Industrial Risk Assessment for Planning and Emergency Response: A case of Ahmedabad

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Industrial Risk Assessment for Planning and Emergency Response:
A case of Ahmedabad

by

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Abstract

A problem related to industrial hazards is that diversification of risk type has increased in recent times. People staying nearby industrial estates in developing countries are more vulnerable, particularly in the absence of governmental facilities to cope with disasters.

It is extremely important to study and evaluate risks related to industrial hazards for people living near industrial estates.

Odhav industrial estate with in the Ahmedabad city limit is selected for study and risk assessment is carried out for 5 Major Accident Hazard (MAH) industries. Possible industrial hazards from chemical storage are identified and hazards foot prints prepared using Arial Locations of Hazardous Atmospheres (ALOHA). Spatial and temporal population distribution is carried out from Traffic Analysis Zone (TAZ) to building level, considering the building characteristics and total floor area. Risk was estimated for day and night time scenario by deterministic approach.

Fire, explosion and toxic gas leakage are three kinds of industrial hazards from LPG, Chlorine and Parathion-methyl in the study area. Population vulnerability is higher for night time scenario than during day time. Risk estimation shows that release of chlorine at industry 2 for wind speed of 1.5 m/s blowing from NW direction has the highest risk. Maximum numbers of people who need hospital treatment is 1300, while another 47 risk death for such an event during night time. Numbers of people below the age group of 6 years are likely to be affected. Maximum number of houses is likely to be affected under the R1 (Slum) and R2 (Low class) housing. Poor people are at higher risk than others.
However, risk values for study area are lesser than anticipated since the hazard foot print and study are have lesser overlap.

Keywords: Industrial hazards, Risk Assessment, Emergency response, Ahmedabad Disasters

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Table of contents

1. Introduction ... 1
1.1. Back ground ... 1
1.2. Research problem ... 1
1.3. Research aim ... 3
1.4. Research objective ... 3
1.5. Research question ... 3
1.6. Research approach ... 4
1.7. Research methodology ... 4
1.8. Research significance ... 6
1.9. Scope and Limitation ... 6
1.10. Expected out come of the study ... 6
2. Literature study: Industrial Hazards and Risk Assessment ... 7
2.1. Introduction ... 7
2.1.1. What is a hazard? ... 7
2.1.2. Classification of hazards ... 7
2.2. Risk Assessment ... 8
2.3. Risk categorisation ... 9
2.4. Risk assessment method ... 10
2.5. Selection of Method ... 11
2.6. Method used and justification ... 12
2.7. Dispersion modelling in ALOHA ... 13
2.7.1. Gaussian model ... 14
2.7.2. Heavy gases ... 15
2.8. Types of fire and explosion modelling in ALOHA ... 15
2.8.1. Fire ... 15
2.8.2. EXPLOSION ... 17
2.9. Salient feature of ALOHA ... 19
2.10. Elements at risk ... 20
2.11. Vulnerability assessment ... 21
2.12. Industrial accidents in India ... 21
2.13. Industrial policy in India ... 22
2.14. Initiative taken by Government of India ... 22
3. Case Study area: Ahmedabad City ... 24

3.1. Introduction: Mega city Ahmedabad also known as Karnavati .. 24
3.2. Ahmedabad profile ... 24
3.2.1. Geographical location ... 24
3.2.2. Climate ... 25
3.2.3. Land use pattern ... 26
3.3. Gujarat Industrial policy 2003 ... 26
3.4. Agency Involve in Industrial activity ... 26
3.5. Industry at glance in Ahmedabad ... 27
3.5.1. Industrial Development in Ahmedabad ... 27
3.5.2. Industrial estate in city ... 28
3.5.3. Hazardous industry in Ahmedabad ... 28
4. Data description and handling ... 29
4.1. Data requirement ... 29
4.2. Data collection ... 29
4.2.1. Primary data collection and description ... 29
4.2.2. Secondary data collection and description ... 30
4.3. Data preparation ... 30
4.3.1. Updating building foot print ... 30
4.3.2. Updating building inventory ... 30
4.3.3. Preparation of estate map ... 30
5. Hazard assesemnt ... 32
5.1. Hazard idetification ... 32
5.2. Consequence scenario ... 33
5.3. Consequence analysis ... 34
5.3.1. Weather conditions ... 34
5.3.2. Worst case scenario ... 36
5.3.3. Weather condition for consequence analysis ... 36
5.4. LPG Hazard foot print ... 37
5.4.1. LPG Scenario 1 ... 37
5.4.2. LPG Scenario 2 ... 38
5.4.3. LPG Scenario 3 ... 39
5.5. Chlorine hazard foot print ... 41
5.5.1. Scenario 1 Chlorine ... 42
5.5.2. Scenario 2 Chlorine ... 43
5.6. Parathion-methyl ... 44

5.6.1. Scenario 1: Parathion- Methyl 45
5.6.2. Scenario 2 Parathion- Methyl 46
5.7. Result 48
6. Vulnerability Assessment 49
6.1. Population distribution 49
6.2. Calculation of population in individual buildings: 50
6.2.1. Gender and worker distribution 52
6.2.2. Age distribution 53
6.2.3. Temporal variation of population 53
6.3. Population distribution on road 53
6.4. Population vulnerability assesment 56
6.5. Summary 58
7. Risk assessment 59
7.1. Introduction 59
7.2. Risk estimation 59
7.2.1. Risk estimation for night time scenario 60
7.2.2. Risk estimation for day time scenario 61
7.3. Summary 61
8. Results and conclusions 62
8.1. Results 62
8.1.1. Risk value on population loss 62
8.1.2. Vulnerable population 62
8.1.3. Vulnerable building 64
8.2. Conclusion 65
8.3. Limitations of study 66
8.4. Recommendations 67
References 68

List of figures

Figure 1-1: Method flow diagram 5
Figure 2-1 : Gaussian distribution (left) and Gaussian spread (right). 14
Figure 2-2 : Figure Cloud spread as a result of gravity................................ 15
Figure 2-3: ALOHA user guide flowchart 20
Figure 3-1: Location map of study area 25
Figure 3-2 Growth pattern of Ahmedabad city from 1411 to 2000.............. 27
Figure 4-1: Building Foot Print Overlay on Google Earth ™ Image 31
Figure 4-2 : Plot level detail for GIDC Odhav 31
Figure 5-1: Location of MAH Unit 32
Figure 5-2: Wind rose diagram for year 2004, 2005 and 2007 35
Figure 5-3 : Hazard foot print for LPG: Scenario 1 (CASE 1)..................... 39
Figure 5-4 : Hazard foot print for LPG: Scenario 1 (CASE 2)..................... 40
Figure 5-5 : Hazard foot print for LPG: Scenario 2 40
Figure 5-6 : Hazard foot print for LPG: Scenario 3 42
Figure 5-7 : Hazard foot print for chlorine: Scenario 1................................ 44
Figure 5-8 : Hazard foot print for chlorine: Scenario 2................................ 45
Figure 5-9 : hazard foot print Parathion- Methyl Case 1.............................. 46
Figure 5-10 : Hazard foot print for Parathion- Methyl: scenario 1 47
Figure 5-11 : Hazard foot print for Parathion- Methyl: scenario 2 48
Figure 6-1 : Study area (ward and TAZ boundary)..................................... 50
Figure 6-2 : Land use classification for residential building........................ 51
Figure 6-3 : Population distribution in building at night time...................... 52
Figure 6-4 : Gender distribution of population in side the building............. 54
Figure 6-5 : Worker distribution of population in side the building 54
Figure 6-6 : Population distribution in building at day time 55
Figure 6-7 : Traffic flow along the road... 55
Figure 8-1: Risk value on population loss for night time scenario............... 62
Figure 8-2 : Gender and age distribution of people likely to be affected from hazards at industry 2... 63
Figure 8-3 : Gender and age distribution of people likely to be affected from hazards at Industry 3.. 63
Figure 8-4 : Gender and age distribution of people likely to be affected from hazards at industry 4... 63

Figure 8-5 : Categories for building likely to be affected from hazards at industry 2... 64
Figure 8-6 : Categories for building likely to be affected from hazards at industry 3... 64
Figure 8-7 : Categories for building likely to be affected from hazards at industry 4... 65

List of tables

Table 2-1: Hazard agent classification 8
Table 2-2 : Source Toxic Scenarios Fire Scenarios Explosion Scenarios in ALOHA. 19
Table 3-1 : Landuse distribution of Ahmedabad.. 26
Table 5-1: Possible hazard in study area 33
Table 5-2 : Possible scenario in study area 33
Table 5-3: Wind frequency distribution Frequency distribution wind 35
Table 5-4 : Effective distance for LPG hazards for scenario 1. 38
Table 5-5 : Effective distance for chlorine hazards for scenario 1 43
Table 5-6 : Effective distance for chlorine hazards for scenario 2 44
Table 5-7 : Effective distance for parathion - methyl hazard scenario 1...... 46
Table 5-8 : Effective distance for parathion - methyl hazard scenario 2...... 47
Table 5-9 : Effective distance of industrial hazards 48
Table 6-1 : Vulnerable population (night time scenario) 57
Table 6-2: Vulnerable population (day time scenario)................................ 58
Table 7-1 : Risk value for night time scenario. 60
Table 7-2 : Risk value for night time scenario 61

List of annexure

Annexure 1 : List of agency working for industrial activity in Gujarat state 71
Annexure 2 : List of major hazardous accidental unit in Ahmedabad city .. 73
Annexure 3 : Data required for study 76
Annexure 4 : Detail land use classification 80

1. Introduction

1.1. Back ground

Fire and release of toxic material are common in industrial accidents. These accidents resulted from human errors or technological failures during the storage, processing or transportation activity. The total deaths in such accident gradually increase with industrial development. Total number of people are death in such accident is higher in India, Mexico and Brazil then any other industrialized country (de Souza Porto and de Freitas 2003). India faces a greater problem due to rapid industrialization coupled with increase in population. India has already experienced Bhopal Gas tragedy, one of the worst industrial disasters in world. It was followed by another serious accident in the "process industry" which occurred on 14 September 1997 at the petroleum refinery of Hindustan Petroleum Corporation Limited (HPCL) at Vishakhapatnam, India (Khan and Abbasi 2001).

Industrial accidents are type of technology hazard. Walker define technology hazards as "*the storage or use of hazardous substances where in the event of a major accident and release of toxic, explosive or flammable materials local people and the nearby environment could be seriously affected* "(Walker, 2000). The risk related to industrial technology of risk is now more serious and diversify compared to past (Tixier, Dusserre et al. 2002).

1.2. Research problem

There is a strong competition among various state governments to attract industrial investments in their respective states in India. Gujarat, which has been the front-runner in the overall economic development of the country, had formulated a new industrial policy in 2003 to promote the investment to lead competition (Gujarat 2003).

Ahmedabad being the economic capital of Gujarat state is one of the largest industrial hubs of western India. Because of its earlier textile industry it is playing a significant role in development of state from the past. In early 1980s industrial transformation took place from textile to chemical dyestuffs manufacturing aided by Europe and North America investment in India. A direct result of this was that many textile mills were closed down and a new type of industry developed in the Ahmadabad such as chemical, plastic and pesticide (Patel. and Modi. 2001).

Three major industrial estates, namely Naroda, Vatva and Odhav and one small industrial estate Behrampur are located with in Ahmedabad city. Various types of industry as example textile, petrochemical, chemical and pharmaceutical are establish with in these four industrial estates.

Even though Naroda industrial estate has a very good ecological network, a toxic gas leakage is reported on 6 Mar 2004. Numbers of people feel skin irritation and breathing problems in near by village because of leakage. About 500 residents of Muthia village were evacuated temporarily after they complained irritation (PTI 2004). On December 18, 1998, twenty-three men were burnt and badly injured when a gas cylinder exploded in Balco Enterprises at Odhav industrial estate (EXPRESS 1998). Safety expert Srinivas Mudrakartha and Jatin Sheth, believe that government has not done the sufficient effort for control and monitoring mechanism for industrial estate (Srinivas Mudrakartha 2006).

Country like India should have more strict regulation then other since Indian has not adequate infrastructure to handle an emergency situation. Also the population affected by such situation in India is comparative higher then any other country (Gupta 2006). The average population density of Ahmedabad city is 18420 persons per sq.km according to 2001 census, with this Ahmedabad stands at the seventh most densely populated city in India. Liberal industrial policy 2003 has increase the probability of occurrence of undesirable situation. In addition to looking at population density shows that subsequently the numbers of vulnerable people are more. So combination of liberal industrial policy and high population density increases the threat of disaster like Bhopal.

It is important for city like Ahmedabad to take advanced steps to estimate the risk and prepare a high-quality risk management plan rather then wait till an undesirable situation occurs. Diversification of industry can add the chances of risks related to the industrial hazards. In this regard many agency and industry have developed different tools of risk prevention, protection and crisis management. Due to the twin factors of the presence of diverse range of industry and absence of advanced technology, it is difficult to estimate the risk using the single developed method. Lack of proper methodologies for assessing the risk due to this industrial activity coupled with lack of technologies to handle the accidents, highlights the need to carry out this type of research.

This study carried out to assess the risk arising due to various industrial and technological activities in Ahmedabad city. This study includes technique to predict the various hazards in predominant weather condition. It also prominence on population distribution at night, day and communicate time.

1.3. Research aim

To assess the area, buildings and population threatened by industrial accidents related to industrial storage of hazardous material in various scenarios and prepare a data base and method that assess effected area in an emergency situation.

1.4. Research objective

1. To prepare hazard foot print caused by industrial/technological processes
    a. To identify possible hazards related to chemical substances used in the industry
    b. To calculate the effect distances for various hazardous substances in different scenarios (BLEVE, VCE, Pool fire, etc.) with the consideration of atmospheric condition

2. To calculate the risk caused by the industrial processes
    a. Identify the elements at risk in surrounding areas of identify hazards
    b. Calculate the vulnerability of the population and buildings
        - To determine the spatial vulnerability of population
        - To determine the temporal vulnerability of population
    c. Calculate the level of risk

1.5. Research question

1. What are possible hazards from the chemical substances used in industries for Ahmedabad?
2. Which is the appropriate GIS application to predict the chemical dispersion behaviour considering the weather conditions?
3. What is the spatial and temporal vulnerability of population for industrial hazards in Ahmedabad?
4. what is level of risk for industrial hazards in study area

1.6. Research approach

To achieve the aim of study the methodology is formulated in three phases. First, hazard identification phase covers collection of information related hazardous materials, storage, process and transportation. Possible types of hazards will be identified from the collected information. Possible categories of the hazards will be fire, explosion and toxic releases.

Hazards foot print will be prepared for identified hazards in each category using the effective distance modeling in second phase. Hazard foot print will help to estimate the zones of influence in surrounding areas of industry. Weather conditions will be incorporated to model the hazard foot print under the various climatic scenarios. At the end of this stage, we will get the hazard foot print for the city. Both these two phases combined will give the level of risk in surrounding areas.

Elements at risk mapping is being carried out as a part of a larger study in risk assessment. Current study will make use of the same elements at risk in order to quantify risk. Risk quantification will be restricted to estimating vulnerability of buildings and population. Different dynamic and social parameters like age-gender, day-night scenarios will be generated. Risk assessment is the will be done for the last phases of study. Dynamic model will be prepared to guide the necessary action at the time of crises situation for city Ahmedabad.

1.7. Research methodology

Formulated three phases Hazard identification, preparation of hazard footprint and risk mapping are further detail out. The flow diagram of entire approach is shown in figure 1-1.

This research is a part of a larger research project being carried out by Mr. Ajay K. Katuri at ITC. The purpose of this research is to prepare a Planning and Decision Support System for Urban Risk Reduction. The preparation of hazard foot print was also coordinated for the larger study and the parts were worked out in current study on "Industrial Risk Assessment".

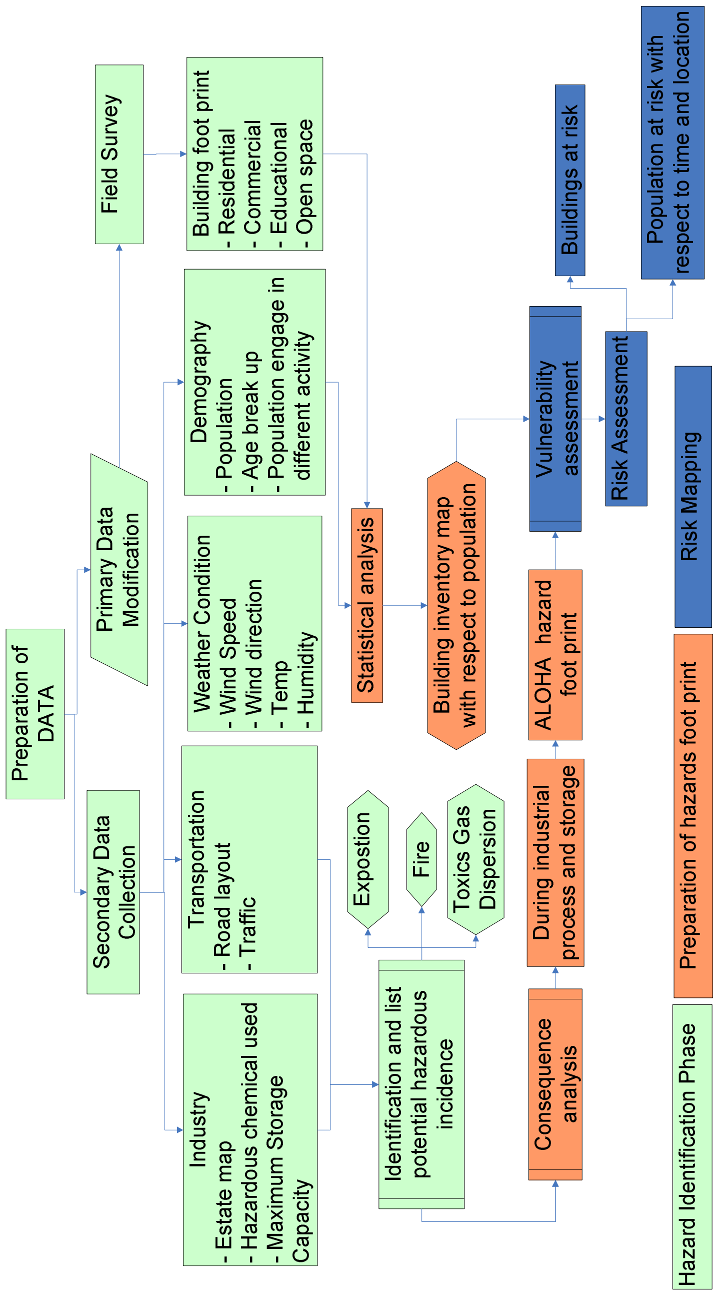

Figure 1-1: Method flow diagram

1.8. Research significance

This study is part of a PhD research work titled "*Development of Spatial Planning and Decision Support Systems for Urban Risk Reduction*". Outcome will provide inputs in above mentioned study. In addition to that it will give valuable input in present off site risk management plan. Technique used for prediction of hazards material behaviour shall help to take immediate action in real time situation which helps to reduction in the loss of human life and property in case of any industrial disaster. Building data based prepared for individual buildings will be help for multipurpose use such as to take immediate action it will guide to evacuate the people from likely to be affected area, nearest medical facility. Same data set and population distribution can be used for urban planning and disaster management.

1.9. Scope and Limitation

Scope of the study limited to the hazards related to chemical used in the industries and hazard for during the transportation of hazards material is limited to the CNG. Population distribution is carried out for residential buildings and on side road for day, night and communicates time. Also, Population engage in commercial activities which are expos to hazards is not cover in study because of unavailability of sufficient data.

Arial Locations of Hazardous Atmospheres (ALOHA) customise application is used to predict the hazard behaviour. Limitation of this model is also taken in account which is discussed in detail in next chapter. More on limitation is discussed in Chapter 8.3 pp. 66

1.10. Expected out come of the study

1. Hazards foot prints for industrial activity for different hazard category.
2. Population distribution in individual building and on road side for study area at different time scenarios.
3. Vulnerable building and population with respect to time and space for different hazards.
4. GIS Database which will help at the time of disaster for emergency planning.

2. Literature study: Industrial Hazards and Risk Assessment

2.1. Introduction

Hazards arising from human activity and interaction with social, environmental, and technological systems are kind of technological hazard. Nuclear technology, pollution, warfare and industrial accident are examples. Technological hazards can be causes during transportation, production, storage or at time of disposal also. Influence area, level of effect and duration of effect is differ bases on types of substance involve in hazards. Addition to that it also behaves different bases on surround environment such as landuse, types of soil, weather condition. This sows study of technological hazards is more complicated than the one of natural hazards. in country like India where industry management is not willing to share hazards related information makes the situation more completed.

