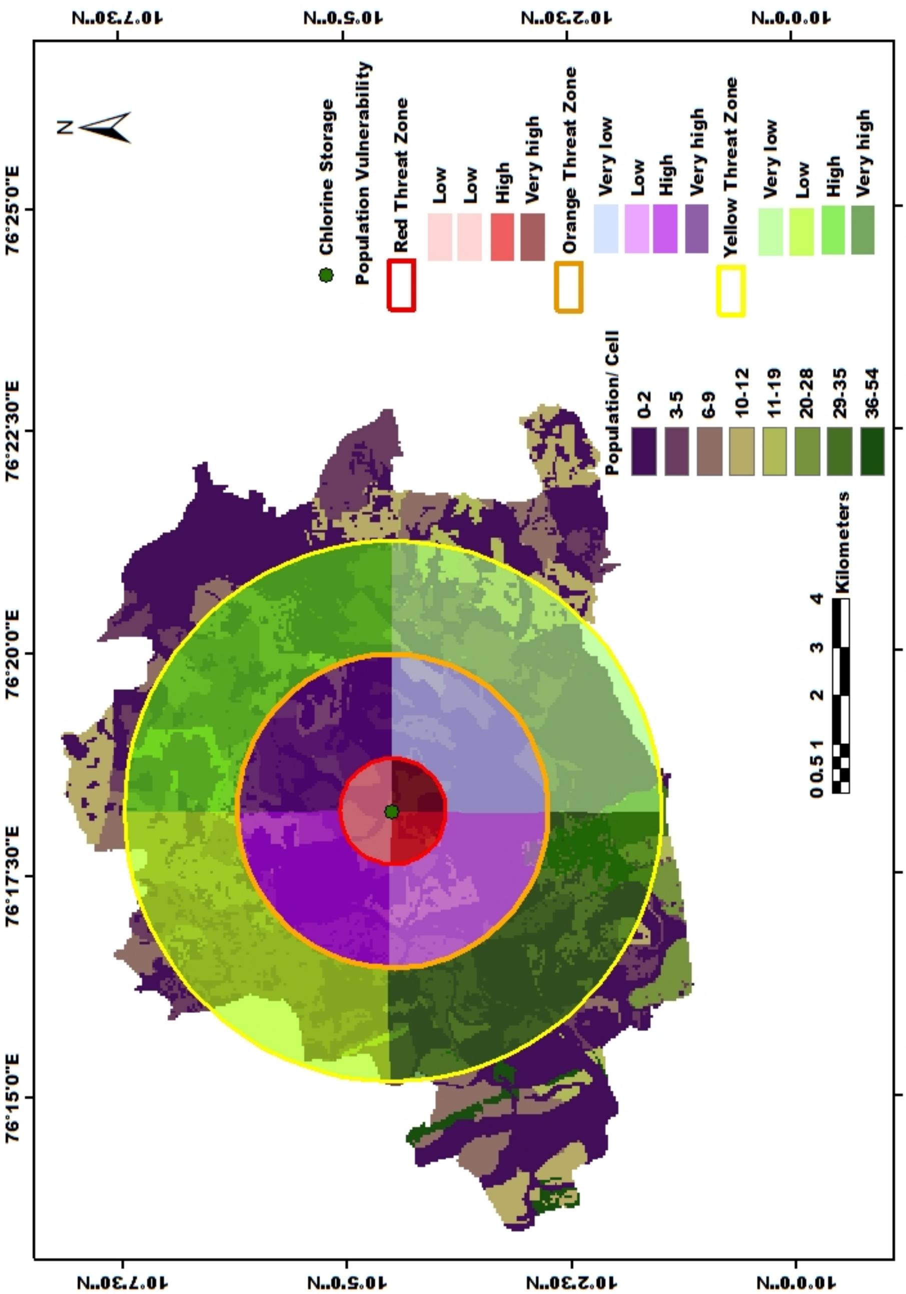


Figure 4.4. Population under the Threat Zone around (four directions) the Storage Facility of Chlorine

Figure 4.4 gives the population structure showing the number of population in each threat zone in different directions. Population structure of figure 4.4. indicates that when the wind direction changes, high variability can be seen in the vulnerable population. Within the orange threat zone, a higher number of population is seen in the NE direction and less population in the SE direction, whereas in the case of yellow threat zone, higher number is observed at SW direction. However, when considering the total number of population (including all the three threat zones), SW direction contains highest number of population. Based on table 4.5, Map 4.10 given below shows the population vulnerability within the threat zones of chlorine.

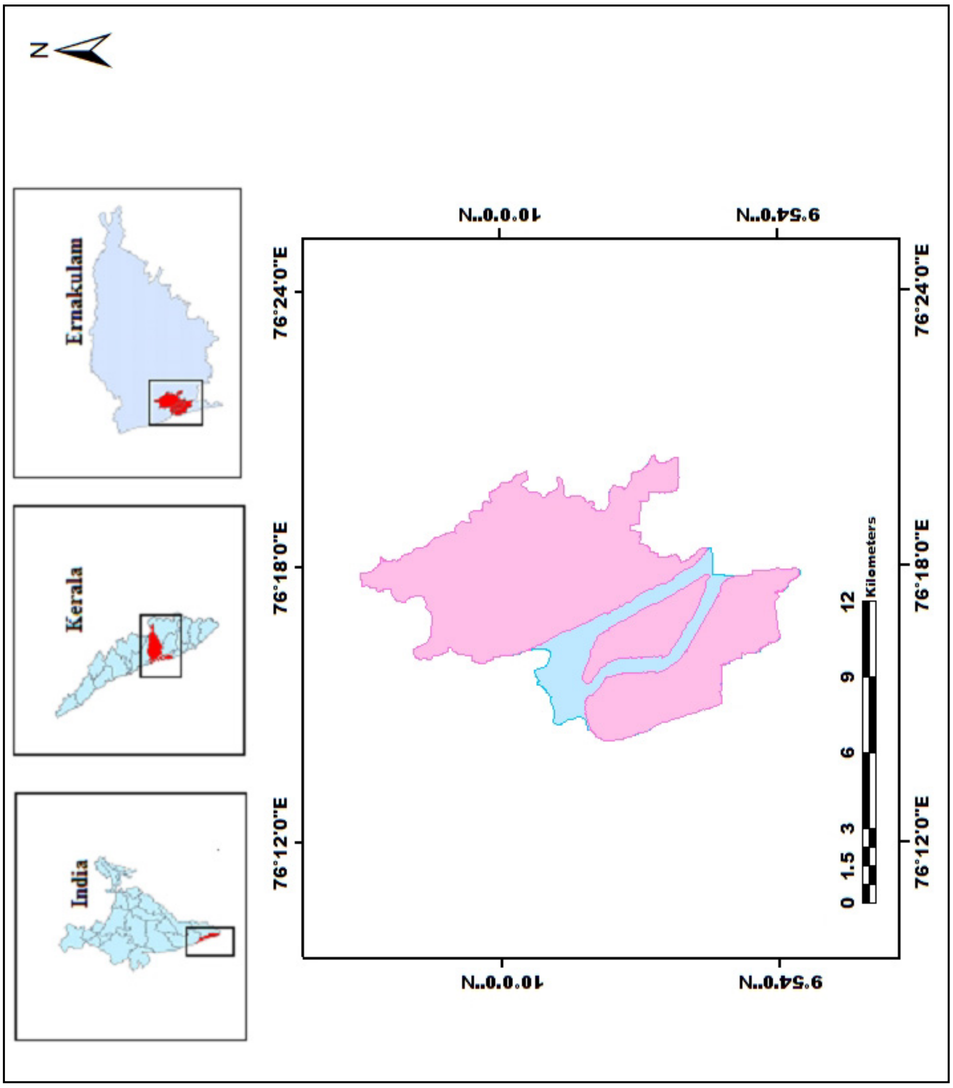


Map 4.10. Population Vulnerability within the Threat Zones of Chlorine Release

4.4.2 Study Area II (Cochin Corporation): Ammonia Release

The ammonia storage tank in Willigdon Island, located at $9^0$57'13" N and $76^0$16' 03" E in Cochin Corporation is considered as Study area-II. The Willingdon Island in Kochi is the largest artificial island in India. The Island is home to some of the best hotels, and commercial and industrial buildings of the City. The Island is significant as the habitat for many establishments including Port of Kochi, Southern Command of the Indian Navy, Customs offices, Central Institute of Fisheries Technology, and various warehouses. Though the island is less populated with permanent residents, all the aforementioned establishments make the area highly populated with their workers.

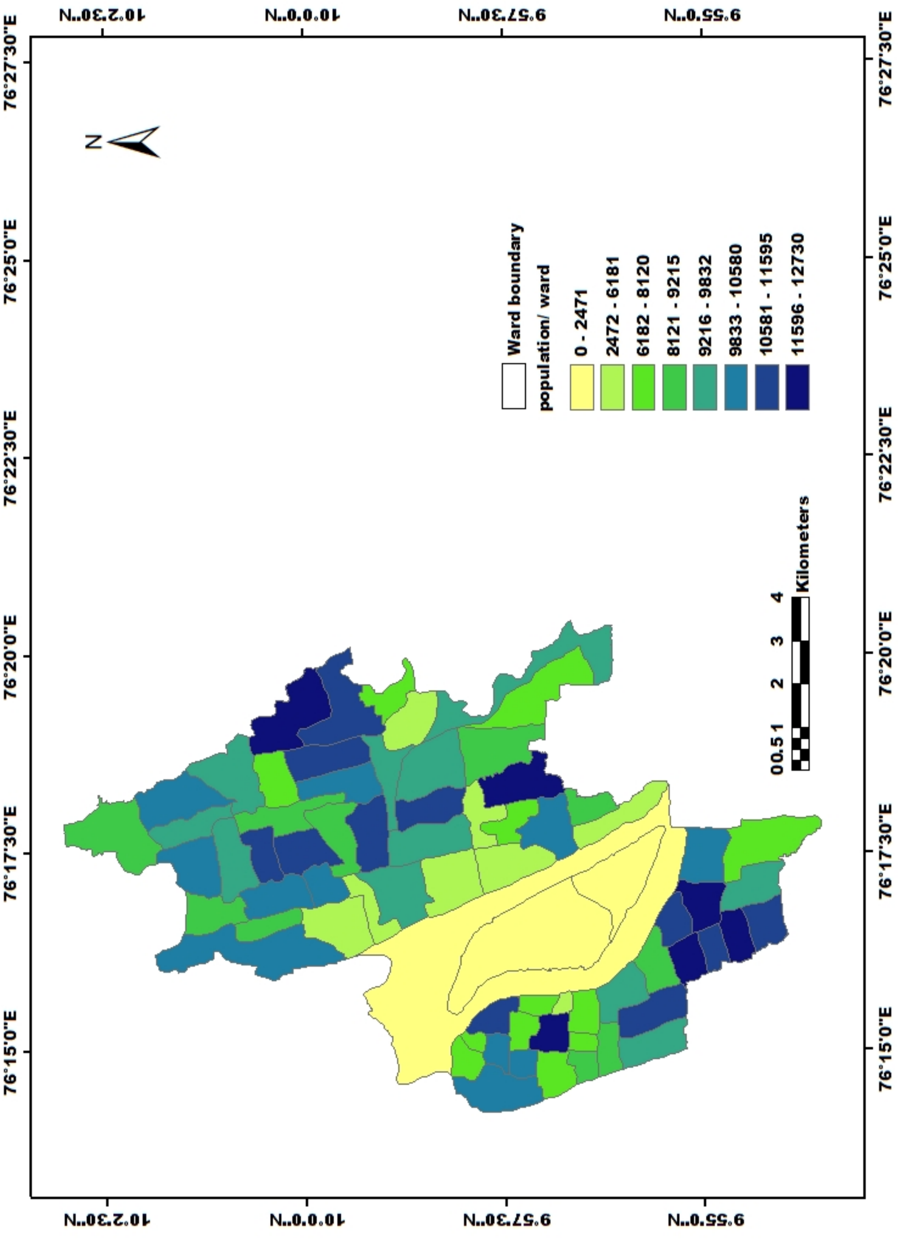
The presence of ammonia storage tank in the heart of Cochin Corporation, close to the naval airport, poses a large threat to life in the City. The 10,000 MT Ammonia Storage Tank is capable of turning Cochin City into another Bhopal. The 3.3 km distance of leakage impact area assessed from the source not only include the Willingdon Island, but also the other areas of Cochin Corporation, as the wind can carry the toxic gas clouds. Therefore, Cochin Corporation as a whole is considered as Study area-II. The Location Map of the Study Area-II is shown in Map 4.11.



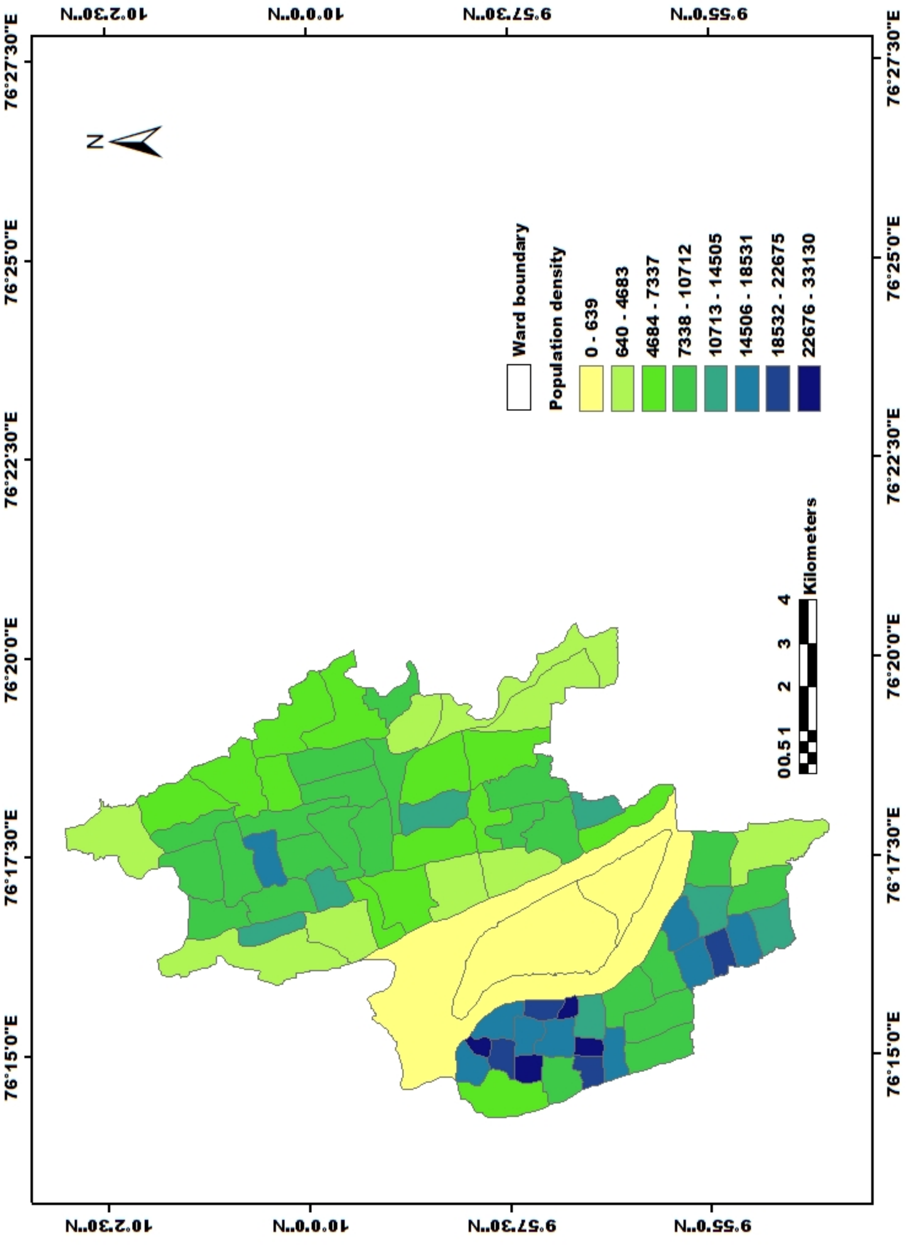
Map 4.11. Location Map of Study Area-II

4.4.2.1 Demographic Details

Both in area and population, the Corporation of Cochin is the largest Municipal Corporation in Kerala, with a total area of 97.09 sq. kms and a population density of 6287/km^2. The Corporation includes 71 wards with a population ranging from 2,471 to 12, 730. Lowest population is observed in Willingdon Island. Map 4.12 represents the population of each ward and density given in Map 4.13.



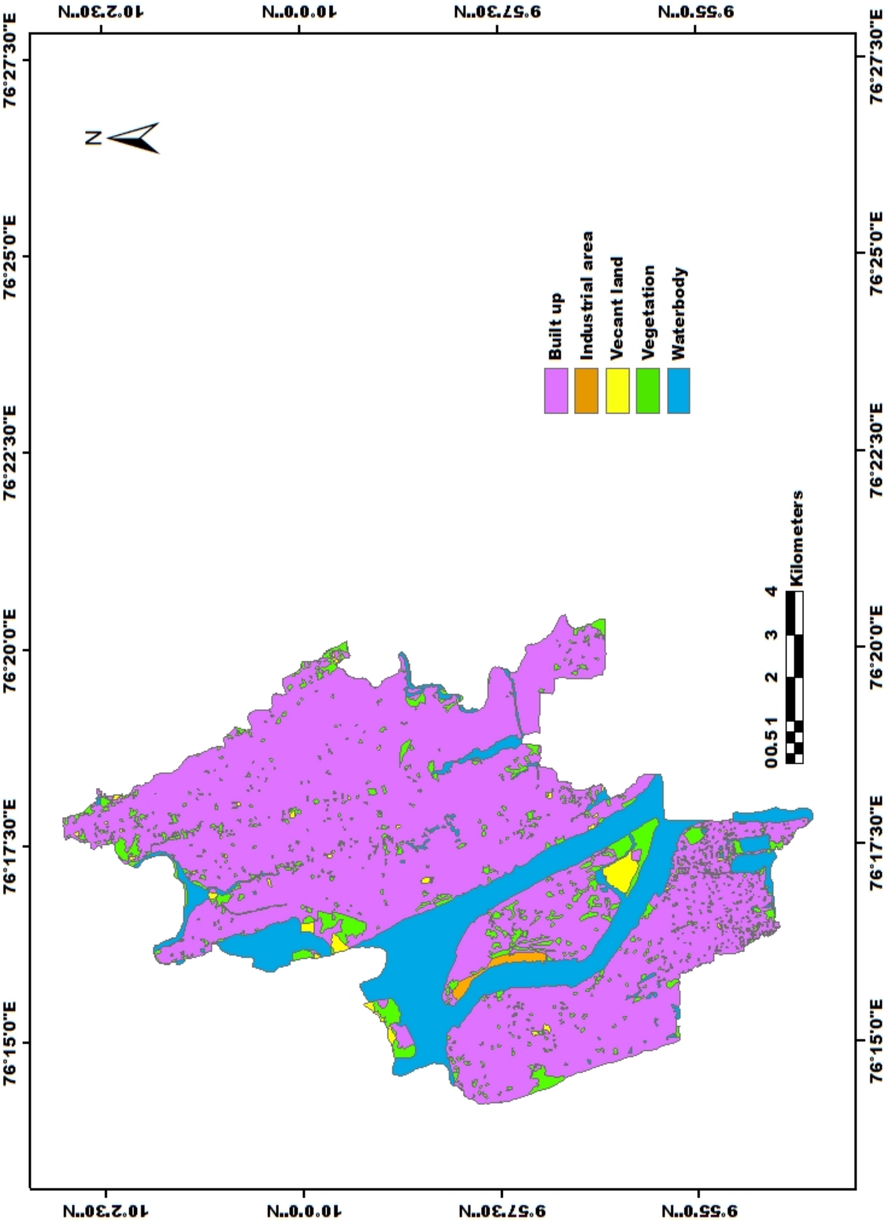
Map 4.12. Population of each Ward in the Study Area-II



Map 4.13. Population density in the Study Area-II

4.4.2.2 LULC Classification

Though a number of small, medium, and large scale industries are located in Kochi, survey reveals that hazardous chemicals are handled only in Willingdon Island which covers only 0.51% of the total Corporation area. A major portion, 73%, of the city covers the entire population of the area within the commercial and residential sectors. Though much of the City area is urbanized, many varieties of mangroves and other vegetations are also seen and it covers 8% of total land area. The city has large water bodies which occupies 18% of total area. The remaining portions, constituting 1% of land, are vacant lands used for special purposes or unused lands. Map 4.14 depicts the LULC classification of Cochin Corporation and proportion of each land cover is given in figure 4.5. Table 4.6 shows the area covered by each land.



Map 4.14. LULC Classification of Study Area-II

Table 4.6. Area covered by each LULC Classes of Study Area-II

SI No	LULC classes	Area (km²)	Proportion of classes
1	Water body	17.93	18%
2	Vegetation	6.8	7%
3	Built up	70.6	73%
4	Vacant land	1.1	1%
5	Industrial area	0.51	1%
Total area		96.94	

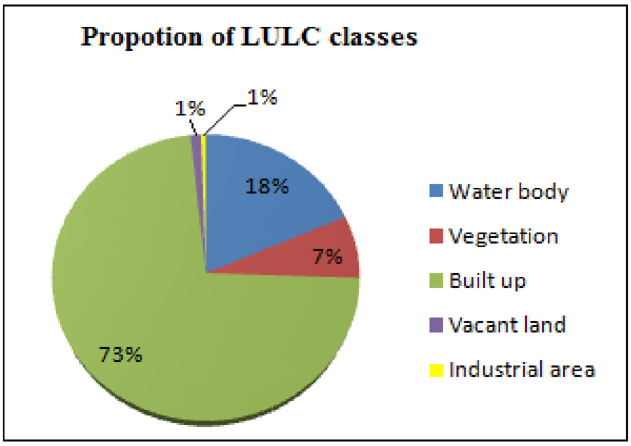
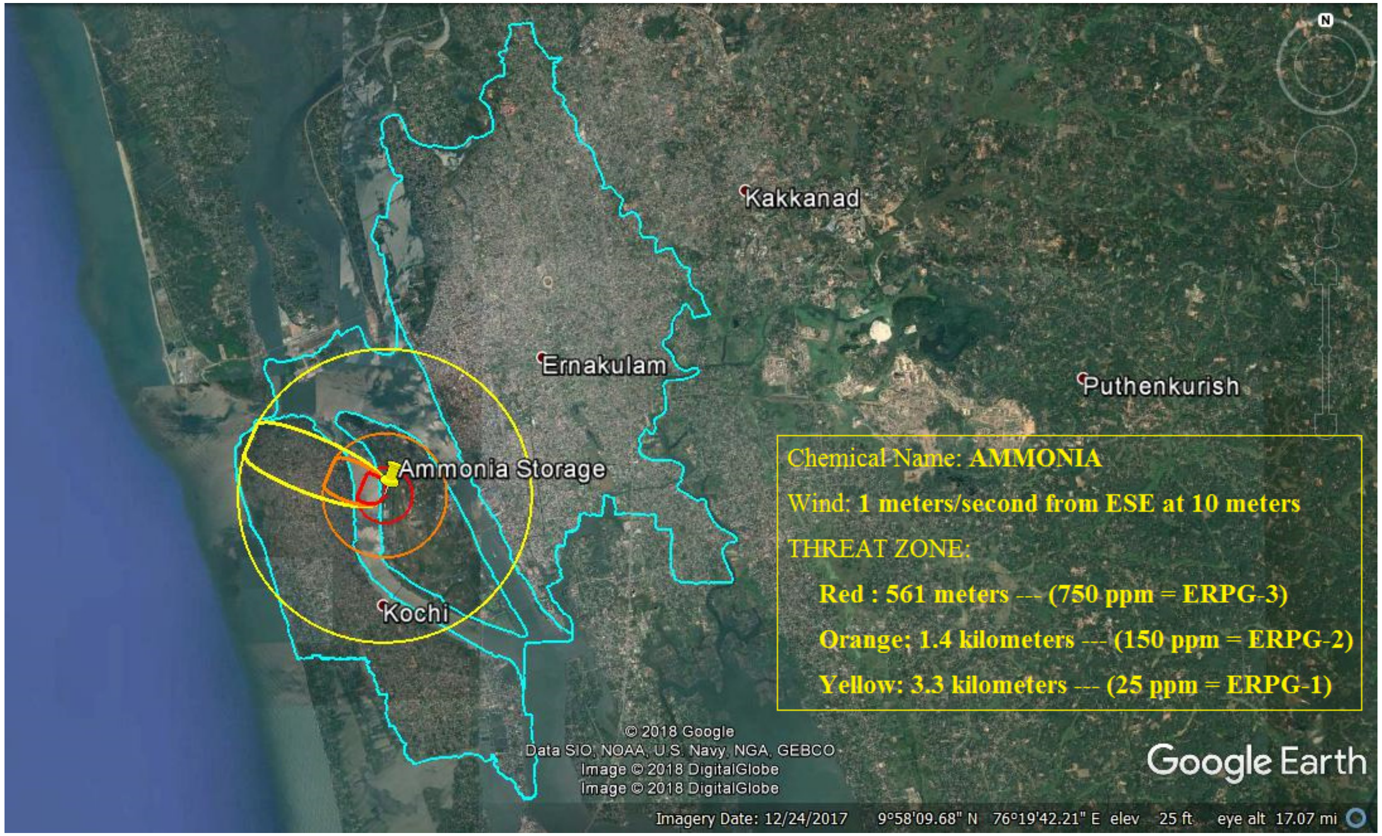


Figure 4.5. Proportion of LULC Classes in Study Area-II

4.4.2.3 Population Vulnerability of Ammonia Release in the Study Area-II

The existing ammonia storage tank at Willingdon Island is posing threat to whole Cochin Corporation area. The worst case scenario of ammonia release at night time indicate that the dangerous red threat zone can extend up to 561 m from the source of release, and orange and yellow threat zones may cover upto 1.4 and 3.3 km.

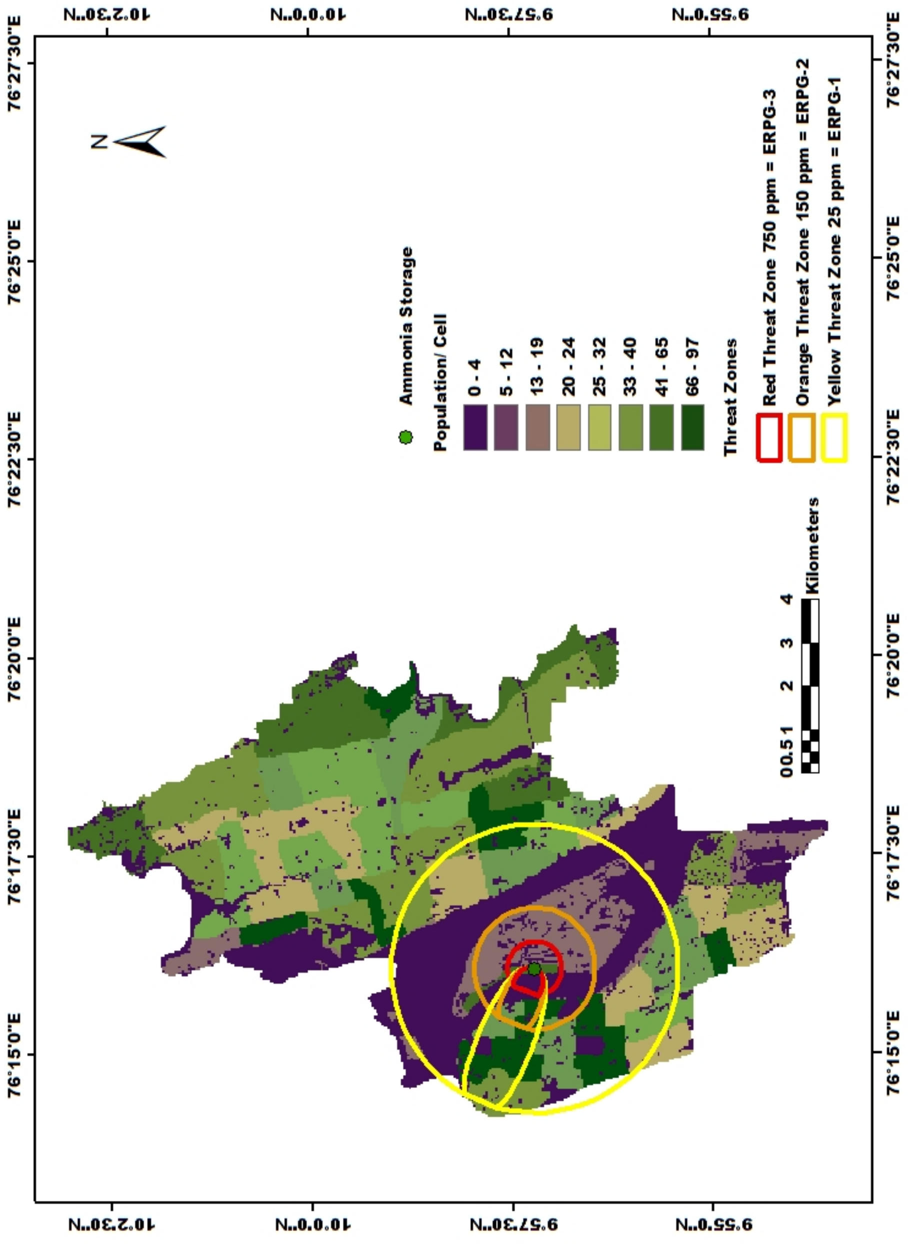
The area which is likely to be impacted by an ammonia leakage is shown in the Google Earth Image (Maps 4.15).



Map 4.15. Location of Ammonia Storage in the Study Area-II and Threat Zones of Ammonia overlaid on Google Earth Image

This map shows the location of ammonia storage facility and threat zones of ammonia release overlaid on the boundary of Cochin Corporation. Wind confidence lines (circles) of each threat zones indicate the area likely to be affected when the wind changes its direction.

The vulnerable population within the threat zones is calculated using the areal interpolation method and is given in table 4.7. The attributes of population distribution map (Map 4.16) provide a clear estimate of population coming under each threat zone separately with different wind directions.



Map 4.16. Population Distribution Map of Study Area-II and Threat Zones of Ammonia Release

Threatened population in four different directions (NE, SE, SW, and NW) is given in table 4.7. The table indicates that the dangerous red threat zone is less vulnerable to population, as this zone does not spread over a highly populated area. The area covered by this zone mainly includes water body and unpopulated vacant land. But if the wind carries the toxic clouds to NE and SE direction only about 10 or more people may be badly affected. In orange threat zone SW direction is highly vulnerable and NE and SE directions are comparatively less vulnerable. Similar to the orange threat zone, in yellow zone SW direction show more number of likely to be affected people than in the other directions. Population structures in each threat zone with different directions are given in Figure 4.6.

Table 4.7. Number of People Likely to be affected in different directions of Ammonia Storage Facility at Study Area-II (Willingdon Island)

Threat Zone	Population likely to be affected in different directions around the Storage Facility				Expected Impact on People
	NE	SE	SW	NW	
Red	10	9	None	None	Life threatening health effect
Orange	340	630	18443	9989	Serious health effect
Yellow	44826	43494	80520	49173	Transient adverse health effect

Note: NE- North East; SE- South East; SW-South West; NW- North West

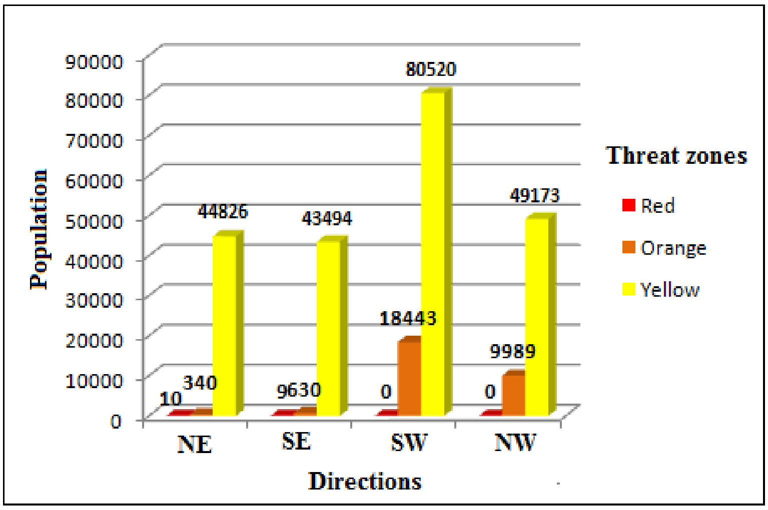
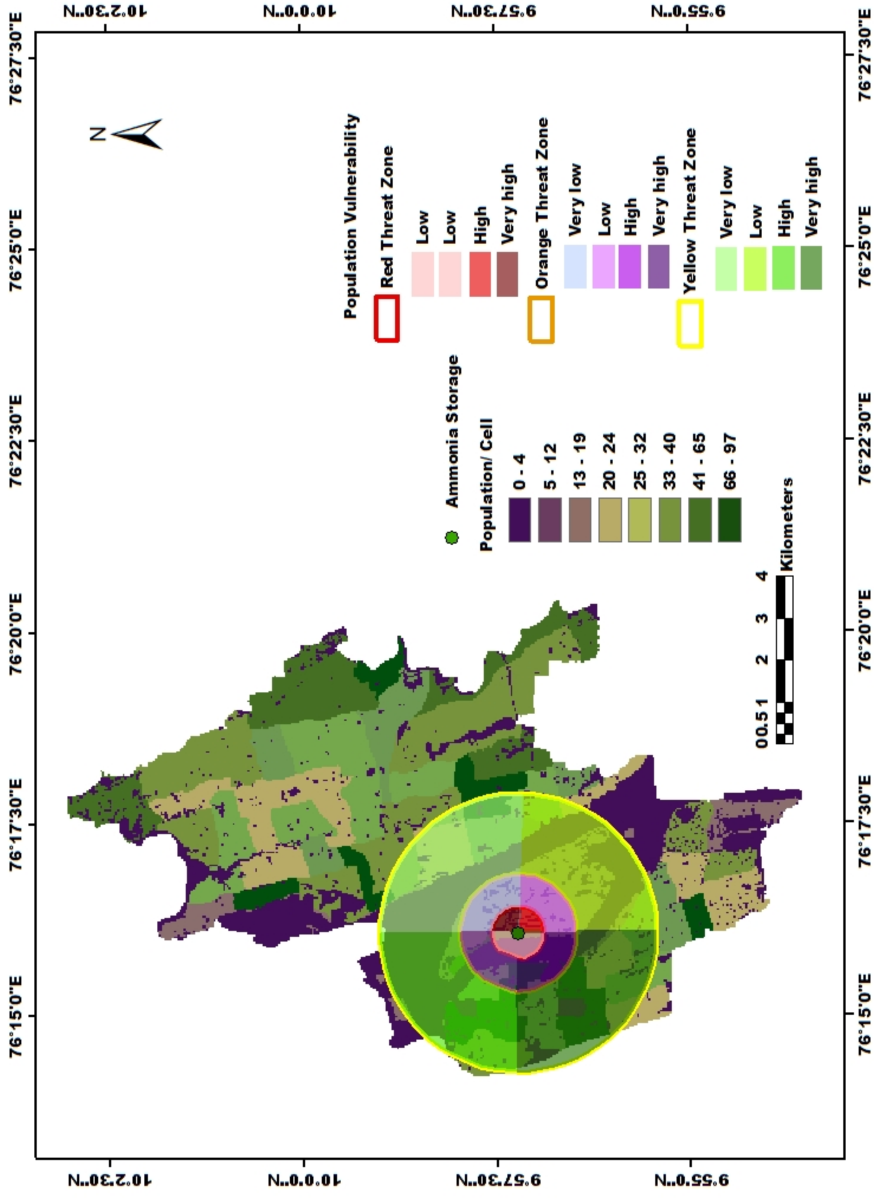


Figure 4.6. Population under the Threat Zones around (four directions) the Ammonia Storage Facility

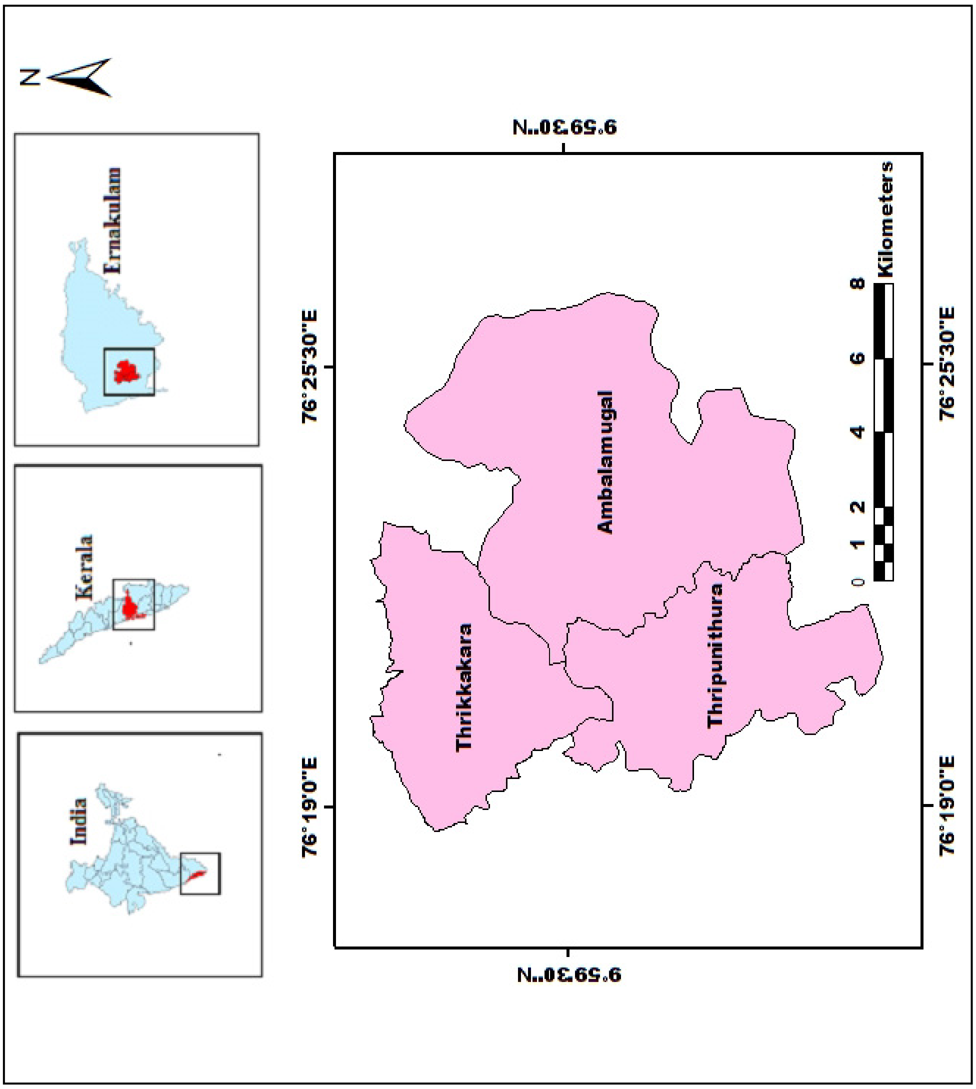
If total population in each direction taken into account, the higher number of population is seen in SW direction, but the dangerous red zone in this direction is comparatively safe. If immediate measures are taken to plug the leakage of ammonia, further spreading can be prevented before it reaches the orange and yellow zones. Using the estimated vulnerable population (table 4.7) in each direction of ammonia storage facility, population vulnerability map was prepared and illustrated in map 4.17.



Map 4.17. Population Vulnerability within the Threat Zones of Ammonia Release (Willingdon Island)

4.4.3 Study Area - III (Ambalamugal and Irumbanam Region): Ammonia and LPG Release

On the basis of the affected distance, study area-III includes two Municipalities (Thrikkakara and Thripunithura) and one panchayath (Vadavucode-Puthencruz). This area is identified with one ammonia storage facility, and two LPG storage facilities. Ammonia storage tank is located at $9^0$58'26" N and $76^0$22'17" E. Two industries which have the storage of LPG are located at $9^0$58'04" N and $76^0$23'05" E and $9^0$58'07" N and $76^0$21'54" E respectively. Ambalamugal, Irumpanam and Karimugal areas of study area-II are heavily industrialized suburbs of City of Cochin. In 2010, Ambalamugal was declared "critically polluted" by the Ministry of Environment and Forests. The location of study area-III is given in Map 4.18.



