Industrial Hazard, Vulnerability and Risk Assessment for Landuse Planning: A Case Study of Haldia Town, West Bengal, India

Anandita Sengupta

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by

Anandita Sengupta

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THESIS ASSESSMENT BOARD

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Scientist

ERRIS Project
Mr. Debanjan Bandyopadhyay

INTERNATIONAL INSTITUTE FOR GEO-INFORMATION SCIENCE AND EARTH OBSERVATION
ENSCHEDE, THE NETHERLANDS
AND
INDIAN INSTITUTE OF REMOTE SENSING (NRSA)
DEHRADUN, INDIA.

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Abstract

Industrial hazards are an increasing source of risk to people and their environment. This is an effect of globalization of production, an increase of industrialization and a certain level of risk of accidents connected with production, processes, transportation and waste management. These risks are associated with the increase of substances in accident condition or with the production of such substances under certain conditions such as fire.

Severe accidents have happened which afflicted thousands of people. These have found expression in the public demand to provide technical and organizational tools for the prevention, mitigation and relief of disasters. Special international attention has focused on accidents of Bhopal, Mexico City, Basel, Sevesco, the “Exxon Valdez” and Chernobyl. Expert groups, institutions, organizations, authorities and institutes work on the problems of prevention and relief on local, regional, national and even global basis. Following these accidents several legislative frameworks were developed in countries. Developing country like India has developed legislation also.

The present research work was carried out for risk assessment of industrial hazards like fire, explosion, and toxic release in the industrial town of Haldia, West Bengal, India. The Haldia industrial region is fast growing into the single biggest manufacturing centre of eastern India with a major concentration of industries like oil refineries, petrochemicals and other chemicals that is supported by a large port complex and other infrastructural facilities. Many of these industries are hazardous in nature. At the same time, it has witnessed a steady induced growth of population, who have come in and settled down in the city because of a “honey pot” effect. With its key locational advantage, the port city is well placed for attracting more investment that would provide fillip to further development.

For the risk assessment purpose, a part of Haldia town (nearby Durgachak Industrial Area) was chosen for detailed study purpose. Vulnerability for buildings and population at different time were calculated with respect to the impact of pool fire, VCE, BLEVE and toxic release hazards. Hazard maps were prepared using the ERRIS (Environmental Risk Reporting and Information System) mapping module. Later, the vulnerability and hazard maps were combined to generate the risk maps and number of buildings and people were calculated.

Risk zonation maps for the whole Haldia town were also prepared for fire, explosion and toxic release hazards. Combining all the risk maps for different hazards, a multi-hazard risk map was prepared for the Haldia Municipal Area to identify the different risk zones. The risk zone map prepared can be used for the future land use planning of Haldia.

Key Words: Industrial hazard, Risk Zonation, Landuse Planning.

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Anandita Sengupta
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Table of Contents

List of Figures

List of Tables

List of Abbreviations & Acronyms

AHP	Analytic Hierarchic Process
AIChE	American Institute of Chemical Engineers
ANP	Analytical Network Process
APELL	Awareness and Preparedness for Emergency at Local Level
APPD	Actual Probable Property Damage
ASM	Analytical Simulation Model
ATC	Acute Toxic Concentration
AVHRR	Advance Very High Resolution Radiometer
BLEVE	Boiling Liquid Expansion Vapour Explosion
BPCL	Bharat Petroleum Corporation Limited
CAMEO	Computer Aided Management of Emergency Operations
CEI	Chemical Exposure Index
CFCL	Consolidated Fibres and Chemicals Limited
CFD	Conceptual Fluid Dynamics
CHEMSAFE	Chemical Safety Information
CNS	Central Nervous System
CI	Consequence Index
DRI	Distribution Rating Index
EAI	Swedish Environmental Index
EHS	Extraordinary Hazardous Substance
EPA	Environmental Protection Agency
EPCRA	Emergency Planning and Community Right-to-know Act
ERRIS	Environmental Risk Reporting and Information System
EVC	Equilibrium Vapour Concentration
FEDI	Fire and Explosion Damage Index
FEI	Fire and Explosion Index
FETI	Fire, Explosion and Toxicity Index
FMEA	Failure Mode Effect Analysis
FMECA	Failure Mode Effects and Criticality Analysis
GIS	Geographical Information System
GPH	General Process Hazard
HAZOP	Hazard and Operability Analysis
HDA	Haldia Development Authority
HIRA	Hazard Identification and Rapid Technique
HPL	Haldia Petrochemicals Limited
HRA	Human Reliability Index
IAPRM	Industrial Air Pollution Risk Model
ICC	Indian Chamber of Commerce
IDLH	Instantaneous Death Lethal Concentration
IFAL	Instantaneous Fractional Annual Loss Index
IHI	Italian Hazard Index
IOC	Indian Oil Corporation
IPSC	Institute of Protection and Security of Citizen

ITC	International Institute of Geo-Information Science and Earth Observation
MAH	Maximum Accident Hazardous
MCAA	Maximum Credible Accident Analysis
MCC PTA	Mitsubishi Chemical Company Purified Terepthalic Acid
MCLS	Maximum Credible Loss Scenario
MHI	Material Hazard Index
MLD	Master Logic Diagram
MPPD	Maximum Probable Property Damage
MSDS	Material Safety Data Sheet
NEPA	National Fire Protection Agency
PHA	Process Hazard Analysis
PRA	Probabilistic Risk Assessment
PSA	Probabilistic Safety Analysis
QRA	Quantified Risk Assessment
RMIS	Risk Management Information System
RRT	Rapid Ranking Techniques
SFHI	Substances Fire Hazard Index
SHI	Substance Hazard Index
SIRP	Systematic Identification of Release Point
SPH	Special Process Hazard
SWeHI	Safety Weighted Hazard Index
TDI	Toxicity Damage Index
TNO	Bureau of Industrial Safety, Netherlands
VCE	Vapour Cloud Explosion

1. Introduction

1.1. General Background

Human kind is living in an age of growing frequency of environmental hazards. As population densities continue to rise, living standards and their expectations improve, and the value of the human property inflates. So the impact of the abnormal and extreme events in the environment becomes even more serious and costly. In fact, many environmental hazards are fabricated, some of them are serious and caused unconsciously or indirectly, for example, landslides resulting from slope destabilization due to excavation for road and railway construction. Human errors those are causative for such hazards cannot be fully rectified and thus it forces to adjust with such hazards. A reasonable estimate of the human life and property that will be affected by such a disaster needs to known so that the authorities can allocate enough resources to alleviate the affected from their miseries. Hence, Preparedness and planning measures requires special attention to mitigate the impact of industrial disasters (Smith 2001).

On the night of December 3, 1984, from the pesticide plant of the M/S Union Carbide India Ltd., Bhopal, India, a deadly poisonous gas methyl isocyanate (MIC) leaked from one of the storage tanks. A cloud of MIC gas remained for an hour over the highly populated are of the city. This resulted in the death toll of over 5000 people during first 3 days of disaster and continued to rise for a month. Children born after this disaster developed genetic abnormalities. Thousands of people crippled permanently. The scientific commission which is studying on the long-term effects of Bhopal gas disaster has received reports of damage to brain, lungs, eyes and even cancer cases among the affected. It is expected that at least 5 to 10 more years of research required to gauge the effect of the gas disaster.

Every year we are confronted with the news related to tragic consequences of industrial accidents in terms of lives, injury to workers, financial resources and a loss of corporate damage. Risk posed by such industrial accidents rise as the density of industries and human population increase. This is particularly prominent in industrial areas of developing countries like India where lack of resources for proper spatial planning, close proximity of residential neighbourhoods and vulnerable communities to potentially hazardous industries, difficulty in sharing information among the administrative bodies and inadequate training of responders make the matter more alarming (ERRIS 2006).

The industrial accidents like the Bhopal Disaster (1984) in India cause a significant blow to not only in the commercial sector, but as such to the national economy. Chemical and Petrochemical industries are the prime sources of industrial hazards. Not only have these, transportation of hazardous chemicals sometimes also lead to an accident. A number of different events and processes, including spillage or sudden release of materials, fire or explosion, can characterize technological accidents. People who live in the vicinity of industries has to live with the multifarious hazards that are omnipresent as associated to such industries. Increasing magnitude of the same hazard results differently on the society and thus if the miseries are quantified sometimes they are not linear, but are exponential many a times. This necessitates assessing the vulnerability of the society based on the different hazard scenarios. The probability of occurrence of a hazardous event at a given magnitude, coupled with vulnerability and the monetary loss that can occur quantifies the risk involved. Thus a quantitative assessment of risk enables to assess the relative impact of the hazard. Today India has more than 60 such areas where levels of risk are high because of the clusters of hazardous industries and the number is increasing with the fast-paced industrial development.

Since 1970's when a number of number of catastrophic industrial accidents took place, the science of Technological Risk Assessment and Strategic Management of such industrial accidents gradually evolved. Thereafter, with the rapid advance in the field of information technology a worldwide effort were initiated to merge the tools of technology and IT with the science of risk assessment.

Keeping all these in view, the Indian Chamber of Commerce (with the financial aid from European Commission) has decided to develop a system of risk management ERRIS (Environmental Risk reporting & Information System). For the first time in India, the system is implemented in Haldia (West Bengal), where several industrial units have been identified as risky for dealing with hazardous chemicals. Thus, the gamut of the project and availability of the resources makes Haldia the ideal choice to carry out research aiming at quantifying the risk involved from an industrial multi-hazard perspective.

1.2. Problem Statement

The state of West Bengal, which was previously the industrial hub of British and also of Independent India, is presently undergoing resurgence through an accelerated phase of industrialization and economic development. It is also located at the heart of the eastern quadrangle comprising Orissa, Bihar, the northeastern States in India and the countries of Nepal, Bhutan, Bangladesh and Myanmar, a region with a total population of about 400 million people. The State's strategic position in the eastern region also makes it the natural gateway to the East.

Looking at the other side of the development scenario, the state and the region is confronted with significant challenges as far as protection of the environment and sustainable use of their natural resources are concerned. The problems include industries running on old and redundant technologies, rapid urbanization resulting in concentration of population in a few growth centers and depletion of natural resources base in ecologically fragile zones

The Haldia industrial region is fast growing into the single biggest manufacturing centre of eastern India with a major concentration of industries like oil refineries, petrochemicals, chemicals that is supported by a large port complex and other infrastructural facilities. Many of these industries are hazardous in nature. At the same time, it has witnessed a steady induced growth of population, who have come in and settled down in the city because of a "honey pot" effect. With its key locational advantage, the port city is well placed for attracting more investment that would provide fillip to further development.

Consequent upon the policy of decentralisation of Industries of the West Bengal Government, Haldia Industrial Complex came into existence through rigorous and efficient industrial planning. Industrial prosperity of the region was more enhanced as Haldia grew into a satellite port of Kolkata. In terms of cargo handling and annual growth it has achieved more than the national average. Haldia acts as an auxiliary port of the Kolkata port, thereby serving the dual purpose of releasing the pressure of Kolkata port as well as the over crowded Kolkata city.

The development and promotion of Haldia as an industrial township has always been a key concern of the State Government. The most important factor for the evolution of Hadia industrial region is the development of port facility at Haldia. Initially it was under the administration of Haldia Dock Complex (HDC). The excellent locational advantage of Haldia and comprehensive port facilities provided by the Haldia port paved the way for the establishment of various Public Sector companies like Indian Oil Corporation and Hindustan Fertilizer. It also attracted private sector giants like Hindustan Lever, Exide Industries, Shaw Wallace to set up their shops along with various small-scale units engaged in engineering and fabrication, automobiles, electrical, food processing, packaging and building materials. With the commissioning of two dream projects - the Rs. 5170-crore Haldia Petrochemicals Ltd and the Rs 1400-crore Purified Terepthalic Acid (PTA) Plant of Mitsubishi Chemical Company, Japan, the growth potential of the industrial region was considerably enhanced.

Therefore, with rapid industrialization taking place in these growth centres there is an urgent need to adopt integrated risk management strategies that will effectively address the issues of contingency planning and response in order to mitigate the adverse consequences of any industrial accident that might occur.

1.3. Aim and Objectives

The present study aims at quantification of the vulnerability and risk for buildings and population, driven by the different hazardous installations of Durga Chak industrial area of Haldia and thus the use of risk zonation related for future land use planning of Haldia. The more specific objectives are:

- To generate hazard scenarios for fire, explosion and toxic release those are possible in and around the study area.
- To quantify the elements at risk and generation of risk zonation.
- To assess the impact of possible hazards on buildings and population.
- To utilize the risk maps for future landuse planning.

1.4. Research Questions

- How to characterize and quantify the elements at risk?
- How to derive a suitable fire, explosion and toxic release hazard map using ERRIS mapping module?
- How to assess the vulnerability of population and buildings for industrial hazards?
- How to utilize the risk maps for future landuse planning?

1.5. Research Hypothesis

- Map indicating the risk for population and property due to various industrial hazard scenarios are useful for perspective landuse planning.
- The risk reduction effort by possible landuse planning activities can be compared and the optimal one can be selected.

1.6. Expected Results

The research will result in a methodology that enables in standardizing the estimation of risk associated with industrial hazards. A multi-hazard perspective of estimating risk will be benefiting stakeholders and the resultant information enables to assess scenarios will help for future landuse planning of the area. Materially, the outputs will be:

- Vulnerability Maps for buildings and population at different time periods.
- Risk estimation for different industrial hazards.
- Risk zonation maps at the town level.

1.7. Research Methodology

The methodology adopted for this research presented in the form of flow chart *(Fig: 1.1)*. In order to generate a Multi-hazard risk map, individual hazard maps for pool fire, vapour cloud explosion, boiling liquid expanding vapour expansion and toxic release were utilised, which were derived by using the ERRIS hazard mapping wizard module *(Ref: Chapter 5).* Vulnerability maps for buildings and population for different types of hazards were also prepared individually based on certain parameters *(Ref: Chapter 6).* To generate a risk map, hazard and vulnerability maps were combined and thus the risk zonation maps were prepared for each hazard types *(Ref: Chapter 7).*

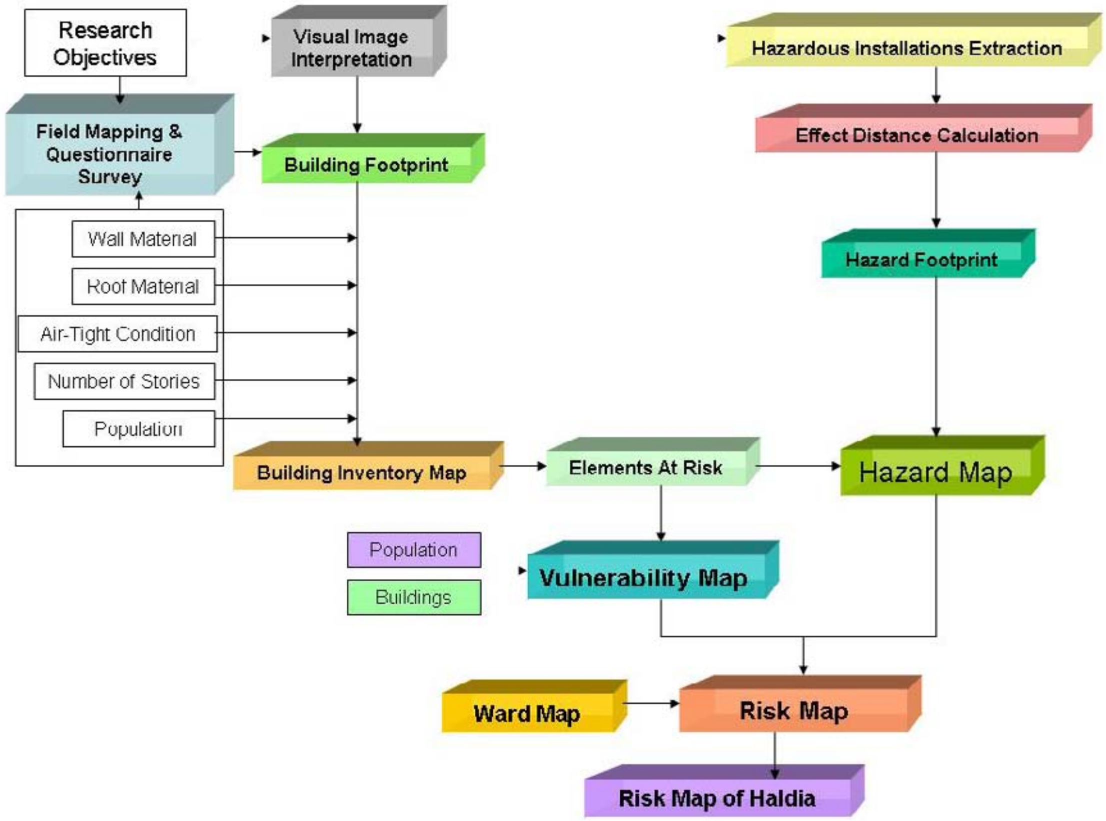

Figure: 1-1. Flow Chart showing the Methodology

1.8. Limitations

Being located near to the coastal area, Haldia is located in restricted zone for which there is a constraint on the use of spatial data (topographic map), due to security reasons. Some pertinent data are not available to carry out the study. There were also instances where data is available, but the agency was not willing to share it because of security reasons.

2. Industrial Hazard: Literature Review

2.1. Introduction

Hazard is a physical situation with a potential for human injury, damage to property and environment or some combination of these. Hazards may be natural or technological. Natural hazards are those that have an effect on population resulting from the natural processes in the environment, like: earthquake, floods, drought, landslides etc. A natural hazard will hence never results in a disaster in areas without vulnerability, e.g. strong earthquake in an uninhabited area. On the other hand, technological hazards are the threats to people and life-support systems that arise from the mass production and transportation of goods and services. Industrial hazard is a type of technological hazard. Industrial hazards can occur at any stage in the production process, including extraction, processing, manufacture, transportation, storage, use, and disposal. Losses generally involve the release of damaging substances (e.g. chemicals, radioactivity, and genetic materials) or damaging levels of energy from industrial facilities or equipment into surrounding environments. This usually occurs in the form of explosions, fires, spills, leaks, or wastes. Releases may occur because of factors that are internal to the industrial system (e.g. engineering flaws) or they may occur because of external factors (e.g. extremes of nature). Releases may be sudden and intensive, as in a power-plant explosion, or gradual and extensive, as in the built-up of ozone-destroying chemicals in the stratosphere or the progressive leakage of improperly disposed toxic wastes.

2.1.1. Nature and Definition of Technological Hazard

Reviewing the literature on technological hazards, we can define technological hazards as the interaction between technology, society and the environment. Technological hazards are socially constructed, not acts of God or an extreme geophysical event: they are products of our society. To the extent that the initiating event arises from a human agency, they have links with some ‘social’ hazards. Beyond this common feature, the term ‘technological hazard’ has been widely interpreted. Thus, the ‘technology’ itself may range from a single toxic chemical to an entire industry such as nuclear power (Cutter). The degree of human involvement also varies. Sometimes occupational and life-style risks are also included. Some researchers, for example, Cutter (1993), include health issues involving long-term exposure to chemical pollutants or low-level hazardous waste as well as the safety issues which threaten group deaths by concentrated releases of energy or materials. Other researchers have drawn attention to the so-called ‘na-tech’ or ‘hybrid’ disasters which occur when natural hazards, such as earthquakes or floods, act as the release mechanism for dangerous oil spills, chemical or radiological materials (Showalter and Myers, 1994).

All technological invention creates risks as well as benefits. The construction of a dam across a river may bring benefits for water supply and hydropower, but it also carries the risk of a flood disaster from structural failure. The true balance between the risks and the benefits is not always apparent (Cutter).

2.1.2. Diversity and Classification of Technological Hazard

In order to understand the range and the diversity of technological hazards it is useful to classify them. Many authors have attempted such as taxonomies like Starr’s (1969) division based on involuntary or voluntary exposure or Rowe’s (1977) scheme based on general risk factors. Other researchers have provided different organizing themes to differentiate between types of technological hazards. Slovic (1987) for example, uses the public perception of risks to develop the categories of risky technologies.

Another approach is to use the broad-based activities or technologies that cause or create environmental risks. These casual domains of environmental risk include the categories of public health, natural resources, economic development, disasters, and new products (Whyte and Burton 1980). Still another classification scheme has evolved that places technological failure into two categories: low probability/ high-consequence events and high-probability/ low-consequence events.

One of the most sophisticated schemes was developed by Hohenemser, Kates and Slovic (1983) that describe the seven-class taxonomy on a three-fold scale of severity based on 12 attributes or descriptors of the risk *(Table 2.1)*. These attributes include the intent to harm, spatial extent of impact, concentration, persistence or length of time remain as threat, recurrent or the time over which significant release recurs, population at risk, time between exposure and occurrence of consequences, annual human mortality, maximum human mortality, number of future generations at risk, potential non-human mortality, and actually experienced non-human mortality.

Table: 2-1. Seven class taxonomy of Technological Hazard

Class	Example
1. Multiple extreme hazards	nuclear war, radiation.
2. Extreme hazards	
a) Intentional biocides	antibiotics, vaccines.
b) Persistent teratogens	uranium mining, rubber manufacture.
c) Rare catastrophes	LNG explosion, air plane crashes.
d) Common killers	auto crashes, coal mining (black lung).
e) Diffuse global threats	fossil fuel, ozone depletion.
3. Hazards	food activities, appliances.

Source: The Nature of Technological Hazard, Cutter. S.

The 'rare catastrophes' category reveals that the most rapid-onset technological accidents stem from failures of human activities in different areas like large-scale structures, transportation and industry. All these areas can provide potentially life-threatening releases of energy and materials. It is generally accepted that the most hazardous materials are high-level radioactive materials, explosives and a limited number of gases and liquids that are poisonous when inhaled or ingested. Many chemicals are a hazard because they are flammable, explosive, corrosive or toxic in low-concentrations. Glickman (1992) focused on an important subset of these materials to analyze the major industrial accidents in which a hazardous material caught fire, exploded or was released as a toxic cloud. Most of these events occurred at refineries and manufacturing plants or during transportation and tended to be linked with the nature and scale of industrial activity (Hohenemser, Kates et al. 1983).

Thus, industrial hazards may be defined as "accidental failures of design or management affecting large-scale structures, transport systems or industrial activities which present life-threatening risks on a community-scale"(Cutter).

2.1.3. Sources and Types of Industrial Hazard

Industrial hazards are those caused by industries and related activities as well as transportation accidents. Sources of such hazards can be hazardous industries mainly of chemical and petrochemicals, chemical warehouses and storages, transportation of hazardous substances, pipelines etc. Fire, explosion, toxic releases are the different type of actions which can be considered for industrial hazards.

2.1.3.1. Fire

It is a situation in which there is a greater than normal risk of harm to people or property due to fire. Fire hazards can take the form of ways that fires can easily start, such as a blocked cooling vent, or overloaded electrical system, where fires can spread rapidly, such as an insufficiently protected fuel store or areas with high oxygen concentrations, or things which, in a fire, pose a hazard to people, such as materials that produce toxic fumes when heated or blocked. There are essentially six types of fires associated with hazardous material discharges, with the type of fire as a function not only the characteristics and properties of the spilled substances but the circumstances surrounding its release and/or ignition (Agency). Following are the different types of industrial fires:

Flame Jets: Transportation or storage tanks or pipelines containing gases under pressures i.e. compressed gases or normally gaseous substances that have been pressurized to the point they become liquids, if somehow punctured or broken during an accident, may discharge gases at a high speed. The gas discharging or venting from the hole will form a gas jet that 'blows' into the atmosphere in the direction the hole is facing, while entering and mixing with air. If the gas is flammable and encounters an ignition source, a flame jet of considerable length may form (cloud of hundreds of feet in length) from a hole less than a foot in diameter. Such jets pose a thermal radiation hazard to nearby people and property and are particularly hazardous if they impinge upon the exterior of a nearby intact tank containing flammable, volatile and/or self-reactive hazardous materials (ERRIS 2006).

Vapour or Dust Cloud Fires: Vapours evolved from a pool volatile liquid or gas venting out from a punctured or otherwise damaged container, if not ignited immediately, will form a plume or cloud of gas or vapour that moves in the downwind direction. If this cloud or plume contacts an ignition source at a point at which its concentration is within the range of its upper and lower flammable limits, a wall of flame may flash back towards the source of the gas or vapour, engulfing anything and everything in its path. People or property caught within the cloud as the flame passes may be severely injured or damaged if not protected (Agency).

Liquid Pool Fires: A liquid pool fire is defined as a fire involving a quantity of liquid fuel such as gasoline spilled on the surface of the land or water. As in prior cases, primary hazards to people and property include exposure to thermal radiation and/or toxic or corrosive products of combustion. An added complication is that the liquid fuel, depending on terrain, may flow down slope from the accident site and into sewers, drains, surface waters, and other catchments. There have been cases where such fires have ignited other combustible materials in the area or have caused BLEVEs (Boiling Liquid Expanding Vapour Explosion) of containers subjected to the flames. On occasion, pools of burning liquids floating on water have entered into the water intakes of industrial facilities and caused internal fires or explosions (Agency).

Fire involving flammable solids: Flammable solids are defined as any solid material, other than one classed as an explosive, which under conditions of normal transportation is liable to cause fires through friction, retained heat from manufacturing or processing, or which can be ignited readily and when ignited burns so vigorously and persistently as to create serious transportation hazard. This class of solids include spontaneously combustible and water-reactive materials. Fires caused by flammable solids are known as flammable solid fires (Agency).

Fire involving ordinary combustibles: Some hazardous materials, including some of the flammable solids, burn with no special hazards beyond those associated with paper, wood, and other common materials of everyday life. For example, wet paper waste may only be considered hazardous because it may ignite spontaneously (Agency).

2.1.3.2. Explosion

An explosion is a sudden increase in volume and release of energy in a violent manner, with the generation of high temperatures and the release of gases. An explosion causes pressure waves in the local medium in which it occurs. Explosion may be natural or artificial. On the Earth, the most natural explosions arise from the volcanic eruption. Most common artificial form of explosion is chemical explosion, generally involving a rapid and violent oxidation reaction that produces large amount of hot gases. Chemical explosion can be of two types, thermal and non-thermal. There are several types of chemical explosion, they are as follows:

Container or Tank Over pressurization Explosions: These events are a result of excessive pressure within a sealed tank or container and are deemed non-thermal explosions. They occur when excessive pressure causes the wall of a tank or container to rupture violently (ERRIS 2006).

Dust Explosion: An explosion which results from the ignition of a mixture of finely divided combustible solids and air. The effect of such an explosion is comparable with the ignition of an equal volume of air mixed with flammable vapour.

Gas or Vapour Explosion: Like airborne dusts, a gas or vapour within flammable or explosive limit concentrations may cause a deflagration, explosion or detonation upon ignition. These events can occur when the fuel-air mixed is confined, partially confined, or completely unconfined, but confinement of the mixture most definitely increase the probability of significant personal injury or property damage.

Condensed Phase Explosion: When the substance that explodes or detonates is a liquid or a solid, the event is often called a condensed-phase explosion or detonation. On the other hand, events involving gases or vapour in air is known as diffuse-phase or gas-phase explosion or detonations.

Boiling Liquid Expanding Vapour Explosion (BLEVE): BLEVE occurs from the sudden release of a large mass of pressurized liquid to the atmosphere resulting from an external flame impinging on the shell of a vessel above the liquid levels, and weakening the shell cause sudden rupture.

2.1.3.3. Toxic Release

Release of toxic gases in the environment due to some failures is known as Toxic Release.

A) Type of Toxic Effects:

Most toxic substances can be classified as irritants, asphyxiants and narcotics, systemic poisons, sensitizers, carcinogens, mutagens, and/or tetragenic substances. Irritants are substances with the ability to cause inflammation or chemical burns of the eyes, skin, nose, throat, lungs and other tissues of the body, which may come in direct contact. Asphyxiants are typically non-toxic gases that may cause injury by inhalation only if they are present in air in such high concentrations that they displace and exclude the oxygen needed to maintain consciousness and life. A good example is nitrogen, a gas that makes up about 78% of the air we breathe and which is perfectly harmless at this level as a component of air. If additional nitrogen or another such asphyxiants were added to the air to the point that the normal oxygen concentration of approximately 21% by volume significantly reduced, thus the situation could become life threatening. Anaesthetics and narcotics include numerous hydrocarbon and organic compounds classified as hazardous chemicals, including some alcohols, act on the body depressing the central nervous system (CNS). Severe exposure may lead to unconsciousness, paralysis of the respiratory system, and possibly death. A few hazardous materials are sensitizers and cause sensitization, means people who are exposed one of these materials may not be abnormally affected in the first time, but may experience significant and possibly dangerous effects even in the presence of very low levels of the containment if ever exposed again (Agency).

B) Instantaneous Vs. Continuous Vs. Finite Duration Discharges:

For the most common methods available for assessment of vapour / gas dispersion hazards, it is required that discharges of vapour or gases into the atmosphere be classified as either being instantaneous or continuous in duration. Instantaneous discharges are those that take place over the course of few seconds or a minute or so and then stop for all intents and purposes. The result of such a discharge is typically a puff of vapour or gas or a distinct cloud. On the other hand, continuous discharges take place over longer periods of time and procedure long stretched-out plumes of gas or vapour such as those typically seen from continuously operating smokestacks. These represents the two extremes by which contaminate emissions may be characterized. Apart from these two, in the real world many discharges are there which are can be categorized neither as instantaneous nor continuous. *Fig: 2.1* shows the isopleths of instantaneous and continuous releases, which are known as finite duration. In this present research, puff model is only considered.

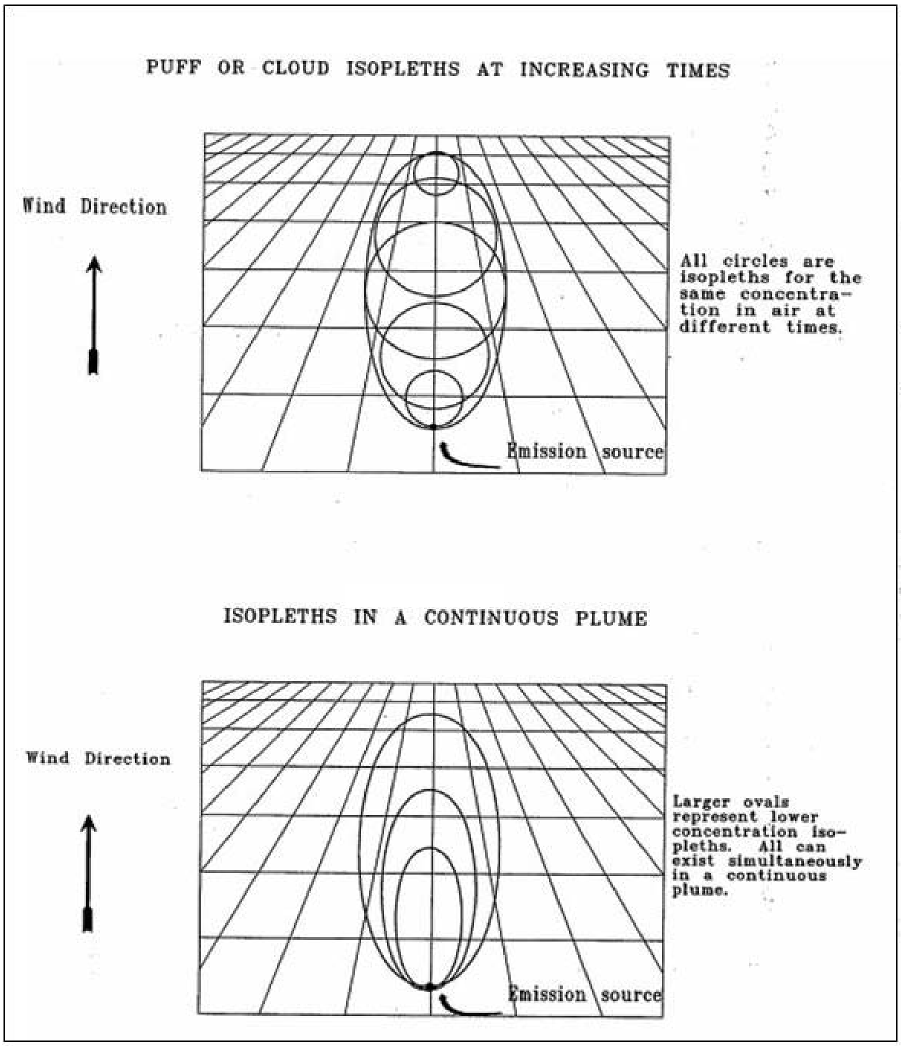

Figure: 2-1. Isopleths for Instantaneous & Continuous Discharge

(Source: Handbook of Chemical Hazard Analysis Procedures)

C) Toxic Release Parameters

Numerous factors influence the size and shape of downwind hazard zones resulting from vapour or gas discharges into the atmosphere (Agency). The factors are as below:

Toxic or Flammable Limit Selection on Hazard Zone Size*:* The concentration of an airborne contaminant decreases with increasing distance along the downwind direction of the cloud or plume path as well as in the crosswind direction. Thus, the choice of a higher toxic or flammable limit for definition of hazard zone boundaries during accident consequence analysis efforts will result in a smaller hazard zone than if a lower limit had been chosen.

Discharge Rates and Amounts: In case of instantaneous release, the total amount (i.e. weight) of vapour or gas released to the atmosphere has an impact on the size and shape of downwind hazard zones. All other factors being same, larger discharge amounts will result in longer and larger downwind hazard zones whereas smaller amounts will result in shorter and smaller zones.

Atmospheric Stability Conditions: The time of a day, the strength of sunlight in the area, the extent of cloud cover and the wind velocity will play an important roll in determining the level of turbulence in the atmosphere and thereby the distances downwind over which airborne containments will remain hazardous. Meteorologists classified atmospheric conditions into six atmospheric stability class (*See Appendix: 1*). It is necessary to understand that atmospheric conditions as it may change with time and that these changes will influence the behaviour of the dispersing cloud or plume.

Gas or Vapour Buoyancy: The overall behaviour of a heavy (negatively buoyant) cloud or plume can be very different than that of a neutrally or positively buoyant cloud or plume and the shape and dimensions of the cloud or plume can be strongly influenced by the duration of the discharge, prevailing atmospheric stability conditions and prevailing wind velocities. For example, an instantaneous discharge of a flammable liquefied gas can result in a flammable or potentially explosive cloud of 25% greater in maximum width than its length under neutral atmospheric conditions when winds are of moderate velocity. *Figure 2.2* shows the behaviour of puff or cloud in different conditions.

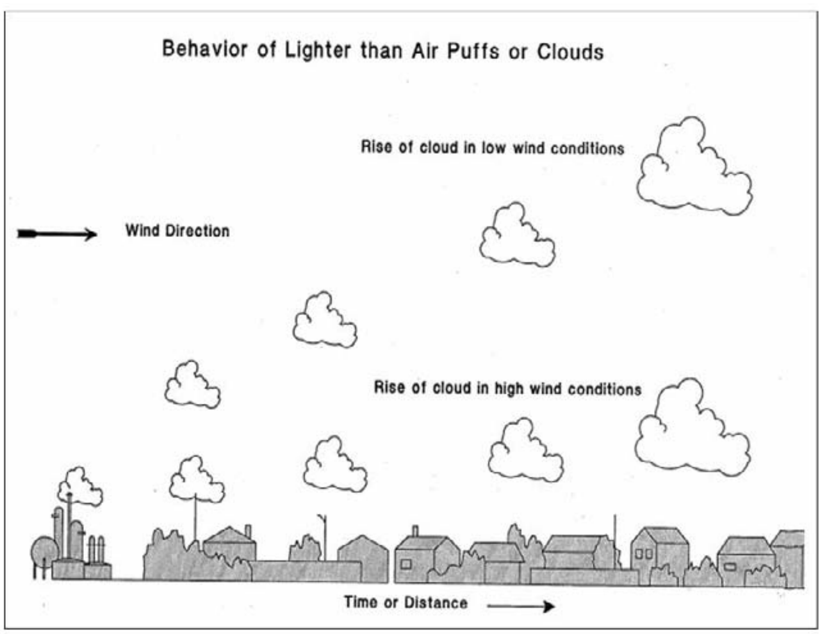

Figure: 2-2. Behaviour of Puffs or Clouds

(Source: Handbook of Chemical Hazard Analysis Procedures)

Source Elevation: The source elevation is an important parameter that affects the rate of dispersion. In most of the cases the release rate changes with respect to the changes of elevation of source. Another important factor also associate with the source elevation factor is the weight of the gas or vapour. Following figure *(Fig: 2. 3)* explains the effects of source elevation.

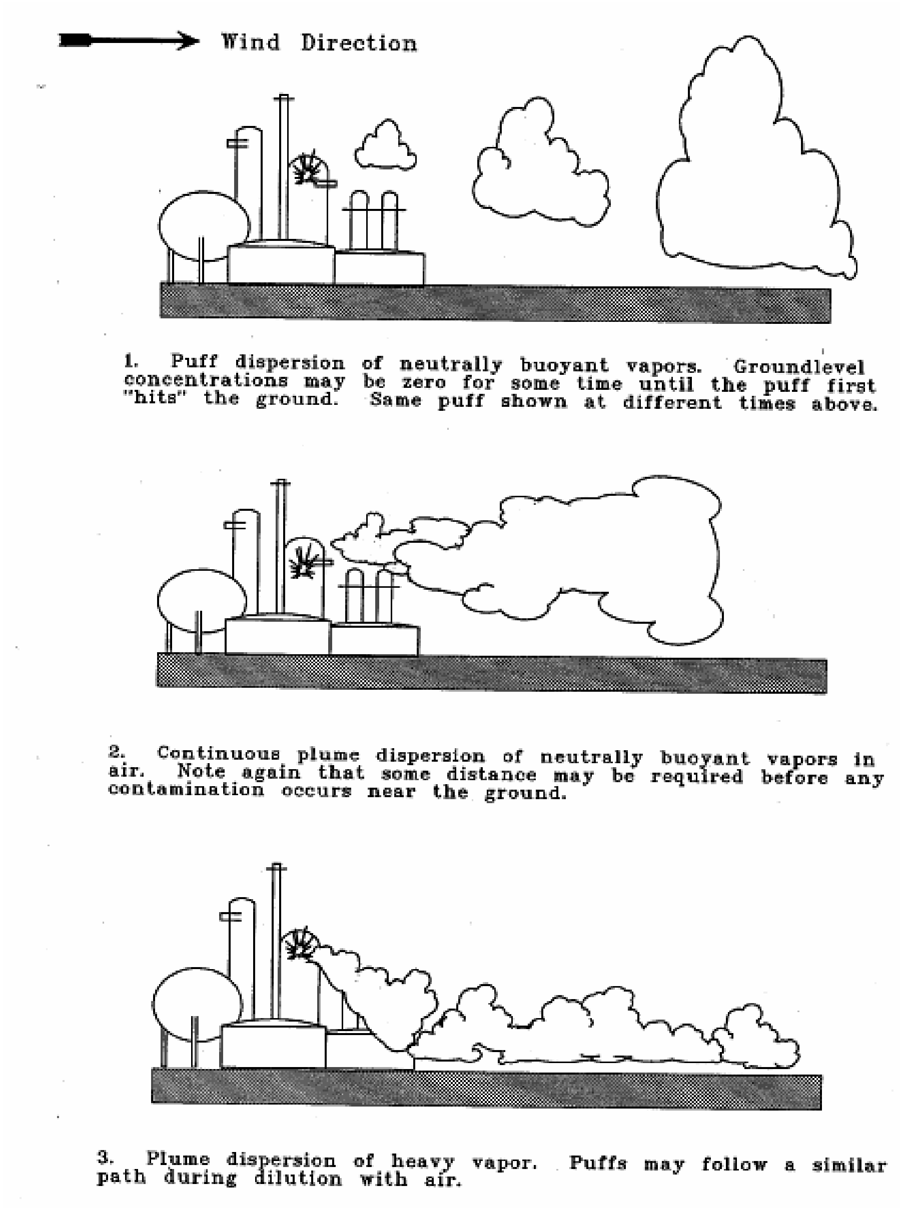

Figure: 2-3. Effects of Elevation on Dispersion of gas

(Source: Handbook of Chemical Hazard Analysis Procedures)

***Physical State of Contaminants**:* Vapours or gases may be released to the atmosphere at relatively low velocities, or may be vented under high pressure as a jet. There are various jet momentum effects that alter puff or plume behaviour, particularly near the source of a discharge. A strong jet of vapour or gas will tend to entrain and mix with air rapidly and thus reduce the containment concentrations. However, these effects become less important as the puff or plume moves downwind.

2.2. Industrial Hazard Risk Assessment

2.2.1. Introduction

Risk assessment may be the most important step in the risk management process, and also the most difficult and prone to error. Risk Assessment in its broad definition is a structured procedure that evaluate qualitatively and/or quantitatively the level of risk imposed by the hazard sources identified within the installation.

Industrial hazard risk assessment at hazardous industrial facilities is an integral part of industrial safety management. In other words, risk assessment is a systematic procedure for describing and quantifying the risk associated with hazardous substances, processes, actions or events. The main goals of risk assessment at hazardous industrial facilities are to provide information related to industrial safety, most hazardous points in terms of safety and reasonable recommendations to reduce the risk (Agency 1999).

The risk assessment process includes the following major phases:
Hazard Identification: Location, identification and characterization of potential source and accident site within the jurisdiction or locality concerned in the process is referred to as hazard identification. This step essentially concludes with the identification and/or postulation of accident scenarios requiring the further consideration and analysis.
Probability Analysis: Evaluation of the likelihood of individual accident in a process is called probability analysis. This step permits the examination and/or prioritization of potential accident scenario in terms of their occurrence.
Consequence Analysis: Evaluation of the consequences and impact associated with the occurrence of postulated accident scenarios in a process is referred to as consequence analysis. This step indicates the understanding of the nature and outcome of an accident and permits the examination and/or prioritization of accident scenario in terms of their potential impact on human and property.
Risk Analysis: Combination of results from the accident probability and consequence analysis efforts to provide a measure of overall risk associated with the specific activity or activities being studied in a process referred to as risk analysis. This step permits the effort to prioritization of accident scenario in terms of overall “risk”.

The scope of Risk Assessment and of all the methods that have been developed for this is recognized as: “to improve the safety of the hazardous installations and to minimize the risk imposed on the surrounding population.” It is obvious that although the various methods may differ in the results provided, quantitatively and/or qualitatively, but they all have the same scope. Therefore, the use of Risk Assessment is to provide the necessary input to a variety of decisions.

2.2.2. Methods for Industrial Hazard Risk Assessment

There are several methods for industrial risk assessment developed by different group of scientists, or by different institutions with different cultures in risk management and with different experience. The Risk Assessment methods can be grouped in four main categories:

- Rapid Ranking Method.
- Qualitative Method.
- Quantitative Method.
- Semi-Quantitative Method.

Moreover, the Quantitative Methods can further be divided into two broad categories: the “Consequence/ Deterministic Approach” and the “Probabilistic/ Risk based Approach”.

2.2.2.1. Rapid Ranking Method

In general, Rapid Ranking Methods include various Hazard and Risk Indices. These methods make use of a number of empirical factors, which are combined to provide a measure of the potential hazard. Indices are extensively used for ranking various units of a chemical process industry based on the hazards they pose of accidents fires, explosions and/or toxic release. This type of ranking enables the professionals to identify the more hazardous units from the less hazardous ones. The Rapid Ranking Methods make use a number of empirical factors, depending on the frequency of occurrence of the accident, which are combined to provide a measure of the potential hazard (Smeder, Christou et al. 1996).

Several indices have been proposed time to time for hazard identification. Noteworthy among them are the 'Dow Fire and Explosion Index', the 'Mond Fire, Explosion and Toxicity Index', 'Italian Hazard Index', the 'IFAL Index', and 'Dow Chemical Exposure Index'.

- **Dow Fire & Explosion Index (Dow FEI)**

This is the most widely used hazard index developed by Dow Chemicals and commonly referred as the Dow Index. It was first reported in 1964 (Smeder, Christou et al. 1996). The Dow FEI relies on the calculation of a fire and explosion index to determine fire protection measures and in combination with a damage factor to derive the base maximum probable property damage (MPPD) . The index is calculated as follows:

- First, a material factor (MF) is obtained. It is a measure of the potential energy released from a material, determined by considering the flammability and reactivity of the material.

- Then, two penalty factors (F1 & F2) are determined, where F1 for general process hazards (GPHs) and F2 for special process hazards (SPHs).

- Then, the process unit hazards factor (PUHF) is to be calculated by multiplying the GPHs and SPHs.

- Finally, the Dow FEI is obtained as the product of the MF and PUHF.

GPHs are the sum of the penalties due to the type of reaction/process, type of chemical handled in the process industry, drainage, and spill control factors of the chemical. SPHs account for the penalty due to operation under hazardous conditions, quality and character of the chemicals handled in the unit. Using these three parameters (MF, GPHs and SPHs) the MPPD is estimated and utilizing credits for hazard control strategies and safety systems, the 'actual probable property damage' (APPD) can be calculated.

The damage radius is derived empirically from the Dow FEI by using the following formula:

*Damage radii = 0.84*Dow FEI.*

Toxic and carcinogenic substances cannot be evaluated through this method.

- **Mond Fire, Explosion and Toxicity Index (Mond FETI)**

The Mond FETI is an extension of the Dow Index. It was developed at the Mond division of Imperial Chemical Industries. The Mond FETI involves making an assessment of hazards in a similar manner that used in the Dow FEI, but taking into additional hazard considerations. The potential hazard is expressed in terms of the initial value of a set of indices for fire, explosion and toxicity (Khan and Abbasi 1998).

In this Index, the material factor is determined as like in Dow method, but in addition, special material hazard factors are also introduced. Moreover, like Dow Index, GPHs and SPHs are also used with some other factors. The toxicity index is calculated using the health factor, quality of chemical in use and the toxicological properties of the chemicals.

In the second edition and subsequent amendments of the Mond Index, "offsetting factors" of hazards were also taken into consideration to compute the final values of indices. Recently, *Tyler et al* .have introduced a modified method for toxicity index calculation considering the effect of acute concentration of the toxic dispersion, and the layout of the affected area. They have also proposed a ranking of the toxicity index on a seven-point scale, from low to severe. Mond Index does not provide any information about economic losses.

- **Italian Hazard Index (IHI)**

The Italian Hazard Index has been proposed by ISPESL, actually a modification of the Dow Index with many similarities concerning their applications (Smeder, Christou et al. 1996). With a number of tables and nanograms, the analyst can determine an overall index depicting the hazard level of the installation. The great improvement is that the Italian hazard Index also permits the handling of toxic substances.

- **Instantaneous Fractional Annual Loss (IFAL) Index**

The Insurance Technical Bureau, UK, developed this index primarily for insurance assessment purposes (Khan and Abbasi 1998). The calculation of IFAL index involves examining each major item of process equipment to assess its contribution to the index. The main hazards accounted by this index are pool fires, vapour fires, unconfined vapour cloud explosions, confined vapour cloud explosions, and internal explosions. In contrast to the Dow and Mond index, the IFAL index is too complex for manual calculation.

- **Dow Chemical Exposure Index (Dow CEI)**

The Dow CEI is a measure of the relative acute toxicity risks. It may be used for initial Process Hazard Analysis (PHA), calculation of a Distribution Ranking Index (DRI), and in emergency response planning (Khan and Abbasi 1998). The information, which is needed for calculation of the Dow CEI, includes:

(i) Physical and chemical properties of the material,
(ii) A simplified process flow sheet,
(iii) Individual units showing vessels and pipe works and
(iv) An accurate plot plan of the industry and its surrounding area.

- **Rapid Ranking Techniques**

'Rapid ranking techniques' (RRT) and databases for hazard identification which are mainly based on the three chemical characteristics of chemicals: toxicity, reactivity and flammability (Khan and Abbasi 1998). These techniques and databases are used in different forms to identify the type of the hazard present in a unit for hazard assessment. Initially a few rapid ranking techniques were evolved. Among them, important ones are Substance Hazard index (SHI), Extraordinary Hazardous Substances (EHS) Classification, and NFPA Ranking System.

Substance Hazard Index (SHI)

SHI is a hazard system ranking index proposed by American Petroleum Institute, is based on the vapour pressure and the toxicity of the chemical being assessed (Khan and Abbasi 1998). It postulates that a high vapour pressure substance disperses more rapidly and an acutely toxic substance can pose damage even at low emission level. The substance hazard index, SHI is calculated as;

$$SHI = EVC / ATC.$$

Where, EVC denotes equilibrium vapour concentration and ATC denotes acute toxic concentration in ppm. SHI value higher than 5000 is considered to be represents the hazardous substance.
This technique enables ranking the chemicals only at their normal operating conditions. The technique does not incorporate the effects of temperature/pressure on the operation, operation conditions, type of unit operation process, site characteristics etc. for calculation.

NFPA Ranking System

National Fire Protection Association (NFPA) has developed a hazard identification and ranking system. Here the chemicals are ranked in different categories based on three different indices for toxicity, flammability and reactivity on 0 to 4(least to mast hazardous) scales. However, presently this is the most recommended technique for ranking chemicals, but its application has been restricted to specific hazard associated with chemicals (Khan and Abbasi 1998).Moreover, the effects of other relevant parameters are accounted externally. Consequently, the use of NFPA ranking system is restricted to assessing hazards under normal conditions.