2.1.1. What is a hazard?

Australian industry standards define a hazard as "*A source or a situation with a potential for harm in terms of human injury or ill-health, damage to property, damage to the environment, or a combination of these*". Hazard is an extreme event that poses risk to human settlements (Deyle 1998). Alexander (1993) defines a hazard as "*the exposure to some risk of disaster in the pre-disaster situation, due to the presence of human population in hazard-prone areas*"

2.1.2. Classification of hazards

Quarantelli states that in the past, hazard was classified based on the hazard sources such as earthquakes, floods, hurricanes, tornadoes, and hazardous material accidents. Later, two major category emerged, natural and technological, based on the its original sources (Quarantelli 1988).

Natural hazards are those that have an effect on population resulting from natural processes. Natural hazards are also defined as are those natural events which may result in a threat to human life, or which endanger the works of man like flood, earth quake, and drought or land slide. Technology hazards like industrial hazards arise because of the mass production, transportation storage or disposal process is life threatening and life supporting resources. It can be defined as the "interaction

between technology society and the environment" (Sengupta 2007). From time to time, technological hazards have been classified in different ways. In 1969, Starr classified hazards based on the exposures such as voluntary and involuntary. In 1976, Lowrance classified them on the basis of the effect like chronic and acute. In 1983 Hohenemser, Kates, and Slovic classified technological hazards in terms of 12 anxiety characteristics.
They have divided technology hazards into three main categories. Hazards which include nuclear war, radiation, and toxics gas are kinds of multiple extreme hazards. Antibiotics, vaccines, uranium mining, asbestosis, LNG explosions, car and airplane are types of extreme hazards.

In 1984, Perrows used probability as parameter and classified hazards as low-probability/high consequences and high-probability/low consequences hazards. In 1987, Solvic classified hazards based on the risk dread/unknown and common/known. In 1992, Perry created a classification based on the different hazard agent like scope of impact, speed of onset duration of impact, health threat, property threat, secondary threat and predictability(HWANG 2003)

Table 2-1: Hazard agent classification

Defining Characteristic	**River line flood**	**Volcanic Eruption**	**Nuclear Power plant Accident**
Scope of impact	Highly variable, land Narrow	Highly variable, broad area	Highly variable, broad area
Speed of onset	Rapid: flash flood Slow: main stem	Rapid	Variable
Duration of impact	Short	Long	Long
Health threat	Water inhalation	Blast, burns, ash inhalation	Ingestion, inhalation, direct radiation
Property threat	Destruction	Destruction	Contamination
Secondary threat	Public health danger from water/sewer	Forest fires, glacial snowmelt	Secondary contamination

Source:(Lindell 1994)

2.2. Risk Assessment

Risk assessment is the overall process of risk analysis and risk evaluation. Risk assessment is a combination of various stages. First stage is the hazard identification where a hazard source, types and location is assessed in the concerned locality.

Second stage is probability analysis. In this stage likelihood of each identified events is worked out. Consequence analysis is third and most important stage. Estimating the amount of impact for each event is part of this stage. An impact of each events are analysed on human and property to rank the severity of accident senior. And last stage is risk analysis. Results from previous two stages are combined and overall risk associated with each event is calculated as part of risk analysis.
In general, risk assessment is the estimation of the quantitative or qualitative value of risk. Risk related to Hazardous material can be assessed for the fixed installation and transportation infrastructure. Method used in this research is to combine the hazard identification and consequence analysis. Probability estimation requires huge amount of data and extensive amount of work which is not possible with in research time limit and absence of data. Probability used in this risk estimation is derived from the past research and which is most acceptable in general.

Fixed installation risk
Release of hazardous material is major risk in the case of fixed installation. This can occur at large refinery, chemical plants and storage terminals, where releases from storage tank or container may arise due to human error like opening or loosening of relief and safety valve, overfills, improper connection or deliberate action. It may be a result of technological failure like tank or container ruptures or equipment failure. This can be grouped in transfer loading and uploading, processing and storage activity.

Transportation risk
In most of the cases a hazard material is transported from its production site to its distribution network or user storage facility. It can be transported by underground pipe network, road and rail network. Hazardous material like natural gases, crude oil, LPG and petroleum product is very common and has considerable higher risk during the transportation. Due to availability of data risk related to transportation of CNG and petrol, only these two were analysed.

2.3. Risk categorisation

Based on the annually probability of any hazard, risk can be classified into various categories. This can be determined from historical data. In general, hazard with higher probability has low vulnerability, and hazard with lower probability has higher vulnerability. The five risk classes can be described as below:
Common accident: These take pace at least one time or more in a year. This could be occurring regularly in local concern.

Likely accident: They generally take place once in 10 year or has an average occurrence of 10 years

Reasonable likely accidents: are events expected to take place once in 10 years and average of 100 years. This means there is probability of 1% to 10 % probability of such even take place in locality of concern in any given year.

Unlikely accident: Events area expected to take places once at 1000 years. This means for given year it has probability of 0.1% for specify scenario.

Very unlikely accident: Events are expected take place less than once in 1000 year.

2.4. Risk assessment method

In order to assess hazard related to industry, a lot of methods have been developed by risk professionals. These are later on transferred to international standards or regulations. Most of them are easy to understand, but broad availability of these some time makes the choice difficult. At the first look some of them seem to be same, but they have different aim, input and results. Some are use to analyse probability of hazard, root or causes of accident or try to demonstrate the failure of system. Tixier has try to divided most of all risk analysis method based on its four characteristics (Tixier, Dusserre et al. 2002) .

1. Deterministic
2. Probabilistic
3. Qualitative
4. Quantitative

At first he has divided all method in two groups; one qualitative and the other quantitative. Qualitative assessment a risk is derive based on the level of judgement, experience and technical knowledge. As it is based on the judgement, knowledge and experience of individual its results are changed with case to case. It is very popular in small scale industry. Second approach is based on numerical model to assess the risk. Good model reduce the individual biasness. Some time its bring in to medium and large scale industry (Ring). Safety review, Check list analysis, What-If-analysis, Hazard and operability analysis (HAZOP), Failure mode and operability analysis (FMEP), Systematic identification of release point (SIRP), Master logic diagram (MLD) and Human reliability index (HRA) are the types of qualitative methods.

Quantitative methods are completed then qualitative method. Scientific study is conduced and measure value is compare with standard level in quantitative method. Aim of this method is to quantification of potential hazard consequence and relevant risk. This can help to identify the possible accidents, its extent and probability. This method are very popular where there is need of prepare a off site disaster management plan. This method gives the magnitude of hazards in numerical terms (Sengupta 2007). Probability risk analysis (PRA), Probability safety analysis (PSA), Quantified risk analysis (QRA) Quantified risk assessment (QRA), Quantitative scenario analysis (QSA), Failure mode effect and critical analysis, Event tree classification, Fault analysis and cause-consequence analysis are type of quantitative method.

This is furthered dived in deterministic, probabilistic or combination of both. Products, the equipment and consequences for various targets, such as people, environment and equipment, are take account in deterministic methods. In probability approach probabilities of hazard situation or frequency or occurrence of potential accident are estimate. Combination of both methods is used where there is a need to study the whole industry. There are a number of methods under each category. Hence, it is very important to select an appropriate method for risk analysis (Tixier, Dusserre et al. 2002)

In addition to above all some type mix of quantitative and qualitative method used for industrial risk assessment. In this hazard zonation is carried out by quantitative approach and risk is calculated based on the probability of event. This study is same technique is used for analysis which is known as Semi-quantitative method.

2.5. Selection of Method

Each method that has been formulated will have its own weakness and strength. A number of factors should be kept in mind while selecting a suitable method of hazard identification and risk assessment.

1. Types of industrial process

What- If studies, process checklists or brainstorming are suitable if industry has simple processes. In normal cases, it is good to use technique like Hazard and Operability Study (HAZOP) or Failure Modes and Effects Analysis (FMECA). This is the systematic and comprehensive technique having a variety of interacting subsystem.

2. Identification of Types of hazards

Type of hazard which is to be investigated also matters while selecting the technique. HAZOP and FMECA are efficient technique for assessing process hazards like equipment failure, but are not good for assessing the hazards like human errors or external effects and influences. Technique likes what-if tend to be broader, and are useful for identifying technology hazards, which take place because of natural events. To study hazards related to human errors, a task analyses is considered the best technique.

3. Level of risk associated

More complex and detail methods are used to identify the hazards having the higher risk. Hazards related to lower risk do not require a detailed analysis. Method like Multilevel Risk Review Process is used, where the initial study concludes higher risk than the defined criteria.

4. Types of hazards that need to be assessed

Type of hazard and the associated technology is also important for selection of the risk assessment method. Like gas dispersion modelling is suitable for hazards related to inflammable gas or liquid leakage. At the same time, selection of technique also depends on the type of system failures like mechanical or electrical failure or human error.

5. Stage of the project lifecycle

Information available for risk assessment and hazard identification is different at different stages of the project. Based on identifying hazard, the layout can be changed at the design stage one. Once it is in operation stage, new hazards knowledge will be gained by operator feed back, plant monitoring, or surrounding environment or other activity. So methods are different for assessing the hazards at design level and operation level (Planningnsw 2003).

2.6. Method used and justification

Industries has a higher amount of storage of hazards chemical is available this study area risk assessment is done for that industries only. Assessment of the frequency of occurrence of potential accident is not carried out for because it is time consuming and required broad range data. As consequence-oriented deterministic method target on consequence effect of considerable accident and not account for quantify the likelihood of these accidents is suitable for study area and match the aim of study. To calculate the risk a probability of occurrence of these accidents is taken from the past studies.

At end of hazards identification for industries a distance effective modelling is used to find the effect at the end point in case of fire, explosion and toxic release under the various scenarios. Effective distance modelling is done by Arial Locations of Hazardous Atmospheres (ALOHA). This followed by the risk estimation done based on probabilistic approach. Even probability value is obtain based on the past study and international standard

2.7. Dispersion modelling in ALOHA

Release of toxic or flammable materials is very common in accident situation. Such hazardous material like gas, liquid, or mixture of both, is release in the environment in case failure of storage tank, pipe network, valve failure or complete failure of vessel. It is very complex to estimate dispersion manner of such complex situation.

A dispersion modelling technique is used in this study is to estimate the concentration and time profile of release toxics or flammable chemical. In most cases, release chemical forms a vapour cloud and travel in the down ward wind direction. So it is very important to account the weather condition in such study along with the other following factor (Planningnsw 2003) .

a. Density of the air compared to air
b. The rate of release
c. Orientation of release
d. Weather stability
e. Wind speed and direction

These gases or particles can react with air and water which has significant effect in calculations in dispersion modelling. The level of effects on people of such material depends on concentration and time of exposure. It is very difficult to estimate the size of cloud and accurate concentration with time. To avoid such problems, it is good to assume certain constants. For safety reasons, the assumption is always based on the worst condition scenario.

A number of computer programs have been developed to project the extant of such hazardous cloud such as AJ Design Software, ARIA risk, SLAB View, EXSIM, Air Dispersion Modelling and ALOHA etc. from all these Arial Locations of Hazardous Atmospheres (ALOHA) is used in this study. A software model ALOHA is developed by the Environmental Protection Agency (EPA) and National Oceanic and Atmospheric Administration (NOAA) office, USA to respond the hazards situation in a short time after the hazards accident take place. It is the extending module of earlier developed Computer Aided Management of Emergency Operation (CAMEO).

ALOHA is a user friendly computer program to generate the scenario of gas dispersion in emergency conditions. ALOHA contain about 1000 chemical database and gives the freedom to define the release source, weather conditions. ALOHA default used the discharge by direct source if no information is available of discharge. If the information is available, user can specify the option like gas pipeline source, puddle source or tank. Second step after estimation of discharge is to calculate the concentration of toxic or flammable gas in down wind direction of wind from the point of source.

Different chemicals behave differently. ALOHA uses two different models based on the chemical density and molecular weight. A Gaussian model for gas lighter than air and heavy gas model for chemicals having higher density then air is used. Air molecular weight is around 29 kilograms per kilomole. If a gas has higher molecular weight than this, ALOHA considers it as heavy gas. If lighter gas is stored at lower temperature than room temperature, it also forms a heavy gas cloud. In such cases, the density of gas cloud is greater then the air density (1.1 kilograms per cubic meter), ALOHA consider the gas to be heavy. Heavy has model is based on DEGADIS model (Spicer and Havens 1989).

2.7.1. Gaussian model

ALOHA uses Gaussian air dispersion model for buoyant gases or gases having the same density as air. This model works on the principle that wind and atmosphere turbulence force material molecules in downwind direction, and hence it spreads out in crosswind and upwind direction with turbulent mixing. Concentration is very high at the release sources and it will get diluted while traveling in crosswind and upwind direction. Hence it will spread out in bell shape. This means concentration is higher in the center top and lower on the sides. After some distance, bell shape spreads and the concentration reduces (Planningnsw 2003), (EPA and NOAA 2007). Figure 2-1

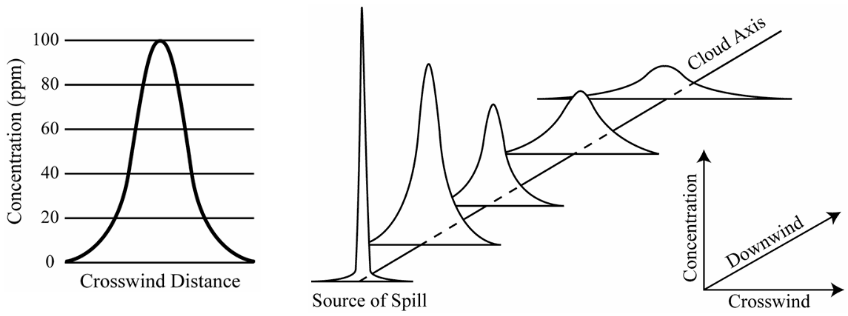

Figure 2-1 : Gaussian distribution (left) and Gaussian spread (right).
Sources: ALOHA manual

Further reading on how ALHOA works for Gaussian gas dispersion is available in Handbook on Atmospheric Diffusion (Hanna 1982), Diffusion from a Steady Source of Short Duration (Palazzi 1982) and Guide to local diffusion of air pollutants (Beals 1971) .

2.7.2. Heavy gases

When gases heavier than air are released, it behaves very differently than neutrally buoyant gases. Heavy gas first slump or sink after release. Then its gravity spreads when it travels in downwind direction; so it moves slightly upwind than the release sources. After travelling at certain distance, the gas starts to dilute due to the air Figure 2-2. When its concentration reaches below 1 percentage than the surrounding air, it behaves like buoyant gas. This depends on the amount of gas release. Higher the amount, greater will be the distance at which it will be diluted (EPA and NOAA 2007). ALHOA works base on the DEGADIS model (Havens and Spicer 1985), heavy gas dispersion model. This model has general acceptances and the extensive amount of testing is carried by authors.

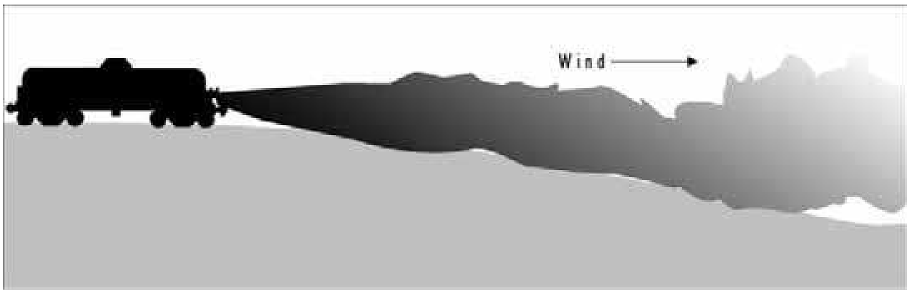

Figure 2-2 : Figure Cloud spread as a result of gravity

ALOHA can also model fire and explosion scenario with the gas dispersion. Probability of any type of hazards occurrence is based on the chemical and sources of release.

2.8. Types of fire and explosion modelling in ALOHA

2.8.1. Fire

A fire is a complex chain reaction of fuel and oxygen which generate heat, smoke, and light. Sparks, static electricity, heat, or flames are major sources to ignite the fine more over if a chemical is above its auto ignition temperature it can also catch the fire without any above mention sources. Chemical properties like volatility, flash point, and flammability limits are help to derive the chances or causes of fire.

Level of fire hazard is measured in thermal radiation Level of Concern (LOC). ALOHA suggest the three zones based on Acute Exposure Guidelines (AEGLs). This value is suggested by American Institute of Chemical Engineers 1994 and Federal Emergency Management Agency.

2.8.1.1. JET FIRE

A jet fire, also know as a flame jet. Released flammable chemical from storage or transported container come in contact with ignited sources and immediately catch the fire and turns in to jet fire. Blowtorch flame takes place in such situation. Because of high kinetic energy jet fire flame has a relevant length in the direction released. A flame jet me be cloud of hundreds of feet in length from a hole less than a foot in diameter.
ALOHA predict thermal radiation LOC based theory that it originate in vertical direction and later on divert in downwind direction. Boiling Liquid Expanding Vapor Explosion (BLEVEs) will take place after jet fire if vessel container is weak and contain`n a liquefied gas. ALOHA can not predict both at time user can run BLEVE scenario after jet fire.

2.8.1.2. POOL FIRE

Uncontrolled combustion of the vapors from a pool of flammable liquid resulted a pool fire. Some time flammable liquid forms a puddle on the ground converted fire flame is also known as pool fire. Liquid contain in pressurize vessels have higher chances to catch the pool fire in situation of liquid loss in atmosphere.

Like jet fire pool BLEVE take place from jet fire. In that case user can model pool fire first then rerun the model keeping the same setting with BLEVE scenario. ALOHA
Can not model the pool fire on water, only pool fires behavior on land can be predict. Other by product hazard from pool fire like smoke, toxic byproduct or spreading of fire by surround material can not be predict by ALOHA.

2.8.1.3. FLASH FIRE

Flammable vapor clouds catch the fire and start to burn quickly is called a flash fire. Primary hazard associated with flash fire is thermal radiation and by product of mixture. Like smoke and toxics particles. ALOHA can predict the flammable area of fire from vapor cloud. Hazards effect of flash fire is measured in Lower Explosive Limit (LEL) and Upper Explosive Limit (UEL). This shows the represent the concentration of flammable chemical in vapor cloud. Air-fuel concentration is between LEL and UEL it will get flash fire when it comes with ignited sources. Based on the past experiment ALOHA use LEL is 60%.

2.8.2. EXPLOSION

An explosion is a sudden increase in volume and release of energy in a violent manner, with high temperature and the release of gases. Accidental situation of exposition is effect of liquid store at high pressure. Violently oxidation reaction of chemical is very common in the industry. Thermal radiation, overpressure, and hazardous fragments (flying debris) are main primary hazards need to be take when dealing the explosion accident.
A primer hazard associated with explosion is over pressure some time known as blast wave. ALOHA predict explosion based on the surrounding situation specify by user. If the explosion take place surrounding by building and tree it predict little higher level then than the actual but damages could be higher. Like the fire thermal radiation ALOHA suggest the default suggest by American Institute of Chemical Engineers 1994 and Federal Emergency Management Agency value and it can be specify by user.

ALOHA can predict the most common fire and explosion Jet Fires, Pool Fires, BLEVEs, Flammable Areas (where a Flash Fire could occur), and Vapor Cloud Explosions with combination of different release cases like Direct, Puddle, Tank, and Gas Pipeline.

2.8.2.1. BLEVEs

Boiling Liquid Expanding Vapor Explosion (BLEVEs) typically occur in closed storage tanks when liquefied gas store under the high pressure. Cooling below the boiling point or storage at the high pressure are two methods to store the gas in liquefied form. But the flammable and nonflammable liquefied gases have chances to react in form of BLEVE in case of container of liquefied gas comes in touch with fire ignited sources increase the pressure in the tank. In case of failure of tank chemical is released with the explosion (BLEVEs).

When the container fails, the chemical is released in an explosion. If the chemical is above its boiling point when the container fails, some or all of the liquid will flash-boil—that is, instantaneously become a gas. If the chemical is flammable, a burning gas cloud called a fireball may occur if a significant amount of the chemical flash-boils. Thermal and over pressure are associated hazards with BLEVE but ALOHA focus on thermal radiation because it impact is always higher then over pressure.