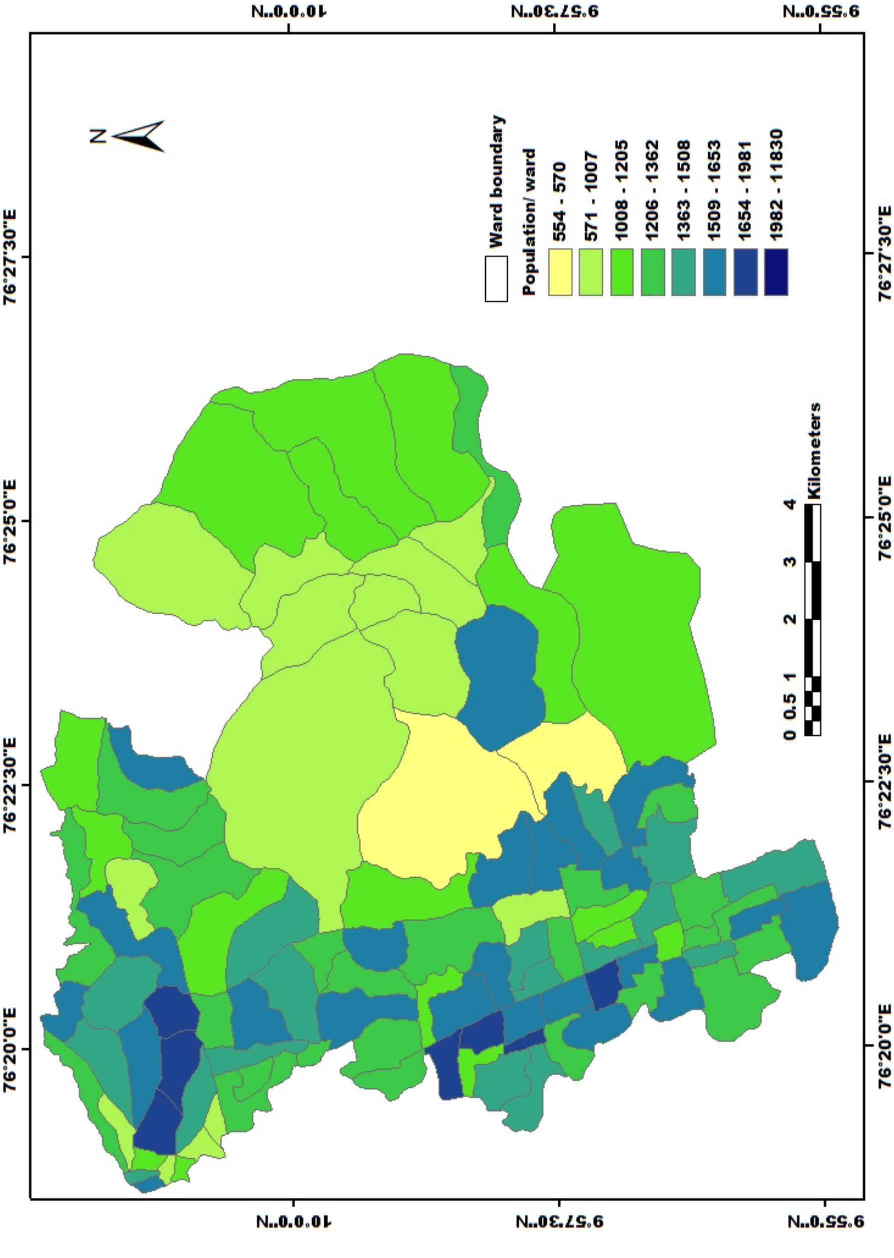
Map 4.18. Location map of Study Area-III

4.4.3.1 Demographic Details

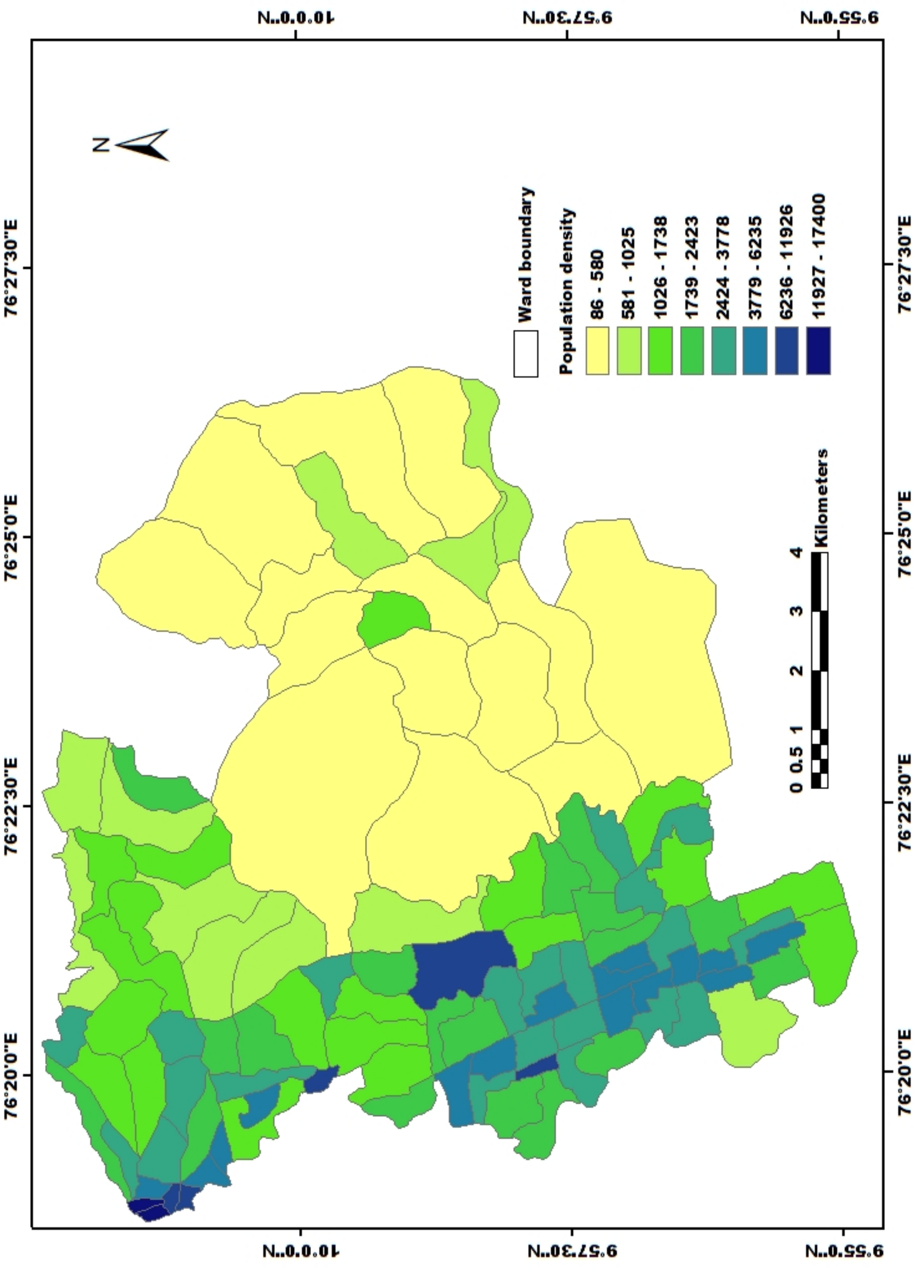
The demographic details of study area-III are given in table 4.8. In total, the population count in the study area-III is 141535. This area covers 104 wards and population number in wards ranges from 554 to 1981. Population range in each ward is shown in Map 4.19 and the density is given in Map 4.20. Compared to Tripunithura and Thrikkakara, Vadavucode-Puthencruz region is less populated.

Table 4.8. Demographic Details of Study Area-III

Administrative boundaries	Area	Population
Thrikkakara Municipality	27.46 sq. km	55,029
Thripunithura Municipality	30.34 sq. km	69,390
Vadavucode-Puthencruz Panchayath	50. 25 sq. km	17,116
Total geographic area	108.05 sq.km	



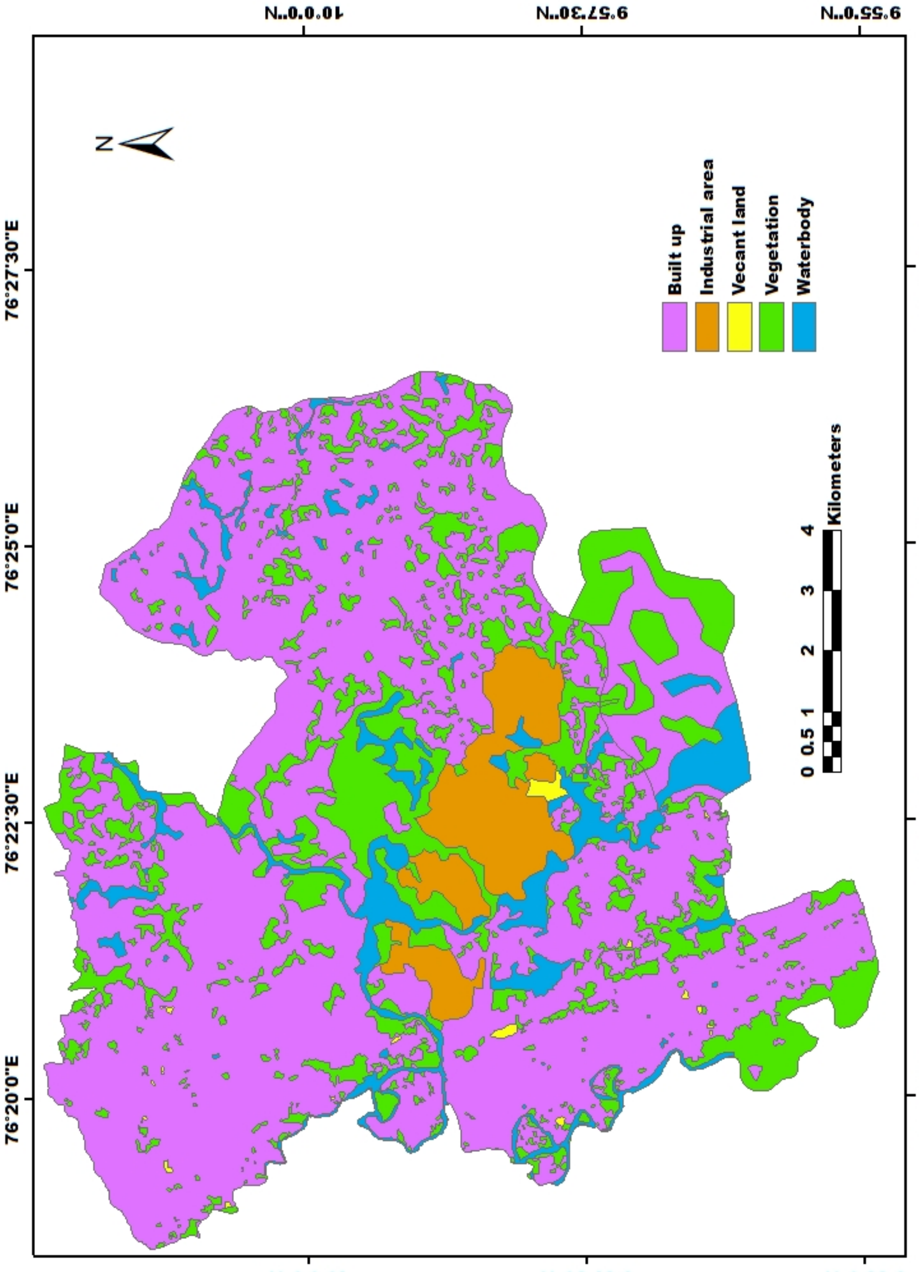
Map 4.19. Population of Each Ward in the Study Area-III



Map 4.20. Population Density in the Study Area-III

4.4.3.2 LULC Classification of Study Area-III

LULC classification shows that 65% of the land is populated with commercial and residential sectors. Thick vegetation can be seen in Vadavukod - Puthenruz area, but it is less in Thrikkakara and Thripunithura area. Vegetation covers 20% of the total land area. Industrial area constitutes 7% of the total area. Industries are mainly located in Ambalamugal, Irumpanam, and Karimugal regions of study area- III. Map 4.21 depicts the LULC classification of the Study Area- III and the pie chart (Figure 4.7) represents the percentage of each land class. Total area of each land class is given in Table 4.9.



Map 4.21. LULC Classification of Study Area-III

Table 4.9. Area covered by LULC Classes of Study Area-III

SI No	LULC classes	Area (km^2)	Proportion of classes
1	Water body	7.03	7%
2	Vegetation	21.9	20%
3	Built up	70.9	66%
4	Vacant land	0.36	Very low
5	Industrial area	7.59	7%
Total area		107.78	

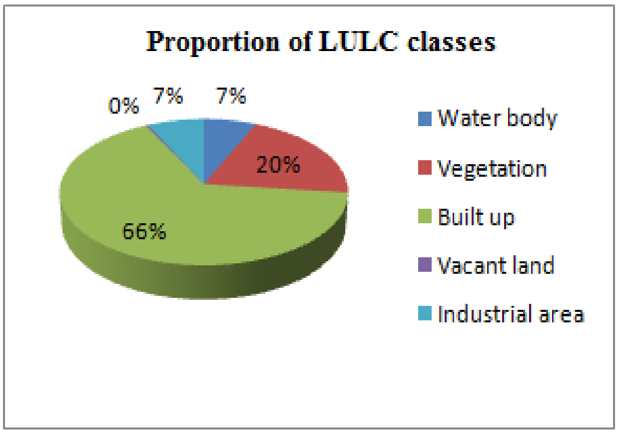
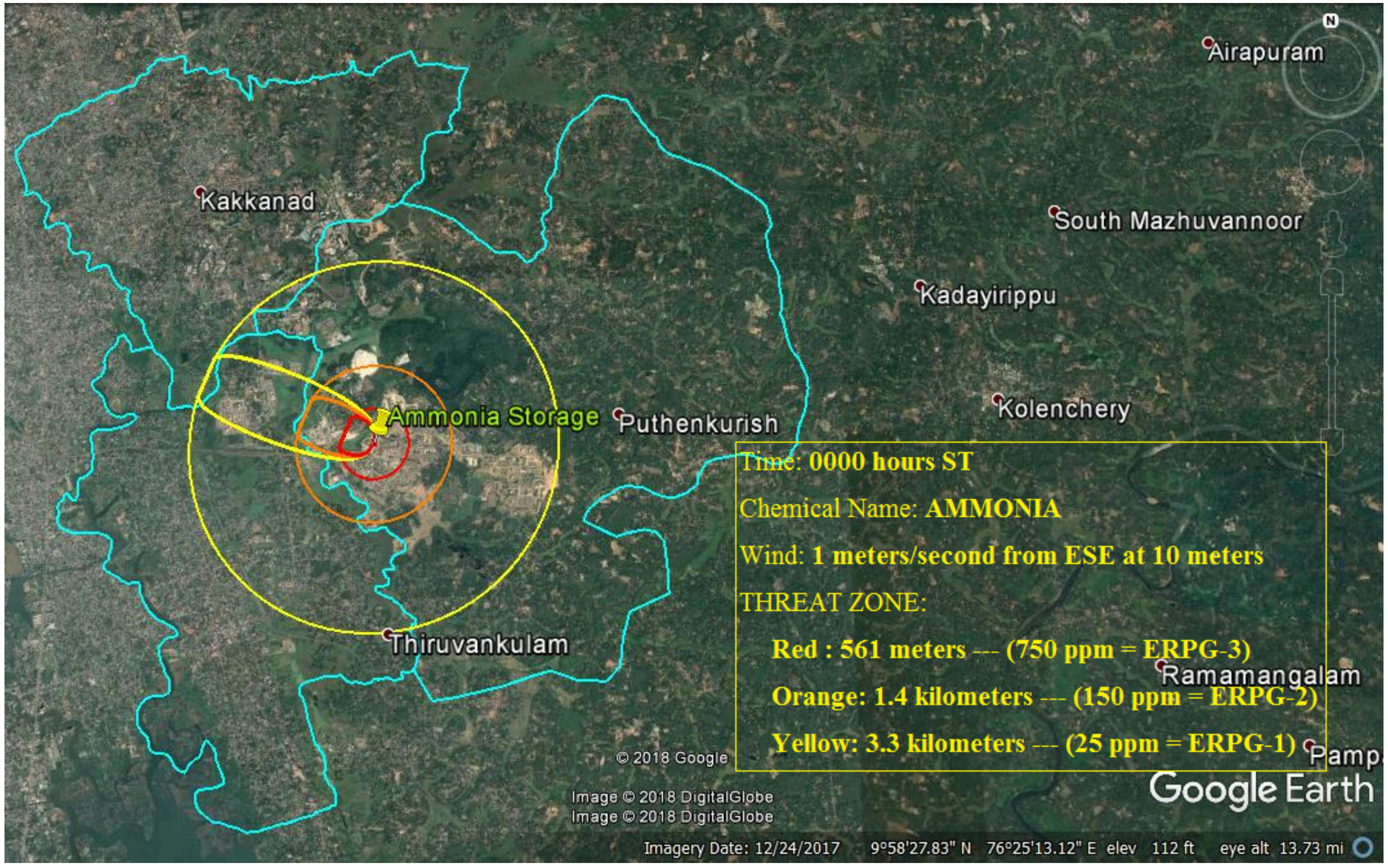


Figure 4.7. Proportion of LULC Classes in Study Area-III

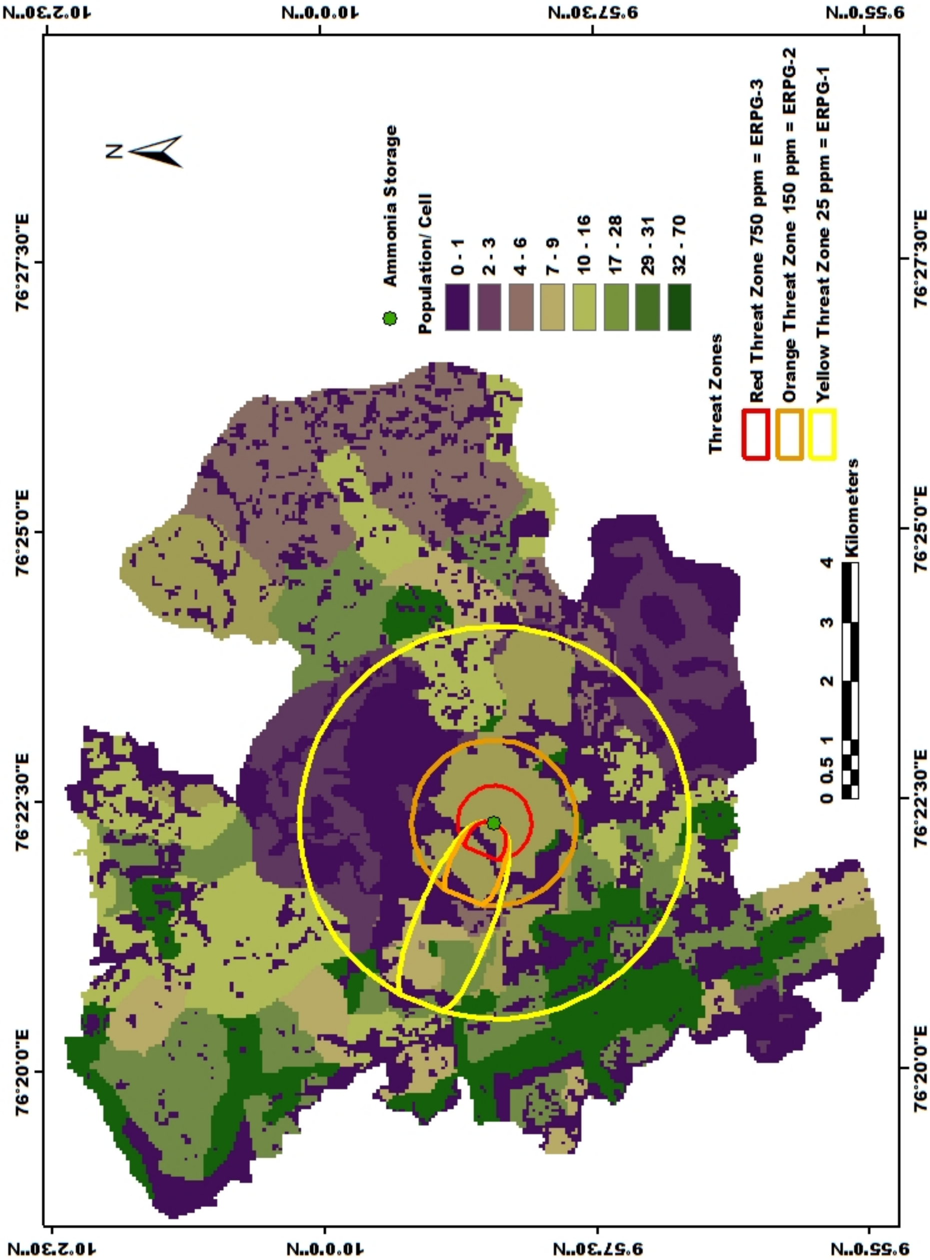
4.4.3.3 Population Vulnerability of Ammonia Storage at Study Area-III

The position of ammonia storage tank at study area-III and its threat zones are shown in Map 4.19. Though the facility is located in Ambalamugal industrial area of Vadavukod-Puthencruz Panchayat, in case of an accident it may spread to the adjoining areas of Thrikkakara and Thripunithura. The Map (4.22) shows the impacted area over the administrative boundaries. The wind confidence line in map represents the change of wind direction and affected distances.



Map 4.22. Location of Ammonia Storage in the Study Area-III and Threat Zones of Ammonia overlaid on Google Earth Image.

The population distribution map prepared using the dasymetric method gives an estimate of number of vulnerable population around the storage facility of ammonia. Ambalamugal and Irumpanam area are highly industrialized, producing many kinds of petroleum products. Cochin refinery is located here. As this area is less populated with permanent residents, population vulnerability is less in this region. But the nearby Thrikkakara and Thripunithura municipalities are densely populated which increases the vulnerability in case the heavy gas clouds reach that area. Population distribution map with threat zones are depicted in Map 4.23. Table 4.10 shows the number of population likely to be impacted by the ammonia release at different directions around the storage facility.



Map 4.23. Population Distribution of Study Area-III and Threat Zones of Ammonia Release

Table 4.10. Number of People likely to be affected in the Study Area-III. (Ammonia Toxicity)

Threat Zone	People likely to be affected in different direction of wind				Expected Impact on People
	NE	SE	SW	NW	
Red	Workers	Workers	Workers	Workers	Life threatening health effect
Orange	Workers	Workers	400	Workers	Serious health effect
Yellow	2274	3620	25910	7744	Transient adverse health effect

Note: NE- North East; SE- South East; SW-South West; NW- North West

The table (4.10) indicates that there are no inhabitants in the most dangerous red zone (red threat zone). But the workers in the factory will be badly injured in the absence of timely protection measures. In the case of orange threat zone, if the toxic clouds move in SW direction from the source, it will badly affect the population of Thripunithura. The number of population estimated in this direction is about 400. If the wind carries the toxic clouds in the other three directions, workers of the industry will experience serious health effects. In the Yellow threat zone, a large number of people are likely to experience transient adverse health effects. In the SW direction of the yellow zone which include about 25,910 people, the threat is very high compared to the other directions. Graphical representation of vulnerable population in each direction is given in the figure 4.8.

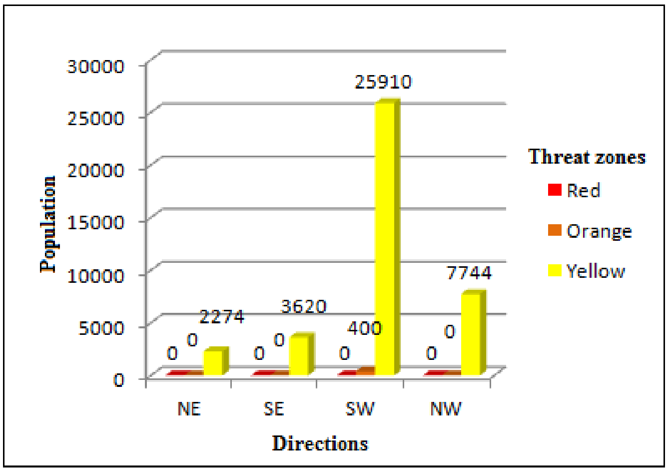
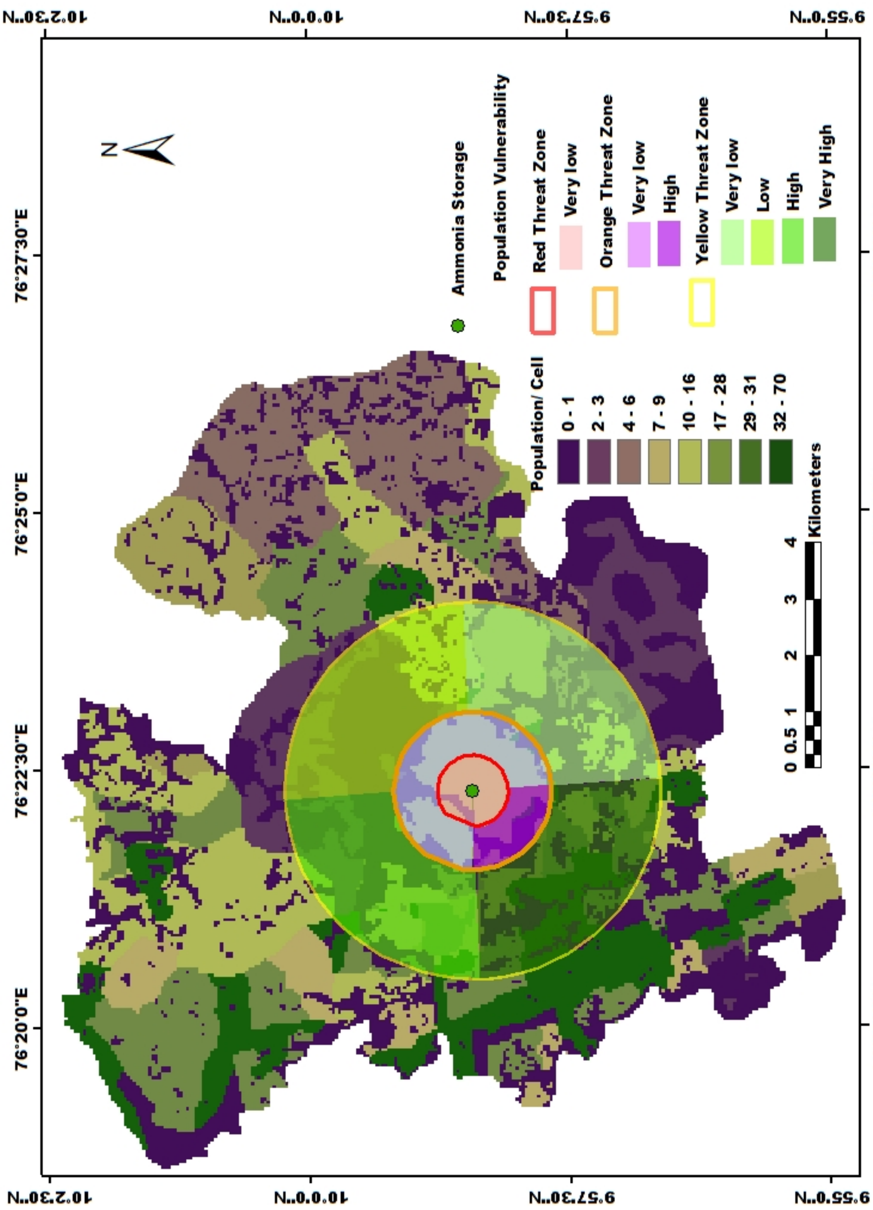


Figure 4.8. Population under the Threat Zones around the Ammonia Storage Facility

When considering the total number of population in each direction separately, it is seen that the SW direction of ammonia storage facility is highly vulnerable with a large number of population. Based on the estimated population given in table 4.10, population vulnerability within the threat zone is depicted in Map 4.24.

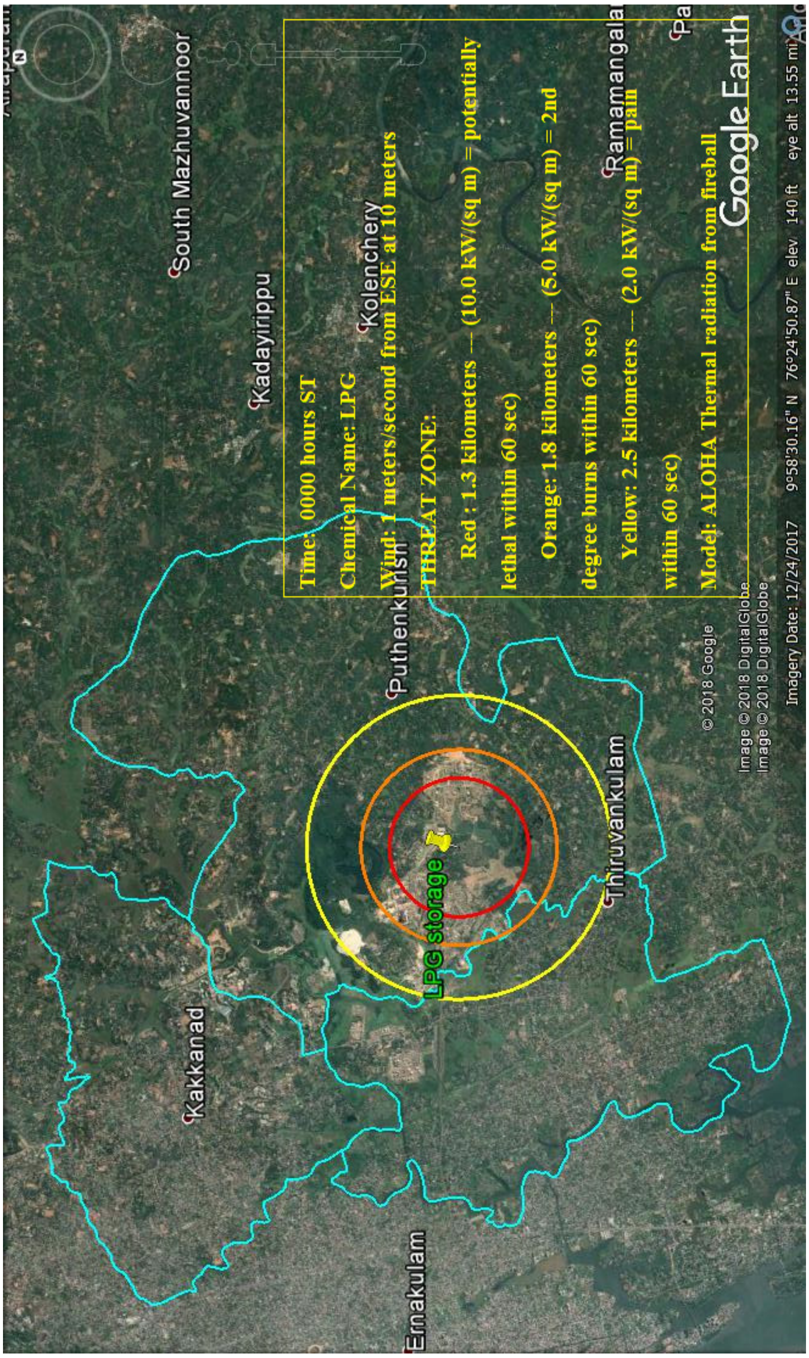


Map 4.24. Population Vulnerability within the Threat Zones of Ammonia Release (Study Area- III)

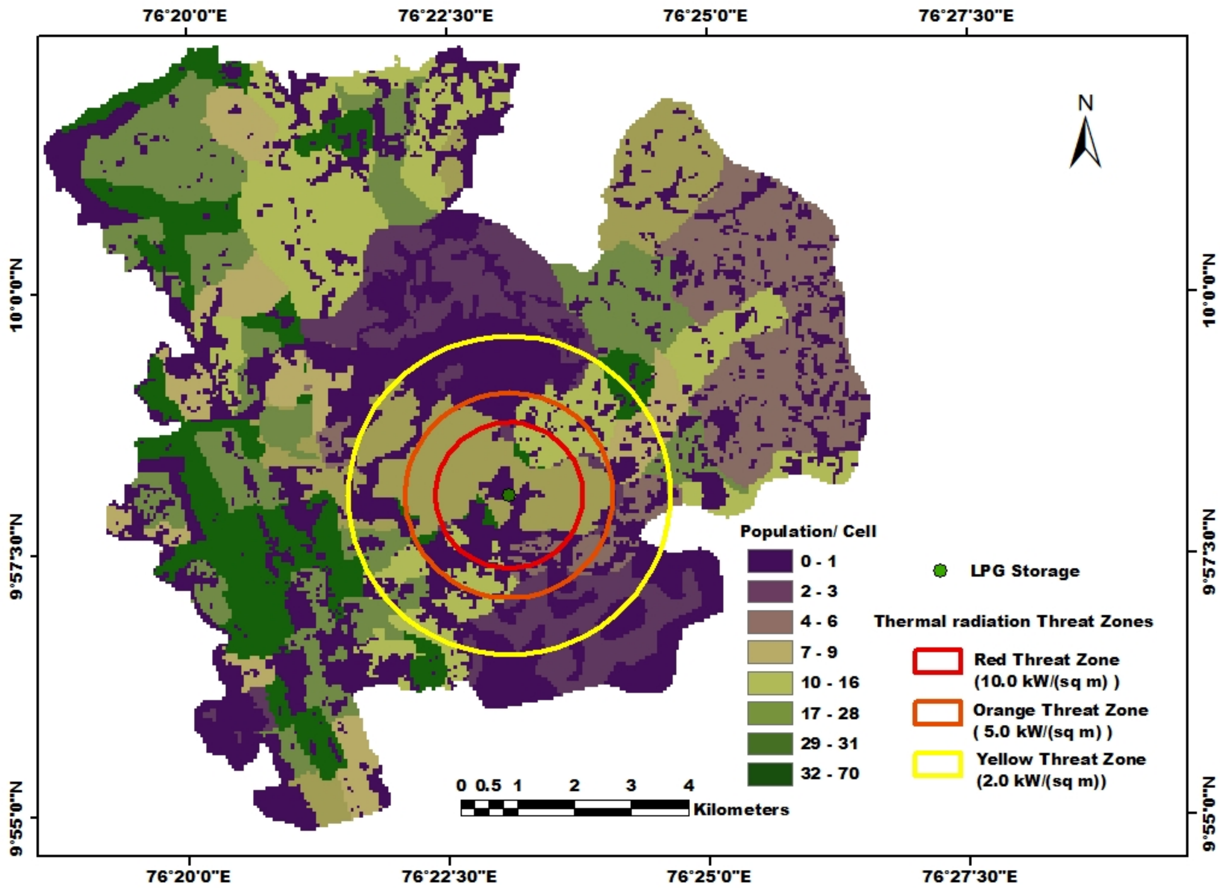
4.4.3.4 Population Vulnerability of (1400 MT) LPG Release at Study Area- III

Of the two hazardous effects of LPG (Flammable area of vapor cloud and BLEVE) modeled in chapter 3, BLEVE shows a more dangerous nature and it can affect larger distances away from the boundary of the industries. Therefore, population vulnerability assessment is carried out by considering the BLEVE effect of LPG. Map 4.22 shows the threat zones of BLEVE of LPG overlaid on the actual location in Google Earth Image. As BLEVE is a sudden explosion, the prevailing atmospheric conditions have less of an effect on the affected area. While taking the protective measures, the area around the storage location should be given equal importance as the tank explodes like a fireball. Therefore, the threat zones are represented as a circle. Map (4.25) shows that, the red threat zone distance is 1.3 km and the distance of orange and yellow threat zones are 1.8 km and 2.5 km respectively.

Map 4.26 shows the population distribution and threat zones' distances. Map (4.23) clearly shows the vulnerability range of threat zones of BLEVE of 1400 MT LPG tank.



Map 4.25. Location of 1400 MT LPG Storage at Study Area-III and Threat Zones of Thermal Radiation of LPG overlaid on Google Earth Image.



Map 4.26. Population Distribution Map of Study Area-III and Threat Zones of Thermal Radiation Affected Area of LPG (1400 MT spherical tank).

Number of population likely to be impacted by the BLEVE is given table 4.11. The population vulnerability analysis shows that the 1.3 km extent of red threat zone may include almost 670 people. The area of less impacted orange and yellow threat zones may include 1671 and 7879 numbers of people. As BLEVE is a sudden explosion, the total 2.5 km extent of threat zone from the source of explosion must be evacuated if there is any chance of a BLEVE. Population structure in threat zones of BLEVE is graphically represented in figure 4.9. Map 4.27 shows the population vulnerability.