- **Hazard Identification and Ranking (HIRA) Technique:**

HIRA is developed as a systematic and comprehensive technique considering the “Multivariate Hazard Identification and Ranking System” developed by F.L.Khan and S.A.Abbasi (Khan, Hussain.T et al. 2001). This system essentially is a combination of two indices: Fire and Explosion Damage Index (FEDI) and Toxicity Damage Index (TDI). The proposed indices have some advantages over the conventional indexing techniques. HIRA methodology is simple in implementation, modular in structure and can be easily automated in software to reduce expert time. The main features of HIRA are as follows:
- It takes into consideration the various process operations and the associated parameters for hazard identification.
- It provides the quantitative results of god reliability.
- Most of the penalties used for computing FEDI and TDI are derived from the tested models of thermodynamics and fluid dynamics. A few numbers of penalties are quantified with the help of empirical models and hazard ranking methods like NFPA and EHS.
- It does not need case-to-case calibration as its magnitude directly related to the level of hazard.
It may be used for very rapid investigation of risk.
Though HIRA aims to be more systematic, comprehensive and reliable than others still it has the following limitations:
- There is no provision to account for the existing control systems and safety measures.
- It does not reflect whether existing control systems are sufficient or not.
- The site-specific attributes have not been incorporated.

In order to overcome its limitations a further refined index has been proposed namely “Safety Weighted Hazard Index” (SWeHI) (Khan and RAmyotte). However, various methodologies are available for safety evaluation and hazard assessment for an industrial area but none of them able to answer of questions like: What may go wrong? How it may go wrong? How likely its occurrence? What would be the impacts? In addition, what control measure would require reducing its impacts and its likelihood of occurrence? To answer these entire questions, a new methodology **SCAP** is developed. It is developed by integrating three existing indices or techniques; namely, Safety Weighted Hazard Index (SWeHI), Maximum Credible Accident Analysis (MCAA) and Probabilistic Hazard Assessment (Analytical Simulation Model ASM).
In SCAP, method following steps is carried out:
➢ Hazard identification by SWeHI.
➢ Quantitative assessment of hazard by MCAA.
➢ Probabilistic assessment of hazard by ASM.
➢ Risk estimation by multiplying damage potential and probability of occurrence.
If the result of risk estimation is not acceptable then along with some safety measure, again the risk estimation should be re-evaluated.

In order to introduce a new methodology for developing safety-related indices, aimed at the relative ranking and comparative assessment of hazardous substances, hazardous installations, units or processes, a multi-criteria analysis technique, namely, “Analytic Hierarchy Process” (AHP) has been proposed.

- **AHP**

AHP developed by *Saaty* in late 1970 has designed to deal with the complex decision-making problems including multi-criteria, in a wide range of application field mainly based on certain parameters that are taken into consideration for hazard assessment (Paralikas and Lygeros 2005). Two major steps can be distinguished in this method;
➢ Structure the problem under consideration in a hierarchical manner. It involves the decomposition of the problem into components, i.e. the identification of relevant parameters, as well as

the organization of these parameters in groups and sub-groups, which are then linked in a hierarchical manner. Thus, it results in the formation of the hierarchy, the hierarchical structure that is representative of the analysis of a specific problem. In the hierarchy, the lowest level is constituted by the alternatives.

- Assignment of weights of each parameter or factor of the problem: This is done through pair wise comparison among all parameters that belong to the same group or sub-group. The parameters are compared in respect to their importance, likelihood or preference, depending on the nature of problem under consideration.

The most important advantage of AHP is the consistency check, which provides an identification of the consistency among the alternatives. On the other hand, one of its disadvantages is its inability to deal with problems that cannot be represented by a straight hierarchical structure, mainly when the parameters are interconnected or interdependent.

In order to deal with the above-mentioned problem, an extension of AHP, the "Analytic Network Process" (ANP) has been introduced. ANP considers the feedback among different elements in order to rank the alternatives.

Furthermore, the proposed methodology was modified based on "Multi-criteria & Fuzzy Logic based concepts" for the relative ranking of the fire hazards of chemical substances and installations by A.N.Paralikas and A.I.Lygeros. In order to describe this new methodology, two indices were introduced, Substance Fire Hazard Index (SFHI) and Consequence Index (CI).

Substance Fire Hazard Index (SFHI)

This index is introduced as a tool for the relative ranking and comparative assessment of hazardous substances according to their fire hazard properties(Paralikas and Lygeros 2005). The calculation of the index is based on 16 properties, which include fire hazard properties, physical properties, special hazard properties and burning properties of the chemical substances. This index is focused on estimating the fire hazards that are related to accidents that could take place at installations that use, process, produce or store hazardous chemicals.

Consequence Index (CI)

This is also introduced as a tool for ranking of industrial units and installations based on accident consequence analysis(Paralikas and Lygeros 2005). Units have been classified according to the "Consequence Potential" that each represents. A 'Consequence Potential' is defined by the total consequences to human health, environment and property that are possible to be caused by an accident at the installation. The calculation of the index is based on 21 consequences categories that have been identified.

Besides these above-mentioned indices for Rapid Ranking Analysis, few more indices, for example: Chemical Exposure Index (CEI), Edward & Lawrence Index, Material Hazard Index (MHI), Swedish Environmental Index (EAI) etc. were proposed.

2.2.2.2. Qualitative Method

This category includes methods aiming at a qualitative presentation and analysis of the imposed risk. Their principal purpose is to identify the possible hazard sources, aiming at its minimization rather than giving a through representation of both likelihood and severity of the possible accidents. The most widespread techniques of this category are as below:

- **Safety Review**

These are commonly walkthrough by a team of experts (who are selected based on their specific level of expertise) to identify the plant conditions or operating procedures that could lead to an accident and results in significant property damage, or environmental impacts. The U.S. Department of Energy has utilized these reviews to evaluate the safety of facilities that perform similar operations with similar materials.

- **Checklist Analysis**

The checklists are possibly the earliest and most intuitive technique. Through the use of the checklist an analyst can easily identify the possible sources of hazard. They usually contain a large number of events and sequences of events (identified by the analyst itself) that can lead to an accident. The success of this technique mainly depends on the experience of both the developers and the users.

- **What-If-Analysis**

As the name suggest it implies a set of questions. Each question becomes a line in the scenario analyses table (Dr. Shickin 2004). The columns in the table contain the What-If question, the 'Consequence/Hazard', 'Recommendation', 'Responsible individual' and a final column for the responsible individual to 'Initial and Date' when the recommendation was addressed and resolved.

- **Hazard and Operability Analysis (HAZOP)**

HAZOP is a simple structured methodology for hazard identification and assessment (Smeder, Christou et al. 1996). It evaluates the consequences through the deviation of the process variables and a number of well-defined questions to verify the adequacy of the existing safety measures or the necessity of the supplementary ones.

Limitation: Unlike the Checklist analysis, the success of this method is not only depends on the experience of the user but also on the familiarity of the user with the plant under study.

- **Failure Mode and Effect Analysis (FMEA)**

Together with HAZOP, FMEA is the most commonly used qualitative technique. FMEA has been historically used very much in the electronic industry (Dr. Shickin 2004). Like What-If Analysis, the results of this technique are normally summarized in a tabular form. The common columnar elements of the table are the 'Component', 'Description' of when used or relied upon, 'Failure Mode', 'Safeguards', and 'Actions'. The main objective of this method is to identify the single point of failure. Within this procedure, the possible modes of failure of each component are identified, together with their causes and consequences in order to detect the possible failure as well as the design changes to reduce the undesired risks. Since FMEA examines the safety of the plant, it is very valuable in the design phase of the installation. This analysis may be extended to form a quantitative Failure Mode Effects and Criticality Analysis (FMECA).

- **Systematic Identification of Release Points (SIRP)**

SIRP is a simple technique aiming at the identification of the overall of all 'conceivable' breaks of components, pipes and vessels of the plant from which a release of flammable or toxic substances can occur (Smeder, Christou et al. 1996). In general, for each component/pipe/vessel, a number of breaks at characteristic hole-sizes, obtained from the statistical analysis of historical failure data, are examined. For each identified release point the quantity of the material released is estimated according too the process conditions. After that a screening is done for the identified release points according to the estimated release rate.

- **Master Logic Diagram (MLD)**

MLD is a deductive technique for identification of possible hazards (Smeder, Christou et al. 1996). It starts from the undesired event and ultimately identifies the sequences of events that lead to an accident. This technique originates from the nuclear field, but later on its application in chemical field has also been identified.

- **Human Reliability Index (HRA)**

This is another systematic identification and evaluation technique for the factors that influence human performance during normal and emergency operation (Dr. Shickin 2004). These factors include: environmental conditions, human skill, psychophysical capability, and the performance of information representation system. The purpose of HRA is to identify the potential human errors in order to develop the recommendations to reduce the undesired risks. This technique is usually performed in conjunction with other risk assessment techniques.

2.2.2.3. Quantitative Method

This category includes the methods aiming at the quantification of the potential accident consequences and the relevant risk (Dr. Shickin 2004). Methods of quantitative risk assessment present a further development of qualitative methods and are characterized by calculation of the risk parameters. By its nature it requires more detailed information of the facility, region of its location and the process. This category can be further sub-divided into two categories: the “Consequence oriented / Deterministic Approach” and the “Risk oriented/ Probabilistic Approach”.

- **Consequence-oriented Approach / Deterministic Approach**

The ‘consequence-oriented ‘approach is based on the assessment of the consequences from the conceivable accidents whereas no attempt is made to quantify the likelihood of these accidents (Smeder, Christou et al. 1996). The concept behind this approach is to avoid the uncertainties related to the quantification of the frequencies of occurrence of the potential accidents.

As the assessment of the frequencies of occurrence of the various accidents is hard and time-consuming task, therefore much criticism has been expressed on the usefulness of the assessed frequencies that given the uncertainty associated with the final estimations.

- **Probabilistic or Risk based Approach**

Probabilistic Risk Assessment (PRA) is a systematic and comprehensive methodology to evaluate risks associated with a complex technological entity. PRA defined Risk as a feasible detrimental outcome of an activity or action. In a PRA, risk is characterized by two quantities: the magnitude (severity) of the possible adverse consequence(s), and the likelihood (probability) of occurrence of each consequence.

Consequences are expressed numerically (e.g., the number of people potentially hurt or killed) and their likelihoods of occurrence are expressed as probabilities or frequencies (i.e., the number of occurrences or the probability of occurrence per unit time). The total risk is the sum of the products of the consequences multiplied by their probabilities.

There are various quantitative methods under this category. Few of them are described as; Probabilistic Risk Assessment (PRA), Probabilistic Safety Analysis (PSA), Quantified Risk Assessment (QRA), Quantitative Scenario Analysis, Failure Mode Effect and Criticality Analysis, Event Tree Analysis, Fault Tree Analysis and Cause-Consequences Analysis.

The main purpose of this process is not only to evaluate the severity of the potential accidents, but also to estimate the likelihood of their occurrence. In general, these methods use more sophisticated tools and in someway they seem more complete in analyzing the risk than any other methods. These methods are more complicated, more time consuming as well as more expensive.

2.2.2.4. Semi-Quantitative Method

In addition to above mentioned methods, a semi-quantitative approach can be adopted for industrial risk assessment. The method is party quantitative and partly qualitative(Bandyopadhyay 2005). The hazard zonation is carried out using a quantitative approach, but the risk assessment is carried out using a qualitative approach.

Thus, Risk = Probability* Vulnerability (Consequences/Effects + Elements at Risk).

Hazard Identification indicates the sources of potential hazard from where an incident can occur. A hazard can be characterized based on certain factors, viz. type of hazardous chemicals (toxic, flammable, explosive, corrosive), amount of hazardous chemical stored at a particular time, type of the storage or process, storage or process parameters. The Probability of occurrence of an event provides an estimation of how often the event occurs. Thus, the main objective of calculation of exact probability is to get a fair estimate of the probability of an event happening to resulting in prioritization of risks. Several methods are there to calculate the probability, namely Historical Accident Analysis, Decision Tree (Quantitative), Failure Mode Effect Analysis (FEMA) etc. Consequences/ Effect modelling is used to estimate the size of a hazard zone in case of Maximum Credible Loss Scenario (MCLS) or other alternative scenarios. Thus, the Consequence or Effect models are used to calculate the end-point distance in case of fire, explosion or toxic release. For different scenarios, the end-point distances are expressed differently.

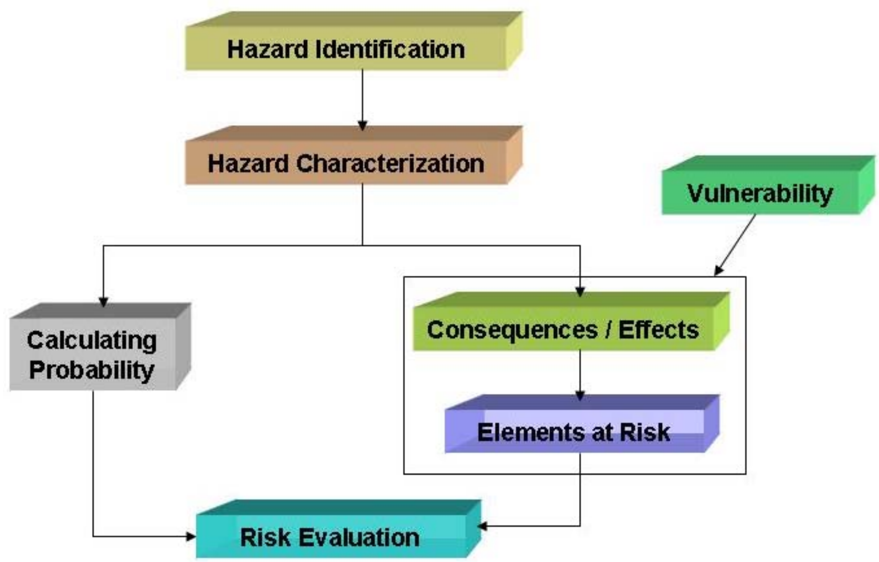

Figure: 2.4. Schematic Diagram of Semi-Quantitative Approach

2.2.2.5. Consequence / Effect Models

The purpose of the modeling was to estimate the offsite consequences of releases of flammable materials from units that are proposed for installation or modification. The modeling was based on equations from the EPA's RMP Off-Site Consequence Analysis Guidance (May 24, 1996) document (Agency 1999) for estimating end point distances for explosion, fire, and BLEVE. The EPA equations for these events were analyzed using EXCEL™ spreadsheet to determine the size of the impact zone *(Ref: Chapter 5)*.

2.3. Remote Sensing and GIS in Industrial Risk Assessment

Researchers report several attempts on the applications of GIS and Remote Sensing in industrial risk assessment. Most applications of Remote Sensing in industrial risk assessment are on post hazard plume monitoring. Chrysoulakis and Prastacos (2002) reports the development of a decision support tool for technological risk management with Remote Sensing and GIS. They have used AVHRR data sets acquired to generate a scenario for the broader area of Athens. It is based on the detection and space time monitoring of the produced plumes by integrating moderate and high spatial resolution satellite imagery with vector data in a GIS platform capable of supporting technological risk management. An integrated information system for urban disaster prevention was developed through combination of GIS, CAD and Expert System in China (Tian, Ren et al. 1997). In United States, the Geodynamics Company also combined GIS with real-time remote sensing data to help California State put out a serious fire happened at Layuna Beach and make effective remediation plan. A data base is designed for urban seismic hazards studies (Tarr 1993). Gui-lian et al., (2000) reports the development of a chemical monitoring and emergency response system combining GIS and expert system for both chemical distribution centers and public response personnel. Marino et al., (1999) reports the integrated use of GIS and Remote Sensing for industrial pollution monitoring in Pianura Pontina is located in central Italy, 70 km south of Rome. A major but that which affects humans in the vicinity very slowly is the air pollution caused by industries. An industrial air pollution risk model (IAPRM) that integrated spatial data on industrial location, estimated air pollution, and housing quality within a GIS environment was used to assess the air pollution risk in Tijuana, Mexico (Obee, Griffin et al. 1998). A state of art real time simulation of accidents in industrial plants is reported by Amoroso and Bezzi (Raheja 2003) .The system separately computes a mathematical model of each physical event involved in the accident, and then periodically combines the outputs of the models to show the whole evolution of the accident.

2.4. Industrial Hazard Risk Management

Generally, Risk Management is the process of measuring, or assessing risk and developing strategies to manage it. Strategies include transferring the risk to another party, avoiding the risk, reducing the negative effect of the risk, and accepting some or all of the consequences of a particular risk. Thus, the term Risk Management may be defined as the systematic application of management policies, procedures and practices to the tasks of analyzing, assessing and controlling risk in order.

2.4.1. Legislation

Most countries today have regulations that potentially hazardous industries and operations need to comply with in order to demonstrate sound environmental and safety performance and minimize the chances of a major accident. Some regulations focus setting up an adequate institutional framework at the administration level to enable proper decision making on issues related to emergency preparedness, response and mitigation while others try to ensure better risk management at the end of potentially hazardous industries. Select clauses in risk related legislation also lays stress on making risk information available to the stakeholders and the public so that they are better prepared to face technological emergency, if the need arises.

Internationally, the Emergency Planning and Community Right-to-Know Act (US) and the Seveso II Directive (EU) are typical examples in developed countries. A comprehensive regulatory regime also forms the cornerstone for better management of technological risks, especially in developing countries like India. The environmental regulations in India are still in process of development and the legal system for polluting and hazardous industries is gradually moving towards the principle of 'polluter pays'. Recently, the Government has also enacted a law to look at different aspects of disaster management planning at the Central, State and District levels (Bandyopadhyay 2005).

2.4.1.1. International Legislation

The *Seveso Directive* was adopted by the European Union adopted the in 1982 as a common response of the European Communities to the disastrous Seveso disaster which occurred in Italy in 1976. The Seveso II Directive which is a amended version of the earlier Seveso Directive is now applicable to the nations of the European Union and aims at preventing major accident hazards involving dangerous substances, and the limitation of their consequences to man and the environment, with a view to ensuring high levels of protection throughout the community in a consistent and effective manner. A central part of the Directive is a requirement for public information about major industrial hazards and appropriate safety measures in the event of an accident. It is based on recognition that industrial workers and the general public need to know about hazards that threaten them and about safety procedures.

The *Emergency Planning and Community Right-to-Know Act (EPCRA*) in the US was passed in response to concerns triggered primarily by the disaster in Bhopal, India, in which more than 2,000 people suffered death or serious injury from the accidental release of methyl isocyanides (ERRIS 2006). To reduce the likelihood of such a disaster the US Congress imposed requirements on both states and regulated facilities involved in storage and handling of toxic chemicals. The EPCRA establishes requirements for all level of governments and industry regarding emergency planning and "Community Right-to-Know" reporting on hazardous and toxic chemicals. It also looks at following aspects of potentially hazardous facilities: Emergency planning Emergency release notification Hazardous chemical storage reporting requirements, and Toxic chemical release inventory

2.4.1.2. Indian Legislation

The Manufacture, Storage and Import of Hazardous Chemical Rules were notified in 1989 under the powers conferred by the Environment Protection Act, 1989 on 27th November, 1989 and were subsequently amended in October, 1994 and in 2000 to widen the scope and provide for a few additional requirements. The principles objectives of the rules are the prevention of major accidents arising from industrial activities, the limitation of the effects of such accidents both on man and on the environment and the harmonization of various control measures and agencies to prevent and limit major accidents.

The Rules on Chemical Accidents (Emergency Planning, Preparedness and Response Rules) notified on 2nd August, 1996 by the Ministry of Environment and Forests under the powers conferred by the Environment (Protection) Act, 1986, complement the Manufacture, Storage and Import of Hazardous Chemicals Rules on accident prevention and preparedness and envisage a four-tier crisis management system in the country – involving the Central Crisis Group the State Crisis Group, the District Crisis Group and the Local Crisis Group to manage emergencies arising out of industrial operations.

The Factories Act of 1948 came into effect; there has been substantial modernization of industrial activities in India. The operation of a large number of potentially hazardous industries producing or using hazardous chemical substances brought into sharp focus the problems related to industrial risks. The Factories (Amendment) Act, 1987 which came into force with effect from 1st January, 1987 introduced special provisions on hazardous industrial activities in the backdrop of the Bhopal Gas tragedy and the Supreme Court's judgment in the Shriram Gas leak Case. It imposed a number of limitations on the factory management with a view to ensure the health and safety of workers as well as the public at large, living in the adjacent areas. The amending Act has also conferred vast powers on the Factory Inspectors with the objective of implementing the safety provisions of the Act.

2.4.2. Policies and Guidelines

The policy framework for reducing technological risk to environment, human health and safety to acceptable levels sets important overall direction for all concerned stakeholders. Internationally such policy framework is now being shaped by precautionary approach which allows organizations to reduce liabilities by anticipating potential risks and preventing environmental hazards. As a result industries are increasingly shifting from a compliance oriented approach to a risk management approach aimed at avoiding expenditures arising from environmental damage in their effort to integrate sustainable development into their business strategies.

2.4.2.1. International Policy

Several international organizations responded to the Bhopal event by calling for stricter industrial safety regulations. UNEP initiated a worldwide program APELL (Awareness and Preparedness for Emergencies at Local Level) in 1988. Many information systems useful to emergency planners and responders have been developed, such as CAMEO (Computer Aided Management of Emergency Operations) developed by National Safety Council, USA, CHEMSAFE of Germany, BATEX of France and AUSTOX of Australia. Some of them, especially CAMEO provide desired types of information about hazardous substances, air dispersion modeling, mapping, and emergency planning information and computational capabilities. In China, a chemical emergency risk evaluation and prediction system is developed by the military and is applied in some cities (Gui-Lian, Yong-long et al. 2000).United Nations recognized the necessity for technological risk management through UN Rio declaration and UN Global Compact (Bandyopadhyay 2005). Another one is The International Chamber of Commerce (ICC) Business Charter for Sustainable Development was initiated as response to the United Nations Charted for Environment and Development (UNCED) by business organizations and corporate.

2.4.2.2. National Policy

The National Environment Policy, 2006 has been formulated as a comprehensive policy statement in response to India national commitment to a clean environment, mandated in the Constitution in Articles 48 A and 51 A (g), strengthened by judicial interpretation of Article 21 and aims to mainstream environmental concerns in all developmental activities. In addition, it focuses on infusing a common approach to the various sectoral, cross-sectoral, including fiscal, approach to environmental management.

Tenth Plan: Disaster Management – The Development Perspective: The Government of India has lately changed its focus in respect of the overall approach to disaster management. The newer approach rightly lays more emphasis on disaster preparedness and planning functions rather than on response and relief. This view is reflected in the Tenth Five Year Plan document which has a detailed chapter on Disaster Management. The plan document emphasizes the fact that development cannot be sustainable without mitigation being built into developmental process. It briefly outlines the global context and the Indian experience of disasters, sets out the institutional and financial arrangements for disaster management and the response towards these in the country, looks at directions for improvement, and concludes with a strategy to facilitate planning for safe national development in the Tenth Plan period.

2.5. ERRIS- A novel initiative in India

Ever year, industrial accidents like Bhopal disaster take their toll on business and communities –in terms of lives, injury to workers and financial resources. India has been witnessing fast paced industrialization since the liberalization of the economy in the early 1990’s. Resultantly, medium sized industrial towns and development zones have been witnessing a steady induced growth of population because of “honey pot” effect. This has in turn leaded to increase in vulnerability of people to industrial risks posed by hazardous industries. It is now well accepted that the accessibility of up-to-date information on industrial hazards, exposed neighborhoods, population vulnerability, resources available for response, etc. in an easily accessible information management system can enable decision makers and responders to better prepare for and to industrial disaster. Therefore, a sound industrial risk management system can go a long way in assisting large industries to prevent accidents from happening and if they don’t happen, take necessary steps to mitigate the risks and bring it under control at the earliest with minimum possible damage to life and property. This way, industries can also lessen the liability which arises because of such accidents.

The Risk Management Information System (RMIS) is an integrated approach to industrial risk management whereby industry management, decision makers and government officials can make use of a spatial GIS based information system to obtain real time information on the hazards present in the industries, nature of the chemicals, process details, site maps and internal emergency management resources available in a particular industry. The information system also contains data about off-site sensitive receptors and population, first responders such as police, fire, medical agencies and may result in formulating decisive response decisions within a short time. The data is stored in a centralized database designed to meet the requirements for risk management and is made available through a customized user interface to responders and stakeholders concern (ERRIS 2006).

2.5.1. Technical Partners

The RMIS has been conceived by the Indian Chamber of Commerce as a corporate social responsibility initiative whereby industries can respond to a risk scenario efficiently and effectively under constrains of time and resources. Two institutions from Europe – the International Institute of Geo-Information Science and Earth Observation (ITC), The Netherlands and the Institute for Protection and Security of Citizen (IPSC), Italy have partnered with Indian Chamber of Commerce (ICC) to provide handholding support for this initiative for the first time in India.

2.5.2. Outline of Risk Management Information System (RMIS)

Industrial risk arises out of the hazardous substances stored and processed in industrial facilities, storage depots and when such substances are transported from one location to another. The availability of information about hazardous facilities and the hazardous substances they store in the form of raw materials, intermediates or products is the key to the development and functioning of any information system for industrial risk management.

The RMIS has been developed with the following objectives:

- Identification and assessment of hazards posed by storages of hazardous chemicals within the industry premises and have all the related information stored in one composite repository- the distributed organization level database.
- Formulate response strategies and emergency management plans for each unit/plant based on spatial information about the plant and surrounding areas.
- Provide support in managing an emergency in real time by predicting hazard footprints arising out of different accident scenario's (fire, explosion and toxic releases) and taking appropriate response actions.
- Use the system for providing training and carrying our preparedness drills and exercise by simulating various accident scenarios and thereby improving preparedness at organization level.

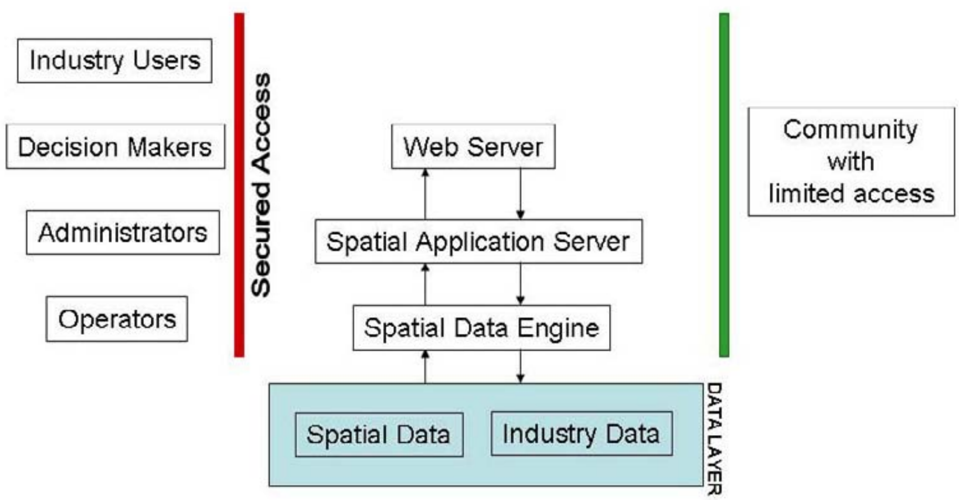

Figure: 2-4. System Architecture of ERRIS

2.5.3. Key Features of the system:

The RMIS uses high resolution satellite imagery for making GIS maps that include exact location of storage sites for hazardous substances with industry site maps, location of critical facilities like educational institutions, hospitals, commercial complexes and response agencies like police, fire stations and administrative buildings as separate point feature geo-database layers.

In addition, detailed attribute information on elements at risk can be stored in the centralized database and linked to the spatial features to enable querying during various stages of disaster risk management, such as emergency planning, preparedness, response and mitigation etc. Such information includes:

- Hazardous Facility/ Industry Information,
- Emergency contact information,
- Hazardous substances inventory,
- Properties of the storage containers, primary and secondary control, containment systems,
- On-site emergency response resources,
- Demarcation of high population risk areas related to the impact by a toxic release, fire or explosion at a nearby hazardous facility,
- Areas that are environmentally sensitive or have fragile ecosystems and critical facilities like educational institutes, hospitals and market places,
- Varying patterns of population occupancy during different times of the day in each of these receptors has been taken into account to provide accurate temporal information to decision makers and responders when they plan for evacuation or location of shelters.

Using the information described above, the RMIS enables the stakeholders with a relatively simple, low-cost, yet powerful way of sharing and accessing critical industry and risk related information for emergency planning or in real-time during an emergency.

Additionally, land use/ land cover classification including agricultural lands, residential areas, villages and slum clusters, industrial and commercial areas, forests and greenbelts, ponds, wetlands and rivers and transportation corridors can be also stored in the system as a land-use geo-database.

2.5.4. Chemical Database (MSDS):

A fully searchable database on Material Safety Data Sheet, commonly known as the MSDS, can be developed for each hazardous chemical that are used by the industries. The MSDS, integrated with the RMIS, can provide the decision makers and the first responders with real-time information on the type of chemicals involved in a risk scenario, properties, and mitigation action to be taken to prevent injuries and damage to vulnerable receptors thereby assisting them in emergency preparedness planning, response and mitigation in the event of an industrial emergency.

2.5.5. Hazard Mapping:

It is an imperative for any risk management information system to provide basic decision support to the users in terms of providing some measure of the extent of damage that a hazard scenario may cause based on which informed decisions can be made by the decision makers and response agencies. This assumes more significance in a developing country like India where in most cases, resources available for emergency response are not adequate and have to be very well managed to mitigate damage and bring the risk under control. The dynamics of risk scenarios involving hazardous chemical can vary widely based on a number of factors like property of chemical involved, nature of storage, nature of release and atmospheric conditions prevailing at the time of accident. Therefore, it is important to calculate the hazard footprint based on accepted consequences models. The RMIS software application integrates accepted screening models to calculate a hazard footprint and overlay it on the GIS map of concerned area.

Presently, the following scenarios can be modelled through the system:

- Pool Fire

- Boling Liquid Expanding Vapour Explosion (BLEVE)
- Vapour Cloud Explosion (VCE)
- Toxic Release.

The “risk map” is also capable of estimating losses to receptors, environment and property thereby helping to take optimal decision with the aim of reducing the damages arising out of the incident.

Figure: 2-5. Hazard Footprint (Toxic Release)

2.5.6. System Architecture

The Risk Management Information System is a customized software application that provides information on various facets of risk management by performing real-time data access, retrieval, analysis and presentation through a web browser based interface and can link spatial maps and non-spatial data from back-end databases so that various queries can be handled, when required. Spatial maps are developed by digitizing high-resolution satellite imagery and the non-spatial database is created by collecting ground level information through field surveys. The information system comprises of the following key components:

- A spatial geo-database storing geometry and attribute data in a Relational Database Management System,
- A set of spatial data server, application servers and web server that can pre-process and extract data from RDBMS, handle queries in real time and forward them to customized user interface,
- A customized, internet browser-based user interface that enables access to the maps and risk related data for users connected to the internet or the local intranet.

The RMIS is based on a thin-client Web-GIS architecture that ensures easy maintainability of the application while at the same time provides scalability to accommodate future changes. Since communication of the various software components are based on the standard HTTP protocol, a high degree of hardware independence can be achieved.

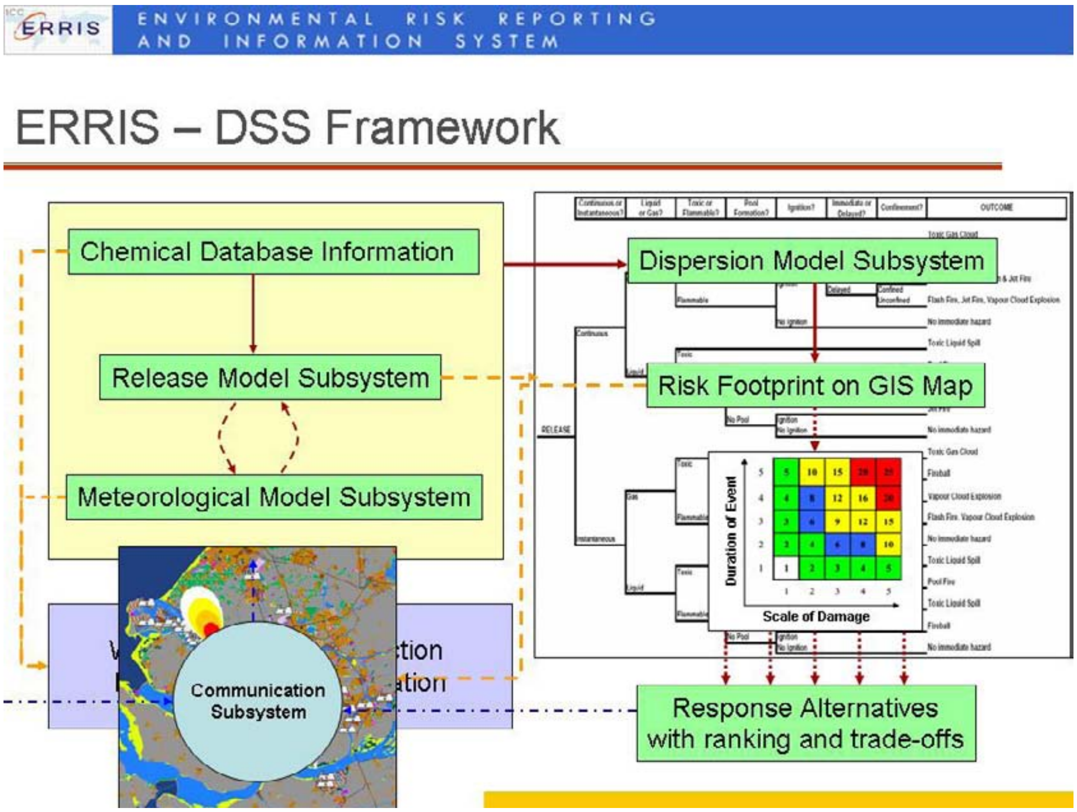

Figure: 2-6. Framework of ERRIS Decision Support System

3. Case Study Town: Haldia

3.1. Introducing Haldia: An Ancillary Port of Calcutta

In the context of progressive deterioration in the navigability of the Hooghly River and the consequent limitations of handling large vessels at the Calcutta Port, the idea of establishing an ancillary port at Haldia was born during the early 50’s. The emerging Port of Haldia (Haldia Dock Complex of the Calcutta Port Trust) brought in its wake in the mid 60’s as recognition of the potentials of developing a port-based urban-industrial centre through establishment of large public and private sector industries in and around it. Setting up a port based urban-industrial complex at Haldia was seen as an instrument for introducing growth in the relatively backward region of Midnapur District.

Through the studies conducted by the Calcutta Port Trust (the then Calcutta Port Commissioners) and other agencies, Haldia was chosen as an ideal site for establishing the ancillary port. It is 56 nautical miles downstream from Calcutta (Kolkata), located at the confluence of the rivers Hooghly and Haldi. The estuarine location and availability of a deep water advantage attracted an oil refinery and a fertilizer plant. The need of a bulk handling port was very strong since the basic raw materials for the production process, such as crude for the refinery and rock phosphate (from Mexico), marinate of potash (from USA, Canada) and common salt (from West Coast of India) were to be imported by sea. The construction of the Fertilizer Complex at Haldia began in 1972 and had to be continued beyond 1980 and completed within 2 years. Although the investment did go up to high but the commercial production has failed to take off even today due to some serious design and process problems. On the other hand, the refinery is functioning well.

3.2. Characteristics of Haldia

3.2.1. Geographical Location

Haldia with an existing industrial base is located 56 nautical miles downstream (1.37 miles = 1 nautical mile) of legendary port Calcutta, the Gateway of Eastern India in the southern tip of Purba (East) Midnapur District in West Bengal. It is located in the estuarine reaches off the River Bhagirathi and the confluence of River Hooghly and River Haldi. The town Haldia lies between latitude 22^0 03‘43.93’’ N to $22^0$04‘53’’N and longitude 88^0 07’53.15’’ E to 88^0 09‘03.61" E. Haldia Municipality or Haldia town lies on the southern tip of the planning area extending over the interfluves of Haldi and Hooghly rivers. The town is not contiguous but the rural area encroaches up to the town area (Das 2002).

For this research the residential area of Durgachak is considered which covers approximately 3 sq. km for vulnerability and risk calculation purpose while the whole Planning Area is considered for land use planning. State Highway 6 bound the detailed study area in east and HPL Link Road demarcates the north boundary. A canal demarcates the western boundary of the study area and the approach road towards industrial area of Durgachak demarcates the southern boundary. *Figure 3.1* shows the location of Haldia town and detailed study area.

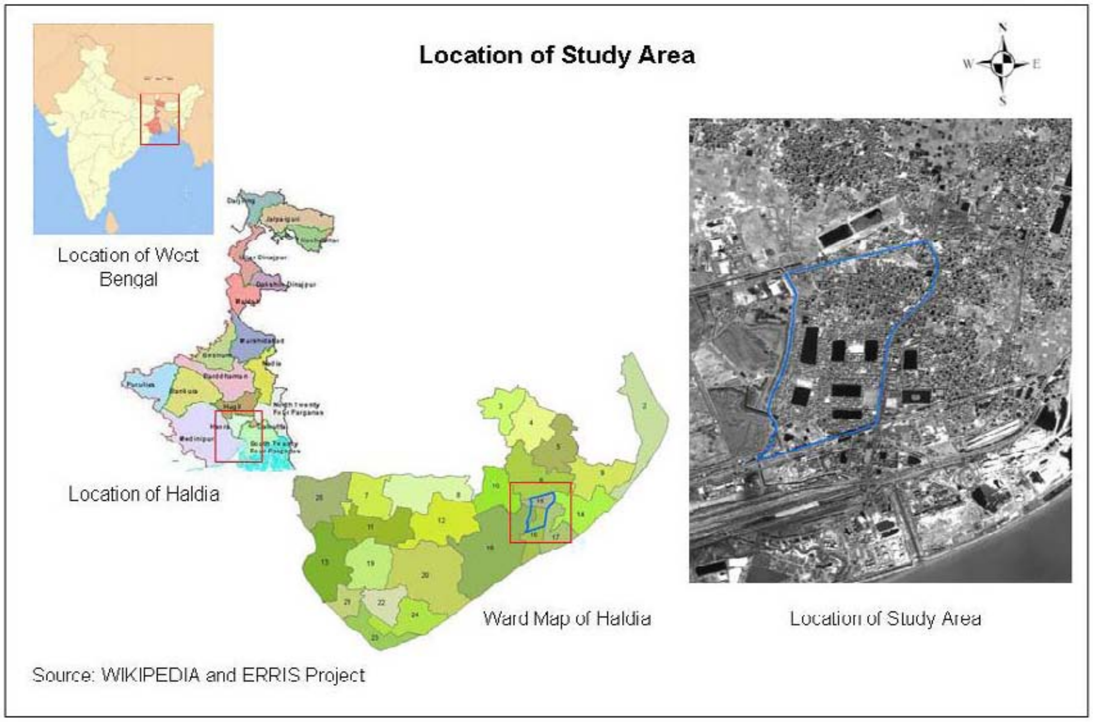

Figure: 3-1. Location of the Study Area

3.2.2. Historic Background

In order to facilitate the handling of bulk of cargo in large containers, the Government of India decided to set up a major port at Haldia in 1959. This decision was followed up with setting up of an Oil Refinery, Township and the Fertilizer Complex. The Planning Commission appointed a study team on Haldia in 1964, and the team submitted its report in 1965 indicating Haldia as a Major Port and related industrial urban activities. In line with this report, the Government of West Bengal set up a Cell under the Development and Planning (Town and Country Planning) Department in 1967 to prepare a comprehensive plan for Haldia. The Cell published its report in 1971 entitled “Haldia Region Interim Strategy Plan”. This plan was primarily a study report based on the growth potentialities of the Haldia region. One of the aspects of this report was to indicate the magnitude of the urban services required to support the port based industries and related activities. This study also indicated the various causes contributing towards the growth of Haldia as an Industrial Urban Complex including the hinterland region, metropolitan region, inter-influence region and the core region. The plan indicated a total urban population of 1.5 lakhs and 3.5 lakhs in 1980-81 and 1990-91 respectively. Subsequently, the Government of West Bengal in the Development and Planning (Town and Country Planning) Department published another report on Haldia in 1975 entitled, “An Outline Development Plan for Haldia Industrial Urban Complex”. This plan indicated a conceptual direction of the physical growth pattern of Haldia. It envisaged a total population of 3.5 lakhs in 1991 and distributed the same over the two nodes at Haldia and Durgachak (Authority).

In the mean time, the State Government took some significant decisions towards the growth of Haldia. Haldia was recognized as one of the growth centres in the State in the backward district of Midnapur. This entitled the perspective entrepreneurs for the package of incentives for setting up industries in Haldia. The West Bengal Industrial and Infrastructural Development Cooperation were set up and were responsible for implementing the major development works for the State Government. A high power authority known as the Haldia Development Board was set up under the Chairmanship of the Chief Minister to guide and monitor the development of Haldia. In 1979, the West Bengal Town and Country (Planning and Development) Act came into force. In 1980 a Planning and Development

Authority was constituted in respect of Haldia Planning Area under the said Town and Country Planning Act. In February, 1985 Government prepared an interim draft Outline Development Plan which provides the base for this plan.

Emergence of Haldia apparently opened up visions of creating a growth node in relatively backward region in the State of West Bengal as well as encouraging a counter-magnet to Calcutta metropolis in terms of industrial depolarization in the Calcutta metropolitan region. The Planning Commission, Govt. of India, during the early years of the Fourth 5-Year Plan period (1969-73) declared Midnapur District as a backward region. To further strengthen the prospect of industrial development in Haldia, the State Govt. of West Bengal in 1972 declared Haldia as a Growth Centre along with seven other towns in the State. The stated objective of the State was to encourage industrial and economic activities in areas other than the Calcutta Metropolitan District (CMD) to reduce pressure on it and create employment opportunities outside CMD. Haldia began to be identified as not merely a subsidiary port of Calcutta (Kolkata) to supplement it's facilities, but also as a new growth centre in the region and a new seaway to the prosperity of the entire Eastern India.

In order to promote the growth centre at Haldia, the Commerce and Industries Department of the State Government announced (1973) took a package of incentives to industrial entrepreneurs. The West Bengal Industrial Development Corporation (WBIDC) was recognized into a full-fledged industrial promotional agency (1973), and a statutory agency called the West Bengal Industrial Infrastructure Development Corporation (WBIDC) was set up (1974) for developing industrial infrastructure in the growth centre, again with a specific focus on Haldia.

By the mid of 70's, with the Haldia Dock Complex functioning, oil refinery commencing production, fertilizer plant construction initiated, petro-chemical complex under negotiation, a large number of industries slinked up for establishment, railway and national highway connections established, state agencies set up for promoting Haldia's rapid growth, and building of the township under progress, Haldia was all set to take off as the Growth centre that was expected to transform a backward regional economy through spatial developmental impacts. Initially Haldia had arrived, but then evidences gathered around the end of 80's with regard to the much-expected growth of Haldia and its spatial impact in the region that not much has been achieved.

The history of urban-industrial development process is replete with the examples of fluctuating fortunes of urban habitations through a cycle of prosperity and stagnation. The role of Calcutta Port Trust (C.P.T) in this revival of Haldia's urban-industrial fortune is potentially crucial. The nature of controlling and promotional policies in relation with the expansion of the activities and functions of the Haldia Dock Complex are considerably influenced by the C.P.T. After all, Haldia's genesis was through a Port function and there is no dearth of cities, all over the World which, for their economic diversification and prosperity, owe a great deal to their ports.

3.2.3. Administrative Structure of Haldia Planning Area

Haldia Planning Area (HPA), as delineated was declared as a planning area under section 9(1) of the West Bengal Town and Country Planning and Development Act in 1979 for the purpose of further development of Haldia. The delineation of HPA is unique, encircled by the River Bhagirathi, Hooghly and Haldi in three sides while the Hijli Tidal Canal separated the planning area from the rest of Mahisadal P.S. area. The total planning area contains 258 mouzas (revenue village) with a total area of 326.85 sq. km. (80517 acres) and a population of 3 91,433 as per as 1991 census. The planning area embraces all the mouzas of the Sutahata, Durgachak, Haldia and Bhawanipur Police Stations and 3 mouzas of Mahisadal Police Station. The planning also contains two urban areas viz. (i) area under Haldia Municipality and (ii) part of Mahisadal Non-Municipal Area. Following figure *(Fig: 3.2)* describes the hierarchical structure of Haldia Planning Area.

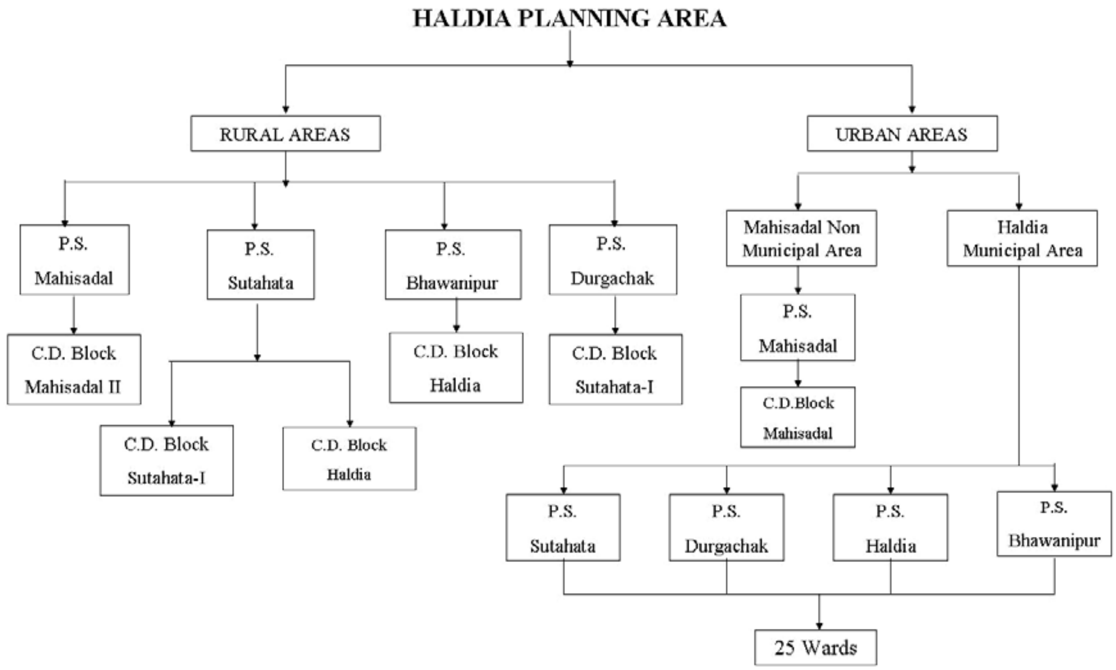

Figure: 3-2. Hierarchical Structure of Administrative Units within HPA

Recently in 2006, the planning area has increased to 760 sq. km. by adding 434 sq. km. to its existing area (i.e.326 sq. km.). The proposed planning area contains 476 mouzas (revenue villages) by including all mouzas of Mahishadal Police Station, 36 mouzas of Nandakumar Block, 140 mouzas of Nandigram Block I and II and 1 mouza of Mendip island.

3.2.4. Physiography

Generally, the land in this region is almost flat and the ground level is 7 to 11 feet above the mean sea level. The land upon which the Haldia Town is situated lies on the combined deltaic plain of Damodar and Kasai River. Therefore, the remnants of natural levees and abandoned channel are seen on the surface topography. The levees are small in length and occurred scattered. Some of the levees remain as an embankment upon which the old settlements are found; otherwise the surface is absolutely flat so that filling of the ground is general nature for building of the town and industrial estates. The normal slope of the surface is from NW to SE. In the mouth of the deltaic plain along the bank of the rivers longitudinal bar have developed thus creates the problem for the movement of the sea along the river. Therefore, draining out of the land is a problem (Biswas 1991).

3.2.5. Soil

The soil of Haldia region is considered as a part of Indo-Gangetic Alluvial Plain (Bengal Basin). The alluvial materials deposited by river Ganges and its tributaries and distributaries have developed the soil of this basin. Generally the soils of Haldia and other coastal areas are more or less salt impregnated due to the diurnal tidal flow of the sea water through creeks. Soils are deep, fine loamy to fine in texture, imperfectly to poorly drain with moderate to very strong salinity hazard. Soils are neutral to slightly alkaline and having exchangeable sodium (below 15%) with high base saturation (Biswas 1991).

3.2.6. Drainage

Haldia Town is flanked by the two rivers Hooghly in the east, north, and Haldi in the south. Small creeks and channels from the main stream intersect the region. However, in many cases they are choked up by alluvial and as they are moribund in nature, thus drainage becomes a problem for the town. After heavy rain patches of individual flooded dot the surface remain as stagnated water. River Hooghly boarders the town in the North and with a big bend it faces to the south and ultimately merges with the Bay of Bengal (Das 2002).

The southern part of the town is bordered by Haldi River. It runs NW to SE direction. It took its origin by the amalgamation of Kasai and Kaliaghai River and ultimately Haldi escape to the Hooghly River. From the point of abundance of water, the Haldia Town is naturally gifted for it's position but the town faces severe problem from the point of view of drinking water.

3.2.7. Climate

Being nearer to the sea Haldia Town enjoys both temperate and hot humid climate. According to Koppen's Climatic Classification Scheme this region comes under Tropical Savannah. The temperate climate may be observed from November to March and the hot humid climate prevails on April, May and June followed by monsoon till October. The maximum temperature throughout the season except two or three months remains within the range of 27^0C to 32^0C while the minimum temperature seldom goes below 10^0C. This temperate climate of this region is favourable for both living as well as for agriculture.

Normally in the last part of June Monsoon arrives in this region and extend up to August. The intensity of rainfall during monsoon is even more than 90%. The average annual rainfall is 148.8 cm. The relative humidity is highest in the month of July and August and lowest in the month of January. The wind direction is generally from south and south-west with low velocity.