2.8.2.2. VAPOR CLOUD EXPLOSION (VCE)

There are number of chemical has a characteristics to built a vapor cloud when it is released in the atmosphere. This chemical has tendency to travel in the downwind direction. If this could comes in contact with an ignition source where concentration is with in the flammable rage it will start to burn. Some time it will burn so fast and resulted explosion. The hazards impact of such a explosion depends on cloud size and type of ignition. Consecration of flammable material also effect on its severity. This hazards area overpressure and hazards fragments. ALOHA can model a overpressure it can model hazard fragments.

Deflagration and detonation

The devastation from the vapour cloud explosion depends on rate at which the flame travels. After starting the flame it will ignite the fire through out the vapour cloud where concentration is in flammable range. The pressure coming out from that explosion can be causes damage the people and property. Higher the speed of flame fronts higher the pressure and higher severe effect. Flame travel speed is 2.2 miles per hour called as deflagration. In worst case its travel fast then this speed is consider as detonation explosion.

Obstruction with could generate the turbulence. This obstruction is means by smaller object. Higher number of small obstruction higher turbulence. This accelerates the front flames which resulted power full blast. This obstruction is defines by the volume blockage ratio. Based on the experiment if volume blockage ratio is less then 1.5 % then it is consider as uncongested cloud which has lower effect compare to if volume blockage ratio is higher then 1.5 % (Congested cloud).

Source Toxic Scenarios Fire Scenarios Explosion Scenarios			
Source	**Toxic Scenarios**	**Fire Scenarios**	**Explosion Scenarios**
Direct			
Direct Release Toxic	Vapor Cloud Flammable	Area (Flash Fire)	Vapor Cloud Explosion
Puddle			
Evaporating	Toxic Vapor Cloud	Flammable Area (Flash Fire)	Vapor Cloud Explosion
Burning (Pool Fire)		Pool Fire	

Tank			
Not burning	Toxic Vapor Cloud	Flammable Area (Flash Fire)	Vapor Cloud Explosion
Burning		Jet fire/Pool Fire	
BLEVE		BLEVE(Fireball & pool fire)	
Gas Pipeline			
Not burning	Toxic Vapor cloud	Flammable Area (Flash Fire)	Vapor Cloud Explosion
Burning (Jet fire)		Jet fire	

Table 2-2 : Source Toxic Scenarios Fire Scenarios Explosion Scenarios in ALOHA.

Source: ALOHA user manual

2.9. Salient feature of ALOHA

a. ALOHA can predict dispersion behaviour of release material in real time situation
b. It has ability to predict for heavy as well as light gas dispersion
c. Checks the input parameters simultaneously and alerts incorrect input of information, which helps minimization of human errors.
d. Ability to predict outdoor as well as indoor concentration
e. Hazards under the different accidental situation can be predict
f. Its gives the result in both text and graphical format
g. Inbuilt database of 1000 chemicals.

Although, ALOHA is user friendly, quick and compact software application, it has the following limitations:

a. ALOHA does not account for change in topography.
b. It considers a constant wind speed and direction at a given height
c. Initially it did not consider buoyancy properties
d. Emergency response is the main aim of ALOHA, so it does not address any long term air quality issues
e. It predicts the effect at minimum 100 meter and maximum 10 km from release sources to the down wind direction
f. Liquid release from the pipe can not be modelled

ALOHA assumes that release substances evaporate and travel in the down ward direction in form of pool surface with out considering any reaction with air or water.

It alerts when the user selects a material which has chance of reaction with water or air (EPA and NOAA 2007), (EPA and NOAA 2007),

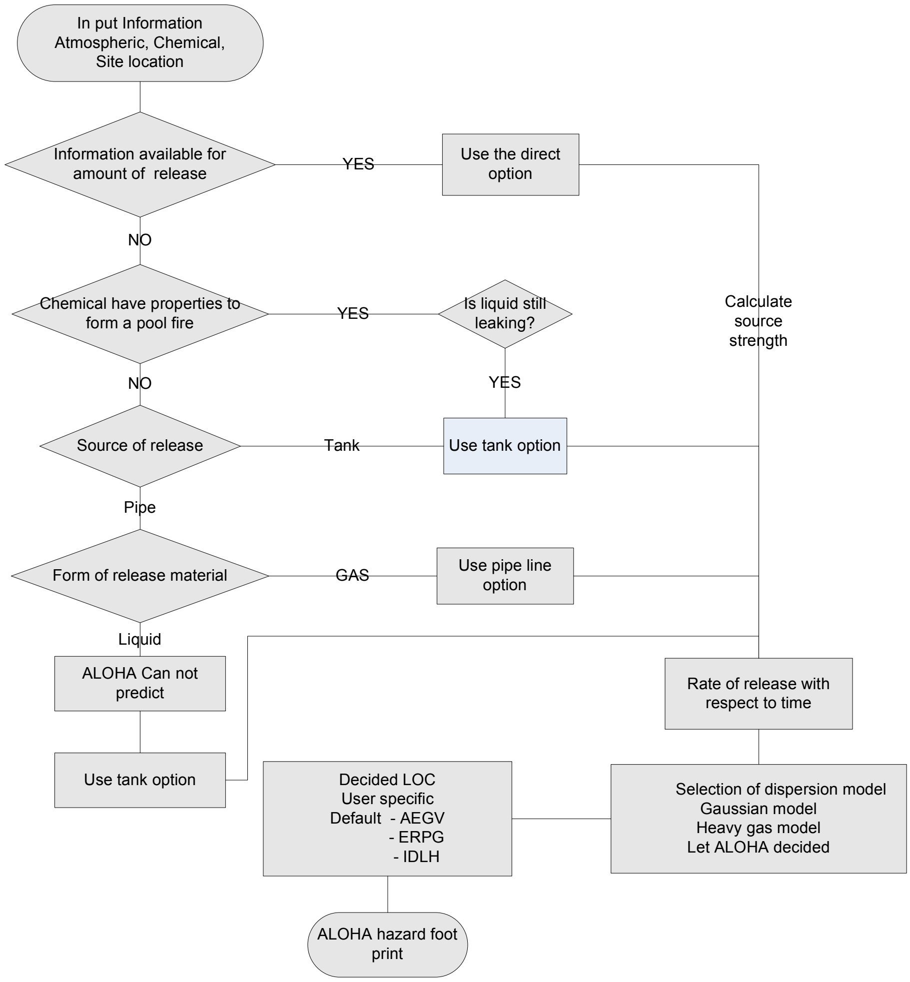

Figure 2-3: ALOHA user guide flowchart

2.10. Elements at risk

To analyse the risk it is important to know the elements at risk. These elements could be environment, human lives, buildings and other properties, trade and various economic practices, infrastructure and utilities. Identification of elements at risk and their relationships with the hazard is an important aspect in risk analysis. The elements at risk are limited up to population because of unavailability of data.

More over, to estimate population at risk is a very critical step. Population distribution varies with time and types of land use in locality. Number of people affected even varies with the time of event take place.

2.11. Vulnerability assessment

In this industrial era, it is difficult to avoid any accident. What we can do is that try to minimise loses of such event. To minimise it is important to know what elements are and at what level of degree that can affect. Vulnerability define "as the degree of damage to a specific element at risk (e.g. building, infrastructure, population etc.) for a specific endangering phenomenon (e.g. fire, explosion or toxic release) with certain intensity"(Westen CJ 2004). In general vulnerability is "degree of loss resulting from the occurrence of the phenomenon". UNDP/UNDRO (1994) defines vulnerability as "the extent to which a community, structure, service, or geographic area is likely to be damaged or disrupted by the impact of a particular disaster hazard, on account of their nature, construction, and proximity to hazardous terrain or a disaster-prone area". Human and building vulnerability increases in cases of inefficient planning and insufficient emergency management or if a particular event is not expected. In cases of industrial hazards like toxic release, children and aged are more vulnerable than adults. Building having a roof and/or wall material like grass, thatch, bamboo, wood, mud and Plastic, polythene are more vulnerable then tiles, stone, galvanised pipe, or concrete material.

2.12. Industrial accidents in India

During 1980s and 1990s, India progressed with industrialisation and achieved one of highest economic growth in the world. This rapid industrialization has created new kinds of hazards. During this phase, India experienced the worst industrial disaster in 1984. On the night of December 3, 1984, a deadly poisonous gas methyl isocyanate (MIS) was released from storage tank from the pesticide plant of M/S Carbide India Ltd., in Bhopal. MIS gas cloud remained over the highly populated area of city. In the first three days total death was above 5000. This number reached over 8000 with time. In addition to that scientific commission study noticed a long term effect like damage to the brain, eyes and cancer.

This was followed by an explosion of liquefied petroleum gas in Nagothane in 1990, which killed 35 and injured 15 persons. Government officials claimed that only 33 people were killed in the tragedy. On 14 September 1997, LPG explosion took place at the petroleum refinery of Hindustan Petroleum Corporation Limited (HPCL) at Vishakhapatnam. Un-official figure claimed around 80 killed in blast where official limited to 33. There are number of such small to medium scale accidents which even not notice by media.

2.13. Industrial policy in India

Government of India realises the importance of industrial legislation for safety of workers as well as vicinity people after experiencing world most terrifying Bhopal gas industrial disaster. The Bhopal gas tragedy of 1984 led to the introduction of a comprehensive legislative framework of Environment (Protection) Act (EP) 1986, administered through Ministry of Environment and Forest. A number of rules have been formulated under this Act related to the major hazardous industries namely emergency planning, and transport of hazardous goods, Manufacture, Storage and Import of Hazardous Chemicals Rules (MSIHC Rules), 1989, Hazardous Wastes (Management and Handling) Rules, 1989, Rules for the manufacture, use, import, export and storage of hazardous micro-organisms, genetically engineered organisms or cells (1989), Public Liability Insurance Act (1991), The Bio-Medical Waste (management and handling) Rules, 1998, Manual on emergency preparedness for chemical hazards (1992), The Chemical Accidents (emergency planning, preparedness, and response) Rules, 1996, A guide to safe transport of hazardous chemicals (1995) were formulated, revised and amended over the intervening years under the EP act 1989 (Gupta 2006). At the same time it is necessary to strengthen the local government to strictly implement the formulated rules. On account of lack of coordination among various institutions, it is difficult to collect data related to hazards. Hence emergency control department are unable to work efficiently (Arifa Nabi and van Westen 2005).

2.14. Initiative taken by Government of India

In India state government is responsible to prepare any kind of disaster management plan and implementation of related program. In such cases on besides formulation and implementation of industrial safety related policy Government of India has taken certain effort to strength state government for design the disaster management plan and policy implementation.

In last decade High Powered Committee (HPC) was setup under the Prime Minister to review and access the issues of disaster management planning at the National and state. National committee for disaster management (NCDM) is established to suggest institutional and legislative measures to cope up with the any kind of disaster with state political party.

NCDM has prepared a hand book for Disaster Risk Management in industry for the Corporate Sector under the India Disaster Resource Network (IDRN) program. Industrial Safety and Disaster Prevention Project is implemented to with joint effort by MoEF and World Bank to promote the cost effective safety measures and disposal of hazardous waste in 1998.

There are number of other efforts taken by same committee to make India safer. At last in tenth five year plan government of India has focus to disaster management. This time government has done effort on preparedness and planning function rather then response and relief. Still experts think that centre government ha more concerned with natural disaster then technological disaster. This is because natural disasters are frequent and number of people are died are much higher then technological disaster in India. Bureaucrats and top official believe that strict action in this direction can be slowdown the economic development of India.

3. Case Study area: Ahmedabad City

3.1. Introduction: Mega city Ahmedabad also known as Karnavati

Sultan Ahmed Shah has built Ahmedabad as his capital in 1411 A .D. on the bank of the river Sabarmati. He has built his new capital with a castle and twelve gates and named it Ahmedabad. The city was earlier known as the "Manchester of the East" because of its textile growth in past. Ahmedabad is second largest city in western India and seventh in India. National level prestigious project like Sabarmati River Front Development a (SRFD) and Bus Rapid Transit System (BRTS) are in progress in Ahmedabad.

3.2. Ahmedabad profile

3.2.1. Geographical location

Ahmedabad's strategic location gives its advantage of proximity to Bombay, commercial capital of India. Western, Middle East and African markets are also accessible through near by port. Ahmedabad was declared as mega city in 2006. The city has expanded along both sides of Sabarmati river bank.

It is lies between longitude 22°56' to 23°1' N and latitude 72°30' to 72°41' E. Average height of 50 m above mean sea level. It is the seventh largest urban conglomeration of India with around 190.84 sq. km and has a population of 4,519,278 including urban agglomeration (Census 2001).

With the limitation of time frame of research, a study narrows down to the part of city. As mention previous there are mainly three industrial estates are located with the city limit (1.2 pg 1). Out of these Odhav industrial estate is considered for analysis. As shown in Figure 3-1 this covers the eastern part of the city. Total 20 traffic analysis zone (TAZ)[1] surrounded by Odhav are selected for study. Selection

[1] Ahmedabad and surrounding of 3000 sq.Km area has been initially divided in to major subregions such as Walled City, AMC east, AMC west, AUDA, GUDA and other villages. These sub-regions have been further divided into 427 traffic analysis zones (TAZ) based on the ward boundaries, census zones, village boundaries, district boundaries of the study area including major highways, railway lines, natural watercourses, land use and population density. (IPTS Study report for Ahmedabad – LB Associates, 2000)

based of TAZ boundary helps to estimate accurate distribution of population. It is the smallest available unit for further analysis. Approximately 23.67 sq. km from the total city area of 190.84 sq. km is covered by 20 TAZ Figure 3-1

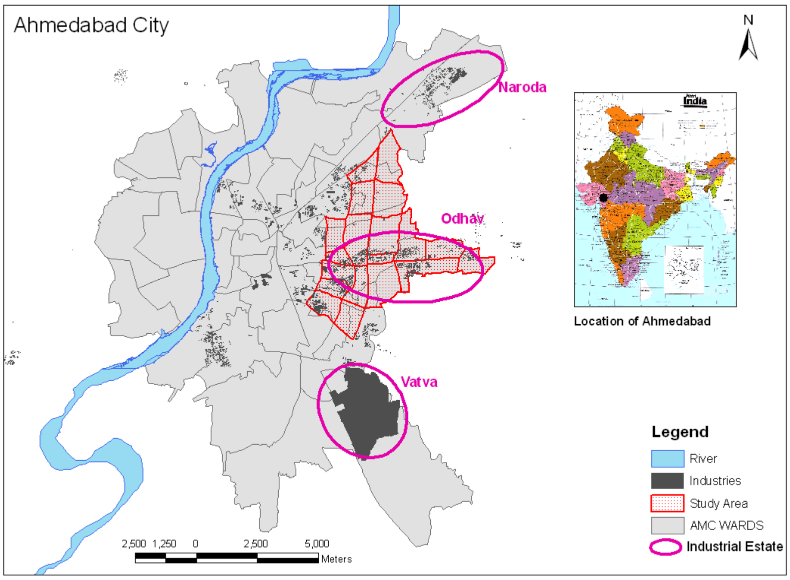

Figure 3-1: Location map of study area

3.2.2. Climate

City has hot and humid climate. The weather condition changes with season. Typically three main seasons are summer, monsoon and winter experience in a year. December-January is reported coldest moth in winter; summer is hottest in May-June. Monsoon sets by middle of June to fist week of August and the average rainfall of last 20 year is 650-750 mm. Relative humidity is around measures 60% and over during South-west monsoon season in last 5 year. In summer, humidity is around 25% while highest humidity goes up to 80 % during monsoon. In general winds are weak over the Ahmedabad. Velocity of wind is moderate in city that vary between 5-7 kmph.

Weather parameter like temperature, humidity, wind speed, wind direction and weather condition are required as input in ALOHA model which is used for dispersion modelling. Monthly data of year 2004, 2006 and 2007 is used to derive predominate weather condition.

3.2.3. Land use pattern

Land use pattern of Ahmedabad is shown in table 4.1.

Land use Type	**Total area Sq.km**	**Area %**
Residential	68.7	36
Commercial	3.8	2
Industry	28.6	15
Open land	45.8	24
Village settlement	9.5	5
Water body	7.6	4
Road	13.4	7
Rail	3.8	2
Other	9.5	5
Total	**190.8**	**100**

Table 3-1 : Landuse distribution of Ahmedabad

Table 3-1.Shows that highest area 36 % is occupied for residential purpose. It is followed by industry 15 %, village settlement 9.5 %. Road and rail is 9%. Ajay K. Katuri states this is almost half than minimum requirement in UDPFI[2] norms (Katuri, Sharifi et al. 2006). This shows the chances of accident while transportation of hazardous material is comparatively high. In this study accident scenario is limited to risk related to petrol and CNG transportation. Very large proposition of 24 % area is vacant in the locality where Ahmedabad Municipal Corporation (AMC) acquired during that period.

3.3. Gujarat Industrial policy 2003

To promote the investment in the state of Gujarat government has introduced a new industrial policy in the state in 2003. The new policy adopted more proactive approach then the reactive approach to encourage free market forces. This policy is formulated to achieve Gujarat vision to see that Gujarat plays a major role in industrial growth in the global arena and becomes an Asian leader. So government has provided the friendly environment in terms of systemic support by limiting its preliminary role. The primary objective of the Industrial Policy 2003 is "*to achieve global competitiveness for Industries in Gujarat*"

3.4. Agency Involve in Industrial activity

Gujarat being one of industrialise state in India, a number of agencies has been created for various purposes like planning, implementation, attracting foreign investment, policy implantation and monitoring and marketing by Government of

[2] Urban Development Plan Formulation and Implementation (UDPFI) Guidelines, Ministry of Urban Affairs and Employment

Gujarat (GOG). List of agency are working in Gujarat state is shown in the Annexure 1

3.5. Industry at glance in Ahmedabad

Ahmedabad as a trading and commercial hub was first started by its ruler Sultan Ahmed Shah in the year 1411. Sultan Ahmed is former ruler from whom the city derived its present name Ahmedabad (its former name being Karnavati).
Trading and commerce accelerated after the formation of its municipality in 1858 and by commencement of railway connectivity with Mumbai in 1864. During that period the city became a hub of textile manufacturing. Historically, Ahmedabad has been one of the most important hub for trade and commerce in western India.

3.5.1. Industrial Development in Ahmedabad

In the past when industrial estate was developed surrounding Ahmedabad, industry was not within the municipal limit. So the regulation under the law is not applicable when the major industrial estate like Vatva, Naroda and Odhav were established. After extension of AMC limit and coming of Ahmedabad Urban Development Authority (AUDA) the development area was extended beyond the limit to looking at the demand. This way restriction came later and area has already developed in a haphazard manner. Major three industrial estates namely Naroda, Odhav and Vatva are now with the AMC limit and surrounded by inhabitants. Graphical representation of the growth of the city is shown in the next Figure 3-2.

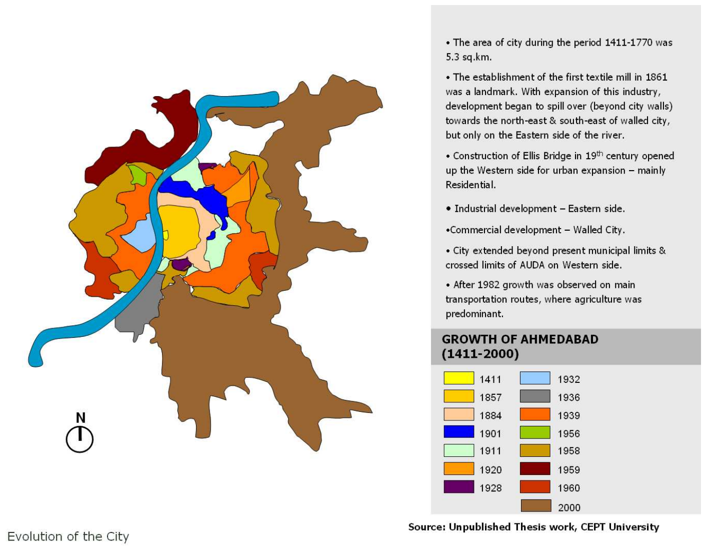

Figure 3-2 Growth pattern of Ahmedabad city from 1411 to 2000

3.5.2. Industrial estate in city

There are total 8 industrial estates in Ahmedabad district. Out of that three main industrial estates fall with in the boundary of Ahmedabad Municipal Corporation (AMC) namely Naroda, Vatva and Odhav. Naroda industrial estate is spread over 30 sq.km areas, and has approximately 700 diverse companies including pharmaceutical, dyes, chemicals and textiles. Vatva industrial estate is established in an area of over 560 ha and includes 2200 industrial units, comprising mainly of 65% engineering, 25% units and remaining other units of a mixed variety. Odhav industrial area extends to 75.42 ha and has 491 industrial plots.