Table 4.11. Total Number of Population under each Threat Zone (1400 MT)

Threat zones	Population likely to be affected	Expected impact on people
Red	670	Potentially lethal
Orange	1671	2^{nd} degree burn
Yellow	7879	Pain

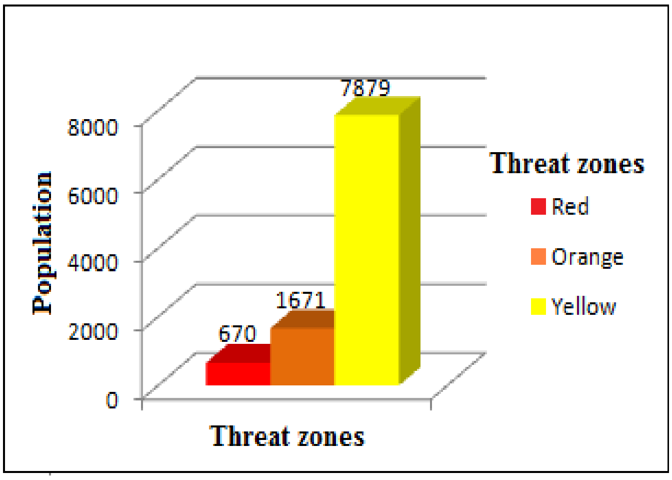
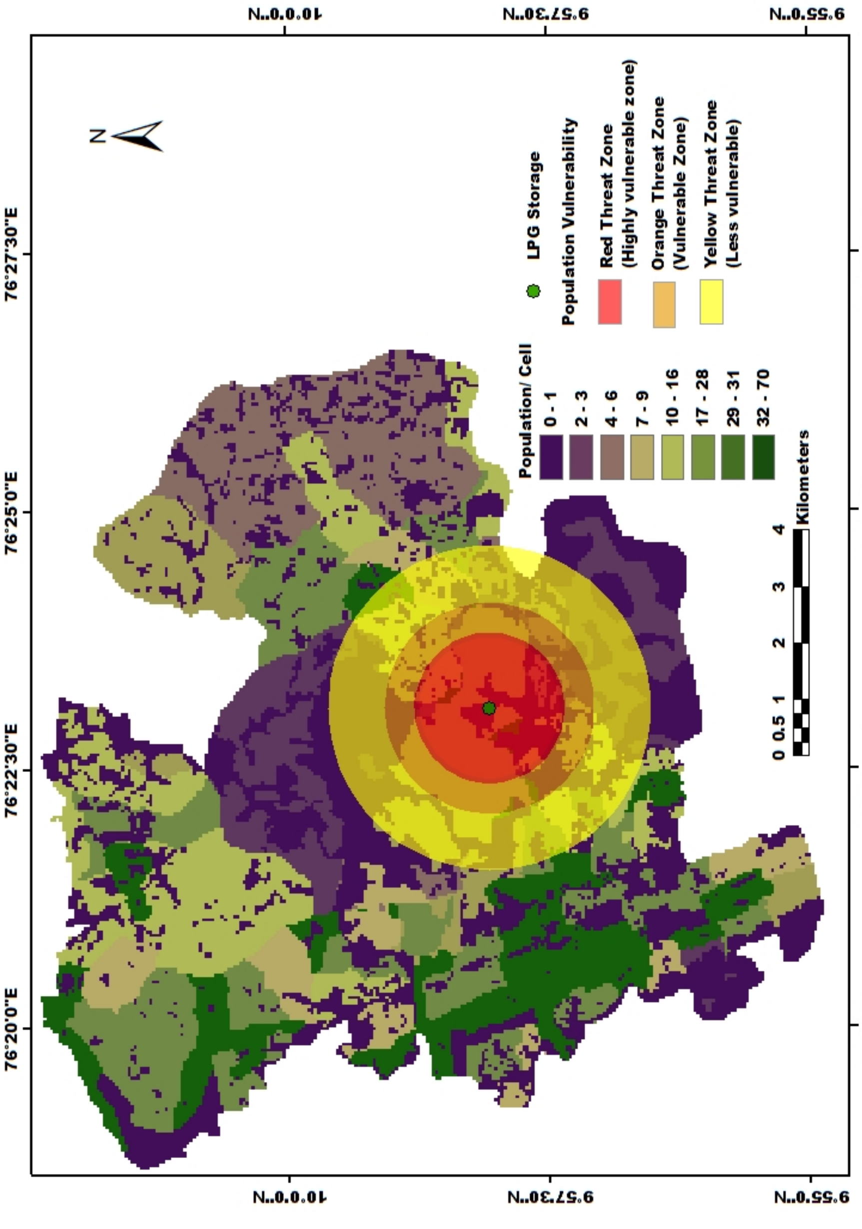


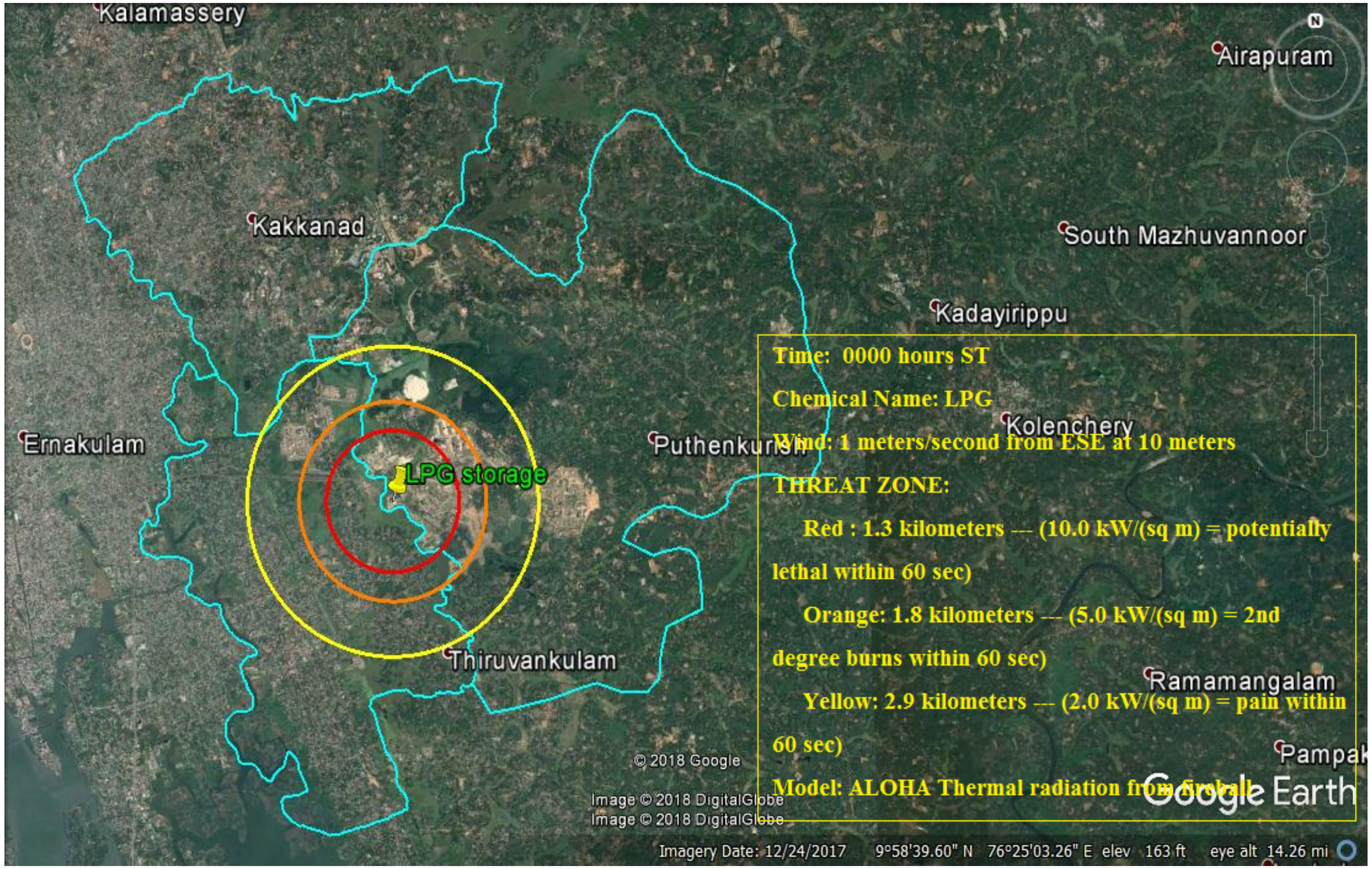
Figure 4.9. Population Structure in Threat Zones of BLEVE (1400 MT)



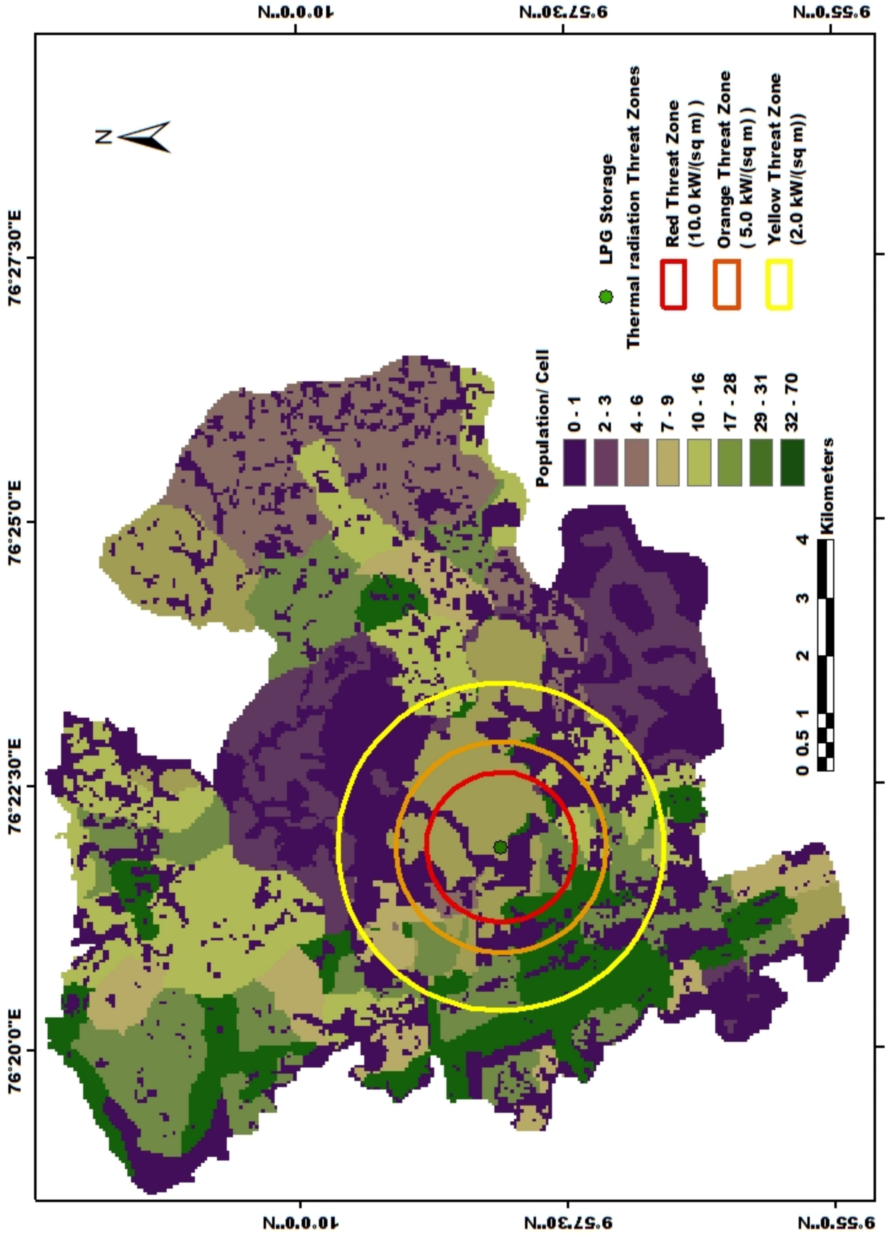
Map 4.27. Population Vulnerability due to the BLEVE of LPG (1400 MT of LPG)

4.4.3.5 Population Vulnerability of LPG Release at Study Area-III (1540 MT of LPG)

Map 4.28 shows the location of 1540 MT of LPG storage and threat zones of BLEVE overlaid on the Google Earth image. The map shows that the BLEVE effect of LPG in this location will be extremely threatening to the heavily populated area of Thripunithura Municipality. From the source, its thermal radiation may extend up to a distance of 2.9 km which includes a major part of Thripunithura. The modeling results show that the red, orange and yellow threat zones' extent are 1.3 km, 1.8 km, and 2.9 km. The dasymetric mapping of population distribution and overlaid threat zones of 1540 MT LPG tank is shown in Map 4.29. Estimated population coming under each threat zone is given in table 4.12. It is also shown in graphical form in Figure 4.10.



Map 4.28. Location of 1540 MT LPG Storage at Study Area-III and Threat Zones of Thermal Radiation of LPG overlaid on Google Earth Image.



Map 4.29. Population Distribution Map of Study Area-III and Threat Zones of Thermal Radiation Affected Area of LPG (1540 MT Spherical Tank).

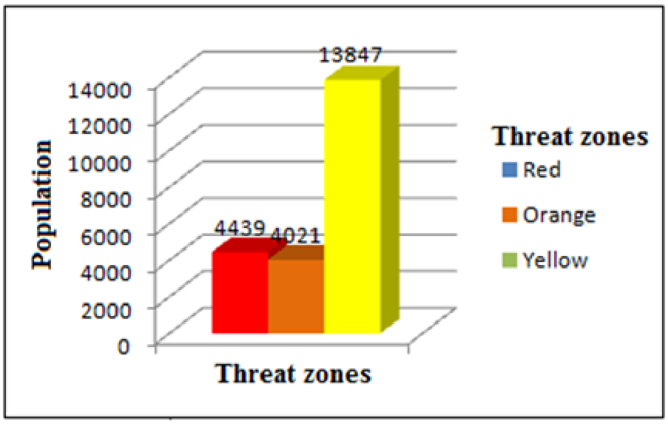
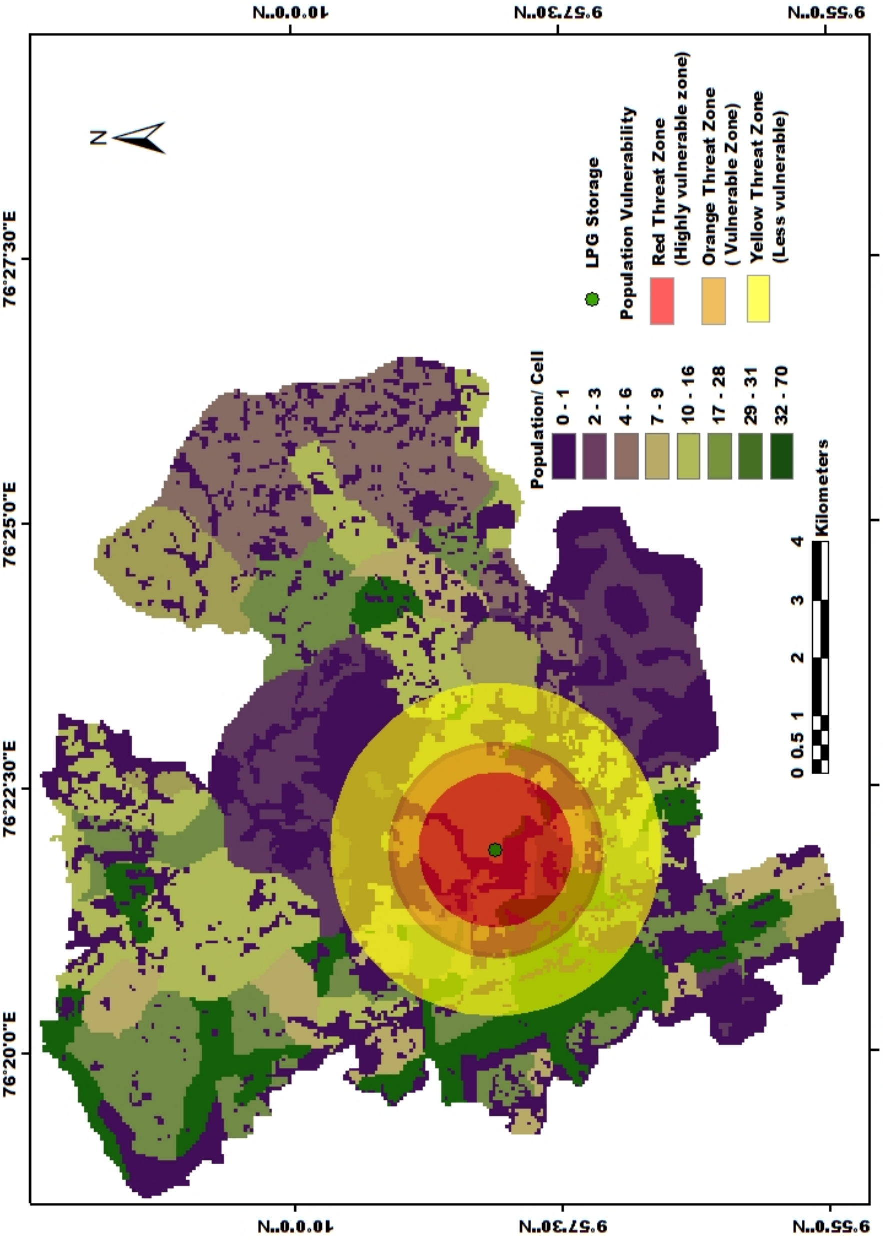


Figure 4.10. Population Structure in Threat Zones of BLEVE (1540 MT)

Table 4.12. Total Number of Population under each Threat Zone

Threat zones	**Population likely to be affected**	**Expected impact on people**
Red	4439	Potentially lethal
Orange	4021	2^{nd} degree burn
Yellow	113847	Pain

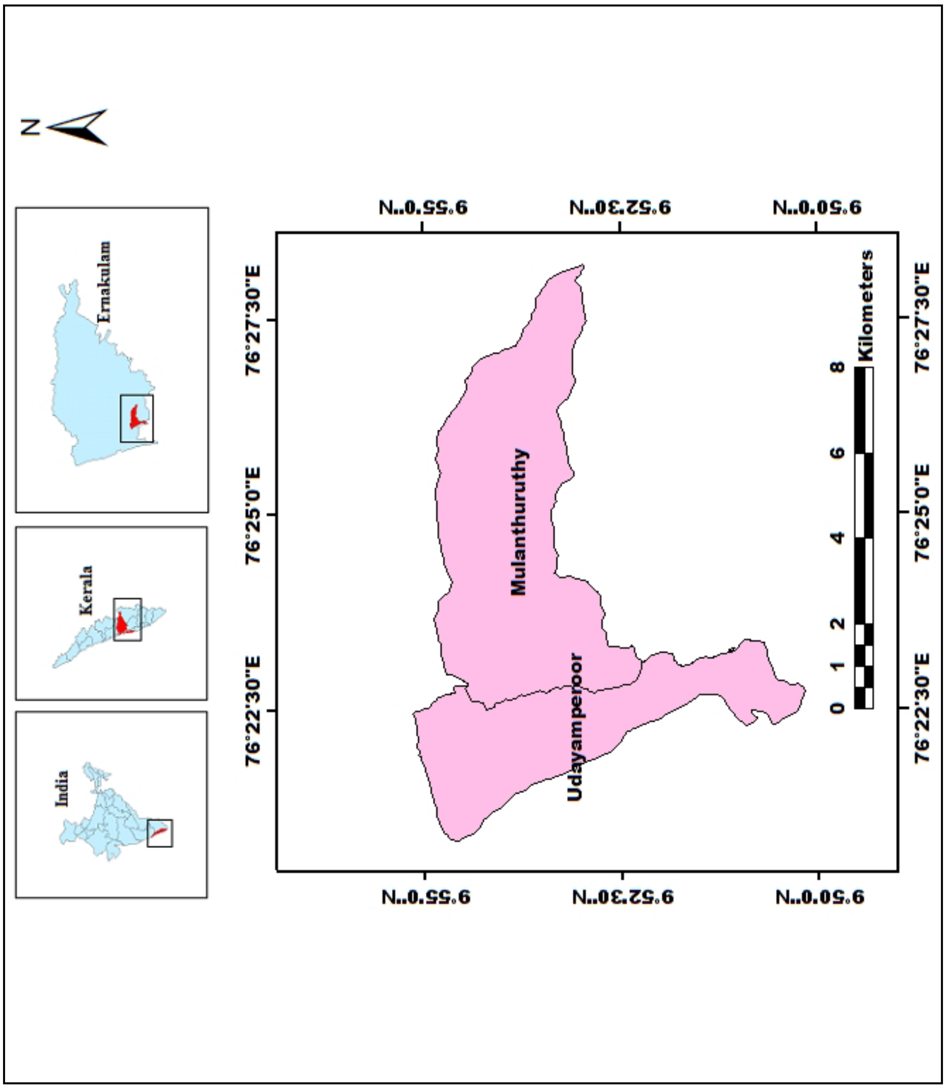
From the table (4.12) it is clear that a large number of people (4439) occupies the dangerous red threat zone. Number of people in the orange zone is less than the red zone. In the case of orange threat zone, a very high number of people may experience pain due to thermal radiation effect of BLEVE. Map 4.30 shows the population vulnerable zone of BLEVE of LPG.



Map 4.30. Population Vulnerability due to the BLEVE of LPG (1540 MT)

4.4.4 Study Area-IV (Udayamperoor) – LPG Release

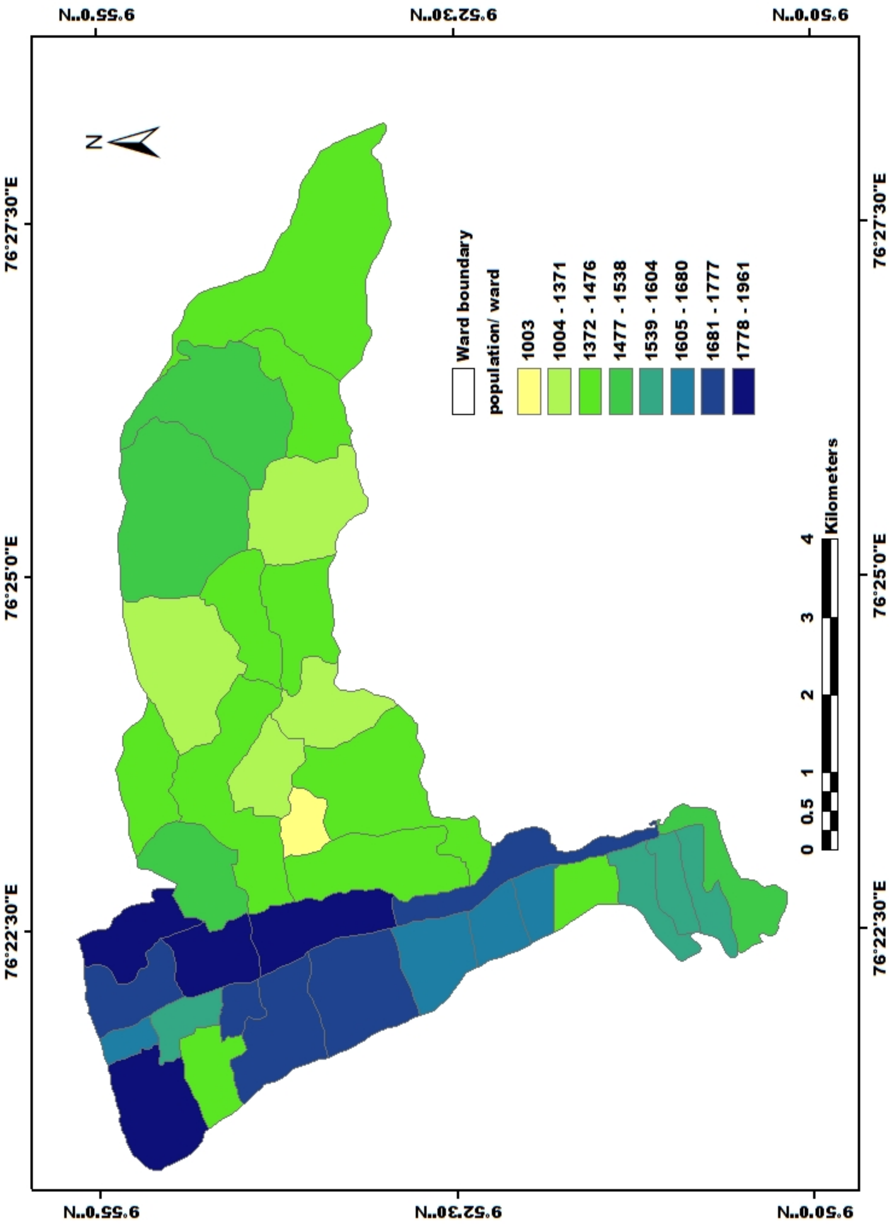
The site of LPG bottling plant at Udayamperoor and the adjoining area likely to be affected by the storage of LPG is considered as study area-IV. The bottling plant is located at $9^0$53'23" N and $76^0$22'34''E in Udayamperoor Panchayath. Though the plant is located in Udayamperoor Panchayath, in case of an accident it may affect the adjoining panchayat Mulanthuruthy. As it is not an industrial area, the plant is located in the middle of residential and commercial area. Study area- IV includes Udayamperoor and adjoining Mulanthuruthy Panchayaths. This area is a small town situated 18 km away from Ernakulam town, on the Ernakulam – Vaikom road. Location of the study area –IV is given in Map 4.31.



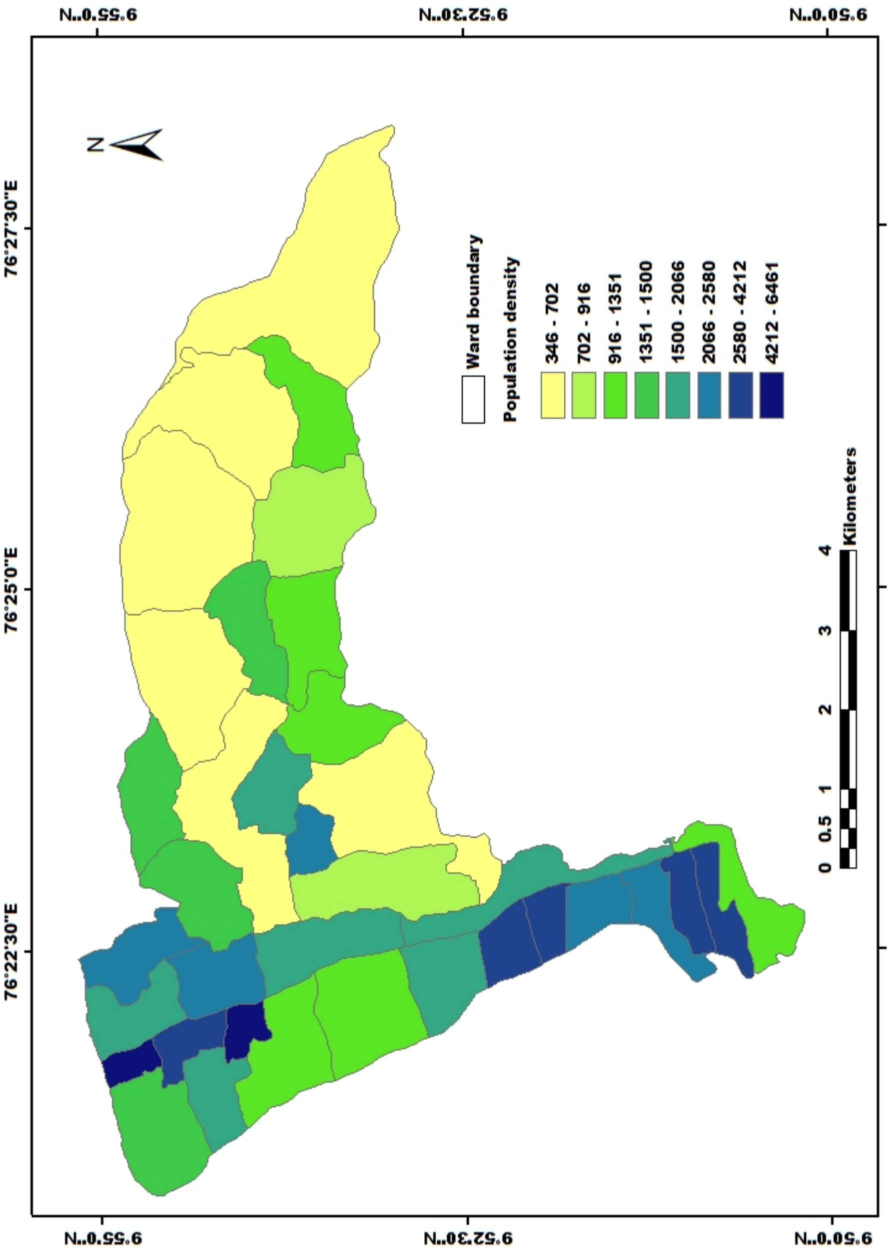
Map 4.31. Location Map of Study Area – IV

4.4.4.1 Demographic Details

Total area of Udayamperoor Panchayath is 16.02 km^2 and about 33523 people are inhabiting this area. The area of adjoining Mulanthuruthy Panchayath is 27.24 km^2 and with a population of nearly 23615. Demographic details of study area-IV are given in table 4.13. Both these areas together include 36 wards and population in each ward of location-4 ranges from 1003 to 1961. Population characteristics of each ward are given in Map 4.32 and density is given in Map 4.33.



Map 4.32. Population of Each Ward in the Study Area-IV



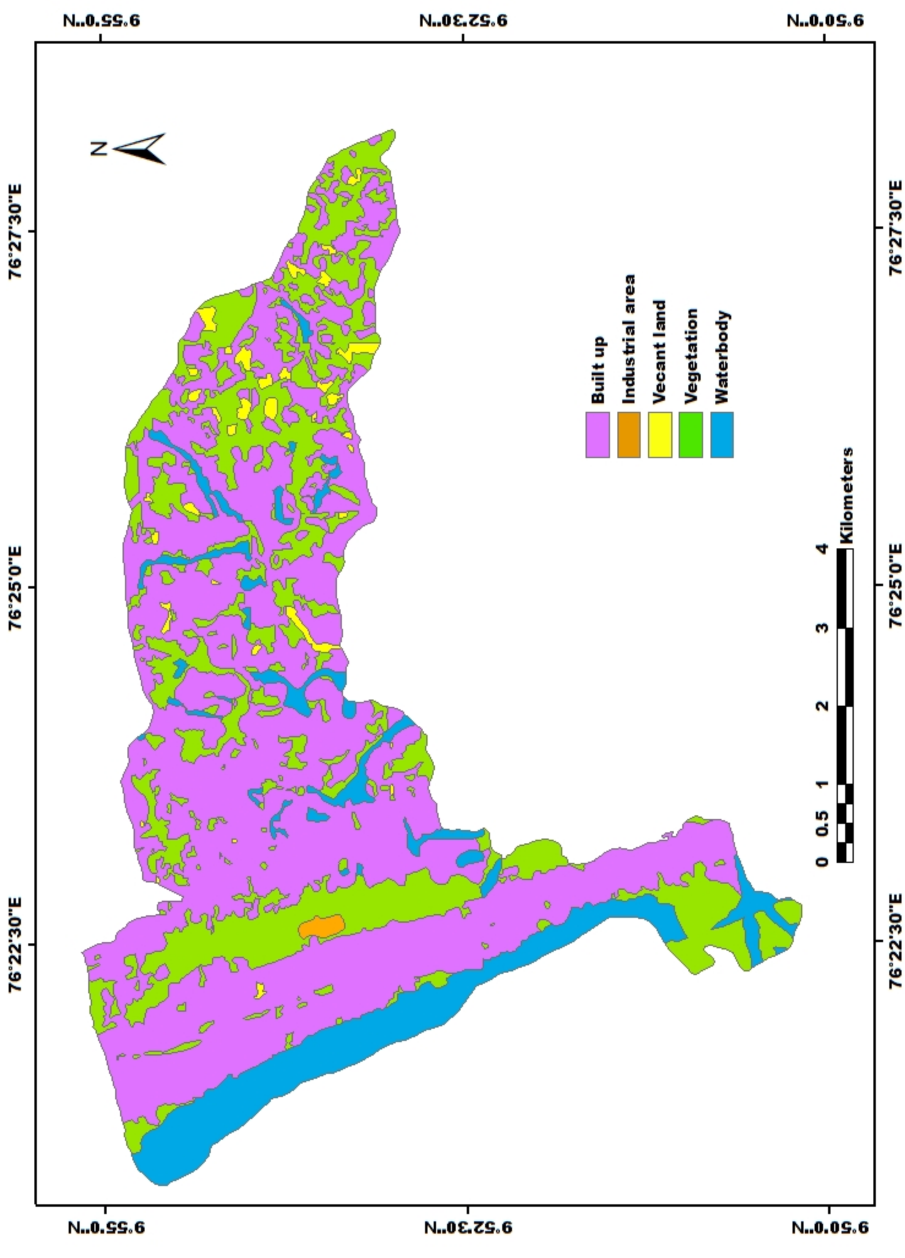
Map 4.33. Population density in the Study Area-IV

Table 4.13. Demographic Details of Study Area- IV

Administrative boundary	**Area (km^2)**	**Population**
Udayamperoor	16.02	33523
Mulanthuruthy	27.24	23615
Total geographic area	43.26	

4.4.4.2 LULC classification

LULC classification of location-4 is depicted in Map 4.34. Figure 4.11 show the proportion of each land classes in study area-IV. Major part of this area is covered by vegetation including paddy cultivation and other agricultural products. Vegetation covers about 27% of the total area. Population spreads over 58.50% of the land. The only industrial unit, LPG bottling plant, takes 0.28% of the total land area. Remaining 12.20% area covers water body and 1.57% of area is left as unused. Area of each land cover is given in table 4.14.



Map 4.34. LULC Classification of Study Area-IV

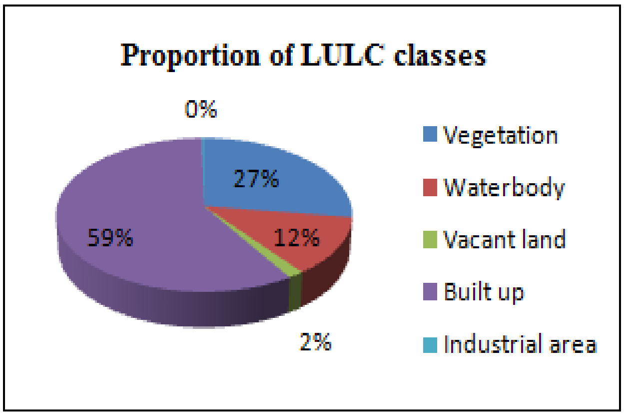


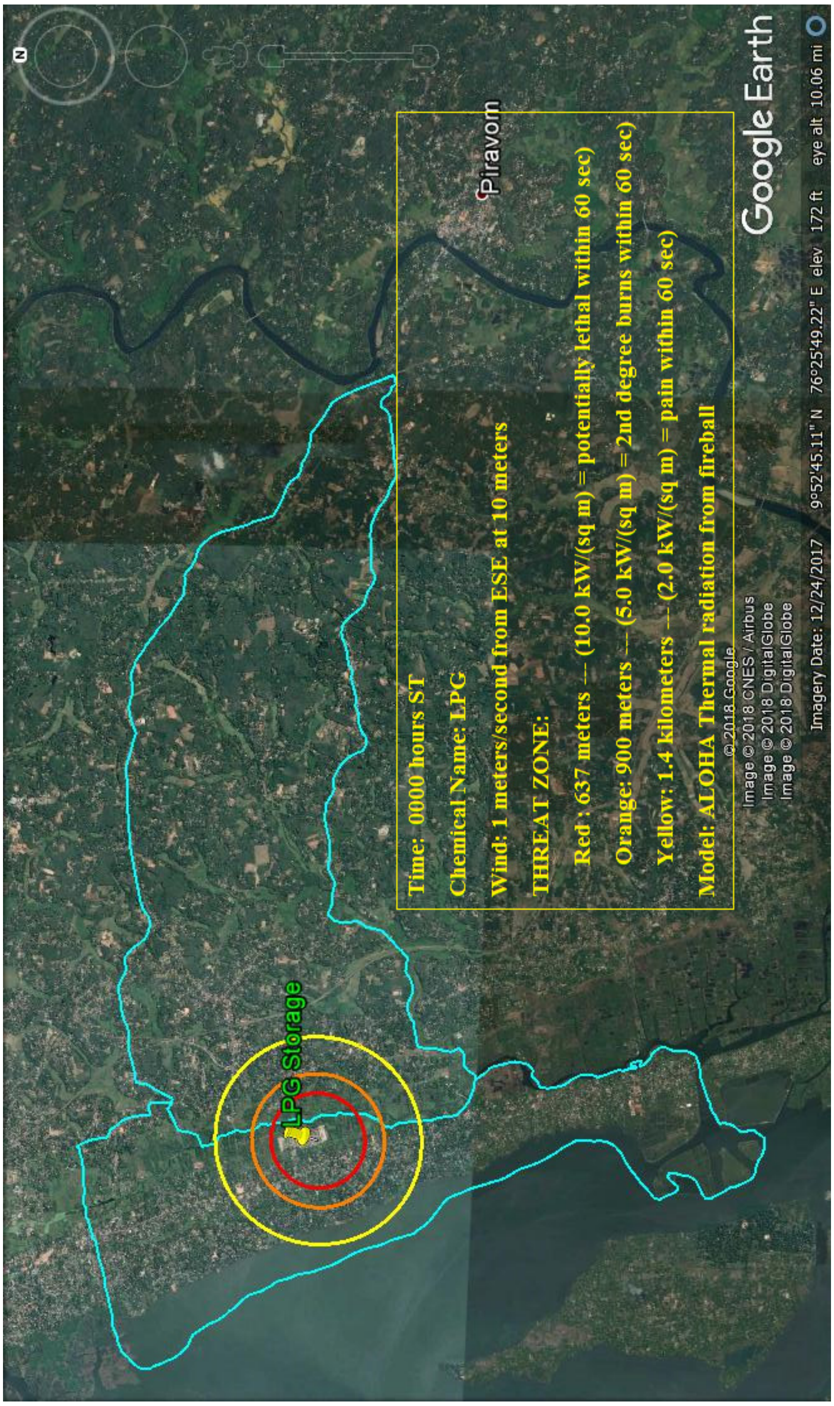
Figure 4.11. Proportion of LULC Classes in Study Area-IV

Table 4.14. Area Covered by Each LULC Classes in Study Area-IV

SI No	LULC classes	Area (km^2)	Proportion of classes
1	Water body	5.3	12%
2	Vegetation	11.8	27%
3	Built up	25.3	59
4	Vacant land	0.68	2%
5	Industrial area	0.12	Very low
Total area		43.2	

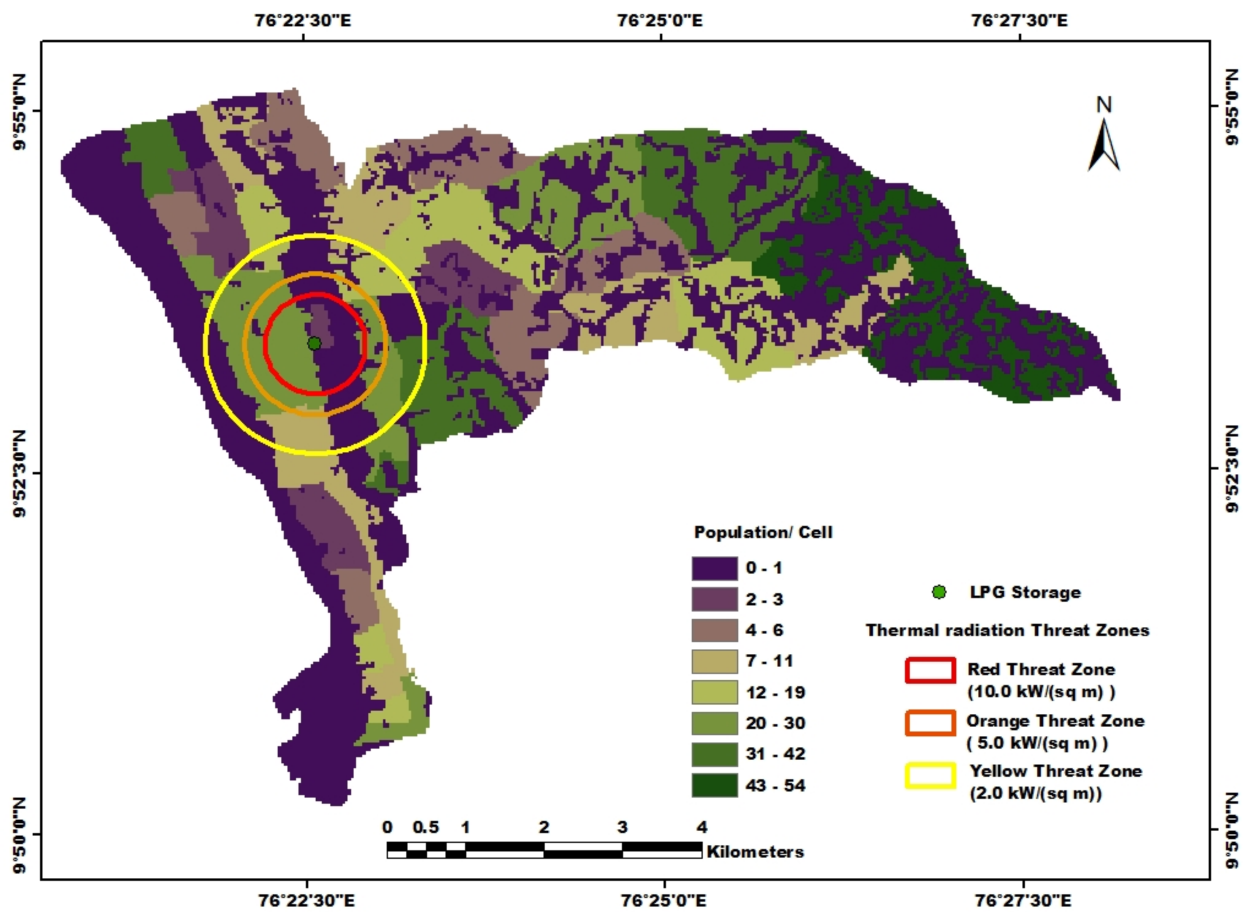
4.4.4.3 Population Vulnerability of LPG Release at Study Area- IV

Map 4.35 shows the location of LPG bottling plant and threat zones of BLEVE. Administrative boundaries are also shown in this map to know the area likely to be affected by BLEVE thermal radiation effect. Chemical release modeling done in chapter 3 indicates that weather condition and wind do not much influence BLEVE of LPG. When the chemical suddenly explodes, thermal radiation will affect all directions as fireball explosion. Modeling of BLEVE hazard of LPG shows that when 150 MT of LPG tank explode due to over pressure, its thermal radiation effect may affect up to a distance of 1.4 km from the source. In this distance, 637 m from the source (red zone) will be highly dangerous and it is considered as potentially lethal. The less impacted orange zone extends up to 900 m in which people may experience 2nd degree burns. Yellow zone is considered as comparatively less hazardous zone but people may experience pain within 60 seconds.



Map 4.35. Location of 150 MT LPG Storage at Study Area-IV and Threat Zones of Thermal Radiation of LPG overlaid on Google Earth Image.

Map 4.36 depicts the population distribution of study area-IV and overlaid threat zones. Due to a tank explosion like a fireball, the threat zones are shown in the form of circles. The land use classification of study area (Map 4.34) indicates that NE and SW directions of the plant are cultivated areas and human inhabitation is less. When there is BLEVE, red threat zone spread over this cultivated area in these directions, whereas SW and NW directions are inhabited and it is expected that more than 1000 number of people will be in the potentially lethal zone. Workers of the plant also will be trapped in this zone. This zone may spread over the populated area and the population distribution map shows that only SE direction is less populated. In yellow threat zone (less dangerous), more than 5000 people may experience pain within 60 s. In this zone also, the SW direction show less populated areas. Table 4.15 shows the affected population due to BLEVE. Population structure in each zone is graphically shown in figure 4.12. Population vulnerability around the LPG storage tank is shown in Map 4.37.



Map 4.36. Population Distribution Map of Study Area-IV and Threat Zones of Thermal Radiation Affected Area of LPG (150 MT Bullet Tank).