The area is often prone to depressions and cyclones. Recently in September 2006, there was a cyclone that causes the agricultural damage as well as loss of human life. *Figure 3.3* showing the devastating effect of recent cyclone (2006).

Figure: 3-3. Devastating Effect of Recent Cyclone

3.2.8. Vegetation

The natural forest over the area becomes totally depleted day by day. Some stray spices of trees, shrubs and herbs are still found today. Under the Social and Community Forestry Programme, several plantations have been raised along the major roads, canal banks and river embankments. The principle plantation species occurring within the area are Acacia varieties (Das 2002).

3.2.9. Land Use Pattern

Haldia has grown rapidly in the last two decades in terms of population and industrial activities. With the setting up of the Haldia Dock Complex in the 70's, an industrial township has been developed in its immediate hinterland. The port town, today, has several industries that include Indian Oil Corporation (I.O.C), Mitsubishi (M.C.C), Hindustan Lever Limited (H.L.L) and other large units related to chemicals and other industrial products. Those industries are mostly located along the river Hooghly and on both sides of the HPL Link Road. This industrial zone represents a source of environmental pollution with the effluents being discharged into kuchha drain and canals leading directly to the river Hooghly. Absence of green buffer results in the spread of pollutants all around.

The residential zone is concentrated mainly at the intersection of arterial roads and the Highways and also at the vicinity of ferry points along the river. Mixed land use has taken place in a linear manner along the major roads with the lower floors being used for commercial purposes and the above floors for residential purposes. The spill over of the commercial activities on the roads has lead to encroachment resulting in narrow right-of-ways. The scene at Durgachak and Ranichak is particularly worse in this respect, thus presenting a haphazard development, acute congestion and encroachment.

However, towards the south the picture is much more soothing with the existence of several townships of HDC, IOC, HFC, Mitsubishi Chemicals, and Haldia Petrochemicals etc. along the river Haldi. The condition of traffic and transportation is equally deplorable. The transport sector in Haldia is characterized by poor road geometrics, absence of pedestrian and parking facilities, level crossing and intermixing of fast and slow moving vehicles.

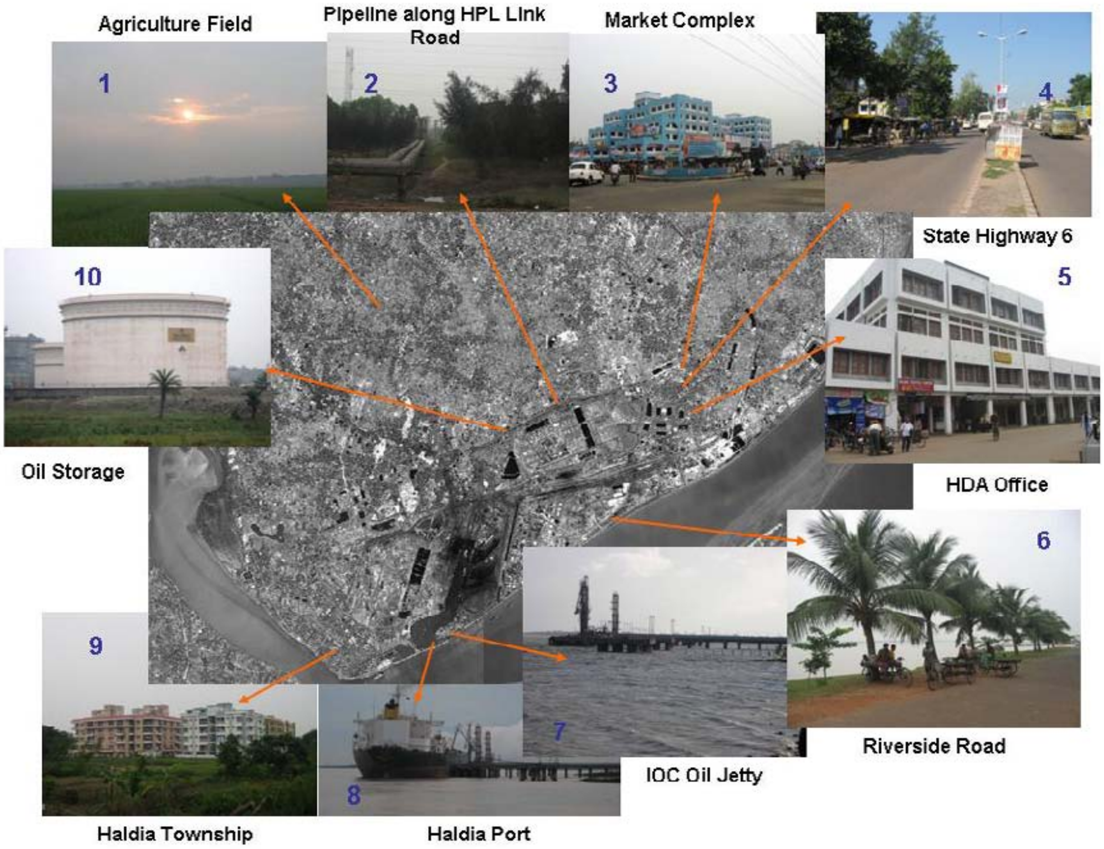

Figure: 3-4. Photographs for Haldia Town

3.2.10. Settlement Pattern

Settlement pattern of the region indicates typical rural structure with scattered small settlements all over the region. The regional balance is bound to undergo tremendous change along with the development of Haldia Urban Industrial Complex when the entire system of the region will emerge in a bifocal urban pattern. This will be evident from the population study to project the total population of the planning area will rise from 23% in 1981 to 38% in 2001 A.D. in order to maintain a balance in respect of population distribution, the anticipated pull of Haldia Urban Complex is to be countered by putting the necessary economic, social and infrastructural inputs in other growth centres.

3.2.11. Rail and Road Network

The planning area is well connected with roads, railways and waterways. NH-41 connects Haldia with the NH-6 at Kolaghat. Panskura-Durgachak Road is another arterial road connecting Haldia to State Highway-6. A railway line also connects Haldia to the main South Eastern Railway line at Panskura and the distance from Panskura is about 69 km by railway. Haldia is also accessible from Diamond Harbour Road in the 24 Parganas District (South) by crossing the ferry between Raichak and Kukrahati over the river Hooghly. It takes about 3-4 hours by road and rail from Kolkata to Haldia and about 2-3 hours via Raichak and Kukrahati.

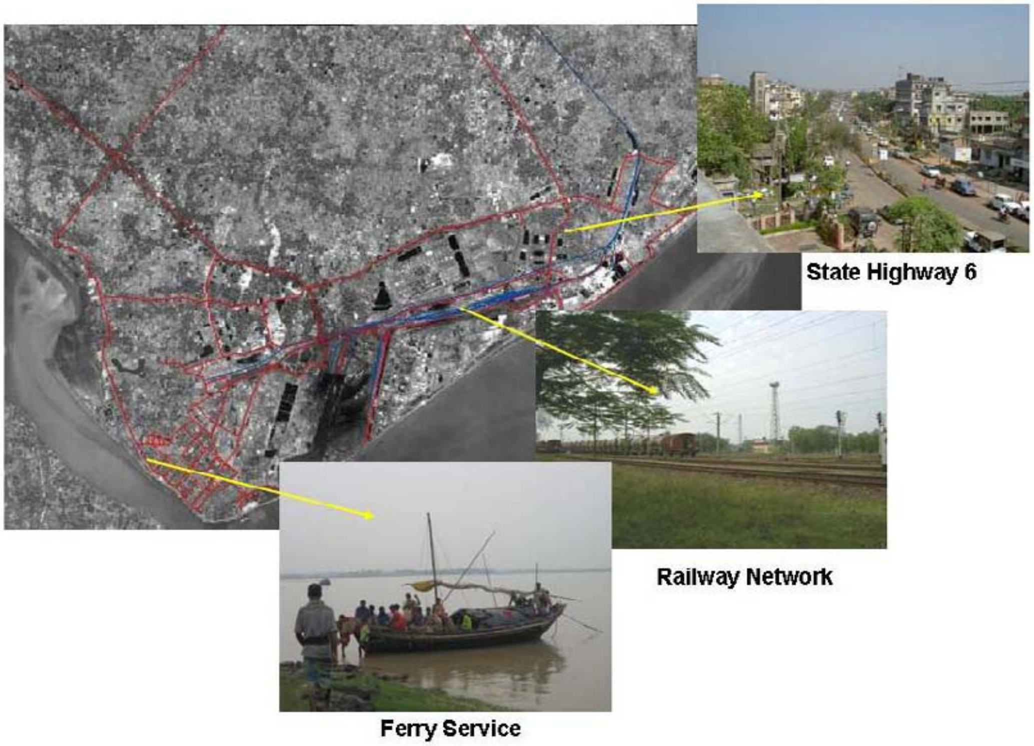

Figure: 3-5. Road and Railway Networks

3.3. Demographic Profile of Haldia

3.3.1. Population Distribution of Haldia Planning Area

Haldia Planning Area had a population of 1.38 lakhs in 1951. In the following decades the population multiplied and became 3.91 lakhs in the year of 1991. The population of Haldia Municipal Area grew rapidly from 9,968 in 1951 to 1, 00,347 in 1991. The following figure *(Fig: 3.6)* explains the change of population of HPA, HM and Non-HM areas over the decades from 1961 to 1991.

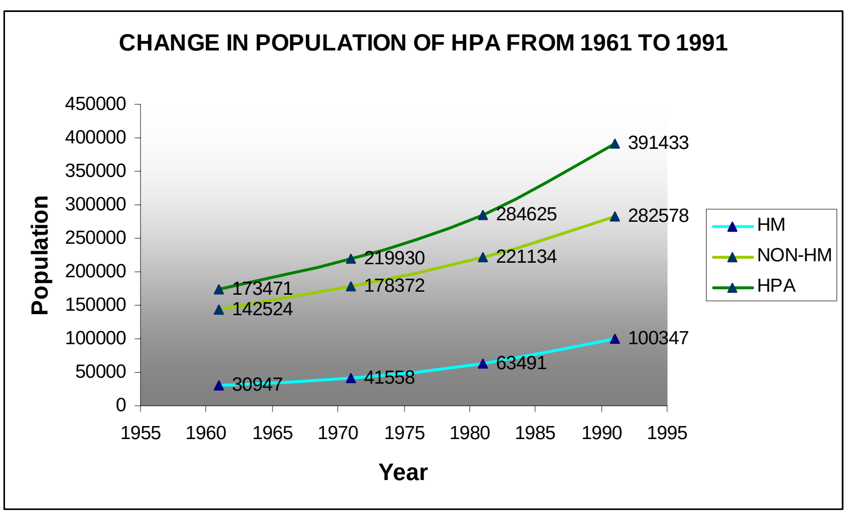

Figure: 3-6. Population Change of Haldia Planning Area

(Source: District Census Handbook, 1961 – 1991)

The density pattern of HPA shows a rapid increase from 5.3 persons per hectare in 1961 to 11.9 persons per hectare in 1991.The urban areas within HM and Mahisadal NM areas are much denser, having densities of 14.52 persons per hectare and 27.6 persons respectively. 1978 was the crucial year when the densities of for HPA, HM, and Non-HM were same. It was only after 1978 when the density of HM accelerated.

The decadal growth of population of HPA increased from 25.85% in 1961-1971 to 37.09% in 1981-1991. The Haldia Municipal Area (69.1 sq. km) itself accounted for 58.05% of the total growth rate in 1981-1991. Both the Planning as well Municipal Area have recorded the highest growth rate in comparison to District and State having figures of 23.5% and 24.7% respectively. This is well evident from the following graph that explains the change of decadal growth rate of population of HPA, HM and Non-HM area.

The level of urbanization of HPA in terms of the share of urban population to total population represented in percentage indicated that it has increased from 4.5% in 1971 to 7.4% in 1981. The level of urbanization was 27.8% in 1991, certainly higher than the District figure of 9.85% but almost same to that of State average of 27.48%.

Share of population of Haldia Planning Area to both the district and the state increased since 1961. In 1981, HPA accounted for only 0.53% of State Population and 4.5 % of District Population. In 1991, its population rose to about 4.69% of District Population and 0.57% of State Population.

3.3.2. Population Distribution of Haldia Municipal Area

Total population of Haldia Municipal Area is 1, 70000 as per 2001 census. Following figure (fig; 3.7) shows the ward wise population distribution of Haldia Municipal Area.

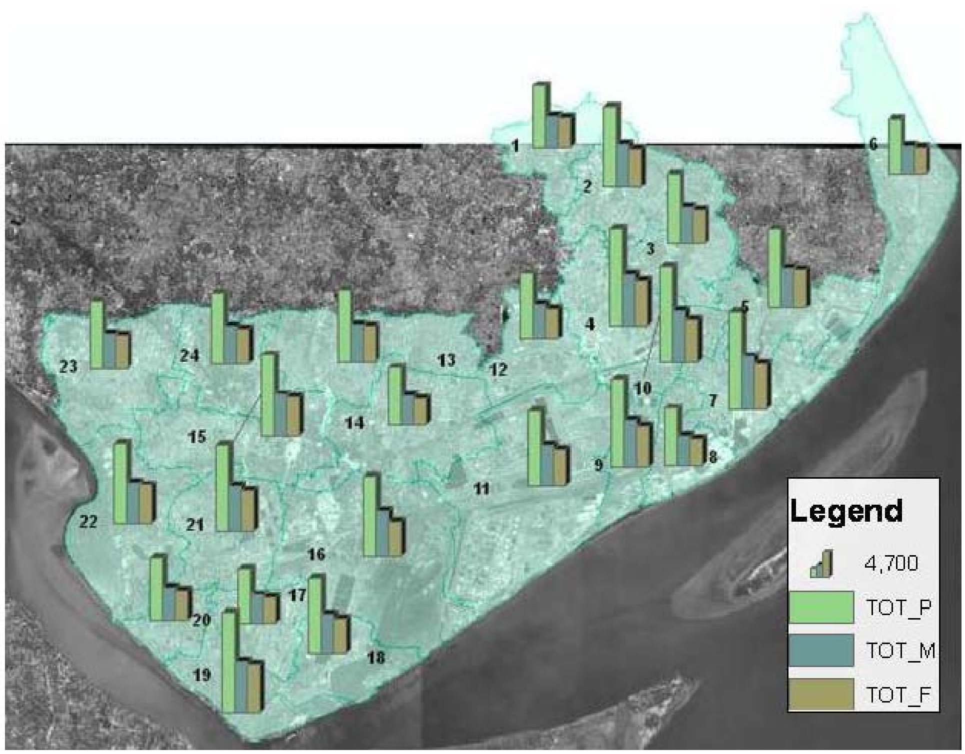

Figure: 3-7. Ward wise Population Distribution of Haldia municipal Area (2001)

3.4. Haldia: An industrial Town

Following the development of WBIDC, a large number of private sector enterprises came forward with the proposals to set up industries in Haldia. Many of these proposals got quickly processed and by the beginning of 1975, eight Private Sector proposals and three Joint Sector proposals were approved by the Government of India and West Bengal. Besides, five Private Sector Projects were proposed by the State Govt. and one Private Sector proposal was waiting for approval of the Central Govt. A detailed study by the Development Planning Department, Govt. of West Bengal, published in 1975, listed a total of 17 (excluding Oil Refinery and the Fertilizer Plant) industries which by 1975, had expressed intention to establish plants in Haldia. Amongst the names listed, there were well known companies like: India Tobacco, Andrew Yule, Hindustan Lever, Bengal Coals, Rallies India, Indian Drugs & Pharmaceuticals, Delhi Cloth Mills, etc. A Ship Building Yard and expansion of the Refinery were also listed. Out of these 17 identified industrial units expected to establish by 1985, but only 5 had started by then.

Besides these industries listed, the State Govt. of West Bengal had very strongly been pressing the Govt. of India to approve the establishment of a Petro-Chemical Complex. This was viewed as the most appropriate propulsive industrial activity in the new growth centre of Haldia, since the essential inputs would be available from the by-products of the refinery located here. Moreover, the need for a Petro-Chemical Complex in this region was strongly felt to feed Calcutta industries and markets as there is a great demand for these products in this area.

The prospect of Haldia becoming a dominant growth centre in the region began to merge in the early 70's. An Interim Strategy Plan for Haldia prepared in 1971 by the Govt. of West Bengal took into account the multiple roles that Haldia could play on four levels of region as follows:

- Hinterland Region: The port functions shared with Calcutta and serving the entire Eastern India region should influence the economy of a vast hinterland region.
- Metropolitan Region: A large part of the Calcutta Metropolitan Region to the west of the river Hooghly would be an area to receive significant impact from the large basic industrial growth potential identified for Haldia.
- Inter-Influence Region: The entire area covering the entire area of Tamluk sub-division consisting of six police stations with Haldia located at the southern tip, would have the strongest influence of Haldia and also the main commuter's zone.
- Core Region (Haldia Urban Region): The area adjacent to and inclusive of Haldia would experience rapid urban spread including growth of business, commerce, administration, social services and facilities.

3.4.1. Spatial Growth of Industries

Except a few brick manufacturing and some cottage industries; there were no trace of industrial activities within the HPA till 1968. In 1979, about 500 hectares of land are found under industrial use and by 1990 it extended by more or less 300 hectares, covering approximately 800 hectares of land for industrial purpose within a short span of time.

3.4.2. Existing Industries

Haldia's existing industrial base, social infrastructure and transportation linkage makes the Town a good choice for the further growth of industries. The upcoming major Petrochemical Complex of Haldia is 'Petrochemical Ltd. and Purified Tetraethyl Acid'. Acid plant of Mitsubishi Chemical Corporation add a new dimension to the possibility by acting as the mother unit for setting up of both upstream and downstream industries (Das 2002).

Figure: 3-8. Location of Existing Industries in Haldia

The existing industries of Haldia are list as below:

- Reliance Petroleum Ltd.
- Haldia Petrochemicals Ltd.
- Exide Industries Ltd.
- Bharath Petroleum Corporation Ltd.
- Consolidated Fibres & Chemicals Ltd.
- Tata Chemicals Ltd.
- Sanjana Cryogenic Storages Ltd.
- MCC PTA India.
- IOC Petronas Pvt. Ltd.
- IBP Co. Ltd.
- Hindustan Petroleum Corporation Ltd
- Hindustan Lever Ltd.
- Haldia Refinery, Indian Oil Corp.

3.5. Summary

This chapter describes the evolution of Haldia as a port town. The brief physical characteristics and its demographic profile also discussed in this chapter. The emergence of Haldia as an industrial town is also considered in this chapter.

4. Database Preparation

This chapter consist of two parts namely data collection and data preparation. It explains the data collection from different government and semi-government organisations as well as from the ERRIS Project Office. The database used in this research was developed as a part of the ERRIS Project so that later on the same can be used to upscale the method of vulnerability assessment for the whole town of Haldia. The questionnaires prepared for collecting the information of buildings of different use/type as well as the questionnaires used for collecting the information from various industries by ERRIS Project are also mentioned (See Appendix). The method of creating building inventory for vulnerability assessment is one of the major parts of discussion in this chapter as well.

4.1. Data Collection

Prior to the actual data collection in the field, the plan for fieldwork was prepared in order to design the data collection that has to be carried out. This included detailing out the information and data that were to be collected from the ERRIS Project Office and other concerned departments. A major portion of the data was collected through field survey. After having a good conception of the topic, the literature review was carried out to have a better understanding of the problems, and thus the methods and approaches to be used were decided. The problems in and around the study area were analyzed and accordingly objectives and methodology were framed depending on the availability of the data. This part includes the collection of the data for the study area in Haldia by field survey. The detailed study area was selected after discussion with the experts from the ERRIS project.

4.1.1. Field Survey

Field survey was broadly divided into two main phases: Reconnaissance Survey and Detailed Survey of the study area. The reconnaissance survey was done after collecting the dataset from the earlier work done by the ERRIS Project. The satellite data and ancillary data are also collected prior to the start of the field survey. The second phase of the field survey dealt with the collection of the data of buildings in the study area and the preparation of a data collection form for vulnerability assessment for the study area based on the reconnaissance survey. It also included the collection of missing data of industries within the vicinity of the study area. The questionnaire was tested for few buildings of different construction and use type within the area and modifications were done thereafter to prepare the final questionnaire for collecting the information. Almost 45 days were spent for collecting the information and data from the field by 3 people.

4.1.2. Design of Questionnaire

The design of the questionnaire for making a building inventory and population details per hour of a building is the major key for industrial hazard vulnerability assessment. The structure of the questionnaire was broadly composed of three major sections such as: identification number, structural condition and population details of the buildings. The first section (i.e. identification data) includes the general building and plot information provided by HDA and simultaneously collected from field survey. The second section (i.e. structural condition) describes the general information about building material, wall material, no. of floors, airtight condition etc. All these data were collected during the survey. The third section deals with the population details per building for every two hours interval.

The questionnaire were prepared in Microsoft Access and later on converted into GIS framework. The detail of these questionnaire forms are given in the appendix (*See Appendix: 2*).

4.1.3. Detailed Study Area Demarcation

For this research the area nearby the Durgachak industrial area is considered as the detailed study area for vulnerability assessment of buildings and population due to fire, explosion and toxic release scenarios. The study area comprises a part of the municipal wards 9 and 10 which covers 3 sq. km. *Figure 4.1* shows the location of the detailed study area.

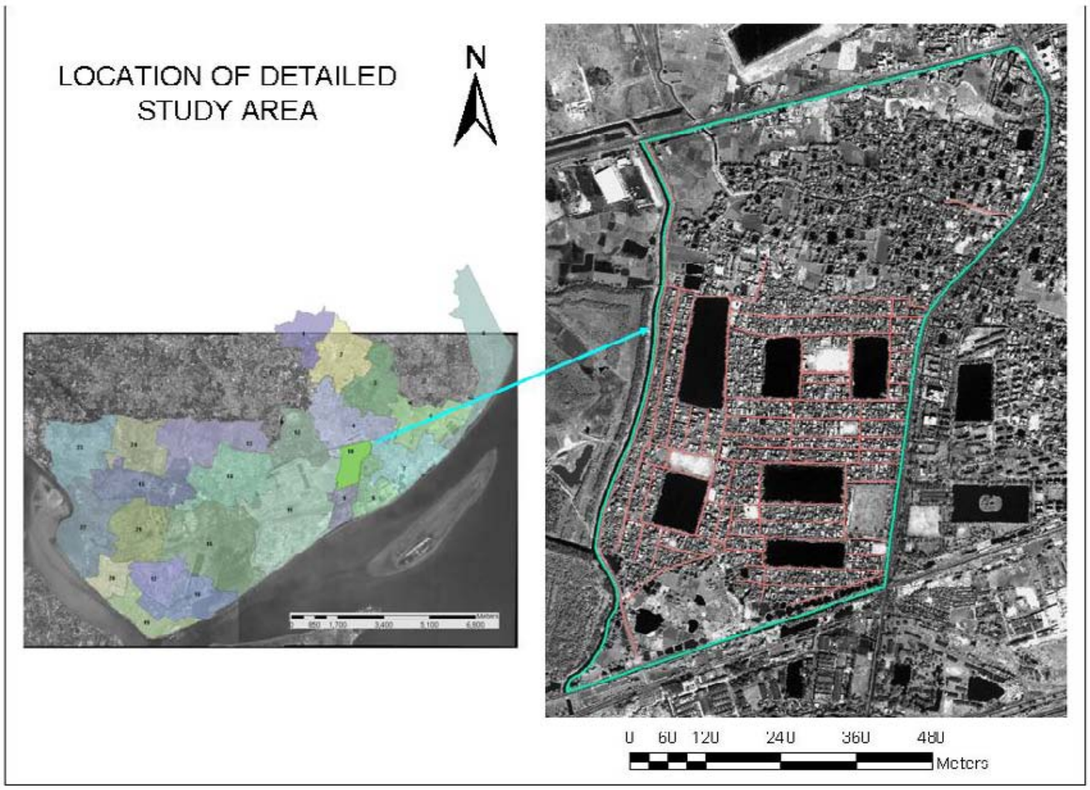

Figure: 4-1. Location of the Detailed Study Area

The area is mainly delineated by physical boundaries. The State Highway 6 demarcates the eastern boundary, HPL Link Road borders the northern boundary and western side is bounded by a canal while the approach road towards industrial area demarcates the southern boundary of the study area. The area is mainly surrounded by the industrial area of Durgachak from three sides which is the main reason to select this particular area for vulnerability assessment. The predominant land use pattern of this study area is residential followed by commercial. In between these two a huge land use patch is there where villages with homestead orchards are the predominant land use pattern. The southern part of the study area is mainly dominated by residential pattern while agriculture is found as the predominant land use for the northern part. The residential area is further divided into 8 blocks namely A, B, C, D, E, F, G and New Colony (NC) by HDA *(Figure: 4.2)*.

The residential areas are mostly developed in a planned manner. Each residential block is divided into plots and each plot has a unique identification number. As such there is no unique address system in this area which creates the difficulty for identification of each building. Even within a single plot two or even more houses were also identified. Therefore, during the field survey each building was assigned a unique number which comprises respective ward number, block number and plot number for identification purpose. The residential area is mainly characterized by medium to low income group of people. Houses having commercial shops in their ground floor are found along the State Highway 6. There are five educational institutes within the study area including primary and high school. The whole area in general can be characterized as haphazard and unplanned development, which can be considered as a good site for comparative vulnerability assessment.

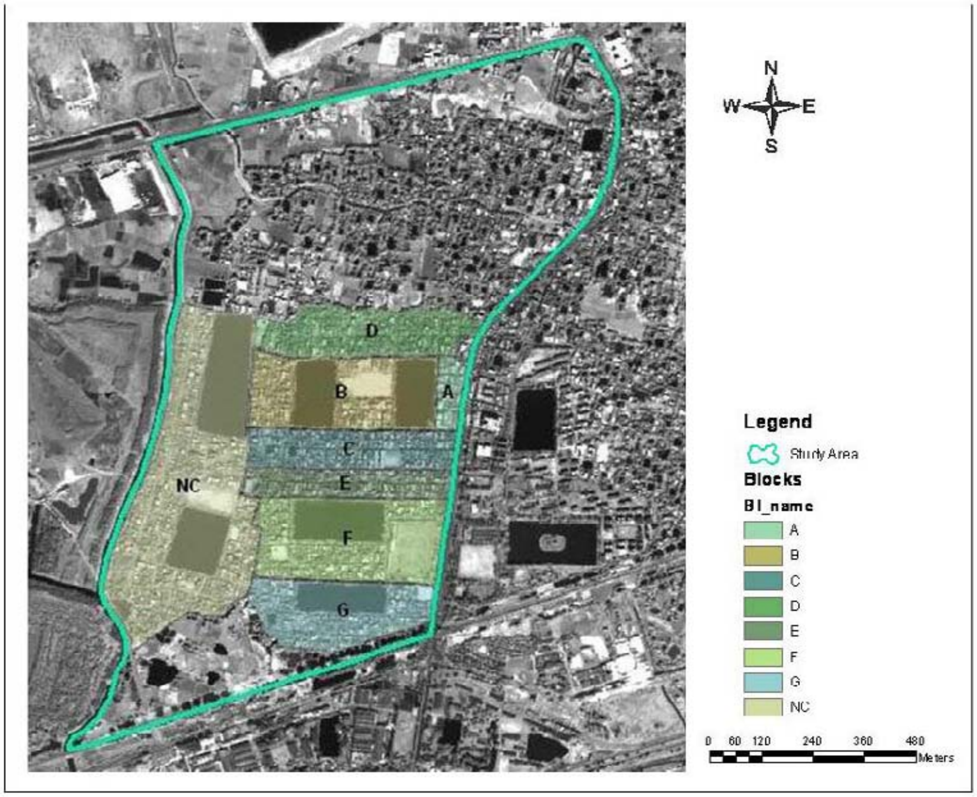

Figure: 4-2. Residential Blocks within the Detailed Study Area

4.1.4. Detailed Survey

During the commencement of the field survey most of the buildings were identified. The details of individual buildings are collected through a field survey to create a database of building inventory and population details for vulnerability assessment purpose. The predominant building occupancy classes found within the study area were residential followed by commercial. The database for 1302 buildings was prepared for the present research work. Priority has given to building structure condition and population per house at certain time interval.

4.2. Data Preparation

Data preparation is the next phase of database generation after data collection. Once data are collected from different sources as well from field survey it is very necessary to arrange the collected data in a proper fashion thus to prepare the database to carry out the analysis successfully.

4.2.1. Remote Sensing Data

For the present research IKONOS Imagery of Haldia was used as a base for generating the database of buildings surveyed. Space Imagine Inc., a US based Earth Observation Company is the premier provider of IKONOS satellite image. IKONOS works on the principle of push broom and simultaneously provides multi-spectral and panchromatic images. In this research, IKONOS panchromatic image is used mainly for generating the building footprint map while multi-spectral image is used for land use identification and classification purpose.

Table: 4-1. Satellite Data used for Research

Satellite Image	Acquiring Date	Ground Resolution	Area
IKONOS Panchromatic	June-04	1 Metre	Haldia, West Bengal
IKONOS Multispectral	June-04	4 Metres	Haldia, West Bengal

4.2.2. Ancillary Data

The ward boundary map of Municipal Area provided by Haldia Municipality was used for the identification of the ward boundary within the detailed study area. Apart from that, plot boundary maps *(Fig: 4.3)* provided by HDA of each residential blocks within the detailed study area (i.e. A, B, C, D, E, F, G and NC) were also used for proper identification of building as to assign a unique identification no for each building.

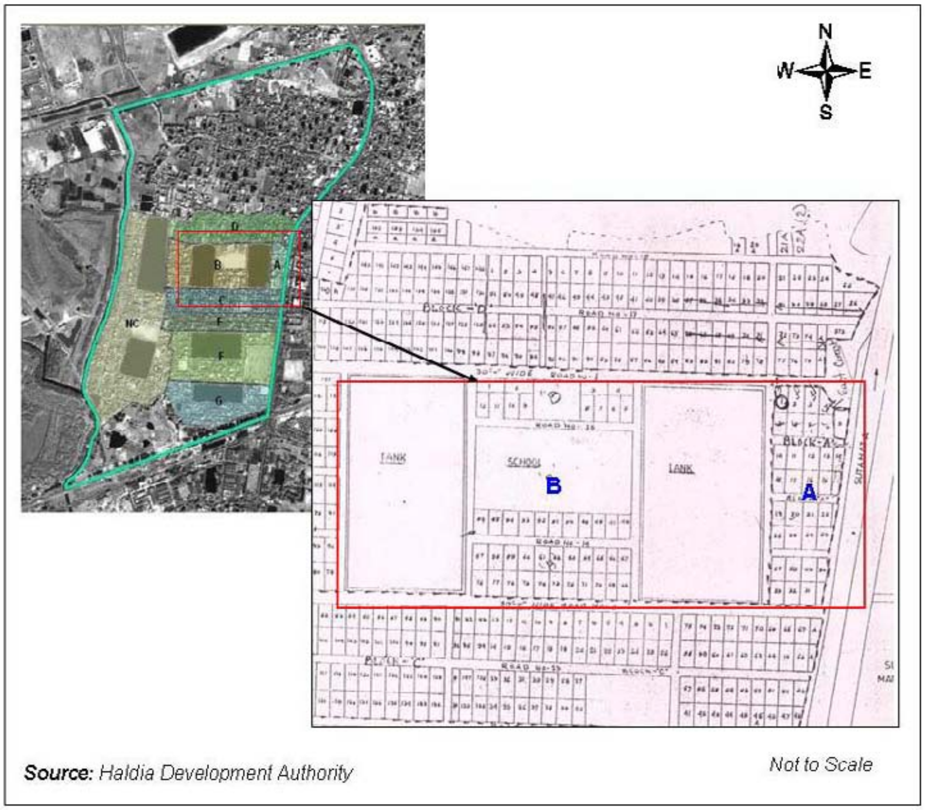

Figure: 4-3. Plot Boundary Map of Residential Blocks

4.2.3. Generation of Building Footprint Map

The main purpose for generating a building footprint map is to add the information of individual buildings collected in the field as attribute data. Firstly the ward boundary map of Haldia was digitized on screen based on the ward map prepared by Haldia Municipality in order to locate the study area. Then the study area was selected and the physical boundary of that was digitized. After digitizing the boundary of the study area, the residential blocks boundaries within the study area were digitized. Finally individual buildings were digitized on screen based on IKONOS image and unique ID's were assigned to each of them with respect to ward no. and block ID *(Fig: 4.4.)*.

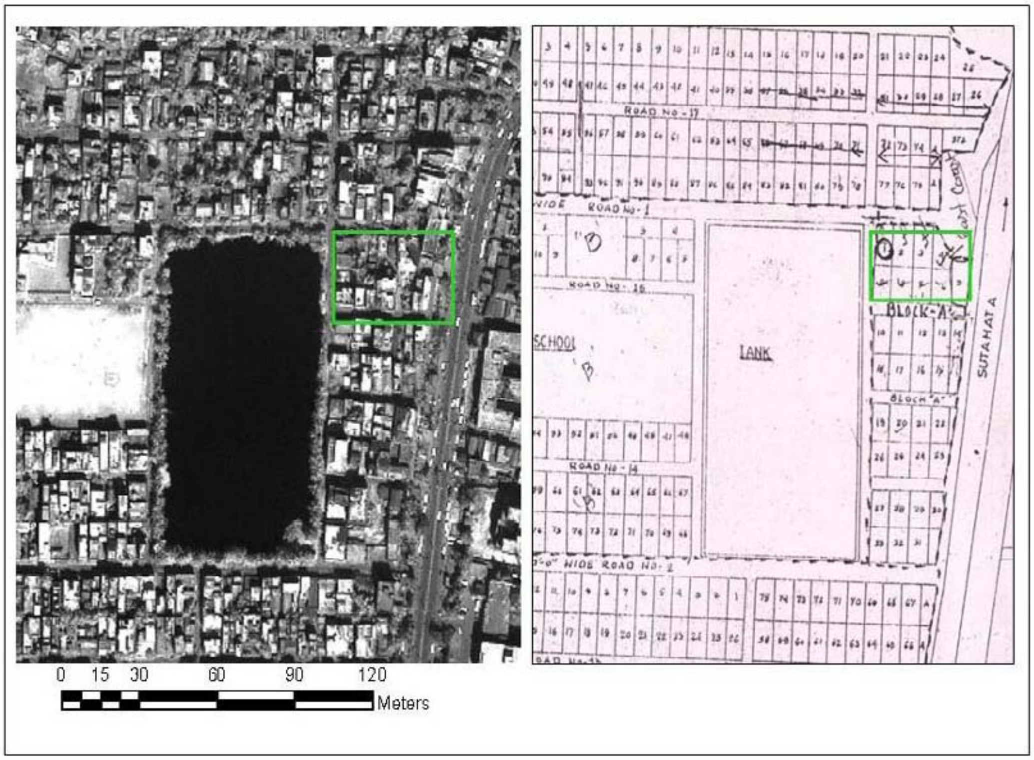

Figure: 4-4. Identification of Individual buildings with respect to Plot Numbers

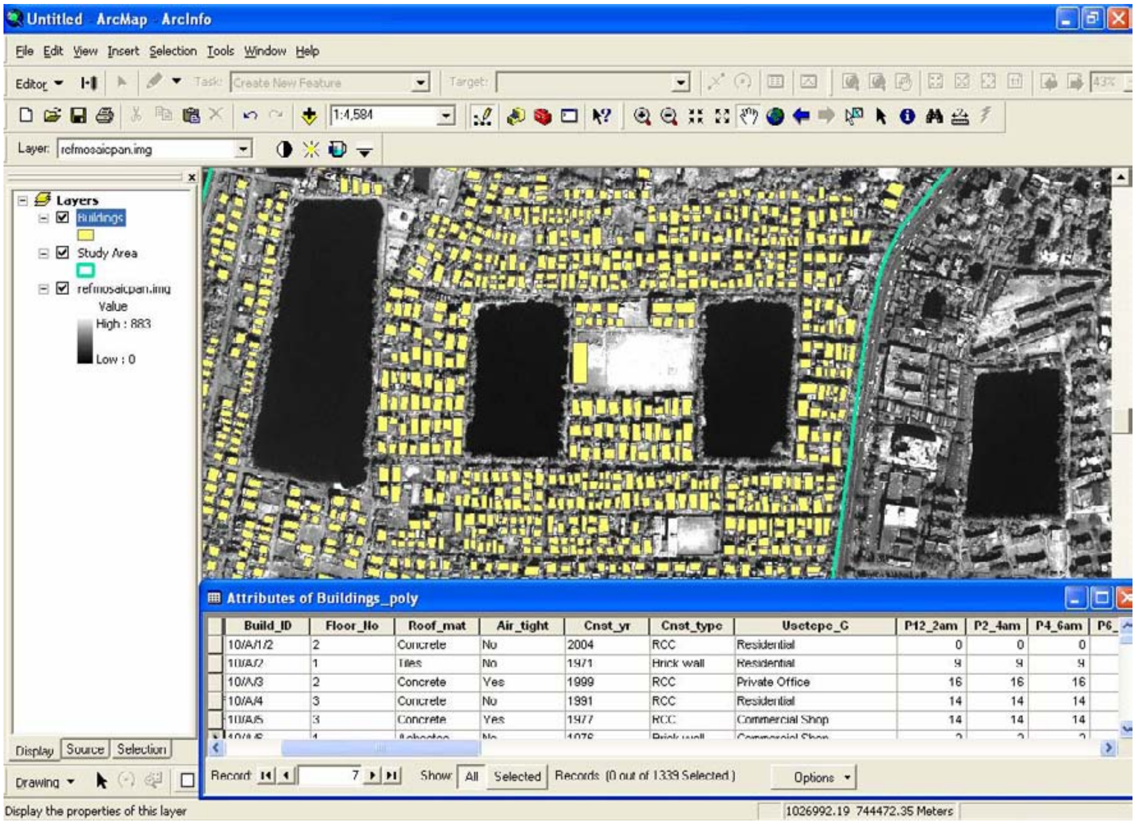

Figure: 4-5. Generation of Building Footprint Map

The *Figure 4.5* shows the digitization of individual buildings within the detailed study area on IKONOS image. The digitization was done with the help of plot boundary map in order to identify the exact location of the building and thus cross checked its unique ID. The detailed information for building construction type as well as population per two hours interval collected are also attached in the attribute table.

4.2.4. Building Inventory of the Study Area

Data for individual building were not available for the study area therefore the data was collected through detailed field survey. Large printouts of IKONOS images along with the plot boundary maps were taken to the field to identify and to assign unique IDs for each building. All the parameters listed in the questionnaire of individual buildings were filled in the data entry form in the field itself. During the field survey itself the data of individual building was entered in an Excel sheet and later on attached in the attribute table of building polygon layer using Arc GIS 9.1 version. Thus the building footprint map was also generated during the field survey.

4.2.4.1. Building Construction Type

In the detailed study area, most of the buildings are RCC with a share of 56% of the total buildings of the area. The majority of RCC buildings are limited to blocks A, B, C. The percentage of the buildings having brick wall is also quite high after RCC construction. Kuchha houses were found in the G block as well as along the western side of the study area. The wall material of these is mostly made off mud. Overall there is a mixture of different building construction which increases the potential of damage. The spatial distribution of buildings under different category of construction is given below *(Fig: 4.6.)*.

Figure: 4-6. Distribution of Different Building Construction Type

Table: 4-2. Distribution of Different Building Construction Type

	Total	RCC	Brick Walled	Kuchha
No. of Buildings	1340	752	424	164
Percentage	100	56.12	31.64	12.24

4.2.4.2. Building Roof Material

Building roof materials were classified into three broad categories, namely concrete, tiles or asbestos and thatched. Most of the buildings of RCC construction type are having concrete roof. Thus concrete roof type is the predominant roof material. Apart from that buildings are found with tiles or asbestos as roof material. Kuchha houses generally have thatched roofs, found mainly in the G block and New Colony along the canal. *Figure 4.7*and *Table 4.3* describes the spatial distribution of different type of roof materials within the study area.

Figure: 4-7. Distribution of Different types of Roof Material

Table: 4-3 No. of Buildings of Different Roof Materials

	Total	Concrete	Tiles	Asbestos	Thatched
No. of Buildings	1340	732	504	39	95
Percentage	100	54.63	37.61	0.67	7.09

Figure: 4-8. Different types of Buildings in the Detailed Study Area

4.2.4.3. Building Air Tight Condition

The air tight condition of a building depends on the construction type as well as on roof material. In the study area mostly the buildings around 75% of the total buildings are not at all air tight thus makes this zone more vulnerable in an event of toxic release. Following figure *(Fig: 4.9.)* showing the spatial distribution of the air tight condition of building within the study area.

Figure: 4-9. Distribution of Air-Tight Condition of Buildings

Table: 4-4 No. of Buildings for different Air-Tight Condition

	Total	No	Yes
No. of Buildings	1340	1004	337
Percentage	100	74.92	25.08

4.2.3.5. Building Height

Height of building is mainly determined by the number of floors. Generally there is a predominance of buildings having one floor. About 50% of the buildings are one storied. In the blocks A, B and C most of the buildings are two or three stories while the buildings in the New Colony (NC) are mostly one storied. Following figure *(Fig: 4.10)* shows the spatial distribution of buildings with different floors.

Figure: 4-10. Distribution of Buildings with Heights

4.2.3.6. Building Age

The buildings within the detailed study area have been constructed in several time periods. Buildings found within the area are mostly recently made but few buildings are there as much as 45 years old. Increase in number of buildings with respect to time is shown in the *Figure 4.11*.

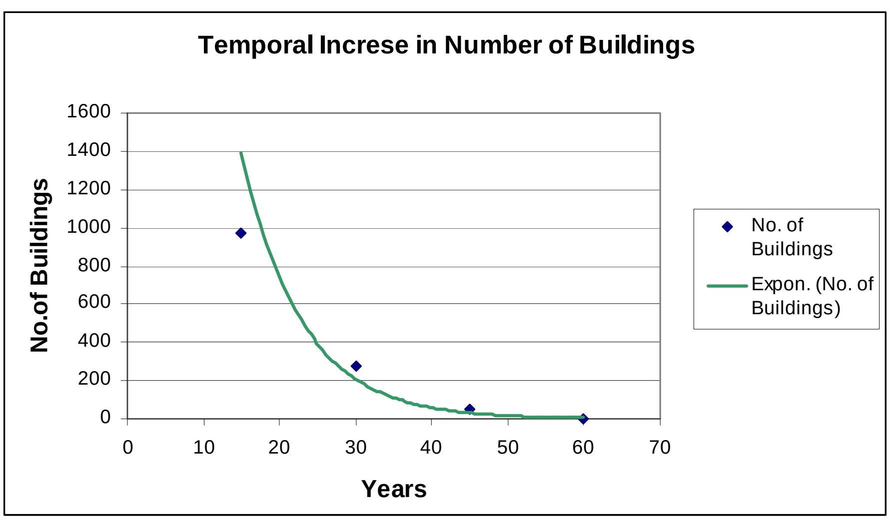

Figure: 4-11. Temporal Increase in Number of Buildings

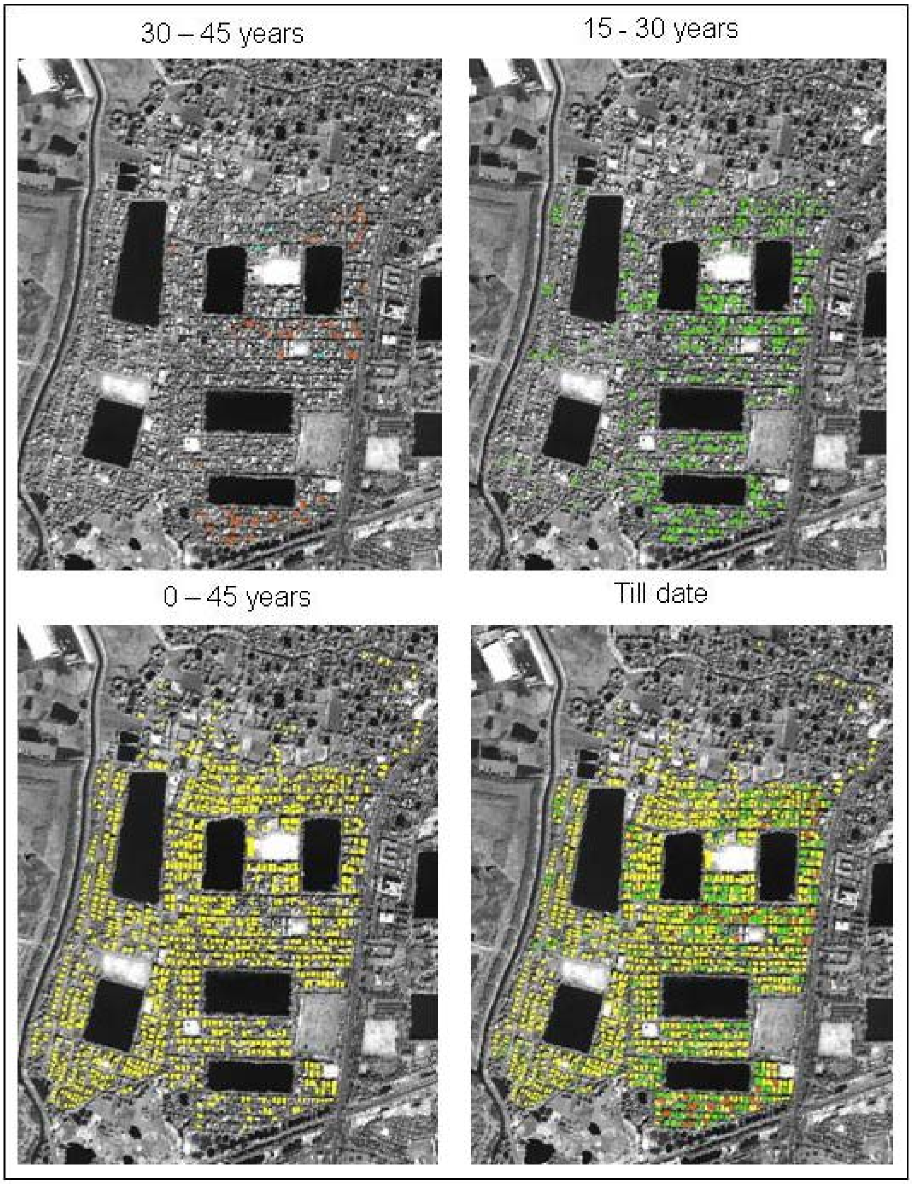

Figure: 4-12. Temporal increase in Number of Building

4.3. Summary

This chapter described the method of data collection from field survey as well as from the ERRIS Project office. The field work procedure and pre-field preparation was also mentioned in this chapter. The preparation of questionnaire also included in this chapter. Moreover, the generation of building footprint map and other building inventory of the detailed study area were also considered in this chapter. The outcome and results of this data collection will be discussed in the following chapters.

5. Hazard Assessment

5.1. Introduction

Hazard can be defined as the probability of occurrence of potentially damaging phenomena within a specified period of time and within a given area. Hazard can be characterized by the triggering factors, type of events and magnitude which includes volume, domino effects, distance, speed etc. (Westen, 2005). Hazard may be either natural or technological. Natural hazard essentially represents extreme fluctuations in average dynamic state of the Earth's environment, such as earthquake, slope instability, flooding etc. On the other hand, technological hazards include industrial hazards, transportation accidents, oil spills etc. Industrial hazards may be of different types: fire, explosions, atmospheric dispersion of toxic gasses. In this research work, pool fire, vapour cloud explosion (VCE), boiling liquid expanding vapour explosion (BLEVE) and toxic release events were taken into consideration for hazard assessment. It is important to that the probability component in the hazard formula given above for these types of hazards will be difficult to quantify, and the hazard is often based on scenarios of industrial accidents, without having quantifying the temporal probability of it.

5.2. Fire

A fire caused by inflammable chemicals is a complex chain reaction where a fuel combines with oxygen to generate heat, smoke, and light. Thermal radiation *(Section: 5.2.2)* is the primary hazard associated with industrial fires. However, if it goes out of control, such fire hazards can also result in an explosion. In addition, as fire is a chemical reaction and in addition to smoke and soot it may result in the formation of a number of gas by-products which sometimes can be hazardous or toxic.

5.2.1. Triggering Factors

A fire hazard in an industry storing or processing inflammable substances can be triggered by one of the following ignition sources: sparks, static electricity, heat, or flames from other heat or flames from another fire. Additionally, if a chemical is above its above auto-ignition it will spontaneously catch on fire without an external ignition source. There are several parameters like volatility, flash point, flammability limits (upper and lower) and explosive limits (upper and lower) which indicate how easily or how readily a flammable chemical will catch fire and then continue to burn (ERRIS homepage).

5.2.2. Thermal Radiation

The industrial fires and resulting thermal radiation originating from it can cause damage or injury from a distance via transmission of thermal radiation. Such radiation, which is completely different from nuclear radiation, will be strongest at the surface of a flame and will become rapidly weaker as moves away in any direction. Consequently, during a major hazardous material release involving fire, property damage and human injuries may occur not only in burning areas, but also in a zone surrounding the fire. The potential to cause damage is measured by the level of thermal radiation. Thermal radiation levels (also referred to as thermal radiation fluxes) are measured and expressed in units of power per unit area of the item receiving the energy. However, since the damage or injury sustained by a receptor is a function of the duration of exposure as well as the level, thermal radiation dosages is also of concern. These dosages are determined by combining radiation levels with exposure time and are expressed in units of energy per unit time per unit area of receiving surface. Following table *(Table: 5.1)* lists some of the known effects of thermal radiation on bare skin as a function of exposure level and time.