3.5.3. Hazardous industry in Ahmedabad

The Government of Gujarat (GOG) has categorised its district on the basis of chemical and industrial hazard category. AA category, A category and B category is given to district based on the industrial unit like highly hazardous, hazardous and less hazardous respectively. Ahmedabad district fall in the second A category of hazardous. GIDC allows the installation of hazard unit within the estate only, so GIDC can maintain fire tenders in state. The density of hazardous installation suggested that all three estates in Ahmedabad Naroda, Vatva and Odhav are comparatively high than other estate in Gujarat state. Name of hazardous industries install in these estates, type of chemical used and maximum storage capacity is listed in Annexure 2

4. Data description and handling

4.1. Data requirement

First task as part of data collection is to prepare a checklist for data require. Data checklist has been prepared based on the available literature as part of field preparation. Part of the data is collected by PhD researcher Mr. Ajay K. Katuri. Required data is categorised mainly in primary and secondary data. This further separated out for data which is available and needs to upgraded or collected during the fieldwork. The data check list is shown in Annexure 3

4.2. Data collection

As mention previous required data is categorise in to primary source and secondary source. As this is part of PhD study most of the primary data like building foot print is available. Secondary data related to industry, climate and demography is collected during the field visit.

4.2.1. Primary data collection and description

The on-going PhD research, provided a detailed building foot print for this current study. The footprint was digitised from the Google Earth imageries and later the attribute information was collected through primary survey. While preparing the field work plan a need is realised to upgrade the building foot. The building blocks are classified into 13 residential, 10 institutional, 3 educational, 10 industrial and other land uses. Other land uses described are: recreational, commercial, transportation, and others. To estimate buildings at risk and total population can be affected with time, same land use classes are further sub classified. Detail classification is show in Annexure 4

During the field work, buildings from Google Earth image were visited at the location and verified as shown in Annexure 4-2. Missing information related to buildings is added as attribute in building foot print. Random checking is also carried out for the earlier map building. It has been realised that available data is good enough to use it for further analysis. Of total 38663 buildings, about 649 buildings (about 2%) were cross checked / added for accuracy. In most cases, the data collected was accurate.

4.2.2. Secondary data collection and description

Secondary data like estate map and industrial name and address are collected from Gujarat Industrial Development Cooperation (GIDC) and Gujarat Pollution Control Board (GPCB). Information related to Major Hazardous Accidental (MHA) unit, types of hazardous chemical used and maximum storage capacity is collected from the office of Chief Inspector Factories. Data related to meteorological information like humidity, wind direction, wind speed and weather conditions is collected from the Indian Metrological Department (IMD) for year 2006 and 2007. Data related to the accidents in industries is collected from the National Institution of Occupational Health (NIOH).
To analyse population at risk, people engaged in various types of commercial activity, educational activity or recreational activity is collected from AMC.

4.3. Data preparation

Creation of spatial data from various secondary sources and establishing a spatial reference was part of data preparation work. Data available was not in GIS format. To bring all data in to same GIS format is also a major task of data preparation.

4.3.1. Updating building foot print

Available building foot print which is prepared needs to update. Google Earth™ data is used for updating building foot print. One meter spatial resolution image is downloaded from free image application, Google Earth™. Available image is geo-referenced based on the vector layer of building foot print. New identified buildings were digitised using ArcMap9.2, ESRI. Final accurate base map is overlaid on satellite data as shown in the Figure 4-1

4.3.2. Updating building inventory

Updated building is verified by ground survey for classification. Building foot print is classified based on its usage i.e residential, institutional, educational, recreational, commercial, industry, transportation, and others. It is further classified based on its specific function and construction pattern for analysis[3].

4.3.3. Preparation of estate map

As mention previously, Odhav industrial estate is selected for study. Figure 4-2 showing plot level detail is collected from the GIDC was in AutoCad format. This map is converted to GIS environment. Geo-referencing is done with help of Google

[3] Refer annexure 4-1 for detail classification

Earth™ image. Information related to industry name, product and location is collected in excel format which is attach with plot level polygon layer of estate with unique id of plot number.

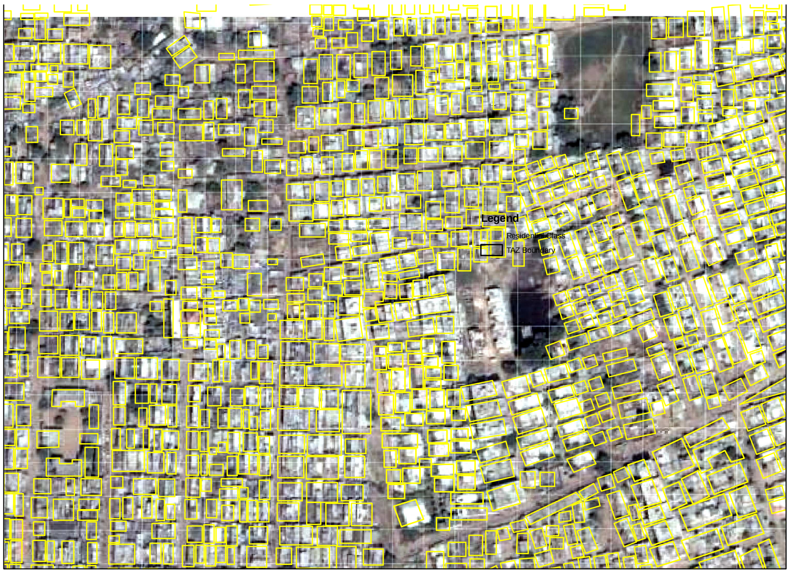

Figure 4-1: Building Foot Print Overlay on Google Earth ™ Image

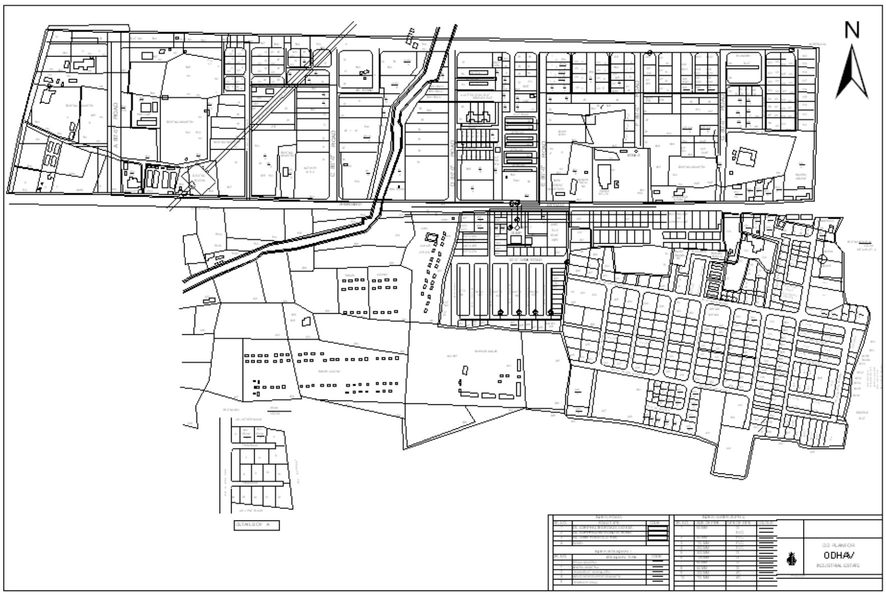

Figure 4-2 : Plot level detail for GIDC Odhav

5. Hazard assesemnt

Hazards identification and preparation of hazard footprint are the first two stages of risk assessment of hazards. Risk assessment is carried out for Major Accident Hazard (MAH) units which are identified by Chief Inspector Factories, Government of Gujarat. Total 5 out of 42 MAH units in Ahmedabad district fall in study area. Names, address, types of hazardous chemical used and maximum storage capacity of all 42 MAH industry units are given Annexure 2.

5.1. Hazard idetification

Hazard identification is the first step in risk assessment. Industrial hazard, oil spill, transportation accident are types of the technological hazards. In this research, study is limited to potential industrial accidents related to chemicals. Fire, explosion and atmospheric dispersion of toxic gases are common types of industrial hazards. As mentioned previously, 5 MAH units are located in the study area. Location MAH units shown in Figure 5-1: Location of MAH Unit. Details of possible hazards from those units are listed in Table 5.1.

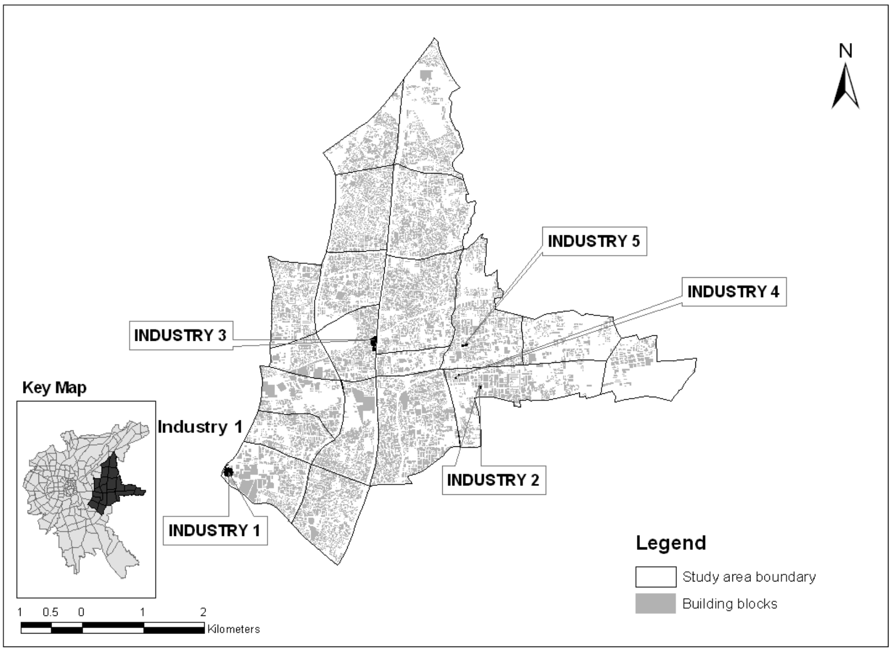

Figure 5-1: Location of MAH Unit

Industry No	Name of the Industry	Chemicals	Maximum Capacity in Tons	Toxics Release	Flammable Vapour	Explosion
1	Mr. XYZ1 ltd	LPG	18.8	YES	YES	YES
2	Mr. XYZ2 ltd	Parathion-methyl	5.2	YES	NO	NO
3	Mr. XYZ3 ltd	Parathion-methyl	1.2	YES	NO	NO
4	Mr. XYZ4 Ltd	Chlorine	20	YES	NO	NO
5	Mr. XYZ5 ltd	Chlorine	18	YES	NO	NO

Table 5-1: Possible hazard in study area

These industries are referring by its number only in this report from this point forward.

5.2. Consequence scenario

Chlorine and Parathion-methyl toxic chemical and Liquid Petroleum Gas (LPG) flammable gases used in the MAH units are critical elements in the study area. Release of toxic materials has both short and long term effects on the human, aquatic and wild life. Since emergency response is main objective of the study, only short term effects on humans are considered for studying the consequences of toxic release, apart from fire and explosion scenarios. Hazards followed by leakage of LPG gas vary according to the surrounding environment of leakage area. Possible scenarios from each industrial unit are listed in Table 5-2.

Table 5-2 : Possible scenario in study area

Scenario	Possible hazards	ALOHA Model
<u>*LPG*</u>		
Not burn	Down wind toxic effect	Yes
	Vapour cloud flash fire	Yes
	Over pressure (Blast force) from vapour cloud	Yes
Burn as jet fire	Thermal radiation	Yes
	BLEVE (If tank failure)	Yes
	Toxic effect of fire by product	No
Burn as fire ball	Thermal radiation	Yes
	Hazard fragments from by product	No

	Down wind toxic effect from by product	No
<u>*Parathion-methyl*</u>	Down wind toxic effect	Yes
<u>*Chlorine*</u>	Down wind toxic effect	Yes

From Table 5-2 it is clear that all possible hazards in the study area can not be predicted by ALOHA model. Due to time constraints, only consequence analysis is carried out for likely threatening events.

5.3. Consequence analysis

The second step after hazards identification is consequence analysis for risk assessment method. Estimation of area that is likely to be affected from the identified hazards and assessment of the level of severity at the end point is a part of consequence analysis. Dispersion behaviour of toxics gases depends on release chemical properties and weather conditions at the time of the accident. To find predominant weather conditions, meteorological data of the last three year (2004, 2005 and 2007) is analysed.

5.3.1. Weather conditions

Dispersion behaviour of release chemical or gases depends on release time weather condition. Weather parameters like wind speed, wind direction, air temperature, cloud cover, ground roughness and relative humidity are required inputs in ALOHA model. Humidity value of 60% and temperature of 36°C is used for study, since these are the average values for the entire year. Ground roughness is assigned a constant value of 0.7 for urban areas according to ALOHA guidelines. Cloud conditions are clear during summer, winter and partly in monsoon also. For analysis, cloud conditions are assumed to be clear for each scenario.

Wind directions and speed change frequently within a day also, and hence it cannot be assumed constant through out the year. To analyse the wind data a free available software WRPLOT view is used. Three year data the of year 2004, 2005 and 2007 were analysed.

Frequency distribution for wind speed (WS) v/s wind direction (WD) is shown Wind rose diagram prepared by WRPLOT view is shown in Figure 5-2.
And frequency distribution is shown in Table 5-3.

Most predominate weather situation is wind speed 1-2 m/s blowing from NW direction(9.1%) followed by wind speed 2-3 m/s blowing from SW direction (8.7/%) and wind speed 1-2 m/s blowing from NE (7.9 %).

Analysis for all assumed scenario which is discuss further are carried out for all three weather condition

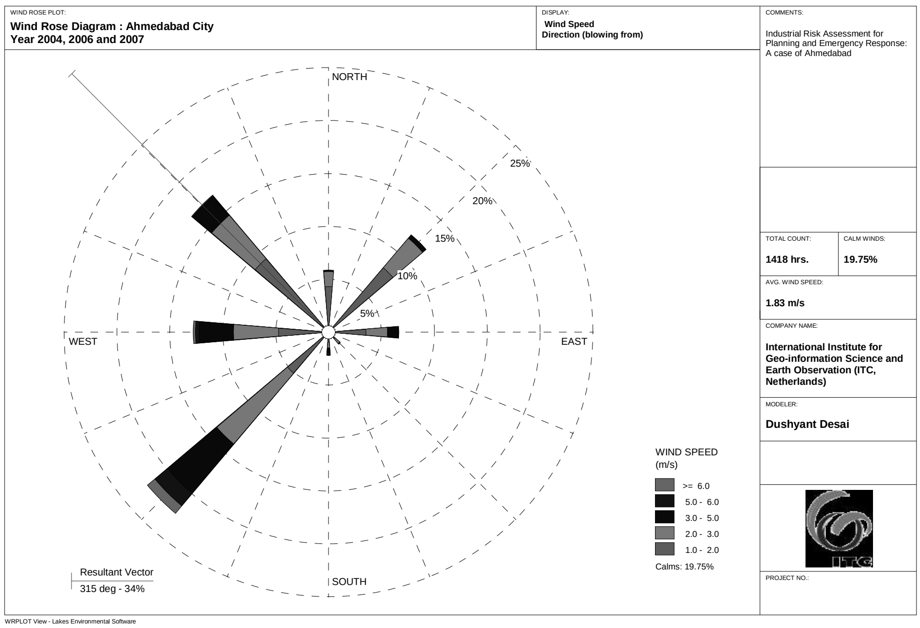

Figure 5-2: Wind rose diagram for year 2004, 2005 and 2007

Wind Speed/Wind direction	1.0 - 2.0	2.0 - 3.0	3.0 - 5.0	5.0 - 6.0	>= 6.0	Total
N	4.3018	1.4104	0.141	0	0	5.8533
NE	7.969	3.6671	0.4231	0	0	12.0592
E	3.5261	2.0451	0.9873	0.0705	0	6.6291
SE	0.7757	0.6347	0.0705	0	0	1.481
S	0.9168	0.5642	0.4231	0.2821	0	2.1862
SW	5.0776	8.7447	6.0649	1.5515	0.9168	22.3554
W	4.725	4.2313	3.244	0.3526	0.2116	12.7645
NW	9.0973	5.3597	2.3272	0.0705	0.0705	16.9252
Total	**36.3893**	**26.6572**	**13.6811**	**2.3272**	**1.1989**	**80.2539**

Table 5-3: Wind frequency distribution Frequency distribution wind

Frequency of Calm Winds: 19.75%
Average Wind Speed: 1.83 m/s

5.3.2. Worst case scenario

Since entry was forbidden in places where hazardous material is stored, certain conditions were assumed for analysis of worst situation scenario.

- Large amounts of hazardous materials stored in a single vessel
- All release of hazardous material takes place at ground level
- For first 10 minutes, release is at ambient pressure
- Unstable wind conditions

To study consequence effects of all identify possible hazards in study area (Table 5-2), a number of scenarios are analyzed. The storage conditions of chlorine and parathion methyl are not known. So the release is assumed as direct sources from storage container. All scenarios are discussed further.

Scenario for LPG

Case 1:
Leakage takes place from 1.5 inch valve till the container is emptied and it does not come in contact with another ignited source.
Case 2:
Leakage takes place from 1.5 inch valve till container is emptied and the gas burns as jet fire.
Case 3: Leakage takes place from 1.5 inch valve, which comes in contact with the ignited source after 20 minutes resulting in tank explosion (BLEVE).

Scenario for Chlorine

Case 1: Leakage takes place from 1.0 X 0.5 inch hole till the container is emptied.
Case 2: Leakage takes place from direct source at 1000 grams/sec for 30 minutes.

Scenario for Parathion-methyl

Case 1: Leakage takes place as direct source at 5000 grams/sec for 15 minutes.
Case 2: Leakage takes place as direct source at 500 grams/sec for 30 minutes

5.3.3. Weather condition for consequence analysis

CASE 1: Wind: 1.5 meters/second from NW at 3 meters
CASE 2: Wind: 2.5 m/s blowing from SW at 3 meters
CASE 3: Wind 1.5 m/s blowing from NE at 3 meters

Ground Roughness: urban or forest Cloud Cover: 0 tenths
Air Temperature: 36° C Stability Class: B
No Inversion Height Relative Humidity: 60%

This weather is used to model all consequence analysis. Above mention scenario for all three chemical are as follows.

5.4. LPG Hazard foot print

Liquefied petroleum gas is a mixture of hydrocarbon gases. It is primarily a mixture of Propane (CAS # 74-98-6)[4], and Butane (CAS # 106-97-8). The usual mix comprises of propane (60%) and butane (40%), though this is dependent on the weather. In winter propane concentration is higher, while in summer butane concentration is higher.

In this study area, Industry 1 has maximum storage capacity of 18.8 tonnes of LPG. Storage details are not available, and hence for the worst case, it is assumed that LPG is stored at ambient temperature in a single tank. For the purpose of analysis, the LPG is considered to be solely consisting of Propane. This assumption is justified because the propane has the lower flash point (- 104°C) among the mixture of propane and butane; and such an analysis would provide conservative results.

5.4.1. LPG Scenario 1

Leak from short pipe or valve in horizontal cylindrical tank
Flammable chemical escaping from tank (not burning)

Tank Diameter: 3 meters	Tank Length: 5 meters
Tank Volume: 35.3 cubic meters	
Tank contains liquid	Internal Temperature: 36° C
Chemical Mass in Tank: 18 tons	Tank is 98% full
Circular Opening Diameter: 1.5 inches	Opening is 0 meters from tank bottom.

Hazards foot prints are prepared for first two predominant wind conditions where wind speed is 1.5 and 2.5 m/s from NW and SW direction respectively. For the third predominate condition, wind speed 1.5 m/s from NE, hazards foot print is likely to be out side the study area, and hence consequence analysis is not carried 1. Hazards foot print prepared by ALOHA is shown in Figure 5-3. Figure 5-4 depicts the first two predominant wind conditions. The results are listed in Table 5-4.