Table 4.15. Total Number of Population under each Threat Zone

Threat zones	Population likely to affect	Expected impact on people
Red	1379	Potentially lethal
Orange	1425	2nd degree burn
Yellow	4514	Pain

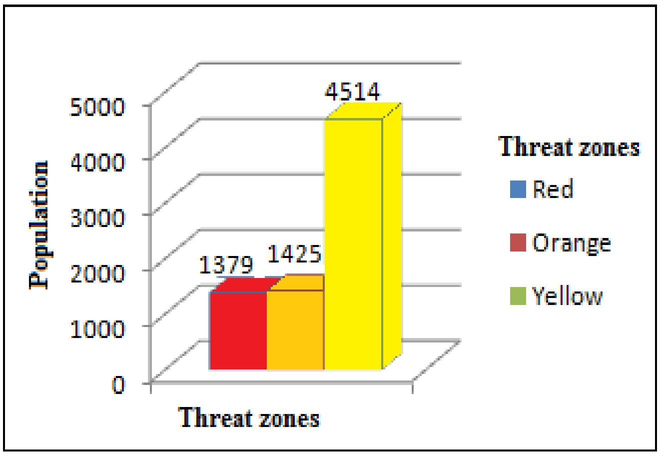
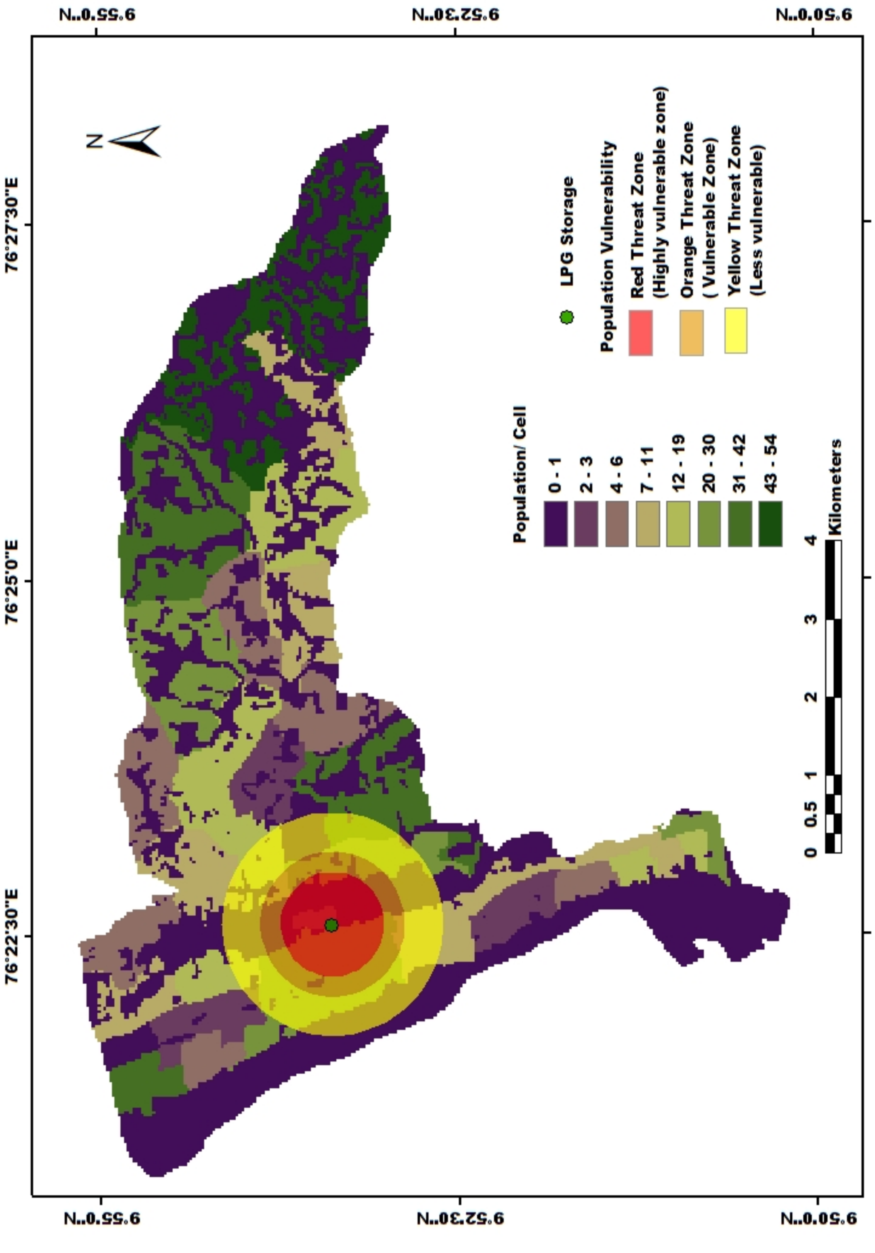


Figure 4.12. Population Structure in Threat Zones of BLEVE



Map 4.37. Population Vulnerability due to BLEVE of LPG (150 MT

4.4.5 Comparison of Vulnerable Population in three Ammonia Storage Locations in Cochin City

As mentioned earlier, there are three locations in Cochin City having ammonia storage, Eloor, Willingdon Island, and Ambalamugal. Comparing the three locations, the ammonia storage facility in Eloor is situated in highly industrialized area, but its locality is populated with permanent residents. In the case of Ambalamugal, it is also an industrial cluster but less populated area. Willingdon Island ammonia storage facility is a part of Cochin Corporation, largest Municipal Corporation in Kerala, and densely populated. The results of population vulnerability study of these three locations are given in table 4.16.

Table 4.16. Population affected by Toxic Ammonia Release from the Storage Facilities at Three Different Locations in the Cochin City

Threat Zones	Affected population(number)			Impact on population
	Willingdon Island	Ambalamugal	Eloor	
Red	19	0	411	Life threatening health effect
Orange	29,402	400	14460	Serious health effect
Yellow	218,013	39,548	84665	Transient adverse health effect

The table shows the total number of population likely to come under each threat zone around the storage facility. It was already mentioned that in all cases, the red threat zone is considered as highly dangerous. In the case of ammonia toxicity, the concentration of chemical estimated in the red threat zone may cause life threatening health effect to the people. Therefore, in any chemical release, population coming within the red threat zone have most priority while taking any protective measures. Before the chemical concentration reaches the estimated orange threat zone (1.4 km), the release of chemical can be plugged or the concentration in the atmosphere can be reduced by taking timely management measures.

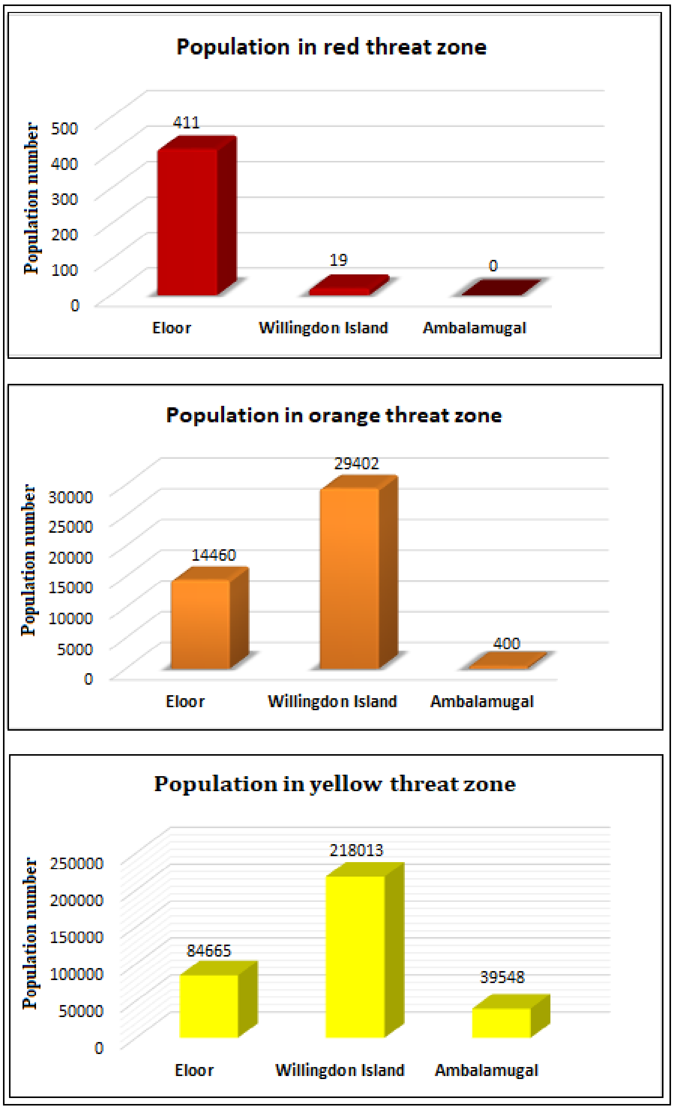


Figure 4.13. Comparison of Vulnerable population in Each of the three Threat Zones in the three different locations in Cochin City (Ammonia release)

Number of vulnerable population in each of the three threat zones in the three different locations are given in figure 4.13. In the case of red threat zone, more vulnerable population are seen near the ammonia storage facility at Eloor industrial cluster (study area-I). And, the location of ammonia storage facility at Willingdon Island (study area-II) is comparatively safe because the evacuation effort or any other preventive measures can be easily applied if the affected population is very less (include about 19 people). In Ambalamugal (study area-II), the location of ammonia storage tank is very safe, as none of the outside population will suffer the high concentration effect of ammonia toxicity. This is because, no permanent residential or commercial area is located in this zone, but the workers of the industry should take immediate protective action in case of ammonia leakage.

When the orange threat zone is taken into account, ammonia storage at Willingdon Island (study area- II) may affect a higher number of population, while less people inhabits the Ambalamugal (study area II) area. In the third (yellow) threat zone, more people are in the study area-II compared to study area- III

In the case of chemical release, the proximity to the source of release have high importance. In such cases, it can be concluded that the study area- I is highly vulnerable.

4.4.6 Comparison of Vulnerable Population in three Locations of LPG Storage Facility in Cochin City.

As mentioned earlier, three locations of ammonia storage facilities with capacities of 150 MT, 1400 MT and 1540 MT were identified. The results of modeling of BLEVE of LPG shows variation in the impacted distance according to the quantity of LPG explodes as a fireball. The vulnerability of population depends upon both the quantity of chemical explosion and the population density of the area. Vulnerable population in all the three locations of LPG storage facilities are given in table 4.17. In study area-III, the LPG storage tank is located in an industrial area with less population but its nearby municipality (Thripunithura) is densely populated. Population vulnerability analysis of LPG in study area III indicate that when 1540 MT of LPG tank explode due to high pressure, its thermal radiation effect may spread up to a distance of 2.9 km including the highly populated area of Thripunithura Municipality.

The storage capacity of 1400 MT of LPG tank is also located in a comparatively less populated area, but its higher capacity compared to the 150 MT tank, in case of a leak, can cover a larger area including a larger number of population.

The LPG bottling plant at study area IV is located in the middle of a highly populated area of Udayamperoor Panchayath. The estimated impacted distance of 150 MT of LPG bullet tank is 1.4 km and the vulnerable population count is given in table 4.17. Compared to other two tanks at study area III, the quantity of LPG storage is very less in this case. This results in a smaller impacted distance. Therefore, the vulnerable population in the area show lesser number than the other two locations. The bottling plant contain a number of such bullet tanks and in case of BLEVE occurring on any one of the tank can lead to a complete destruction of the plant and the after effect will be unimaginable.

Table 4.17. Population Affected by the Thermal Radiation of LPG BLEVE from the Storage Facility at Three Different Locations in Cochin City.

Threat Zones	Affected Population (number)			Impact on Population
	Study Area- III		Study Area-IV	
	1400 MT	1540 MT	150 MT	
Red	670	4439	1379	Potentially lethal
Orange	1671	4021	1425	2nd degree burn
Yellow	7879	113847	4514	Pain

Figure 4.13. shows the vulnerable population in each threat zone with different location. It is clear from the figure that in all the three threat zones, higher number of population is observed in the case of 1540 MT LPG tank at Study Area III.

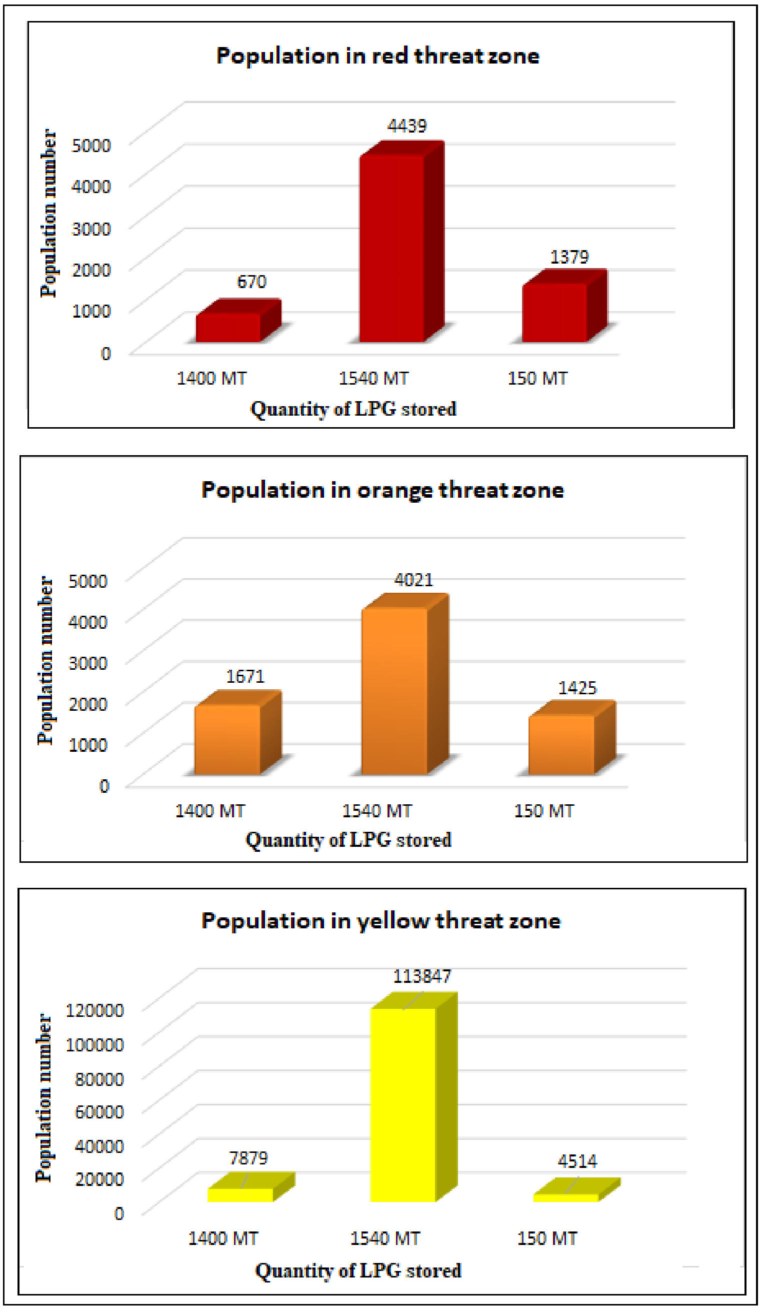


Figure 4.14. Comparison of Vulnerable Population in each of the Three Threat Zones in the three different locations of Cochin City (BLEVE of LPG)

4.5 Conclusion

This chapter provides an approach to assess and quantify the human vulnerability to hazardous chemical release in the vicinity of chemical industrial clusters of Cochin City. Unlike, natural calamities (eg: flood), many of which are predictable as to the time of occurrence as well as impact area, chemical hazards have well defined spatial impact area, but are totally unpredictable as to the time of occurrence. A chemical accident from a storage installation are normally confined to the area surrounding the installation. This chapter concentrated on exploring the concepts and methodology of analyzing population vulnerability to accidental release of hazardous chemicals in the vicinity of chemical industrial clusters. A GIS based methodology for mapping the population distribution is adopted and the threat zone footprint of the accidental release of chemical under specified condition is evaluated.

The vulnerable population due to hazardous chemical release depends on various factors such as population density near the chemical installation, amount of chemical released, hazardous nature of the chemical, dispersion distance of the chemical, and proximity of the population to the chemical installation. The results show that the people residing in highly populated areas near the accident site tend to be more vulnerable. It is clear from the chemical dispersion modeling done in chapter 3, that chlorine diffuse to larger distances in the atmosphere than LPG and ammonia. Larger the dispersed area, the larger will be the impacted population. In study area- I chlorine release will result in highly vulnerable situation than ammonia release. Though an industrial area, the peripheries of the chemical installations are populated with permanent residents, mainly the industrial workers. Therefore, even a small scale release of chemical may cause high risk. Though the study area -II is highly populated, the location of the ammonia storage tank is comparatively in a safer place in the case of a small scale release, because almost 400 m radius around the installation is covered by water body and vacant land (including large ground). The population vulnerability analysis of study area-III indicates that the highly dangerous zone of ammonia and LPG is not much vulnerable to human population. But large scale release of chemical or if the leakage cannot be plugged off in time by taking immediate action, it will lead to a highly risky situation. LPG bottling plant at Udayamperoor is the isolated industry from the other industrial cluster of Cochin City and its location threaten thousands of people around the plant. NE and SE directions of the plant are safe from any kind of risk in case of small scale releases. But its NW and SW directions are so populated that even small scale releases can create high risk.

As it is not possible to relocate the industries to other safer places, the only precautions we can take is to be prepared to prevent and reduce the impact. Knowledge of the spatial distribution of population, as well as the vulnerable population can help to be better prepared for accidental chemical releases and to develop appropriate mitigation strategies to reduce the risks for the area under consideration. Population vulnerability assessment helps for prioritizing risk management, especially for how to protect risk target against the chemical releases. Based on the knowledge of vulnerable population, emergency preparedness and mitigation plan can be prepared in advance.

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Chapter 5

EMERGENCY PREPAREDNESS AND PLANNING

Contents

5.1 Introduction

The intensity of human suffering caused by an event of chemical hazard is huge and it can affect many aspects of people's life such as health, housing, security and other life amenities. That is why it is vital to have an emergency management preparedness, so that the impact of disaster on people and their assets can be minimized. This will help to launch an effective and efficient coordination among the responders when a disaster strikes. The main aim of such preparedness and planning is to reduce suffering and save lives. The chemical emergency management or emergency response can be defined as providing the technology, tool and practices that enable disaster response organizations to systematically manage information from sources and collaborate effectively to assist survivors, mitigate damage and help communities rebuild. (Emergency management, 2010). The past history of hazardous releases and experiences have shown that pre-planned and practiced procedures for handling an emergency can considerably reduce loss of life and minimize damage to property and environment. Thorough preparedness and planning are prerequisites for an effective response to chemical hazards

Emergency preparedness means identifying the actions that need to be taken in the event of a chemical incident. Because the emergency caused by a chemical release depends on the hazardous nature of the chemical and its location characteristics, a suitable emergency model should be prepared based on these factors. The emergency planning should cover neighboring populations of the chemical storage facility (Bourdeau & Green, 1989). It must be based on the hazardous nature of the chemical and should include Evacuation details, Rescue of injured people, Corrective action to minimize the leak or at least minimum exposure to people, fire fighting action etc.

The overall objectives of emergency preparedness are,

- To safeguard human life
- To ensure evacuation and medical treatment required for vulnerable persons.
- To contain the incident and bring it under control within the shortest possible time
- To restore normalcy at the earliest.

5.1.1 Using Technology to Improve Chemical Emergency Management Capabilities

Organizations that are engaged in chemical disaster management need technological solutions that will enable them to provide easiest response and recovery assistance to the people who are likely to be impacted when the disaster strikes. An integrated information system tool can assist the effective management of industrial accidents originating from hazardous facilities. GIS based emergency response system offers efficient handling of a large amount of data in the form of maps and it also facilitates easy access to spatial and non-spatial emergency information of location characteristics, affected population, emergency resources for managing the emergency event, etc. Wang et al. (2002) developed a chemical monitoring and emergency response system integrating GIS and expert system for public response personnel and hazardous chemical storage industries.

The chemical emergency management creates a number of interdependent issues which need intensive communication and coordination among organizations and jurisdictions for an effective management. Because of the complexity in the coordination of various management systems, a design of an effective management strategy has received wide attention by environmental planners (IImavirta, 1995). The GIS provides a tool to design an interactive system that facilitates comprehensive disaster management (Anon, 1994; El-Raey et al., 1996; Kashiwagi & Takeda, 1997). The application of GIS in managing chemical spills and releases is a developing research area both for fixed- facilities and transportation spill (Chang et al., 1997).

For managing a chemical emergency situation, a lot of technical and practical information is required in advance. The information such as location of the hazards, knowledge of the substance involved, key person in charge, location and extent of emergency control, geological and meteorological information and dispersion pathways, etc. have to be coordinated while dealing with an emergency situation.

In the present study, all the required data were collected from concerned departments and field surveys using GPS. All collected spatial information are plotted on a map to prepare a response plan. This chapter describes the various components of an emergency management plan and focuses on how GIS applications can be used for providing spatial information that are essential in effective management.

5.2 Emergency Organizations and Responsibilities to Coordinate the Emergency Situation

The most important requirement during an emergency situation is a well-coordinated effort for effective management and control. This calls for identification of personnel and resources that will be involved in each functions of emergency planning such as fire fighting, medical management, rescue and combat, evacuation, communication, etc.

It is essential to identify a central authority such as a District emergency authority, who will take responsibility for coordination of the activities of various responders at the time of disaster like hospitals, emergency medical services, police, fire brigade, transportation, etc. The response agencies and other emergency personnel should be always at a high state of alert.

This section specifies roles and responsibilities of each sector.

5.2.1 District Emergency Authority (District Collector)

The District collector is nominated as the Chairman of the District Crisis Group (DCG). He has the overall responsibility of the offsite emergency management in the District. DC selects first and second alternate officers to act on his behalf during an emergency situation. In association with its members, the DCG identifies and assesses the adequacy of resources available in the district to combat various possible emergency scenarios and prepare a plan to build the resource base to the required level. District Collector will formulate the response objectives and strategies for various possible off-site emergency scenarios, with assistance from all the members of DCG.

5.2.2 Member Secretary (Director of Factories)

Director of factories define roles and responsibilities of LCG/DCG members and other members of the LCGs from time to time and update the same. He uses his good knowledge of the industries and their operations and knowledge of the area with respect to location of resources and facilities, communication and transport network and should disseminate this information to other members of the DCG and LCG. He is responsible to organize meeting of DCG every 45 days (as per chemical accident rule). He also is responsible to conduct mock drills at least once every year and monitor progress, weaknesses etc. and forward the report to State Crisis Group and update the off-site emergency plan in consultation with the members of DCG.

5.2.3 Communication Coordinator (G M- Telephones)

A strong communication network between the personnel responsible for carrying out rescue, control, and other related tasks is very essential, particularly as a number of different agencies or organizations at the local, district, state, and even national level have important roles.

Communication coordinator identifies and keeps updated list of all available means of communication / emergency warning system such as land telephones, cell phones, walkie-talkie, cable TV, radio station etc. that can be used during an emergency. He identifies and lists all the members of DCG/LCG and other emergency personnel who have walkie-talkie and prepare a list of frequency and address code for contacting them during an emergency. He makes an arrangement to establish a system in the telephone exchange to simultaneously contact all people having telephone connection so that in case of emergency, people residing in the areas likely to be affected can be apprised of the emergency and guide the actions to be taken by these people.

Prepare and keep updated a list of contact information of sensitive areas prone to large gathering of people at any given time such as educational institutions, cinema halls, hospitals, prisons, etc. which may require urgent notification. The communication coordinator in association with the Member Secretary and the Transport coordinator identify sensitive areas along the major transport corridor of the district and provide them with communication facilities. The communication coordinator also has the responsibility to prepare standard message formats in English and local language to be used in radio / TV broadcast or outdoor communication through loudspeakers to facilitate and reduce time necessary to alert the public of an emergency and inform them of the protective actions to be taken.

Establish and list warning systems for different levels of emergencies. (It must be noted that the warning system for an emergency does not sound like the wailing sounds of siren which are used by industries to signify beginning / end of shifts (For accident scenarios having off-site consequences, long siren of 30 seconds duration followed by short siren of 10 seconds duration at least 10 times). The warning system finalized and approved by the DCG must be publicized so that it becomes common knowledge amongst the members of the public. The communication coordinator assesses the efficiency and identify the bottlenecks in the main and alternate communication systems and warning systems during mock drills and remove the bottlenecks in the systems where necessary.

5.2.4 Technical Coordinators (Experts in Industrial Health and Safety)

In consultation with the District Collector, the technical coordinators identify response strategy. They provide regular training to first responders and support agencies. They have the power to decide which areas require evacuation and residents of which areas may be advised to take alternative shelters. They also assist the Evacuation Coordinator in identifying safe areas to be designated as assembly points and rehabilitation shelters for emergency use and safe routes for their transfer to rehabilitation shelters based on possible wind direction. In coordination with the Member Secretary and other members of the DCG, the Technical Coordinators analyze past chemical accidents as regards the extent of damage, place of occurrence, cause of occurrence, frequency of occurrence, etc. and assess the actions then taken for mitigation of the emergency.

5.2.5 Safety Coordinator (Environment Engineer, State Pollution Control Board)

The Environmental Engineer of Pollution Control Board is responsible for ensuring that all industries comply with the rules and regulations set forth by the government. The Environmental Engineer have the responsibility to keep a record of meteorological conditions in different areas of the district from IMD (Indian Meteorological Department) and keep a ready reference phone book carrying phone numbers of persons in IMD responsible for providing the information as regard the prevailing and predicted wind direction.

5.2.6 Fire and Rescue Coordinator (District Fire Officer)

The Fire and Rescue coordinator lists all the resources available with the district Fire Department and assesses the sufficiency of the same in terms of men and materials that may be required during a major chemical emergency and ensure that the requisite resources are procured. He also conducts regular fire drills at fire stations and ensure active participation of the fire personnel in mock drills. Based on the possible emergency scenario, the Fire and Rescue Coordinator assesses the number of men and material that may be required during an emergency. He has the responsibility to establish special rescue squads and train them for rescue of entrapped persons in high hazard zones.

5.2.7 Medical Coordinator (District Medical & Health Officer)

The district Medical and Health officer identifies and keep the lists of resources available with the hospitals, dispensaries, clinics, etc. (many hospitals and clinics across the country already have plans for non-chemical related emergencies and therefore have the basic elements of a plan that can be expanded to cope with hazardous material emergencies). It is the responsibility of the District Medical Coordinator to compile the first–aid and comprehensive treatment procedures for each toxic substance handled in the District, which has the capability of affecting a large section of population. The Medical Coordinator takes responsibility to formulate a system for quick establishment of triage stations. He identifies and stock specific antidotes/medicines based on the common chemicals handled in the District. Also, he should prepare an inventory of specific antidotes/medicines available with different agencies such as hospitals, chemist shops, drug wholesalers and prepare a plan for quick procurement of the same in large numbers during an emergency.

5.2.8 Utility Coordinator (Superintending Engineer, State Electricity Board)

The Superintending Engineer of the State Electricity Board is the authority responsible for ensuring supply and maintenance of the electricity in the District. He defines roles and responsibilities of his local representative (Member of LCG) and provides training to him and other staff who may have to be involved in the emergency operation. He prepares and keep updated a list of contact information utility sub-stations or distribution points, which need to be informed to switch off the power supply in a particular area if required. Also identify agencies, which give portable Diesel Generator (DG) sets on hire, as alternate source of power may be required during an emergency to perform combat activities. The Utility Coordinator also have the responsibility to formulate a plan for procurement and quick development of such equipment during an emergency.

5.2.9 Material Coordinator (Additional or Sub Divisional District Magistrate)

The Material Coordinator procure a list of all the Personal Protective Equipment (PPE) and other combat materials, from the members of DCG that may be required by them during an emergency and compare with the actual stock available. He should also prepare and keep an updated inventory of the above materials available with response agencies and industries. The Material Coordinator formulates a plan for distribution of PPEs and other materials / equipment to response personnel. In addition, he also should identify sources of food, wheel chairs, general medicines, and recreation facilities that may be required at rehabilitation centers during an emergency.

5.2.10 Evacuation and Rehabilitation Coordinator

In association with the technical & transport coordinators, main and alternate assembly points should be identified based on different wind directions where people can assemble for getting evacuated. He has to identify evacuation routes based on different wind directions through which the assembled population can be taken to temporary shelters. Other responsibilities of Evacuation and Rehabilitation Coordinator are estimating the number of persons that may need to be evacuated, identify temporary shelters in different wind directions, prepare a plan for evacuation of people from hospitals, schools, police station, Cinema theater, etc. if they are likely to fall in the hazard zone.

5.2.11 Transport Coordinator (Regional Transport Officer)

The transport coordinator should prepare a list of vehicles fitted with sirens, Public address system and walkie-talkies, available in the district and short list those that can be made use of for warning general population during an emergency. The Transport Coordinator establishes agreements with public and private bus companies, ambulance services, and agencies having water tankers for provision of water supply to residential areas, temporary shelters and for fire fighting, during an emergency situation. In association with the evacuation and rehabilitation coordinator, the transport coordinator identifies routes for response agencies and alternate routes for evacuation of general public for different wind directions. He also has the responsibility to provide training to at least some of the drivers on emergency procedures and on use of Self Contained Breathing Apparatus (SCBA), if entry might be necessary or may unexpectedly occur (due to shift in wind direction of other factors) to zones with toxic air contaminants.

5.2.12 Security Coordinator (Superintendent of Police)

The Superintendent of Police assess the requirement of manpower and vehicles in coordination with the Member Secretary, rescue coordinator and assess whether the resources currently available for sufficiency. He also assesses the requirement of Personal Protective Equipment (PPEs) that might be required while patrolling the evacuated hazard zones during an emergency and ensure that the police personnel likely to be near the areas or likely to be affected are trained in the use of PPEs. In association with the evacuation and rehabilitation coordinator, he should prepare a plan for evacuation of prisoners, from prisons or police stations, from such areas which are likely to fall in the hazard zone. The interaction and overall organogram of emergency coordination is given in Annexure III.

5.3 Mapping of Facilities or Resources available in the City for Effective Management

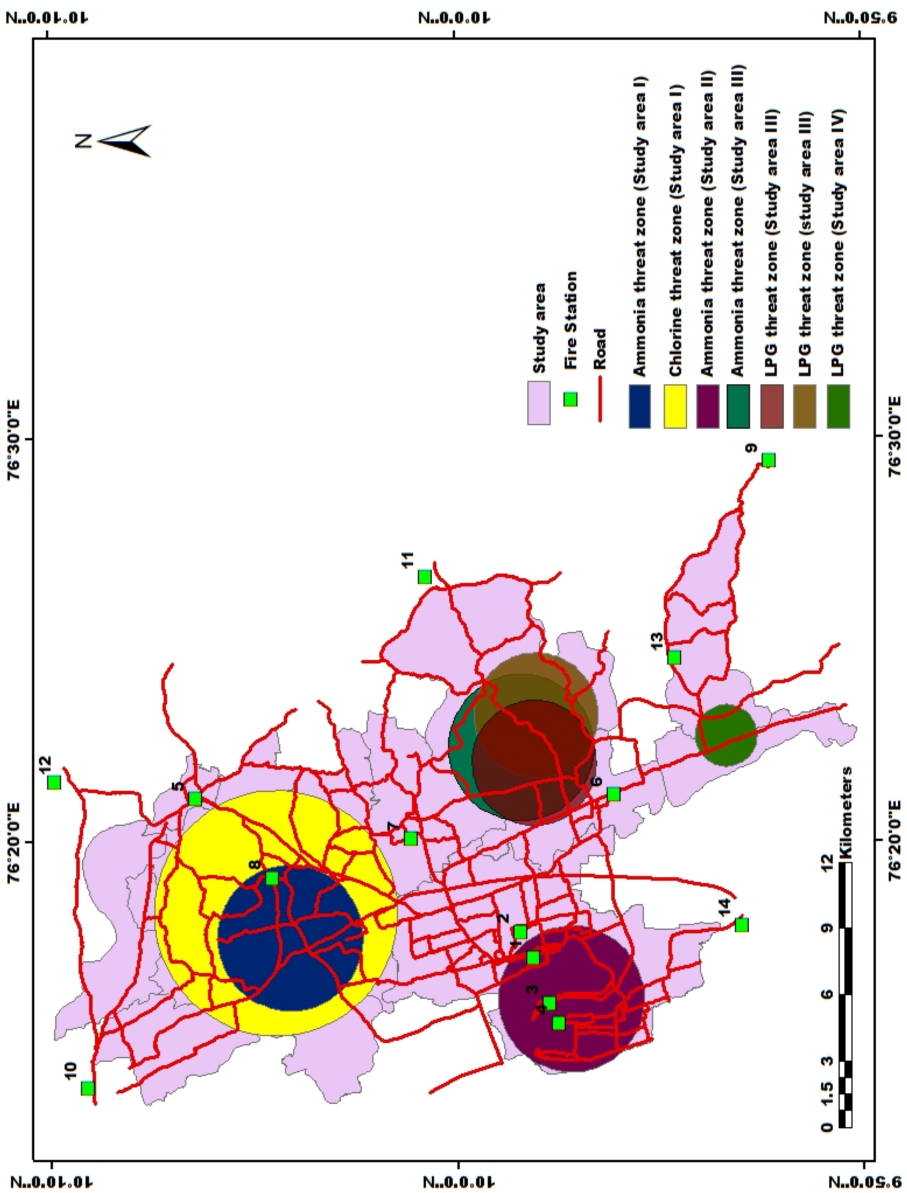
For protecting the public from hazardous chemical releases, an appropriate protective action should be taken quickly by the emergency personnel. Well-coordinated effort among different agencies and individuals are required for an effective management. To make the emergency actions more effective, the responders need to know various geographical information such as definite location of chemical release, spatial extent of release, spatial distribution of population, nearby transportation routes, and other emergency resources available nearer to the accident site. Spatial extents of hazard and population characteristics are described in the previous chapters. This section describes the emergency resources available nearer to the accident site in the study area for taking an immediate action.

During an emergency, there is a critical time constraint on locating and delivering available resources, generating relevant information and distributing it to appropriate parties in a timely manner. In such cases relevant data are crucial for making rapid decisions about where to focus attention and how to distribute limited resources. However, these kinds of situations can be timely managed with the use of reliable and accurate geospatial data, especially in situations when disasters escalate rapidly.

The emergency resources available within the nearest location of accident sites are very crucial in taking immediate action for the management of chemical hazards. The resources of importance include police force, fire fighting resources, and medical resources. These resources have vital link in the entire emergency planning and response process. If there is an accident, first response will be taken by the resources which are available nearer to the accident site.

5.3.1 Firefighting Resource

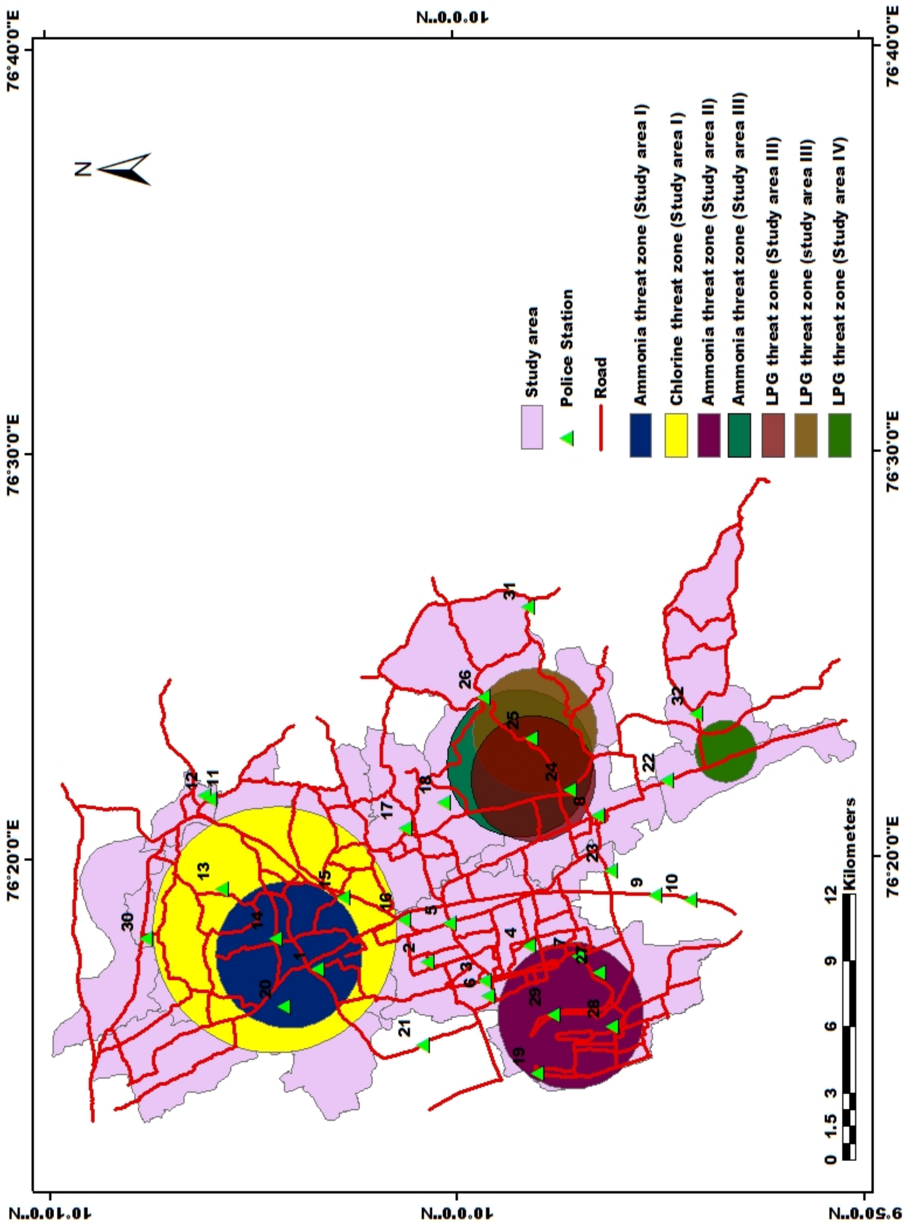
Fire fighters are the primary Emergency Responders. While taking effort to prevent the chemical release, they provide support and protection for technical experts who may be required to carry out special operations to contain a chemical release such as sealing a chemical leak, repairing damaged pipeline etc. The fire fighters provide an on-scene assessment of emergency status to Fire Control Room, Police Control Room, and District Emergency Authority. The response of fire fighters to different hazardous material differ with the chemical and hazardous nature of that material. Before entering the "Hot Zone", each crewmember should wear necessary PPEs and they should work in pairs, taking care of each other. Map 5.1 shows the locations of fire and rescue station in the City. The details of the resources currently available in each station is given in table AI.1 (Annexure I). Using the numbers given in map associated with each fire station's location, the user can easily refer the table to get all the details regarding each forestation resources.



Map 5.1. Location of Fire Stations

5.3.2 Police Resource

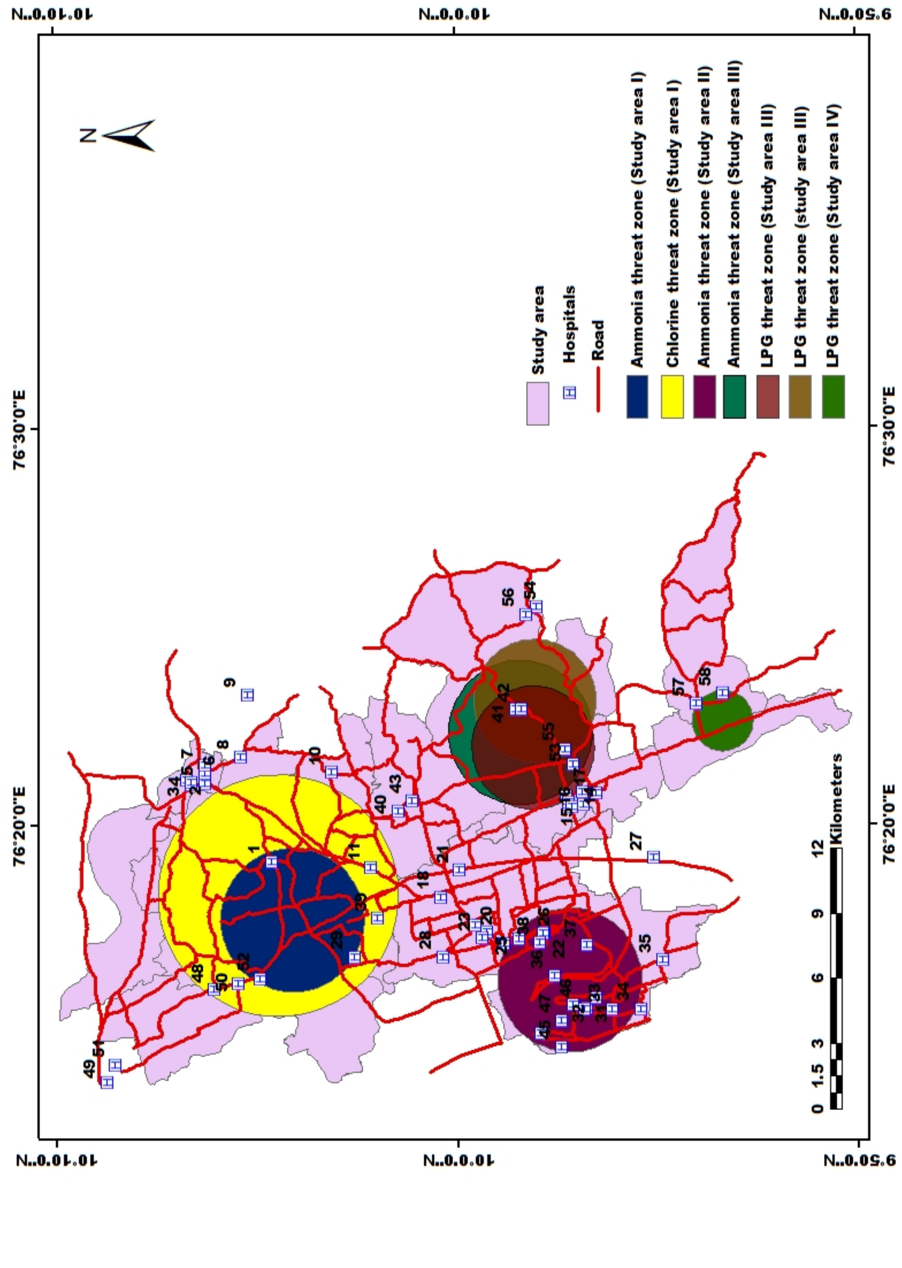
During an emergency, police play a vital role. Many of the functions can only be accomplished under the leadership of police force including mob control, control of traffic, directing evacuation effort, etc. They make an arrangement for information to general public for self-protection and emergency actions. Locations of Police Stations are shown in map 5.2, and the details of which can be obtained by referring the table AI.2 (Annexure I) using the number given in the map.