Table: 5-1 Thermal Radiation Burn Injury Criteria

KW/m2	Btu/hr-ft	Time for Severe Pain (sec)	Time for 2nd Degree Burn (sec)
1	300	115	663
2	600	45	187
3	1000	27	92
4	1300	18	57
5	1600	13	40
6	1900	11	30
8	2500	7	20
10	3200	5	14
12	3800	4	11

Source: Handbook of Chemical Hazard Analysis Procedures

5.2.3. Pool Fire

Pool fire is one of the important consequences of industrial fire hazard *(Ref: Chapter 2)*. A pool fire is defined as a fire involving a quantity of liquid fuel spilled on the surface of the land or water. Depending on the terrain, pool fire may flow down slope from the source to other lower catchments. In some cases, if the fire is beyond control then heat from pool fire may weaken the leaking tank and ultimately cause it to fail completely or cause BLEVE. Occasionally, pools of burning fuels floating on water have entered into water intakes of industrial facilities and caused internal fires or explosions. Moreover, burning fuels that entered into the sewers or drains not completely full of liquid may cause underground fires and/or threaten to industrial as well as municipal facilities at their receiving end point.

5.2.3.1. Pool Area

In the event of a discharge that results in formation of a pool of liquid on the ground, it is necessary to obtain an estimate of the area of the pool. This estimate, required for pool fire hazard model, requires the following parameters information:

- Molecular weight of the liquid
- Specific gravity of the liquid
- Discharge rate of the liquid from its container
- Discharge of liquid discharge
- Normal boiling point of the liquid
- Temperature of the liquid in its container
- Ambient environmental temperature
- Wind velocity
- Vapour pressure of the liquid at ambient temperature
- Area to which the liquid may be if a secondary containment system is present.

5.2.3.2. Equation for Estimation of Effect Distance for Pool Fire

A factor used for estimating the distance to heat radiation that could cause injuries from an exposure of a certain duration was developed based on the equations presented in the American Institute of Chemical Engineers (AIChE) document "Guidelines for Evaluating the Characteristics of Vapour cloud Explosions, Flash Fires and BLEVEs" and in the Netherlands TNO document, "Methods for the Determination of Possible Damage to People and Objects Resulting from release of Hazardous Materials"(1992) (Agency). The AIChE and TNO documents present a point-source model assuming that a selected fraction of the heat of combustion is emitted as radiation in all directions. The radiation per unit area received by a target at some distance from the point source can be determined by:

$$q = \frac{f\ m\ H_c\ \tau_a}{4\pi x^2}$$

Equation: *5-1 Radiation received by Target per unit from a point source*

Where:	q	=	Radiation per unit area received by the receptor (Watts per square metre)
	m	=	Rate of combustion (kilograms per second)
		=	Atmospheric transmissivity
	HC	=	Heat of combustion (joules/kg)
	f	=	Fraction of heat combustion radiated
	x	=	Distance from point source to receptor (metres).

The fraction of combustion energy dissipated as thermal radiation (f) is reported to a range from 0.1 to 0.4. To develop factors for estimating distances for pool fires, this fraction was assumed to be 0.4 for all the regulated flammable substances. The heat radiation level (q) was assumed to be 5,000Watts per square metre that could cause second degree burns from a 40-second exposure. It was assumed that people would able to escape from the heat in 40 seconds. The atmospheric transmissivity ( ) was assumed equal to one.
For a pool fire of a flammable substance with a boiling point above the ambient temperature, the combustion rate can be estimated by the following empirical equation:

$$X = H_c \sqrt{\frac{0.0001\,A}{5000\,\Pi\,(H_v + C_p\,(T_B - T_A))}}$$

Equation: *5-2 Combustion Rate above Ambient Temperature*

Where:

X	=	Distance to the 5 kilowatt per square meter endpoint (m)
HC	=	Heat of combustion of the flammable liquid (joules/kg)
HV	=	Heat of vaporization of the flammable liquid (joules/kg)
A	=	Pool area (square metre)
CP	=	Liquid heat capacity (joules/kg-ºK)
TB	=	Boiling temperature of the liquid (ºK)
TA	=	Ambient temperature (ºK)
0.0001	=	Constant.

Table: 5-2 Heat of Combustion of Flammable Substances

Chemical Name	Physical State at 250 C	Heat of Combustion (joules/kg)
Hydrogen	Liquid	33,775
Methane	Gas	50,029
Pentane	Liquid	44, 697
Propane	Gas	46,333

A "Pool Fire Factor" (PFF) was calculated for each regulated flammable liquid and gas (to be applied to gases liquefied by refrigeration) to allow estimation of the distance to the heat radiation level that would lead to second degree burns. For the derivation of this factor, ambient temperature was assumed to be 298 K (250 C). Other factors are same as discussed as above. The PFF with boiling points above ambient temperature was derived as follows:

$$PFF = H_c \sqrt{\frac{0.0001}{5{,}000\pi \ [H_v + C_p(T_b - 298)]}}$$

Equation: *5-3 Calculation of PFF above Ambient Temperature*

Distances where exposed people could potentially suffer second degree burns can be estimated as the PFF multiplied by the square root of the pool area (in square feet). Distance may be estimated from the PFF and the pool area as follows:

$$d = PFF \times \sqrt{A}$$

Equation: *5-4 Estimated Distance from PFF and Pool Area*

Where: d = Distance (feet)
PFF = Pool Fire Factor
A = Pool Area (square feet).

The purpose of the pool fire model is to compute the radius of the circular zone around a fire which is people may experience the lethal burns due to thermal radiation exposure. Additionally this will also calculate the radius of the zone in which the second degree burns or severe pains may be experience by the exposure.

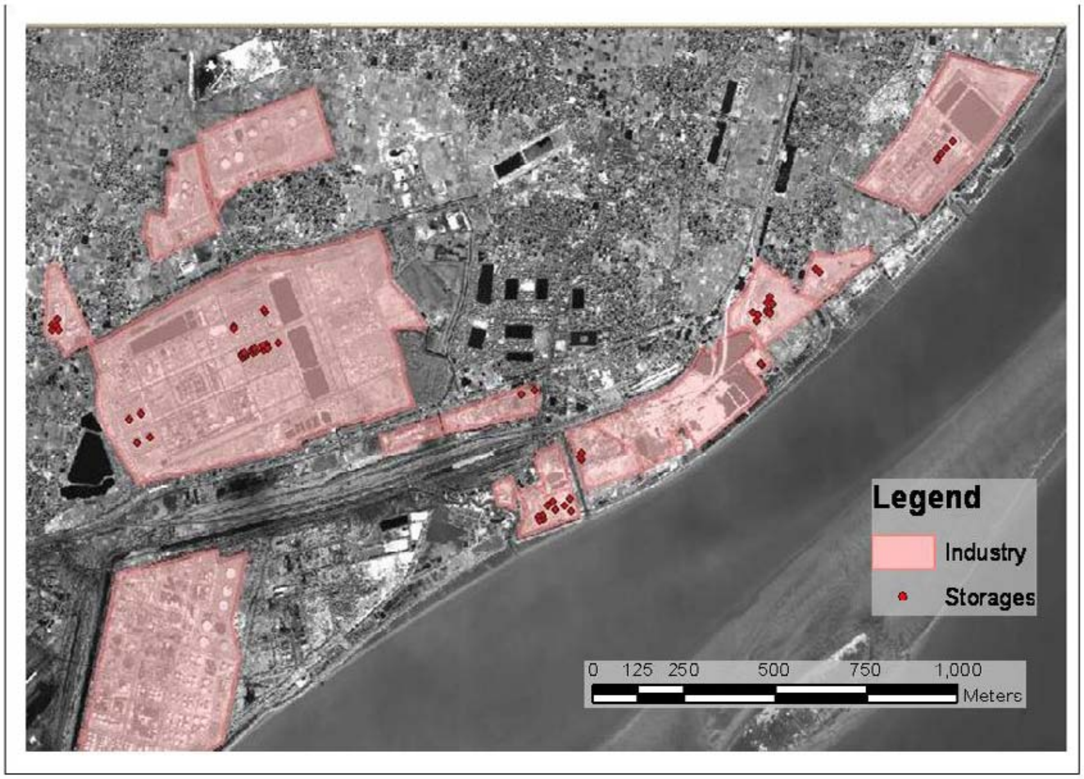

Figure: 5-1. Location of Storages causing Pool Fire

5.2.4. Pool Fire Hazard Footprint

The industrial town Haldia has several MAH (Maximum Accident Hazardous) industries dealing with hazardous chemicals. All industries have number of storages of different chemicals. Based on flammability and other chemical properties pool fire event occur from few of them. The storages from where pool fire event might occur are given in the *Table 5.3*.

Table: 5-3 Calculated End Point Distance to Radiation Exposure of 5 KW/m2 for Pool Fire

Industry Name	Storages	Chemical Name	Total Amount (MT)	Expected Pool Area (sq. m)	Calculated Effect Distance (m)
Reliance	RHMTTK-01	Motor spirit	10,000	300	62
	RHMTTK-02	Hi-speed diesel	20,000	300	61
	RHMTTK-03	Hi-speed diesel	20,000	300	61
	RHMTTK-04	Motor spirit	10,000	300	62
	RHMTTK-05	Motor spirit	10,000	300	62
HPL	HPL-SP01	Ethylene	1111	250	65
	HPL-SP02	Ethylene	1111	250	65
	HPL-TK01	Naphtha	29,000	500	92
	HPL-TK02	Naphtha	29,000	500	92
	HPL-TK03	Naphtha	29,000	500	92
	HPL-TK04	Naphtha	29,000	500	92

	HPL-TK05	Pentane Reagent Grade	2950	250	61
	HPL-TK06	Benzene	4720	250	26
	HPL-TK08	Slope Oil	1000	250	27
	HPL-TK09	Hi-speed diesel	80	250	55
	HPL-TK10	Hexane	600	250	46
	HPL-TK11	Hexane	750	250	46
	HPL-TK12	Hexane	750	250	46
	HPL-TK13	Hexane	750	250	46
	HPL-TK14	Hexane	750	250	46
	HPL-TK15	Hexane	400	250	46
	HPL-TK16	Benzene	1070	250	26
	HPL-TK17	Benzene	1070	250	26
	HPL-TK18	C6 Raffinate	1210	250	65
	HPL-TK19	C6 Raffinate	1210	250	65
	HPL-TK20	Cyclopentane	1030	250	61
	HPL-TK21	Cyclopentane	1030	250	61
Exide	Exide-UT01	Hi-speed diesel	35	250	55
	Exide-B001	LPG	30	250	65
	Exide-B002	LPG	30	250	65
BPCL	BPCL-TK02	Naphtha	1950	250	65
	BPCL-TK04	Hi-speed diesel	10590	300	61
	BPCL-TK05	Hi-speed diesel	10680	300	61
	BPCL-TK06	Furnace Oil	2900	250	55
	BPCL-TK07	Furnace Oil	2900	250	55
	BPCL-TK12	Naphtha	7350	250	65
	BPCL-TK13	Hi-speed diesel	2465	250	55
	BPCL-TK15	Furnace Oil	6760	250	55
	BPCL-TK16	Furnace Oil	6740	250	55
	BPCL-TK17	Naphtha	9450	250	65
CFCL	CFCLTK01	Acrylonitrile	9252	250	46
	CFCLTK02	Acrylonitrile	9252	250	46
	CFCLTK03	Acrylonitrile	1234	250	46
MCC	MCCPTA - TK01	Paraxylene	30000	500	66
	MCCPTA - TK02	Paraxylene	30000	500	66
	MCCPTA - TK03	Paraxylene	30000	500	66
	MCCPTA - TK04	Paraxylene	30000	500	66
HL	1101	Hi-speed diesel	8400	250	55
	1102	Hi-speed diesel	8400	250	55
HPCL	HPCL-T001	Hi-speed diesel	6375	250	55
	HPCL-T002	Hi-speed diesel	6375	250	55

	HPCL-T003	Hi-speed diesel	6375	250	55
	HPCL-T004	Hi-speed diesel	6375	250	55
	HPCL-T005	Motor spirit	730	250	57
	HPCL-T006	Motor spirit	730	250	57
	HPCL-T014	Furnace Oil	5340	250	55
	HPCL-T015	Furnace Oil	2670	250	55
	HPCL-T016	Furnace Oil	5340	250	55
	HPCL-T017	Motor spirit	1460	250	57
	HPCL-T018	Motor spirit	1460	250	57
IBP Co.	HLTK-02	Hi-speed diesel	1	250	55
	HLTK-03	Furnace Oil	1	250	55

Using the ERRIS Hazard Mapping Module, pool fire hazard footprints were calculated to an end point distance of 5KW/m2 for a 40 seconds exposure which may results in second degree burns for all hazardous storages in the near vicinity of the study area. Following are the maps showing the hazard footprints of different storages.

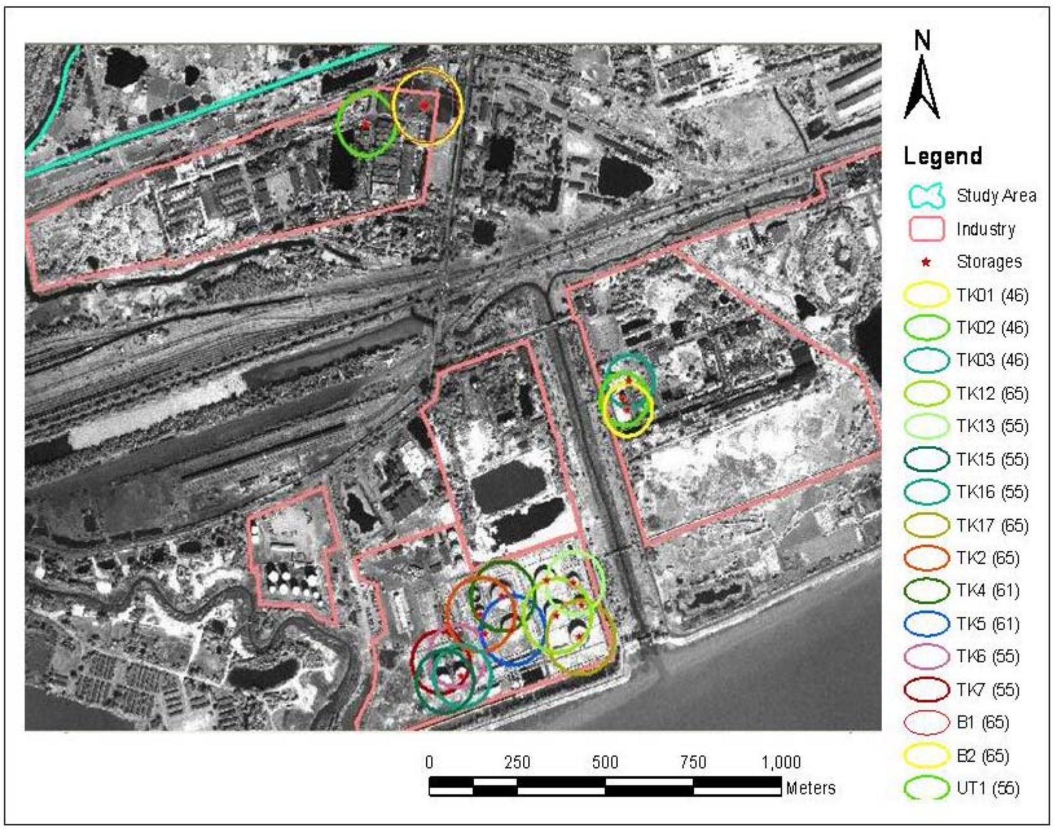

Figure: 5-2. Pool Fire Hazard Footprint from storages (Exide, CFCL, BPCL)

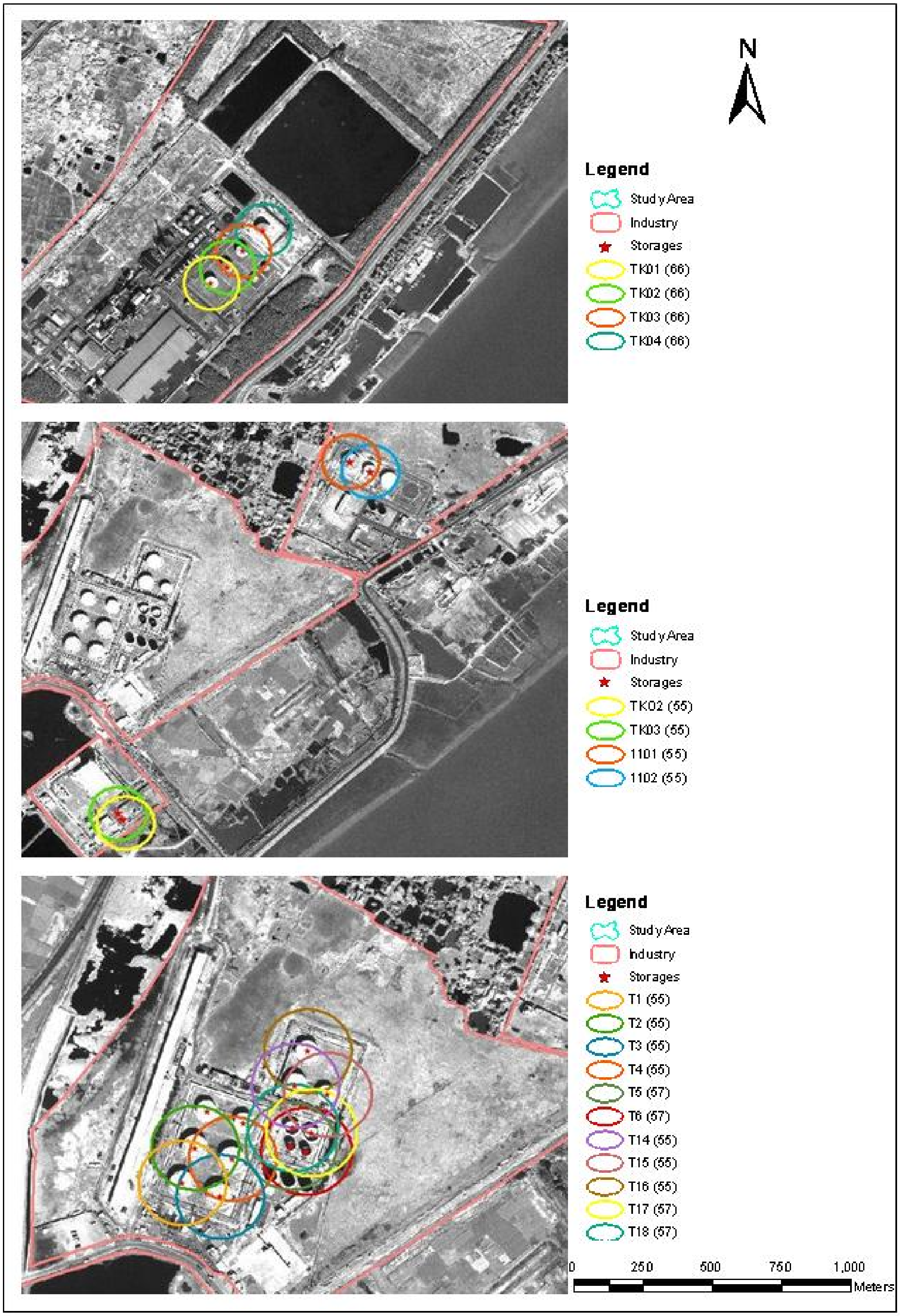

Figure: 5-3. Pool Fire Hazard Footprints from storages (MCC, IBP Co., HL, HPCL)

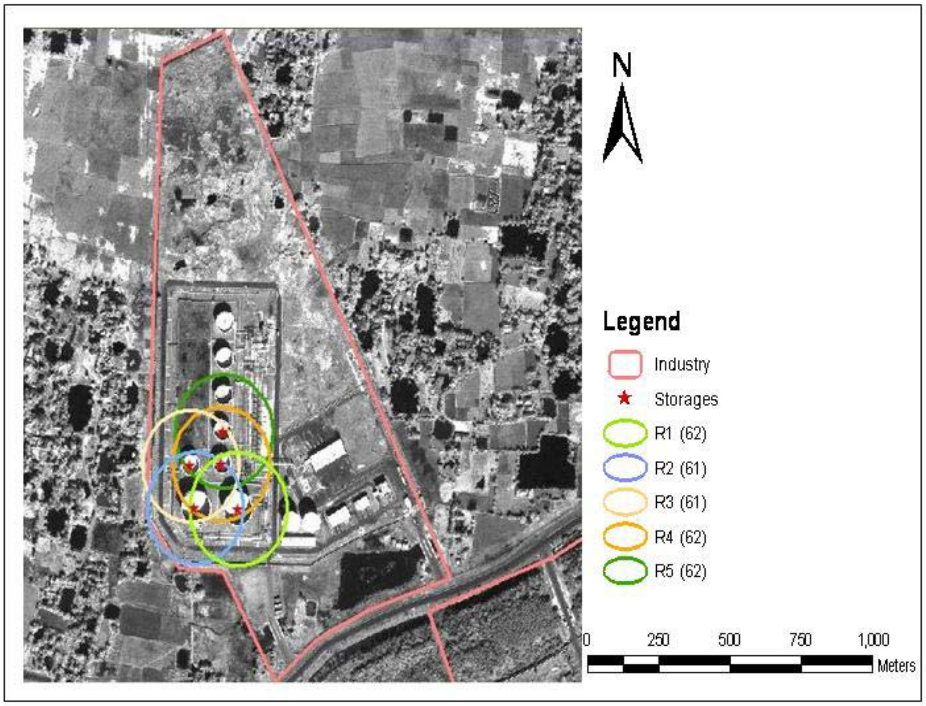

Figure: 5-4. Pool Fire Hazard Footprints from storages (Reliance)

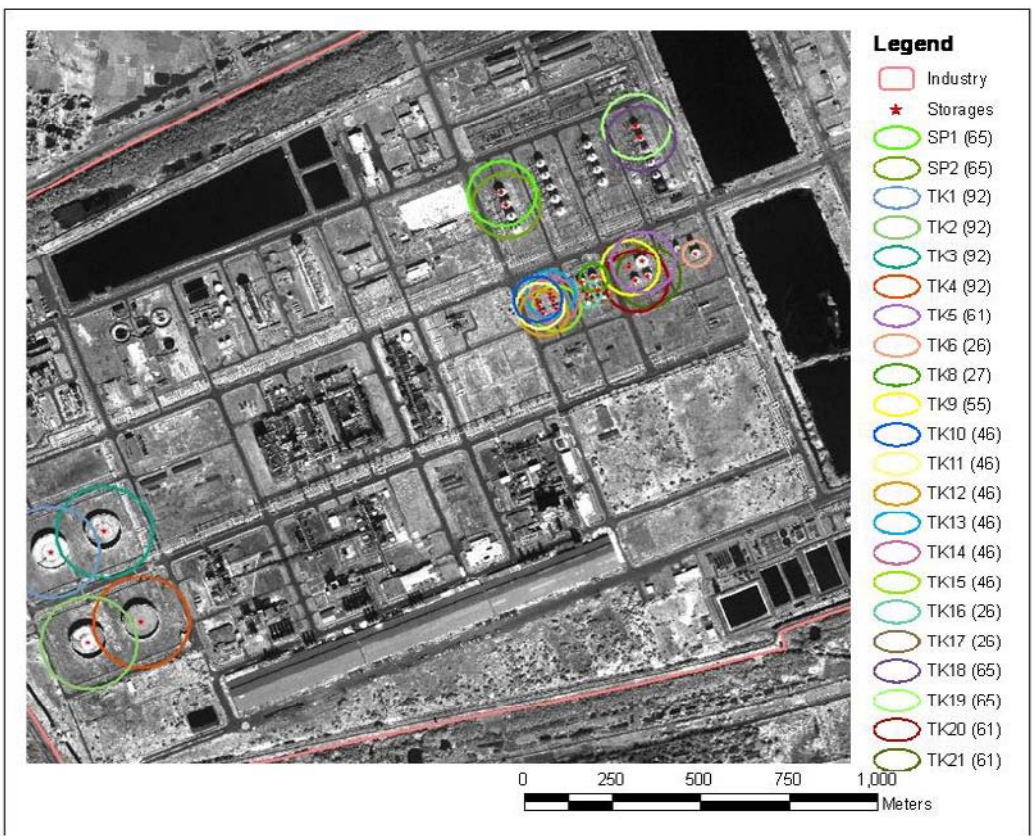

Figure: 5-5. Pool Fire Hazard Footprint from storages (HPL)

5.2.3. Pool Fire Hazard Map

As such the impact of pool fore is not so widely spread like an explosion or toxic release. The effect area is mainly depends on the size of pool area based on nature of chemical and its physical and chemical property. In Haldia most of the cases the impact of pool fire are primarily confined within the industrial area but later on it can be cause BLEVE. Most of the area of Haldia municipality is therefore free from thee impact of this hazard. Following figure *(Fig: 5.6)* showing the hazard map of Haldia.

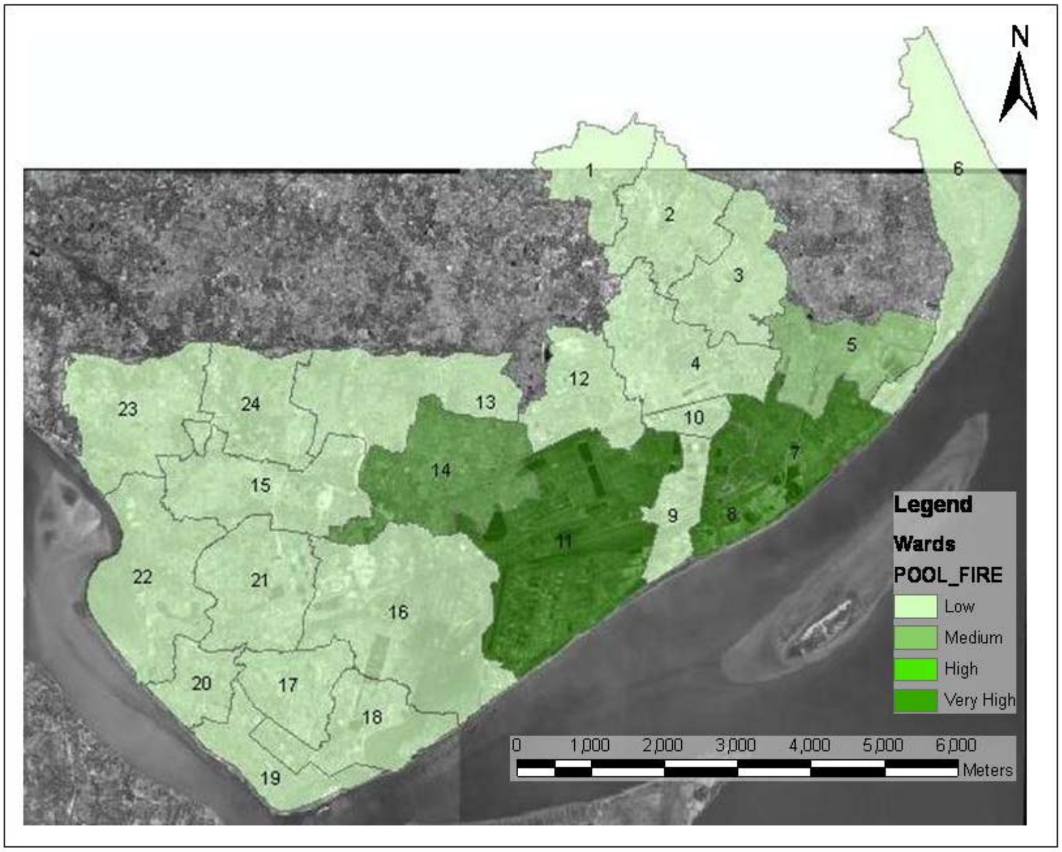

Figure: 5-6. Pool Fire Hazard Map of Haldia Municipal Area

Table: 5-4. Pool Fire Hazard Map of Haldia Municipal Area

Sl. No.	Category	Number of Scenarios	Number of Wards
1	Low	0 - 2	19
2	Medium	3 - 4	1
3	High	5 - 6	1
4	Very High	More than 20	3

It can be conclude that as such the detailed study area is not at all under any hazard footprint of any storage. So the detailed study area can be assumed as low hazard category. *Figure: 5.7* showing the pool fire hazard map per mapping unit wise for the detailed study area.

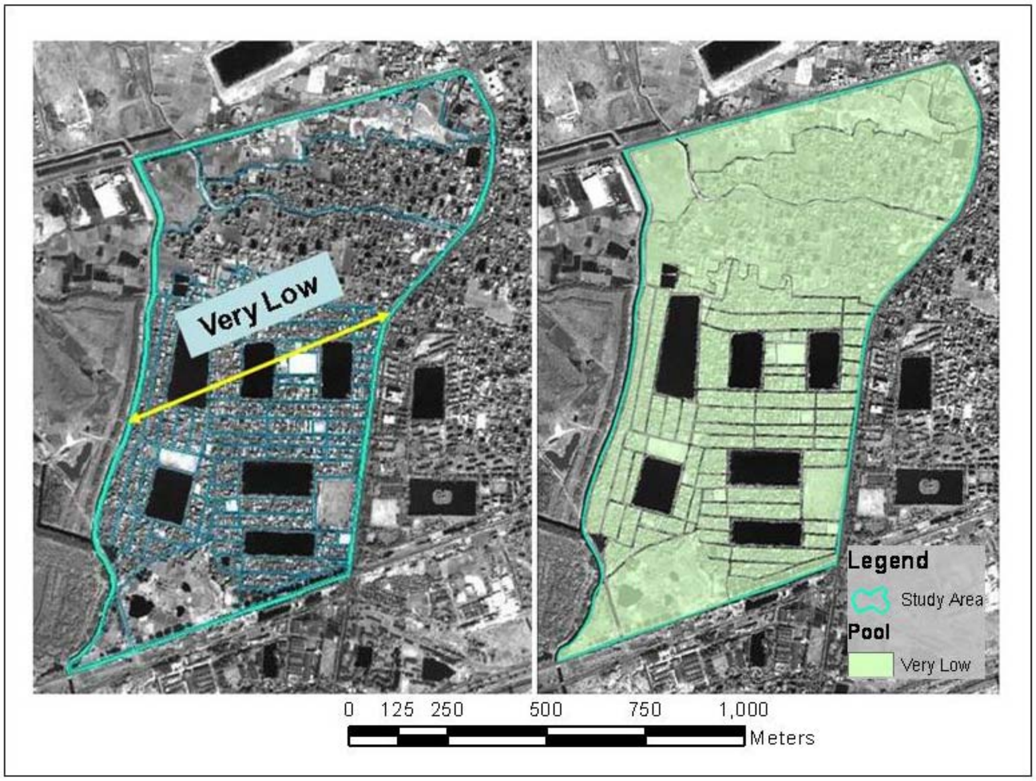

Figure: 5-7. Pool Fire Hazard Map of the Detailed Study Area

5.3. Explosion Hazard

Explosion can be defined as a sudden and intense release of energy that often produces noise, high temperatures, flying debris and even a pressure wave. Industrial explosions involving hazardous chemicals can be of many types and thus the cause and effect of the explosion also varies with respect to the type of chemical. Three types of hazards are primarily associated with explosion, namely: thermal radiation, overpressure and hazardous fragments (e.g. flying debris).

5.3.1. Explosion Overpressure

One of the major hazards associated with any explosion is overpressure. Overpressure, also called a blast wave, refers to the sudden onset of a pressure wave after an explosion. This pressure wave is caused by the energy released in the initial explosion and travel at the speed of sound radiating outward like a large burst of air with its strength weakening as it moves away from the source. If the pressure wave has enough strength then it may cause widespread damage to both human lives as well as to property. A high intensity pressure wave can lift the people on the ground and throw them up against nearby buildings or trees while at the lower intensity it can also affect pressure-sensitive organs like ears and lungs. In addition to these, explosion can cause substantial damage *(Table: 5.5)* to buildings with weak structures like kuchha / shanty houses.

Table: 5-5. Building Damage Estimate for Explosion

Peak Overpressure (psia)	EXPECTED DAMAGE
0.03	Occasional breakage of large windows under stress.
0.30	Some damage to home ceilings; 10% window breakage.
1.00 - 0.50	Windows usually shattered; some frame damage.
1.00	Partial demolition of homes; made uninhabitable.
8.00 - 1.00	Range serious/slight injuries from flying glass/objects.
2.00	Partial collapse of home walls/roofs.
3.00 - 2.00	Non-reinforced concrete/cinder block walls shattered.
12.2 - 2.40	Range 90-1% cardrum rupture among exposed population.
2.50	50% destruction of home brickwork.
4.00 - 3.00	Frameless steel panel buildings ruined.
5.00	Wooden utility poles snapped.
7.00 - 5.00	Nearly complete destruction of houses.
10.0	Probable total building destruction.
29.0 - 14.5	Range for 99-1% fatalities among exposed populations due to direct blast effects.

Source: Handbook of Chemical Hazard Analysis Procedures

5.3.2. Vapour Cloud Explosion (VCE)

Among several types of explosions, Vapour Cloud Explosion (VCE) is one of the major types *(Ref: Chapter 2)*. When a flammable chemical is released into the atmosphere, it forms a vapour cloud that will disperse as it travels downwind. If the cloud encounters an ignition source, the parts of the cloud where the concentration is within the flammable range (between the LEL and UEL) will burn instantaneously. In some situations, the cloud will burn very fast and would result in the formation of a blast wave with considerable overpressure.

5.3.2.1. Equation for Estimation of Effect Distance to 1 psi overpressure for VCE

For a worst case release of flammables gases and flammable liquids, the release rate is not considered. The total quantity of the flammable substance is assumed to form a vapour cloud. The entire content of the cloud is assumed to be within the flammable limits, and the entire cloud is assumed to explode. For the worst case analysis, 10 percent of the flammable vapour in the cloud is assumed to participate in the explosion (i.e. the yield factor is 0.10). Consequence distance to an overpressure level of 1 pound per square inch (psi) may be determined by using the following equation, which is based on the TNT-equivalency method:

$$X = 17\left(0.1\ W_f\ \frac{H_{Cf}}{H_{CTNT}}\right)^{1/3}$$

Equation: *5-5 Consequence Distance for 1 psi overpressure per inch*

Where: X = Distance to overpressure of 1 psi (meters)

Wf = Weight of flammable substance (kg)

HCf = Heat of combustion of flammable substance (joules/kg)

HCTNT = Heat of combustion of trinitrotoluene (4.68 E+06 joules/kg) (TNT).

The factor 17 is a constant for damages associated with 10 psi overpressures. The factor 0.1 represents an explosion efficiency of 10 percent. To convert distances from meters to miles, the output has to be multiplied by 0.00062.

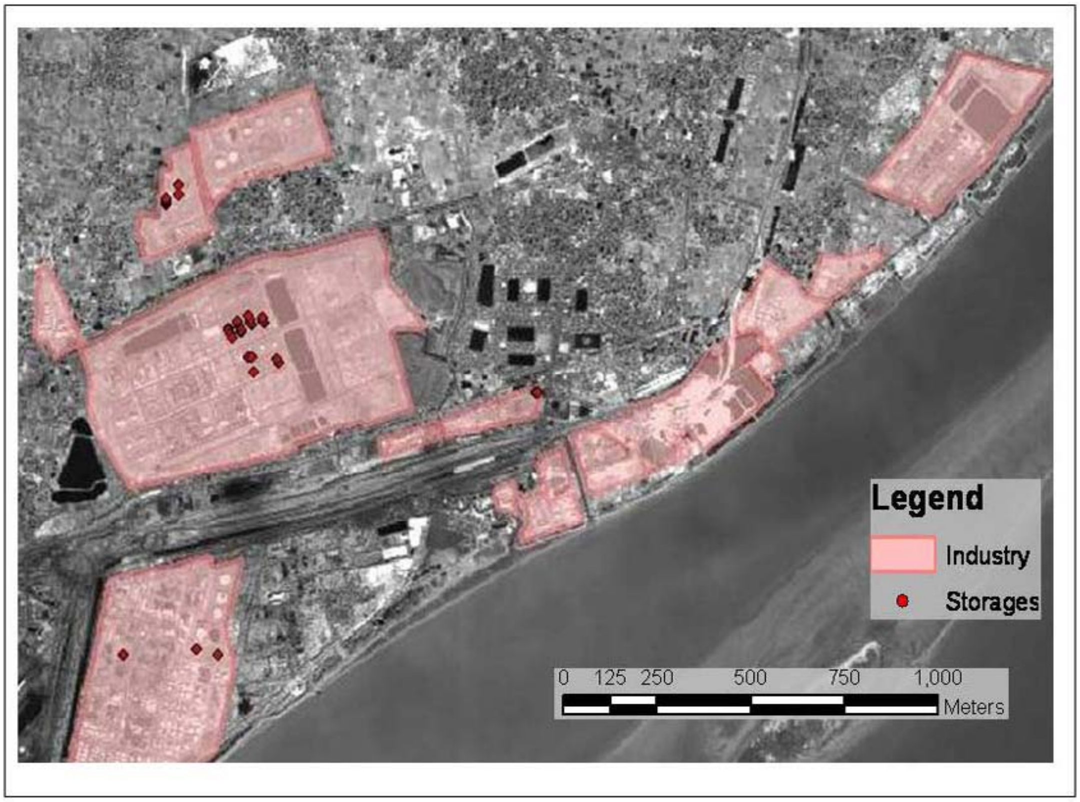

Figure: 5-8. Location of Storages causing VCE & BLEVE

5.3.3. Vapour Cloud Explosion (VCE) Hazard Footprint

Using the ERRIS Hazard Mapping Module a set of hazard footprint to an endpoint overpressure of 1 pound per square inch (psi) was calculated based on the above mentioned standard equation simulating an explosion involving flammable/explosive chemicals. However, it does not take into account possible damages that may be caused by hazardous fragments such as those generated by ruptured fragments of the vessels or structures involved in the explosion. The following tables (*Table: 5.6*) shows the result for the storages from where VCE might be happened along with the maps for individual industries.

Table: 5-6 Calculated Effect Distance to Overpressure of 1psi for VCE

Industry Name	Storages	Chemical Name	Total Amount (MT)	Calculated Distance (m)
HPL	HPL-B001	Hydrogen	60	899
	HPL-B002	Hydrogen	60	899
	HPL-B003	Propane	90	749
	HPL-SP01	Ethylene	1111	1685
	HPL-SP03	Ethylene	1111	1685
	HPL-SP04	Ethylene	1111	1685
	HPL-SP05	LPG	1900	2049
	HPL-SP06	LPG	915	1610
	HPL-SP07	Butane	1880	2018
	HPL-SP08	Butane	1880	2018
	HPL-SP09	Butane	1881	2018
	HPL-SP10	1,3 Butadiene	1196	1738
	HPL-SP11	1,3 Butadiene	1196	1738
	HPL-SP12	1,3 Butadiene	1196	1738
	HPL-SP13	C4-Raffinate	915	1601
	HPL-SP14	C4-Mix	1710	1968
	HPL-SP15	C4-Mix	1710	1968
	HPL-SP16	Propylene	1130	1714
	HPL-SP17	Propylene	1130	1714
	HPL-SP18	Propylene	1130	1714
Exide	Exide-B001	LPG	30	521
	Exide-B002	LPG	30	521
IOC Petronas	IOC Petronas-B001	Propane	150	887
	IOC Petronas-B002	Propane	150	887
	IOC Petronas-B003	Butane	600	1393
	IOC Petronas-B004	Butane	600	1393
	IOC Petronas-TK01	LPG	16000	4140
	IOC Petronas-TK02	LPG	16000	4140
IOC	IOCTK-05	LPG	600	1401
	IOCTK-06	Motor spirit	18076	4249
	IOCTK-07	Naphtha	4454	2715

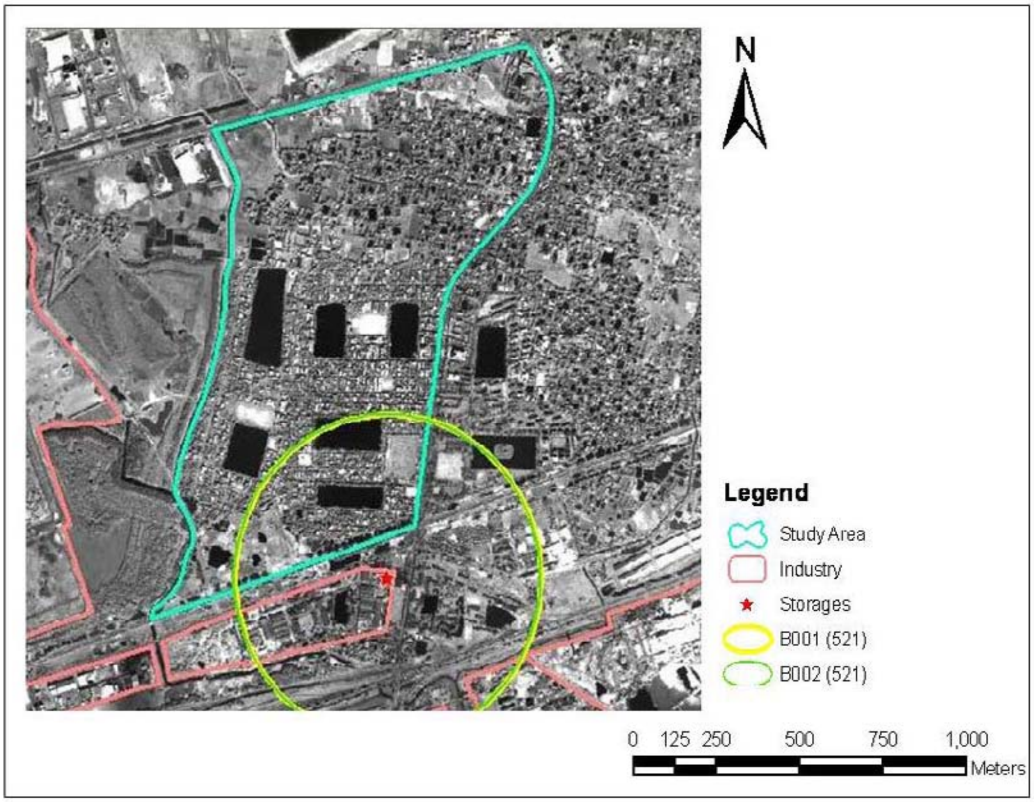

Figure: 5-9. VCE Hazard Footprint from Storages (Exide)

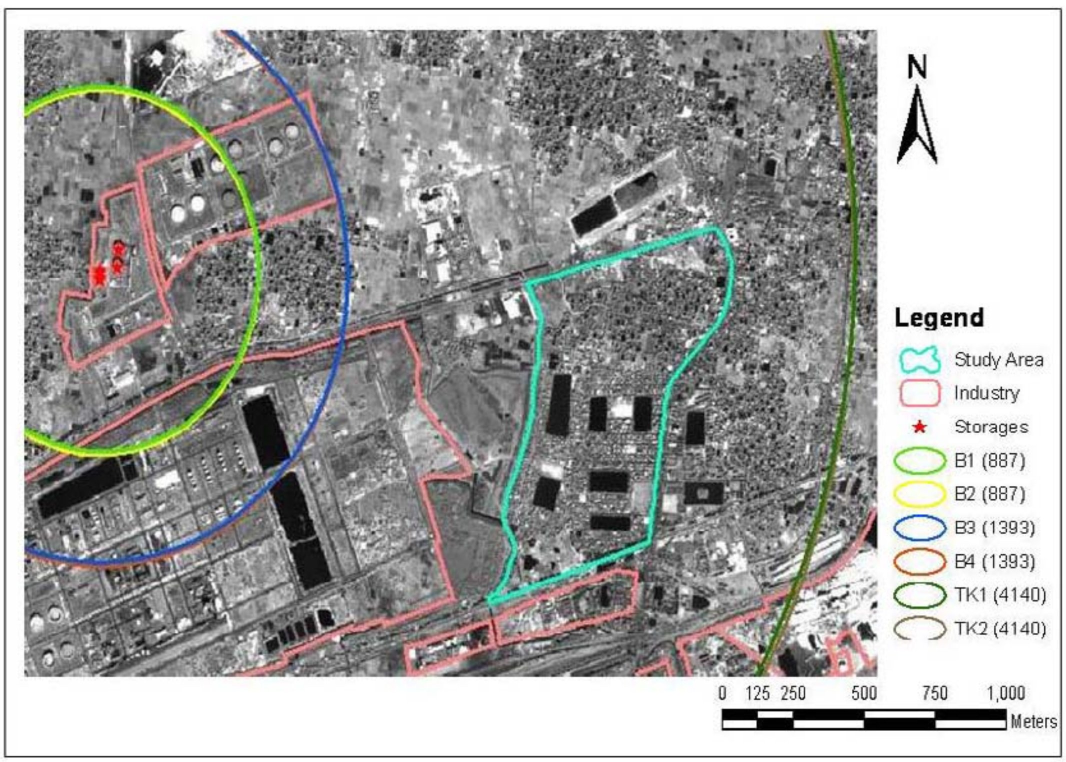

Figure: 5-10. VCE Hazard Footprint from Storages (IOC Petronas)

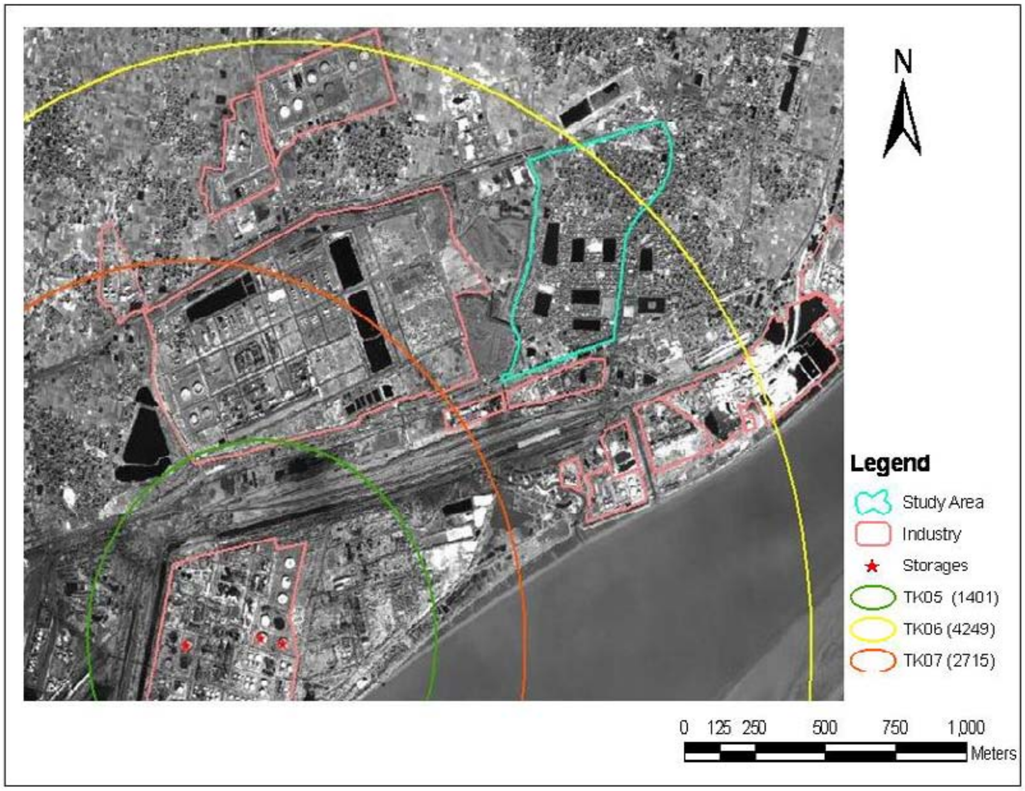

Figure: 5-11. VCE Hazard Footprint from Storages (IOC)

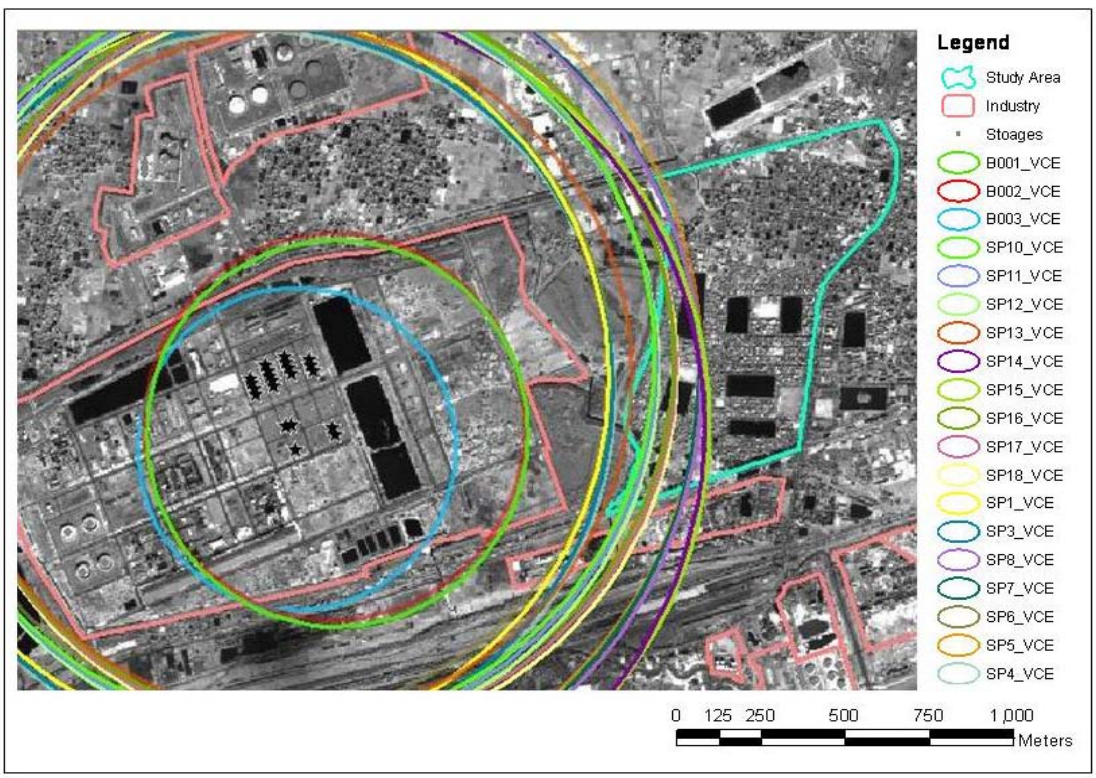

***Figure*: 5-12. VCE Hazard Footprint from Storages (HPL)**

5.3.4. VCE Hazard Map

After overlaying the different possible scenarios from all storages, the Haldia Municipal area was categorised in terms of Very High, High, Medium and Low VCE Hazard zones. The area of the industrial complexes and the surrounding areas are categorized as Very High because these areas included within the all hazard footprints of storages. While the wards which are far away from the storages having less chance to get affected from possible scenarios. *Figure 5.13* showing the VCE hazard map of Haldia Municipal area.