4 Chemicals are often identified by their unique Chemical Abstract Service (CAS) Numbers

Wind Direction	Wind Speed	Distance in km		
	m/s	AEGL1[5]	AEGL2[6]	AEGL3[7]
NE	1.5	0.247	0	0.095
SW	2.5	0.2	0.2	0.2

Table 5-4 : Effective distance for LPG hazards for scenario 1.

Note:

Acute Exposure Guideline Levels (AEGLs) are Toxic Levels of Concern (LOCs) that can be used in ALOHA to predict the area where a toxic gas concentration might be high enough to harm people. The AEGLs are under development by the National Research Council's National Advisory Committee on AEGLs. More details is available at http://www.epa.gov/oppt/aegl/index.htm

5.4.2. LPG Scenario 2

Leakage from 1.5 inch valve in horizontal cylindrical tank till its gets emptied and burnt as a jet fire.

Effect of weather condition is negligible for this scenario, and a consequence analysis is carried out for wind speed of 1.5 meters/second from NW at 3 meters height.

Flammable chemical is burning as it escapes from tank

SOURCE STRENGTH

Tank Diameter: 3 meters Tank Length: 5 meters

Tank Volume: 35.3 cubic meters Internal Temperature: 36° C

Tank contains liquid Chemical Mass in Tank: 18 tons

Tank is 98% full

Circular Opening Diameter: 1.5 inches

Opening is 0 meters from tank bottom

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[5] AEGL-1: The airborne concentration of a substance above which it is predicted that the general population, including susceptible individuals, could experience notable discomfort, irritation, or certain asymptomatic non sensory effects. However, the effects are not disabling and are transient and reversible upon cessation of exposure.

[6] AEGL-2: The airborne concentration of a substance above which it is predicted that the general population, including susceptible individuals, could experience irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape

[7] AEGL-3: The airborne concentration of a substance above which it is predicted that the general population, including susceptible individuals, could experience life threatening health effects or death.

Hazard foot print for LPG scenario 2 prepared by ALOHA is shown in Figure 5-5. LPG will burn as jet fire for 31 minutes after release under assumed situation. Maximum rate of burn is 586 kilograms/min. Total 16,329 kilograms amount will burn in 31 minutes. As per Acute Exposure Guideline Levels (AEGLs) it is predicted that the extents of yellow threat AEGL 1 (2.0 kW/(sq m) = pain within 60 sec) is predicted to extend for more then 28 meter, orange threaten zone AEGL 2 (5.0 kW/(sq m) = 2nd degree burns within 60 sec) is predicted to extend for more then 18 meter and red threaten zone AEGL 3 (10.0 kW/(sq m) = potentially lethal

5.4.3. LPG Scenario 3

SOURCE STRENGTH

Leakage from 1.5 inch valve comes in contact with the ignited source after 20 min resulting in tank explosion involving 100 % mass (BLEVE).

Flammable chemical tank explosion when it escapes from tank

Tank Diameter: 3 meters Tank Length: 5 meters

Tank Volume: 35.3 cubic meters

Tank contains liquid Internal Temperature: 36° C

Chemical Mass in Tank: 18 tons Tank is 98% full

Circular Opening Diameter: 1.5 inches

Opening is 0 meters from tank bottom

As effect of weather condition is negligible for this scenario, a consequence analysis is carried out for Wind speed 1.5 meters/second from NW at 3 meters height.

Flammable chemical tank explosion when it escapes from tank

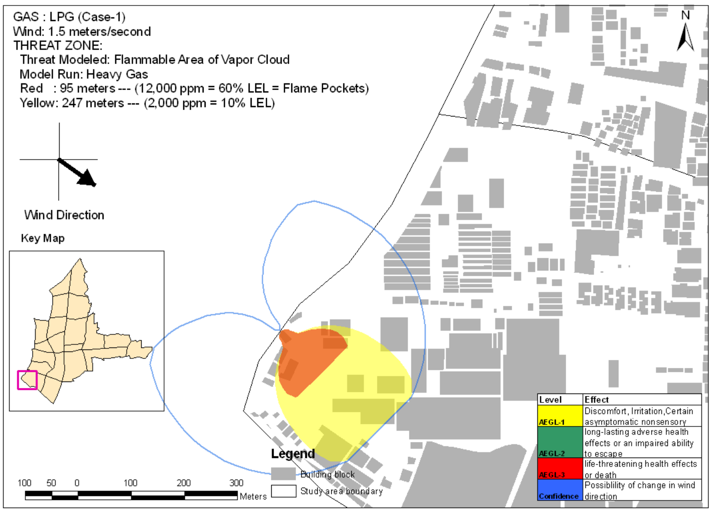

Figure 5-3 : Hazard foot print for LPG: Scenario 1 (CASE 1)

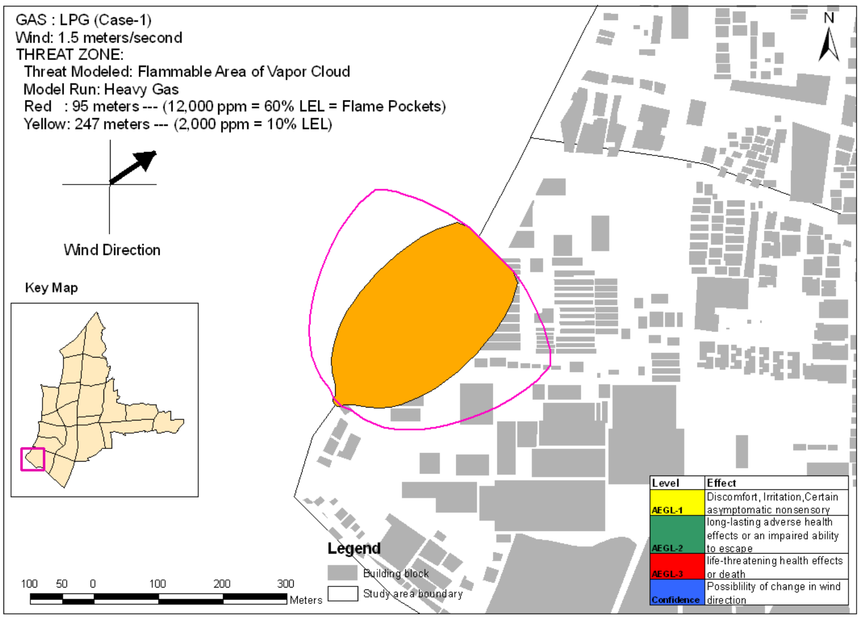

Figure 5-4 : Hazard foot print for LPG: Scenario 1 (CASE 2)

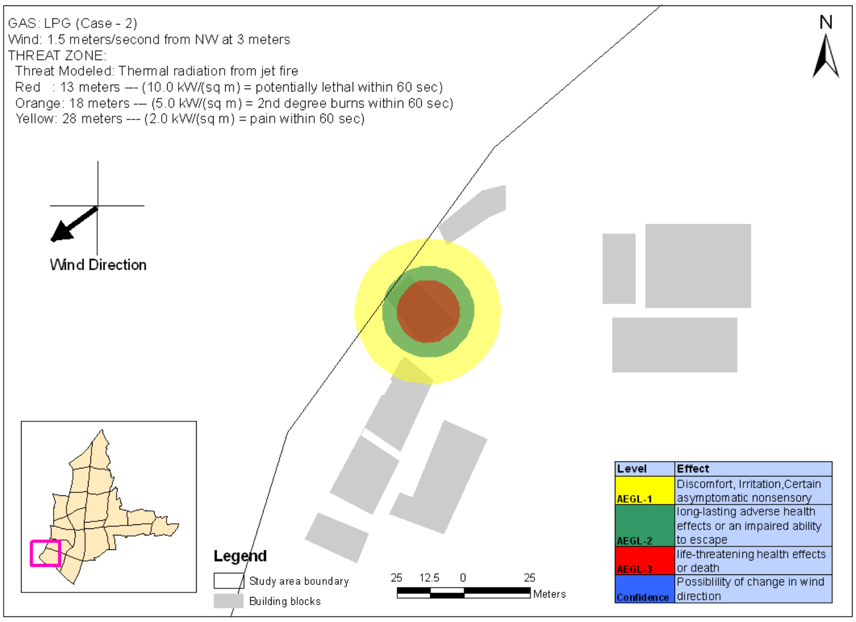

Figure 5-5 : Hazard foot print for LPG: Scenario 2

SOURCE STRENGTH

Tank Volume: 35.3 cubic meters
Tank contains liquid Internal Temperature: 36° C
Chemical Mass in Tank: 18 tons Tank is 98% full
Circular Opening Diameter: 1.5 inches Opening is 0 meters from tank bottom

Hazard foot print prepared by ALOHA shown in Figure 5-6. LPG will burn for 10 seconds. As per Acute Exposure Guideline Levels (AEGLs), yellow threat AEGL 1 (2.0 kW/(sq m) = pain within 60 sec) is predicted to extend for more then 703 meters. Similarly, orange AEGL 2 (5.0 kW/(sq m) = 2nd degree burns within 60 sec) threat is predicted to extend for more then 452 meters, while red threat AEGL 3 (10.0 kW/(sq m) = potentially lethal within 60 sec) is predicted to extend for more than 320 meters. Fire ball diameter is 147 meters from the source to the down wind direction (SW).

5.5. Chlorine hazard foot print

Chlorine is the non-metallic chemical element of CAS[4] number 7782-50-5. It is a greenish yellow gas with a strong suffocating odor. It is not flammable, but is toxic if inhaled. Chlorine is widely used for water purification and for preparation of many compounds. Two industrial industry 4 and industry 5 use chlorine as raw material. They have a maximum storage capacity of 20 tonnes and 18 tonnes respectively.

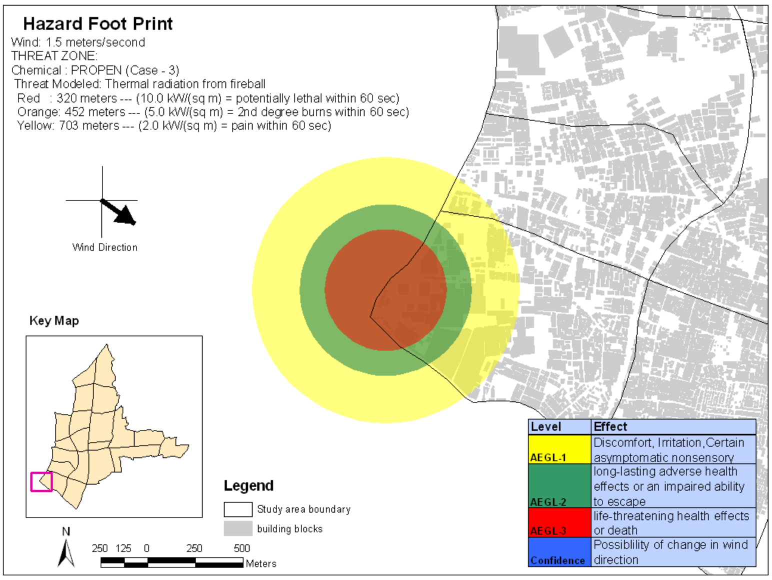

Figure 5-6 : Hazard foot print for LPG: Scenario 3

5.5.1. Scenario 1 Chlorine

Leakage from hole size 1 X 0.5 inches till the vertical tank gets emptied.

Industry 4 in study has maximum storage capacity of 20 tonnes and industry 5 has maximum storage capacity of 18 tonnes. In this scenario Hazard modeling is done for Shyam Chemicals Pvt. Ltd

SOURCE STRENGTH

Tank Diameter: 4 meters	Tank Length: 2 meters
Tank Volume: 25.1 cubic meters	Internal Temperature: 36° C
Tank contains liquid	Chemical Mass in Tank: 20 tons
Tank is 52% full	Opening is 0 meters from tank bottom
Opening Length: 1 inches	Opening Width: 0.5 inches

Hazards foot print prepared by ALOHA for chlorine toxic gas release under the assumed scenario 1 for all three predominant wind conditions is shown in

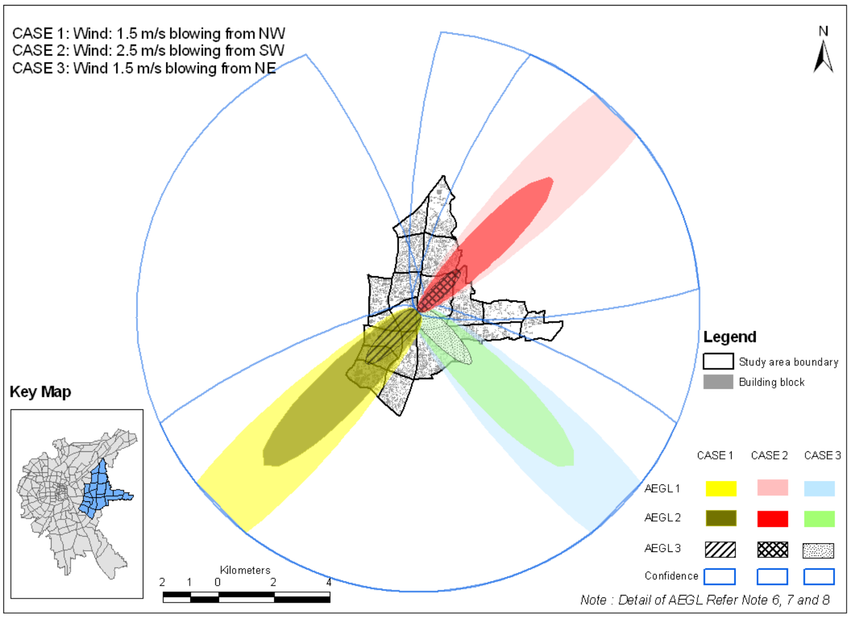

Figure 5-7. Effective distance at the end point is listed in listed in

	Wind Direction	Wind Speed	Distance in km		
		m/s	AEGL 1	AEGL 2	AEGL 3
Case1	NW	1.5	2.6	7.8	> 10
Case 2	SW	2.5	2.1	6.7	> 10
Case 3	NE	1.5	2.6	7.6	> 10

Table 5-5 : Effective distance for chlorine hazards for scenario 1

5.5.2. Scenario 2 Chlorine

Leakage takes place for 10 min as direct source at rate of 1000 grams/sec.

In this scenario hazards modeling is done for Industry 4 where maximum storage is 20 tonnes.

SOURCE STRENGTH:

Direct Source: 1000 grams/sec Source Height: 0

Release Duration: 10 minutes Release Rate: 60 kilograms/min

Total 600 kilograms chlorine will be released in 10 minutes. This chemical may flash boil and/or result in two phase flow.

In this scenario, hazard modeling is done for Parikh Enterprises Pvt. Ltd.

Hazard foot print prepared by ALOHA for chlorine toxic gas release under the assumed scenario 2 for all three predominant wind conditions is shown Effective distance at the end point is listed in Figure 5-8

	Wind Direction	Wind Speed	Distance in km		
		m/s	AEGL 1	AEGL 2	AEGL 3
Case1	NW	1.5	0.824	2.7	5.1
Case 2	SW	2.5	0.628	2.1	4.3
Case 3	NE	1.5	0.824	2.7	5.1

Table 5-6 : Effective distance for chlorine hazards for scenario 2

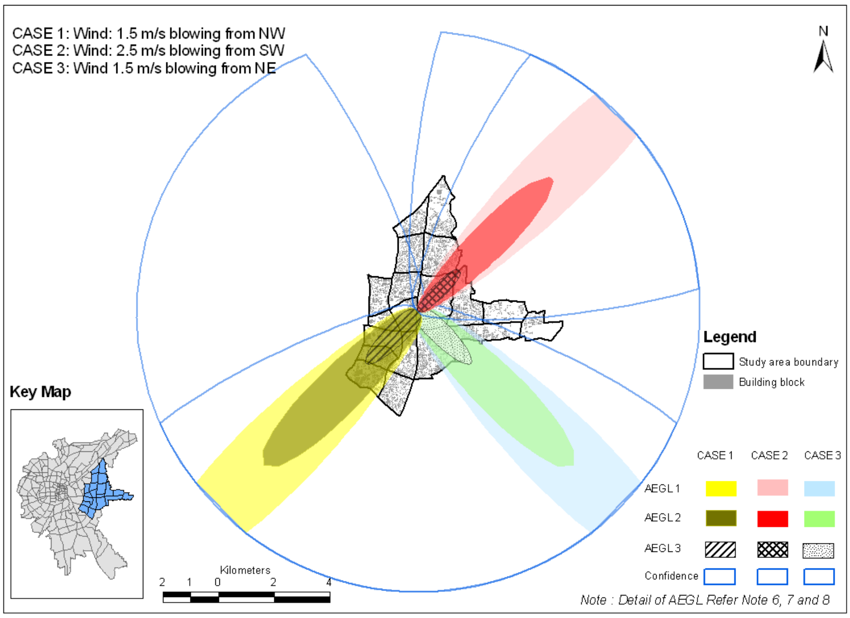

Figure 5-7 : Hazard foot print for chlorine: Scenario 1

5.6. Parathion-methyl

Parathion- Methyl is a white crystalline solid dissolved in a liquid solvent carrier. The commercial product is a tan liquid (xylem solution) with a pungent odour. It is slightly soluble to insoluble in water. If it comes in to the direct contact with humans, it can affect the central nervous system, blood, heart, liver and eyes.

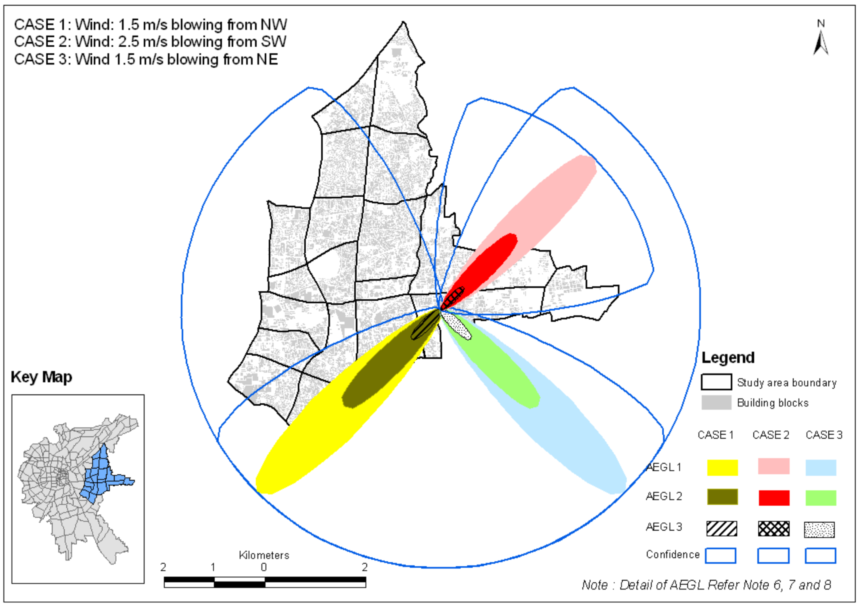

Figure 5-8 : Hazard foot print for chlorine: Scenario 2

Industry 2 has industry 3 in study area (Odhav GIDC) with maximum storage capacities of 5.2 tonnes and 1.2 tonnes respectively. The plant with the capacity of 5.2 tonnes (Industry 2) is selected for analysis. Analysis is done for same weather condition as previous case (5.3.3 pg 36) with third most frequent wind speed at 1.5 m/s from NE direction throughout the year.