Map 5.2. Location of Police Stations

5.3.3 Medical Facilities (Hospitals)

Following a chemical accident, to minimize potential morbidity and mortality, early critical care life support is crucial. The first responsibility to manage the victims of a chemical disaster is to come under the care of hospitals. Cochin City and surrounding areas have excellent medical infrastructure. But the survey reveals that none of these hospitals have special burn treatment facilities. The nearest burn treatment units are present only at Thiruvananthapuram Medical College Hospital (about 250 km from Cochin), where there are 4 special burn beds (Ernakulam off-site.1). There is a need to augment burn treatment facilities in the district. Map 5.3 shows the major hospital locations in the city. Their contact details and other information are given in table AI.3 (Annexure I).



Map 5.3. Location of Hospitals in Cochin

Establishment of triage stations: If mass causality situation occur, field hospitals should be established near the hazard site by the medical team to take care for the injured. The triage stations also help to identify, stabilize, and transport more serious cases to hospitals and evaluate and color code (red, yellow, and green codes are proposed) the victims. Red indicate critical, yellow for stable and green for walking wounded. Medical officers who man the triage station should maintain a checklist for the number of victims sent to a particular hospital. This helps to know when the hospital capacity is reached and refuse further admission of victims to the same hospital.

Medical support for response personnel: Where deemed necessary, properly equipped medical personal and one or more ambulances shall be made available to check and treat injured or contaminated response personnel if necessary. These medical emergency personnel shall check the vital signs and general health of all personnel who will don specialized protective gear and enter 'Hot' and 'Warm' zones, wearing fully encapsulating protective suits. The health of potentially exposed response workers shall be rechecked upon completion of their duties.

Medical support at temporary shelters: It is the responsibility of the local medical coordinator to ensure the wellbeing of evacuees at the shelter place. For this, the medical coordinator can assign teams to take care of people who become ill during evacuation or later. The doctors who take the responsibility of such work should be aware of the signs and symptoms of health problems related to exposure of hazardous chemicals so that they can easily provide necessary treatment and care to the victims

5.3.4 Roads and Vehicles

The main roads, to and from the units, used for emergency management activities should be in a good condition. During monsoons the rain deteriorates the condition of the roads. In such situations, the alternate route has to be found. If evacuation is needed in an emergency, quick arrangement of requisite vehicles has to be made. The district transport authority can arrange the requisite number of vehicles in an emergency situation for the evacuation of people who are likely to be impacted by the accident. Main road networks passing through the City are given in the maps depicted above (map 5.2 or 5.3).

5.3.5 Emergency Communication System

In the case of chemical emergency, time is critical, therefore prompt notification will be a key factor in saving several lives. In emergency situations where large scale effect is envisaged on public, communication coordinator is required to rush to the incident site and will dispatch teams to notify general public. It is important that all the warning and notification teams should be given the same set of instructions. Dissimilarity in warning signals/notification and instruction can lead to devastating confusion not only among the receptors but also the team members.

Time is very critical in emergency scenarios that require public evacuation or related protective actions and does not permit lengthy discussions or deliberations as to whether an evacuation is warranted or how large an area should be considered at risk. For making informed decisions about where to focus attention and where to distribute limited resources, it is crucial to collect relevant data. However, accurate, reliable, and timely geospatial data can give useful information, especially where disasters develop rapidly.

5.4 Evacuation

Accidental release of hazardous chemicals sometimes requires evacuation of people from certain areas to prevent injury or death. The evacuation areas may be those directly affected by the chemical or those may be potentially affected during the course of the incident. Evacuation is a complex responsibility and decision about whether or not to evacuate as well as about evacuation distance are taken at the time of actual release and it is incident specific.

The first evacuation consideration is determining whether an evacuation is necessary. The public can be protected from the effects of hazardous chemical discharges into the atmosphere by two ways. One method is evacuation or relocation of threatened population to shelters in safe areas away from accident site. The other method is giving instructions to people to remain inside their homes or places of office until the danger situation is over. But the decision to evacuate depends upon the quantity/rate of release, type of building, and prevailing wind velocity.

In- place sheltering Protection: Airborne release of hazardous chemicals sometime necessitate evacuation, but not always. Airborne chemicals released move downwind very rapidly in some situation. In such cases, there would not be enough time to evacuate the residents. And in short-term release incidents, evacuation is not necessary. In such circumstances, often the most prudent action for protecting the nearby population would be to make them remain inside the building with the doors and windows closed. More sensitive population such as the elders, children, and sick, may get more injury during evacuation than if they stay inside and putting simple counter measures into effect. Changes in wind velocity and direction are difficult to predict and may affect the evacuees, if evacuation were undertaken during a release. Therefore, it is difficult to estimate how long the community would be exposed to a toxic cloud.

Evacuation of people: A skilled judgment is necessary while taking decision about evacuation. If the release occurs over a long period and it cannot be controlled within a short time, then evacuation may be the sensible option. It involves a comprehensive effort to identify both the nature of release and surrounding circumstances. The spread of hazardous substances in the atmosphere is affected by numerous factors. Evacuation decision makers must carefully consider each of these factors while taking decision about evacuation. They are,

a) Physical and chemical properties of the released material

b) Amount of released material

c) Atmospheric conditions

d) Rate of release

e) Potential duration of release

(All the above mentioned factors are explained in detail in chapter 3).

Evacuation Tasks: For an effective and orderly evacuation, emergency management personnel should cover the following tasks.

- Identification of the specific area to be evacuated
- Protective gear to be provided
- Timely instructions to be given to evacuees
- Transportation of evacuees
- Assistance to be given to special population
- Identification of safe and proper shelter locations
- Security of evacuated area
- Control of traffic and pedestrians
- Proper communication procedures.

5.4.1 Factors to be Considered while Planning an Evacuation

5.4.1.1 Identification of the Specific Area to be Evacuated and Population in a Hazardous Area:

Local authorities which is responsible for managing the emergency situation should be aware about the population surrounding the hazardous installation, because the wind carries the hazardous cloud in its way in any direction around the hazardous installation.

Population vulnerability analysis carried out in chapter 4 give a clear distribution pattern of population. A detailed analysis was also carried out to estimate the population within the threat zones and the result gives an accurate estimate of people to be evacuate from the impact zone. In the case of chlorine and ammonia toxicity release, the evacuated area largely depends upon the wind direction. In the dispersion modeling carried out in chapter 3, wind direction was assumed to be from SE direction. It will never be same for another accident, and even in the same accident, wind changes its direction from time to time. If the leak continues for hours, wind may cover all the directions around the installation. Therefore, for a long time release of ammonia and chlorine, it is better to evacuate the area around the installation to a considerable extent depending upon the concentration of the chemical in the atmosphere. In the case of LPG BLEVE, irrespective of direction, all area around the installation should be evacuated immediately.

5.4.1.2 Identifying Sensitive Area to be Evacuated

To ensure a safe and effective evacuation of buildings, a number of factors should be considered. Number of people to be evacuated, their transportation facility, communication barriers, etc. should be taken into account. Considering these factors, the local authority can take decision about which building need priority of evacuation such as schools, hospitals, offices, residences, commercial establishments, prisons, stadium, government buildings etc.

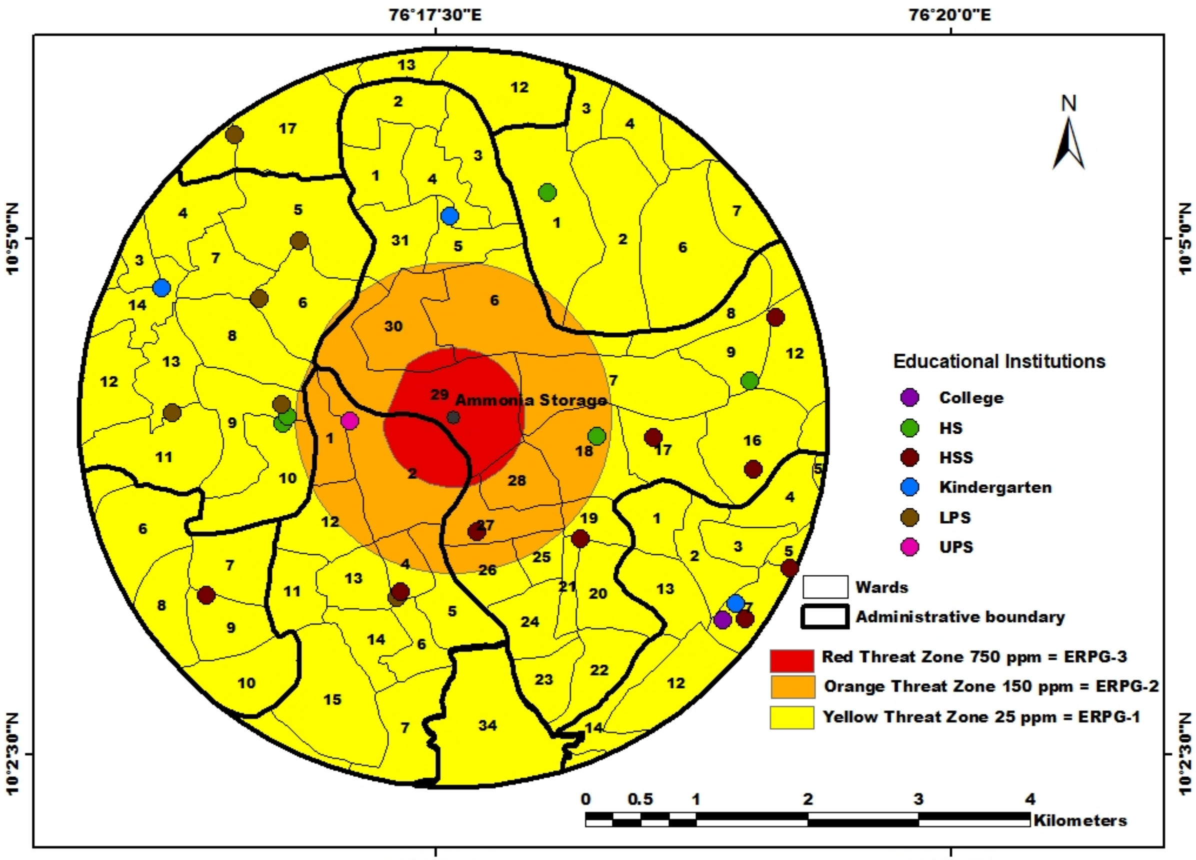
Once it is established that the concentration of the chemical released into the atmosphere is such that shelter-in-place can provide protection only to people residing in pucca houses, evacuation exercise for the remaining population becomes necessary. Under such circumstances, sensitive areas or places having high population such as neighboring industries, educational institutions, prisons, hospitals, cinemas, etc. are the most vulnerable and in need of immediate evacuation. It is the duty of the communication coordinator to ensure that such institutions are promptly informed and also directed to the future course of action. Residential areas also requires special attention.

Mapping of such sensitive areas with their exact location will be a useful information to take immediate decision at a glance on where the highly populated buildings are located and which buildings (having high population) need quick evacuation from the threat zone while the chemical release is continuous. In the following section locations of sensitive places likely to be affected by the release of LPG, ammonia, and chlorine in each study area is mapped based on the result of dispersion modeling done in chapter 2.

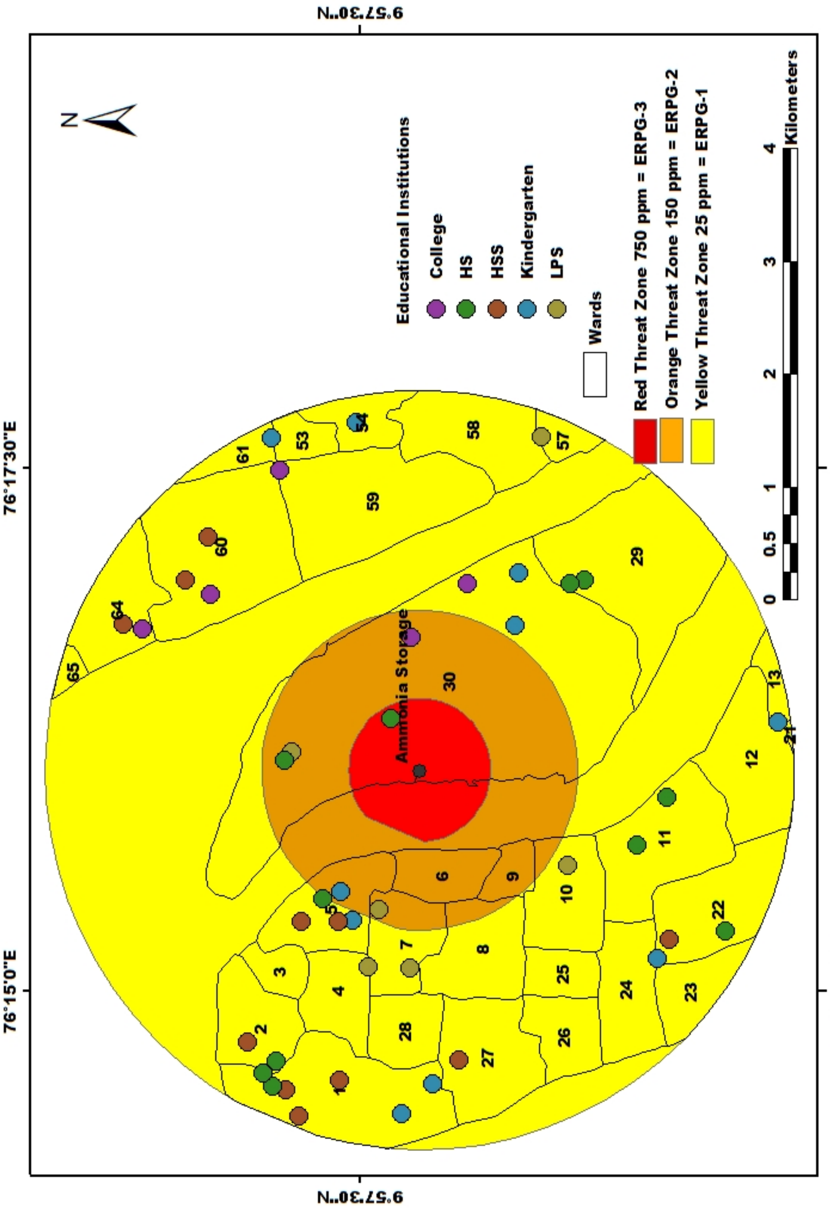
5.4.1.2.1 Educational Institutions

The following maps shows the Educational institutions coming under the threat zones of LPG, ammonia, and chlorine at different locations. Maps also show the ward number, so that emergency management personnel can easily trace the location. In maps, the educational institutions are classified as Kindergarten, Lower Primary School (LPS), Upper Primary school (UPS), High School (HS), Higher Secondary School (HSS), and Colleges. Some High schools and Higher Secondary schools also run with Lower primary classes nearer to its compound. The toxic effect or thermal radiation effect of chemicals quickly affect the lower age children than the high age girls and boys. Therefore, while taking evacuation kindergarten and LP School children must need special care.

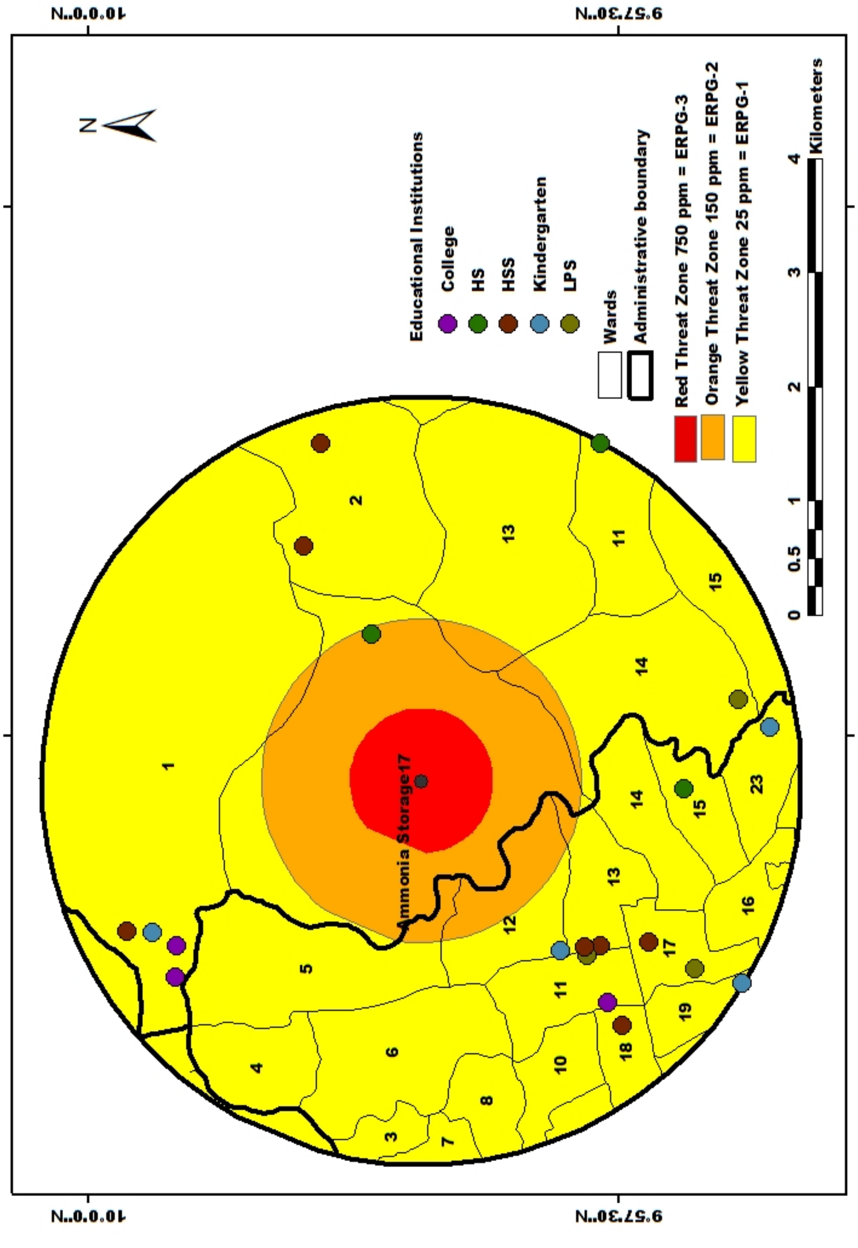
Map 5.4, 5.5 and 5.6, shows educational institutions in the threatened zones of ammonia release at study areas-I, II, and III respectively. Mapping indicates that, in all the three locations, none of the institutions can be badly affected by ammonia release. But the concentration level of ammonia in orange threat zone may affect some of the institutions in study areas- I and II. In the case of study area-III all the institutions are safe from orange zone. Yellow threat zone may include large number of institutions in each study area.



Map 5.4. Location of Educational Institutions Coming under Ammonia Threat Zone in Study Area-I



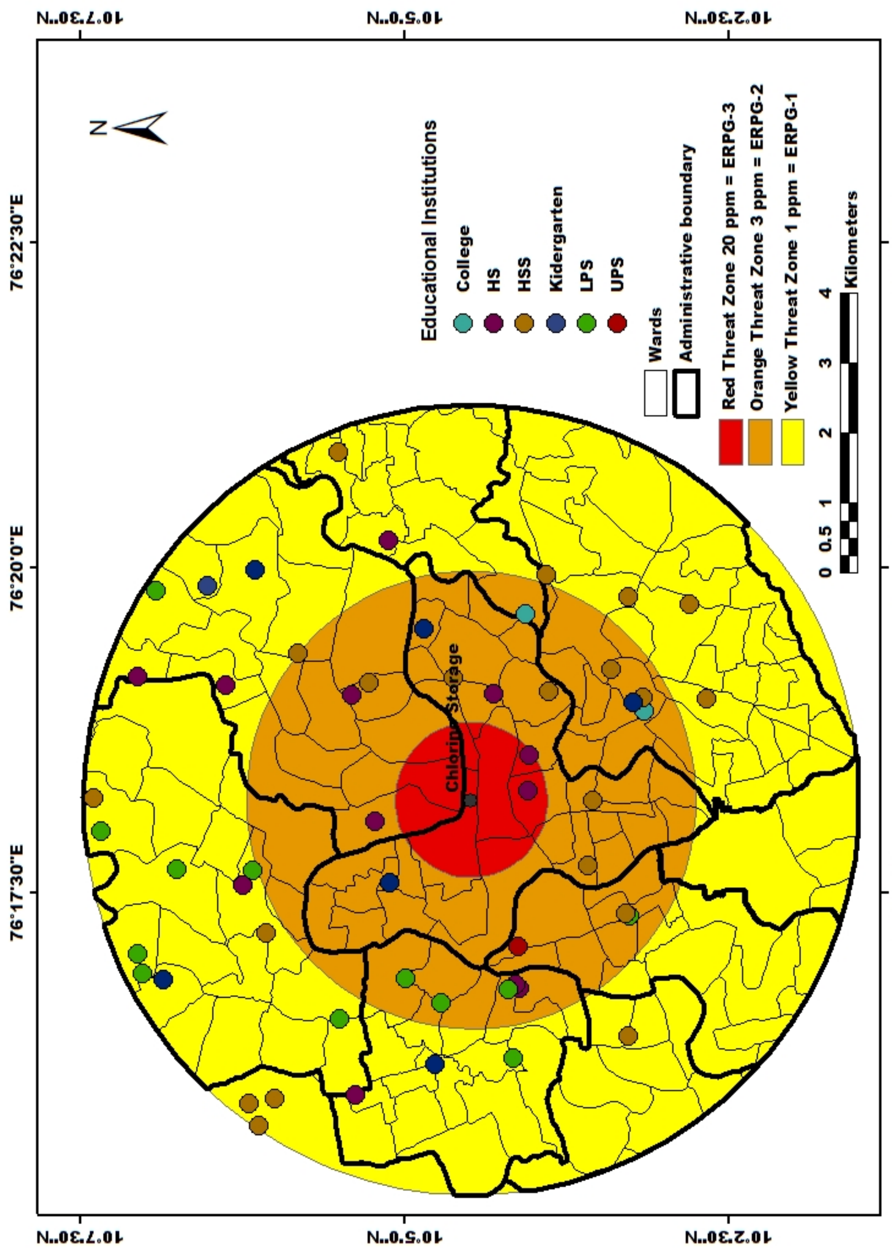
Map 5.5. Location of Educational Institutions Coming under Ammonia Threat Zone in Study Area-II



Map 5.6. Location of Educational Institutions under Ammonia Threat Zone in Study Area-III

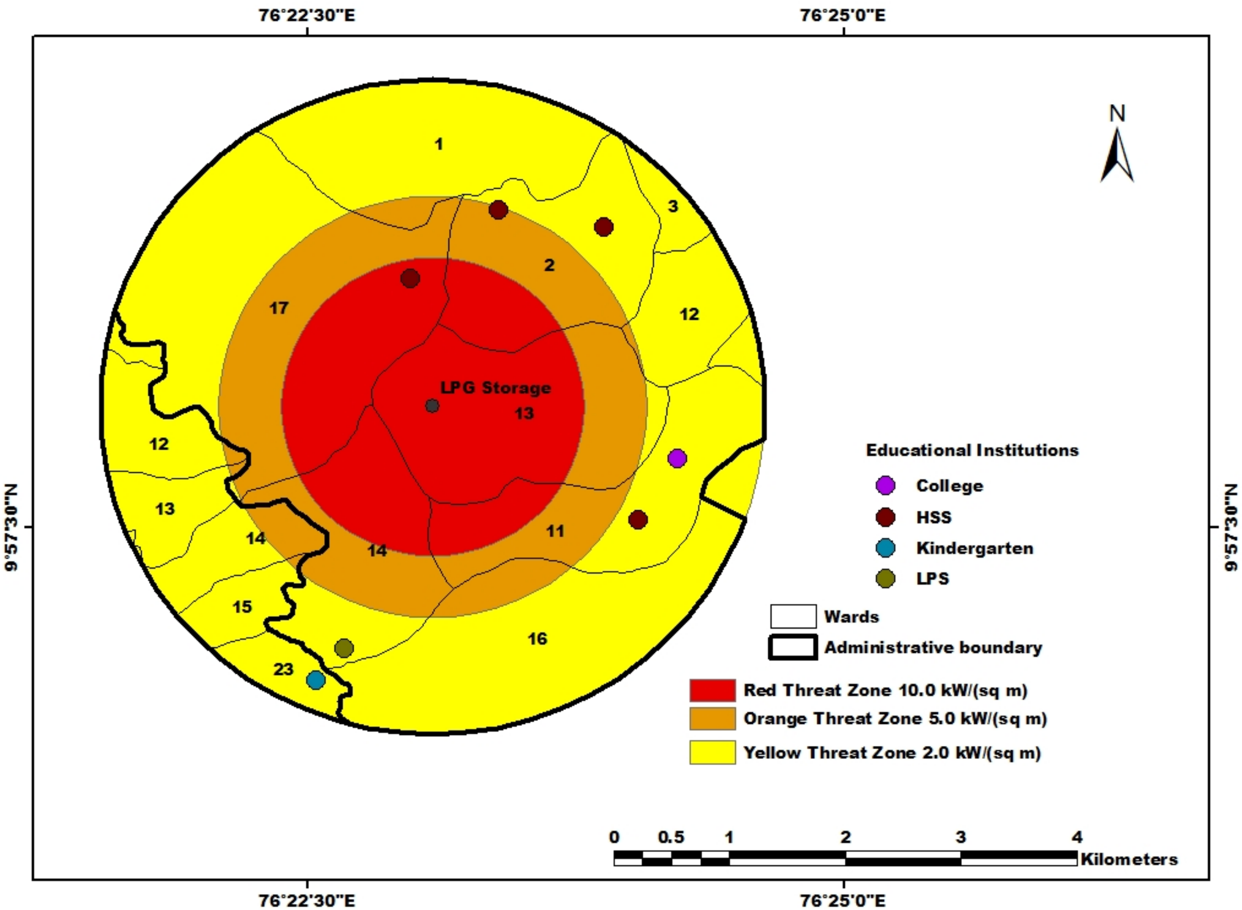
As mentioned in the previous chapters, red threat zone is the most dangerous, and concentration level of ammonia likely to be present in this zone may quickly affect the children. Fortunately, none of the school is situated within the estimated red threat zone distance of ammonia release in study area – I and study area- III. But in study area-II, Kendriya Vidyalaya School is situated near the ammonia storage facility, only 440 m away. Even a small leakage of ammonia will very badly affect the children in this school. The concentration level of ammonia exposure in the orange zone may be tolerable for elders, but it is intolerable for children. Therefore, as a precaution, it is better to evacuate the school from this area. Chemical concentration in the orange threat zone is in more diluted form, but if necessary, evacuation measures should be taken at the right time. If the leak cannot be controlled, the exposure duration will increase and lead to some physical problems, especially in children. Details of educational institutions threatened by ammonia release in each of the three locations (Study area I, II, and III) are given separately in table AII.1, AII.3 and AII.6 respectively (Annexure II).

Map 5.7 Shows the vulnerable educational institutions under the threat zones of chlorine. As chlorine disperses to large distances very quickly, it may also threaten large number of educational institutions. The map 5.7 shows that two Schools are situated inside the highly dangerous zone. The orange zone also includes large number of schools. Details of the educational institutions threatened by the chlorine release are given in table AII.2 (Annexure II).



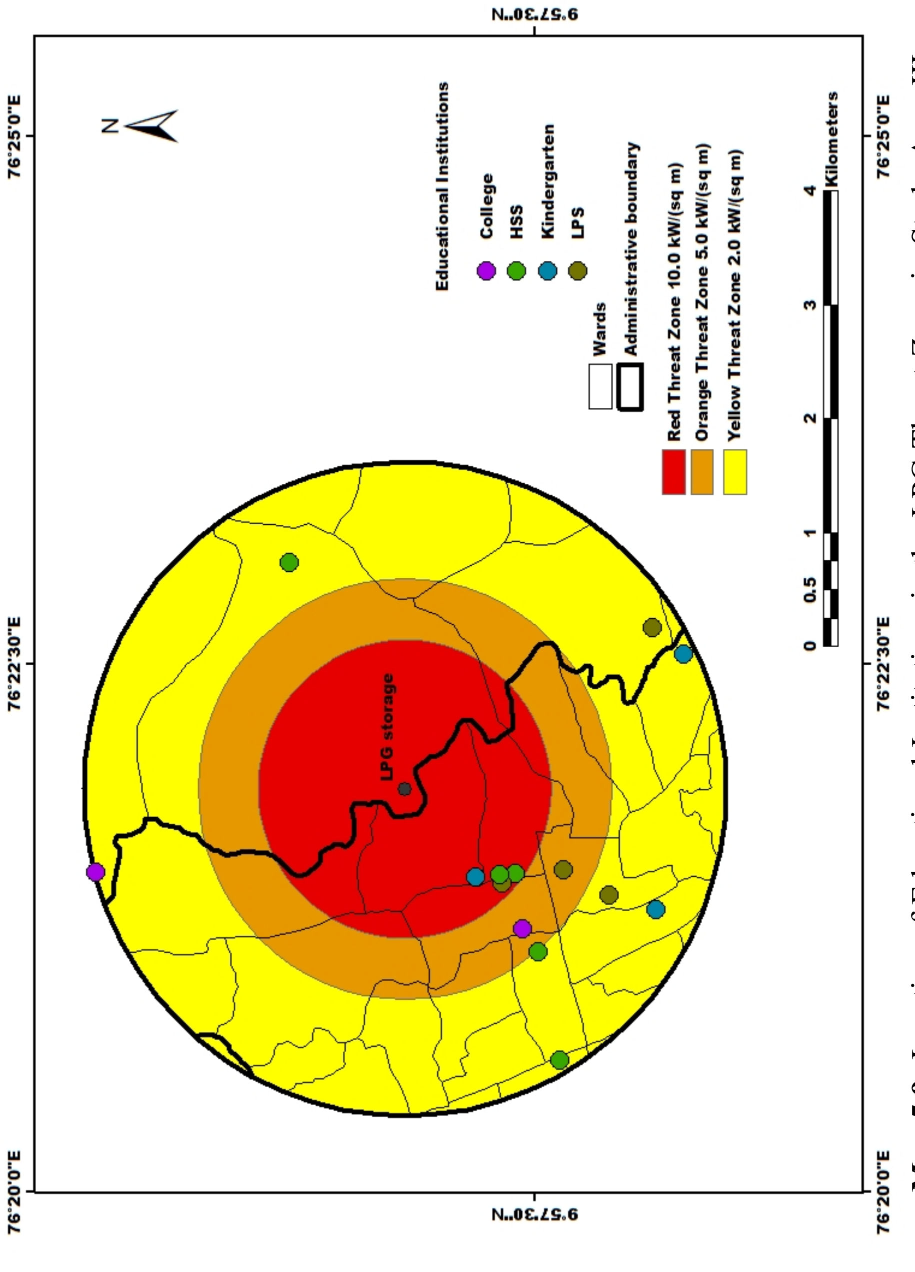
Map 5.7. Location of Educational Institutions Threatened under Chlorine Release in Study Area-I

Map 5.8, 5.9 and 5.10, show the educational institutions threatened by an LPG explosion at study area III (1400 MT LPG and 1540 MT LPG) and study area IV (150 MT). The red threat zone of 1400 MT LPG shows only one school and 1540 MT shows three schools including one kindergarten. None of the schools come under the estimated extent of red threat zone of LPG explosion in Study area- IV. But, preferably during evacuation procedure, irrespective of severity of the three threat zones (Red, Orange and Yellow), equal importance should be given to all educational institutions. This is because, in contrast to release of a chemical, LPG explosion (BLEVE) is a sudden action.

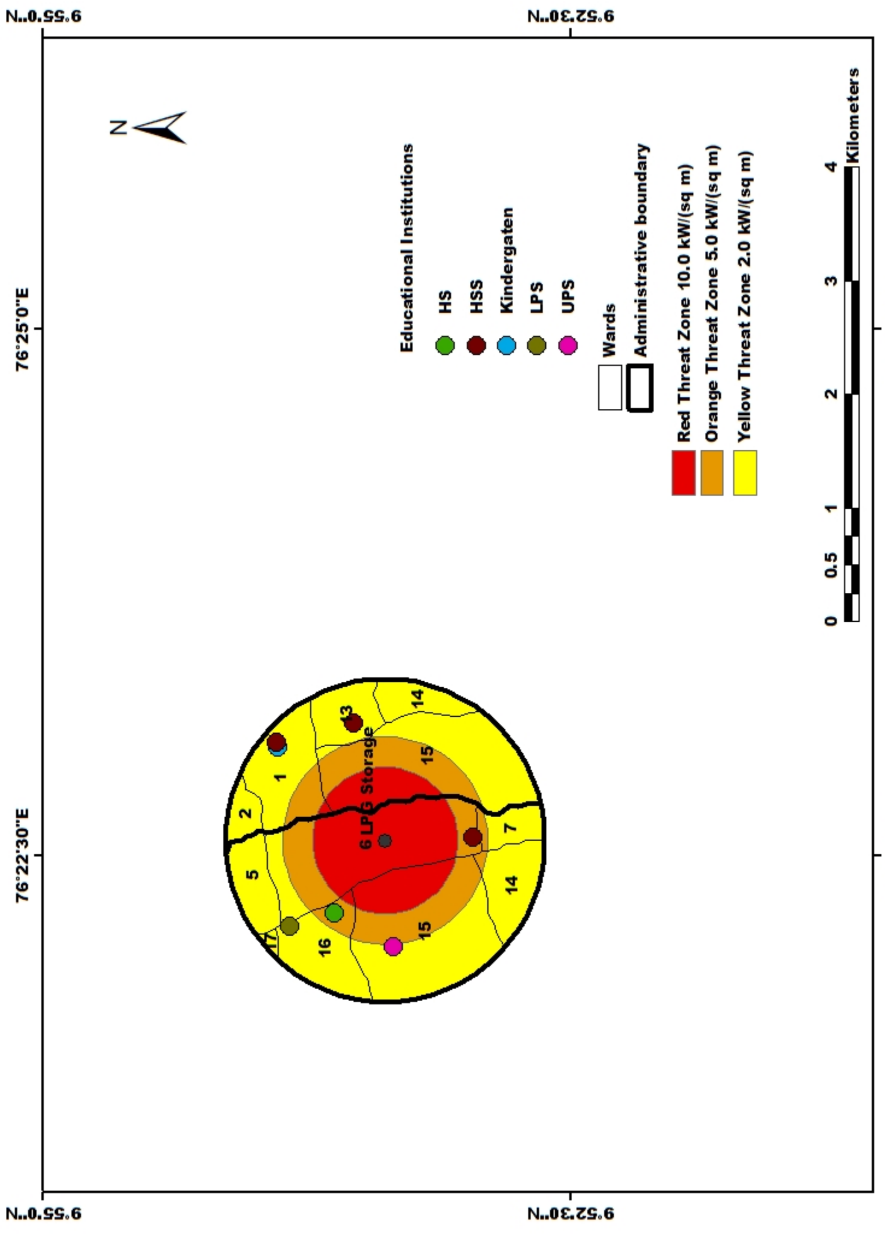


Map 5.8. Location of Educational Institutions under the LPG Threat Zone in Study Area-III (1400 MT LPG)

Children in lower age will be very badly affected by the thermal radiation effect of BLEVE even in the orange threat zone. So, if there is any chance of BLEVE, at once the evacuation procedure should start to relocate the children from schools. Details of educational institutions threatened by LPG BLEVE at three locations are given in Tables AII.4, AII.5, and AII.7 (Annexure II).



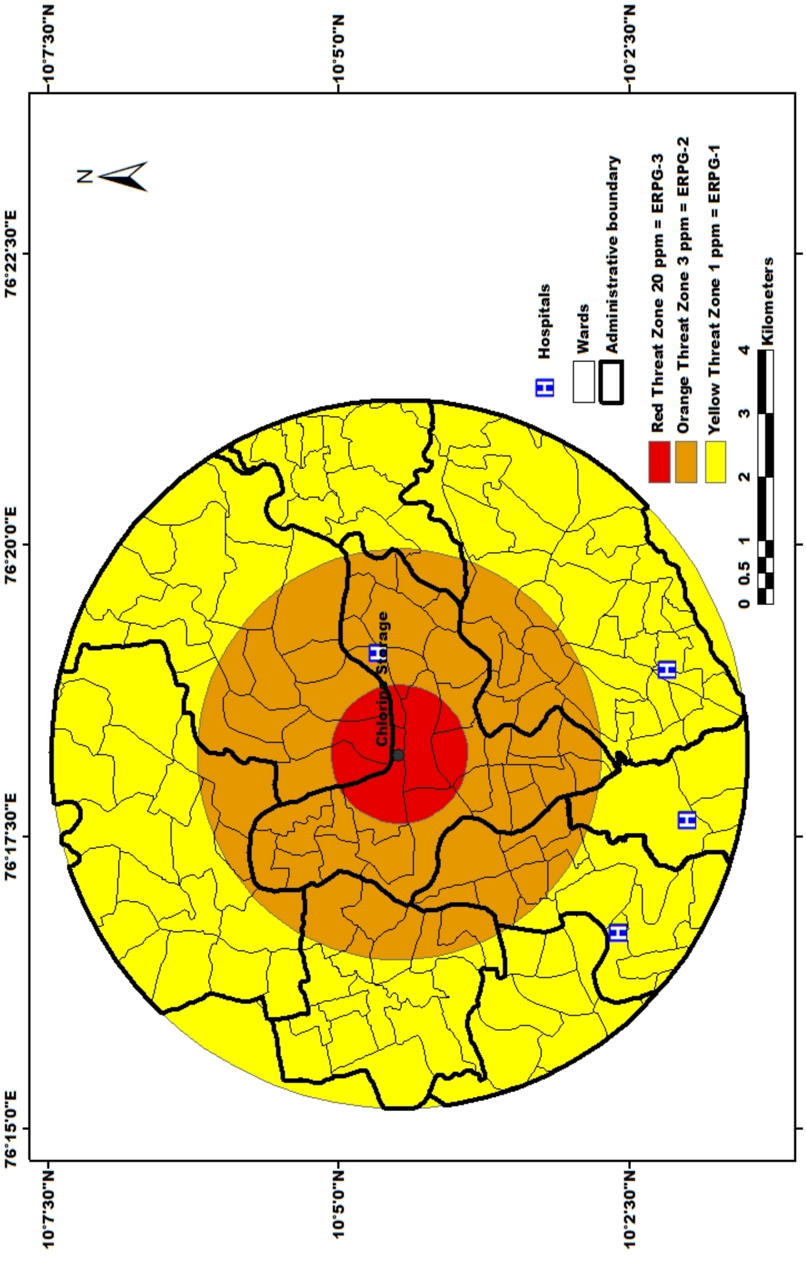
Map 5.9. Location of Educational Institutions in the LPG Threat Zone in Study Area-III (1540 MT LPG)



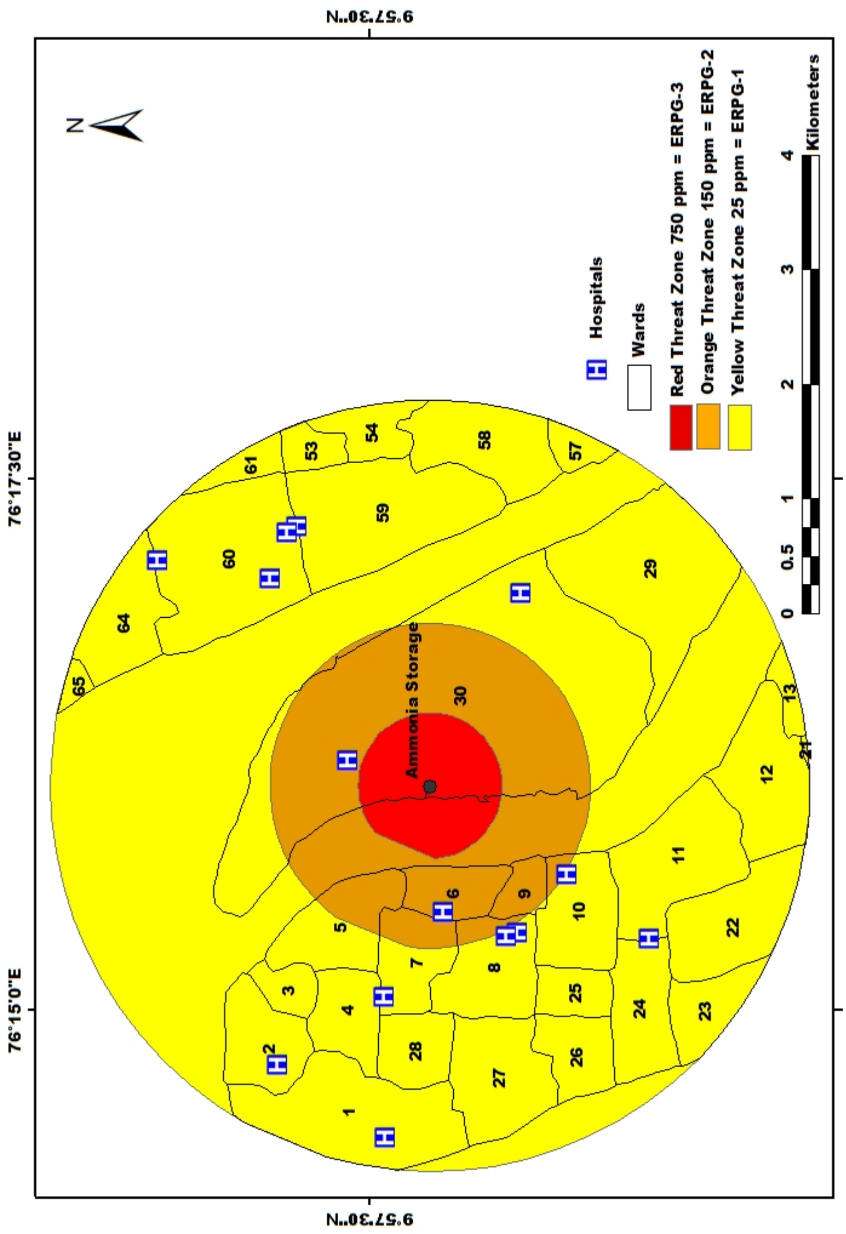
Map 5.10. Location of Educational Institutions in the LPG Threat Zone in Study Area-I V

5.4.1.2.2 Hospitals

Hospitals are yet another sensitive place which need immediate relocation of patients, if evacuation is necessary. Maps 5.11 and 5.12 given below show the location of hospitals which are likely to fall under the threat zones of Chlorine in study area-I and Ammonia in study area-II respectively. In both the maps, hospitals are safe from highly dangerous red threat zone. As the patients in the hospitals are susceptible to toxic releases, even though they are located in the orange of yellow threat zones, they should get special care and should be prepared for evacuation.