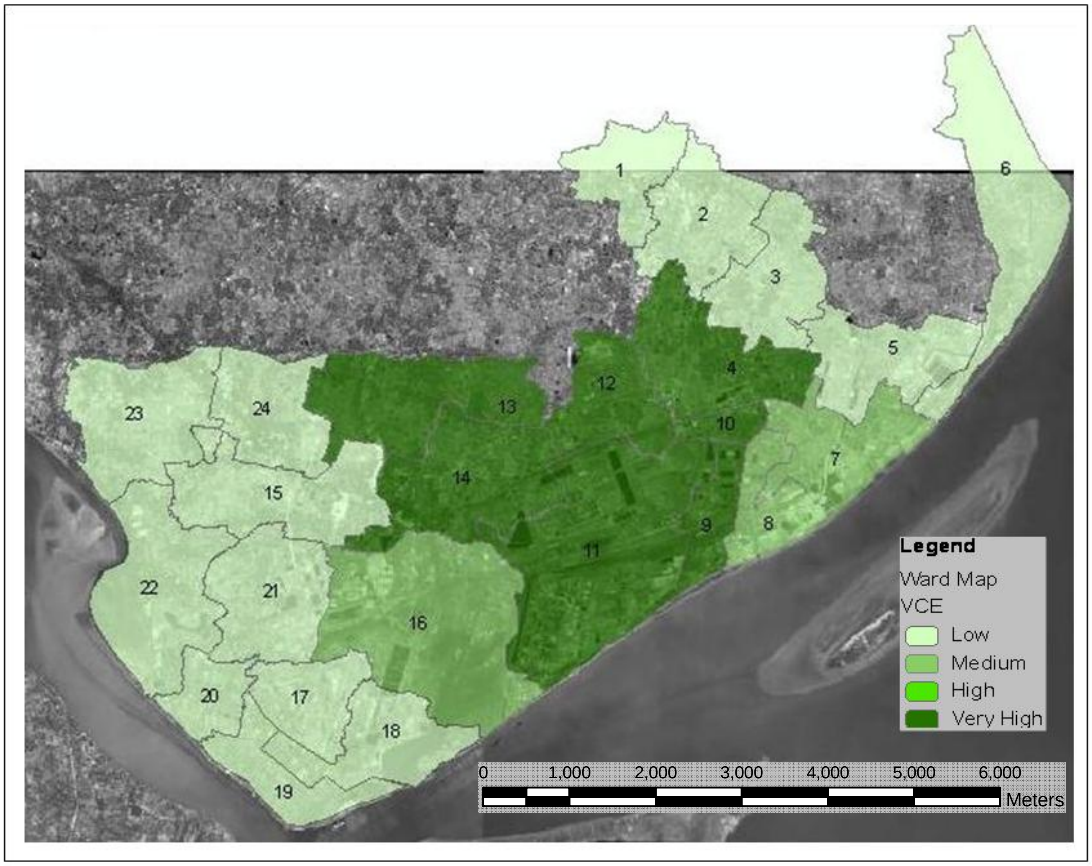

Figure: 5-13. VCE Hazard Map of Haldia Municipal Are

Table: 5-7. VCE Hazard Map of Haldia Municipal Area

Sl. No.	Category	Number of Scenarios	Number of Wards
1	Low	0 - 2	14
2	Medium	3 - 4	3
3	High	5 - 6	0
4	Very High	More than 20	7

Following the same method, the detailed study area was also categorised into groups: High, Medium and Low. But as such there is no industrial area within the boundary so very high category was not found in this area. *Fig: 5.14.A* shows the overlay of possible hazard footprints on map while *Fig: 5.14 (B)* showing the hazard map in terms of mapping units.

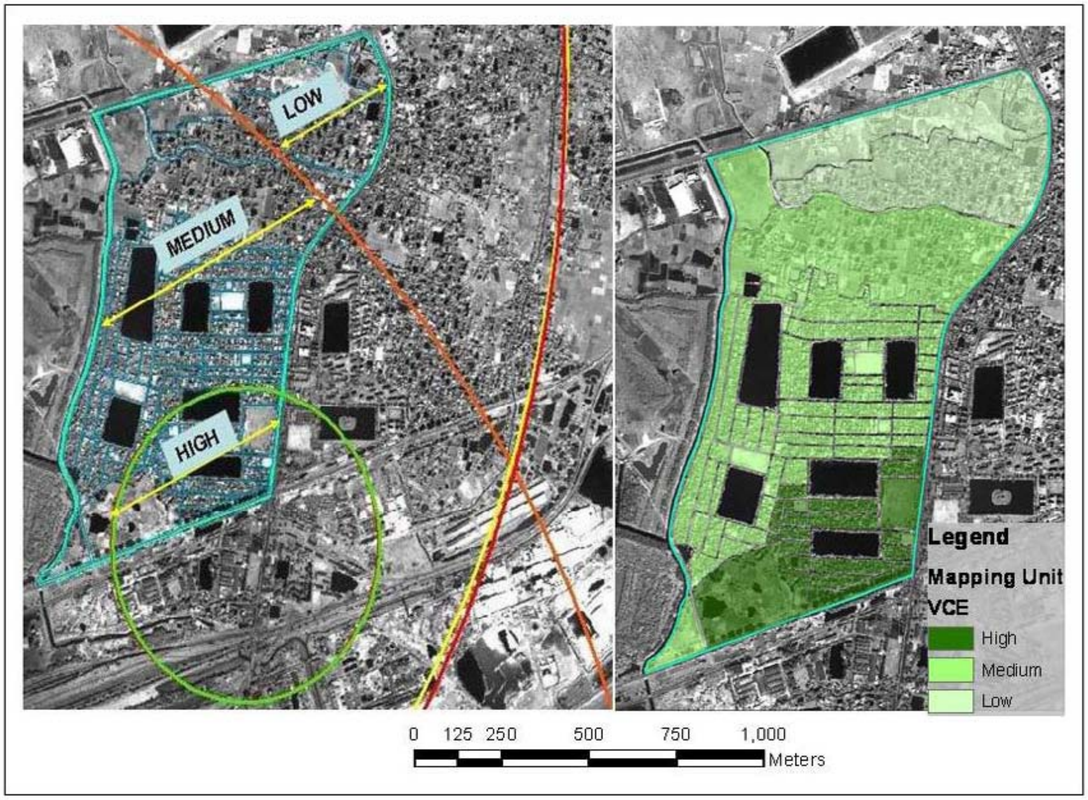

Figure: 5-14. (A) & (B) VCE Hazard Map of Detailed Study Area

5.3.5. Boiling Liquid Expanding Vapour Explosion (BLEVE)

BLEVE stands for Boiling Liquid Expanding Vapour Explosion and may typically occur in closed storage tanks that contain a flammable liquefied gas under pressure. When such a pressurized vessel gets heated by fire, this leads to increase the pressure within the container, the tank ruptures and fails and the chemical is released as an explosive fireball. Such explosions can be extremely hazardous. When the liquid is water, the explosion is usually called a steam explosion.

5.3.5.1. Mechanism

BLEVE can occur in a vessel that stores a substance that is usually a gas at atmospheric pressure but is a liquid when pressurized (for example, liquefied petroleum gas, LPG). The substance will be stored partly in liquid form, with a gaseous vapour above the liquid filling the remainder of the container. If the vessel is ruptured for example, due to corrosion, or failure under pressure, the vapour portion may rapidly leak, dropping the pressure inside the container and releasing a wave of overpressure from the point of rupture. This sudden drop in pressure inside the container causes violent boiling of the liquid, which rapidly liberates large amounts of vapour in the process. The pressure of this vapour can be extremely high, causing a second, much more significant wave of overpressure (i.e., an explosion) which may completely destroy the storage vessel and project it as shrapnel over the surrounding area.
BLEVE does not require a flammable substance to occur, and therefore is not usually considered a type of chemical explosion. However, if the substance involved is flammable, it is likely that the resulting cloud of the substance will ignite after the BLEVE proper has occurred, forming a fireball and possibly a fuel-air explosion. BLEVE can also be caused by an external fire nearby the storage vessel causing heating of the contents and pressure build-up.

5.3.5.2. Equation for Effect Distance to radiation of 5KW/m2 for BLEVE

The equations used to estimate impact distances for BLEVE are summarized below:

$$X = \sqrt{\frac{2.2\, t_a\, R\, H_c\, W_f^{\,0.67}}{4\,\Pi \left[\dfrac{3.42 \times 10^6}{t}\right]^{0.75}}}$$

***Equation** 5-6 Calculation of Effect Distance to radiation for BLEVE*

Where: X = distance to the 5 kilowatts per square meter endpoint (m)
R = radiative fraction of the heat of combustion (assumed to be 0.4)
ta = atmospheric transmissivity (assumed to be 1)
Hc= heat of combustion of the flammable liquid (joules/kg)
Wf= weight of flammable substance in the fireball (kg)
t = duration of the fireball in seconds (estimated from the following equations)

For Wf < 30,000 kg $t = 0.45\, W_f^{1/3}$ and For Wf > 30,000 kg $t = 2.6\, W_f^{1/6}$

5.3.6. BLEVE Hazard Footprints

Using the ERRIS Hazard Mapping Module a hazard footprint was generated to an endpoint overpressure of 1 pound per square inch (psi) based on above mentioned equations from all possible storages. Following table *(Table: 5.8)* mention the calculated effect distances for all storages followed by the maps of scenarios for different storages of Haldia.

Table: 5.8. Calculated End Point Distance to Overpressure of 1 psi for BLEVE

Industry Name	Storages	Chemical Name	Total Amount (MT)	Calculated Distance (m)
HPL	HPL-B001	Hydrogen	60	429
	HPL-B002	Hydrogen	60	429
	HPL-B003	Propane	90	320
	HPL-SP01	Ethylene	1111	936
	HPL-SP03	Ethylene	1111	936
	HPL-SP04	Ethylene	1111	936
	HPL-SP05	LPG	1900	1191
	HPL-SP06	LPG	915	891
	HPL-SP07	Butane	1880	1165
	HPL-SP08	Butane	1880	1165
	HPL-SP09	Butane	1881	1165
	HPL-SP10	1,3 Butadiene	1196	973
	HPL-SP11	1,3 Butadiene	1196	973
	HPL-SP12	1,3 Butadiene	1196	973
	HPL-SP13	C4-Raffinate	915	883
	HPL-SP14	C4-Mix	1710	1132
	HPL-SP15	C4-Mix	1710	1132
	HPL-SP16	Propylene	1130	958
	HPL-SP17	Propylene	1130	958
	HPL-SP18	Propylene	1130	958

Exide	Exide-B001	LPG	30	193
	Exide-B002	LPG	30	193
IOC Petronas	IOC Petronas-B001	Propane	150	405
	IOC Petronas-B002	Propane	150	405
	IOC Petronas-B003	Butane	600	746
	IOC Petronas-B004	Butane	600	746
	IOC Petronas-TK01	LPG	16000	2779
	IOC Petronas-TK02	LPG	16000	2779
IOC	IOCTK-05	LPG	600	753
	IOCTK-06	Motor spirit	18076	2856
	IOCTK-07	Naphtha	4454	1672

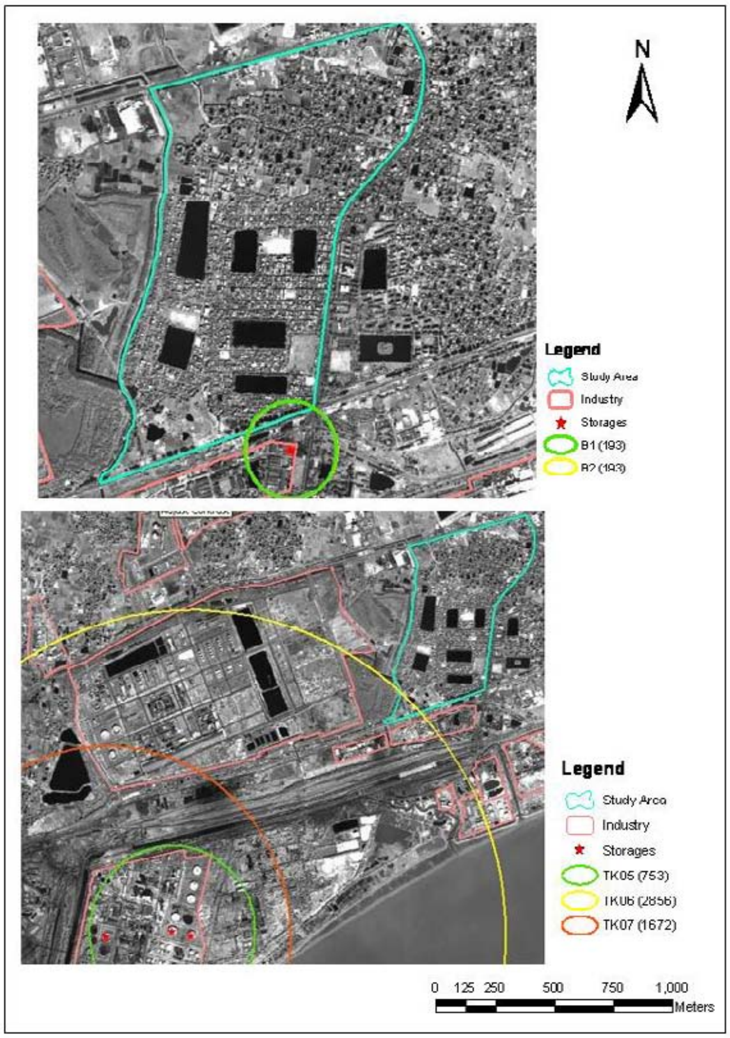

Figure: 5-15. BLEVE Hazard Footprint from Storages (Exide & IOC)

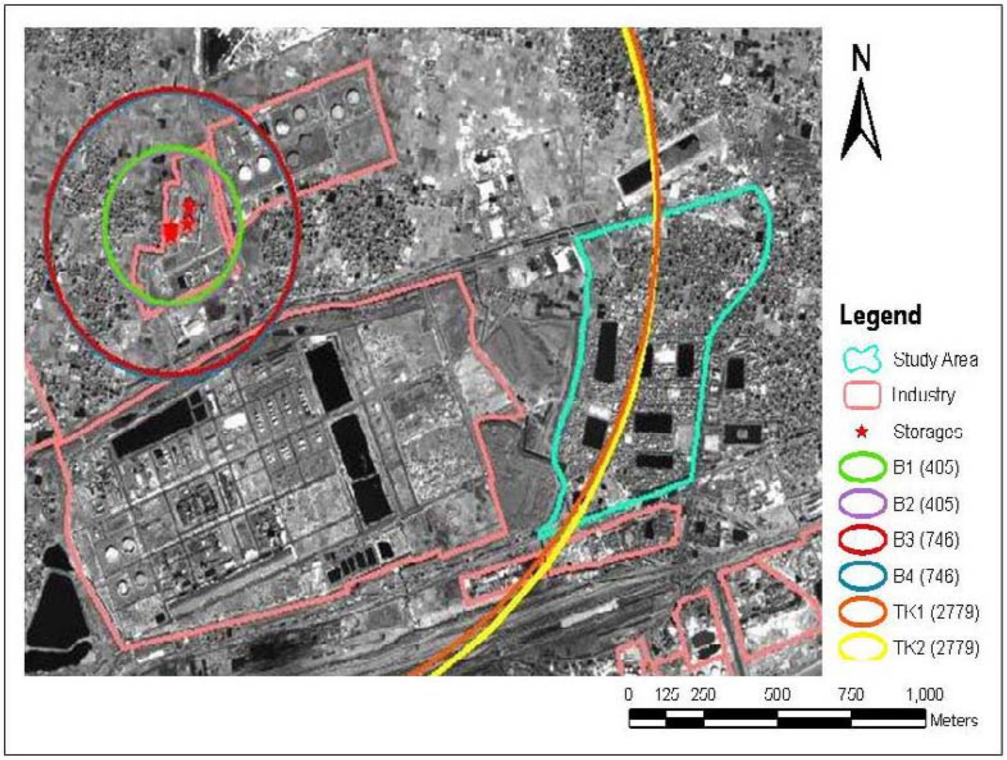

Figure: 5-16. BLEVE Hazard Footprint from Storages (IOC Petronas)

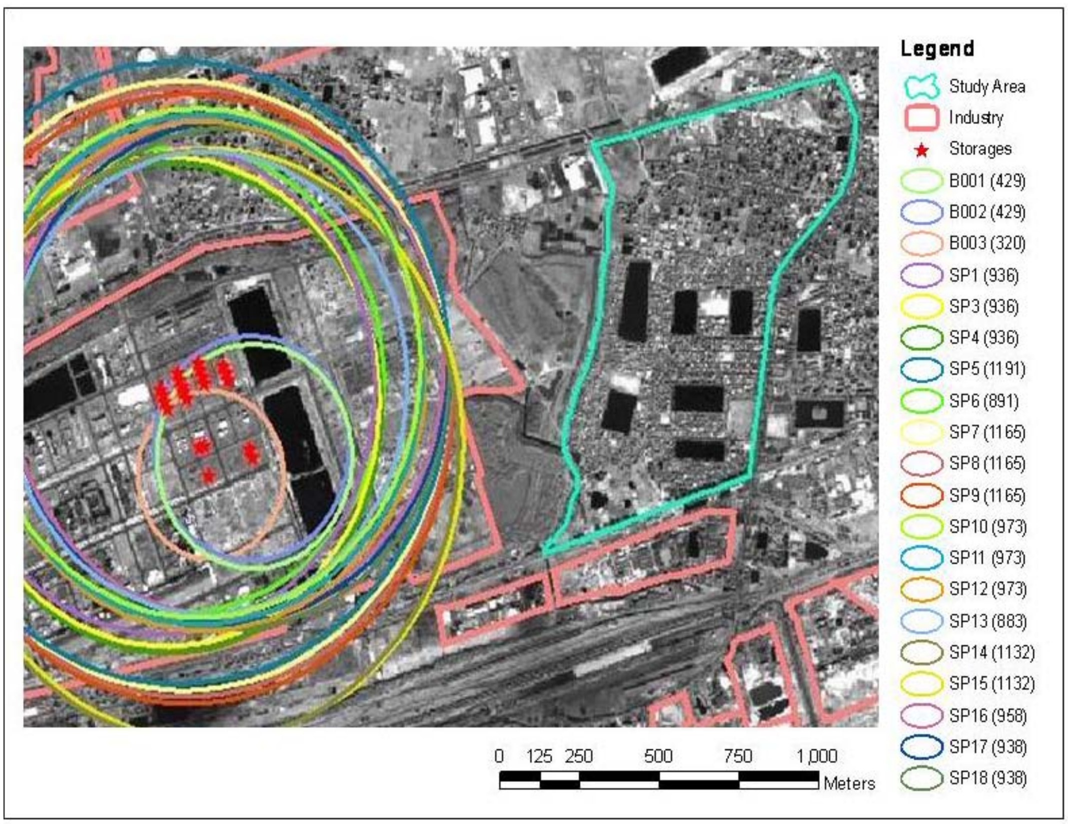

Figure: 5-17. BLEVE Hazard Footprint from Storages (HPL)

5.3.7. BLEVE Hazard Map

After overlaying the hazard footprint of all possible scenarios from all storages, the Haldia Municipal area was categorised in terms of Very High, High, Medium and Low VCE Hazard zones. *Figure 5.18* shows the BLEVE hazard map of Haldia Municipal area.

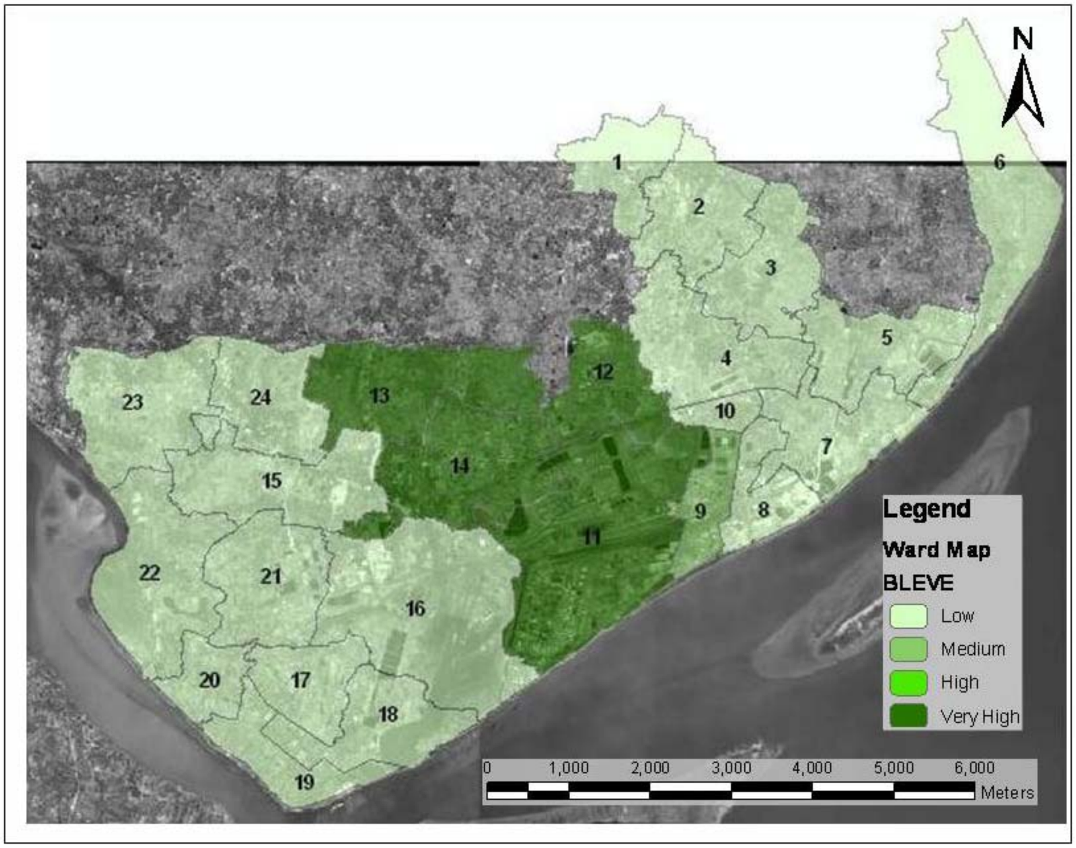

Figure: 5-18. BLEVE Hazard Map of Haldia Municipal Area

Table: 5.9. BLEVE Hazard Map of Haldia Municipal Area

Sl. No.	Category	Number of Scenarios	Number of Wards
1	Low	0 - 2	19
2	Medium	3 - 4	1
3	High	5 - 6	0
4	Very High	More than 20	4

The detailed study area was also categorised into groups: High, Medium and Low following the same method. *Fig: 5.20.A* shows the overlay of possible hazard footprints on map while *Fig: 5.19.B* showing the hazard map in terms of mapping units.

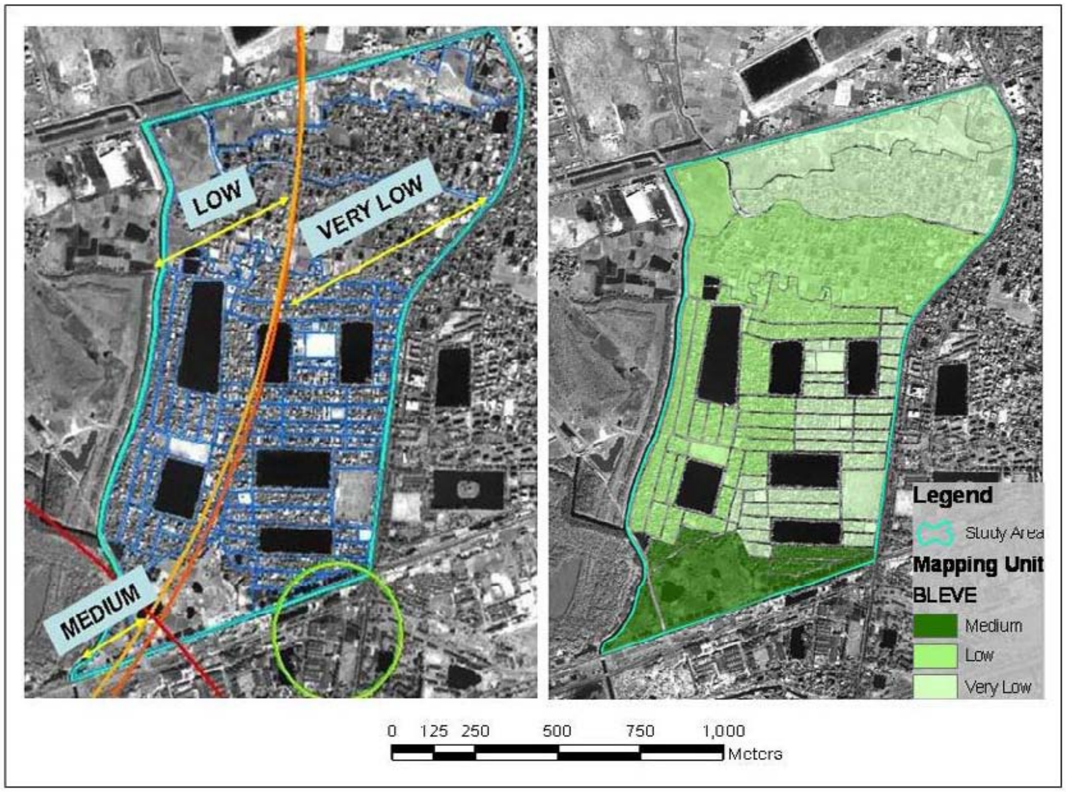

Figure: 5-19. (A) & (B) BLEVE Hazard Map of Detailed Study Area

5.4. Toxic Release Hazard

Although hazardous materials can pose both short-term and possibly long-term toxicological threats to terrestrial and aquatic wildlife and plants, the immediate concern during significant discharges is protection of human life and health. Consequently, this section addresses the toxicity and toxic hazards posed to the public by chemical substances. Toxic materials, be they solid, liquids, or gases/vapours, can affect human being as well living creatures via three primary routes of entry, namely: inhalation, ingestion and direct contact with skin or eyes *(Ref: Chapter 2)*. Toxic release may either be instantaneous or continuous. Though most of the chemicals have certain amount of toxicity in it, based on the amount the chemicals can are further categorised into two groups: toxic and highly toxic chemicals. For this present research work, instantaneous source (puff) is only considered for estimation of effect distances for highly toxic chemicals (e.g. ammonia, chlorine).

5.4.1. Atmospheric Dispersion Equation for Instantaneous Sources

Though there are several empirical equations for estimating the dispersion for a continuous or plume source, but unfortunately there is a lack in case of instantaneous or puff sources for the same. Only Turner's workbook provides a simplified equation that may be used for estimation purpose. Cases of instantaneous release (as from an explosion) or of short-term releases (on the order of seconds) are often of practical concern. To determine concentrations at any position downwind, it must be consider the time interval after the time of release and diffusion in the downwind direction as well as lateral and vertical diffusion. Though the determination of the path or trajectory of the puff is of considerable importance, but it is very difficult to calculate. This is most important in the case if concentrations are to be determined at specific points. Determining the trajectory is of less importance in the case where knowledge of the magnitude or of the concentration for particular downwind distances or travel time is required without the need to know exactly at what points these concentrations occur. An equation that may be used for estimates of ground-level concentrations downwind from a release from a height (H) is as follows:

$$c(\chi,\gamma,o,\mathrm{H}) = \left[\frac{2Q_T}{(2\pi)^{1.5}\sigma_\chi\sigma_\gamma\sigma_z}\exp\left\{-\frac{1}{2}\left(\frac{\chi-ut}{\sigma_\chi}\right)^2\right\}\right]\times\exp\left[-\frac{1}{2}\left(\frac{\mathrm{H}}{\sigma_z}\right)^2\right]\exp\left[-\frac{1}{2}\left(\frac{\gamma}{\sigma_\gamma}\right)^2\right]$$

Equation: 5-7 *Calculation for ground level concentration downwind from a release*

Q represents the total mass of the release and ( ) are not necessarily those evaluated with respect to the dispersion of a continuous source at a fixed point in space. This equation can be simplified for the centreline concentrations and ground-level emissions by setting y = 0 and H = 0, respectively. The ( ) in the equation refers to the dispersion statistics following the motion of the extending puff. The ( ) is the standard deviation of the concentration distribution in the puff in the downwind direction, and t is the time after release. There is no dilution in the downwind direction by wind speed. The speed of the wind mainly serves to give the downwind position of the centre of the puff, shown as the exponential involving ( ). Wind speed may influence the dispersion indirectly because the dispersion parameters ( ), ( ) and ( ) may be functions of wind speed. The ( )'s and ( )'s for an instantaneous may be assumed to be equal. The problem that remains is to make best estimates of ( ).

5.4.2. Toxic Release Hazard Footprints

Using the ERRIS Hazard Mapping Module a hazard footprint was generated based on above mentioned equations from all possible storages. The storages which contain highly toxic chemicals are only taken into consideration in this present research. Following table *(Table: 5.10)* mention the calculated effect distances for all storages followed by the map *(Fig: 5.20)* of scenarios for different storages of Haldia.

Table: 5.10. Calculated End Point Distance to Toxic Release

Industry Name	Storages	Chemical Name	Total Amount (MT)	IDLH Concentration (mg/m3)	Calculated Distance (m)
Exide	Exide-B004	Ammonia	1500	210	8200
Tata	Tata-TK01	Ammonia	1500	210	8200
Sanjana	SCTK01	Ammonia	10000	210	8500
IOC	IOCTK-02	Ammonia	30	210	4900
	IOCTK-03	Chlorine	1	29	2400

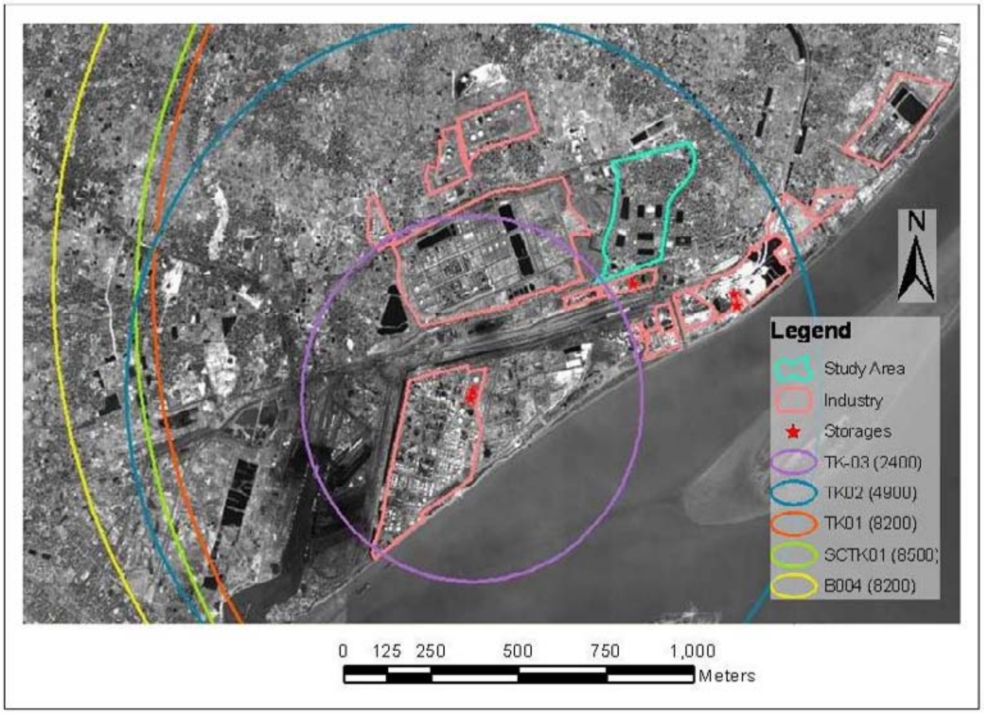

Figure: 5-20. Toxic Release Hazard Footprints from different Storages

5.4.3. Toxic Release Hazard Map

After overlaying the hazard footprint of all possible scenarios from all storages, the Haldia Municipal area was categorised in terms of Very High, High, Medium and Low VCE Hazard zones. *Figure 5.21* shows the hazard map for toxic release of Haldia Municipal area.

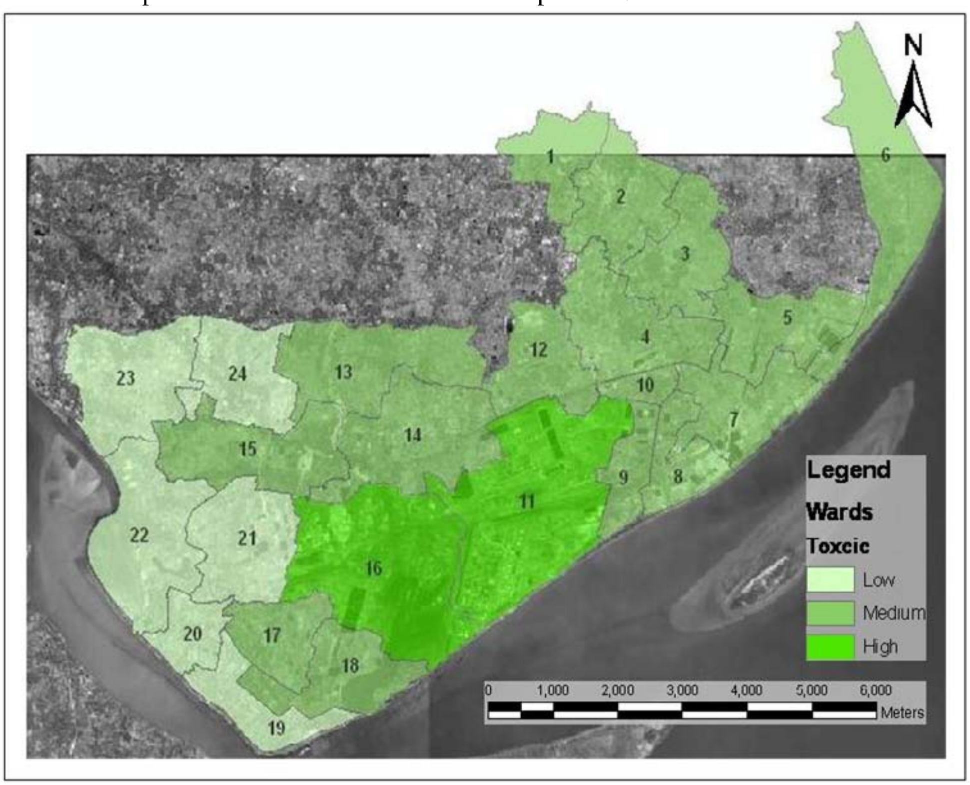

Figure: 5-21. Toxic Release Hazard Map for Haldia Municipal Area

Table: 5-8. Toxic Release Hazard Map of Haldia Municipal Area

Sl. No.	Category	Number of Scenarios	Number of Wards
1	Low	0 - 2	6
2	Medium	2 - 4	16
3	High	5 - 6	2

Following the same method, the detailed study area was also categorised into groups. But as the hazard footprints of possible scenarios covered the study area, so the whole area is being categorised as high. *Fig: 5.22.A* shows the overlay of possible hazard footprints on map while *Fig: 5.22.B* showing the hazard map in terms of mapping unit.

Figure: 5-22 (A) & (B) Toxic Release Hazard Map of Detailed Study Area

5.5. Summary

This chapter describes the assessment of different industrial hazards namely: pool fire, vapour cloud explosion, boiling liquid expanding vapour explosion and toxic releases. For each hazard the effect distance of hazardous storages for all possible scenarios were calculated after ERRIS Hazard Mapping Module. The hazard maps were prepared for the detailed study area as well as for the Haldia Municipal Area on the basis of number of scenarios. The hazard maps of the detailed study area will be multiplied by the calculated vulnerability of respective mapping units *(Ref: Chapter 6*) in order to estimate the risk for buildings and population *(Ref*: *Chapter 7).*

6. Vulnerability Assessment

6.1. Introduction

Vulnerability is defined 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. Thus, vulnerability is a function of hazard intensity or type and the characteristics of the elements, which are at risk. (Westen, 2004).
Two methods are there for vulnerability assessment, namely qualitative and quantitative. Qualitative methods refer to the expression of degree of vulnerability in terms of high, moderate or low. On the other hand, quantitative methods refer to the expression of vulnerability in terms of values, expressed on a scale between 0 (no damage) to 1 (total damage/loss) or as a percentage. In this research work, the qualitative method was adopted for the vulnerability assessment for individual buildings and population for the detailed study area and later on at a more aggregate level (i.e. both on a general grid level as well as per mapping unit) in order to identify the vulnerable zones. The study is limited to evaluating the building and population vulnerability only. Vulnerability will be calculated as separate aspect for the entire study area, depending on type of hazard and elements at risk. The effect distances as calculated in the previous chapter *(Ref: Chapter 5)* will later be combined with the vulnerability maps to estimate the risk *(Ref: Chapter 7).*

6.2. Building Vulnerability Assessment

The assessment of building vulnerability has a great importance for any type of hazard. The aspect of building vulnerability assessment is important for two essential reasons. Firstly such an assessment can be used as a base for population vulnerability assessment and secondly determining the building vulnerability on an individual basis gives the basis for preparedness and mitigation planning such as retrofitting of vulnerable buildings which in turn can decrease the population vulnerability (both inside and outside the buildings). Building vulnerability assessment is most important in the southern part of the study area as most of the buildings are spread in this area *(Figure: 6.1).* The method for building vulnerability assessment was developed with the idea of establishing a process for building vulnerability assessment not only for the study area but also for the entire town of Haldia. For this purpose two different aggregation levels have been considered, so that the analysis results are not displayed for each individual building, which would actually represent a false sense of detail and the whole area can be categorized into high, medium and low vulnerable zones. The first method divides the study area into larger grid cell with a size of 100 metres by 100 metres. The second method uses the mapping units, which are consisting of groups of buildings, bounded by streets, or by particular types of land use (e.g. water body, agricultural land etc.). The two levels of generalization are shown in the Figure: 6.2. In the building vulnerability assessment several parameters were taken into consideration and weightages and ranks were assigned to them based on the type of hazard as well as the condition of the buildings.

Figure: 6-1. Building Footprint Map of the Detailed Study Area

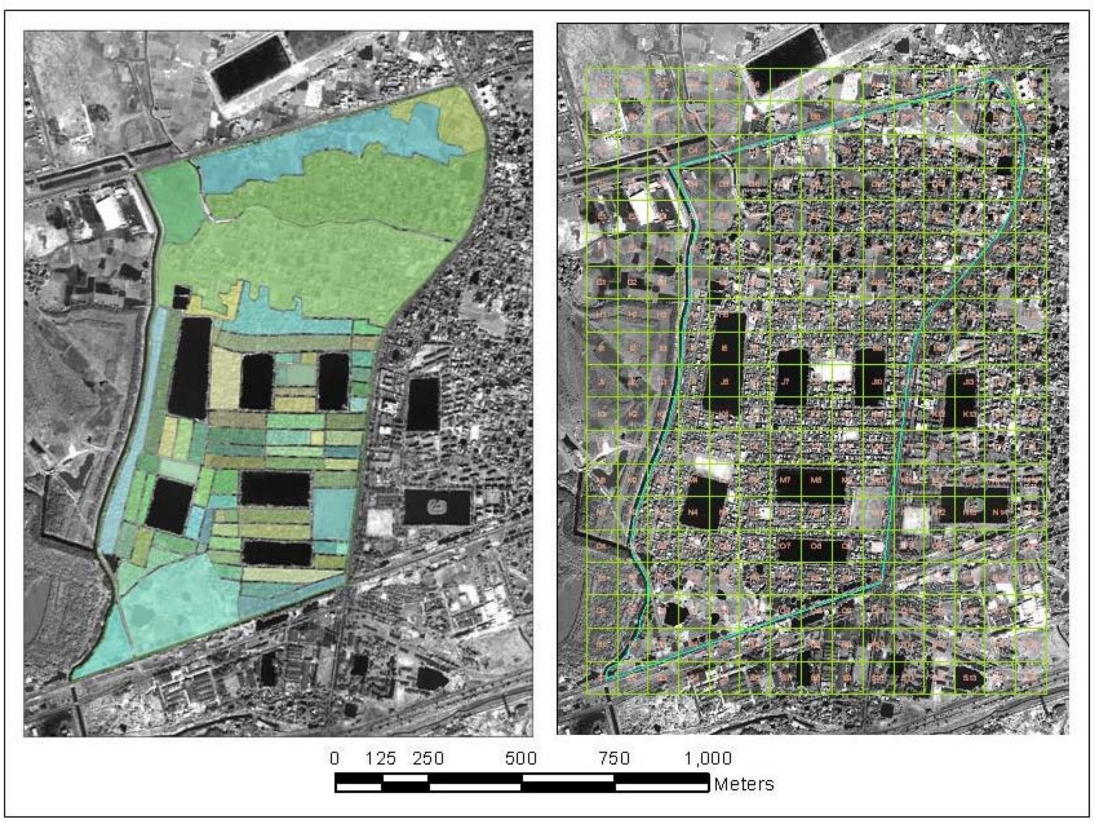

Figure: 6-2. (A) & (B) Mapping Unit & Grid Approach for Vulnerability Assessment

6.2.1. Building Vulnerability for Pool Fire

In a simple sense fire is controlled by a combination of fuel, heat and oxygen. Fire can be natural or manmade. However fire in an urban environment is mainly manmade. Industrial fire is another cause for an urban fire. In the industrial town of Haldia industries mainly manufacturing industries as well as storage tanks are the prime source for fire hazard. Most of these hazardous industries and storages are located within the near vicinity of the detailed study area for which the area becomes more vulnerable with respect to hazard. There are several consequences in case of industrial fire. In the present research work only pool fire is considered.

A pool fire hazard vulnerability map was prepared for the detailed study area based on certain parameters, such as; building construction type characterized by the type of wall material and roof material. Weightages were assigned to different parameters/themes depending on the severity observed in the local condition. The weightages of the themes were taken a value from 1 (low) to 10 (high), based on the construction material. Roof material is assumed to be the most important parameter for the fire hazard because once a building is gutted by fire will easily spread to the neighbouring buildings if they have same type of roof materials. Thus maximum weightage 10 is assigned to the roof material. Building material (i.e. wall material) is another important parameter and thus assigned to the weightage of 3. It is also to mention here that other factors were not taken into account, such as space between individual buildings, or the distance to water bodies. In the study area as most of the buildings are more or less situated at an average distance so this factor was not assigned with a particular weightage like others. The weightage and ranking of the different parameters for building vulnerability assessment in case of pool fire hazard are given in the following *Table 6.1*.

Table: 6-1. Weightage and Ranking for Pool Fire Vulnerability of Buildings

Sl. No.	Parameters	Weightage	Contents	Rank	Total Weight	Normalized Weight
1	Roof Material	10	Thatched	10	10	10/13=0.77
			Tiles/Asbestos	6		
			RCC	2		
2	Building Material	3	Kuchha	10	3	3/13=0.23
			Brick walled	4		
			RCC	2		
					13	1

Using ARC GIS SQL vector operations, the weightages were calculated for individual buildings that are at different levels of fire hazard vulnerability was calculated. The expression used to calculate the pool fire hazard vulnerability for individual building:

Pool Fire Vulnerability = [0.77(Rank of Roof Material) + 0.23*(Rank of Building Material)].*

Using the above mentioned weightages and ranks for different parameters each individual building were identified by a certain degree of vulnerability in terms of high, medium and low. The vulnerability value for pool fire ranges from 2 to 15. Based on this range vulnerability index was considered where value 2 to 4 represents low, 5 to 9 represents medium and10 to 15 represents the high category. The following table *(Table: 6.2.)* shows the number of buildings under different categories of vulnerability for pool fire.

Table: 6-2. Buildings in Different Vulnerability Categories for Pool Fire

Sl. No.	Category	Range of Weights	Number of Buildings	Percentage (%)
1	High	10 - 15	93	7.14
2	Medium	5 - 9	477	36.64
3	Low	0 - 4	732	56.22
Total			1302	100

Figure 6.3 shows the spatial distribution of buildings under different pool fire hazard categories.

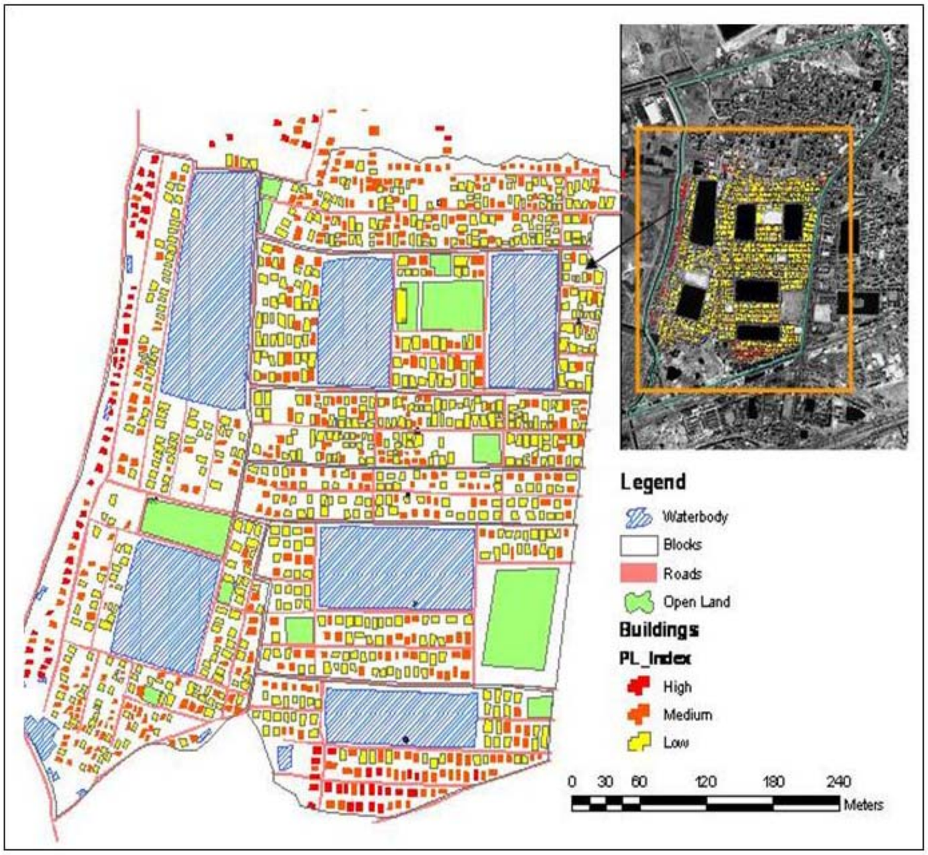

Figure: 6-3. Building Vulnerability for Pool Fire Hazard

The results for the individual buildings were generalized for the grids on the basis of the predominance of the buildings in terms of vulnerability within the grid. The spatial distributions of different categories of grids are shown in the Figure *6.4.A*. Also a representation was made based on the mapping units, which is shown in the Figure *6.4.B*. It can be seen from the Figure *6.4.A* that the representation of the results in the grid could be misleading as some of the grids are partially covering the water bodies in the study area, leading to a wrong impression of the building vulnerability.