5.6.1. Scenario 1: Parathion- Methyl

Leakage of Parathion- Methyl takes place from direct source at rate of 1000

SOURCE STRENGTH

grams/sec for 10minutes.
Direct Source: 5000 grams/sec Source Height: 0
Release Duration: 10 minutes
Release Rate: 300 kilograms/min
Total Amount Released: 3,000 kilograms

Hazard foot print prepared by ALOHA for parathion – methyl release under the assumed scenario 1 for all three predominant wind conditions is shown in Figure 5-10. Effective distance at the end point is listed in Table 5-7

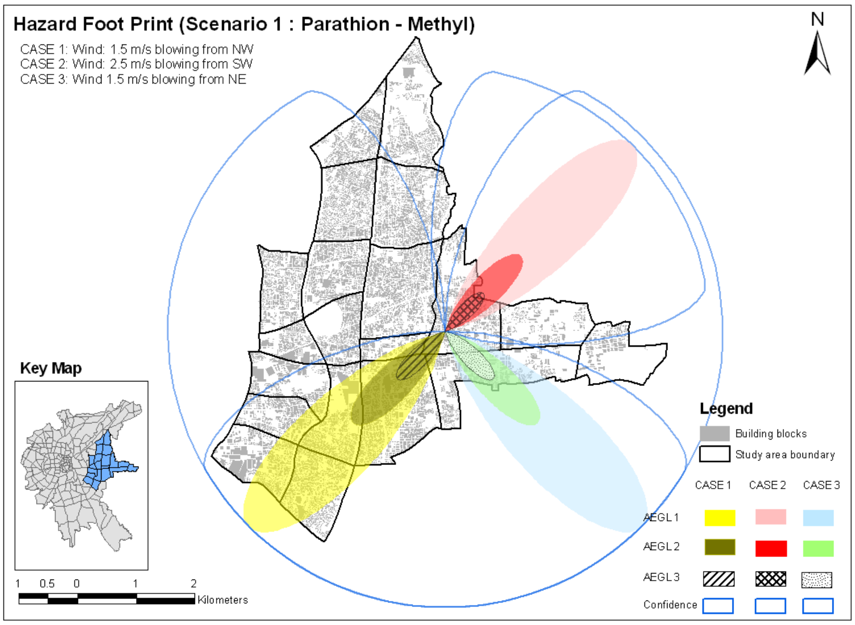

Figure 5-10

Figure 5-9 : hazard foot print Parathion- Methyl Case 1

	Wind Direction	**Wind Speed**	**Distance in kms**		
		m/s	**AEGL 1**	**AEGL 2**	**AEGL 3**
Case1	NW	1.5	1.2	2.2	5.1
Case 2	SW	2.5	0.628	2.1	4.3
Case 3	NE	1.5	1.2	2.2	5.1

Table 5-7 : Effective distance for parathion - methyl hazard scenario 1

5.6.2. Scenario 2 Parathion- Methyl

Parathion- Methyl leakage takes place a from direct source at rate of 100 kg/min for 30 minutes.

SOURCE STRENGTH

Direct Source: 100 kilograms/min Source Height: 0
Release Duration: 30 minutes
Release Rate: 100 kilograms/min
Total Amount Released: 3,000 kilograms

Hazard foot print prepared by ALOHA for parathion – methyl release under the assumed scenario 2 has same weather conditions as the previous three and is shown in Figure 5-11. Effective distance at the end point is listed in Table 5-8.

Table 5-8 : Effective distance for parathion - methyl hazard scenario 2

	Wind Direction	**Wind Speed**	**Distance in kms**		
		m/s	**AEGL 1**	**AEGL 2**	**AEGL 3**
Case1	NW	1.5	3.8	1.4	0.628
Case 2	SW	2.5	3.0	1.1	0.551
Case 3	NE	1.5	3.8	1.4	0.628

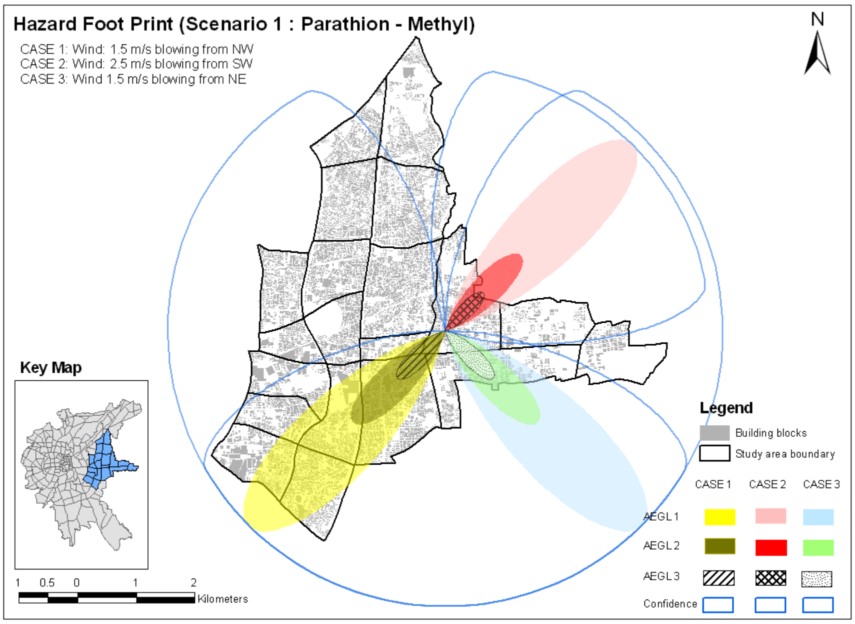

Figure 5-10 : Hazard foot print for Parathion- Methyl: scenario 1

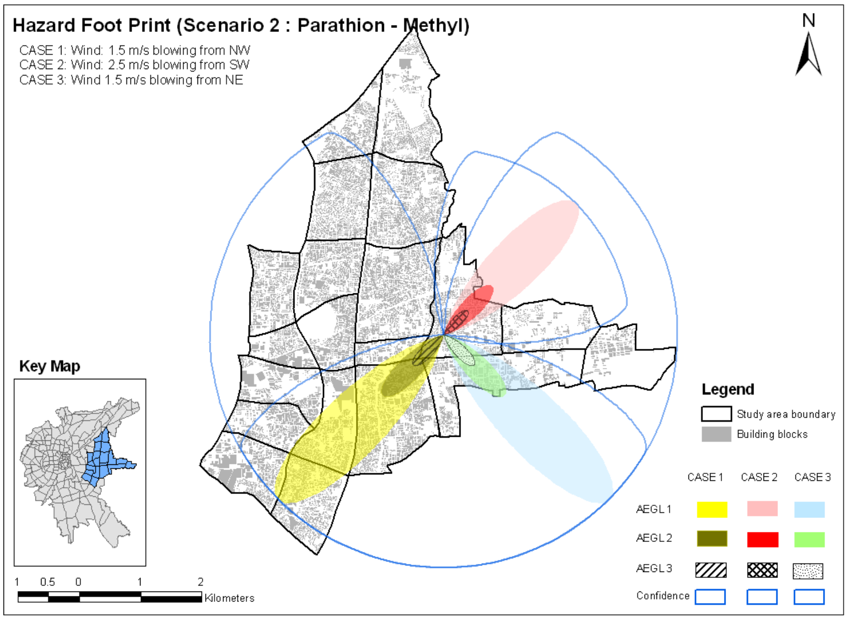

Figure 5-11 : Hazard foot print for Parathion- Methyl: scenario 2

5.7. Result

This chapter describes hazards identification and calculation of end distance point as per AEGLs guide line for selected scenarios using ALOHA model. The analysis is carried for three most predominant weather conditions of year (2004, 2005 and 2007). Calculated effective distance under various levels of AEGLs is listed in Table 5-9.

					Calculated End Point Distance (km)		
			WD	WS	Yellow zone	Orange Zone	Red Zone
Industry	Chemica	Scenario			AEGL 1	AEGL 2	AEGL 3
Industry 1	LPG	Not burn	NE	1.5	0.247	0	0.095
			SW	2.5	0.2	0.2	0.2
	LPG	Burn as jet fire	NW	1.5	0.028	0.018	0.013
	LPG	Explostion	NE	1.5	0.703	0.452	0.147
Industry 2	Chlorine	Leakage from hole	NW	1.5	> 10	7.8	2.6
			SW	2.5	> 10	6.7	2.1
			NE	1.5	> 10	7.6	2.6
Industry 3	Chlorine	Leakage as direct sources	NW	1.5	0.824	2.7	5.1
			SW	2.5	0.628	2.1	4.3
			NE	1.5	0.824	2.7	5.1
Industry 4	Parathion-methyl	Leakage at 1000 grams/sec for 10min	NW	1.5	1.2	2.2	5.1
			SW	2.5	0.628	2.1	4.3
			NE	1.5	1.2	2.2	5.1
Industry 5	Parathion-methyl	Leakage at rate of 100 kg/min for 30 min	NW	1.5	3.8	1.4	0.628
			SW	2.5	3	1.1	0.551
			NE	1.5	3.8	1.4	0.628

Table 5-9 : Effective distance of industrial hazards

6. Vulnerability Assessment

In general for quantification purposes degree of loss to a given element at risk is defined as vulnerability (Katuri, Sharifi et al. 2006). However a working definition of vulnerability is provided by Plers Balaik who defines it as “characteristics of person or group in terms of their capacity to anticipate to cope with resists and cover from the impact of hazards”. Some groups in society are more prone than other groups. Concept of vulnerability clearly involves varying magnitude from high to low level vulnerability. These groups could be based on the economic class, caste, ethnicity, gender, disability, seniority, age and sex. Effect of inhalation of toxic gas could depend on age of person. Children under age 6 year are likely to be more affected than an adult. Taking this into consideration, the total population in study area is distributed according to age. Vulnerability assessment is limited to human beings in this study.

6.1. Population distribution

Total area of Ahmedabad city is approximately 190.84 sq.km., which is managed by Ahmedabad Municipal Corporation (AMC). The surrounding urban jurisdiction area has been developed by Ahmedabad Urban Development Authority (AUDA). This area is much greater then AMC limit area. AMC area is divided in to 43 municipal wards for administrative purposes. Municipal area is further divided in to 147 TAZ[1] levels for transportation planning of the city. Population and traffic behaviour data is available at TAZ level which is the smallest mapping unit available for the city. Part of the city taken as study area covers 20 TAZ. Total population with in this area is 64, 6919. Main objective of population vulnerability assessment is to estimate the precise number of people in all age groups at different times that are likely to be affected if a particular identified event takes place. To achieve the higher accuracy, population distributions is done at building level from the smallest available mapping unit TAZ.

There are 38,663 buildings in the study area. These buildings are classified mainly in two categories to estimate the distribution of number of people within these buildings at different time. The first category is residential, while the second comprises of institutes, commercial, industrial, educational and all others combined together. Total 34,729 buildings are in residential category which accounts for 92 % of the total buildings in study area. There are two village settlement within the city area which is taken as single unite because it is not possible map individual building separately. Population distribution is conducted only for the residential buildings for night time (8:30 PM to 7 AM) and day time (7 AM to 2 PM).

Study conducted by (Singh 2005) shows that in Indian context, around 2 % of the population is away from their house during the night time. These may be people working in night shifts, like the security guards. To simplify calculations, it is assumed that during the night time, total population stays at home. This is because the study area is a core business district surrounded by Odhav industrial estate. Built up area is a key criterion for distribution of population in residential buildings. Built up area is derived from high resolution satellite data (Google Earth TM), while the number of floors and types of buildings is collated from the field survey as part of PhD research titled "*Development of Spatial Planning and Decision Support Systems for Urban Risk Reduction*" by Mr. Ajay K. Katuri. Population details are available at TAZ level which are further disaggregated in to gender, workers and different age categories from wards level census data.

6.2. Calculation of population in individual buildings:

Population in each building is calculated in a sequence of following four steps.

1. The total floor area for each building is calculated on the basis of the following formula:

Total floor area for TAZ =

$$\sum \textit{Built Up Area x Number of } \text{Floors} \;\ldots.. \text{(A)}$$

2. Population per unit floor area can be assumed to be same for all classes of buildings. In general looking at the Indian urban characteristic density in slums is higher than other classes of housing. To overcome this problem, population distribution is calculated separately for both classes of housing.

Population residing in slum areas in each ward are taken from the census data. From the building footprint, buildings under the category R1(Annexure 4) are

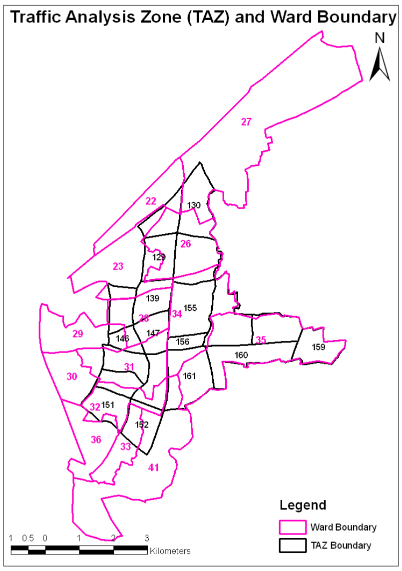

Figure 6-1 : Study area (ward and TAZ boundary)

defined as slums. Details of TAZ 158 is shown in Figure 6-2

Figure 6-1 shows that TAZ unit is smaller than a ward. In addition to that boundary of TAZ and ward is not the same. In that case one TAZ could be part of one or even more than one wards.

Due to this configuration of TAZ, following steps are taken to derive the slum population at TAZ level.

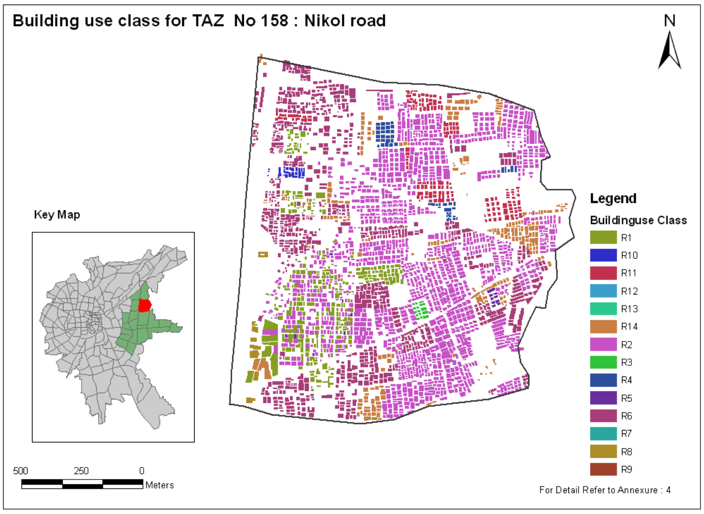

Figure 6-2 : Land use classification for residential building

3. Slum population for TAZ (i) =

$$\sum \frac{Slum\ population\ of\ ward\ in\ which\ TAZ\ (i)\ is\ located}{No\ of\ wards\ in\ which\ TAZ\ (i)\ is\ located} \text{ .... (B)}$$

4. Value obtained from equation (B) is distributed in individual building based on floor area of each building in following fashion.

Population/built up =

$$\frac{Slum\ population\ of\ TAZ}{Total\ Floor\ Area\ of\ TAZ} = \frac{B}{A} \text{ ……………… (C)}$$

5. Population in individual building =

$$\frac{Polpulation}{Built\ Up}\ x\ (Built\ Up\ Area\ x\ Number\ of\ Floors) \text{..(D)}$$

Using the same steps, population in other categories of building from R2 to R12 (Annexure 4) is also calculated. Total population of other category is derived by subtraction the slum population from TAZ population. In equation C the population in the other category is considered in place of slum population. Population distribution in side the building at night time is shown in Figure 6-3 . After distribution total population in study area is 645,478. The difference 1,441 between the actual and distribution is because of error in geo-referencing in wards boundary with TAZ boundary.

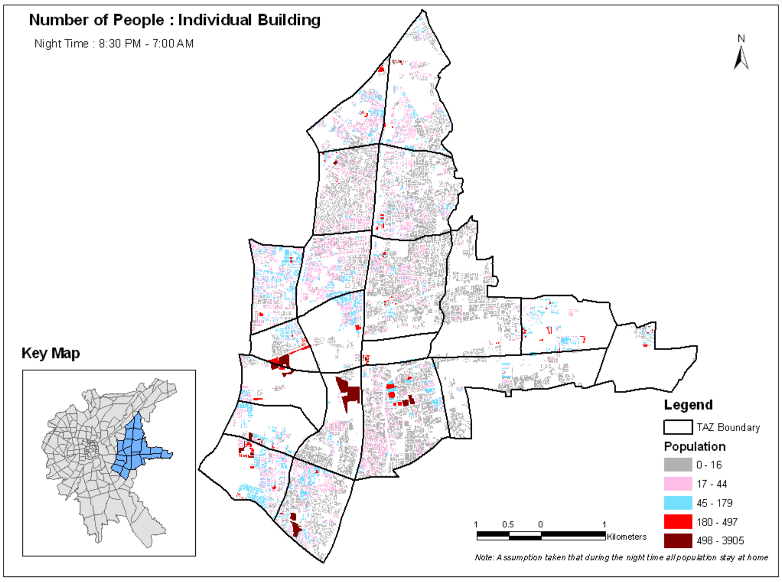

Figure 6-3 : Population distribution in building at night time

6.2.1. Gender and worker distribution

Estimation of number of males, females and number of workers in individual building is estimated from the total number of people in the buildings. Estimation of working population in residential building is important, because at office time working people are not present in the residential building and so they are not likely to be affected if any accident takes place during that time.

At the level of TAZ, census data only provides the figures for total population and no individual breakup on the basis of gender etc are provided. To estimate the gender and worker distribution at building level, ward data is first segregated at TAZ level. Method used in population distribution is also used to segregate the gender and working population at TAZ level from wards. Ratio of male-female and percentage of working population from total population at TAZ level is applied to the individual building. Chances of accuracy are higher in this way because TAZ is the smallest mapping unit in the study area. Gender distribution inside the building shown in Figure 6-4 pg54 . Worker distribution is shown in Figure 6-5 pg 54

6.2.2. Age distribution

Age distribution is essential at the building level, because children below 6 years are more susceptible to greater injuries than adults. Moreover, school going children are not present in residential buildings from 8 A.M. to 2 P.M. If an accident takes place at that time, this section of population is not likely to be present in the residential building. 1981 census data is available for male and female population under various categories at the city level. This ratio is applied to individual buildings after deriving the gender distribution at building levels (6.1. pg 49).

6.2.3. Temporal variation of population

As mentioned before it is assumed that all people stay at home during the night. Workers are not present at home from 7-18 hours, while school or college going students are not present at home from morning 7-14 hours. Study conducted by (Singh 2005) shows that in Indian context around 2.2 % of non working females are away from home for maximum 2 hrs during that time. This time varies between 9-14 hours. For simplification of distribution, movement of non working females during this time is not considered (Singh 2005).

Number of people in building during daytime (7:00 AM to 2:00PM) =

Total population - workers - population below the age 19 year

Population distribution inside the building during day time is shown in Figure 6-6 pg 55

6.3. Population distribution on road

People travelling on the road at the time of accident are more vulnerable than people in side various buildings. It is thus important to estimate the number of people who are likely to be affected directly while estimating risk.