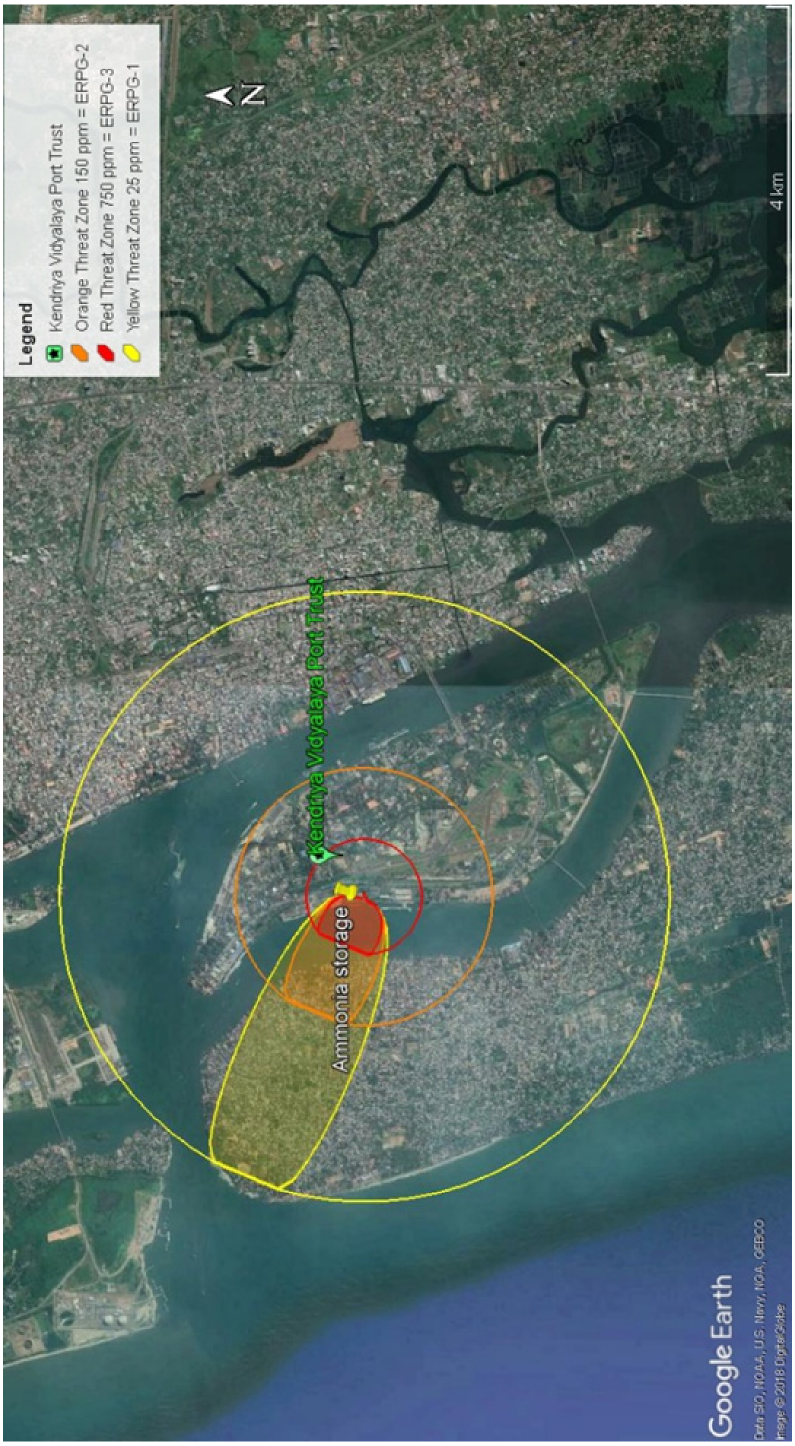
Map 5.11. Location of Hospitals in the Threat Zones of Chlorine in Study Area- I



Map 5.12. Location of Hospitals in the Threat Zones of Ammonia in Study Area- II

The study shows that the worst-case ammonia leak distance is 3.3 km, which do not directly affect any medical facilities critically in study area-I. Only two hospitals are likely fall within the Yellow zone. In study area-III two hospitals fall within the orange zone. In the case of an LPG explosion in the Study area-III, two hospitals may need special protection. In the study area-IV, hospitals are far away from the LPG storage plant. Details of hospitals which are vulnerable to hazardous substance release and explosion are given in Annexure II (Table A II.8, Table A II. 9, and Table AII.10)

Threat at a point: ALOHA can calculate the approximate time the chemicals take to reach a particular point in a given condition and can predict the concentration level of chemical at that point, if the leak is continuous. Based on that, decision can be taken about whether to evacuate any particular area like any school, hospital or any other sensitive area. For example: Map 5.5 shows that the location of one of the schools is within the red threat zone of ammonia release in Willingdon island. The school is situated 440 m away from ammonia storage facility in Willingdon Island. If the release continues, by applying the current scenario details, it is easy to predict the approximate time the chemical reach may take to the school and appropriate measures can be taken. Map 5.13 shows the location of school in Google Earth image and the following graph (figure 5.1) shows the time and concentration of ammonia at the point of school. ALOHA estimated that at the point of school, chemical can reach in 35 minutes (in the given scenario) and the concentration level can exceed ERPG-3 in 12 minutes.



Map 5.13. Location of School within the Red Threat Zone of Ammonia Release at Study Area-II

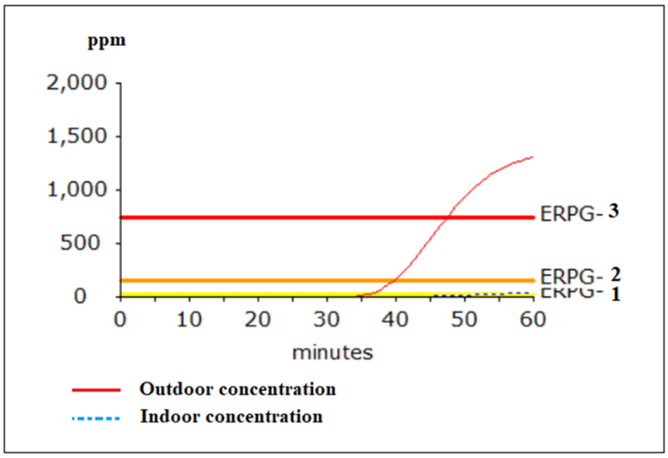


Figure 5.1. Concentration level of Ammonia at a Point (school- 440 m away from ammonia storage facility)

5.4.1.3 Evacuation Routes and Selection of Rehabilitation Centers for Evacuees

A major evacuation center will be established following a decision by the Emergency Operation Controller. This decision will be made in consultation with the members of the Emergency Management Committee. It is convenient to select the evacuation center as nearest as possible to their homes. The evacuation of people from individual residences who require special notification or assistance (such as senior citizens and physically handicapped people) can be facilitated, if public officials have compiled a list of those homes requiring personal attention.

Table 5.1. Details of the Items and Criteria for Ranking of Potential Rehabilitation Centers

No	Items	Criteria
1	Location	Cross Wind, Distance from potential emergency site
2	Capacity	500, 1000, 1500 persons Number of rooms Size of each room
3	Food	Proximity to market of areas from where food and refreshments can be made available
4	Potable Water	Availability of potable water
5	Sanitation	Number of toilets and wash rooms for every 100 persons
6	Security	Boundary, fence, security guards, or possibility of deployment of police personnel
7	Facilities for physically handicapped	Beds, wheel chairs- proximity to areas from where it can be made available at short notice.
8	First aid/ Medical help	Proximity to hospitals/ nursing homes, chemist shops and provision of doctor at the center
9	Structural Stability	Special consideration should be given in case of explosion hazard potential in the nearby industry

The table 5.1 provides details of the items and criteria for ranking of potential rehabilitation centers. Potential centers can be gauged based on these criteria and ranked to get the best suited for a particular emergency scenario (Off-site emergency plan, 2006).

It is essential to define evacuation routes well in advance in overall planning process to avoid any obstruction of traffic and with easy access to the shelter places. The rout should be clearly spelt out in the warning signals along with the location of shelters to where the people with automobiles should proceed and people without automobile should be picked up by buses/trucks or vans.

Since the wind direction at the time of accidental release of chemical cannot be predetermined and it is variable with time, it is necessary to find more than one option for evacuation for any hazardous chemical release.

As soon as an evacuation has been declared, police and auxiliary personnel should be prepared to control traffic on evacuation routes, to keep non-evacuation related traffic off the roads and remove any vehicles that break down and cause a slowdown / obstruction of traffic.

5.5 Technical Action for Chemicals handled in the Industry

5.5.1 LPG

LPG Handling and Storage

LPG is stored only in purpose-designed pressurized vessels or cylinders and appropriately labeled. Access to storage area should be restricted and any ignition source in the storage area should be avoided. All electrical equipment in the area of storage should be flameproof. All equipment and discharges should be earthed properly to avoid any possibilities of fire. Cylinders containing compressed oxygen or other oxidizers should be kept away from the LPG storage. While handling LPG, suitable protective cloths should be worn. Deficiencies of tank such as damage or leaks should be inspected periodically. Fire extinguishers must be made available in and near the storage area.

Measures during Accidental Release of LPG

First of all, evacuate all non-essential personnel from the area of leakage and thoroughly ventilate the contaminated area. Attempt can be made to disperse the gas to a safe location. The most important safety considerations in loading and unloading LPG are keeping all sources of ignitions away from the area, avoiding unnecessary release and making sure suitable fire extinguishers are available. For LPG fire, dry chemical or carbon dioxide types of fire extinguishers are suitable.

LPG leaks in transfer piping can be easily detected by the appearance of frost at the point of leakage. Even an extremely small leak can be identified by applying liquid soap diluted with water or by applying other leak detector solution. Special gas detectors are available for detecting LPG leakage. The personnel taking part in emergency management need to be familiar with the characteristics of LPG. Unless the source of leakage is stopped or the valve closed, it is important not to extinguish a fire. If done, the unburned vapor cloud accumulates and there is a possibility of a more serious hazard, including explosion, than if the escaping gas was allowed to burn. But, if a fire is in progress and LPG storage tank is exposed, it is of prime importance to keep the container cool, especially the vapor space, by applying hose streams of water until the fire is properly extinguished.

Personal Protection: Wear self-contained breathing apparatus when entering an area where oxygen depletion has occurred. When handling containers, safety goggles, gloves and shoes, or boots should be worn.

For skin protection, it is recommended to wear loose- fitting overalls, preferably without pockets.

Disposal Method: Disposal of propane should be undertaken only by the personnel familiar with the gas and the procedures for disposal. If it becomes necessary to dispose, the best procedure is to burn it in suitable burning unit available in the plant in accordance with the appropriate regulations.

First aid Measures: As LPG is asphyxiating, remove the victims to fresh air and provide artificial respiration if breathing has stopped. Give external cardiac compression, if heart beat is absent. Clothes that adhere to the skin due to freezing should not be removed and should be given immediate medical treatment. If a person is affected by frostbite, slowly warm the exposed portion by rinsing with warm water. If there is any eye contact, rinse eyes with water and obtain medical treatment immediately. In the unlikely event of ingestion in high concentrations, central nervous system depression may be caused. In such cases immediately obtain medical treatment.

5.5.2 Chlorine

Chlorine Storage

Cylinders and huge ton containers must be stored in cool, dry, relatively isolated areas, protected from weather and extreme temperature changes. If stored indoors, fire resistant construction is recommended. Also, natural ventilation should be provided. If stored outside, storage area should be clean so that the accumulated trash does not pose a fire hazard. Cylinders should be secured tightly and kept upright and ton containers should be stored on their sides. They should be placed on rails a few inches above the floor.

Full and empty containers should not be stored together and all containers should be protected from external heat or steam lines. Chlorine containers should be segregated from combustible, organic or easily oxidisable materials especially should be isolated from other compressed gas containers and hydrocarbon chemicals. Containers should not be stored where they can drop or heavy objects can fall on them or where vehicles can strike them. Subsurface storage areas should be avoided.

Accidental Release Measures for Chlorine

Leaks in chlorine should be given prompt attention. If they are not promptly corrected, chlorine leaks always get worse. When chlorine leaks occur, authorized, trained personnel equipped with suitable respiratory protection, should reach the location at once and take immediate action. No person should be allowed to work alone on a chlorine leak whenever possible. Until the leak has been stopped, all persons should be kept away and in case of extensive leak, all persons in the path of the leak should be evacuated. Potentially exposed person should be moved to a point upwind of the leak, because chlorine is heavier than air and collected at lower elevations. Therefore, higher elevations are preferable while chlorine leaks occur. To escape in the shortest time, the persons already in the contaminated area should move cross wind.

If the leak is serious, it must be notified to the local authorities and reporting releases to government authorities is required in some cases. Wind direction indicators and chlorine monitors can supply useful information in case of a leak. Chlorine leak can be identified with the help of ammonia vapors. If white cloud forms when ammonia vapors are directed at leak, it indicates the source of chlorine leak. For this, use plastic squeeze bottles containing aqua ammonia (commercial 26^0 Baume aqua ammonia should be used). If a leak occurs in the equipment piping, at once the chlorine supply should be cut off and the pressure should be relieved. Necessary repairs should be made immediately. If welding is needed, the system should be purged with dry air or non-reactive gas. Do not spray water on a chlorine leak because of corrosive action of wet chlorine

Specific actions should be taken to reduce the leaks. If chlorine is escaping as a liquid from any point of the container, it should be shut off, if possible, so that chlorine escapes as gas instead of liquid. The quantity of chlorine that escapes from a gas leak is about one fifteenth the amount that escape from a liquid leak through the same size hole. Another action which can be taken to reduce the leak is to reduce the pressure from the container by absorbing and reacting chlorine gas from the container into caustic soda solution. Caustic soda solution absorbs and reacts with chlorine most readily. If there is a fire incident anywhere near the chlorine release, efforts must be made to prevent the chlorine gas from reaching the fire. Chlorine will intensify the fire, since it is a very powerful oxidising agent, and no ordinary firefighting effort will be able to control this fire.

Disposal of Chlorine: If a leak occurs at a consuming location, it may be best to dispose of the chlorine through the regular consuming process or to run a temporary line to the consuming point. If the consuming process cannot handle chlorine under emergency condition, a standby alkali absorption system should be considered. The gas leakage can be passing through a reducing agent with a trap in the line. Sodium bisulphate and sodium bicarbonate solution can be used as a reducing agent.

Personal Protective Equipment: Suitable protective equipment for emergency use should be available outside of chlorine rooms near the entrance and away from areas of likely contamination. As it very badly affects the respiratory system, respiratory protection should be made available. Most chlorine releases are at low concentration where the oxygen content in the air is greater than 19.5%, then chemical cartridge respirators (upto 10 ppm) or canister gas masks (25 ppm, maximum) would offer adequate protection when dealing an emergency situation. Wear positive pressure breathing apparatus and full protective clothing.

First aid Measures

Emergency Life Support Procedures: Acute exposure to chlorine may require decontamination and life support for the victims. Emergency personnel should wear protective clothing appropriate to the type and degree of contamination. Air-purifying or supplied-air respiratory equipment should also be worn, if necessary. Response vehicles should carry supplies such as chlorine resistant plastic sheeting and disposal bags to assist in preventing spread of contamination.

Inhalation Exposure: First of all, move the victim to fresh air. Emergency personnel should avoid self-exposure to chlorine. If no pulse is detected in the victim, provide CPR (Cardiopulmonary Resuscitation). Artificial breathing should be given if breathing is absent. Obtain authorization and/or further instructions from the local hospital for administration of an antidote or performance of other invasive procedures.

Dermal / Eye Exposure: If eyes exposure has occurred, eyes must be flushed with lukewarm water for at least 15 minutes. The victim should be washed on the exposed skin areas for at least 15 minutes with soap and water.

5.5.3 Ammonia

Handling and Storage: Ammonia is stored in a refrigerated condition by reducing the temperature to -33°C in a cylindrical flat-bottomed tank. The storage area should be away from populated areas so that high risk can be avoided in case of leaks. Avoid prolonged exposure of the container to fire or heat. Leak sensors should be sited all around the storage facility and should be connected with alarm system so that in the event of a leak, an alarm will sound even in the absence of personnel.

Accidental Release Measures

As the gas has noxious odor, it will help to drive people away even under concentration far lower than is required to cause chemical intoxication to passersby. Only trained personnel designated to handle emergencies should attempt to stop the leak by wearing respiratory equipment and protective cloths of a type suitable for ammonia. Use a fog-water spray to knock down small amount of ammonia release. The reaction of ammonia with water is exothermic and hence pouring water into pool of liquid ammonia is not advisable. However, water can be used effectively to spray onto ammonia vapor plumes. It is important to prevent water from entering inside the ammonia container. Care should be given to prevent the contaminated water entering sewers or drains. The disposal of the ammoniacal water must be done carefully to avoid environmental pollution. The water may be neutralized as necessary. Turn the leaking container if possible, so that gas escapes rather than liquefied gas. Leakage of ammonia can be controlled by making an arrangement of water spray at tank top and water curtains around compressors house and ammonia transfer pumps.

If necessary, ventilate the area using forced-draught ventilation. In the case of a large spill, evacuate all unprotected personnel to upwind areas. The contaminated area can be neutralized with dilute acid, and deluge with plenty of water. Until all gas has been dispersed, the area should be kept isolated.

For nearby population, it is better to stay indoors by shutting the windows and doors than trying to escape, when a small scale ammonia leak occurs. As it is soluble in water, putting wet towels around door edges will be advisable. If necessary, wrap wet towel around the head. If the victim can go to the bathroom, run the shower.

Disposal of Ammonia: Ammonia may be disposed of by discharge into water of sufficient volume to absorb it and the resultant ammonium hydroxide must be disposed off in an environmentally safe manner. The disposal method should not be harmful to aquatic life. Large amounts of ammonia should only be handled by the gas supplier.

First Aid Measures: Move the victims to fresh air and if breathing is difficult, trained personnel should administer emergency oxygen. Immediately call a poison center or a doctor if there are symptoms of pulmonary edema. Treatment is urgently required in such cases. If there is any skin contact flush with lukewarm and gently flowing water for 5 minutes. Do not attempt to rewarm, apply direct heat, or rub the affected area. Cloths that stick to the skin should be carefully cut off and remove the rest of the garment. In case of any eye contact, immediately flush with lukewarm and gently flowing water for 5 minutes. All first aid procedures should be periodically reviewed by a trained doctor familiar with the chemical ammonia.

5.6 Conclusion

This chapter reviews the requirements which are needed to reduce the risks from a chemical release. It also contributes to a better understanding of emergency response roles of various agencies. Application of GIS described in this chapter demonstrates various spatial information that are essential for real time emergency management. It reveals that GIS can be an efficient tool for effective response to chemical emergencies. Therefore, a real time emergency response system, integrated with GIS, is suggested for the effective management of hazardous chemical releases. The technical focus of a real time response system is placed on integrating relevant spatial data, properly updated, helps rapid identification of the risk areas and management possibilities at a glance and are also very helpful for quick and effective response decision.

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Chapter 6

CONCLUSION

History of the chemical accidents reveals that, in spite of all precautionary measures accidents do happen due to human errors. Hence, added to still more stringent rules and regulations, it is essential to be prepared to minimize the impact of chemical accidents. At present, the authorities prepare off-site emergency plans, which have to be practiced at least once a year. But during these well-arranged and pre-planned mock drills, nothing dangerously happen beyond their anticipations. Of course, these essential and well-coordinated routine practices provide an experience to manage the situations without any delay and give awareness to each management personnel their own duties. But it is to be remembered that emergency situations following a chemical release is incident specific, and usually beyond all expectations, especially in the case of airborne chemicals, because almost 50% vulnerability of such incidents is based on the surroundings of the chemical installation. The supplementary factors which contribute to the vulnerability are weather conditions, surrounding population density, land use land cover (LULC) pattern, etc. Therefore, the emergency personnel and agencies, besides being well educated of their own specific roles, during the necessary immediate actions, they should have all the relevant geographical and meteorological information readily available, once the accident occurs.

Several methods were used in earlier studies to evaluate the risks of chemical hazards. In contrast to the traditional mathematical models, to assess the risk, the present study uses consequential modeling with the help of computer software. It is found that the hazardous dispersion models using computer software has several advantages over the mathematical modeling in risk assessment and emergency management. Even though the mathematical models are extremely useful tools, it is difficult to be implemented manually and it is laborious and time consuming. Time is one of the most important constraint in handling a crisis situation. Considering this, through the present study an attempt is made to assess the risk and vulnerability using the spatial data with the help of GIS and the model ALOHA. The study proves that for providing timely accurate answers to geographical queries during an emergency situation, GIS applications are uniquely helpful. The consequence analysis using computer software, ALOHA, used in this study found that it can easily be run by entering accurate data. Hence, it can be useful even at the time of the accident. Moreover, it provides an intuitive visualization of impacted area. Identifying areas that are most vulnerable to hazard has immense value in all the stages of chemical disaster management.

The dispersion modeling using ALOHA carried out for LPG, Ammonia and Chlorine releases, which is of particular relevance to the study area, shows that, this model is very useful for delineating the impacted area during an emergency. In the present study, modeling was done by varying the atmospheric conditions. The result indicates that the dispersion of gas clouds is largely influenced by the prevailing meteorological parameters, especially wind speed, direction and atmospheric stability. Of the three chemicals, chlorine exposes a larger population to the impact than ammonia, and LPG. Ammonia is about 300 times less toxic than chlorine. The expansion of the ammonia cloud into the atmosphere will be suppressed by precipitation in any form, such as drizzle, rain, snow etc. But it can keep the cloud more dense in the initial accident area. In the case of LPG, BLEVE effect in the industrial area is highly dangerous. Because, if BLEVE occurs in any LPG tank in an industry, the result can be the explosion of the entire industrial area, at the worst, and the after effects cannot even be predicted. In the study area-IV, BLEVE effect is modeled by considering the quantity of only one bullet tank and the result shows that it may affect an area within 1.4 km radius. This can cause subsequent blasts of other storage tanks in the vicinity. The location of this bottling plant in the middle of a highly populated area makes it more dangerous.

The large storage and continuous use of hazardous materials in MAH industries inevitably generates a growing threat to the local community and the surrounding environment. Population density in the affected area is the most important vulnerable factor. Mere calculation of population density in an area do not show the exact location where the population is concentrated and even uninhabited areas may be highlighted as inhabited. The dasymetric mapping method used in this study solved this problem and gives an accurate distribution of population. The impacted area modeled using ALOHA could be easily integrated with dasymetric mapping and areal interpolation method in Arc GIS gives an estimation of the number of population likely to be threatened by a chemical release. From the resulting map, emergency management personnel can easily understand at a glance where the population is concentrated within the threat zone of chemical release and its related attribute can provide exact number of population in the area, which needs immediate and subsequent evacuations. Such population vulnerability maps will be a very useful information during evacuation procedures.

This study also provides an overview of the necessary coordination in chemical disaster management by discussing the roles of different agencies, which can be redefined with the help of GIS. The primary challenges in handling emergencies are accessibility of relevant information, locating, utilizing and distributing the available resources to appropriate agencies within a limited time to enable evacuation of affected people in a timely and coordinated manner without creating panic and stampede. Such issues can be addressed properly with the help of GIS. The primary benefits of GIS in emergency preparedness and planning phase lie in the integration of spatial information and their dissemination. At present, there are no common standards to enable organizations to share their resources and efficiently get organized during a disaster. GIS data layers, with regular upgradations, containing information about various available resources under different organizations, can assist in effective coordination during emergency situations.

More than the findings of this study, it gives an insight into the methods that can be adopted to minimize the risk during a chemical accident with the integration of ALOHA and GIS. This study also reveals that GIS is a useful tool to explore the consequences of chemical hazards.

Also, such data layers can be of immense help in handling natural calamities as well.

Suggestions

In case of chemical releases, we cannot predict the atmospheric conditions at the time of accidents. Therefore, four most probable scenarios were modeled in this study. Among these four scenarios, the worst case scenario was considered for vulnerability analysis and to provide some management strategies. But it has to be remembered that emergency situations change with each time it occurs. The emergency plan written in book format can only provide only a common knowledge about dealing with an emergency situation, but may not be able to provide all useful information that need to be considered for taking appropriate action as and when required, which are unique and accident-specific. Therefore, a Real Time Decision Support System (RTDSS) should be introduced into emergency management.

The result of this work can be used as a model for preparing a RTDSS, which contains more elaborate supplementary data that could be in the form of digital format. This kind of Decision Support system with periodic upgradations can be easily used for real time accident management. This study reveals that a RTDSS can be easily achieved through the integrated application of ALOHA and GIS. ALOHA is a very userfriendly application which can provide a fast estimation of impacted area at once in case of an accident. For this, information about all hazardous chemical handlers in the City including all dimensions regarding the storage tank, etc. should be always available in the database of users to apply easily at the event of a chemical release. In turn, the GIS database should contain all the relevant geographic information of the area around the industry such as current population, changes in LULC pattern, road networks, establishment of new buildings (residences, hospitals, schools, cinema theaters, etc.) and availability of resources for effective management. All database layers should be routinely updated so that in the event of a chemical release, it can be readily used. For example, after a chemical release, it is necessary to know whether there is any hospitals that are likely to affected by the release. In such a case, dispersion modeling in ALOHA can be easily done within minutes (with an experienced person) by entering the current release scenario and atmospheric conditions. The modeling will give approximates of release patterns and this can be easily overlaid on the GIS database layer of hospitals, if it is readily available. The GIS database layer can also provide all the necessary information regarding contact numbers, address, number of patients admitted, number staff, ambulance services etc. as an attribute data.

Evacuation of vulnerable population is one of the most effective response strategies during a chemical disaster. Evacuation is clearly safer with respect to the specific hazards posed by a toxic gas or vapor release, but has certain limitations and may pose newer problems. For example, a major evacuation takes time and may not be feasible once large amounts of toxic gases or vapors have actually entered the atmosphere. Indeed, asking people in the path of a toxic cloud or plume to leave their homes may in effect create panic and may cause greater harm than good in some case. Thus, large-scale evacuation in response to toxic gas or vapor hazards are best considered when:

- There is a strong possibility of a toxic discharge, though the discharge has not yet taken place, and there appears to be time available to relocate people.
- The discharge has taken place but people are sufficiently far downwind to permit time for evacuation
- People not yet in the direct path of a cloud or plume, but may be threatened by a shift in the wind direction
- Telling people to shelter-in-place might not fully protect them from serious consequences.

Automatic leak detectors should be installed near all LPG, ammonia and chlorine storage facilities. In the case of ammonia and chlorine, as they are highly toxic, leak detection level set in the detector should be below the human detection level so that even a small leak can be controlled before it is detected by a human.

In addition to a "book plan", emergency actions must be rehearsed extensively and regularly for sound performance on demand and for ensuring better co-ordination at all levels. Ensuring emergency preparedness at all times is essential. This can be achieved through regular mock drills and continuously raising the level of awareness at the field level.

Future Work

- The present study focuses mainly on human vulnerability to risks from accidental releases of chemicals from stationary facilities. Vulnerability to accidental releases from mobile units (transportation of hazardous chemical) can be tackled in future studies.
- Domino effect in chemical industry clusters is another area which can be explored in chemical hazard studies in Cochin City.
- The Road Network Analysis in GIS is also recommended as a powerful tool to be developed in future to find the easiest and convenient route for carrying out various emergency activities without any obstruction. However, this methodology relies heavily on numerous data as an input.
- Modeling studies incorporating more frequent weather parameters (e.g. hourly observations in all the seasons) as well as terrain features can be undertaken, the results of which can be readily applied in case of an accident.
- Disaster management authorities should employ qualified hands to regularly update the industrial, geographic and infrastructure modifications in the GIS and modeling platforms so that more accurate and up to date information is available to the rescue authorities in case of industrial accidents.

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Annexures

Annexure I

Resource Data

Table AI.1. Fire Stations in an Around the MAH Industries

	Fire Stations	Contact	Manpower	Number of fire tenders	Ambulance	Fire Suits	SCBA
1	Fire and rescue station TD junction, Ernakulam	0484 - 235 5101	29	4	0	4	2
2	Fire and rescue station Kadavanthra, Ernakulam	0484 220 5550	42	6	1	6	7
3	Port Fire Station Indira Gandhi Rd Willingdon Island	0484 266 6555	32	5	2	10	20
4	Fire and rescue Station Mattancherry	0484 222 5555	18	2	0	3	2
5	Fire and rescue station, Periyar Nagar, Aluva	0484 262 4101	25	5	0	6	4
6	Fire and rescue station Choorakad, Thrippunithura	0484 277 5388	17	2	1	2	2
7	Fire and rescue station Mythripuram, Kakkanad	0484 2423100	22	3	1	3	3
8	Fire and rescue station HIL Colony, Eloor	0484 254 5500	17	2	0	2	2
9	Fire and rescue station SH 42, Piravom	0485 224 2373	19	3	1	0	2
10	Fire and rescue station Vedimara, North Paravur	0484 244 3101	24	4	1	3	2
11	Fire & rescue station Pattimattom	0484 268 7115	15	2	0	2	1
12	Fire and rescue station Angamaly South	0484 245 2101	27	4	1	3	6
13	Fire and rescue station Mulanthuruthy	0484 274 2800	8	1	0	0	1
14	Fire and rescue Station Aroor	0478 287 2455	15	2	1	1	2

Table AI.2. Medical Treatment Available in and Around the MAH Industries

	Name of Hospitals	Contact	Bed Capacity	Ambulance available
1	ESI -Government Hospital Udyogamandal, Eloor	0484 254 5632	100	1
2	MediHeaven Hospital Periyar Nagar, Aluva	0484 263 0016	200	2
3	Arogyalayam Hospital Periyar Nagar, Aluva	0484 262 5252	240	2
4	Najath Hospital Bank Junction, Aluva	0484 262 3693	200	3
5	Karothukuzhi Hospital Pvt. Market Rd, Aluva	0484 262 5228	230	3
6	Government Hospital Railway Station Rd, Aluva	0484 262 4040	217	2
7	Lakshmi Hospital Sub Jail Road, Aluva	0484 263 1481	100	3
8	Carmel Hospital Asokapuram, Aluva	0484 262 5346	245	3
9	Rajagiri Hospital Chunagamvely, Aluva	0484 665 5000	600	8
10	Govt. Medical College HMT Colony, North Kalamassery	0484 241 1460	700	6
11	KIMS Hospital Salem - Kochi Highway, Pathadipalam, Edappally	0484 294 1000	200	3
12	Lakshmi Hospital SN Junction, Thrippunithura	0484 277 6981	300	1
13	Varma Hospital, General Hospital Tripunithura	0484 278 1506	200	1
14	Vijaya Kumara Menon Hospital General Hospital North Fort Gate Thrippunithura	0484 277 7619	100	1
15	Devi Hospital, General Hospital Kottakakom, Thrippunithura	0484 415 1515	260	1
16	Sree Agasthhaya Medical Centre General Hospital, Tripunithura	0484 277 7039	0	0

17	Government Hospital Kottakakom, Thrippunithura	0484 277 7315	146	1
18	Renai Medicity Mamangalam, Palarivattom	0484 288 0000	800	6
19	PVS Memorial Hospital Banerji Rd, Kaloor	0484 418 2888	300	3
20	Lisie hospital Kacheripady, Ernakulam	0484 240 2044	1,000	6
21	Ernakulam Medical Centre Palarivattom	0484 290 7000	300	3
22	Medical Trust Hospital Pallimukku, Ernakulam	0484 235 8001	700	8
23	Specialists' Hospital Kacheripady, Ernakulam North	0484 288 7800	250	4
24	City Hospital Pullepady, Ernakulam	0484 236 1809	280	4
25	Krishna Hospital Mahatma Gandhi Rd,Ernakulam	0484 236 8230	300	2
26	Cochin Hospital Pallimukku, Ernakulam	0484 237 8980	150	2
27	Lakeshore Hospital Nettoor, Maradu	0484 270 1032	350	8
28	Lourdes Hospital Vaduthala,Ernakulam	0484 412 5555	750	6
29	Aster Medcity South Chittoor, Ernakulam	0484 669 9999	1300	20
30	Gautham Hospital Chullickal, Kochi	0484 221 0510	200	2
31	Laxmi Hospital Thoppumpady, Kochi	0484 222 6758	150	1
32	Jesus Hospital Thoppumpady, Kochi	0482 223 4567	150	1
33	Jacobs Multispeciality Hospital Thoppumpady,Kochi	0484 222 0410	300	3
34	Jishy Hospital Mundamveli, Kochi	0484 223 1740	150	1

35	Our Lady`s Hospital Palluruthy, Kochi	0484 223 2955	10	0
36	Cochin Port Trust Hospital Willingdon Island, Kochi	0484 266 6401	200	2
37	Sanjivani Hospital Willingdon Island,Kochi	0484 289 2517	450	6
38	Lakshmi Hospital Pallimukku, Kochi	0484 238 2112	350	2
39	Amrita Institute of Medical Sciences Ponekkara, Edappally	0484 285 1234	1300	14
40	Sunrise Hospital Thrikkakara, Kakkanad	0484 416 0000	580	8
41	AMAS BPCL - Government Hospital, Karimugal, Ambalamugal	-	150	1
42	Ambalamugal Medical Aid Society Ambalamugal	-	100	0
43	Thrikkakara Municipal Co-Operative Hospital - Thrikkakara	0484 242 3310	200	1
44	Fort Kochi Government Hospital, Taluk Headquarters, Fort Kochi	0484 221 6444	240	1
45	ESI Hospital Thamaraparambu, Fort Kochi	0484 221 6578	200	1
46	Westside Hospital Private Limited Kappalandimukku, Mattancherry	0484 222 7979	100	1
47	Sangeeth Hospital Mattancherry	0484 222 4943	200	1
48	Govt. Hospital Chithira Junction, Koonammavu	0484 251 3587	100	1
49	Taluk Head Quaters Hospital, North Paravur - Government Hospital North Paravoor	0484 244 2365	155	1
50	Carmel Hospital Thirumuppam, Varapuzha	-	250	1
51	Don Bosco Hospital Chendamangalam, North Paravoor	0484 244 4875	300	2

52	Varapuzha Medical Centre & Research Centre For Injuries - Varapuzha	084825 13437	100	1
53	St Georges Medical Mission Hospital Karingachira, Thrippunithura	0484 277 8676	200	1
54	Varikkoli Leprosy Hospital Thiruvaniyoor	0484 273 0054	300	2
55	ESI hospital - Medical Clinic Irumpanam, Thrippunithura	0484 277 3045	50	0
56	Puthencruz Medical Centre Puthenkurish	-	100	0
57	MMC Hospital Pallithazhu, Kochi	094474 59782	25	0
58	Hail Mary Hospital Kanjiramattom, Perumpilly	0484 274 0315	200	1

Table AI.3. Police Stations in and around the MAH Industries

	Name of police station	Phone
1	Cheranalloor Police	0484 243 0227
2	Elamakkara Police Station	0484 253 0700
3	Ernakulam Town North Police Station	0484 239 0280
4	Kadavanthara Janamaithri Police Station	0484 220 7844
5	Janamythri Palarivattom Police Station	0484 234 5850
6	Central Police Station Kacheripady, Ernakulam	0484 239 4500
7	Thevara Police Station	0484 235 9350
8	Tripunithura Police Station	0484 278 0228
9	Panangad Police Station Panangad, Ernakulam	0484 270 0201
10	Hill Palace Police Station Vaikom Road, Thrippunithura	0484 278 0228
11	Aluva East Police Station	0484 262 4006
12	Traffic Police Station Sub Jail Rd, Aluva	0484 262 3450
13	Binanipuram Police Station	0484 260 7083
14	Eloor Police Station	0484 254 6365
15	Kalamassery Police Station	0484 253 2050
16	City Traffic Police Station (East) Edappally	0484 234 4852
17	Thrikkakara Police Station	0484 242 2365
18	Police Station Info Park Kakkanad	0484 242 6010
19	Fort Kochi Police Station	0484 221 5055
20	Varapuzha Police Station	0484 251 3073
21	Mulavukad Police Station	0484 275 0772
22	Udayamperoor Police Station	0484 279 4089
23	Maradu Police Station	0484 270 5659
25	Armed Reserve Police Station Irumpanam, Thrippunithura	–
26	Ambalamedu Police Station	0484 272 0491
27	NORA Police Station - Traffic Police Station Willingdon Island	–
28	Thoppumpady Police	0484 222 4033
29	Harbour Janamaithri Police Station Willingdon Island	0484 266 6005
30	Alangad Police Station	0484 267 1101
31	Puthencruz Police Station	0484 276 0264
32	Mulanthuruthy Police Station	0484 274 0262

Annexure II

Sensitive Places within the Threat Zones of Chemical Release

Table A II.1. Educational Institutions within the Threat Zones of Ammonia Release in the Study Area-I