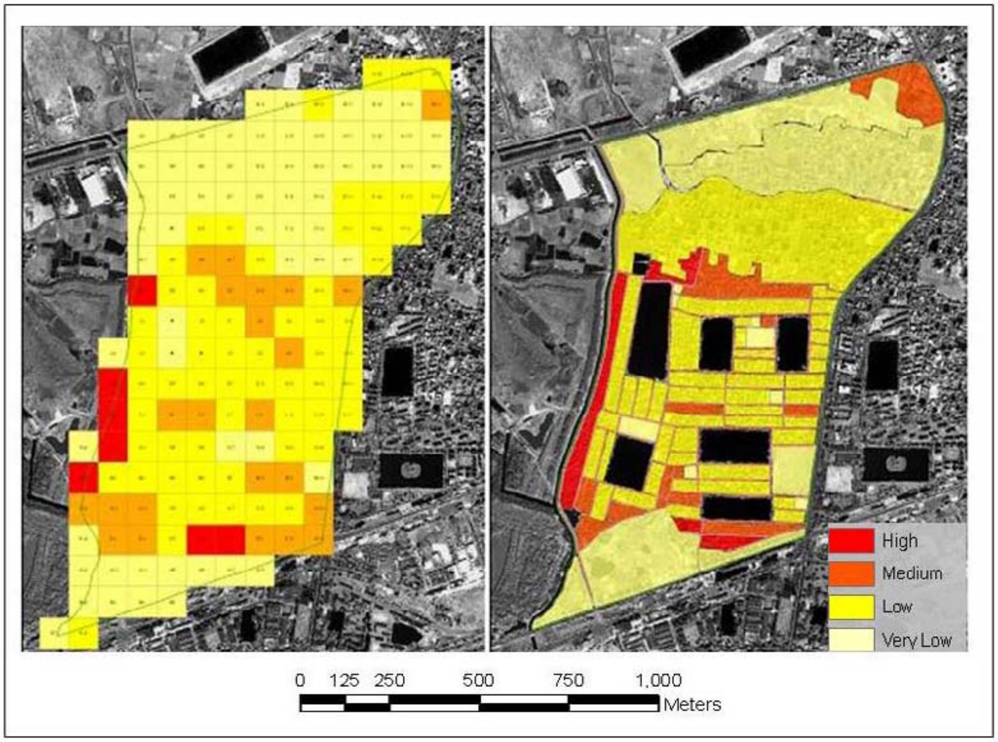

Figure: 6-4. (A) & (B) Grids and Mapping Units under different categories of Building Vulnerability for Pool Fire

6.2.2. Building Vulnerability for VCE

The vulnerability map for the Vapour Cloud Explosion hazard was prepared based on certain parameters, such as; building material (wall material), roof material and number of stories of buildings. Weightages are assigned to different parameters/themes depending on the effect of vapour cloud explosion and severity observed in the local condition. Roof material is assumed to be the most important parameter for vapour cloud explosion because the roof collapse might be one of the most direct effects of the explosion. Thus maximum weightage 10 is assigned to roof material. Building material, the next important parameter, is given weightage value of 6. The third important parameter taken into consideration is number of stories of a particular building. In case of an explosion event there is a chance of taller buildings will get much more effected which make leads to more vulnerable. Thus for vulnerability assessment of building this parameter is assigned to a weightage of 5. The weightage and ranking of the different parameters for building vulnerability assessment in case of vapour cloud explosion are given in the following *Table 6.3.*

Table: 6-3. Weightage and Ranking for VCE Vulnerability of Buildings

Sl. No.	Parameters	Weightage	Contents	Rank	Total Weight	Normalized Weight
1	Roof Material	10	Thatched	10	10	10/23=0.43
			Tiles/Asbestos	6		
			RCC	2		
2	Building Material	8	Kuchha	10	8	8/23=0.35
			Brick walled	4		
			RCC	2		
3	No. of	5	Three/Four	5	5	5/23=0.22

	Stories		Two	3		
			One	1		
					23	1

The following expression was used to calculate the vapour cloud explosion hazard for individual buildings:

VCE Vulnerability = [0.43*(Rank of Roof Material) + 0.35*(Rank of Building Material) + 0.22*(Rank of No. of stories)].

After calculating the total weight value each individual building was classified in a degree of vulnerability in terms of high, medium and low. For VCE the vulnerability value ranges from 2 to 13. The vulnerability index was prepared based on this range where value 2 to 3 represents low category, 4 to 9 represents medium category while 10 to 15 represents high category. The following table *(Table: 6.4.)* shows the number of buildings under different categories of vulnerability for VCE hazard:

Table: 6-4. Buildings in different vulnerability categories for VCE

Sl. No.	Category	Range of Weights	Number of Buildings	Percentage (%)
1	High	10 - 15	98	7.53
2	Medium	4 - 9	477	36.63
3	Low	0 - 3	727	55.84
Total			1302	100

There are only 98 buildings failing under high explosion hazard class with a share of 7.53% of the total buildings. The number of buildings falling under the category of medium is 477 having a share of 36.63
% of the total number of building. The low category shares more than 55% to the total number having a total number of 727 buildings. *Figure 6.5* shows a spatial distribution of buildings under different explosion (VCE) hazard categories.

As this analysis uses a number of factors in the analysis for vulnerability, several other factors were not taken into account. One important factor is the so-called “shadow effect”, where smaller buildings might be protected from the blast of an explosion, because a taller building is standing close to it, in between the building and the explosion site. In order to take this factor into account, the exact location of the explosion should be know, and a separate vulnerability map should be made for each individual scenario. Given the time limitations this was not possible in this present research.

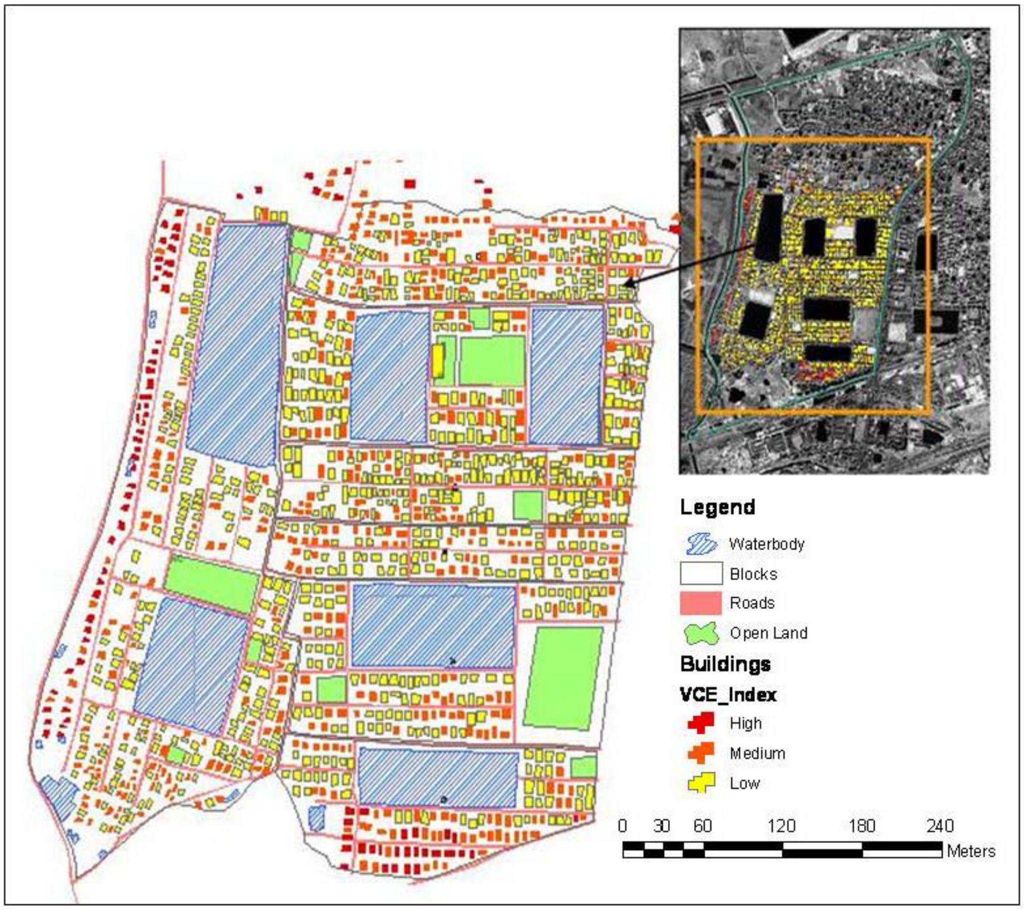

Figure: 6-5. Buildings Vulnerability for Vapour Cloud Explosion Hazard

Based on the analysis for individual buildings finally the grids were categorized on the basis of the predominance of the building in terms of vulnerability within the grid. The spatial distributions of different categories of grids are shown in the *Figure 6.6.A*. Also a representation was made based on mapping units, which is shown in *Figure 6.6.B.*

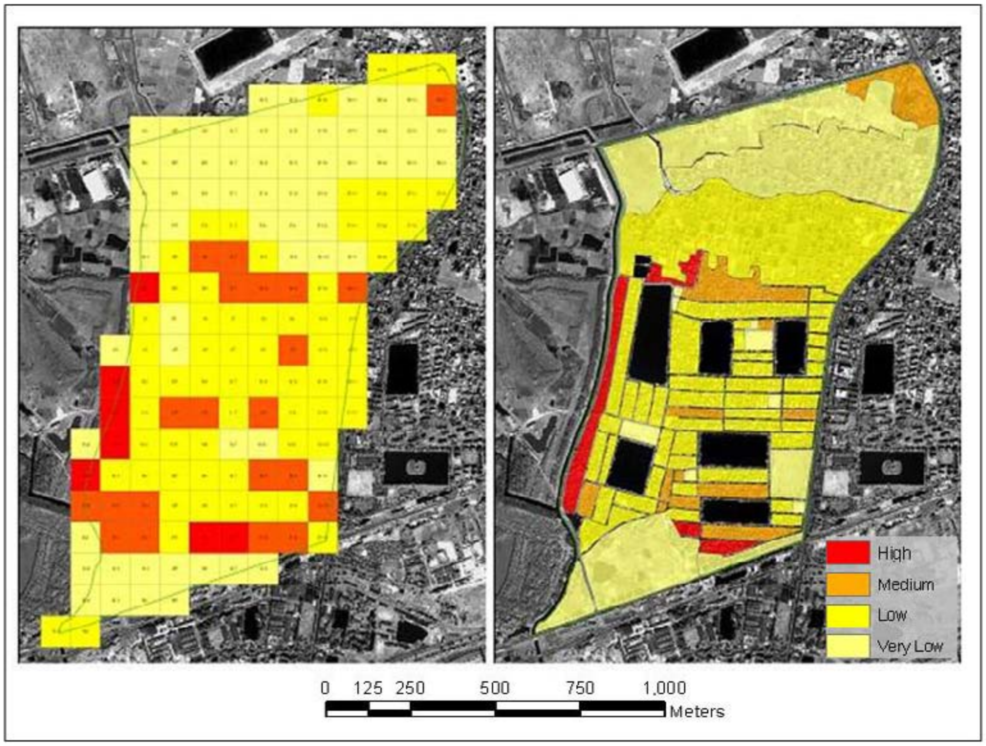

Figure: 6-6. (A) & (B) Grids & Mapping Units indicating different categories of Building Vulnerability for VCE

6.2.3. Building Vulnerability for BLEVE

Boiling Liquid Expanding Vapour Explosion is a consequence of explosion results from fireballs or from flame jets. Thus it is much more hazardous with respect to population as well as for buildings. The BLEVE hazard vulnerability map can be prepared for the study area based on certain parameters, such as; building construction type (wall material), roof material and number of stories. Weightages are assigned to different parameters depending on the severity observed in the local condition. The number of stories of a building is the prime important factor for the BLEVE hazard because if in between a building and the source of BLEVE a taller building would be there then it might be protect the smaller ones though it depends on also the direction from which the BLEVE comes. Thus this parameter was assigned with a weightage of 10. Roof material and building material were assumed to be the next most important parameters because of their strength to withstand the explosion. Thus a weightage of 8 was assigned to both roof materials as well to building material. The weightage and ranking of the different parameters for building vulnerability assessment in case of boiling vapour cloud explosion are given in the following *Table 6.5.*

Table: 6-5. Weightage and Ranking for BLEVE Vulnerability of Buildings

Sl. No.	Parameters	Weightage	Contents	Rank	Total Weight	Normalized Weight
1	Number of Stories	10	Three/Four	6	10	10/26=0.38
			Two	4		
			One	2		
2	Roof Material	8	Thatched	10	8	8/26=0.31
			Tiles/Asbestos	4		

			Concrete	2		
3	Building Material	8	Kuchha	10	8	8/26=0.31
			Brick walled	3		
			RCC	1		
					26	1

The expression was used to calculate the BLEVE hazard for individual building is as follows:

BLEVE Vulnerability = [0.38*(Rank of 'number of Stories') + 0.26*(Rank of 'Roof Material') + 0.26*(Rank of 'Building Material')].

Using the above mentioned weightages and ranks to the different parameters each individual building were assigned by a certain degree of vulnerability in terms of high, medium and low. For BLEVE the vulnerability value ranges from 2 to 11. The vulnerability index was prepared based on this range where value 2 to 3 represents low category, 4 to 6 represents medium category and 7 to 11 represents high category. The following table *(Table: 6.6.)* shows the number of buildings under different categories of vulnerability for vapour cloud explosion hazard:

Table: 6-6. Buildings in Different Vulnerability Categories for BLEVE

Sl. No.	Category	Range of weights	Number of Buildings	Percentage (%)
1	High	7 - 11	94	7.21
2	Medium	4 - 6	94	7.21
3	Low	0 - 3	1114	85.56
Total			1302	100

Most of the buildings within the study are falling in the low category of vulnerability. Out of 1302 buildings, 1114 buildings were categorized in this class having a share of 85% to the total number of buildings. Other two categories shares only 14% of the total number of buildings. Following figure *(Fig: 6.7.)* the spatial distribution of buildings under different explosion (BLEVE) hazard categories.

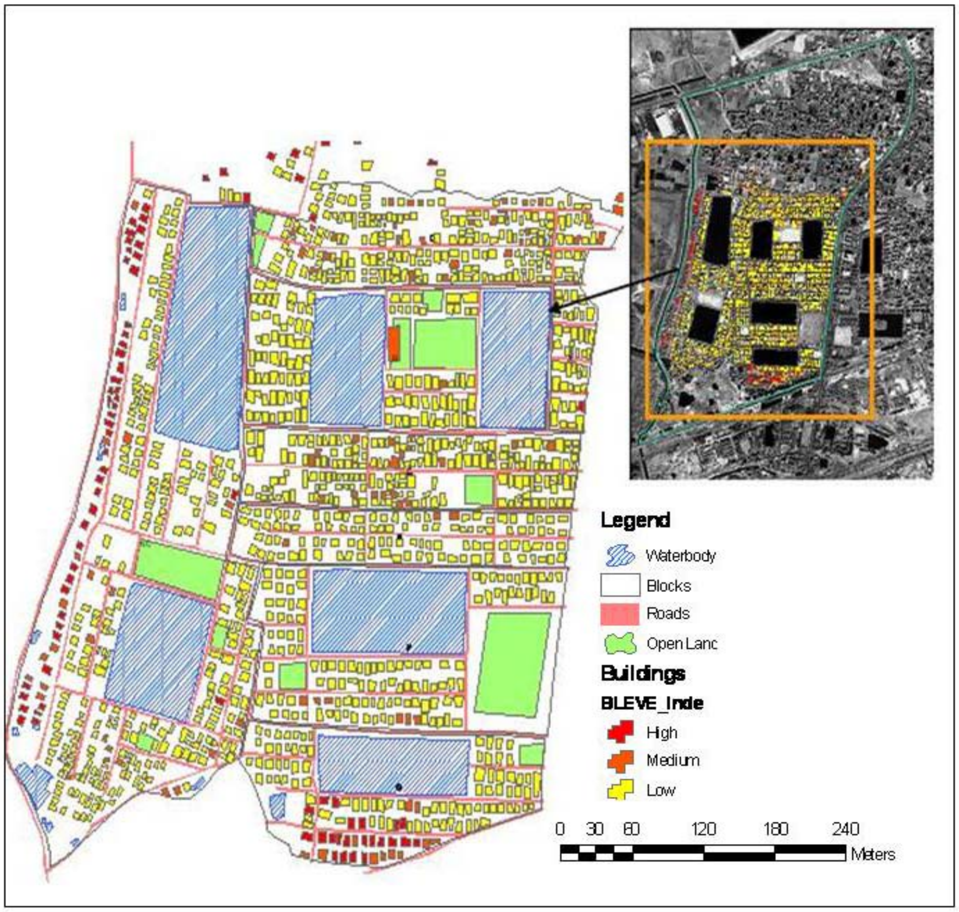

Figure: 6-7. Buildings Vulnerability for Boiling Vapour Cloud Explosion Hazard

After calculating the vulnerability of individual buildings in the study area, the result was generalized in a way to identify the vulnerable zones in terms of low, medium or high. For this purpose the same analysis done at two higher levels. Following figures *(Figure: 6.8.A & B)* shows the result of generalization at upper levels i.e. at grid level as well as for mapping units.

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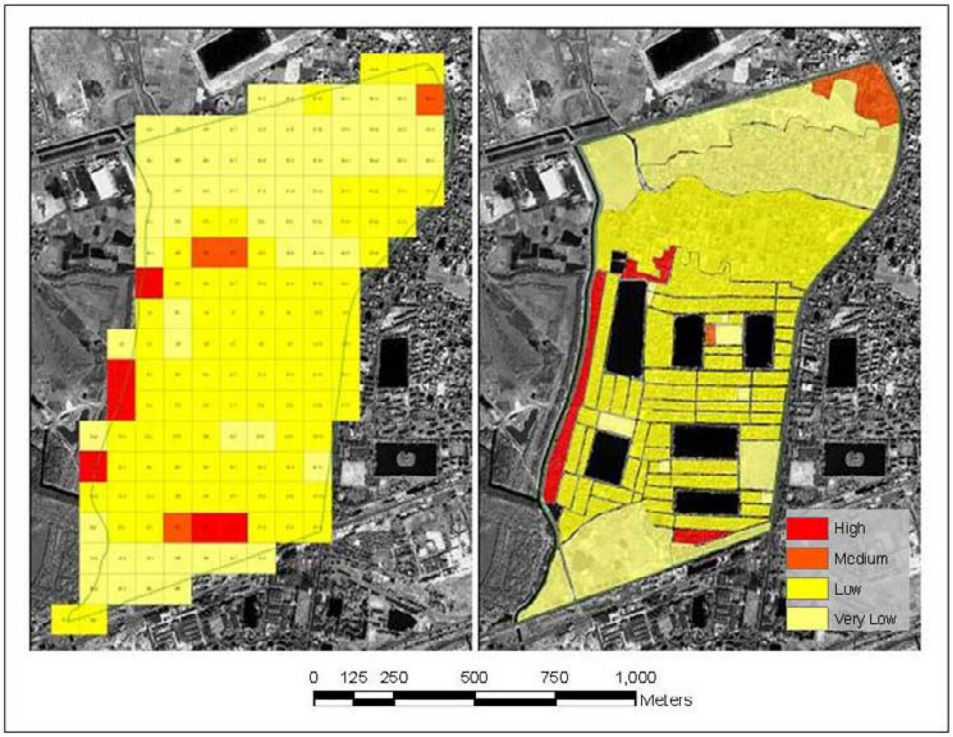


Figure: 6-8. (A) & (B) Grids & Mapping units showing different categories of Building vulnerability for BLEVE

6.2.4. Building Vulnerability for Toxic Release

Also an assessment was made for the vulnerability assessment related to toxic release hazard based on the same parameters above mentioned. For toxic release hazard, the air tight condition of the building was assumed to be the most important factor. In case of a toxic release event if the building is air tight then there will be less chance for people to inhale the toxic gas which is harmful for their health. Therefore, the maximum weightage 10 is assigned to the air tight condition of the building. But if a building is far away from the source of toxic release in that case there will be less probability for the people might be affected though the building is not at all air tight. However, this aspect will be taken into account in risk assessment (*Ref: Chapter 7*), where the vulnerability and hazard factors are combined. The height of a building is also an important parameter for building vulnerability assessment in case of toxic release. Normally toxic gas is heavier than air, so it will float over the surface. So in toxic release event the short buildings are much more vulnerable than the tall buildings. Thus the number of stories is considered to the next important factor and assigned a weightage of 8. The air tight condition of a building mainly depends on roof material and building material. These two parameters are thus assigned with a weightage of 2. The weightage and ranking of the different parameters for building vulnerability assessment in case of toxic release are given in the following *Table 6.7.*

Table: 6-7. Weightage and Ranking for Toxic Release Vulnerability of Building

Sl. No.	Themes	Weightage	Contents	Rank	Total Weight	Normalized Weight
1	Air Tight Condition	10	No	10	10	10/22=0.46
			Yes	1		
2	No. of story	8	One	10	8	8/22=0.36
			Two	6		
			Three/Four	2		
3	Building Material	2	Kuchha	10	2	2/22=0.09
			Brick walled	4		
			RCC	2		
4	Roof Material	2	Thatched	5	2	2/22=0.09
			Tiles/Asbestos	3		
			Concrete	1		
					22	1

The following expression was used to calculate the toxic release hazard for each individual building:

TR Vulnerability = [0.46*(Rank of Air Tight Condition) + 0.36*(Rank of No. of Stories) + 0.09*(Rank of Building Material) +0.09*(Rank of Roof Material).

Using the above mentioned query each individual building was assigned by a certain degree of vulnerability in terms of high, medium and low. For toxic release the vulnerability value ranges from 1 to 10. The vulnerability index was prepared based on this range where value 1 to 3 represents low category, 4 to 6 represents medium category and 7 to 10 represents high category. The following table *(Table: 6.8.)* shows the number of buildings under different categories of vulnerability for toxic release event:

Table: 6-8. Buildings in Different Vulnerability Categories for Toxic release

Sl. No.	Category	Range of weights	Number of Buildings	Percentage (%)
1	High	7 - 10	881	67.66
2	Medium	4 - 6	194	14.90
3	Low	0 - 3	227	17.44
Total			1302	100

Most of the buildings in the area are within the medium category of vulnerability class. This category comprises of 670 buildings and has a share of 51.46 % to the total number of buildings. The number of buildings falling under the category of high is 410 having a share of 31.49 % next to the medium category. The low category shares less than 20% to the total number having a total number of 222 buildings. Following figure *(Fig: 6.9.)* shows the spatial distribution of buildings under different levels of toxic release hazard classes.

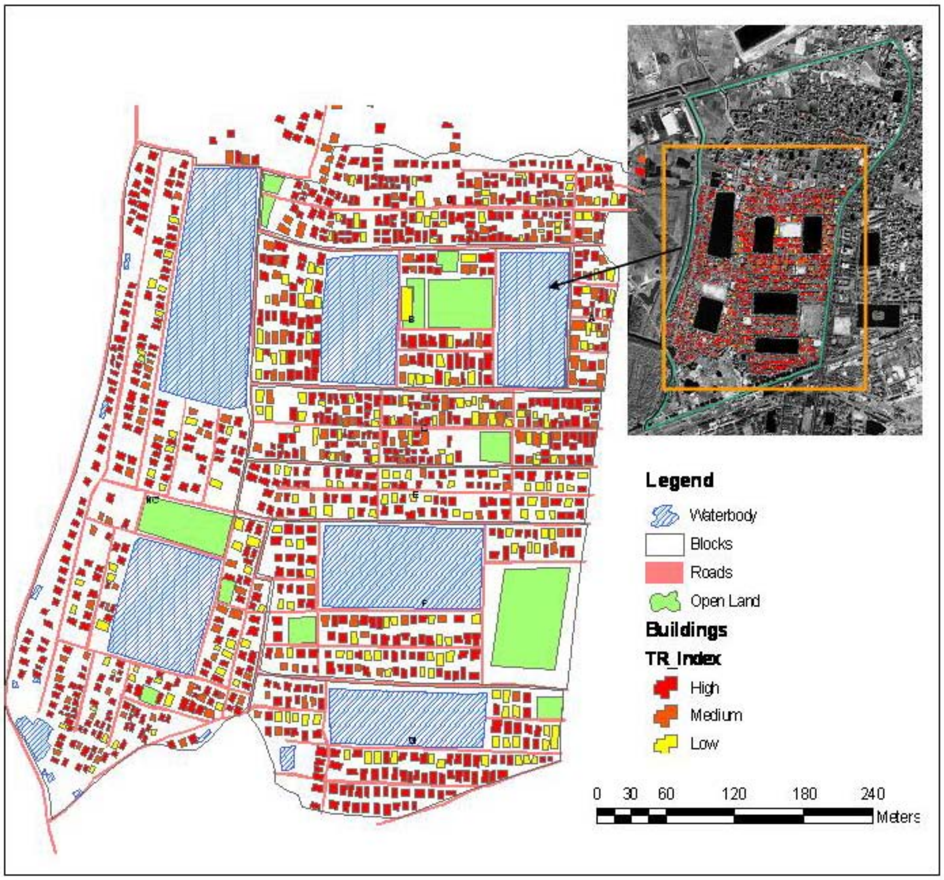


Figure: 6-9. Buildings Vulnerability for Toxic Release Hazard

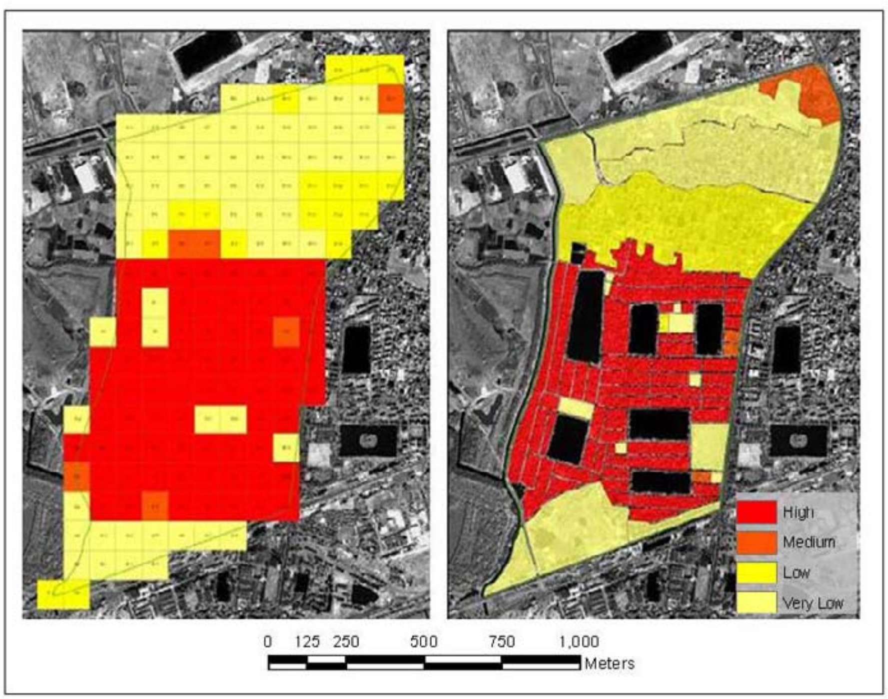


Figure: 6-10. (A) & (B) Grids & Mapping units under different categories of building Vulnerability for Toxic Release

6.3. Population Vulnerability Assesssment

Population is one of the major elements at risk for any type of hazards either natural or industrial. The main objective to assess the vulnerability of population is to get a fair estimate of the number of people who might be affected if an event happened. Preparedness and mitigation plan can be prepared in advance based on the result of population vulnerability. Population vulnerability in a particular place depends on the structural vulnerability (i.e. building vulnerability) due to a particular hazard. As for example in the case of earthquake the population vulnerability will be changing mainly based on the structural vulnerability which in turn depends on the intensity and severity of the earthquake. Likewise in case of an industrial hazard (e.g. fire, explosion or toxic release) population vulnerability also varies with respect to the variation in structural vulnerability. Population vulnerability of a particular place also changes in different time periods of a particular day. Thus it plays a significant role in risk assessment for any type of hazard. For this research work, population vulnerability has been carried out for the study area with respect to different time periods. In this section the population distribution indoors and outdoors will be analyzed for different scenarios depending on the time of the day. The relation between building vulnerability, hazards and population vulnerability will be analyzed in the following chapter *(Ref: Chapter 7).*

6.3.1. Population of the Study Area

In the detailed study area, which is the most populated part of Haldia, the population vulnerability assessment, has been carried for different time periods. In general the southern part of the detailed study area has a higher population density as most of the residential buildings are located there. In the northern part only a few scattered houses with homestead orchards exist, and the density is quite low. The southern part mainly consist of six residential blocks *(Ref: Chapter 4)* which are much more vulnerable in terms of population. Moreover the existence of MAH industries near the boundary of the study area also increases the population vulnerability. Total population of this area being 12,500 contribute about 10% to the total population of Haldia Municipal Area *(Ref: Chapter 3).*
The buildings of the detailed study area were categorized into three groups: Low, Medium and High based on the number of population per building. The low category consists of 1116 (85.71%) buildings with population less than 20 persons per building. The medium category consists of 142 (10.91%) buildings with a population of 20-40 persons per building and rest of the buildings are falling in the high category with a population of more than 40 persons per building. Buildings in different categories of population distribution are given in the *Table 6.9.*

Table: 6-9. Buildings in Different Categories of Population Distribution

Sl. No.	Category	No. of Persons per building	No. of Buildings	Percentage (%)
1	Low	<20	1116	85.71
2	Medium	21-40	142	10.91
3	High	>40	44	3.38
Total			1302	100

The estimated population for the detailed study area is based on the observation of the number of households per building which is multiplied by the average household size observed in the detailed study area that was arrived from field survey also calculated. There are 2500 households in the detailed study area. The average household size derived from the detailed field survey is 5. Thus the population of the detailed study area is 12,500.

[Estimated Population] = [Number of buildings]*[Average Household Size]

6.3.2. Classes of Buildings

For population vulnerability assessment it is also important to know the urban land use type of the buildings. The classification of buildings provided a real time scenario that allows to calculate how the vulnerability of particular building changes in different time periods mainly based on use of buildings. The living pattern of the people is also important to determine the hours of use of different buildings.

Based on the use the buildings of the detailed study area was classified into five classes namely, i) Residential, ii) Commercial, iii) Institutional, iv) Public Buildings and v) Mixed uses. Most of the buildings (about 95% of the total buildings) within this area are used for only residential purpose. The category “Institutional” refers to the buildings used mainly for school, office etc. The category “Public Buildings” includes temples, mosques, community halls, clubs, lodge, restaurants etc. Mixed category represents the buildings used for more than one activity. There are 22 buildings which are used for commercial purpose on the ground floor while other floors are used for other activities such as residential. These buildings are identified as mixed use type. The buildings mainly along the State Highway 6 fall under mixed use class. Though the commercial activities are mainly concentrated along the State Highway 6 a few commercial shops are also there around the stadium. *(Table: 6.10.)*

Table: 6-10. Buildings with Different Uses

Sl. No.	Use Type	Number of Buildings	Percentage (%)
1	Residential	1235	94.85
2	Commercial	29	2.23
3	Institutional	6	0.46
4	Public Buildings	10	0.76
5	Mixed	22	1.7
Total		1302	100

Most of the working people in the study area are working in the nearby industries in shifts of 8 hours duration. For the people who are not engaged in the industries the working hours are from 10.00 am in the morning to 5.00 pm. So the population vulnerability is higher for residential building in the night time than daytime while institutions like schools, colleges have more causality if an event occurs during the daytime. Thus with respect to building use as well as living pattern of the residents the degree of vulnerability changes.

6.3.3. Temporal Distribution of Population inside Buildings

An industrial accident may happen at any time with an adverse effect on population. The information about the number of people inside the buildings as well as on the street at different time periods is important for causality estimation. In this present research work, population within the buildings for the detailed study area were estimated for different time periods of a day i.e. morning (6 AM to 10 AM), day (10 AM to 6 PM), evening (6 PM to 10 PM) and night (10 PM to 6 AM). The people within a particular building in different time period depends on the different use type of that building. Following figure *(Fig: 6.11)* shows the number of people inside the buildings at different time periods of a day.

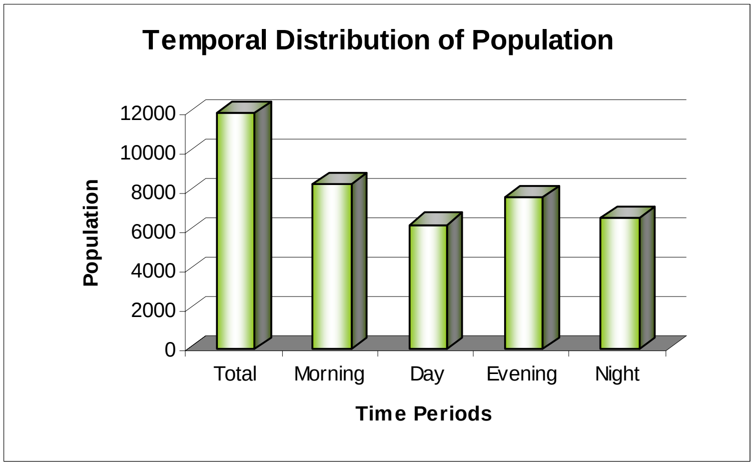


Figure: 6-11. Temporal distribution of Population inside buildings

Considering the figures it can be interpreted that the buildings are much more vulnerable during morning and evening time than daytime and night time respectively. Through out the whole day the total the population inside the buildings is highest during the morning time (6 AM to 10 AM) which accounts to 70% of the total population while the lowest during daytime (10 AM to 6 PM) which is only 52% of the total population. During the evening time (6 PM to 10 PM) the concentration increases from daytime and comprises and accounts to 64% of the total population. Figure 6.12 shows the temporal distribution of population (inside the buildings) for the detailed study area.

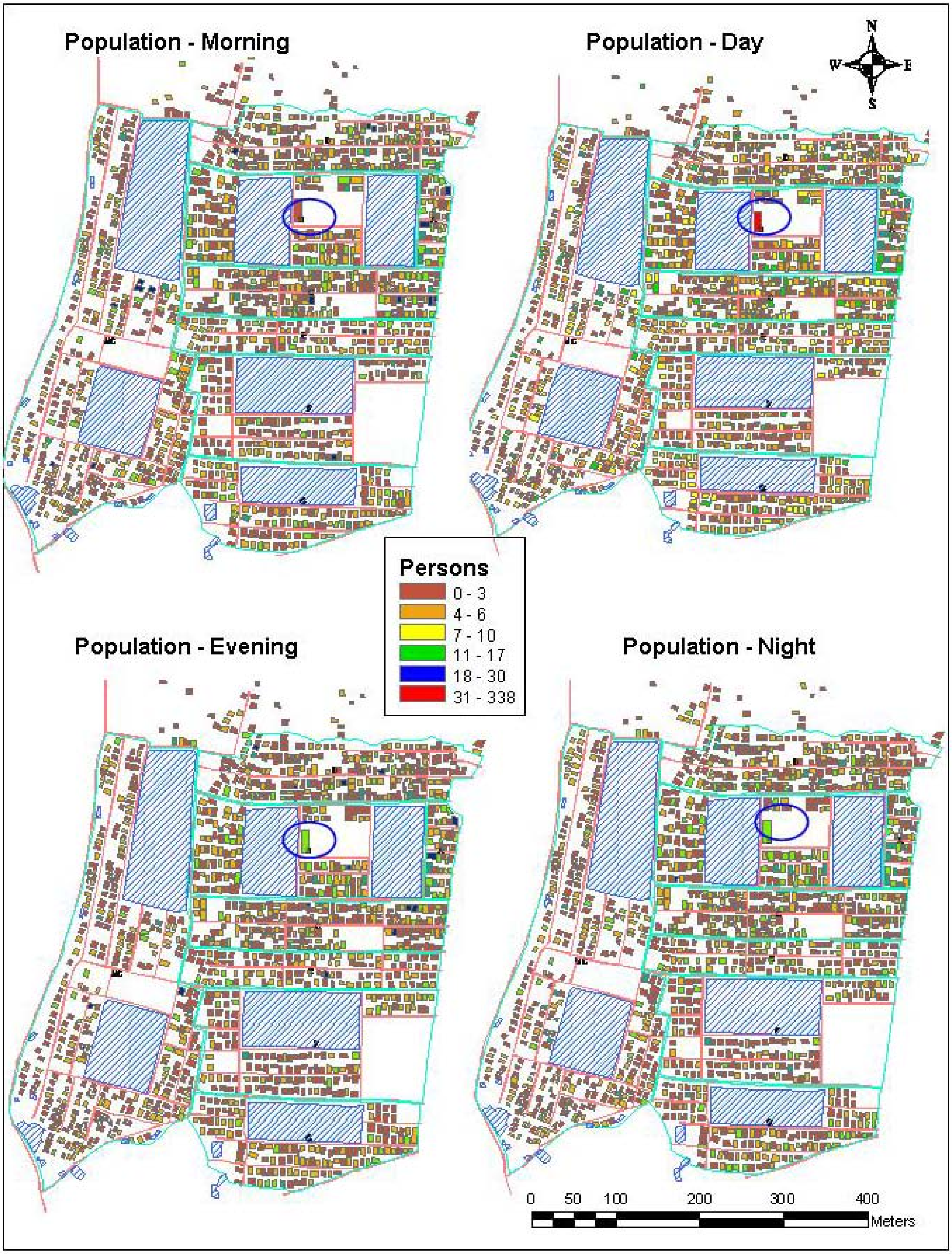


Figure: 6.12. Temporal Distribution of Population inside the buildings

6.3.4. Temporal Variation of Population Vulnerability per Building

Depending on the lifestyle of people, the degree of vulnerability of a building in terms of number of population also changes. In the earlier section it is mentioned that with respect to time how the population distribution varies. The analysis shows that residential buildings are more vulnerable during morning time in comparison to other time as population is higher during this time. As 95% of the total buildings in the detailed study area come in the residential category, the casualities can be higher if an accident occurs during morning and night time. The buildings that have more activity during the daytime will have more casualities than those buildings which have less activity during this time. Institutional buildings, commercial areas includes in this category. There are two high schools, three primary schools and few private offices within the study area which are particularly vulnerable during daytime for having high concentration of population. It is also observed that most of the students of these schools are coming from the study area itself while few numbers of students also come from the surrounding areas. Commercial areas are also more active during the daytime as well as in the evening than morning and night time with large number of floating populations which in turn increases the vulnerability for the entire area. There are 29 buildings such buildings found under this category along State Highway 6. As public buildings are used only in the daytime, population of these buildings is more vulnerable during the daytime, i.e. working hours (10.00 AM to 6.00 PM). In the study area 10 public buildings are identified. Apart from these types there are few buildings used for residential as well as for commercial purposes (mixed use) are vulnerable both for daytime and night time. The temporal variation of population vulnerability (inside the buildings) expressed in terms of Low, Medium and High categories for the entire study area is shown in the *Figure 6.13.* The temporal changes in vulnerability for population during several time periods per mapping unit are also shown in the *Figure 6.14.*

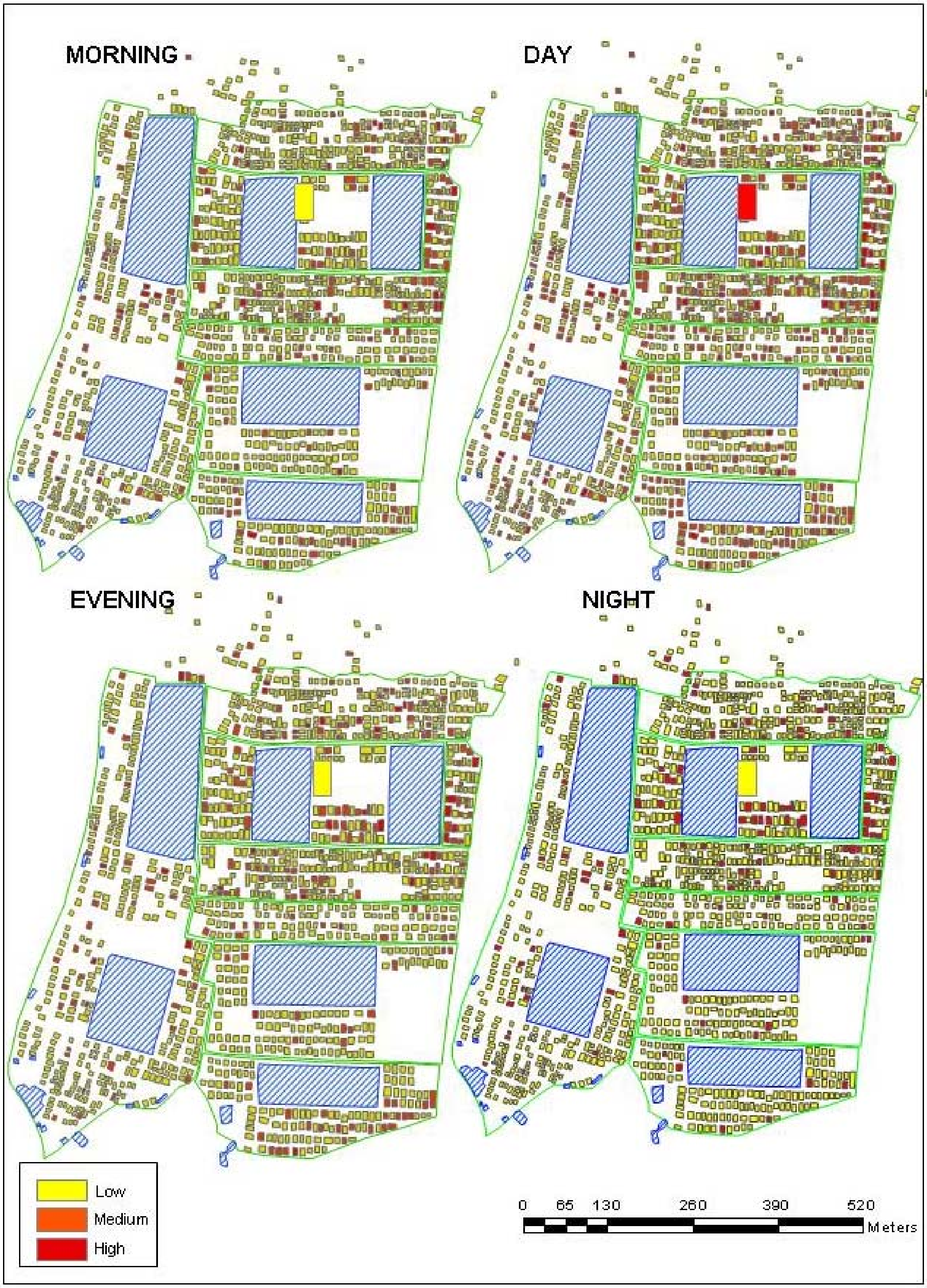


Figure: 6-12. Temporal Variation of Population Vulnerability inside the buildings

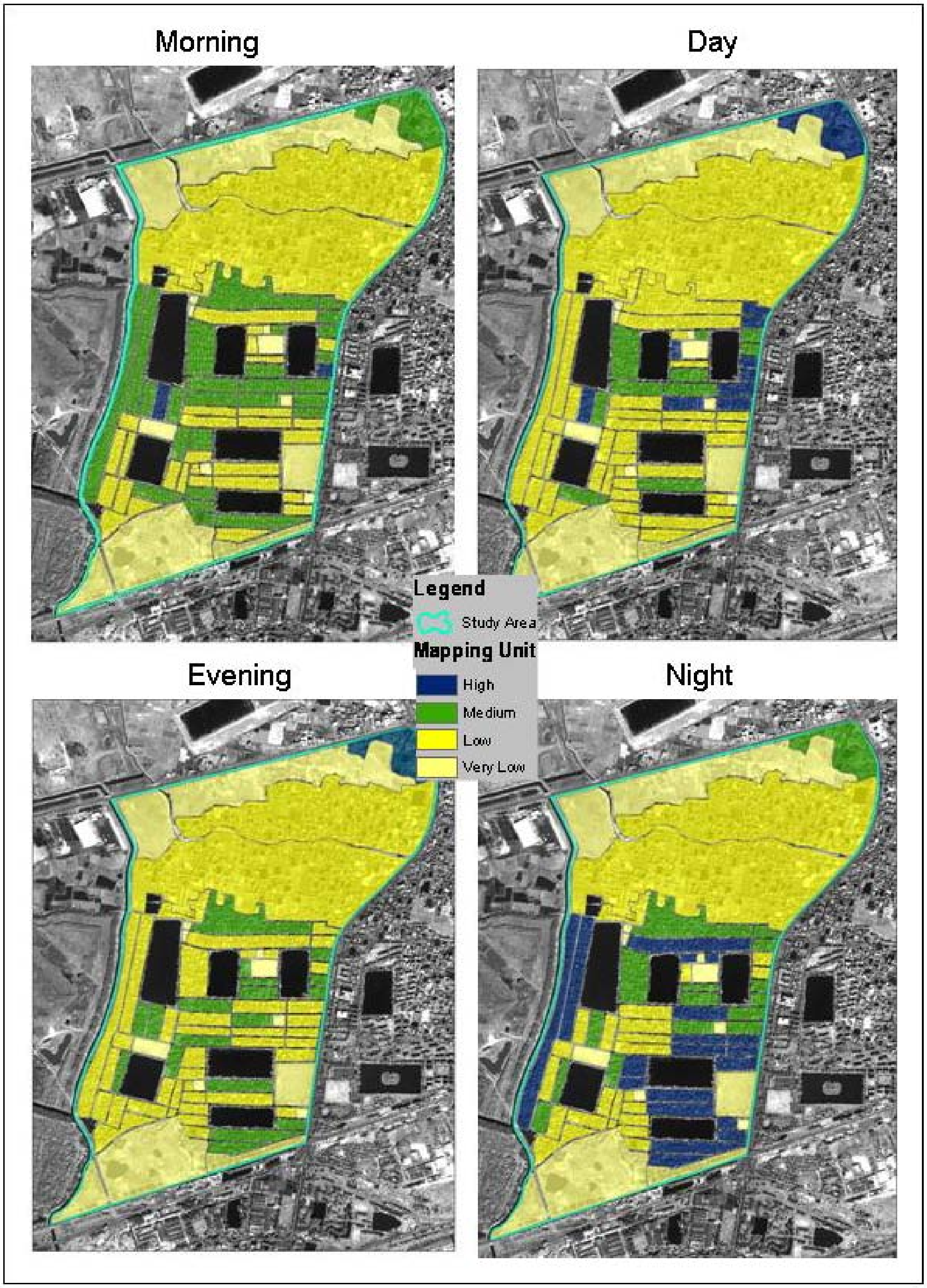


Figure: 6-13. Temporal Variation of Population Vulnerability per Mapping Unit

6.3.5. Temporal Variation of Population Vulnerability on Roads

The road network of an area plays an important role for providing goods and services to the people of the area. The functionality of roads is directly concerned with the community since the disruptions affects the entire population. Moreover the road network of an area provides a framework for mitigation purpose. Thus the vulnerability assessment of roads is a major concern for an area.

In this research, vulnerability assessment was done for roads with respect to the number of people on the road during a particular time. The concentration of population on road depends on the activity and lifestyle of people. Population vulnerability on roads changes during the different time periods of a day. During the communicating time roads are much more vulnerable because the working people as well as the school going children are assumed to be on the roads. Following figure *(Fig: 6.15.)* shows the temporal variation of population on the roads within the study area.

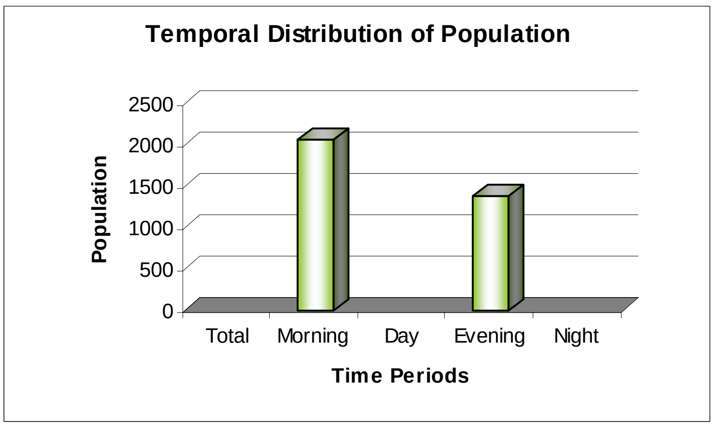


Figure: 6-15. Temporal distribution of Population on Roads

An analysis was done for the vulnerability of population on roads during the communicating time for two times of a day, i.e. morning 10.00 AM and evening 6.00 PM. From the analysis it is clearly shown that about 20% of the total population is expected to be move on the road during the morning time while the percentage increase in the evening time due to the floating population. Thus the roads adjoin to the school complex are more vulnerable just before and after the school hours (i.e. 10.00 AM to 5.00 PM). *Figure 6.16* shows an example of road vulnerability in terms of people with respect to location of a school within the study area.

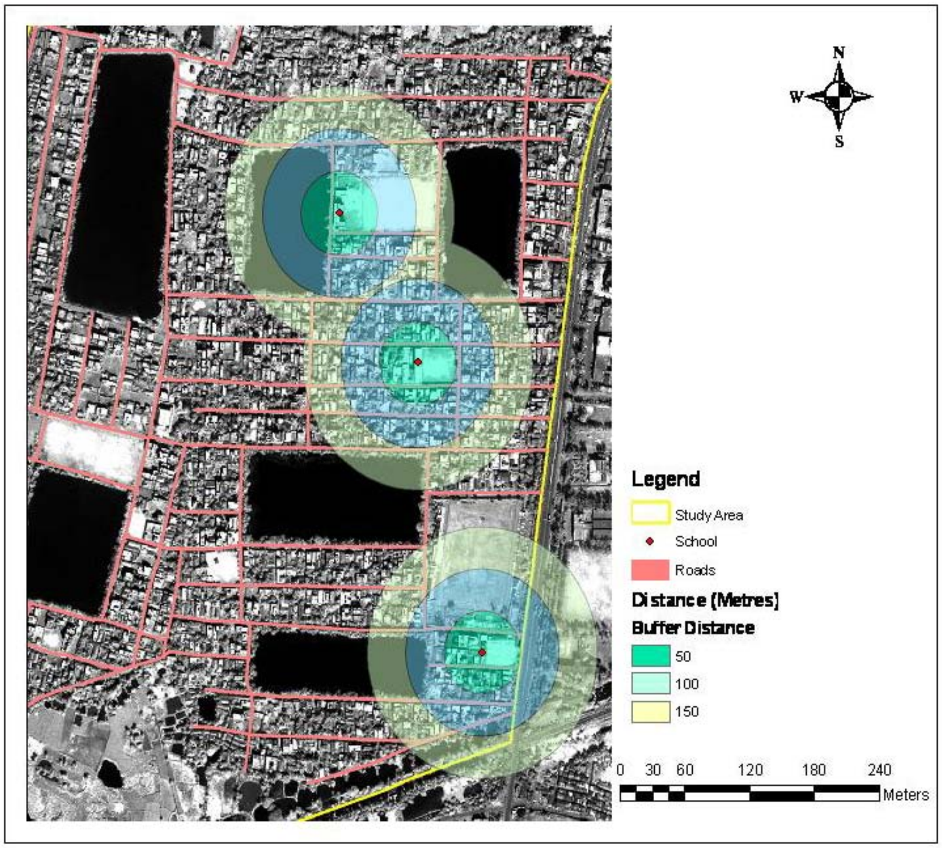


***Fig: 6.16. Approach for Road Vulnerability Assessment from Schoo*l**

From the above figure it can be interpreted that the roads within a buffer distance of 50 metres of a high school are more vulnerable because of higher concentration of school going children. The quantitative analysis of road vulnerability based on several parameters was not taken into account in this research work. One of the most important parameters is the width of individual roads. In order to classify the roads in terms of degree of vulnerability it is also important to consider the exact number of people in certain period. Given the time limitations this was not done in this study.