There are 20 TAZ zones in the study area. Origin and destination data collected under Bus Rapid Transport System (BRTS) project is used to conduct traffic assignment modelling. Total 58715 origin and destination surveys for peak and off peak hours is carried for Ahmedabad city under the BRTS project. Numbers of people are entering each TAZ (Attraction trip) and going out (Production trip) from each TAZ for peak and off peak time is used for this task. Traffic assignment study is carried out for both peak and off peak hours. Results obtained from traffic assignment modeling in Flowmap7.3 software is shown in Figure 6-7 pg 55

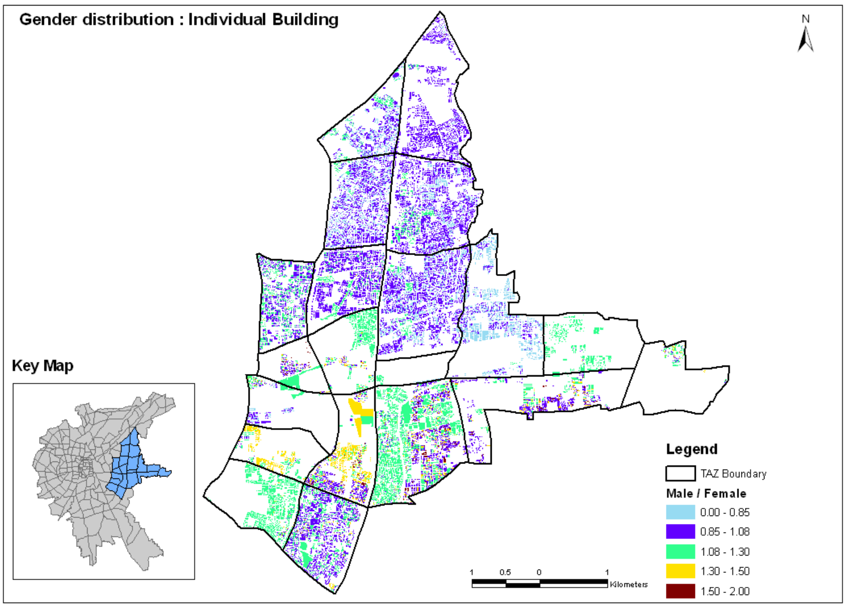

Figure 6-4 : Gender distribution of population in side the building

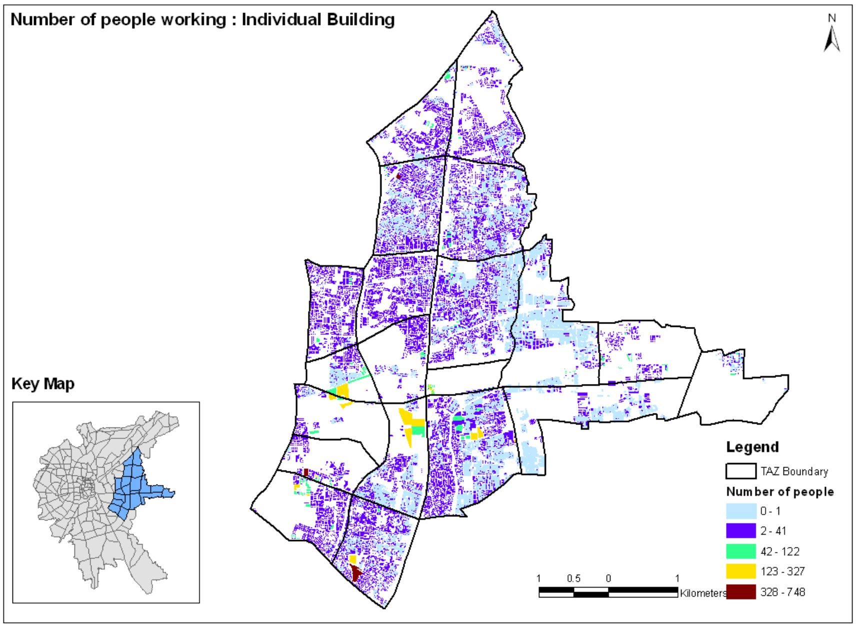

Figure 6-5 : Worker distribution of population in side the building

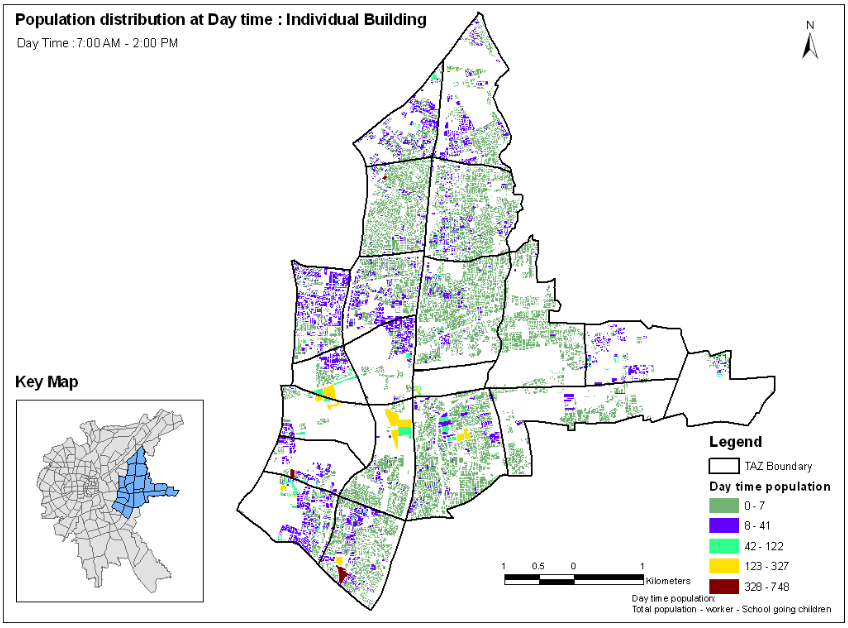

Figure 6-6 : Population distribution in building at day time

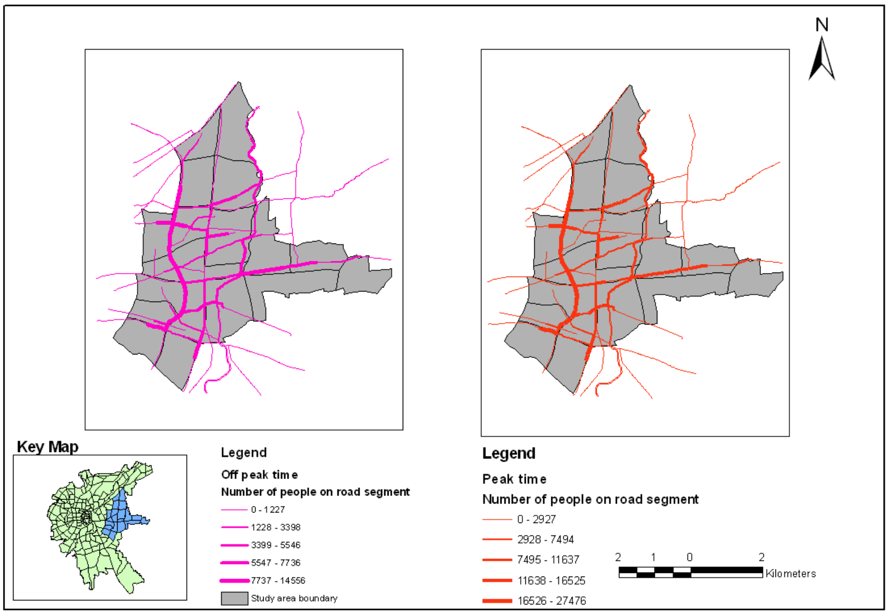

Figure 6-7 : Traffic flow along the road

Fields data is available for some of routes in study area. Comparison between model output and field data for some of routes indicates that predicted traffic value is around 8 % higher. This is because FlowMap7.3 software uses Gravity model which works on the shortest distance method. This method is not accurate for accurate traffic flow assignment but it gives a good idea of flow pattern. Flowmap 7.3 is used in this study since it requires less input information and is user friendly.

6.4. Population vulnerability assesment

After preparing the hazard foot print and population distribution, further analysis is carried out to estimate the number of people like to be affected for hazards. More people are likely to be affected if the accident occurs during night time.

Hazards foot prints are overlaid on population distribution layer to estimate the total number of people affected by the individual hazards. Numbers of people that might need hospital treatment is also (vulnerability of population) estimated. In an earlier study Gurjar has derived the total cancer risk due to hazardous chemicals in the state of Gujarat (Gurjar and Mohan 2003). Data from that study is used to ascertain the individual health risks for those people who may need hospital treatment. Based on the given data, the annual risk factor for hospitalization and mortality will be 2.45×10^{-3} and 8.95×10^{-5} respectively.

This value varies with level of hazards. In the present study, individual health risk is higher for people who are affected by AEGL3 limit then the AEGL1. Due to the non availability of sufficient information, it is assumed to be same for all levels of exposure. The number of people likely to die and those requiring hospital treatments is calculated by the following two formulae respectively:

Number of people likely to be affected in all categories from hazards × Health risk factor for people needs treatment

Number of people likely to be affected in all categories from hazards × Health risk factor for people

Number of people that are vulnerable for day and night time scenarios are shown in Table 6-1 and Table 6-2

					No of people			
Industry	**Chemical**	**Scenario**	**WD**	**WS (m/s)**	**Affected**	**Died**	**Need treatment**	**Total Vulnerable**
1	LPG	Not burn	NW	1.5	0	0	0	0
			SW	2.5	12	0	0	0
	LPG	Burn as jet fire	NW	1.5	0	0	0	0
	LPG	Explosion	NW	1.5	7252	1	18	19
2	Chlorine	Leakage from hole	NW	1.5	566006	51	1410	1461
			SW	2.5	252217	23	628	651
			NE	1.5	409241	37	1020	1056
3	Chlorine	Leakage as direct sources	NW	1.5	198661	18	495	513
			SW	2.5	47506	4	118	123
			NE	1.5	521611	47	1300	1346
4	Parathion -methyl	Leakage as direct source	NW	1.5	267510	24	667	690
			SW	2.5	47075	4	117	122
			NE	1.5	519137	47	1293	1340
5	Parathion -methyl	Leakage as direct source	NW	1.5	216274	19	539	558
			SW	2.5	30441	3	76	79
			NE	1.5	451177	40	1124	1165

Table 6-1 : Vulnerable population (night time scenario)

					No of people			
Industry	**Chemical**	**Scenario**	**WD**	**WS**	**Total Affected**	**Died**	**Need treatment**	**Vulnerable**
1	LPG	Not burn	NW	1.5	0	0	0	0
			SW	2.5	10	0	0	0
	LPG	jet fire	NW	1.5	0	0	0	0
	LPG	Explosion	NW	1.5	248	0	1	1
2	Chlorine	Leakage from hole	NW	1.5	34983	3	87	90
			SW	2.5	17060	2	43	44
			NE	1.5	23388	2	58	60
3	Chlorine	Leakage as direct sources	NW	1.5	12915	1	32	33
			SW	2.5	3272	0	8	8
			NE	1.5	30574	3	76	79
4	Parathion -methyl	Leakage as direct sources	NW	1.5	17361	2	43	45
			SW	2.5	3928	0	10	10
			NE	1.5	31051	3	77	80
5	Parathion -methyl	Leakage as direct sources	NW	1.5	15319	1	38	40
			SW	2.5	2996	0	7	8
			NE	1.5	28090	3	70	73

Table 6-2: Vulnerable population (day time scenario)

6.5. Summary

The first phase of this chapter describes the estimation of temporal variability of population in residential buildings in the study area. Population density in various classes (Slum and other) is considered as a key parameter. Origin and destination (OD) data collected under the BRTS (Bus rapid Transport System) is used to calculate number of people likely to be affected on the roadside. Population vulnerability is calculated in last part of this chapter. Table 6-1 reveals that highest vulnerable population (1461) arises out of hazard at industry 2. This is followed by industry 3 (1346) and 4 (1340). This sequence is same for day time scenario as well. Risk assessment is carried for these hazards for both day and night time scenario.

7. Risk assessment

7.1. Introduction

After completition of hazard identification and mapping of elements at risk, this chapter deals with risk quantification as the third and final phase of study. Risk is defined “as the expected number of lives lost, persons injured, damage to property and disruption of economic activity due to a particular landslide hazard for a given area and reference period” (Westen 2004). Based on mathematical calculations, “Risk is the product of hazard, vulnerability and cost of the elements at risk”(Westen 2002). It can be define as in terms of formula as

7.2. Risk estimation

Risk = $\left(H\ x \sum \left(V\ x\ A\ \right)\right)$**…………………………………………….(1)**

Where:
H = Hazard expressed as probability of occurrence within a reference period (e.g., year)
V = Physical vulnerability of a particular type of element at risk
A = Amount or cost of the particular elements at risk (e.g., number of buildings, cost of buildings, number of people, etc.).

To estimate the risk [using formula (1)], the required input value is H (Probability of occurrence). Calculating the probability occurrence is a very detailed task and requires an extensive data set which is not available for the study area. To overcome this limitation, a value calculated by Cozzani in Piombino, Italy is used for present study. He has used risk-based approach for calculation of expected occurrence frequency of possible accident scenarios for fixed risk sources in Piombino. This method approach is followed in the United Kingdom and Netherlands for certain cases of hazards (Cozzani, Bandini et al. 2006). His study for various hazardous chemical reveals that the frequency probability for constant release of toxic gas varies from 9.47×10^{-7} to 3.03×10^{-5} annually. By considering the worst case scenario, the higher probability value of 3.03×10^{-5} annually is taken for risk analysis. Probability for occurrence for LPG jet fire and LPG explosion is 1.5×10^{-6} and 1.0×10^{-6} respectively. Direction of wind is also important in case of toxic chemical release. Hence percentage of wind direction is also considered while calculating individual risk.

Second required input [using formula (1)], is V*A, which is the number of vulnerable people. This has already been derived (Refer 6.4, pg 56). Since released toxic gas scenario have no effect on housing and buildings, hence the buildings at risk are not relevant.

Risk estimation is carried out for both day and night time. Risk value for time spent on commuting is also important, since population along the road will be in direct contact with hazards. Due to time constraints and lack of information, study is not extended to commuting time scenario.

7.2.1. Risk estimation for night time scenario

As mentioned before, during night time all people are assumed to be staying at home. The calculated risk for all possible hazards is listed in Table 7-1 : Risk value for night time .

					H		VA	R
Industry	**Chemicals**	**Scenario**	**WD**	**WS**	**Probability of event occurrence**	**wind condition (% of year)**	**Vulnerable**	**Risk (People)**
1	LPG	Not burn	NW	1.5	-	0.9	0	0.0000
			SW	2.5	0.0000015	0.87	0	0.0000
	LPG	jet fire	NW	1.5	-	0.9	0	0.0000
	LPG	Explosion	NW	1.5	0.000001	0.9	19	0.0000
2	Chlorine	Leakage from hole	NW	1.5	0.0000303	0.9	1461	0.0443
			SW	2.5	0.0000303	0.87	651	0.0198
			NE	1.5	0.0000303	0.8	1056	0.0320
3	Chlorine	Leakage as direct sources	NW	1.5	0.0000303	0.9	513	0.0156
			SW	2.5	0.0000303	0.87	123	0.0037
			NE	1.5	0.0000303	0.8	1346	0.0408
4	Parathion -methyl	Leakage as direct sources	NW	1.5	0.0000303	0.9	690	0.0209
			SW	2.5	0.0000303	0.87	122	0.0037
			NE	1.5	0.0000303	0.8	1340	0.0406
5	Parathion -methyl	Leakage as direct sources	NW	1.5	0.0000303	0.9	558	0.0169
			SW	2.5	0.0000303	0.87	79	0.0024
			NE	1.5	0.0000303	0.8	1165	0.0353

Table 7-1 : Risk value for night time scenario.

7.2.2. Risk estimation for day time scenario

People staying at home are likely to be affected while analyzing the day time scenario. Refer (6.2.3 Pg. 53) for details of population distribution according to the day time scenario.

Industry	Chemicals	Scenario	WD	WS	Probability of event occurrence	wind condition (% of year)	Vulnerable	Risk (People)
1	LPG	Not burn	NW	1.5	-	0.9	0	0
			SW	2.5	0.0000015	0.87	0	0
	LPG	Burn as jet fire	NW	1.5	-	0.9	0	0
	LPG	Explosion	NW	1.5	0.000001	0.9	1	0.0000
2	Chlorine	Leakage from hole	NW	1.5	0.0000303	0.9	90	0.0025
			SW	2.5	0.0000303	0.87	44	0.0012
			NE	1.5	0.0000303	0.8	60	0.0015
3	Chlorine	Leakage as direct sources	NW	1.5	0.0000303	0.9	33	0.0009
			SW	2.5	0.0000303	0.87	8	0.0002
			NE	1.5	0.0000303	0.8	79	0.0019
4	Parathion-methyl	Leakage as direct sources	NW	1.5	0.0000303	0.9	45	0.0012
			SW	2.5	0.0000303	0.87	10	0.0003
			NE	1.5	0.0000303	0.8	80	0.0019
5	Parathion-methyl	Leakage as direct sources	NW	1.5	0.0000303	0.9	40	0.0011
			SW	2.5	0.0000303	0.87	8	0.0002
			NE	1.5	0.0000303	0.8	73	0.0018

Table 7-2 : Risk value for night time scenario

7.3. Summary

This chapter describes the calculation of risk for possible hazards in three most predominant wind directions. Table 7-1and Table 7-2 illustrates that the predicted risk to population from industrial hazards is very low in the study area. Highest risk to population is from industry 2, followed by industry 3 and 4 respectively for the night time scenario. Risk value at night time scenarios is much higher than day time scenario. Possible reasons are discussed in the next chapter.

8. Results and conclusions

The main aim of study is to assess the area, buildings and population threatened by industrial accidents in the study area. Hazards foot print prepared for identified hazards is described in Chapter 5. Chapter 6 describes mapping of elements at risk, while risk value is calculated in Chapter 7. This chapter discusses the number of people and residential building categories which are likely to be affected by hazards in case an event takes place.
The answers of all the research questions are enumerated in the Conclusions section.

8.1. Results

8.1.1. Risk value on population loss

Fire, explosion and toxic gas leakage are three kinds of hazards are possible in 5 MAH units in the study area. LPG, Chlorine and Parathion-methyl are hazardous chemicals used in these industrial units. Vulnerable index for all analyzed scenarios in various MAH units are shown in Figure 8-1. Risk value for estimated population loss is shown in Figure 8-1

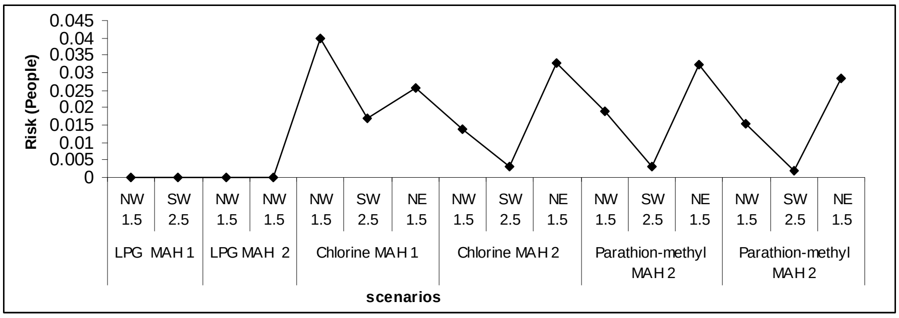

Figure 8-1: Risk value on population loss for night time scenario

8.1.2. Vulnerable population

If any of the three highest risk events occurs, then the number of people likely to be effected in such a scenario is calculated. The calculations are made both according to age and gender to enable preparation of risk management plan for the entire study area.

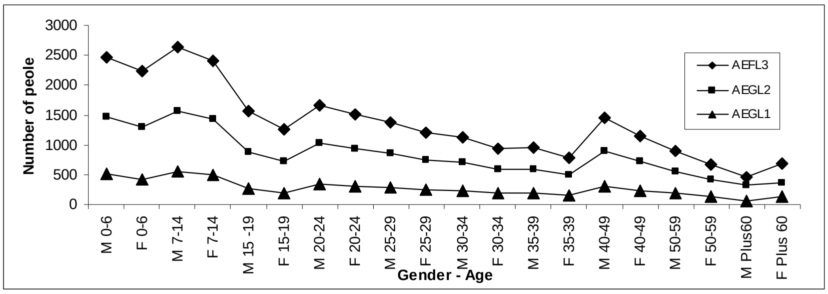

Figure 8-2 : Gender and age distribution of people likely to be affected from hazards at industry 2

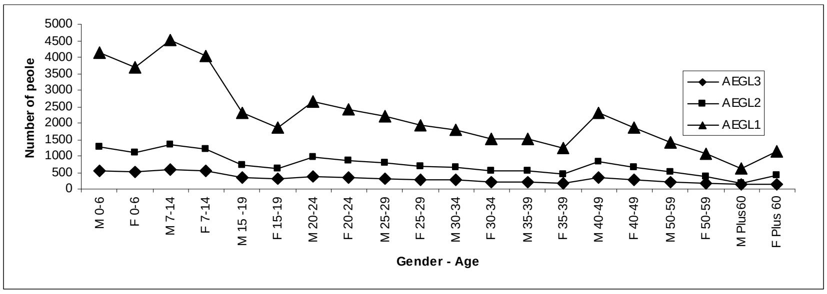

Figure 8-3 : Gender and age distribution of people likely to be affected from hazards at Industry 3

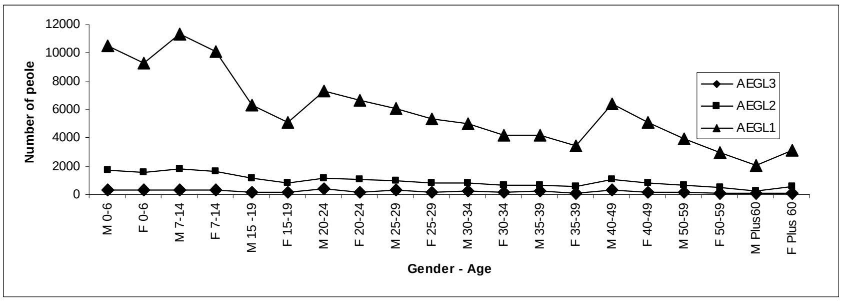

Figure 8-4 : Gender and age distribution of people likely to be affected from hazards at industry 4

Figure 8-2 - Figure 8-4 reveals that children (1-14 years) are more likely to be affected compared to other categories, for all cases of hazards. Although hazards at industry 2 has a higher risk, but number of children likely to affected from hazards at industry 3 is more than that of industry 2. Refer the foot notes 5, 6, and 7 on page number 42 for information on the level of effects under AEGL1, AEGL2 and AEGL3.