Name of the Institution	Place	Ward Number	Contact
Red Threat Zone			
Nil			
Orange Threat Zone			
Kasturba English Medium School	Eloor	27	0484 2532124
FACT School	Eloor	18	0484 2553297
St marys UP School Cheranalloor	Cheranallur	2	0484 2430459
Yellow Threat Zone			
Little flower LP School	Alangad	17	0484 2512570
Al Farookhia Higher Secondary School	Cheranallur	4	0484 2431104
GOVT LP School	Cheranallur	4	0484 2353459
Edayar Government High School	Edayar	1	4842557304
Crescent Kindergarten	Eloor	4	9048687908
MES Eastern School	Eloor	9	0484 2556171
St.Joseph's Girls High School	Eloor	9	0484 2512191
Eloor Municipality Govt HSS	Eloor	12	0484 2545440
St. Ann's Public School	Eloor	16	0484 6066345
MES udyogamandal School	Eloor	17	0484 2551214
Guardian Angels' HSS	Eloor	21	0484 2557150
Higher secondary School of Jesus	Kadamakkudy	7	0484 2431590
Government VHS	Kalamassery	13	0484 2556944
Rajagiri College	Kalamassery	13	0484 255 5568
Rajagiri Kindergarten	Kalamassery	13	0484 2911202
Rajagiri Public School	Kalamassery	13	0484 2911202
Christ The King Nursery School	Varappuzha	3	9048789923
St.Joseph's LP School	Varappuzha	6	0484 2517413
St. mary's LP School	Varappuzha	6	0484 2512212
Holy Infants Boys High School	Varappuzha	9	0484 2512219
Holy Infants LP School	Varappuzha	9	0484 2516892
Infant Jesus Lower Primary School	Varappuzha	13	484-2516031

Table A II.2. Educational Institutions within the Threat Zones of Chlorine Release in the Study Area-I

Name of Educational Instituion	Category	Place	Contact
Red Threat zone			
FACT School	HS	Eloor	0484 2553297
MES udyogamandal School	HS	Eloor	0484 2551214
Orange Threat zone			
LP School Panayikulam	LPS	Alangad	-
Neericode Aganvadi	Kindergarten	Alangad	-
Holy Infants LP School	LPS	Cheranallur	-
St marys UP School Cheranalloor	UPS	Cheranallur	-
Holy Infants Boys High School	HS	Edampaadam	0484 2512219
Edayar Government High School	HS	Edayar	-
Crescent Kindergarten	Kindergarten	Eloor	0484 2557150
Eloor Municipality Govt HSS	HSS	Eloor	
Govt. L. P. School	LPS	Eloor	0484 2545440
Guardian Angels' HSS	HSS	Eloor	-
Kasturba English Medium School	HSS	Eloor	-
Lower Primary school	LPS	Eloor	-
MES Eastern School	HS	Eloor	0484 2532124
St. Ann's Public School	HSS	Eloor	0484 2557687
St. mary's LP School	LPS	Eloor	0484 6066345
Stella Maris Daycare play school	Kindergarten	Eloor	0484 2512212
Rajashree S M Memorial School	Kidergarten	Kadungalloor	0484 2603828
Government VHS	HSS	Kalamassery	0484 2556944
Rajagiri College	College	Kalamassery	0484 2911202
Rajagiri Kindergarten	Kindergarten	Kalamassery	0484 2911202
Rajagiri Public School	HSS	Kalamassery	0484 2911401
SCMS	College	Kalamassery	0484 2623803
St. Joseph Public School	HSS	Kalamassery	099956 64262
St.Joseph's LP School	LPS	Varapuzha	0484 2513018

St Mary's L P School	LPS	Varapuzha	0484 251 2212
St. Joseph's HSS	HSS	Varapuzha	0484 2512191
Yellow threat zone			
Government High School	HS	Alangad	-
Infant Jesus Senior Secondary School	HSS	Alangad	0484 2670267
Koduvazhanga SN LP School	LPS	Alangad	-
Panayikulam Little Flower High School	HS	Alangad	070255 92344
Sacred Heart LP School	LPS	Alangad	-
Farookhia Higher Secondary School	HSS	Cheranallur	0484 2431104
Ideal Public School	HSS	Choornikkara	0484 2629314
SPW High School	HS	Choornikkara	-
Higher secondary School of Jesus	HSS	Kadamakkudy	0484 2431590
Divya Play School	Kindergarten	Kadungalloor	-
Government High School West	HS	Kadungalloor	0484 2543993
Sri sai Vidya Vihar	HS	Kadungalloor	0484 2671483
St.John's visitation Public school	HSS	Kadungalloor	0484 2061079
Kendriya Vidyalaya	HSS	Kalamassery	0484 2532860
Najath Public School	HSS	Kalamassery	0484 2550912
St. Paul's International School	HSS	Kalamassery	0484 2555495
Chavara Darsan CMI Public School	HSS	Koonammavu	0484 2511162
St.Philomena's HSS	HSS	Koonammavu	0484 2512364
Viswadeepti Vidyalaya Public School	HSS	Panayikulam	0484 2512062
St.Joseph's Girls High School	HS	Varappuzha	0484 2512191
Christ The King Nursery School	Kindergarten	Varapuzha	-
Government HSS	HSS	Varapuzha	-
Infant Jesus Lower Primary School	LPS	Varapuzha	-
Isabellade Rosis Public School	HS	Varapuzha	0484 2516733
Little flower LP School	LPS	Varapuzha	-

Table A II.3. Educational Institutions within the Threat Zones of Ammonia Release in the Study Area-II

Name	place	Ward Number	Contact
Red threat zone			
K V Port trust	Willingdon Island	30	0484 266 7102
Orange threat zone			
Phulwari School	Mattancherry	5	0484 222 7089
SSNKM Sharda Mandir	Mattancherry	7	0484 2210775
Anti submarine Warfare (ASW) School	Willingdon Island	30	-
Willingdon Island Government H S	Willingdon Island	30	0484 266 6922
Willingdon Island Govt. LPS	Willingdon Island	30	0484 266 6922
Yellow Threat zone			
Bharatiya Vidya bhavan	Ernakulam	60	0484 235 1242
Maharaja's College	Ernakulam	60	0484 235 2838
SRVn Government Model VHSS	Ernakulam	60	0484 237 6944
St Teresa's College	Ernakulam	64	0484 235 1870
St Teresa's Convent Girls' HSS	Ernakulam	64	0484 235 1744
Time Kids	Ernakulam	54	099465 57557
INS Dronachaya (Kids)	Fort Kochi	1	
Kochi Government Nursery School	Fort Kochi	1	
Santa Cruz HSS	Fort Kochi	1	0484 221 6589
St Mark's School	Fort Kochi	1	0484 221 5127
St. mary's AIGHS School	Fort Kochi	1	0484 221 5262
St.John Britto School	Fort Kochi	1	
The Delta study	Fort Kochi	1	0484 221 6583
Fathima Giirls HS	Fort Kochi	2	0484 221 5299
St Paul's Public School	Fort Kochi	2	0484 221 7276
Santa Maria H S S	Fort Kochi	22	0484 2215127
Edward Memorial Government HSS	Fort Kochi	27	0484 222 0433
Aasia Bai H S S	Mattancherry	5	0484 222 9555
Phulwari School	Mattancherry	5	0484 222 7089
Sri Gujarati Vidyalaya H S S	Mattancherry	5	0484 320 9164
Saraswathy Vidya Mandir	Mattancherry	7	0484 221 2849
TD H S and L P	Mattancherry	7	0484 222 5920
Smart kids play school	Mattancherry	61	0484 222 4246
K V INS Dronacharya	Mundamveli	22	0484 223 1399
Kidzee	Mundamveli	22	099958 35846
Fr. Damien's Finishing School	Thevara	57	
Radcliffe School	Thoppumpady	10	0484 222 1740
Our lady's Girls H S	Thoppumpady	11	
St Sebastains LP and HS	Thoppumpady	11	0484 223 3582
K V1 Kochi	Willingdon Island	29	0484 266 8472
KV 2	Willingdon Island	29	0484 266 8344
Naval K G school	Willingdon Island	30	0484 266 7050
Navy children School	Willingdon Island	30	0484 287 4793
Seamanship School	Willingdon Island	30	

Table A II.4. Educational Institutions within the Threat Zones of LPG (1400 MT) Release in the Study Area-III

Name of the Institution	Place	Ward Number	Contact
Red Threat zone			
Cochin Refineries School	Ambalamugal	17	+91 484 282 3512
Orange threat zone			
G.V.H.S.S, Ambalamugal - School	Ambalamugal	2	
Yellow threat zone			
Shine Kids Pre School	Mamala	23	91 89435 08151
SNLP SCHOOL MAMALA	Mamala	14	91 484 278 6957
Hagia Sophia Public School	Ambalamugal	11	+91 484 273 4300
Chemists College of Pharmaceutical Sciences and Research	Ambalamugal	11	+91 484 645 5523
Dawn International School	Ambalamugal	2	+91 94475 77770

Table A II.5. Educational Institutions within the Threat Zones of LPG (1540) Release in the Study Area-III

Name of the Institution	Place	Ward Number	Contact
Red threat Zone			
Lake Mount Global Public School	Thripunithura	13	-
S.N.D.P Lower Primary School	Thripunithura	13	-
Saraswathy Mandiram English Medium School	Thripunithura	13	0484 211 4318
Irumpanam NSS Nursery School	Thripunithura	12	
Orange threat Zone			
Medical Trust Institute of Medical Sciences	Thripunithura	11	0484 284 3502
Vocational Higher Secondary School	Thripunithura	16	0484 277 4853
The Choice School	Thripunithura	18	0484 277 5692
Yellow threat Zone			
Cochin Refineries School	Ambalamugal	17	0484 282 3512
Kodamkulangara School	Thripunithura	18	
Rajagiri School of Engineering & Technology Kakkanad	Trikkakara	1	0484 266 0999
Shine Kids Pre School	Vadavucode	23	89435 08151
SNLP SCHOOL MAMALA	Vadavucode	14	0484 278 6957
Smartkidz Play School	Thripunithura	17	92875 94304
M.D.M. Lower Primary School	Thripunithura	16	0484 277 7877

Table A II.6. Educational Institutions within the Threat Zones of Ammonia Release in the Study Area-III

Name if the institution	Ward Number	place	Contact
Red Threat Zone			
Nil			
Orange Threat Zone			
Cochin Refineries School	17	Ambalamugal	0484 282 3512
Yellow Threat Zone			
Hagia Sophia Public School	11	Ambalamugal	0484 273 4300
Dawn International School	2	Ambalamugal	94475 77770
G.V.H.S.S, Ambalamugal	2	Ambalamugal	-
Lake Mount Global Public School	13	Irumpanam	-
S.N.D.P Lower Primary School Irumpanam	13	Irumpanam	-
Saraswathy Mandiram English Medium School	13	Irumpanam	0484 211 4318
Rajagiri School of Engineering & Technology	1	Kakkanad	0484 266 0999
Rajagiri Centre for Business Studies	1	Kakkanad	0484 242 6554
Rajagiri Christu Jayanthi Kindergarten	1	Kakkanad	0484 242 6460
Rajagiri Christu Jayanthi Public School	1	Kakkanad	85920 11124
Shine Kids Pre School -	23	Mamama	89435 08151
SNLP SCHOOL MAMALA	14	Mamama	0484 278 6957
Smart kidz Play School	17	Thrippunithura	92875 94304
M.D.M. Lower Primary School	17	Thrippunithura	0484 277 7877
Bhavan's Munshi Vidyashram	15	Thrippunithura	0484 277 4247
Vocational Higher Secondary School	17	Thrippunithura	0484 277 4853
The Choice School	18	Thrippunithura	0484 277 5692
Medical Trust Institute of Medical Sciencesnam	11	Thrippunithura	0484 284 3502
Irumpanam NSS Nursery School	13	Thrippunithura	0484 277 5033

Table A II. 7. Educational Institutions within the Threat Zones of LPG (150 MT) Release in the Study Area-IV

Name of the Institution	Place	Ward Number	Contact
Red Threat Zone			
Nil			
Orange threat zone			
St.Sebastian's Public School	Udayamperoor	6	0484 279 3760
S.N.D.P Higher Secondary School	Udayamperoor	16	0484 279 4080
Yellow Threat Zone			
Hail Mary School	Mulanthuruthy	13	0484 274 0229
St.Ephrem Seminary Public School	Mulanthuruthy	1	
T.I.M.E. Kids Preschool	Mulanthuruthy	1	75609 90898
Anandadayani English Medium School	Udayamperoor	15	
Government Primary School	Udayamperoor	16	

Table A II.8. Hospitals within the Threat Zones of Ammonia and Chlorine in the Study Area-I

Ammonia Release	**Red Threat Zone**		
	Nil		
	Orange Threat Zone		
	Nil	-	-
	Yellow Threat Zone		
	ESI Hospital	Eloor	0484 2545632
	Aster Medcity	Cheranallur	0484 6699999
Chlorine Release	**Red Threat Zone**		
	Nil	-	-
	Orange Threat Zone		
	ESI Hospital	Eloor	0484 2545632
	Yellow Threat Zone		
	Aster Medicity	Cheranallur	0484 6699999
	Amrita Institute of Medical Sciences	Edapally	0484 2851234
	KIMS Hospital	Edapally	0484 2941000

Table A II.9. Hospitals within the Threat Zones of Ammonia in the Study Area-II

Name of Hospital	**Place**	**Ward number**	**Contact**
Red Threat Zone			
Nil	-	-	-
Orange Threat Zone			
Cochin Port Trust Hospital	Willingdon Island	30	0484 2666401
Westside Hospital Private Limited	Mattancherry	6	0484 2227979
Jesus Hospital	Thoppumpady	10	
Yellow Threat Zone			
Cochin Hospital	Ernakulam	60	0484 2378980
Krishna Hospital	Ernakulam	64	0484 2368230
Lakshmi Hospital	Ernakulam	60	0484 2382112
Medical Trust Hospital	Ernakulam	60	0484 2358001
ESI Hospital	Fort Kochi	1	-
Fort Kochi Government Hospital	Fort Kochi	2	0484 2216444
Gautham Hospital	Fort Kochi	29	0484 2210510
Sangeeth Hospital	Mattancherry	7	0484 2224943
Jacobs Multispeciality Hospital	Thoppumpady	24	0484 2220410
Sanjivani Hospital	Willingdon Island	30	0484 2892517

Table A II. 10. Hospitals within the Threat Zones of Ammonia and LPG in the Study Area-III

Ammonia release	Name of Hospital	Place	Contact
	Red Threat Zone		
	Nil	-	-
	Orange Threat Zone		
	Nil	-	-
	Yellow Threat Zone		
	AMAS BPCL - Government Hospital	Ambalamugal	-
	Ambalamugal Medical Aid Society - Hospital	Ambalamugal	-
LPG release (1400 MT)	**Red Threat Zone**		
	Nil	-	-
	Orange Threat Zone		
	Nil	-	-
	Yellow Threat Zone		
	AMAS BPCL - Government Hospital	Ambalamugal	-
	Ambalamugal Medical Aid Society - Hospital	Ambalamugal	-
LPG release (1540 MT)	**Red Threat Zone**		
	Nil	-	-
	Orange Threat Zone		
	Nil	-	-
	Yellow Threat Zone		
	AMAS BPCL - Government Hospital	Ambalamugal	-
	Ambalamugal Medical Aid Society - Hospital	Ambalamugal	-
	Lakshmi Hospital	Thrippunithura	0484 277 6981

Annexure III

Organogram of Emergency Response Teams

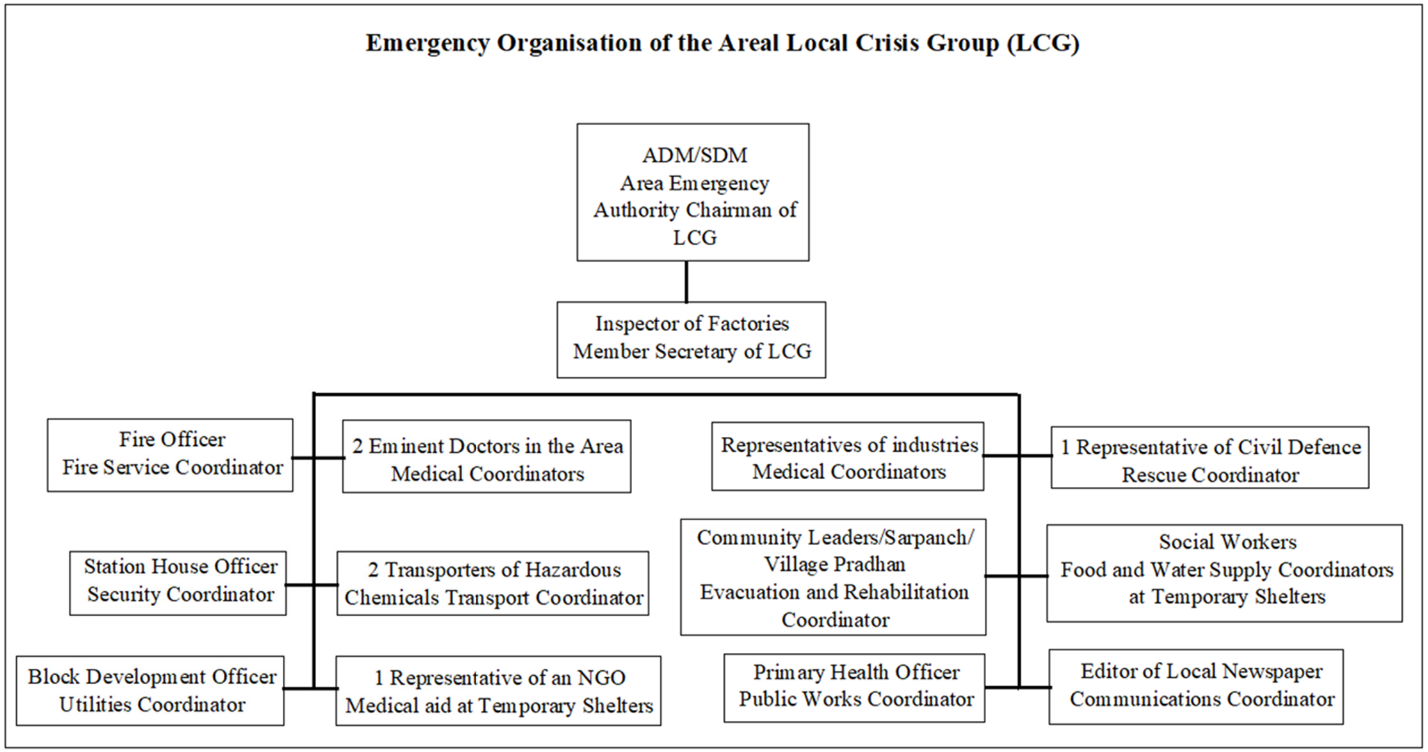

Figure. AIII. 1

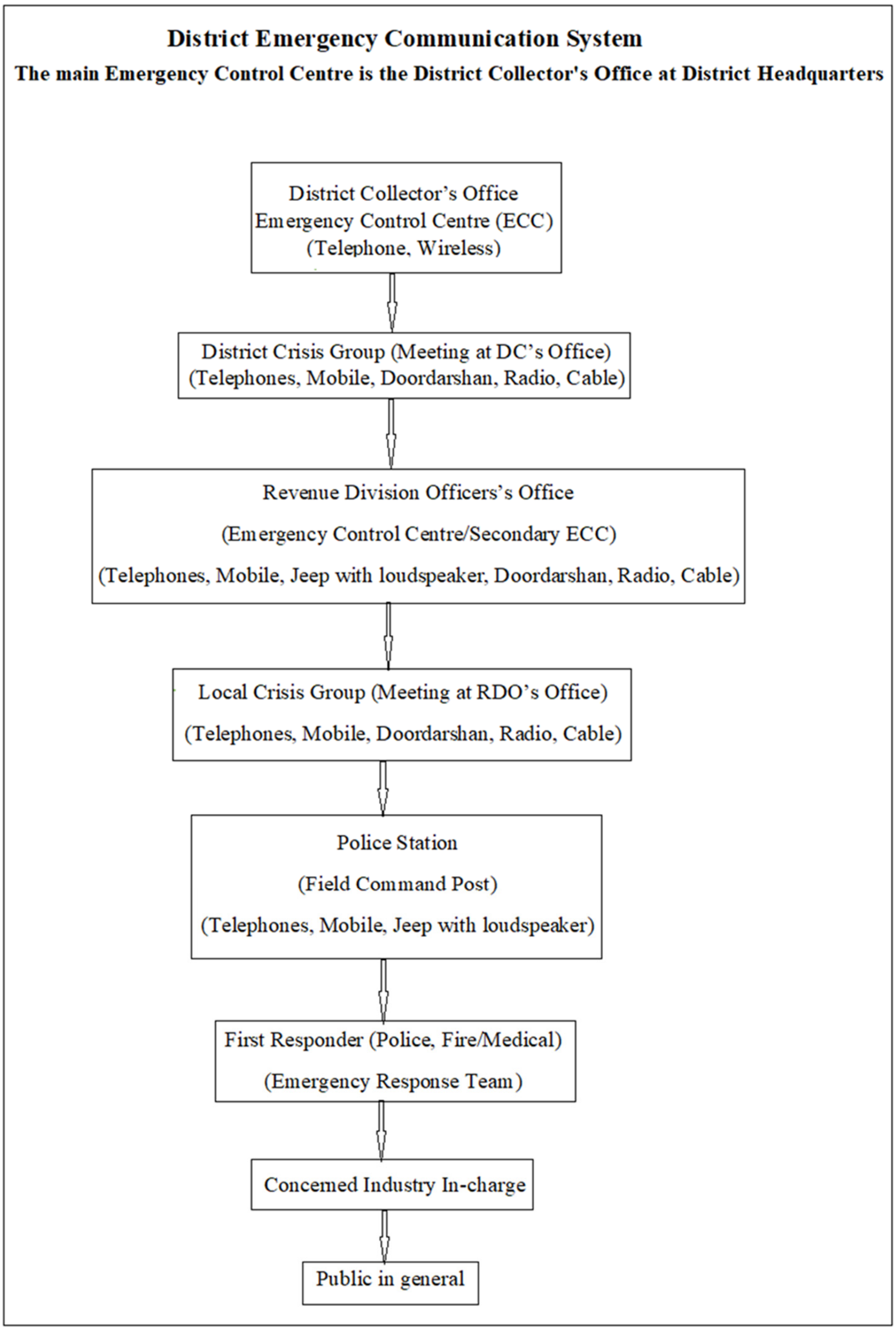

Figure A III. 2

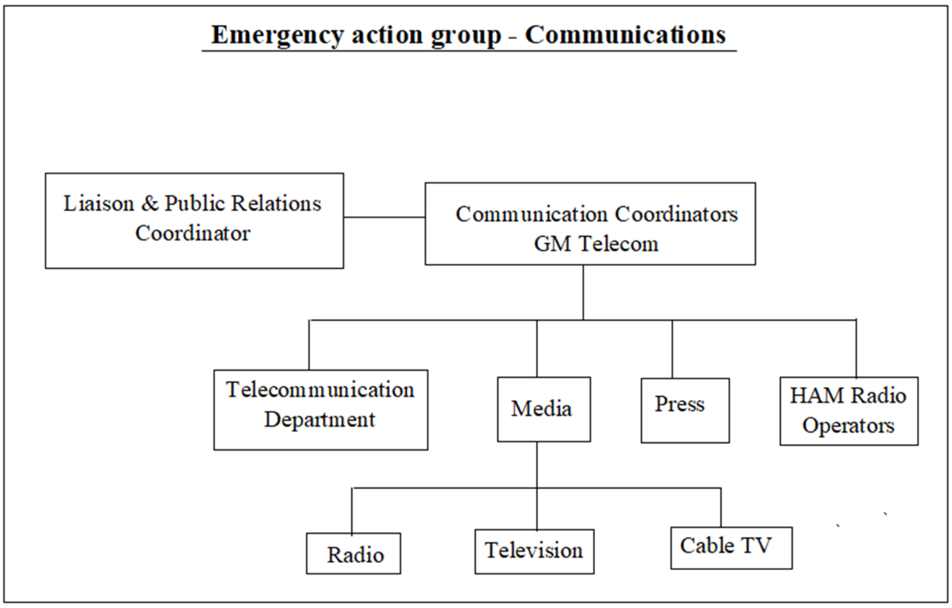

Figure AIII.3

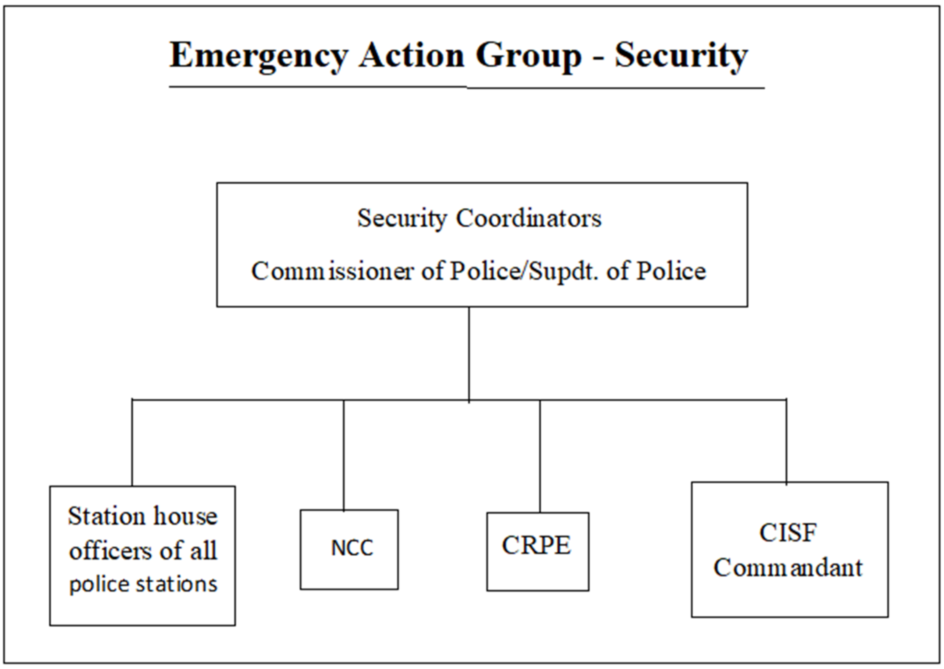

Figure A III.4

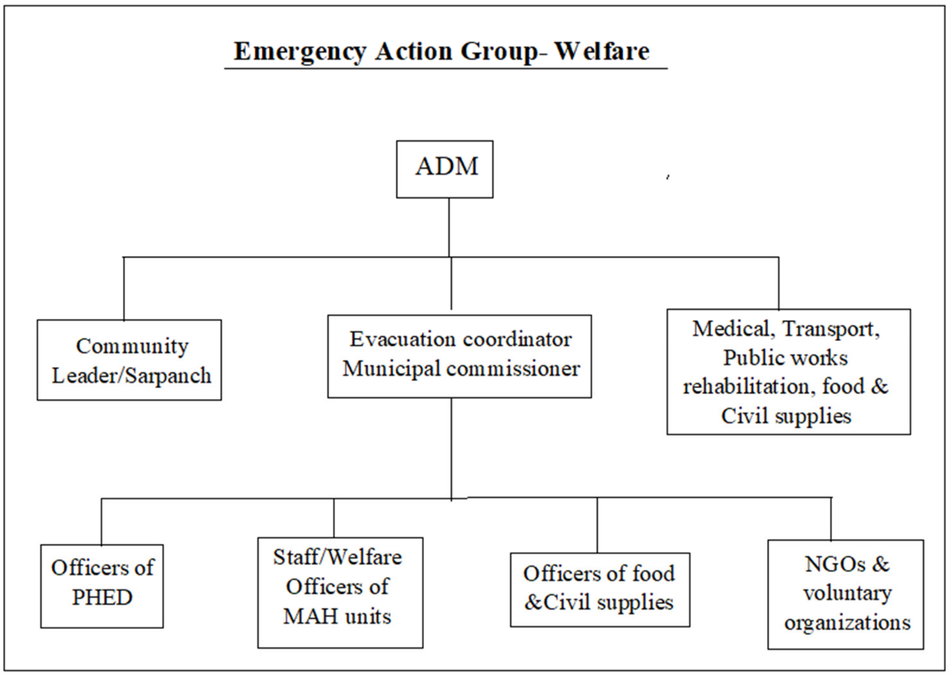

Figure AIII.5

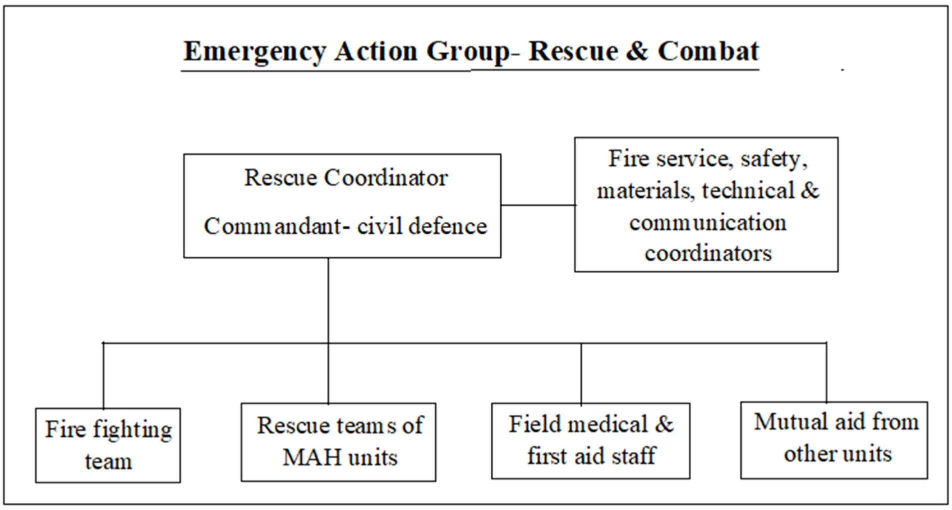

Figure A. III.6

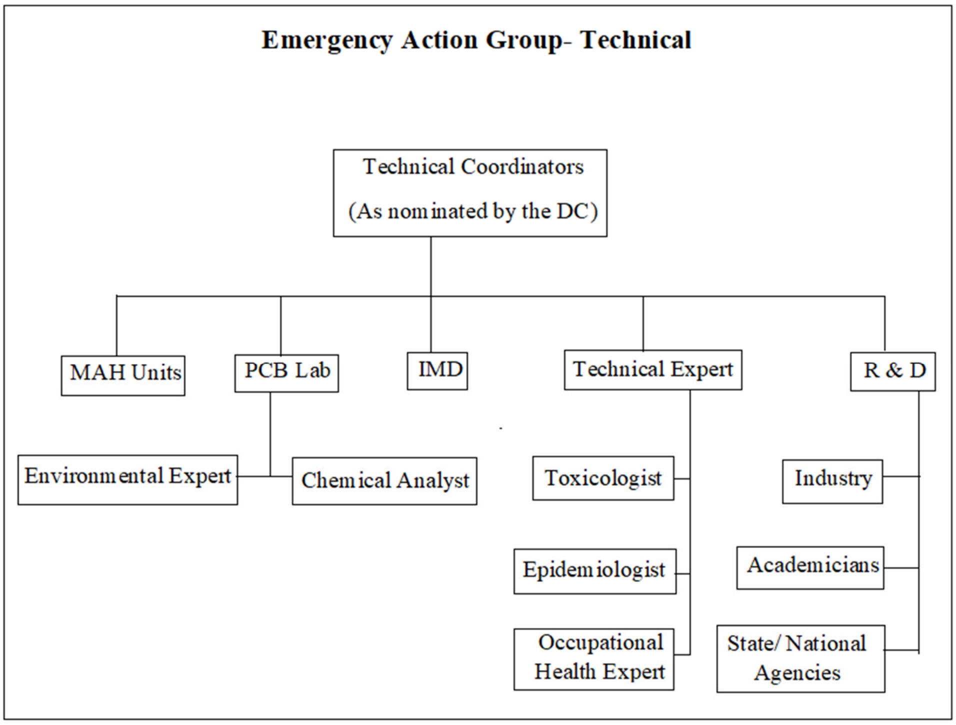

Figure AIII.7

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List of Abbreviations

AIChe	-	American Institute of Chemical Engineers
ACAS	-	Aloha Conversion Analysis and Summary
AEGLs	-	Acute Exposure Guideline Levels
AHCA	-	American Health Care Association
AIChe/ CCPS	-	American Institute of Chemical Engineers/ Center for Chemical Process Safety
ALOHA	-	Areal Locations of Hazardous Atmospheres
BLEVE	-	Boiling Liquid Expanding Vapor Explosion
CAMEO	-	Computer Aided Management of Emergency Operations
CCG	-	Central Crisis Group
CDP	-	City Development Plan
CPR	-	Cardio Pulmonary Resuscitation
CRA	-	Community Risk Assessment
DC	-	District Collector
DCG	-	District Crisis Group
DEGADIS	-	Dense Gas Dispersion Model
DG	-	Diesel Generator
DGFASLI	-	Directorate General Factory Advice Service and Labor Institutes
ECC	-	Emergency Control Centre
EPA	-	Environmental Protection Agency
ERD	-	Emergency Response Division
ERPG	-	Emergency Response Planning Guidelines
ESRI	-	Environmental Systems Research Institute
FACT	-	Fertilizers and Chemicals Travancore Limited
GACL	-	Gujarat Alkalies and Chemicals Limited
GIS	-	Geographic Information System
GPS	-	Global Positioning System
HAZMAT	-	Hazardous Materials
HPCL	-	Hindustan Petroleum Corporation Limited
IDLH	-	Immediately Dangerous to Life or Health

IMD	-	India Meteorological Department
IOC	-	Indian Oil Corporation
IPCL	-	Indian Petrochemicals Corporation Limited
LCG	-	Local Crisis Group
LEL	-	Lower Explosive Limit
LOC	-	Levels of Concern
LPG	-	Liquefied petroleum gas
LULC	-	Landuse-Landcover
MAH	-	Major Accident Hazard
MIC	-	Methyl Isocynate
MoEF	-	Ministry of Environment and Forest
MSIHC	-	Manufacture, Storage and Import of Hazardous Chemical
NDMG	-	National Disaster Management Guidelines
NIST	-	National Institute of Standards and Technology
NOAA	-	National Oceanic and Atmospheric Administration
OCA	-	Offsite Consequence Analysis
OSHA	-	Occupational Safety and Health Administration
PPE	-	Personal Protective Equipment
SCBA	-	Self Contained Breathing Apparatus
SCG	-	State Crisis Group
TCC	-	Travancore Cochin Chemicals
TLV-TWA	-	Threshold Limit Value–Time Weighted Average
UEL	-	Upper Explosive Limit
US DHS	-	United States Department of Homeland Security
US EPA	-	United States Environmental Protection Agency
VCE	-	Vapor Cloud Explosion
WHO	-	World Health Organization

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List of Publications

A. Paper presented in National conferences:

- Anjana, N. S., Amarnath, A. & Harindranathan, Nair. M. V., Risk assessment of toxic releases of ammonia and impacted population, 26th Swadeshi Science Congress, Central Marine Fisheries Research Institue (CMFRI), Kochi, Organised by Swadeshi Science movement, 7-9 November 2016.
- Anjana. N. S., Amarnath. A & Harindranathan Nair M V., Hazardous gas leakage and effect of atmospheric variables on its dispersion., 27th Swadeshi Science Congress, Amrita Viswa Vidyapeetham, Amrita University, Kollam., Organised by Swadeshi Science movement, 7-9 November 2017.

B. Journal Publications

- Anjana, N. S., Amarnath, A., & Nair, M. H. (2018). Toxic hazards of ammonia release and population vulnerability assessment using geographical information system. Journal of environmental management, 210, 201-209.
- Anjana, N. S., Amarnath, A., Chitra S. V., Harindranathan Nair M. V., Subin, K. J.(2015).Population Vulnerability Assessment around a LPG storage and Distribution Facility near Cochin Using ALOHA and GIS., International Journal of Engineering Science Invention. 4(6).23-31.
- Chithra, S. V., Amarnath, A., Harindranathan, Nair. M. V., Anjana, N. S., (2015). Impact of Impervious Surfaces on the Environment., International Journal of Engineering Science Invention. 4(5). 27-31.

- Chithra, S. V., Amarnath, A., Sajith, K. S., Anjana, N. S., Harindranathan, Nair M. V., (2015). Mapping and Change Ditection of Built- up Impervious Surfaces in and around Kochi using GIS., International Journal of Engineering and Science Research. 5(6).403-410.
- Anjana, N. S., Nair, M. H., Sajith, K. S., Amarnath, A., & Indu, I. (2018). Accidental release of ammonia from a storage tank and the effects of atmosphere on the affected area using ALOHA. *Indian Journal of Scientific Research*, 1-8.

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Reprints of Papers Published

1) Population Vulnerability Assessment around a LPG storage and Distribution Facility near Cochin Using ALOHA and GIS

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

International Journal of Engineering Science Invention
ISSN (Online): 2319 – 6734, ISSN (Print): 2319 – 6726
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Population Vulnerability Assessment around a LPG Storage and Distribution Facility near Cochin using ALOHA And GIS

Anjana N S[1,*], Amarnath A. [2], Chithra S.V. [3], Harindranathan Nair M. V. [4], Subin K Jose[5]

School of Environmental Studies, Cochin University of Science and Technology, Kochi, India

ABSTRACT: The growth of chemical industries has increased the hazard, risk and vulnerability of the population and the environment. Although accidents in major chemical industries are less frequent, they do pose severe hazard to life and can create havoc on the immediate environment depending on the toxicity of the materials involved, terrain features and meteorological conditions and demography. During a sudden release of hazardous chemicals from a storage tank due to accidents or improper handling, the chemicals may quickly evaporate and form a large cloud of gas which may remain in the planetary boundary layer (PBL). Liquefied Petroleum Gas (LPG), appearing in various hazardous substances lists, can pose a significant vapour hazard, which may cause spontaneous combustion and explosion. This study considers accidental release of LPG and associated risks imposed on society by modelling their dispersion using ALOHA (Areal Location of Hazardous Atmosphere) air dispersion model and human vulnerability assessment using GIS. ALOHA can approximately calculate the area that would be affected by chemical hazards. In this study, using ALOHA, the five possible hazardous outcomes of LPG release are assessed. Mapping of threat zones associated with the accidental release of LPG is done with the help of Arc GIS.

KEY WORDS: *Hazardous material, ALOHA, BLEVE, Arc GIS, Population vulnerability, LPG*

I. INTRODUCTION

Improper handling and accidental release of hazardous chemicals pose serious public health hazards. The intensity of such accidents depends on the nature of release, toxicity of the material, population density and meteorological factors. LPG is one of such chemicals, which can create a significant vapour hazard. The common LPGs in general use are commercial propane, comprising predominantly propane and/or propylene, and commercial butane [1]. There are several studies which focused on an estimation of risks posed by LPG and other hazardous materials during transportation by road [2, 3, 4]. Although the accident from a storage facility is extremely rare, the explosion in IPCL Gas Cracker Complex at Nagothane in Maharashtra, in 1990 [5] and Vapour Cloud Explosion of HPCL refinery at Vishakhapatanamin 1997 are unforgettable incidents [6]. Both the accidents caused the death of more than 50 people each. Previous accidents reveal that, since the accidents are unpredictable, advance identification of potential risks arising due to sudden release of hazardous chemicals from storage facility is essential for reducing loss of life and minimize damage to property and environment. This study is focused on assessing the risks and vulnerability of population around a hazardous material storage.

To assess the population vulnerability, suitable methodologies and tools are integrated in this study. Vulnerability has been defined in various ways such as the threat of exposure, the capacity to suffer harm and the degree to which different social groups are at risk [7, 8]. In this study, vulnerability is assessed by the population which is at risk during an accidental release of LPG. Zhang et al, [4] assessed the risk imposed on human population during the transportation of hazardous material using a two–step process of modeling their dispersion and combining its results with the population distribution. In this study, to assess the population which are at risk, various hazard scenarios created by accidental release of LPG from the storage facility was modeled using ALOHA and the most dangerous one among them is identified for detailed analysis in the study area. This result is used for the estimation of population in the vulnerable area around the facility. Li et al [9] developed a conceptual model of human vulnerability to chemical accidents and proposed a GIS (Geographical Information System) based methodology for mapping the human vulnerability. Cutter et al, [7] in their study, population density was used to reflect relative human vulnerability in an urban area. The knowledge of land use pattern surrounding the hazardous storage facilities as well as other relevant geographical details required for emergency management using GIS helps in rapidly identifying the area at risk at a glance, and is also very helpful for making effective response and decisions for administrators and emergency managers [10].

II. STUDY AREA

Ernakulam District is the industrial hub of Kerala State in south India, where a number of Major Accident Hazard (MAH) chemicals are handled regularly. The LPG bottling plant, operated and managed by Indian Oil Corporation, is located between 9^0 53' 35" N latitude and 76^0 22'30" E longitude at Udayamperoor GramaPanchayat (Figure 1), which is a densely populated village. The adjoining Panchayath near to this installation is Mulanthuruthy which is also populated similarly. Total population of Udayamperoor and Mulanthuruthy Panchayaths is 29,523 and 19,417 respectively. A unique feature of the Kerala is that it is a continuously populated region with varying densities of population, which adds to the vulnerability during major hazards.