6.4. Summary

This chapter describes the assessment of building vulnerability for fire, explosion (VCE and BLEVE) and toxic release scenarios. Temporal changes in population distribution inside the buildings and on roads also mentioned in this chapter. Population vulnerability estimation for different times inside the buildings as well on the roads also described as a major section of this chapter. The outcome of all analysis will be integrated with the outcome of previous chapter *(Ref: Chapter* 5) in the following chapter *(Ref: Chapter 7).*

7. Risk Assessment

7.1. Introduction

Risk can be defined as the expected damage or loss because of potentially damaging phenomena within a given period and within a given area (Westen, 2004). Conventionally risk can be expressed as follows:

Risk = Hazard * Vulnerability.

Risk Assessment in its broad definition is a structured procedure that evaluates qualitatively and/or quantitatively the level of risk imposed by the hazard sources. The process of risk assessment involves hazard identification, probability and/or consequences analysis and risk evaluation. For industrial hazard like fire, explosion or toxic release, the main purpose of risk assessment is to help the decision makers how to eliminate or reduce the level of risk posed by the hazardous installations. A risk assessment must be carried out for every installation irrespective of nature and amount of chemical stored and thus enable the industry and the local authorities to decide about the safety measures.

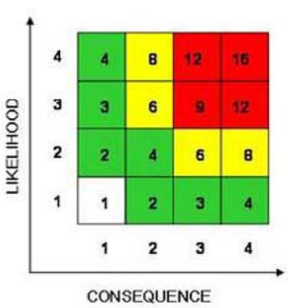
In this research risk assessment was done for buildings and population for fire, explosion and toxic release hazard separately. Hazard and vulnerability assessment was done separately in the previous chapters *(Ref: Chapter 5 and 6).* Risk for the detailed study area was calculated by combining the results of hazard and vulnerability assessment for the detailed study area. For this purpose a risk matrix was prepared, from which each possible combination of hazard and vulnerability was identified in terms of different levels of risk.

7.2. Risk Estimation

Risk can be considered as a multiplicative factor of severity of hazard and vulnerability of the elements. Thus, risk can be expressed as follows:

Risk = [Probability / Likelihood of Accidents] * [Vulnerability of Elements at Risk].

For the purpose of risk estimation, a risk matrix *(Fig: 7.1)* was prepared to categorise the different possible combination of degree of vulnerability with the severity of a particular hazard. In the matrix, values are assigned to different categories of vulnerability and hazard to get the combined results (risk) in value and then categorised into different classes.



Ranking	Significance
9 - 16	High
5 - 8	Medium
2 - 4	Low
< 1	Negligible

Figure: 7-1. Risk Matrix

7.3. Risk Estimation for Pool Fire Hazard

Pool fire is one of the consequences of industrial fire. The impact of pool fire on buildings as well as on population is not due to fire but also the thermal radiation being the main damaging factor associated with pool fire. A Pool fire hazard map was prepared by overlapping the hazard footprints of all possible events based on the empirical equations. Vulnerability for buildings and population was also calculated for pool fire hazard separately. For building vulnerability parameters (wall materials, roof materials) were taken into consideration. Each parameter was assigned with rank and weightages based on their importance for that particular hazard.

7.3.1. Risk Estimation of Buildings

A risk map for buildings within the detailed study area was prepared by combining the result of building vulnerability and Pool Fire hazard map. At first vulnerability for individual buildings *(Fig: 6.3)* was calculated based on the parameters like: construction type, roof material, air-tight condition and number of stories etc. and later on the result of individual buildings were generalised in mapping units *(Fig: 6.4.B)*. From the hazard point of view the entire area is in low category *(Fig: 5.7)*. The hazard and vulnerability maps were represented in different categories, namely: high, medium, low and very low. By multiplying the value of hazard of a mapping unit with the vulnerability value of respective mapping unit a pool fire risk map for buildings was prepared *(Fig: 7.3)*.

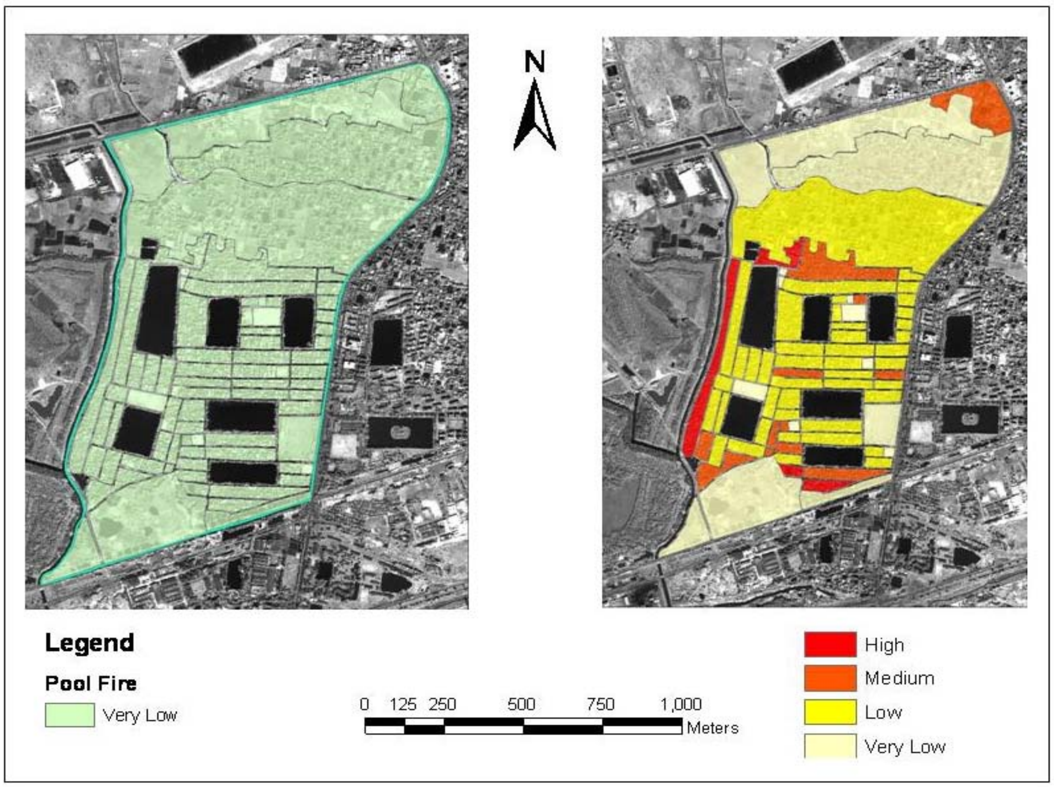


Figure: 7-2. (A) Pool Fire Hazard Map and (B) Pool Fire Vulnerability Map

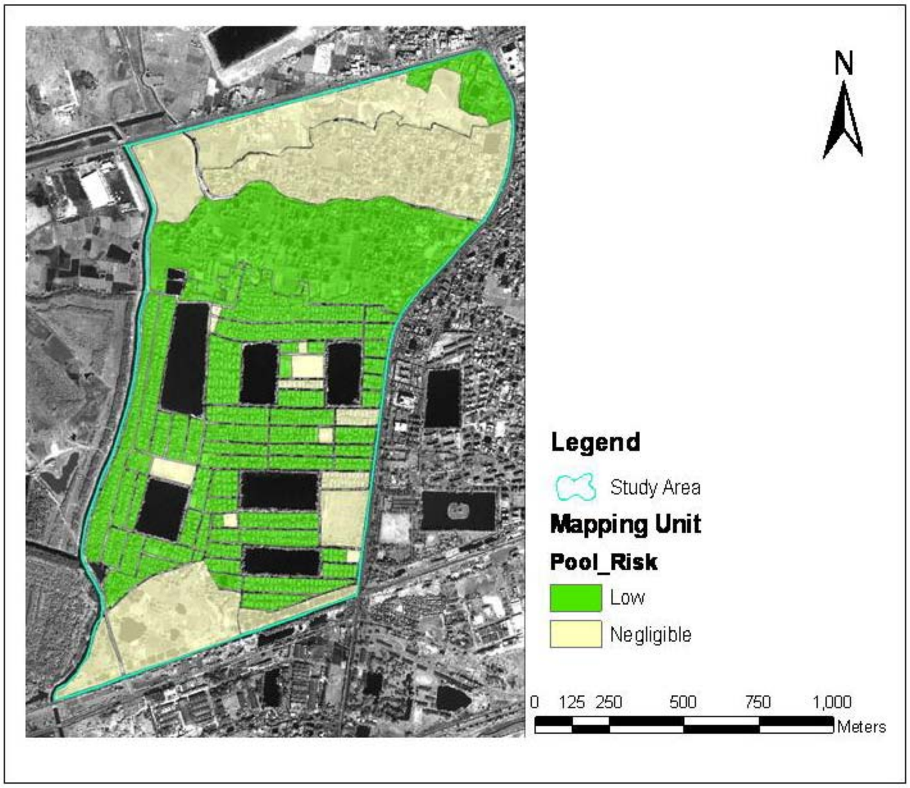


Figure: 7-3. Risk Map of Buildings for Pool Fire

Mapping units were categorised into different level of risk (low and negligible) based on the range of combined result of hazard and vulnerability respectively. Number of buildings in different risk categories along with their vulnerability category is given in the following table *(Table: 7.2.).*

Table: 7-1. Buildings in Different Risk Categories for Pool Fire

Risk Category	Number of Buildings	Vulnerability Category		
		High	Medium	Low
Low	1182	86	456	640
Negligible	120	7	21	92

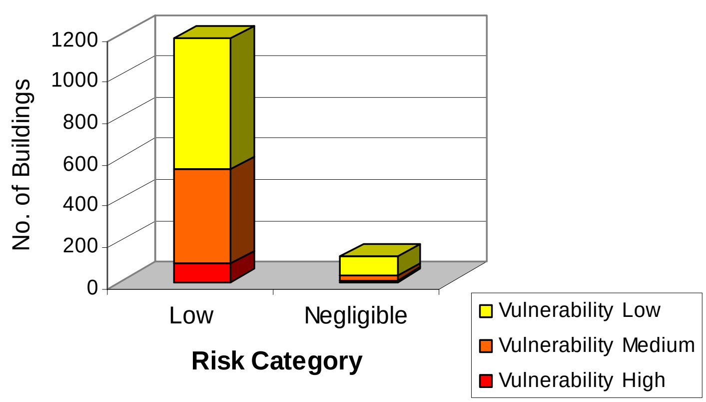


Figure: 7-4. No. of Buildings in Different Risk Categories

7.3.2. Risk Estimation of Population inside Buildings

Risk of population due to industrial hazard depends mainly on the type of hazard and on the building vulnerability. Besides, different time period of a day is an important parameter for population risk estimation. For pool fire hazard, vulnerability for each individual building was calculated based on the structural parameters and then generalized in mapping units. Based on the number of people inside the buildings at a certain time, the mapping units were classified in terms of low, medium and high categories *(Fig: 6.14)*. Combining the results of temporal distribution of population inside the building with hazard type, risk was estimated for population at different time of a day *(Fig: 7.5).*

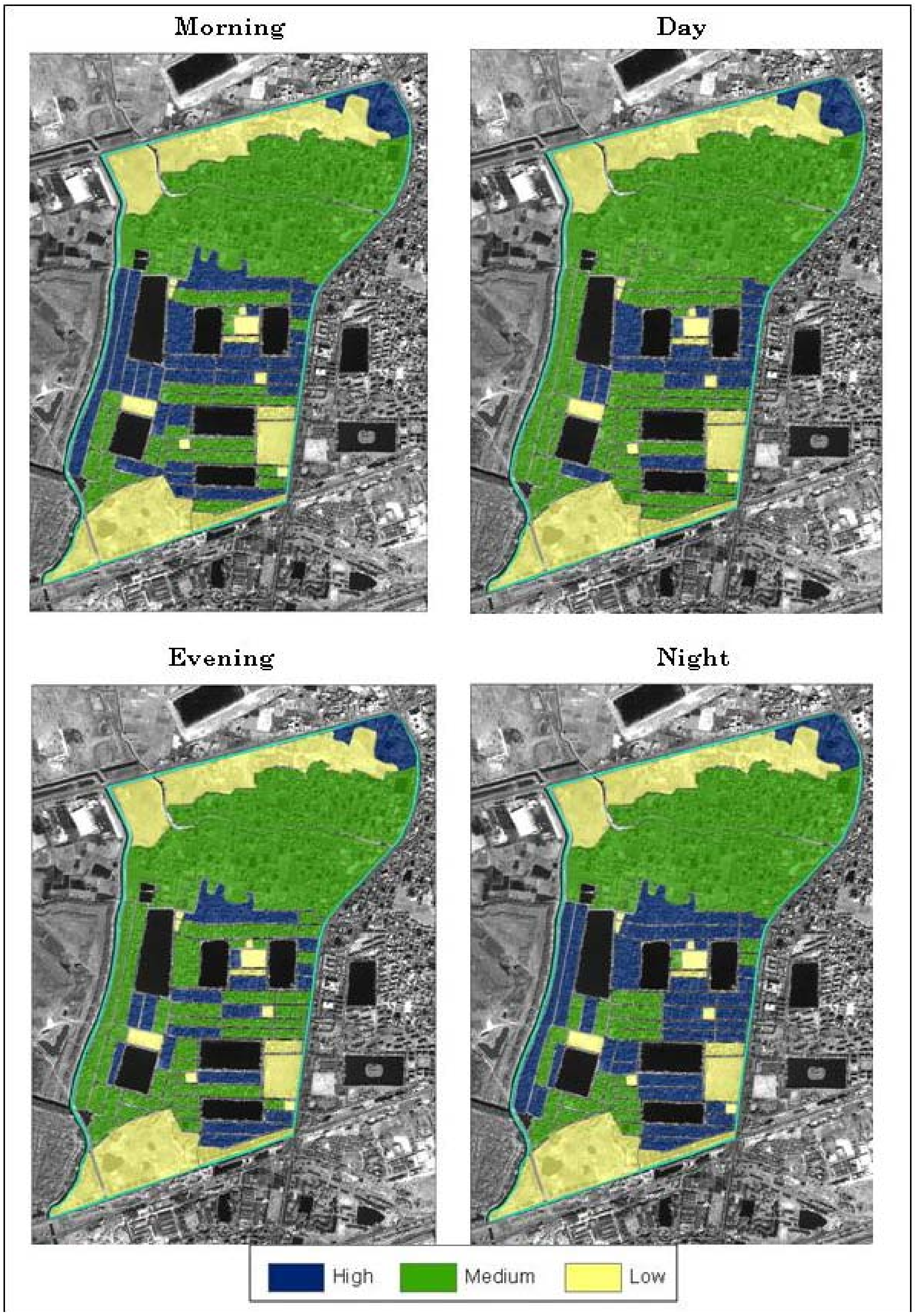


Figure: 7-5. Mapping Units in Different Population Risk Category for Pool Fire

The risk map for population was prepared considering the number of population inside the building at a particular time of a day with respect to hazard type. Number of people at risk at particular time was estimated by multiplying the average household size and the number of buildings at a particular category. Following table *(Table: 7.2)* showing the number of buildings in different risk categories based on the concentration of people inside the buildings. The population vulnerability at a certain time irrespective of other factors also changes with the change in building vulnerability. In case of pool fire the thatched roof buildings are more vulnerable and thus the level of risk for the people inside these buildings also increases. The total number of people in risk at a certain time can also be further categorised based on the building vulnerability. The total number of people in risk at a certain time can also be further categorised based on the building vulnerability.

Table: 7-2. Number of Population at Risk in Different time for Pool Fire

Scenario	Population Risk Category	Total Building	Building Vulnerability			Average Household Size	Total Population at Risk
			High	Medium	Low		
Morning	Moderate	730	58	248	424	5	6480
	Low	529	31	215	283		
	Negligible	37	2	13	22		
Day	Moderate	387	0	113	274	3	3888
	Low	872	89	350	433		
	Negligible	37	2	13	22		
Evening	Moderate	408	22	160	226	4	5184
	Low	851	480	67	304		
	Negligible	37	2	13	22		
Night	Moderate	492	874	69	313	6	7776
	Low	212	371	14	145		
	Negligible	37	2	13	22		

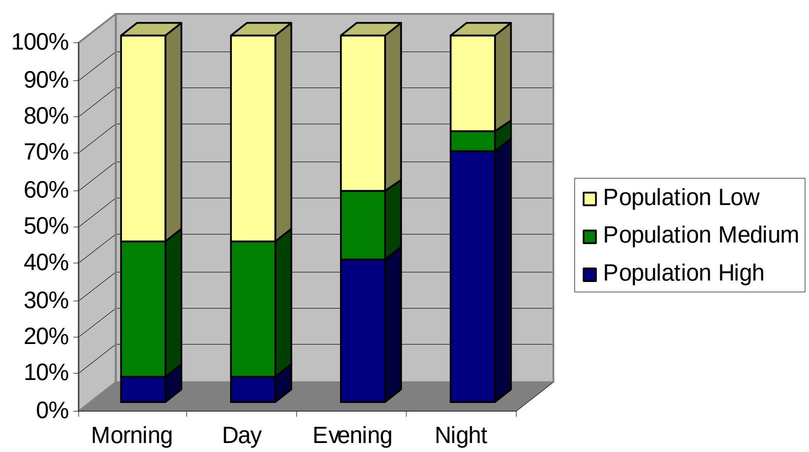


Figure: 7-6. Percentage of Population at different Risk Levels w.r.t. Building Vulnerability

Table: 7-3. Population at Different Risk Levels

Time	People at Risk			
	High	Medium	Low	Total
Morning	455	2380	3645	6480
Day	273	1428	2187	3888
Evening	2016	960	2208	5184
Night	7482	576	2880	7776

7.4. Risk Estimation for VCE Hazard

VCE is one of the consequences of explosion. The impact of VCE on buildings and on population mainly depends on the degree of overpressure. In this present research work, the effect distances for the storage failure were calculated based on the EPA on the assumption of 1 psi overpressure. The impact of VCE mainly depends on the atmospheric pressure as well as temperature. The amount of overpressure also changes with respect to chemical properties of chemical used. A VCE hazard map was prepared with the help of hazard footprint from storages of all possible scenarios. Vulnerability of buildings and population due to VCE hazard was also calculated separately. Both hazard and vulnerability were expressed in terms of High, Medium and Low.

7.4.1. Risk Estimation for Buildings

Risk map for buildings for VCE was prepared on the basis of building vulnerability for VCE and hazard map. Building vulnerability per mapping unit was done on the basis of result of individual building vulnerability and classified into three groups *(Fig: 6.6.B).* From the hazard map *(Fig: 5.14.B)* it can be seen that the detailed study area can be categorised into high, medium and low based on the number of scenarios from where there might be a chance to get affected. Integrating the maps of building vulnerability with respective hazard map, risk map for buildings due to VCE was prepared *(Fig: 7.8).*

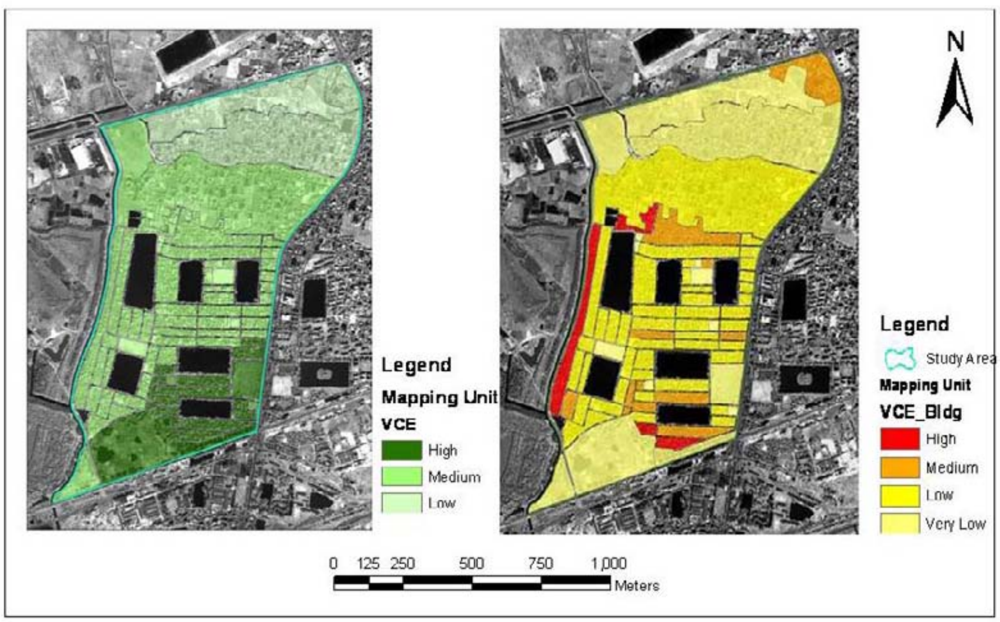


Figure: 7-7. (A) VCE Hazard Map and (B) VCE Vulnerability Map

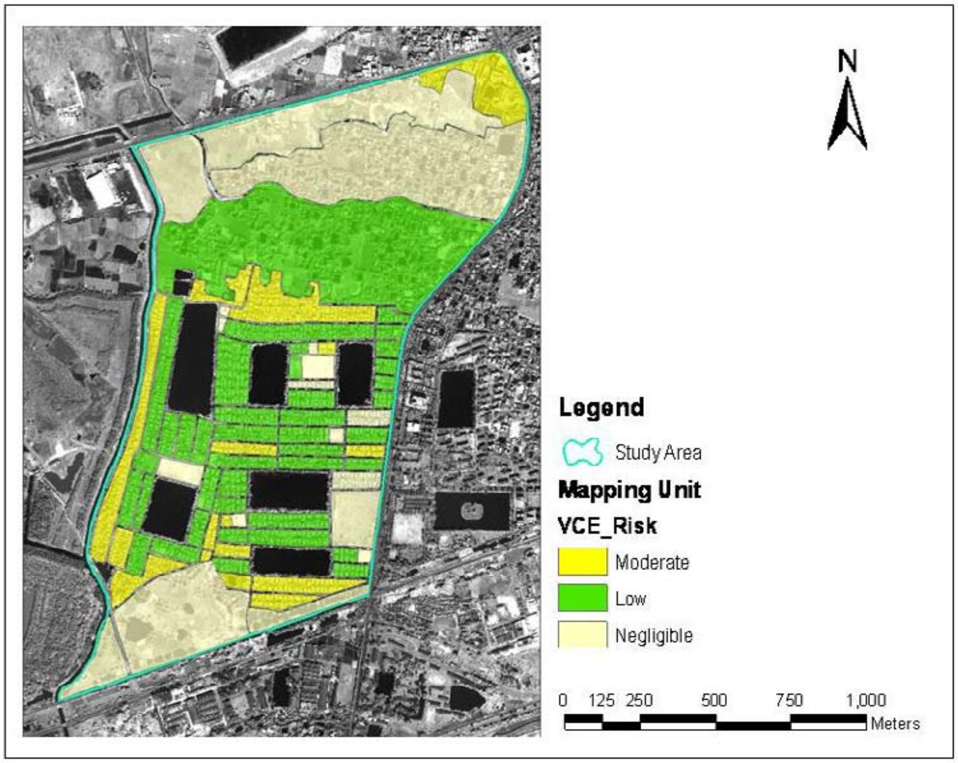


Figure: 7-8. Risk Map of Buildings for VCE

Following table *(Table: 7.5)* mention the number of buildings having different degree of vulnerability in the low category of VCE hazard risk.

Table: 7-4. Buildings in different Risk Levels

Risk Category	Number of Buildings	Vulnerability Category		
		High	Medium	Low
Moderate	381	83	178	120
Low	772	12	248	512
Negligible	66	2	42	22

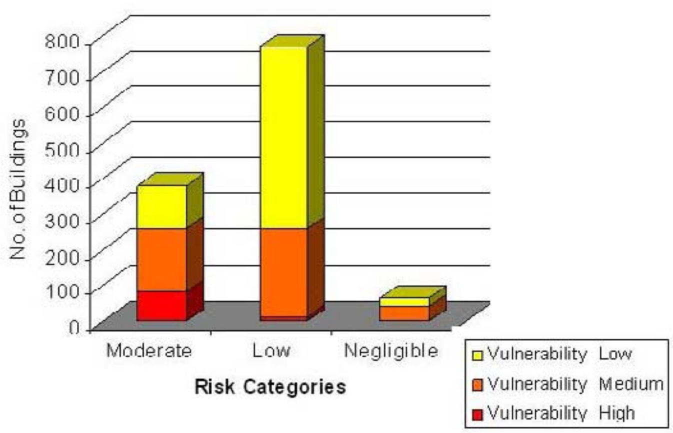


Figure: 7-9. Buildings in Different Risk Categories for VCE

7.4.2. Risk Estimation of population inside Buildings

For VCE hazard, vulnerability for each individual building was calculated based on the structural parameters and then generalized in mapping units. Based on the number of people inside the buildings at a certain time, the mapping units were classified in terms of low, medium and high categories *(Fig: 6.14)*. Risk map for population for different time period was prepared by combining the results of temporal population distribution and hazard maps. *(Fig: 7.10)*.

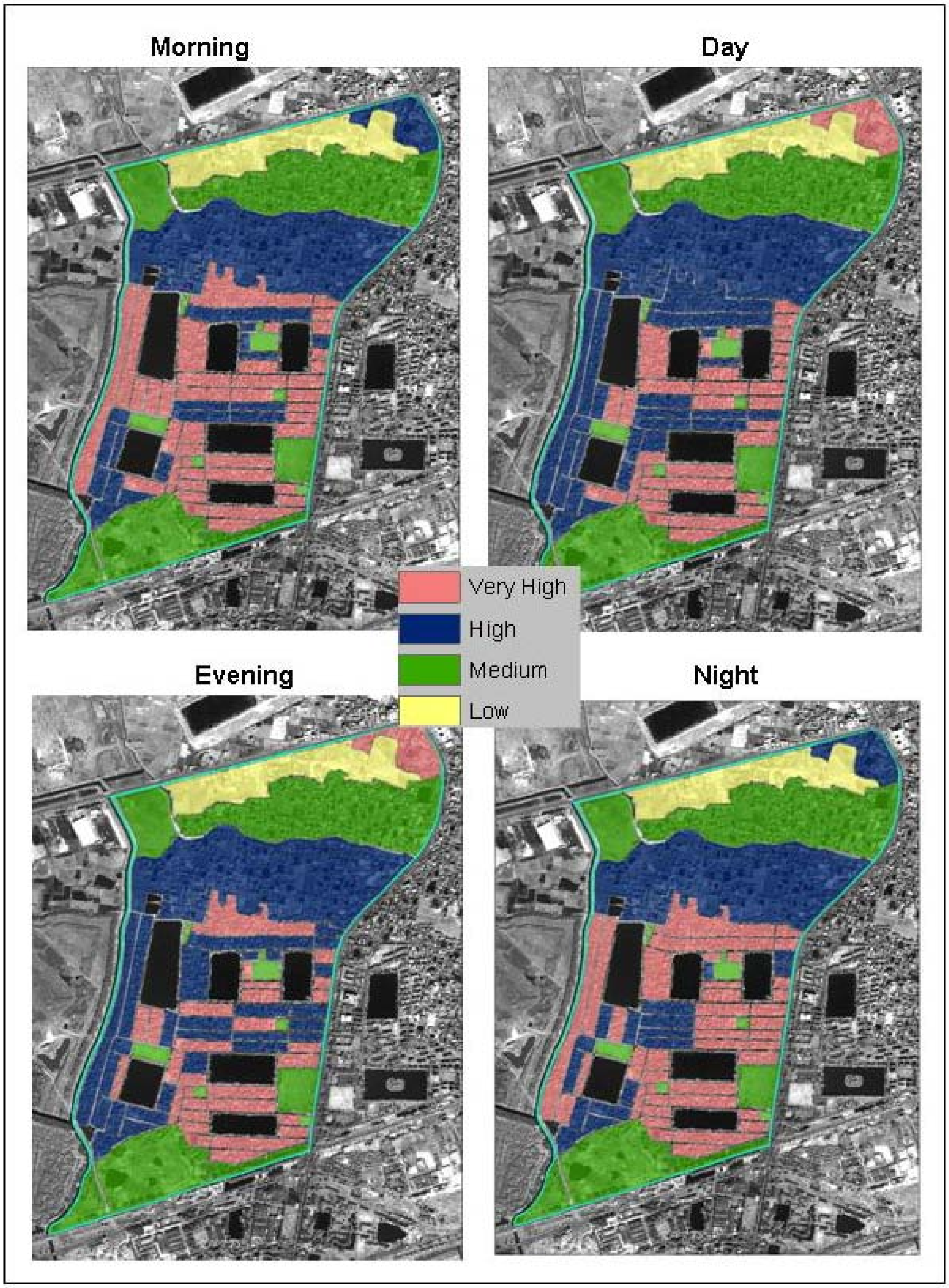


Figure: 7-10. Mapping Units in Different Population Risk Category for VCE

Following table *(Table: 7.5)* showing the number of buildings in different risk categories based on the concentration of people inside the buildings. The number of population in different risk category was estimated by multiplying the average household size at a particular time with the number of buildings. The population vulnerability at a certain time irrespective of other factors also changes with the change in building vulnerability. The table also explains the relation of building vulnerability as well population vulnerability.

Table: 7-5. Number of Population at Risk in Different time for VCE

Scenario	Population Risk Category	Total Building	Building Vulnerability			Average Household Size	Total Population
			High	Medium	Low		
Morning	Very High	875	74	298	503	5	6335
	High	386	18	162	206		
	Medium	6	2	3	1		
Day	Very High	601	23	379	199	3	3882
	High	687	71	273	343		
	Medium	6	2	3	1		
Evening	Very High	561	27	215	319	4	5264
	High	749	67	263	419		
	Medium	6	2	3	1		
Night	Very High	961	76	347	538	6	7776
	High	329	18	126	185		
	Medium	6	2	3	1		

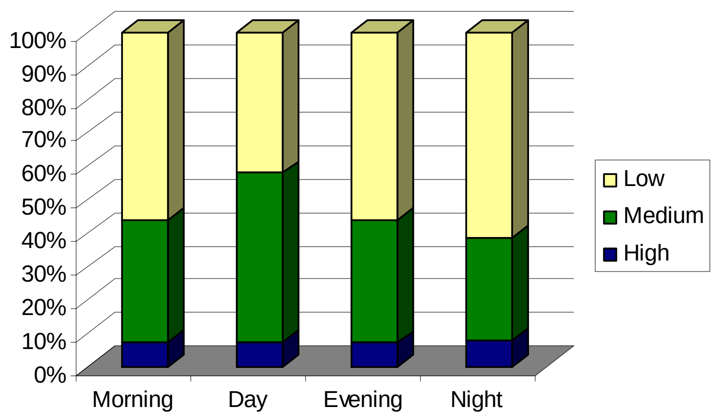


Figure: 7-11. Percentage of Population at Different Risk Level for VCE

Table: 7-6. Number of Population at Different Risk Levels

Time	People at Risk			
	High	Medium	Low	Total
Morning	470	2315	3550	6335
Day	288	1959	1629	3876
Evening	384	1924	2956	5264
Night	576	2154	4344	7074

7.5. Risk Estimation for BLEVE Hazard

BLEVE is another consequence of explosion. The impact of BLEVE on buildings and on population mainly depends on the degree of overpressure. In this present research work, the effect distances for the storage failure were calculated based on the empirical equations on the assumption of 1 psi overpressure. A BLEVE hazard map was prepared with the help of hazard footprint from storages of all possible scenarios. Vulnerability of buildings and population due to BLEVE hazard was also calculated separately.

7.5.1. Risk Estimation for Buildings

Like other hazards, risk map for buildings for BLEVE was prepared on the basis of building vulnerability for BLEVE and hazard map. Individual building vulnerability *(Fig: 6.7)* was calculated based on certain parameters. For BLEVE hazard, number of stories of a building is another important parameter taken into consideration for vulnerability assessment. Building vulnerability per mapping unit was done on the basis of result of individual building vulnerability and classified into three groups *(Fig: 6.8.B)*. The hazard map *(Fig: 5.19.B*) of the detailed study area explains the different hazard zones within the area. Integrating the maps of building vulnerability with respective hazard map, risk map for buildings due to BLEVE was prepared *(Fig: 7.13).*

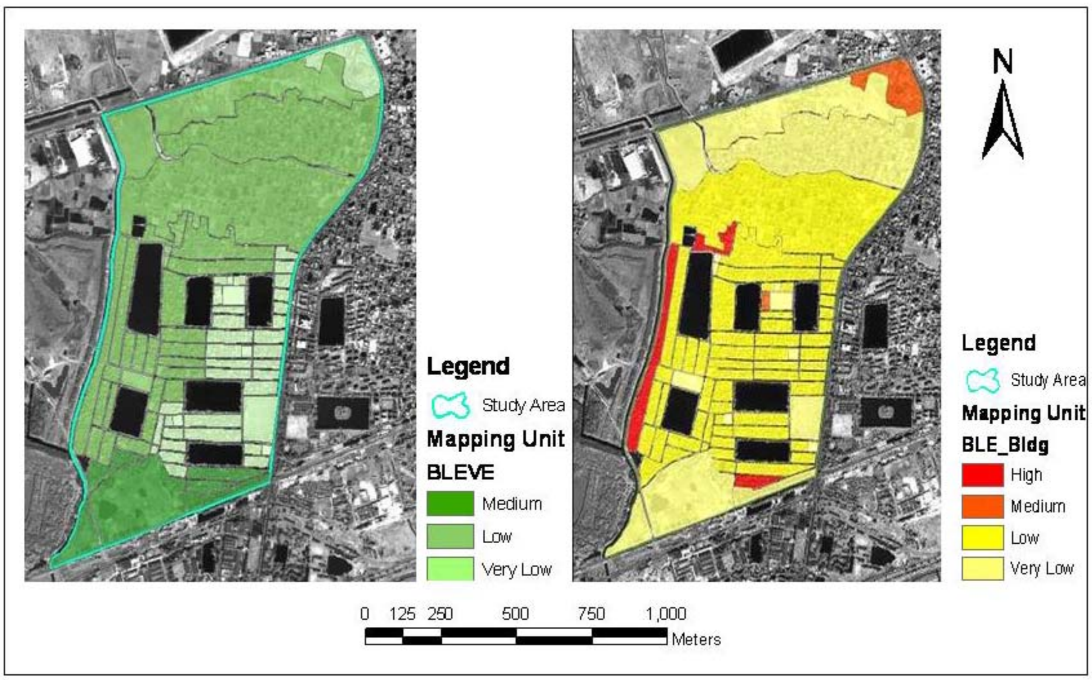


Figure: 7-12. (A) & (B) BLEVE Hazard Map and Vulnerability Map

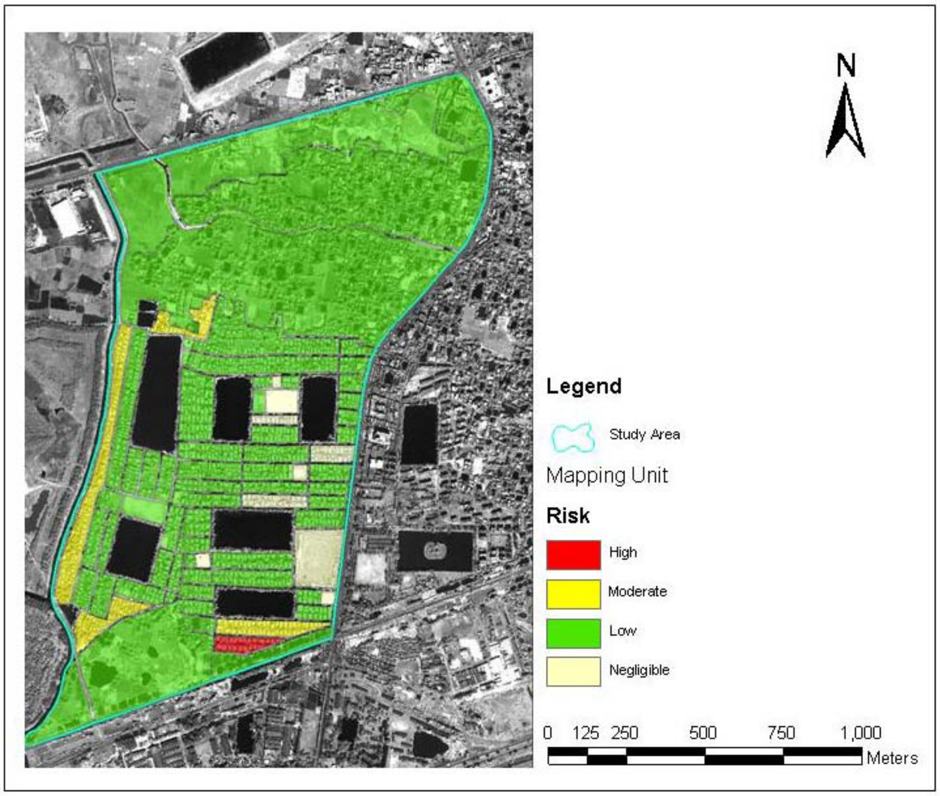


Figure: 7-13. Risk Map of Buildings for BLEVE

Table: 7-7. Number of buildings in Different Risk Category

Risk Category	Number of Buildings	Vulnerability Category		
		High	Medium	Low
High	22	14	8	0
Moderate	148	59	12	77
Low	1066	20	71	975
Negligible	61	0	3	58

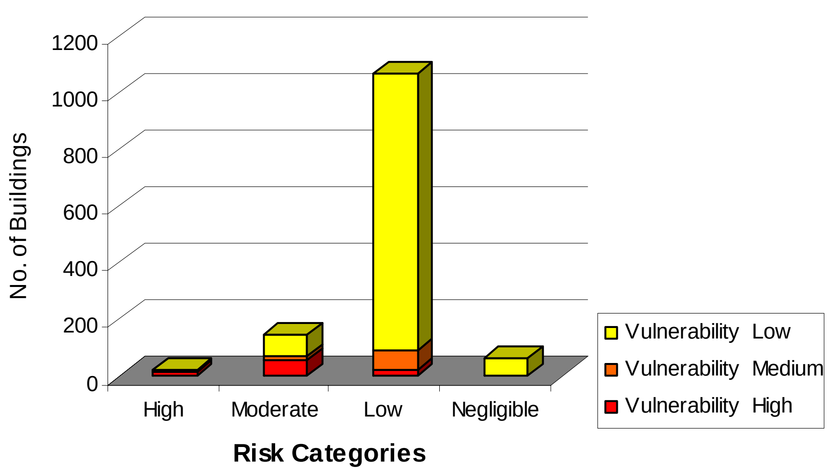


Figure: 7-14. Buildings in Different Risk Categories for BLEVE

7.5.2. Risk Estimation for Population inside Buildings

Like other hazards, a risk map for population was prepared based on the results of temporal distribution of population inside the building *(Fig: 6.14)* along with hazard type at different time of a day *(Fig: 7.15)*.

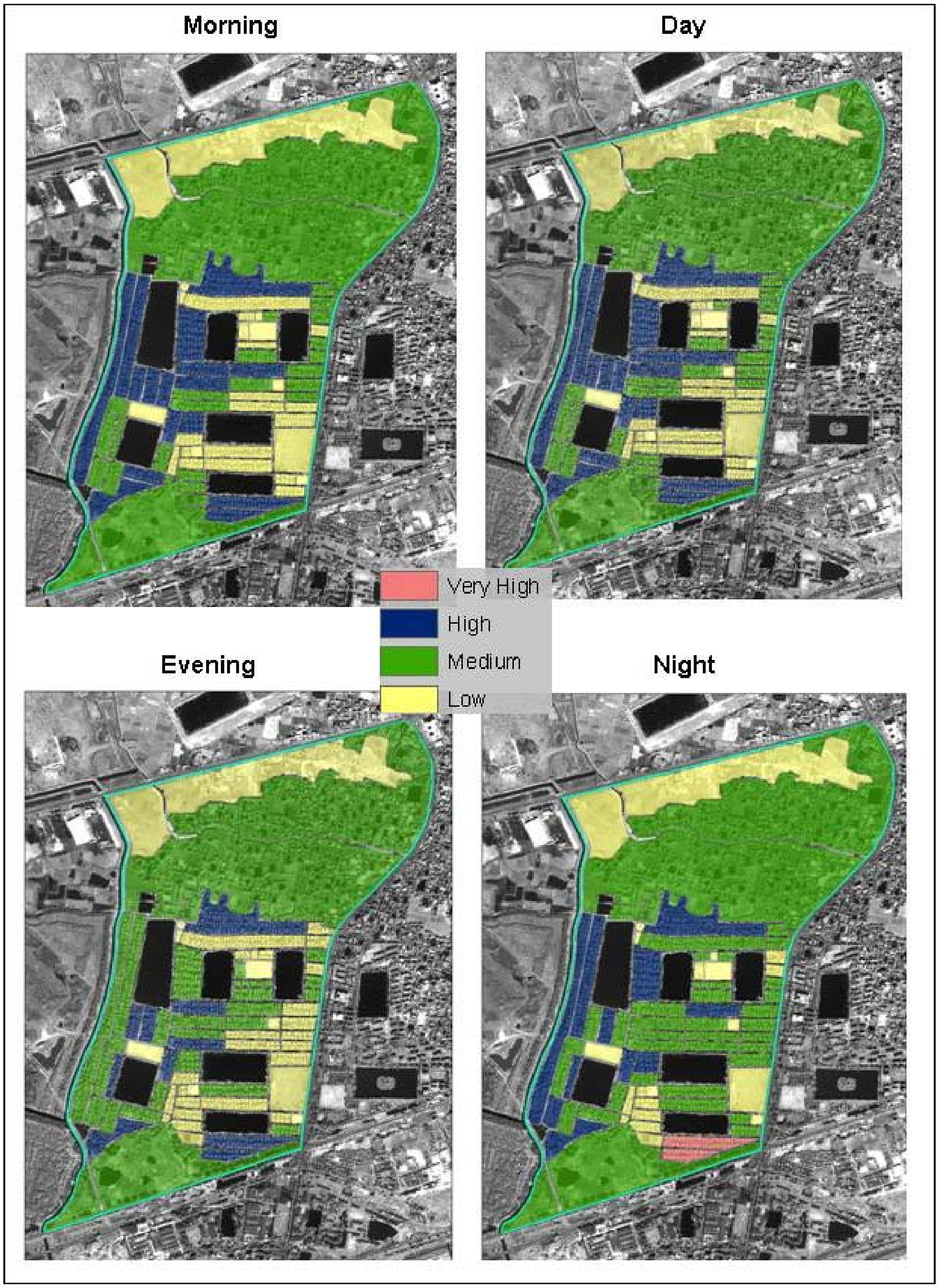


Figure: 7-15. Mapping Units in Different Population Risk Category for BLEVE

Table: 7-8. Number of Population at Risk in Different time for BLEVE

Scenario	Risk Category	Total Building	Building Vulnerability			Average Household Size	Population
			High	Medium	Low		
Morning	High	585	71	48	466	5	6410
	Medium	376	15	28	333		
	Low	321	0	18	313		
Day	High	874	91	71	712	3	3855
	Medium	411	2	21	388		
	Low	0	0	0	0		
Evening	High	319	24	31	264	4	5184
	Medium	590	68	43	479		
	Low	387	1	20	366		
Night	Very High	66	20	10	36	6	8178
	High	432	50	33	349		
	Medium	785	42	59	684		
	Low	80	1	3	76		

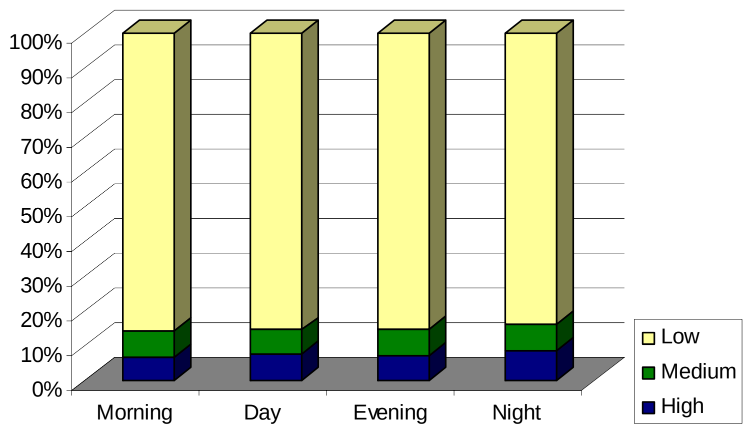


Figure: 7-16. Percentage of Population at Different Risk Level for BLEVE

Table: 7-9. Number of Population at Different Risk Level

Time	People at Risk			
	High	Medium	Low	Total
Morning	430	470	5510	6410
Day	279	276	3300	3855
Evening	372	376	4436	5184
Night	678	630	6870	8178

7.6. Risk Estimation for Toxic Release Hazard

Toxic release is another important industrial hazard with larger impact on population rather than any other hazards. Due to toxic release as such there is less possibility for building damage but the vulnerability or risk of people to might get affected from the release of toxic gases depends on the building condition. In this present research work, based on the equation for instantaneous sources, the toxic release scenario was prepared and vulnerability of building as well population both was calculated based on the scenarios.

7.6.1. Risk Estimation for Buildings

Toxic release hazard risk map for buildings was prepared on the basis of building vulnerability and toxic release hazard map. Individual building vulnerability *(Fig: 6.9)* was calculated based on certain parameters. In addition to other parameters, the air tight condition of the buildings was also taken into consideration with maximum weightage for building vulnerability assessment. If the building is not air tight then due to release of toxic gases the people inside the building might be affected more. Building vulnerability for toxic release per mapping unit was done on the basis of result of individual building vulnerability and classified into three groups *(Fig: 6.10.B)*. The hazard map *(Fig: 5.22.B)* of the detailed study area explains the different hazard zones within the area. Integrating the maps of building vulnerability with respective hazard map, risk map for buildings due to toxic release was prepared *(Fig: 7.18)*.