8.1.3. Vulnerable building

Since the three most vulnerable hazards belong to the category of toxic releases, there is no direct effect on building structures. However, the number of residential buildings falling under affected area in various land use categories (Annexure 4) are summarised below.

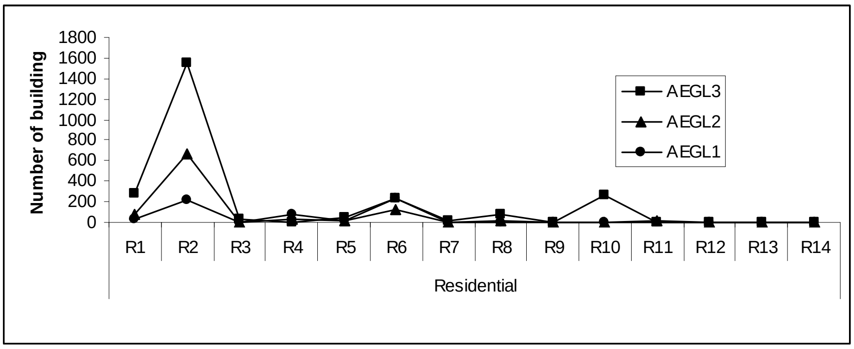

Figure 8-5 : Categories for building likely to be affected from hazards at industry 2

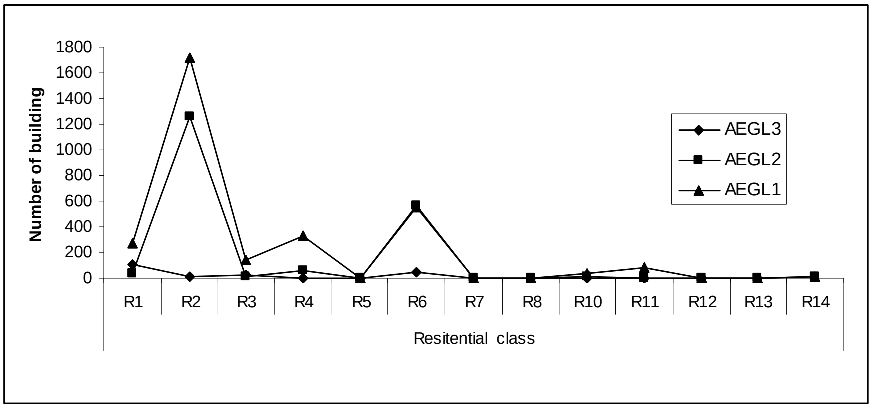

Figure 8-6 : Categories for building likely to be affected from hazards at industry 3

Figure 8-5 -- Figure 8-7 indicates that the maximum number of buildings likely to be affected in all three hazards are R1 (Slums) and R2 (Low class housing) followed by R6 (apartment < 3 floors). Since slums and low class housing are more likely to be affected, we can safely conclude that it is the poor people who are more vulnerable.

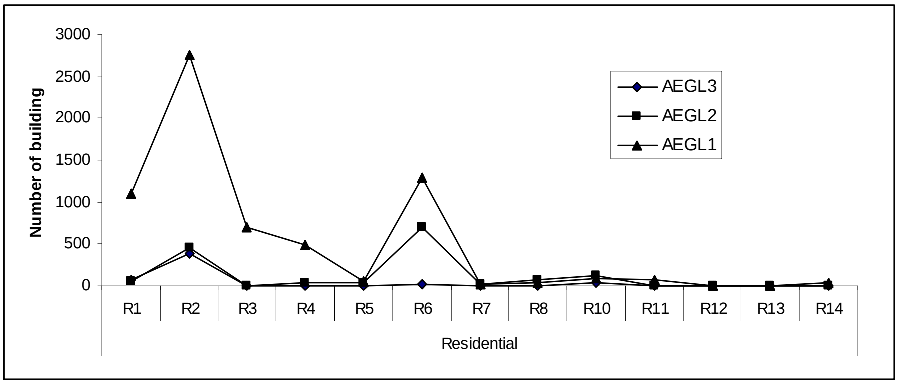

Figure 8-7 : Categories for building likely to be affected from hazards at industry 4

8.2. Conclusion

The study encompasses various likely industrial hazards in an urban area, with reference to Ahmedabad city.
Five industrial units under the MAH category are located with in the study area. LPG gas, Chlorine and Parathion-methyl are the main hazardous chemicals used in these industries. Possible hazards from these chemical are jet fire, explosion and leakage of toxic materials.

ALOHA model which is used in this study is not able to predict all possible hazards in the study area. Fire or downwind toxics effects of byproducts which will be generated by LPG gas can not be modeled by ALOHA. Hazard modeling has been carried out for fire, explosion scenario for LPG and downwind toxics effect of Chlorine, Parathion-methyl and LPG for three predominant weather conditions (2004, 2005 and 2007).

Population distribution is another major task in the study. Population is distributed from TAZ to building level separately for slums and other types of housing. Difference between the actual population and distributed population in the study area is a mere 0.23% ,which is negligible. People traveling on road who directly come in contact with released hazardous materials are calculated using Flowmap 7.3 education version. The result outcome indicates that major traffic for peak and off-peak hour occurs through the North-South corridor (Figure 6-7). Peak hour time traffic is higher than off-peak hour by whopping 53 per cent.

Risk estimation shows that release of chlorine from industry 2 for a wind speed of 1.5 m/s blowing from NW direction has the highest risk (0.0443 people). This is followed respectively by release of chlorine from industry 3 and release of Parathion-methyl from industry 4 when wind speed of 1.5 m/s blows from NE direction.

Risk value calculated in the study is much lesser than expected. Two possible reasons could be postulated for this.

First, the geographical extent of the hazard area is much higher than our study area. Moreover, only a portion of the study area falls under the possible hazard coverage map. The total area and population covered by the hazard is much more, but it does not overlap entirely with our study area. The intersection of our study area with the hazard coverage being lesser, the extent of area and population falling under risk category in study area is lesser than the total population at risk.

The health risk data has been obtained from official statistics, which tends to be on the lower side. This also resulted in the final figure of vulnerable population being lesser than anticipated.

In addition, children below the age 14 year are more likely to be affected by hazards at industry 4. Vulnerability assessment reveals that poor people staying in slums and low class houses are more likely to be affected than other housing classes. The highest risk arises by hazards at industry 2, while more children are likely to be affected by hazards at industry 3. People living in low class housing or slums are more likely to be affected by hazards at industry 4.

8.3. Limitations of study

- Non working people and people engaged in commercial activity are not taken into account in the study. Hence the risk for daytime scenario is lower than that of the night time scenario.
- Level of severity caused by hazard is also dependent on the building construction materials. Due to the lack of information on the materials used for construction, it was not considered while calculating the risk.
- Flowmap 7.3 software used for traffic assignment modeling uses the shortest distance method. The shortest distance method can not provide accurate information of people who are travelling along inner or minor roads.

- Assessment of risk requires very detailed information of population, and its spatial and temporal distribution. However such information was not available in study area, and hence it was ignored.

8.4. Recommendations

- Ground verification of temporal and spatial aspects of population distribution needs to be conducted before embarking on risk management plans.
- Detail information such as traffic volume survey, cost of travelling and vehicle speed if used as an input in Flowmap software can provide a better idea of people travelling behaviour.
- Numbers of poor people likely to affected is more. Hence there is an urgent need to make provisions for free medical facilities in the study area.
- This study can be further extended to prepare a detailed city level risk management plan for Ahmedabad city. However such an attempt would require information regarding movement of non working people, people engaged in commercial activity as well as types of building material.

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Annexure 1 : List of agency working for industrial activity in Gujarat state

Authority	**Purpose/clearance**
iNDEXTb	For identification of project, project formulation and counseling on various Government formalities to set up an industrial project in Gujarat.
Secretariat for Industrial Assistance	IEM/LOI/LOP
Office of the Development Commissioner	100% EOU - for automatic approval
Foreign Investment Promotion Board	Foreign equity approval
Concerned DIC or Industries Commissionerate	SSI No through DIC/incentives registration/ incentives claim/Govt land/site clearance/powerloom registration
Gujarat Industrial Development Corporation (GIDC)	GIDC Estate: acquiring land, building plan approval, water connection
Gujarat Pollution Control Board	Clearance from pollution angle – NOC/consent
Gujarat Electricity Board	Sanction of power, cost estimates for drawing the line and execution for giving power connection.
Gujarat Energy Development Agency	Non-conventional sources of energy
Energy & Petrochemicals Department	Captive power
Gujarat Industrial Investment Corporation Ltd (GIIC)	Term loan
Gujarat State Financial Corporation Ltd. (GSFC)	Facliate the fund for industrial activity
Reserve Bank of India	Public issue, automatic approval for foreign technology, collaboration agreements
Regional Office of Textile Commissioner (GOI)	Power loom registration
Commissionerate of Geology & Mining	Mining of minerals – prospecting licence/mining lease
Commissionerate of Food & Drug Administration	Registration from Food & Drug Administration for manufacturing

Chief Inspector of Steam, Boiler & Smoke Nuisance	Boiler Registration
Directorate of Explosives	Storage of explosive materials
Continue from previous from page	
Chief Inspector Factories	Handling of hazardous items, factory registration
Commissioner of Tourism	Registration of hotels
Milk & Milk Products Board	Registration for milk products
Registrar of Companies	Company registration
Registrar of Firms	Firm registration
Gujarat Maritime Board	Port clearance
Collectorate of Customs & Central Excise	Customs bonding for 100% EOUs located outside SEZ
Bureau of Indian Standards	Quality registration
Ministry of Environment & Forests (GOI)	Environment impact assessment
Forest & Environment Department	Environmental clearance

Annexure 2 : List of major hazardous accidental unit in Ahmedabad city

Sr.No	Name of Industry	Hazardous chemical	Max Capacity in Tones	Toxics Release	Flammable Vapor	Explosion
1	Advance Petro Chemical	Ethylene oxide	12	YES	YES	YES
2	AIMCO Pesticide	Carbofuran	10	YES	NO	NO
		Phorate	30	NO	NO	NO
3	Ashima dyecot	LPG	18.8	NO	YES	YES
4	Baroda minerals Grinding	Parathion-Methyl	11	YES	NO	NO
5	Bharat pesticides	Parathion-Methyl	5.2	YES	NO	NO
6	Bharat pesticides	Parathion-Methyl	1.2	YES	NO	NO
7	CHEMET Chemicals	Parathion-Methyl	1	YES	NO	NO
8	Dharangadhara Chemicals	Phorate	2	NO	NO	NO
9	ENCORE natural polymers	Ethylene oxide	25	YES	YES	YES
10	Ganesh pharmacies	Chlorine	2	YES	NO	NO
11	Gujarat Agro Chemicals	Parathion-Methyl	0.5	YES	NO	NO
12	Gujarat industries	Parathion-Methyl	0.2	YES	NO	NO
		Phorate	5	NO	NO	NO
		ENP	1	NO	NO	No

13	Gujarat LPG bottling	LPG	60	NO	YES	YES
14	Gujarat Pesticides	Parathion-Methyl	0.5	YES	NO	NO
15	GUJCOMSAl	Parathion-Methyl	1.75	YES	NO	NO
16	Hindustan gum	LPG	19	NO	YES	YES
17	HPCL POL depot	Motor Spirit	2562			
18	Indian oil corporation	Gasoline	6195	NO	YES	YES
19	INDICHEM	Parathion-Methyl	1	YES	NO	NO
20	Jay Chloral Chemical	Chlorine	12.6	YES	NO	NO
21	Jayendra kumar hiralal	Ethylene oxide	13.5	YES	YES	YES
22	Karnavati Chemicals	Chlorine	73.8	YES	NO	NO
23	Matangi Industries	Ethylene oxide	15	YES	YES	YES
24	Mayur Dye Chemicals	Ethylene oxide	12.8	YES	YES	YES
25	Meghmani organics	Chlorine	12.6	YES	NO	NO
26	Metro dye-chem	Ethylene oxide	21.5	YES	YES	YES
27	Pratiksha chemicals	Chlorine	19	YES	NO	NO
28	R.K. Item diates	Ethylene oxide	7	YES	YES	YES

29	Rohan Dys	Oleum (Sulphar trioxide)	55	No	YES	NO
30	Sagar drugs	Ethylene oxide	21.8	YES	YES	YES
31	Shiv Chemicals	Chlorine	22	YES	NO	NO
32	Shree chem	Chlorine	22	YES	NO	NO
33	Shyam Chemicals	Chlorine	18	YES	NO	NO
34	Sun Chloro chemical	Chlorine	15	YES	NO	NO
35	Super Industries	Parathion	0.4	YES	NO	NO
		Phorate	4.5			
36	The Arvind Mill	Naphtha	3200	NO	YES	YES
37	Vimal pesticides	Phorate	5	NO	NO	NO
38	Dintex Dychem	Ethylene oxide	15	YES	YES	YES
39	Pioneer Agro industries	Monodchroto-phos	400kg			
		Melathion	500kg			
		Tech. Forate	200kg			
40	Gujarat krushi	Parathion	500kg	YES	NO	NO
		Forate	600kg			
41	Gujarat Super Phosphate	Hexaconazole	changing			
		Acipet	changing			
42	Anar Chemicals	Chlorine	12.9	YES	NO	NO

Annexure 3 : Data required for study

Type of data	Method of collection	Source	Status
Building foot print	High Resolution Satellite data		Need to be upgrade
Institute Detail			
School	Secondary Data, Field Visit	AMC, AUDA Field survey	Need to be upgrade
Police station	Secondary Data	Gujarat state police housing corporation limited	Need to be upgrade
Fire bridge	Secondary Data	Fire Brigade Department	Need to be upgrade
Hospital	Secondary Data	Health and family welfare department	Available
Government Health Center	Secondary Data		Available
Private health care	Secondary Data		Available
Building Usage			
Residential	Field Visit	Field survey	Available
Recreational	Field Visit	Field survey	Available
Hotel	Field Visit	Field survey	Available
Government Office	Field Visit	Field survey	Available
Private office	Field Visit	Field survey	Available
Shopping Center	Field Visit	Field survey	Available
Shop	Field Visit	Field survey	Available
Religious Building	Field Visit	Field survey	Available
Historical Monument	Field Visit	Field survey	Available
Petrol station	Field Visit	Field survey	Available
Building condition			

Type of data	Method of collection	Source	Status
Construction Material	Field Visit	House hold census	Available
Roof condition	Field Visit	House hold census	Available
Height	Field Visit	House hold census	Available
Building Age	Field Visit	House hold census	Available
Other			
Open Space	Secondary Data, Field Visit	AMC, AUDA Field survey	Need to be upgrade
Community center	Secondary Data, Field Visit	AMC, AUDA Field survey	Need to be upgrade
Food zone	Secondary Data, Field Visit	AMC, AUDA Field survey	Need to be upgrade
Vacant Plot	Secondary Data, Field Visit	AMC, AUDA Field survey	Need to be upgrade
Market area	Secondary Data, Field Visit	AMC, AUDA Field survey	Need to be upgrade
Infrastructure			
Road	Secondary Data, Field Visit	AMC, AUDA Field survey	Available
ESR	Secondary Data, Field Visit	AMC, AUDA Field survey	Available
Waste water treatment plan	Secondary Data, Field Visit	AMC, AUDA Field survey	Available
Drinking water treatment plan	Secondary Data, Field Visit	AMC, AUDA Field survey	Available
Industry Attribute			
Industrial Foot print	Remote sensing	Image Interpretation	Need to be upgrade
Name of Industry	Secondary Data	Gujarat pollution control Board, Gujarat Industrial Corporation	Not Available
Types of material handle: Process,	Secondary Data		Not Available

Type of data	Method of collection	Source	Status
Storage, transport			
Chemical Storage amount	Secondary Data		
Built up area	Secondary Data		Not Available
Final Product	Secondary Data		Not Available
Hazards Material	Secondary Data		Not Available
Weather			
Wind Direction	Secondary Data	Metrological Department	Not Available
Wind Speed	Secondary Data	Metrological Department	Not Available
Temperature	Secondary Data	Metrological Department	Not Available
humidity	Secondary Data	Metrological Department	Not Available
			Not Available
Demographic (Detail at building Level)			
Population at ward and TAZ level	Secondary Data	AMC, AUDA	Available
Population age breakup at ward and TAZ level	Secondary Data	AMC, AUDA, Census	Available
Density at ward/TAZ level	Secondary data	AMC, AUDA	Not available
Built area at ward/TAZ level	Secondary data	AMC, AUDA	Not available
Age break up	Secondary Data, Field Analysis	Filed visit, Census	Not Available
Traffic			
Traffic volume	Secondary Data	BRTS Survey	Available

Annexure 4 : Detail land use classification

	Land use class		**Explanation**
	Residential		
1	R1	Make-shift,/ squatter dwelling	Slums, temporary housing, unplanned
2	R2	Small, single, low class houses	Individually constructed, unplanned
3	R3	Mix low class houses & (work)shops	
4	R4	Row housing	Tenements, usually upto 2 floors
5	R5	Row housing, shops/offices in ground floor	Tenements, usually upto 2 floors
6	R6	Apartment buildings < 3 floors	Planned buildings - Society 1
7	R7	Appartment buldings with stilts/parking < 3 floors	Planned buildings - Society 2
8	R8	Apartment buildings > 3 floors	including ground floor office, etc
9	R9	Appartment buldings with stilts/parking > 3 floors	including ground floor office, etc
10	R10	Single independent houses	Societies
11	R11	Banglows	with wide open spaces around
12	R12	Hostel, Hotels, Student homes, Dormitories	
13	R13	Pole Houses in Old City	Old and sturdy, packed very closely, high density
14	R14	Other	
	Institutional		
13	I1	Government offices closed to public	Corporation / ward / zone offices
14	I2	Government office open to public	Post office,
15	I3	Police station	Essential facility for emergency response
16	I4	Fire brigade	Essential facility for emergency response
17	I5	Ambulance service	Essential facility for emergency response
18	I6	VS Hospital	Essential facility for emergency response

19	I7	Civil Hospital	Essential facility for emergency response
20	I8	Medical care space	Doctor's clinic, single room units, …
21	I9	Dispensary, clinic, nursing home	Nursing Home, Maternity home, X-ray clinic etc
22	I10	Military buildings in Cantonment area	Might be utilized for emergency response
23	**Educational**		
24	E1	School (primary, kindergarten)	includes aanganwadi/balwadi, pre-school, …
25	E2	School (secondary)	excludes student hostels, boarding houses,
26	E3	School (university, college)	excludes hostels, staff quarters
27	Cultural /Recreational / Religious		
28	C1	Covered space for cultural activities	Theatre, cinema, museum, library
29	C2	Trade fair, conference center, hall	Sports hall, covered sports facility, trade fair
30	C3	Community center	Meeting places
31	C4	Religious buildings	Temple, church, mosque etc.
32	C5	Garden / parks / sports field	Party plots, marriage plots
33	C6	Cemetery, cremation space	
	Commercial		
34	O1	Mix of shops, offices, workshops	Without substantial residential components
35	O2	Market area	Market stalls, in open air
36	O3	Shopping malls	department stores, super markets,
37	O4	Hotel, motel, resort,	with indication of Nr of rooms
38	O5	Office Buildings	Multi-storey office buildings
39	**Industrial**		
40	M1	Mix of various small industrial activities	Type of activities might be hazardous
41	M2	Light industrial zone	Service industries, workshops, small factories,
42	M3	General Industry	Not hazardous
43	M4	Hazardous Industry	Possible explosion, fires, toxic

			release
44	M5	Storage of flammable goods	includes LPG, CNG, petrol, diesel,
46	M6	Storage of toxic goods	Type should be mentioned
47	M7	Water treatment plant	Critical facility
48	M8	Sewage treatment plant	Critical facility
49	M9	Power Plant	Critical facility
50	M10	Electricity Distribution Station	Critical facility
51	**Transportation**		
52	T1	Public transport terminal	Railway station, bus station
53	T2	Service station, petrol filling station	Possible explosion, fires
54	T3	Parking area, open spaces	Possible evacuation area
55	T4	Street	
56	T5	Main street	
57	T6	Highway	
58	T7	Square	
59	T8	Railway	
60	**Miscellaneous**		
61	V1	Unused space	
62	V2	Agricultural area	
63	V3	Actual use unknown	Inaccessible, secret, invisible

Source: (Katuri, Sharifi et al. 2006)