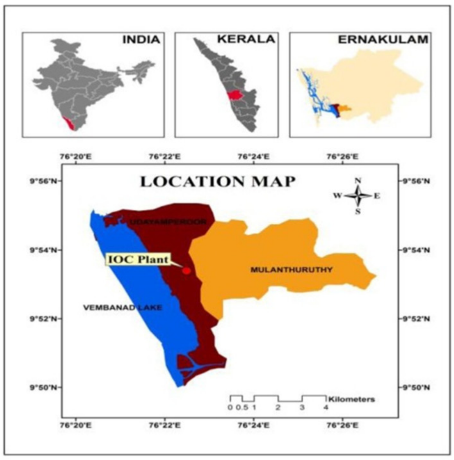

Figure 1: Study area map

III. MATERIALS AND METHODS

Information about the storage facilities and possibilities of LPG leaks was collected from the plant administrators as well as concerned Government departments. Other secondary data regarding the distribution of population was collected from Panchayat authorities. Land use pattern and regional boundaries were determined from toposheets as well as Google Earth. For assessing the risk imposed on population by an accidental release of LPG from a storage facility, the following methodologies were adopted:-

1. Analysis of various hazardous outcomes of an accidental LPG release using ALOHA; The threat zone distance, gas concentration and thermal radiation due to an accidental LPG release is modelled for five possible hazardous outcome scenarios. The most dangerous scenario among them is identified and its threat zone distance was overlaid on the actual location map given by Google Earth.
2. Assessment of vulnerable area within the threat zone using Arc GIS 9.3 software; Populated areas coming under the threat zone was demarcated using GIS. The geostatistical analyst tool in GIS provides necessary information about the population distribution pattern of the area surrounding the plant.

3.1. Areal Location of Hazardous Atmosphere (ALOHA)

ALOHA dispersion model is a Gaussian Plume model, which was developed and is supported by the Emergency Response Division (ERD) within the National Oceanic and Atmospheric Administration (NOAA) in collaboration with the Office of Emergency Management of the U. S. Environmental Protection Agency (EPA). It is a part of the CAMEO software suite, a system of software applications used widely to plan for and respond to chemical emergencies. ALOHA employs Levels of Concern (LOC) to address the impact of toxic air plume, fires and explosion on human population. LOCs for toxic inhalation hazards are specific to the chemicals. Thresholds for inhalation toxicity are extracted from CAMEO chemicals. Acute Exposure Guideline Levels (AEGLs) are public exposure guidelines, which are developed for accidental chemical release events, are stored within the data files integrated into ALOHA. ALOHA's threat zone represents the area within which the ground level gas concentration exceeds the level of concern at any time [11]). There are several studies focusing on the consequences of accidental release of LPG using ALOHA [12, 13].

3.1.1. Hazard and Scenario Analysis by ALOHA

Basic data fed into the ALOHA model and the assumptions taken for predicting the damage potential of LPG are the following.

Location

Udayamperoor
Latitude $9^0$53' 35"N Longitude 76^0 22'30" E

Chemical data

Name; Propane
Molecular weight; 44.10 g/mol
Ambient boiling point; -42.0 ^{0}C
Vapour pressure at Ambient Temperature; greater than 1 atm

Atmospheric data

Wind; 2 m/s from west-south west (WSW) at 10 meters height during day time
Ground roughness; open country
Stability class: B (slightly unstable)
No inversion height
Relative humidity: 75%

Source strength

In the present case, a leak from a hole of 10 cm in diameter is considered. An accidental tank explosion, which is highly unlikely, will be considerably more hazardous.

Tank diameter: 3.5 meter
Tank volume : 312 cubic meters
Chemical mass in tank: 150 tons
Internal temperature: 29^0 C
Tank contains liquid
Tank is 85% full

3.2. Geographical Information System (GIS)

GIS is an effective tool to deal with spatial data. In this study, Arc.GIS 9.3 software is used to display the threat zone over the spatial land use pattern. The geostatistical analyst in spatial analyst toolbox of Arc.GIS 9.3 provides tools for viewing the population distribution pattern in the threat zone area.

The combined use of GIS and ALOHA is used for vulnerability assessment. The information provided by both the software, like the hazard consequence area (affected area), the populated area within this threat zone etc are considered for vulnerability assessment. The density of population in the area is also taken into account.

IV. RESULT AND DISCUSSION

There are 10 LPG bullet tanks installed in this plant (7 tanks with 150 MT capacity each and 3 tanks with 100 MT capacity each) with a combined capacity of 1,350 metric tons. Usually, the tanks are filled about80% to 85 % making the total storage more than 1,000 MT at any point of time. The LPG contained in only one tank (150 MT) is considered for the prediction of hazard in the ALOHA model.

If a flammable and toxic chemical is released, but does not immediately catch fire, a vapour cloud will form and multiple hazards are likely to occur depending on the meteorological conditions, release pattern of the chemical etc. The leak of LPG from a storage tank can be a jet fire (if the hole is only a puncture), flash fire (when the vapour cloud catches fire), vapour cloud explosion (when the cloud explodes) or Boiling Liquid Expanding Vapour Explosion (BLEVE) [8]. LPG, even though slightly toxic, is not poisonous in vapour phase, but can however, suffocate when in large concentration due to the fact that it displaces oxygen [14].

4.1. Scenario Analysis using ALOHA

Depending on the nature of LPG release, five possible hazardous outcomes mentioned above are graphically represented below predicted using ALOHA.

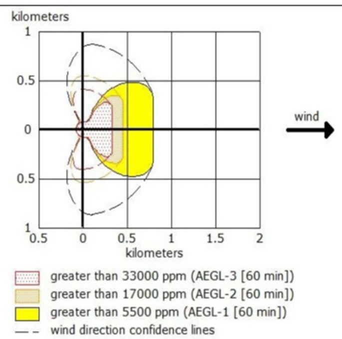

Figure 2: Toxic Area of Vapour Cloud

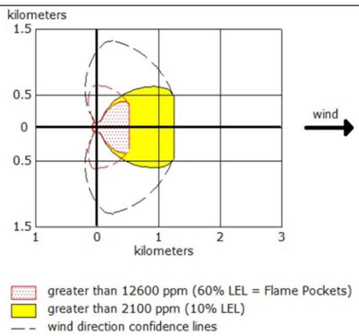

Figure 3: Flammable area of vapour cloud

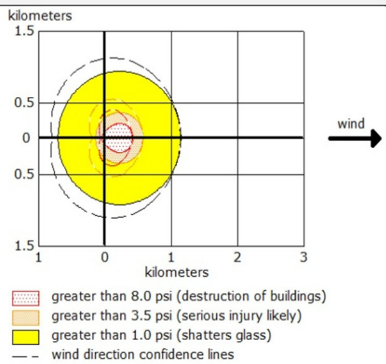

Figure 4: Blast Area of Vapour Cloud

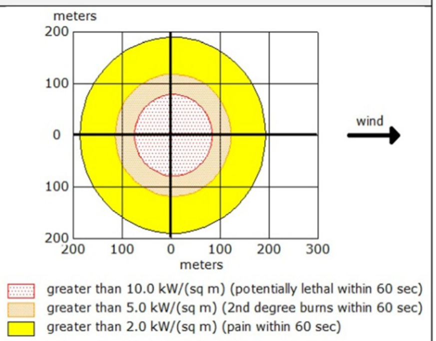

Figure 5: Thermal radiation threat zone(jet fire)

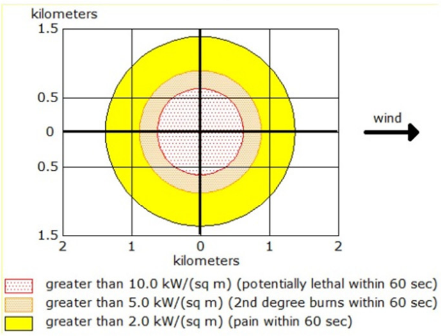

Figure 6:. Thermal radiation threat zone (BLEVE)

Table I shows the result of scenario analysis and its potential hazard distance. The result shows that the thermal radiation effect by BLEVE of LPG is very hazardous. Compared to other scenarios BLEVE is the most effective and dangerous hazard associated with failure of LPG storage tank as it has thermal radiation effect even on short exposure in a short duration. Besides, the area that would be affected by BLEVE is comparatively large and within a short span of time it has the potential to destroy large area. The explosion in one storage tank may trigger a secondary accident in a nearby tank, which in turn may lead to a tertiary accident, and so on. Hence, the probability of such chain of reactions (domino effect) is to be considered for hazard management. The area that would be affected by BLEVE from only one tank (150 MT) is only considered in this study for the estimation of vulnerable population. The domino effect has to be considered separately.

4.3 Assessment of Population Vulnerability

Figure 7 shows the thermal radiation threat zone created by BLEVE which is overlaid with the actual location given in the Google Earth. The maximum societal risk estimated up to a distance of 1300 m from the point of leakage is plotted in the figure.

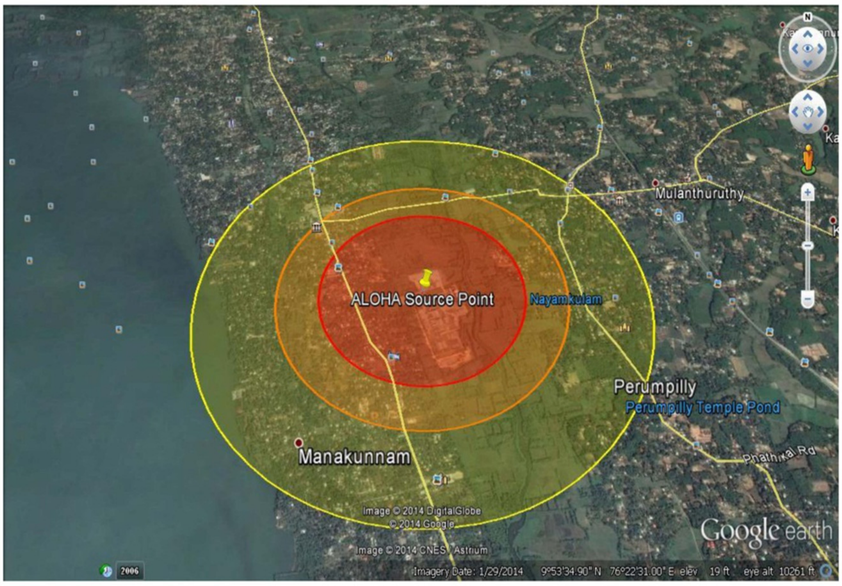

Figure 7: Threat zone overlaid on Google Earth Map

Considering the location of the industry and the threat zone distance, it is clear that the most seriously affected region at the time of accident will be the area coming under Udayamperoor and Mulanthuruthy panchayaths. Hence, the entire area coming under these two panchayaths is taken for the vulnerability study. Both the panchayaths together has a combined area of 50.32 km^2. From the land use classification of the area (figure 8) it is clear that out of the total area of the panchayaths, settlements cover 23.678 km^2 and the remaining portion is comprised of water body and various vegetations including agriculture.

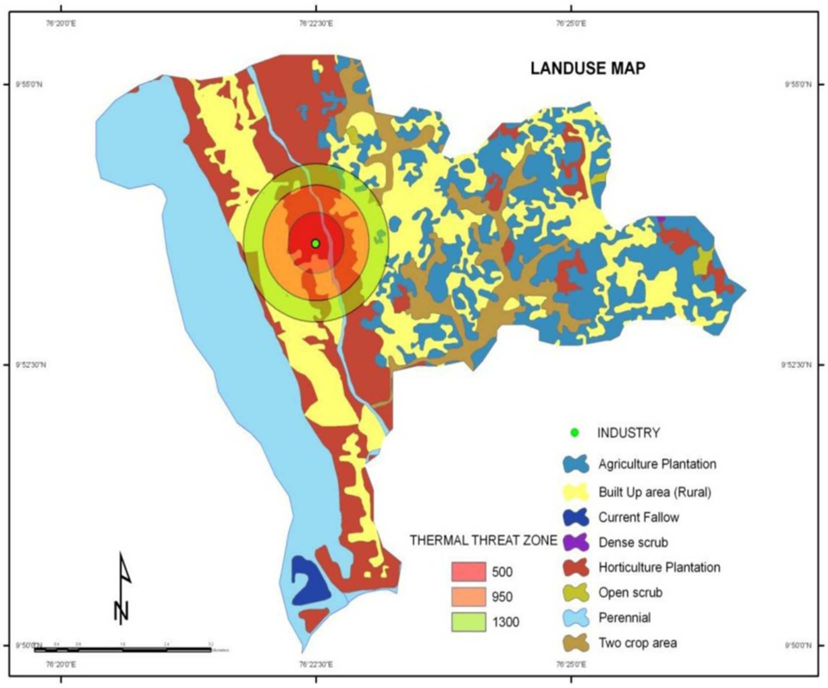

Figure 8: Land use classification map

When the area of settlements is taken in to account, the population density in total built up area is estimated to be 2039 per km^2. The estimated population coming under each threat zone based on population density is given in table II. People coming under the red threat zone (0.785 km^2surrounding the plant), may experience thermal radiation of 10 kw/m^2. It is potentially lethal. Orange threat zone covering 2.04885 km^2 and thermal radiation effect is 5.0 kw/m^2 which can cause 2^{nd} degree burns. In the yellow threat zone (2.47275 km^2) people may experience severe pain due to thermal radiation effect of 2.0 kw/m^2.

Table II: Estimated population at each threat zone

Threat Zone	*Estimated area of settlements in each zone (km^2)*	*Population in the Threat zone*	*Health effect*
Red	0.083136	169	Potentially lethal
Orange	0.801252	1633	2^{nd} degree burn
Green	0.951252	1939	Pain

The spatial illustration of the hazardous area can provide the responders essential information such as the definite location of chemical plant and its surrounding land use pattern which will be helpful for identifying the areas which must be evacuated urgently in case of a hazard. Information such as the hazard distance, its effect at each zone etc. can be linked to population distribution pattern (Figure 9). Also, it helps the planners in keeping a buffer zone around the plant without human inhabitation.

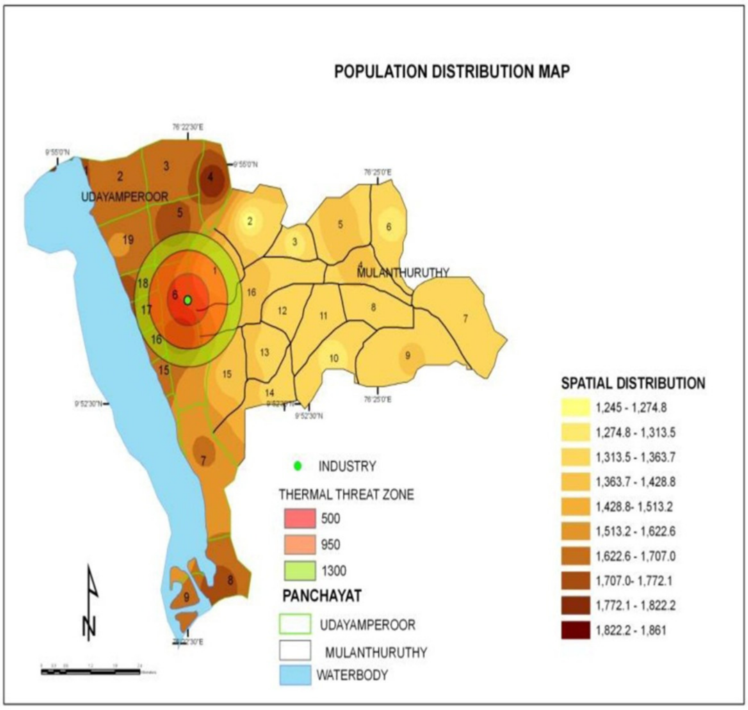

Figure 9: Population distribution pattern

In this study, application of GIS is utilized for illustrating the population vulnerability. For the effective management of a chemical emergency, the responders need to know enough geographical information.

V. CONCLUSION

In this study, two conceptual models (ALOHA and GIS) are overlaid to understand the vulnerability of neighbouring population in case of an accidental release of LPG are presented. ALOHA predicts the area that can become hazardous due to different hazard scenarios created by the accidental release of LPG. Comparing the five possible outcomes of LPG release, it can be concluded that BLEVE is the most dangerous one among them. Secondly, using the tools provided by GIS helps in assessing the spatial extent and land use pattern of the area under threat. Combing these two approaches, the specific population that are likely to be affected are identified. Such an integrated approach will be an essential and useful tool for assessing the vulnerable area around hazardous industries for the response team including industrialists, risk experts, District Crisis Groups (DCG) etc. to manage an emergency situation including timely evacuation of people. This system is helpful not only during actual emergency situation but also during pre-emergency state for planning and mock trials of major chemical emergencies so that the number of causalities can be minimized. At present, formulation of prevention and mitigation strategies and mock drills to face chemical disasters are confined within the industries with strict regulations and safety audits. People living outside the industries are usually unaware of the occurrence of the accident as has happened in the case of Bhopal Gas Tragedy. And the resulting panic also causes avoidable injuries and death. Since the accidents are unpredictable and sudden, it is very important to maintain a sufficient buffer zone around all hazardous chemical industries without any human inhabitation.

VI. ACKNOWLEDGEMENT

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Research article

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

N.S. Anjana*, A. Amarnath, M.V. Harindranathan Nair

School of Environmental Studies, Cochin University of Science and Technology, Kochi, Kerala, India

A R T I C L E I N F O

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A B S T R A C T

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

* Corresponding author. School of Environmental Studies, Cochin University of Science and Technology, Kochi 22, Kerala, India.
E-mail addresses: renjuanjanas@gmail.com, ses@cusat.ac.in (N.S. Anjana).

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0301-4797/

(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

emergency response personnel estimates of the spatial extent of chemical hazards (Robert et al., 2013). 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 Arc map. The information that is provided by the integrated application of ALOHA and GIS is functional in a real time emergency management. Compared to other software programs, ALOHA is very easy to run and give fast estimation of 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. If a lighter gas such as ammonia, when 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 gets suspended in the lower atmosphere. In such cases ALOHA considers the gas to be heavy. Heavy gas dispersion calculation used in ALOHA are based on DEGADIS model (Dense Gas Dispersion model) (Havens Jerry and Thomas, 1985; Spicer and Hevens, 1989)

To estimate the rate at which the chemical is released in to the atmosphere, the model evaluates various factors such as phase released (liquid, gas, or mixed phase), the driving pressure, and the nature of rapture of 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 release and the ambient atmospheric conditions at the time of accident (Anandita, 2007). 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. Data summary required for ALOHA modeling are given below.

3.2.1. Chemical data

Chemical name: ammonia
Molecular weight: 17.03 g/mol.
Ambient boiling point : -33.4^0C
Vapour pressure at Ambient Temperature: >1 atm.
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

3.2.2. Weather information

Atmospheric conditions prevailing at the time of accident influence the dispersion of toxic cloud (Chakrabarti and Jigisha, 2011). The factors significantly affecting the dispersion of gas clouds are velocity and direction of wind and atmospheric turbulence (Inanloo and Tansel, 2015). Though temperature and humidity have less effect, thermal inversion plays a decisive role in the dispersion of heavy gas clouds in the atmosphere (Joaquim, 2008). But, a heavy gas cloud, in contrast, lingers close to the ground as it disperses, and is not normally affected even by low-level inversions. Since it is not possible to predict the time and prevailing atmospheric conditions at the time of accident, four different scenarios were considered in this study to model the dispersion of ammonia so that the variations in the affected areas can be understood. Four scenarios selected in different weather conditions are given below in Table 2.

Stability class has a big effect on ALOHA's prediction of the threat zone size in the dispersion scenarios. To choose the stability class, ALOHA uses wind speed and cloud clover, solar insolation (NOAA and EPA, 2007). Based on these factors, the choice of stability classes of ALOHA for the above atmospheric conditions are E, C, D, and B for scenario I, II, III, and IV respectively. The explanation of each class is given in Table 3.

The stability classes are based on Pasquill's six stability classes, classes A to F, to represent different degrees of atmospheric turbulence (Pasquill, 1961). Here D represents a neutral stability condition, in which turbulence generated by the wind may cause the clouds to disperse to a larger distance from the source of release. E represents a stable atmosphere, in which a cold layer of the atmosphere settles near the ground in which vertical mixing is inhibited. B and C are associated with unstable atmospheric conditions occurring when sun's radiation heats up the ground resulting in the gas clouds dispersing along with the characteristic updrafts and downdrafts. Stability class B is moderately unstable and C is slightly unstable.

3.2.3. Topography

Topography of an area plays a very vital role in the dispersion of contaminants. It affects the velocity field and turbulence as the wind moves around and over these features. ALOHA accommodates only three options as input for topography regarding ground roughness such as 'Open country', 'Urban or Forest', and 'Open Water'. The present study consider 'Urban or forest' option.

3.2.4. Source strength

Source parameters of the chemical's escape into the atmosphere are as follows.

Tank type: vertical cylindrical tank.
Chemical mass in the tank: 10,000 tons.
Tank orientation: Length: 14 m.
Diameter: 38 m.
Volume: 15.878 cubic meters.
State of chemical: Liquefied gas.
Internal temperature : -33.2^0C

Table 2
Weather data used for Modeling Source: Indian Meteorological Department.

Atmospheric Parameters	Winter		Summer	
	8.30 a.m.	5.30 p.m.	8.30 a.m.	5.30pm
	Scenario 1	Scenario II	Scenario III	Scenario IV
Wind Speed	1.9 m/s	5 m/s	1.3 m/s	5 m/s
Temperature	22.8 0 °C	31.0 0 °C	25.6 0 °C	32.2 0 °C
Humidity	78%	66%	85%	75%

Table 3
Explanation of stability classes.

Stability classes	Atmospheric condition
B	Moderately unstable
C	Slightly unstable
D	Neutral atmosphere
E	Stable atmosphere

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Table 4
Areal distribution of land-use classes.

Sl No	LULC class	Area (km^2)
1	Water body	13.25
2	Vegetation	30.29
3	Built up	85.34
4	Vacant land	2.24
5	Industrial area	3.10

3.2.5. Assumptions considered for the study

In normal case, accidental release of ammonia from a storage tank is usually due to equipment failure, such as a ruptured vessel or improper positioning of valves. Improper positioning of valve is considered here for ammonia release. It is assumed that the chemical escapes into the atmosphere through a pipe connection during the loading or unloading operations. The pipe connection of the storage vessel is 2 inches in diameter and it is assumed that 100% of it is the hole diameter through which the chemical is released into the atmosphere.

3.3. Assessment of vulnerable population due to the toxic impact of ammonia 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, surrounding land use, and the vulnerable location susceptible to damages. To estimate the vulnerable population, the population likely to come under the threat zone of ammonia toxicity, a number of GIS database layers were prepared. The layers prepared are LULC (Land use - Land cover) of study area, administrative ward boundaries, population distribution pattern of each ward and layer of threat zone.

LULC classification of the study area with minimum number of classes essential for dasymetric analysis were derived from IRS Resourcesat 2 LISS 4 satellite imagery and were subjected to Maximum likelihood classifier algorithm for supervised classification of the satellite data. LULC Classes used are Populated area, Water body, Vegetation, Vacant land and Industrial area. Industrial area was demarcated with the aid of previously prepared vector layer of Eloor industrial zone. Image classification accuracy were assessed using error matrix method and has shown an accuracy of 92.4%. Areal distribution of different land-use classes are given in Table 4.

All administrative boundaries were demarcated using the Panchayath map as the base map and were verified with ground truthing. Attributes of population number in each ward were then incorporated within the administrative boundaries to prepare raster layer of ward-wise population. All the layers prepared were then analyzed using dasymetric mapping method (Eicher and Brewer, 2001) to prepare population distribution map. After

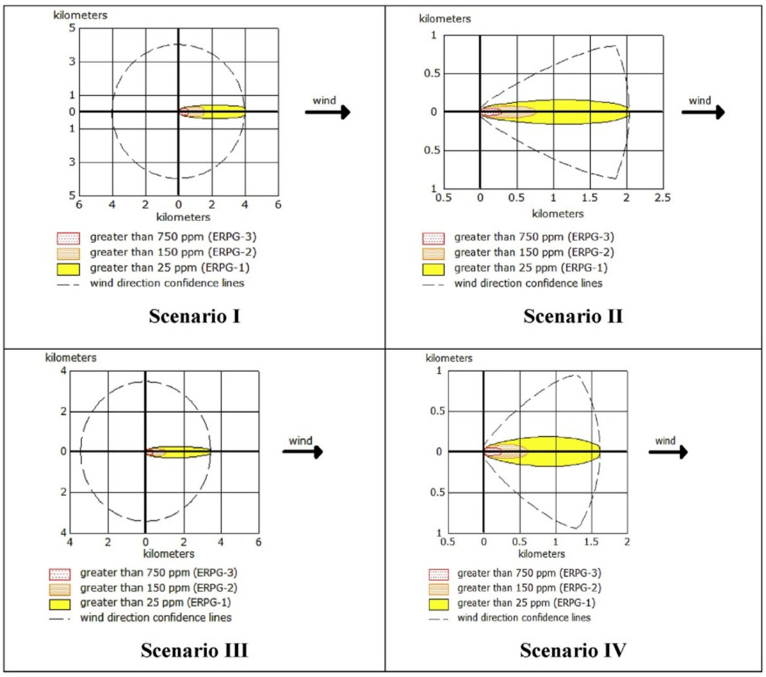

Fig. 1. (Scenarios I and II represent the spatial extent of ammonia release at 8.30 a.m. and 5.30 p.m. in winter and Scenarios III and IV represent the spatial extent at 8.30 a.m. and 5.30 p.m. in summer).

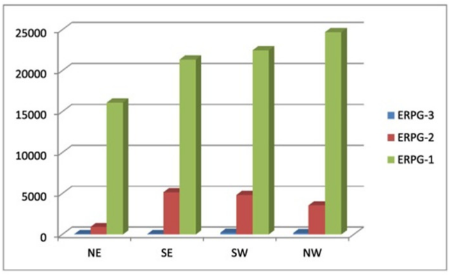

Fig. 2. Comparison of Vulnerable Population at directions around the Ammonia Storage Facility.

deriving the population distribution pattern in the study area, areal interpolation method were used to estimate the population coming under the threat zone (Chakraborty and Armstrong, 1996). Then the analytical capabilities of GIS were used to provide a clear estimate of the population inside the threat zone, which can be expressed as follows.

$$\textbf{POP} = \sum_{i=0}^{n} Pi + \sum_{j=0}^{m} (Pj*aj'/aj)$$

Where,

- ***n***: number of ward entirely enclosed by the footprint (whose boundaries may not coincide with the impact zone boundary)
- ***Pi***: population of a ward entirely enclosed by the footprint. $i = 0,1,2,3 \ldots\ldots\ldots\ldots, n$
- ***m***: number of wards partially contained within the footprint (whose geographical boundaries do not entirely coincide with the footprint boundary)
- **Pj**: population of the ward partially contained the footprint; $j = 0,1,2,\ldots,m$
- ***aj***: total area of populated region of partially contained wards (calculated from the GIS laduse classification layer)
- ***aj'***: area of populated region of partially contained wards that is enclosed within the footprint;

The complete methodology used in this study is summarized in the following Flow chart 1

4. Result and discussion

4.1. Risk assessment using ALOHA

The double-walled, double-integrity refrigerated ammonia tank located in Eloor industrial area is considered as the potential source of ammonia release in this study. If ammonia is accidently released into the atmosphere, the immediate danger associated with it is the toxic inhalation hazard. Modeling of toxic inhalation hazards of ammonia, considering four different atmospheric conditions, were done and the results are given below.

ALOHA employs levels of concern (LOCs) to address the toxic inhalation hazards on human population. LOCs are concentrations of airborne chemicals associated with adverse health effects and it is specific to chemicals. ERPGs' (Emergency Response Planning Guidelines), public exposure guidelines, developed for accidental chemical release events stored within the data files of ALOHA is used in this study for LOC. ERPGs estimate the chemical concentrations at which people may begin to experience some form of health effects if they are exposed to that hazardous airborne chemical for 1 h [31].

The area where there is a possibility of exposure to toxic vapors is represented graphically as threat zone. Each zone represents the area within which the ground-level exposure exceeds the level of concern (LOC) at some time after the beginning of a release. The threat zone contour runs through points where the maximum concentration of ammonia equals the LOC. The graphical representation of four scenarios is given in Fig. 1.

All scenarios are graphically represented in Fig. 1. In all the scenarios in Fig. 1, 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 ERPG values such as ERPG-3, ERPG-2, and ERPG-1. ERPG-3 is the maximum airborne concentration, 750 ppm, considered as the worst-case level, above which there is a possibility of experiencing life threatening health effect or death. The concentration of chemical in second level, ERPG-2, is taken as 150 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 ERPG-1 level identifies the concentration 25 ppm, which is noticeable due to odor, discomfort and irritation. Below the maximum airborne concentration level predicted in each zone (ERPG-1, ERPG-2, and ERPG-3) the people could be exposed for up to 1 h without experiencing any adverse health effect.

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 result of ALOHA modeling of ammonia leak in four 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 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 winter than in summer. When time of occurrence is taken into account, it is observed that the morning time is more dangerous than the evening time as it shows the larger impacted distance. The study also indicate that the stable atmospheric condition, E, is the most

Table 5
Impacted distance of toxic hazard of ammonia from the source of leakage.

Toxic Levels of Concern	Concentration levels	Affected distance from the source of leakage			
		Winter		Summer	
		Scenario I 8.30 a.m.	Scenario II 5.30 p.m.	Scenario III 8.30 a.m.	Scenario IV 5.30 p.m.
ERPG-3	>750 ppm	579 m	309 m	375 m	257 m
ERPG-2	>150 ppm	1.5 km	780 m	1.1 km	625 m
ERPG-1	>25 ppm	4.0 km	2.1 km	3.5 km	1.6 km

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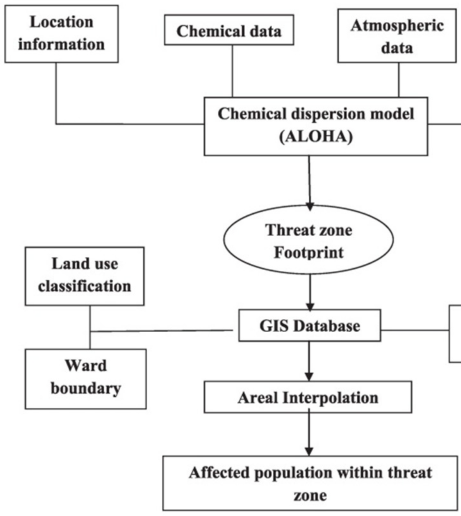
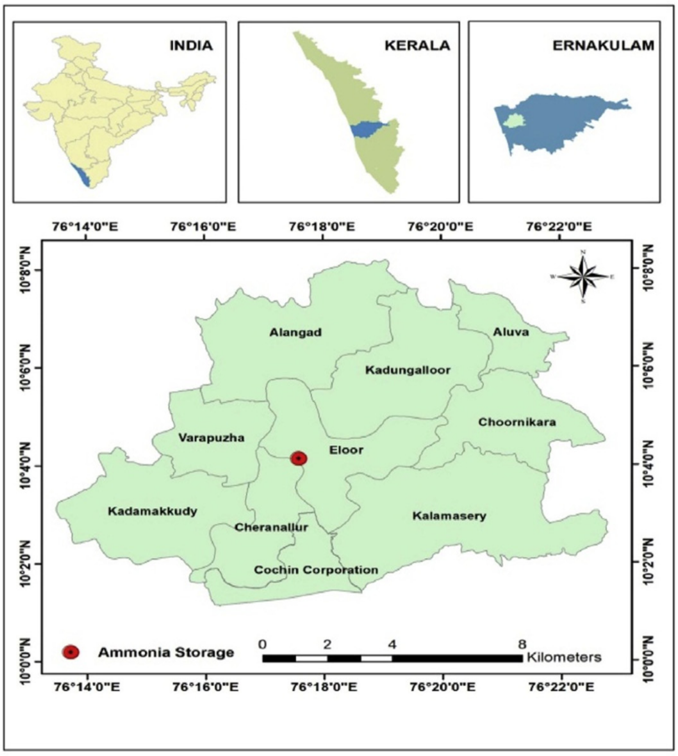
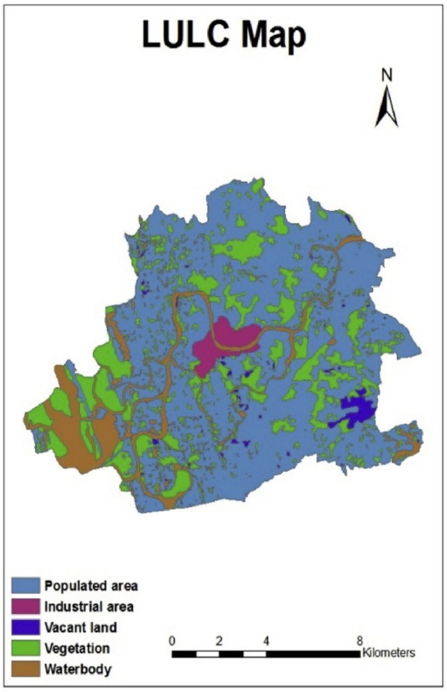


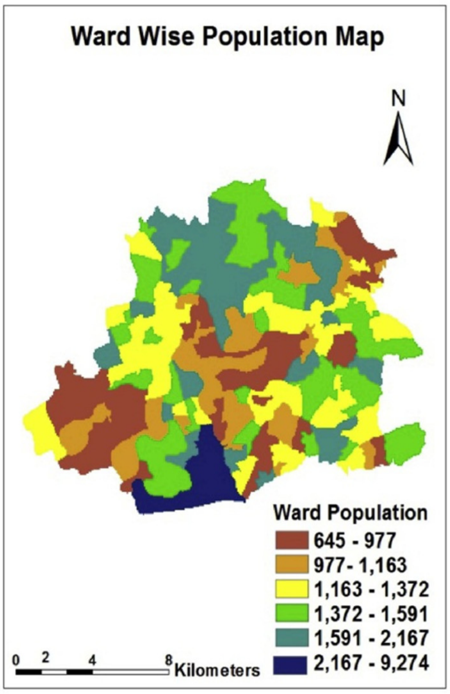
Map 1. Study area.



Map. 2. LULC of the Study area.



Map.3. Population of each ward in the study area.



Map 4. Population concentration or distribution over the study area.

dangerous in the case of chemical spill because the toxic vapour cloud of ammonia is readily dispersed far from the source of release resulting in large number of people being exposed to higher risk. The numerical representation of Fig. 1 is given in Table 5, which gives a clear idea of how the impacted area change with time and season.

Of the four scenarios, the maximum impacted distance is observed in scenario-I, 4 km from the source, based on weather condition. In the case of Scenario II, III, and IV the impacted distance is 2.1 km, 3.5 km and 1.6 km respectively. The risk associated with impacted area of ammonia is dependent upon the population which is likely to come under the threat zone.

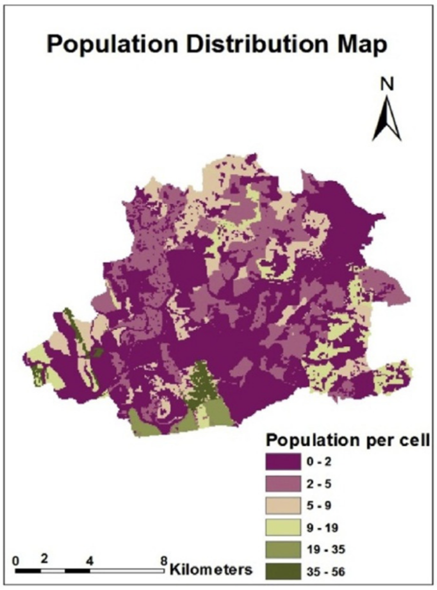
4.2. Population vulnerability assessment

For reducing injuries, causalities and death, it is necessary to assess the human vulnerability in the residents of industrial area [32]. The result of modeling of four scenarios under different atmospheric conditions indicates that the weather conditions have a significant role in the occurrence of impacted area of chemical hazard. Nobody can predict an occurrence of an accident or the time and prevailing weather conditions. Therefore, in this study the maximum hazardous distance, 4 km from the source, obtained for scenario-I is considered as the worst case scenario. For assessing the population under threat, this worst case is taken into account.

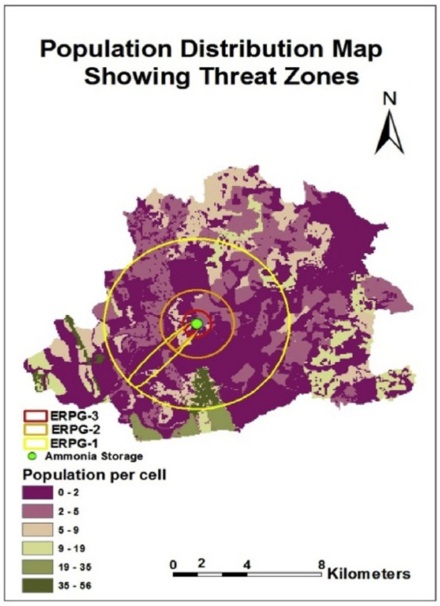
As mentioned above in the methodology section, different layers prepared with the help of GIS for estimating the vulnerable population is illustrated in maps given below. Map 2 shows the LULC pattern of the study area and Map 3 illustrates the population characteristics in each ward of the area.

Out of the total area selected for the study, 64% of the land is covered by residential and commercial sectors. If this populated area is taken into account, the population density in the area is approximately 2465 people per km^2. LULC pattern and human demographic data were superimposed to generate a population distribution map to estimate the number of people coming under each threat zone (Map 4). Threat zones for the worst case scenario were then overlaid on this map to give a clearer picture at a glance to show where the more number of people are clustered in each threat zone (Map 5).

In the Map 5, the threat zones are in SW direction of the source. When hazardous chemical are released into the atmosphere, the wind carries the toxic clouds and dispersion take place in its direction. Therefore, the vulnerable population will be in the direction of wind. As it is not possible to predict the wind direction, which is usually calm in winter mornings, at the time of accident, the population vulnerability assessment within a 4 km radius around the source of ammonia leakage is taken into account. The 4 km radius around the plant is divided into four directions (NE, NW, SE, and SW) and the number of people likely to come within



Map 5. Threat zones overlaid on the population map.



Flowchart.1. Conceptual framework used to estimate population under threat due to ammonia leakage.

each direction is estimated separately with the help of analytical capabilities of Arc GIS. The result of estimation of vulnerable population is given in Table 6.

The areal interpolation method gives a clear estimate of the vulnerable population, which need immediate protection in case of a chemical accident. The numbers of affected population in each ERPG level help to take an immediate action for site-specific evacuation. When a chemical emergency occurs, the first priority is always given to life safety. When considering ERPG level-3, more people are likely to be impacted if the toxic clouds are moving in SW direction. In ERPG levels-2 and 1, more number of people are affected in NW direction and SW directions respectively. This data can be used by the emergency planners to know how much population should be immediately evacuated from the toxic cloud moving direction at the time of accident. Fig. 2 represent the comparison of vulnerable population at different directions around the ammonia storage facility.

The result shows that if the toxic clouds are moving in NW direction of the storage, more number of people will be vulnerable than if the wind is towards other directions because of higher population density in this direction.

As it is difficult to relocate the ammonia storage facility to less populated areas, to mitigate the potential risk, building of high enough protective walls around the storage facility can prevent the dispersion of ammonia by inhibiting the wind effect. Added to this, if automated water spray nozzles are installed, controlled by ammonia detectors, the risk can be effectively reduced because ammonia is soluble in water and hence air-borne pollution can be avoided. These solutions can be much more economical than the relocation of the storage facility to some sparsely populated areas. Also, such practically and economically viable solutions can be effective in preventing disasters in case of accidental releases of ammonia.

5. Conclusion

In this study, the main focus was on assessing the extent of hazard areas in case of accidental release of ammonia under different atmospheric conditions and an assessment of likely-to-be affected population. 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 ammonia vapour, the threat zone was found to extend to an inhabited area of 4 km in the case of worst case scenario.

The Analytical capabilities of GIS provide an overview of how much population need to be evacuated from the area in case of an emergency. 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 an effective preparedness and timely evacuation after an accident. This

Table 6
Vulnerable Population in different directions around Ammonia Storage Facility.

Toxic Levels of concern	Concentration Levels	People likely to be affected in different direction of wind				Expected Impact on People
		NE	SE	SW	NW	
ERPG-3	>750 ppm	Workers in the industries	50	200	161	Life threatening health effects or death
ERPG-2	>150 ppm	925	5160	4825	3550	Experiencing significant adverse health effects
ERPG-1	>25 ppm	16,114	21,364	22,486	24,701	Does not pose a health risk but may be noticeable due to odor, discomfort, irritation.

Note. NE- North East, SE- South East, SW- South West, NW- North West

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.

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