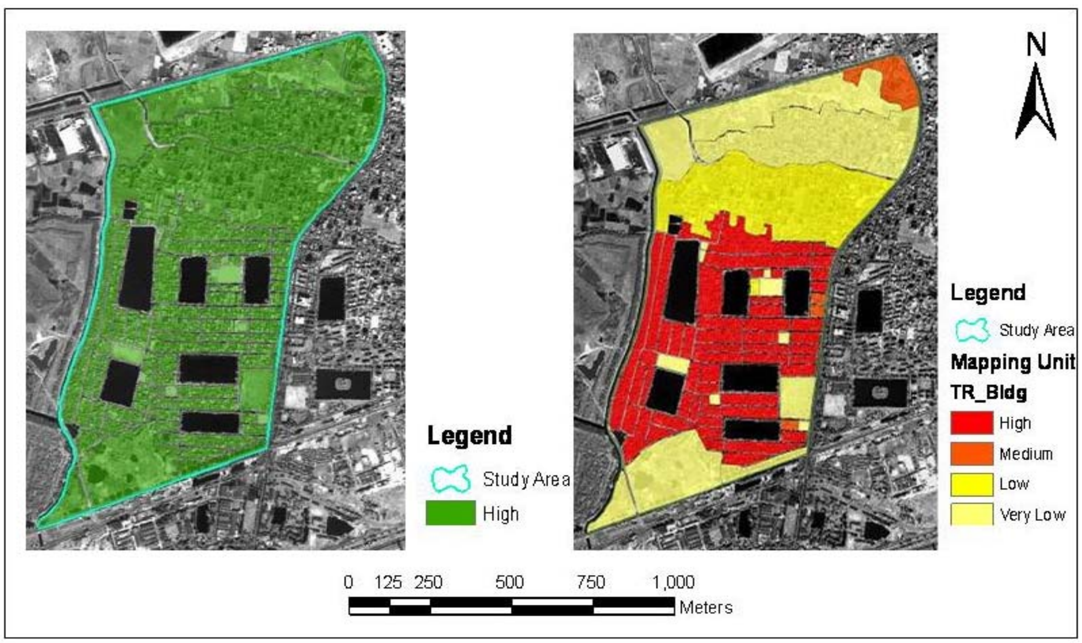


Figure: 7-17. (A) Toxic Release Hazard Map & (B) Vulnerability Map

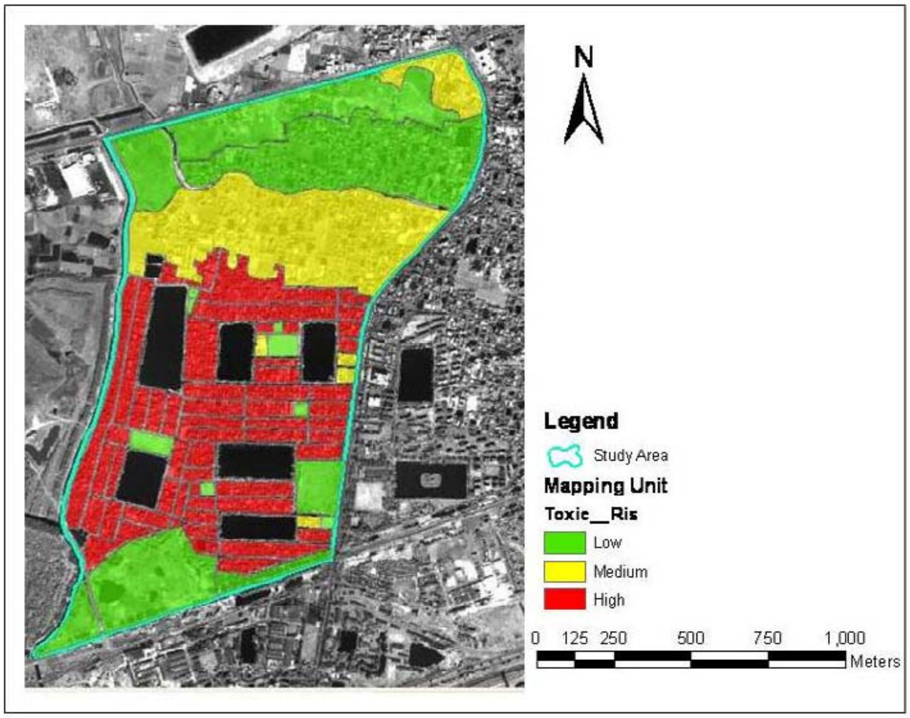


Figure: 7-18. Risk Map of Buildings for Toxic Release

Table: 7-10. Buildings in different Vulnerability Category

Risk Category	Number of Buildings	Vulnerability Category		
		High	Medium	Low
High	1248	851	171	226
Moderate	35	23	11	1
Low	11	9	2	0

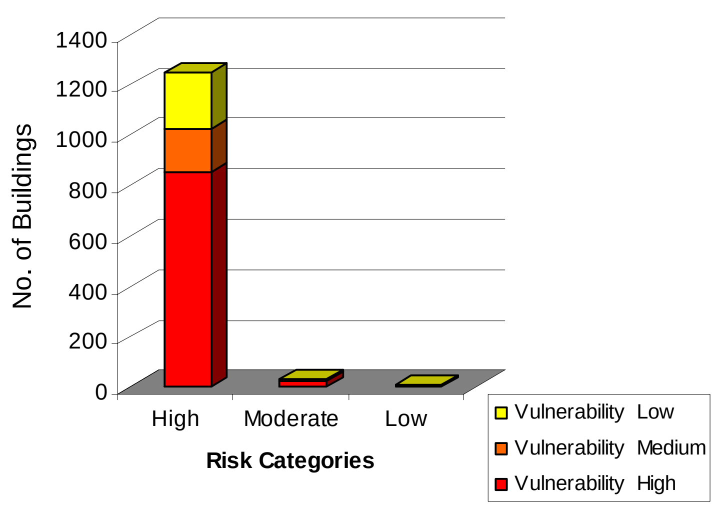


Figure: 7-19. Buildings in Different Risk Categories for Toxic Release

7.6.2. Risk Estimation for Population inside Buildings

Population vulnerability for toxic release hazard is a major concern. The vulnerability of the people inside the building also depends on the building air-tight condition. If the building is air tight, then there is less chance for getting affected but on the other hand if the building is not at all air-tight then people have more chance to get affect.

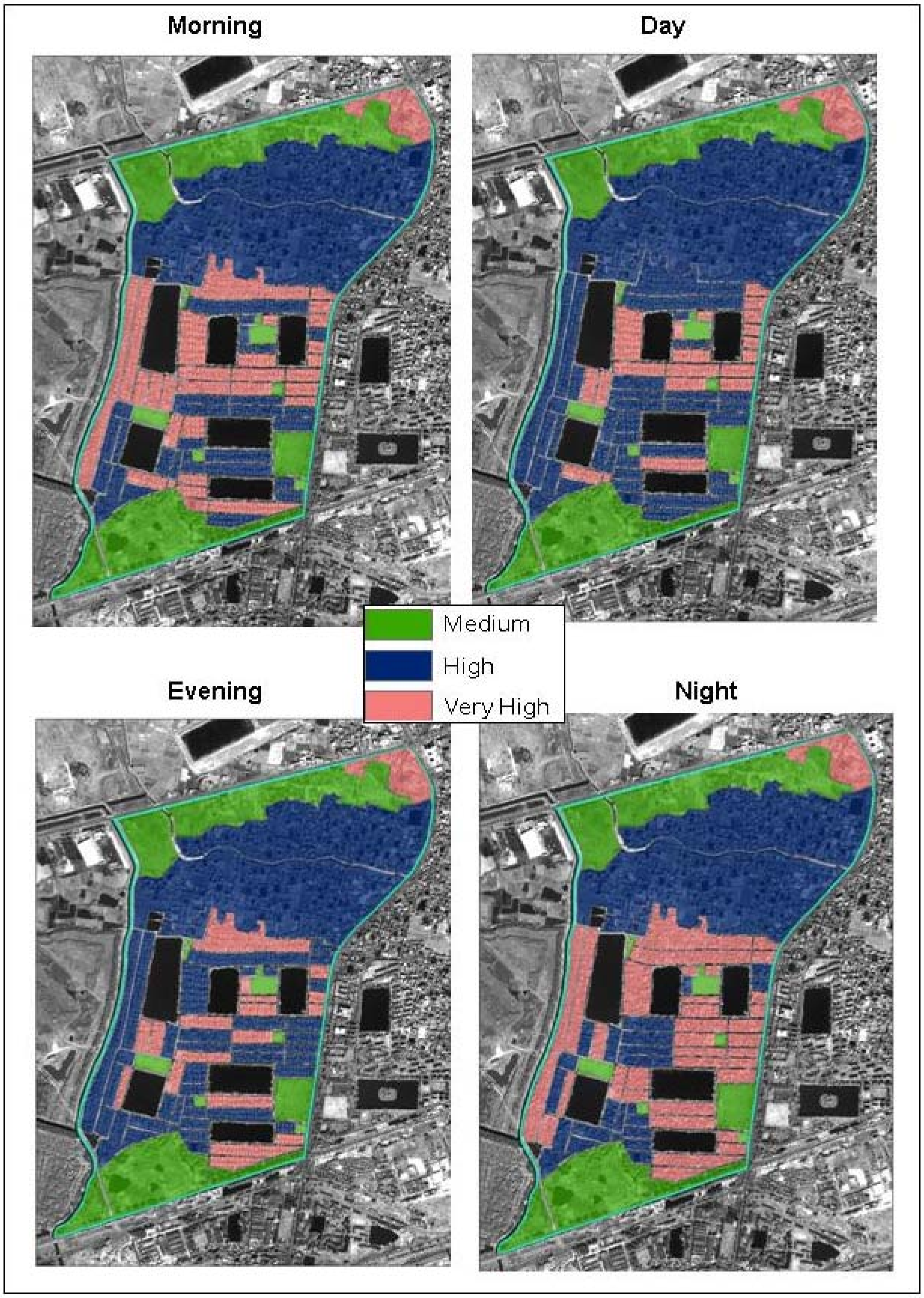


Figure: 7-20. Mapping Units in Different Population Risk Category for Toxic release

Table: 7-11. Number of Population at Risk in Different time for Toxic release

Scenario	Risk Category	Total Building	Building Vulnerability			Average Household Size	Population
			High	Medium	Low		
Morning	Very High	730	487	117	126	5	6820
	High	544	372	72	100		
Day	Very High	388	225	79	84	3	3869
	High	903	648	112	143		
Evening	Very High	453	304	62	87	4	5216
	High	817	554	119	114		
Night	Very High	905	615	126	165	6	6366
	High	385	258	65	62		

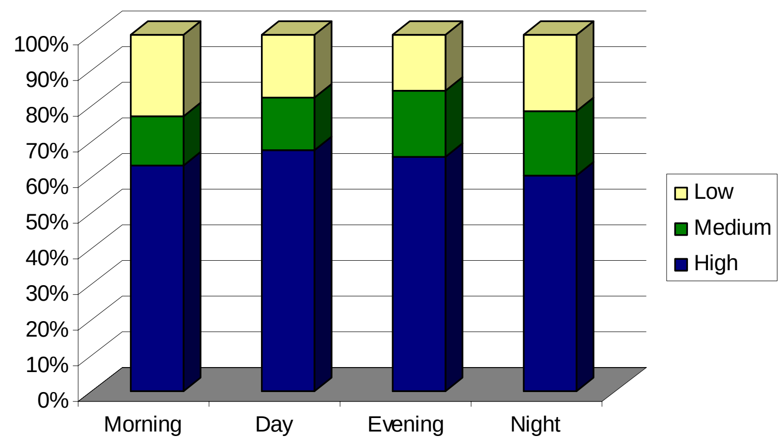


Figure: 7-21. Percentage of Population at different Risk Level w.r.t. Building Vulnerability

Table: 7-12. Number of Population at Different Risk Level

Time	People at Risk			
	High	Medium	Low	Total
Morning	4295	945	1550	6820
Day	2615	573	681	3869
Evening	3432	980	804	5216
Night	3858	1146	1362	6366

7.7. Summary

This chapter describes the risk estimation of buildings and population for pool fire, VCE, BLEVE and toxic release event. The number of buildings and people were also calculated foe each risk category. This output of this chapter is the combination of previous chapters. The risk estimation procedure for the detailed study area can be also used for the town to identify the risk zones at town level *(Ref: Chapter 8).*

8. Risk Assessment of Haldia

8.1. Introduction

Haldia is one of the most rapidly growing industrial towns of West Bengal. The most important factor for the evolution of Haldia Industrial Region is the development of port facility at Haldia. The excellent location advantage of Haldia and excellent port facilities, paved the way for establishment of industries mainly petrochemicals and chemicals. Today seventeen MAH industries *(See Appendix)* handling with hazardous chemicals are there within the town. Most of the industries are situated in the along the river Hooghly as well as in the middle part of Haldia Municipal Area near vicinity of the residential areas. In the accidents like Bhopal, it was clearly demonstrated that the consequences of any industrial accidents can be severely affected by the juxtaposition of dangerous sites with the high population density. The situation for Haldia is also same.

In this present research, hazard map was prepared for the Haldia Municipal Area individually for pool fire, VCE, BLEVE and toxic release *(Ref: Chapter 5)*. A multi-hazard map was prepared for the entire municipal area by combining the results of different hazards. The municipal wards were identified at different level of risk so that to estimate the level of risk for individual wards in terms of population. The level of risk changed with the changes in land use pattern was also analysed.

8.2. Land Use Pattern

To deal with the land use aspect, it is necessary to overview the past and present situation of land use pattern in order to plan for future. The landuse pattern of Haldia Municipal Area changed a lot in the last few decades.

8.2.1. Existing Land Use

Land use surveys for Haldia Planning Area (HPA) covering the entire area have been conducted in the year 2001. Haldia has grown rapidly in the last two decades in terms of population and industrial activities. With the setting up of the Haldia Dock Complex in the 70's, an industrial township has been developed in its immediate hinterland. The port town, today, has several chemical industries that include I.O.C., M.C.C., Haldia Petrochemicals and others. These industries are mostly located along the river Hooghly and on both sides of HPL link Road. This industrial zone presents a spectre of environmental pollution with the effluents being discharged into kuchha drains and canals leading directly to the river Hooghly. Absence of any significant green buffer has resulted in the spread of pollutants all around (Authority 2002).
The residential zone is concentrated mainly at the vicinity of arterial roads and the Highway and also at the pockets around the ferry points along the river. Mixed land use has taken place in a linear manner along the major roads. The spill over of the commercial activities along the road with encroachments led to narrow right-of-ways. Towards the south of the Haldia Municipal area the condition is different with the existence of several townships of industries along the river Haldi. There is also a proposal of developing the riverfront of the Haldi River which would provide the city its much needed recreational zone. The condition of traffic and transportation is equally deplorable. The transport sector in Haldia is characterised by poor road geometrics, absence of pedestrian and parking facilities. *(Ref: Chapter 3)*. The following figure *(Figure: 8.1 & 8.2)* shows the percentage of different landuse categories in HPA and Haldia Municipal area for year 2001.

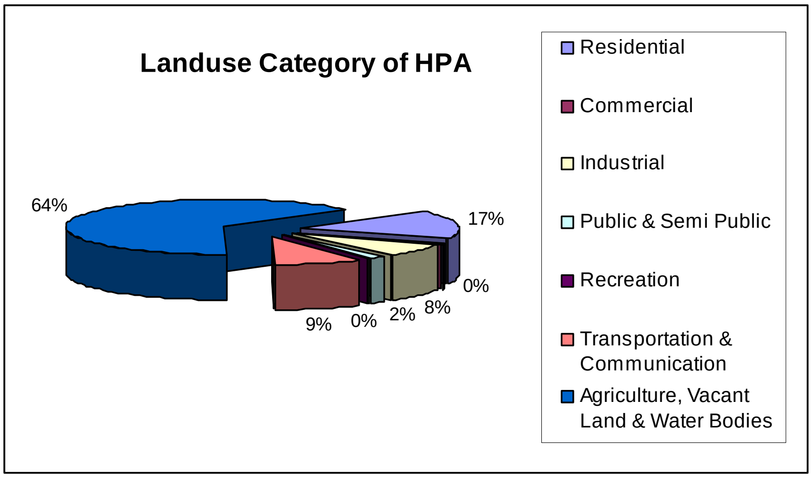


Figure: 8-1. Landuse Pattern of Haldia Planning Area (2001)

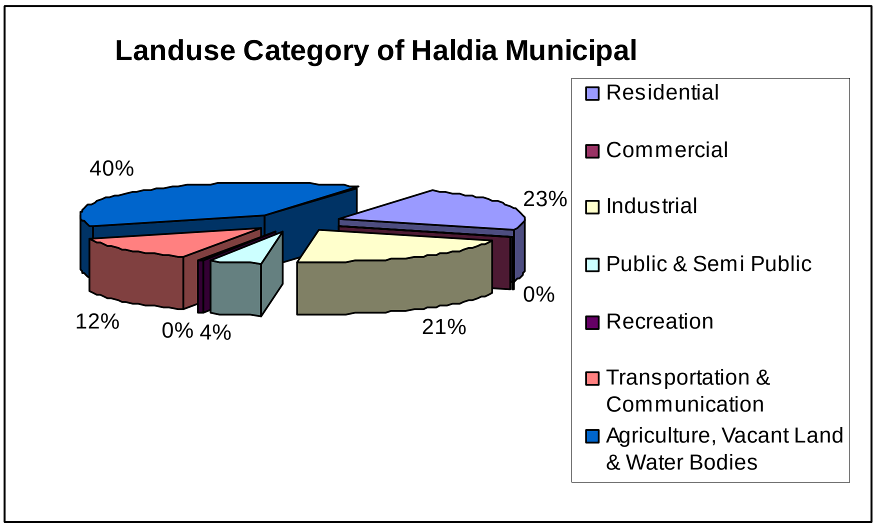


Figure: 8-2. Landuse Pattern of Haldia Municipal Area (2001)

8.2.2. Future Land Use

In order to arrive at the distribution of land use, it is necessary to establish the criteria for choice of different land uses in the spatial frame of the town. Haldia Planning Authority prepared a land suitability matrix had been evolved on the basis of goals, objectives and standards to establish Landuse compatibility between Municipality/Panchayats and various postulated landuses. Major landuse categories have been considered are namely residential, commercial, manufacturing, public & semi-public, recreation, transportation & communication and agriculture.

The present trend of land allocation for industrial use along the river Hooghly and HPL Link Road is to be continued. Further, residential development along the State Highway is to be strictly prohibited. Location of the industrial belt both to the north and south of the existing settlement along SH-6 necessitates provision of green buffer to prevent spread of pollutants to the residential area. However, the major portion of population is to be residing along the river Haldi. The riverfront of River Haldi is to be developed as the recreational hub and a major tourist spot. For better accessibility, a Central Spine, running parallel to the embankment road is to be developed. *Figure 8.3* shows the Perspective plan of Haldia in 2025 (Authority 2002).

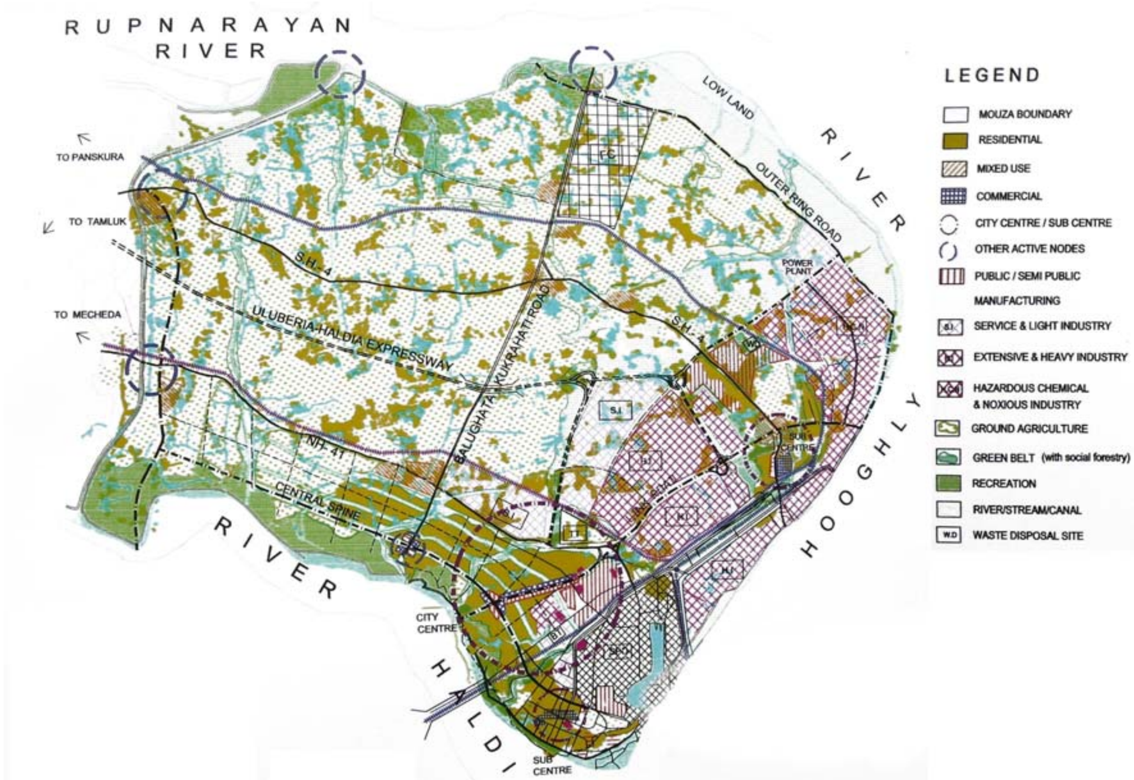


Figure: 8-3. Perspective Plan of Haldia Planning Area (2025)

(Source: Haldia Development Authority)

8.2.3. Changes in Landuse Pattern

Land use pattern of Haldia changes a lot in the last few decades. Following table *(Table: 8.1)* shows the expected changes in landuse pattern of Haldia Municipal Area in 2025 in comparison to 2001.

Table: 8-1. Comparative Study of Changes in Landuse Patterns of Haldia Municipal Area

Land use Categories	2001		2025	
	Area (in Hectare)	%of Total Area	Area (in Hectare)	%of Total Area
Residential (R)	2299.97	22.00	2665.88	25.50
Commercial (C)	59.04	0.41	372.18	3.56
Industrial (M	2227.17	21.30	1724.98	16.50
Public & Semi Public (PS)	463.68	4.44	808.13	7.73
Recreation (R)	48.66	0.46	1600.58	15.31
Transportation & Communication (T)	1254.53	12.00	3037.02	29.05
Agriculture, Vacant Land & Water Bodies (A)	4101.39	39.39	245.68	2.35
Total	10454.44	100.00	10454.44	100.00

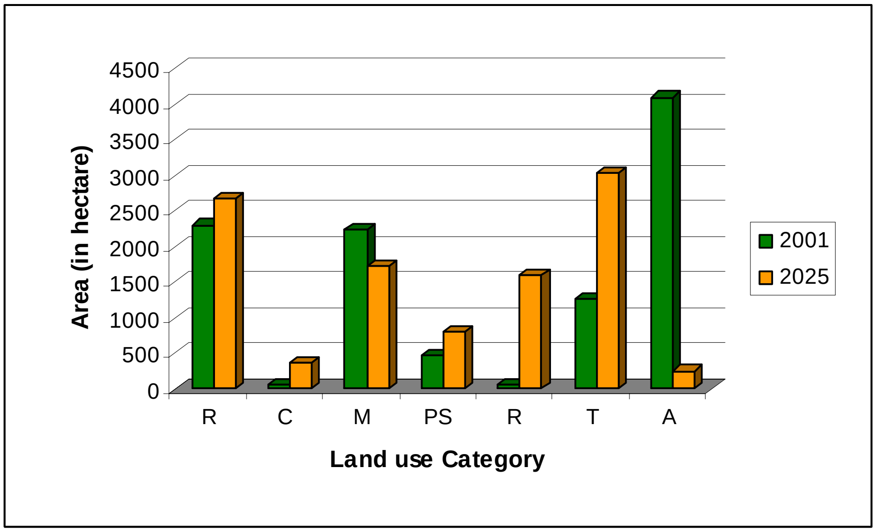


Figure: 8-4. Changes in Landuse of Haldia Municipal Area

It is shown that percentage of the area under agriculture and vacant land will decrease from 40% to about 2.35% while the percentage of area under transportation will increase from 12% to 30%. Apart from these the percentage of residential and commercial land use categories will also increases prominently. The land use pattern also changes in the Haldia Planning Area. Following table (*Table: 8.2.)* shows the expected changes in land use category for HPA in 2025.

Table: 8-2. Comparative Study of changes in Landuse Pattern of Haldia Planning Area

Land use Categories	2001		2025	
	Area (in Hectare)	%of Total Area	Area (in Hectare)	%of Total Area
Residential (R)	5578.64	17.30	7098.64	22.02
Commercial (C)	126.94	0.39	751.18	2.33
Industrial (M)	2451.22	7.60	4231.39	13.28
Public & Semi Public (PS)	525.38	1.63	2005.29	6.22
Recreation (R)	48.66	0.15	2079.44	6.45
Transportation & Communication (T)	2820.85	8.75	3981.57	12.35
Agriculture, Vacant Land & Water Bodies (A)	20687.72	64.18	12041.42	37.35
Total	32239.41	100.00	32239.41	100.00

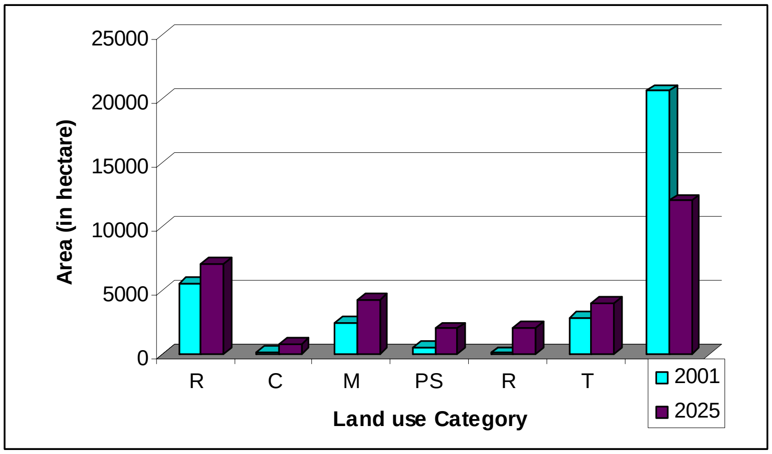


Figure: 8-5. Changes in Landuse of Haldia Planning Area

Like Haldia Municipal area, the percentage of agricultural category is expected to be decreased in 2025 from 64.18 % to about 37.35 %. The percentage for other categories is expected to be increase in 2025. Commercial and industrial areas are expected to increase significantly and might be there is a chance to increase the potentiality of industrial risk.

8.3. Multi-Hazard Map of Haldia Municipal Area

The hazard maps for entire Haldia Municipal Area were prepared for pool fire, VCE, BLEVE and toxic release *(Ref: Chapter 5).* Wards were categorised in very high, high, medium, low groups, depends on the severity of the different hazards individually (Fig: 8.6).

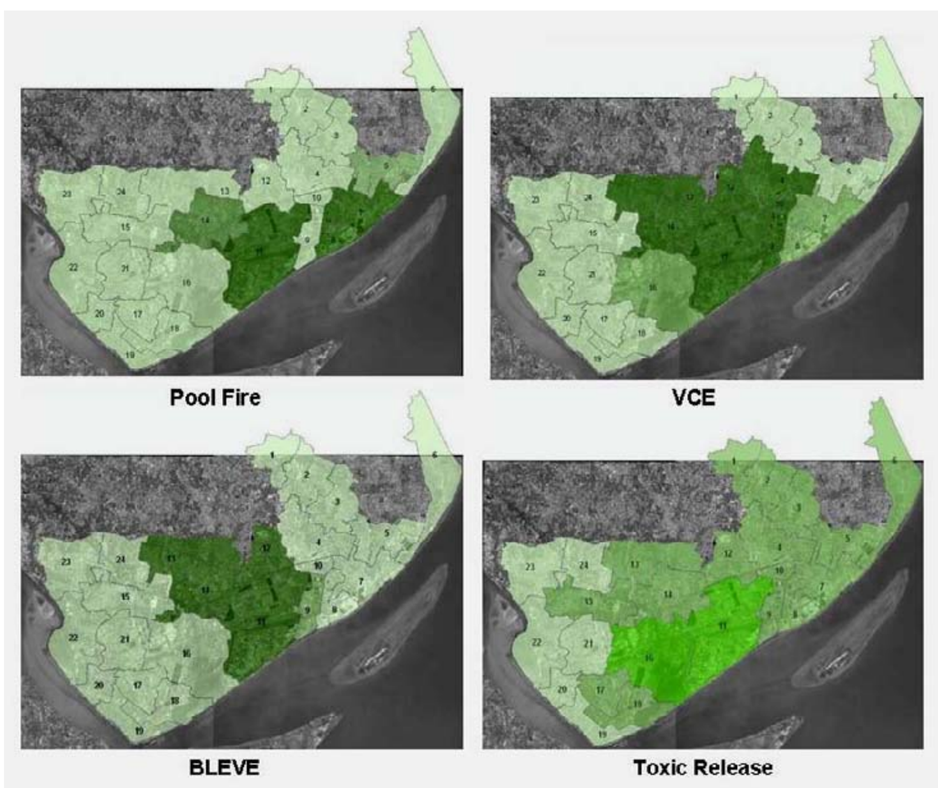


Figure: 8-6. Hazard Maps of Haldia Municipal Area

Few wards are found to be as remain high for all type of hazards. These wards have high probability of occurrence to get affected by any type of hazards. Thus the population of these wards also have high chance to might get affected. For the pool fire hazard, most of the wards fall under low category of hazard as because the impact of pool fire is not widely spread from the source of the event. While on the other hand, most of the wards fall under high category in case of toxic release.

In the present research, the wards which are highly hazardous for all events were identified by a multi-hazard risk assessment. All the individual hazard maps for the Haldia Municipal area were combined to generate a multi-hazard map for the same. From the planning point of view these wards are not suitable for residential purposes. Wards which have less chance to get affected were also identified with respect to any type of hazard. Following figure *(Fig: 8.7)* shows the wards having high probability and less probability to get effected from any hazards respectively.

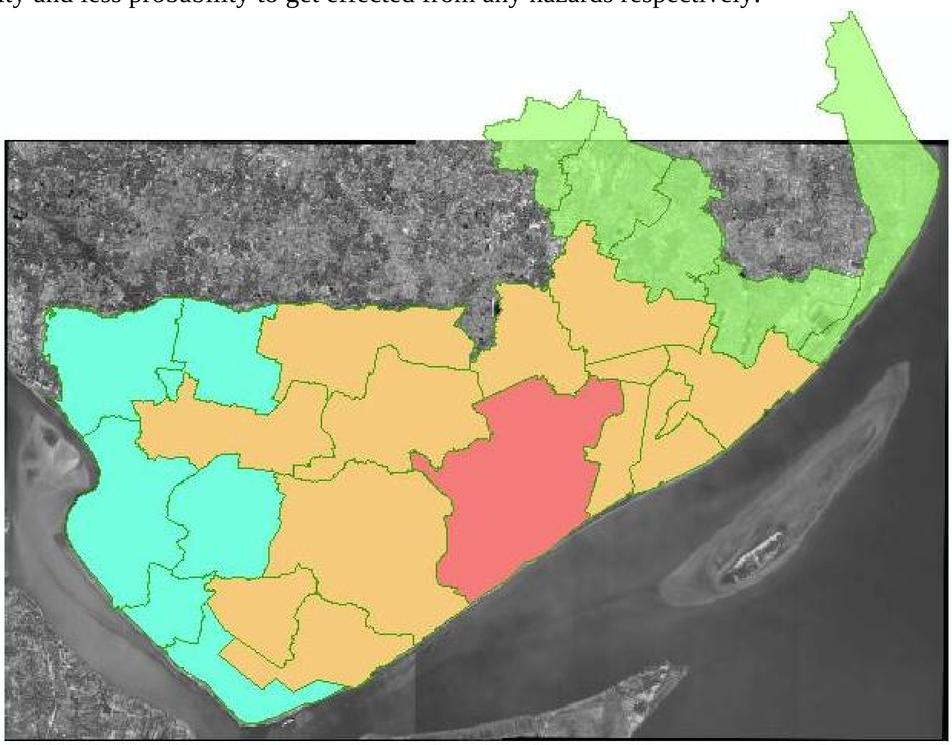


Figure: 8-7. Multi-Hazard Map of Haldia Municipal Area

Considering the multi-hazard risk map of Haldia Municipal area, wards were identified as high, medium and low risk category. From this map the number of population in different risk category can be estimated based on the ward wise population data. Following figure (Fig: 8.8) shows the percentage of population at different level of risk for the whole municipal area.

Table: 8-3. Number of buildings and households in Different Risk Categories

Risk Category	Total Population	No. of households
Very Low	41911	6987
Low	43841	8061
Medium	86960	18868
High	7117	1648

8.4. Summary

This chapter describes how the industrial risk evolved in Haldia with respect to time. The multi-hazard map of Haldia Municipal area was prepared considering different types of industrial hazards.

Population and number of households were estimated for different type of risk categories. Thus the risk zone map for the Haldia Municipal area can be used for the future landuse planning.

9. Conclusions and Recommendations

This chapter presents the conclusions in the form of answers to research questions which are based on research objectives and recommendations for the further research. The main objective of the research was to estimate the vulnerability and risk of industrial hazards and to utilize the risk maps for future landuse planning. In the research, Haldia was taken as a case study town and in particular the residential area near Durgachak industrial region for vulnerability assessment of buildings and population at different time of the day and thus to generate the risk map.

The frequent occurrences of industrial accidents in India provoke the necessity for industrial hazard assessment. Industrial hazard assessment is also important for landuse planning. There is an urgent need to estimate the number of people residing in and around industrial area who might get affected by any accidents. Many developed countries have adopted legislations for landuse planning taking risk as a criterion. Developing countries like India still now couldn't implement risk assessment in landuse planning mainly due to lack of centralised database information Thus the present research is an attempt to estimate the vulnerability and risk for industrial hazard and the utilisation of the risk maps for future landuse planning.

9.1. Conclusion

In the following section the research questions and objectives will be reviewed and will be answered where is it possible.

Question: 1. How to characterize and quantify the elements at risk?

The identification of the elements at risk for an industrial hazard was done based on the type of hazard characteristics. For the present research population and buildings were identified as elements at risk due to the location of several MAH industries in the vicinity. The study area is located at the centre of the Haldia town is bordered by MAH industries from three sides. The area is one of the most densely populated areas of Haldia. The buildings of this area are also vulnerable for fire, explosion as well for toxic release hazards.
For quantification purpose, a detailed household survey was done for the area. Building information and population details for different time periods were collected and thus generated the database for vulnerability assessment.

Question: 2. How to derive a suitable fire, explosion and toxic release hazard map using ERRIS mapping module?

Risk assessment being the multiplicative factor of hazard and vulnerability, highlight the importance of hazard calculation. Also the vulnerability of particular elements at risk changes with the changes in hazard intensity.
In the present research work, pool fire, VCE, BLEVE and toxic release hazards were considered for risk assessment, The dynamics of risk scenarios involving hazardous chemical can vary widely based on a number of factors like property of chemicals involved, nature of storage, nature of release and atmospheric conditions prevailing at the time of accident. Therefore, it is important to calculate the hazard footprint based on accepted consequence models. Using the ERRIS Mapping module, footprint maps for industrial hazards were mapped. For mapping first the effect distances for each storage was

calculated based on the empirical EPA equations. Using the GIS overlay operations, all the hazard footprints were overlaid and hazard maps were generated.

Question: 3. How to assess the vulnerability of population and buildings for industrial hazards?

For vulnerability assessment of population and buildings, it is important to consider the type of the hazard. The vulnerability of a particular element at risk also changes with the type of hazard.
For building vulnerability assessment several parameters like wall material, roof material, air tight condition and number of stories of the buildings were considered and assigned with weightages and ranks with respect to the impact of particular hazard. Combining all the weightages and ranks of parameters, vulnerability for individual buildings was estimated for different hazards separately and represented them in grid unit as well as with mapping units.
Population vulnerability was also done with respect to hazard type, building vulnerability at different time periods as number of people inside the building also changes with respect to time periods. It is shown that the vulnerability of a building with respect to population also changes time to time.

Question: 4. How to utilize the risk maps for future landuse planning?

For the future landuse planning, it is very important to consider the risk factor as a criterion. Land use planning depends on factors like availability of land, proximity to roads, surrounding landuses and others. But the utilisation of land in proper way depends on the risk factor also.
In the present research, a multi-hazard map was prepared for the entire Haldia Municipal Area. It can be shown that most of the residential areas are falling under the medium to high risk zones. Moreover, residential areas are located within the vicinity of MAH industries. Thus the location of the industries also increases the probability of damage to buildings as well as population due to any industrial hazards.
For landuse planning purpose, it is very important to consider the risk zonation map as a base for land allocation.

9.2. Recommendations

The method that was used in this research is a first attempt to estimate vulnerability and risk for industrial hazards in India. In order to make this operational a number of improvements have to be implemented:

Hazard assessment procedure can be improved by developing a method that calculates effect buffers (with changing values) instead of effect distances, where all buildings or population within the effect distance apparently has the same degree of damage but in reality, the further away from the source the damage will be less.

For hazard assessment purpose, the meteorological factors have to considered along with the chemical properties of the hazardous chemical. The propagation of an effect zone depends on the wind speed and wind direction. For toxic release hazard, based on the wind direction, the size of the impact area also changes. For an explosion it is very important to consider the atmospheric condition especially temperature, pressure as well as humidity.

Detailed hazard assessment should be done for each individual building wise not as grid or mapping unit wise. To generate the hazard map, effect distance maps were overlaid on the mapping units, wherein mapping units were categorised based on the number of hazard scenarios. But sometime the hazard footprint divides a particular mapping unit into two, in that case one has to consider the predominant category, thus the hazard assessment became more generalized.

For building vulnerability assessment, building parameters (wall material, roof material, air-tight condition, and number of stories) were taken into consideration and assigned weights and ranks with respect to hazard type. Instead of assigning weights to parameters, building vulnerability can also be done with respect to effects of hazards in terms of temperature, pressure, etc. and thus quantification can be also done for the degree of damage to buildings. This would require a calculation of hazard that displays more than 1 effect distance for a particular event, in fact calculating effect buffers instead of effect distances.

More factors should be involved in the vulnerability assessment. Distance between two adjacent buildings should be considered for building vulnerability assessment in case of pool fire. For VCE, an important factor is the so-called “shadow effect”, due to which smaller buildings might be protected from the blast of an explosion, because a taller building is standing close to it, in between the building and the explosion site, can be considered. In order to take this factor into account, the exact location of the explosion should be known, and a separate vulnerability map can be generated for each individual scenario.

For building vulnerability assessment, two different generalisation approaches were evaluated. Of these, the grid approach gives a misrepresentation of the real situation. Rather than the grid approach, the mapping unit approach is more appropriate, but it depends whether the mapping units have been correctly outlined, and give homogeneous units with respect to elements at risk, land use and also hazard type and magnitude. So for the vulnerability assessment of buildings at town level, the mapping unit approach can be considered better. Mapping units can be identified based on the predominant landuse pattern.

Based on the building vulnerability, population vulnerability can be calculated as a function of the hazard degree. For toxic release hazard, the degree of vulnerability for people inside the buildings depends on the vulnerability of that particular building, in terms of the amount of air-tightness. In this study the vulnerability of people outside of buildings was not evaluated, due to time constraints. This should also be taken into account in future studies.

Road vulnerability in terms of population can also be calculated. The quantitative analysis of road vulnerability in terms of population depends on several parameters. One of the most important parameters is the width of individual roads. In order to classify the roads in terms of degree of vulnerability, it is also important to consider the exact number of people traversing at a specific period.

Apart from physical building vulnerability and general population vulnerability, also many other types of vulnerability could be taken into account. For example infrastructural vulnerability, looking at roads, drinking water provision, and electricity. Also the pollution effects of toxic release on a longer term, and its effect on agriculture and water and air quality should be considered in a complete risk assessment.

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Glossary

Auto-ignition Temperature	The ignition or auto-ignition temperature of solid, liquid or gaseous substances is the minimum temperature necessary to initiate or cause self-sustaining combustion in absence of a flame or spark.
Catastrophic Incident	An accident with an outcome effect zone that extends off site into the surrounding community.
Chemical Hazard	A hazard involving chemicals or processes which may realize its potential through agencies such as fire, explosion, toxic or corrosive effects.
Confined Explosion	An explosion of a fuel-oxidant mixture inside a closed system (e.g. vessel, buildings)
Consequence Analysis	The analysis of the expected effects of incident outcome cases independent of frequency or probability.
Critical Pressure	Below the critical temperature, the maximum level of pressure which maintains the liquid phase of the substance.
Critical Temperature	A temperature above which a substance cannot exist in a liquid phase regardless of the pressure.
Dispersion	The process of dilution of hazardous substance by the surrounding fluid or air.
Domino Effects	The triggering of secondary events, such as toxic releases, by a primary event, such as explosion, so that the result is an increase in consequences of an effect zone. Generally only considered when a significant escalation of the original incident results.
Dust Explosion	An explosion which results from the ignition of a mixture of finely divided combustible solids and air. The effect of such an explosion is comparable with the ignition of an equal volume of air mixed with flammable vapour.
F/N Curve	A plot of cumulative frequency against consequences (expressed as number of fatalities).
Fire Point	Lowest temperature at which the heat of combustion of burning vapour is capable of producing sufficient vapour to enable combustion to continue.
Fire Storm	An extremely large area of fire resulting in a tremendous in-rush of air which may reach hurricane force.

Fireball	A fire burning sufficiently rapidly for the burning mass to rise into the air as a cloud of ball.
Flame Speed	The speed with which a flame front propagates relative to a fixed point.
Flash Fire	The combustion of flammable vapour and air mixture in which flame passes through that mixture at less than sonic velocity, so that negligible damaging overpressure is generated.
Ignition Temperature	The lowest temperature at which substance will ignite spontaneously (substance will burn without a flame or other ignition source).
Jet Fire	Fire resulting from pressurized release of gas and/or liquid.
Jet Flame	The combustion of material emerging with sufficient momentum from an opening.
Lethal Concentration (LC50)	The concentration of airborne material, the four-hour inhalation of which results in the death of 50% of the test group within 14 days observation.
LFL (Lower Flammable Limit)	The lowest concentration of a flammable vapour gas in air at which a self-sustaining flame may be initiated.
Plume	The gas cloud resulting from a continuous release.
Pool Fire	The combination of material evaporating from a layer of liquid at the base of a fire.
Puff	The gas cloud resulting from an instantaneous release.
UFL (Upper Flammable Limit)	The concentration of flammable substance in air above which combustion will not propagate.
Vapour	It is a state of gas which can be liquefied by the application of pressure alone without reduction in temperature.
Vapour Cloud Explosion	An explosion in the open air of a cloud made up of a mixture of flammable vapour or gas in air.

Appendix

Appendix: 1 Atmospheric Stability Classes

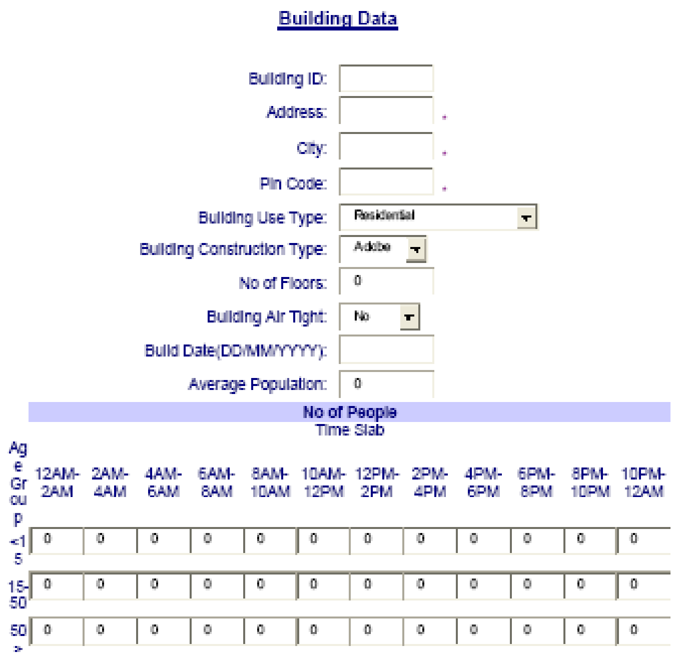
ATMOSPHERIC STABILITY CLASS SELECTION TABLE

A -- Extremely Unstable Conditions
B -- Moderately Unstable Conditions
C -- Slightly Unstable Conditions
D -- Neutral Conditions*
E -- Slightly Stable Conditions
F -- Moderately Stable Conditions

	Daytime Conditions			Nighttime Conditions	
	Strength of sunlight				
Surface Wind Speed, mph	Strong	Moderate	Slight	Thin Overcast greater than or = 4/8 Cloudiness**	less than or = 3/8 Cloudness
Less than 4.5	A	A - B	B	-	-
4.5 - 6.7	A - B	B	C	E	F
6.7 - 11.2	B	B - C	C	D	E
11.2 - 13.4	C	C - D	D	D	D
Greater than 13.4	C	D	D	D	D

*Applicable to heavy overcast conditions day or night
**Degree of Cloudiness = Fraction of sky above horizon covered by clouds.

Appendix: 2 Questionnaire Format for Building Survey



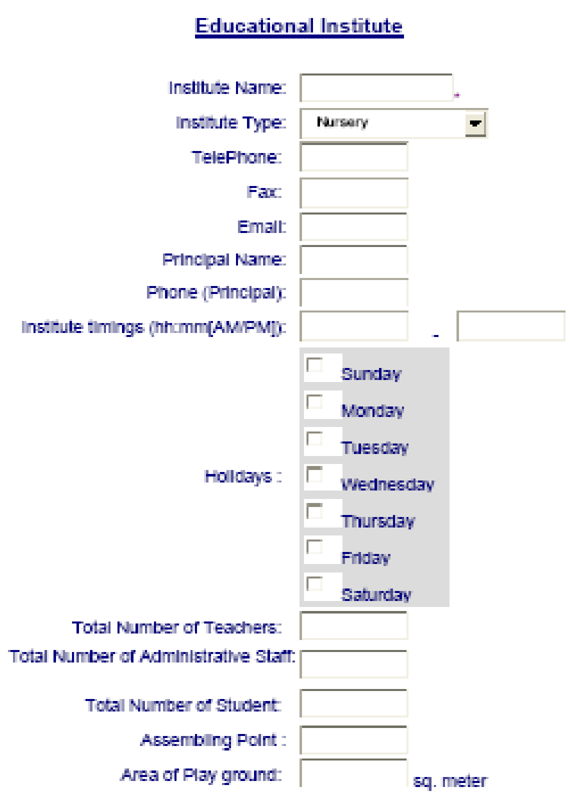
Building Data

Building ID:
Address:
City:
Pin Code:
Building Use Type: Residential
Building Construction Type: Adobe
No of Floors: 0
Building Air Tight: No
Build Date(DD/MM/YYYY):
Average Population: 0

No of People
Time Slab

Age Group	12AM-2AM	2AM-4AM	4AM-6AM	6AM-8AM	8AM-10AM	10AM-12PM	12PM-2PM	2PM-4PM	4PM-6PM	6PM-8PM	8PM-10PM	10PM-12AM
<15	0	0	0	0	0	0	0	0	0	0	0	0
15-50	0	0	0	0	0	0	0	0	0	0	0	0
50 >	0	0	0	0	0	0	0	0	0	0	0	0

Appendix: 3 Questionnaire Format for Educational Institute Survey



Educational Institute

Institute Name:
Institute Type: Nursery
TelePhone:
Fax:
Email:
Principal Name:
Phone (Principal):
Institute timings (hh:mm[AM/PM]): -
Holidays : Sunday, Monday, Tuesday, Wednesday, Thursday, Friday, Saturday
Total Number of Teachers:
Total Number of Administrative Staff:
Total Number of Student:
Assembling Point :
Area of Play ground: sq. meter

Appendix: 4 Database generated for Building Vulnerability Assessment

Block	Plot ID	Building ID	No. of Floors	Build Date	Construction Type_G	Roof Material	Air Tight	Use Type_G	Use Type_F
A	1	10/A/1/1	2	12	RCC	Concrete	Yes	Residential	Residential
A		10/A/1/2	2	2	RCC	Concrete	No	Residential	Residential
A	2	10/A/2	1	35	Brick walled	Tiles	No	Residential	
A	3	10/A/3	2	7	RCC	Concrete	Yes	Private Office	Residential
A	4	10/A/4	3	15	RCC	Concrete	No	Residential	Residential
A	5	10/A/5	3	29	RCC	Concrete	Yes	Commercial Shop	Residential
A	6	10/A/6	1	30	Brick walled	Asbestos	No	Commercial Shop	
A	7	10/A/7	3	15	RCC	Concrete	Yes	Commercial Shop	Residential
A	8	10/A/8/1	2	2	RCC	Concrete	No	Residential	Residential
A		10/A/8/2	3	20	RCC	Concrete	No	Commercial Shop	Residential
A	9	10/A/9	1	1	RCC	Concrete	No	Residential	
A	10	10/A/10	1	20	Brick walled	Tiles	No	Residential	
A	11	10/A/11	2	24	RCC	Concrete	Yes	Residential	Residential
A	12	10/A/12	3	10	RCC	Concrete	No	Commercial Shop	Residential
A	13	10/A/13/1	1	22	RCC	Concrete	No	Residential+ Shop	
A		10/A/13/2	1	10	Brick walled	Asbestos	No	Residential+Lab	
A	14	10/A/14/1	3	5	RCC	Concrete	Yes	Commercial Shop	Residential
A		10/A/14/2	1	5	RCC	Concrete	No	Commercial Shop	
A	15	10/A/15/1	2	6	RCC	Concrete	Yes	Residential	Residential
A		10/A/15/2	1	10	RCC	Concrete	No	Residential	

Appendix: 5 Database generated for Population Vulnerability Assessment

Building ID	12am-2am	2am-4am	4am-6am	6am-8am	8am-10am	10am-12pm	12pm-2pm	2pm-4pm	4pm-6pm	6pm-8pm	8pm-10pm	10pm-12am
10/A/1/1	7	7	7	7	5	2	2	2	5	5	5	7
10/A/1/2	0	0	0	0	0	0	0	0	0	0	0	0
10/A/2	9	9	9	9	9	7	7	7	7	9	9	9
10/A/3	16	16	16	16	16	20	20	20	20	14	14	16
10/A/4	14	14	14	14	14	10	10	10	12	14	14	14
10/A/5	14	14	14	14	25	23	14	14	30	25	25	14
10/A/6	2	2	2	0	0	0	0	0	0	0	0	2
10/A/7	6	6	6	6	8	8	8	8	8	9	9	6
10/A/8/1	13	13	13	13	13	12	12	12	15	15	13	13
10/A/8/2	0	0	0	0	0	0	0	0	0	0	0	0
10/A/9	9	9	9	9	9	9	9	9	9	9	9	9
10/A/10	8	8	8	8	7	6	6	7	8	8	8	8
10/A/11	13	13	13	8	8	3	3	3	3	8	8	13
10/A/12	1	1	1	1	1	1	1	1	1	1	1	1
10/A/13/1	2	2	2	2	2	2	2	2	2	2	2	2
10/A/13/2	10	10	10	10	7	5	3	3	5	5	7	10
10/A/14/1	11	11	11	11	0	0	11	11	0	0	0	11
10/A/14/2	8	8	8	7	6	6	7	7	6	6	6	8
10/A/15/1	2	2	2	1	1	1	2	2	1	1	2	2
10/A/15/2	4	4	4	4	10	10	10	10	10	10	4	4