CONSEQUENCE EVALUATION OF CHLORINE GAS RELEASE FROM THE INDUSTRIAL AREA OF BHAGWANPUR (UTTARAKHAND) AND DURGAPUR (WEST BENGAL)

A DISSERTATION

Submitted in partial fulfillment of the requirements for the award of the degree
of

MASTER OF TECHNOLOGY
in
DISASTER MITIGATION AND MANAGEMENT

By
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ROORKEE - 247 667 (INDIA)
MAY 2015

CANDIDATE DECLARATION

I hereby certify that the work that is being presented in this **M.Tech Dissertation REPORT**, entitled "**CONSEQUENCE EVALUATION OF CHLORINE GAS RELEASE FROM INDUSTRIAL AREA OF BHAGWANPUR (UTTARAKHAND) AND DURGAPUR (W EST BENGAL)**" in partial fulfilment of the requirements for the award of the Master of Technology in Disaster Mitigation and Management, submitted to the Centre of Excellence in Disaster Mitigation and Management, Indian Institute of Technology Roorkee, India, is an authentic record of my work carried out under the guidance of Dr. Shishir Sinha, Professor, Department of Chemical Engineering & CoEDMM, IIT Roorkee.

The matter embodied in this has not been submitted for the award of any other degree.

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This is to certify that the above mentioned statement made by the candidate is correct to the best of my knowledge.

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ACKNOWLEDGEMENT

I feel great pleasure in expressing my deep and sincere thanks and deep sense of gratitude to my guide **Dr. SHISHIR SINHA,** Professor, Department of Chemical Engineering & CoEDMM, Indian Institute of Technology Roorkee, for his valuable guidance, keen co- operation, useful criticism and self-confidence which has contributed much in the work and my personal encouragement.

I would like to thank to **Dr. B.K Maheshwari**, Head of the Department of Centre of Excellence in Disaster Mitigation and Management (CoEDMM) and **Dr. Ajay Gairola,** Professor, Department of Centre of Excellence in Disaster Mitigation and Management for providing me the best of facility during my work.

Above all, I want to express my heartiest gratitude to all the Professor and non-teaching staff of the department, my parents for their support, which has always been a constant source of inspiration.

21/5/2015
Date:

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ABBREVIATONS

MSI - Manufacturer Storage and Import

HAZOP - Hazard and Operability

FTA - Fault Tree Analysis

FMEA - Failure Mode Effect Analysis

MAH - Major Accident Hazard

TLV - Threshold Limit Value

MCAA - Maximum Credible Accident Analysis

ALOHA - Areal Location of Hazardous Atmosphere

ERM - Environmental Resource Management

PHAST - Process Hazard Analysis Software Tool

USEPA - United States Environmental Protection Agency

CEPPO - Chemical Emergency Preparedness and Prevention Office

NOAA - National Oceanic and Atmospheric Administration

EPA - Environmental Protection Agency

DEGADIS - Dense Gas Dispersion

AEGL - Acute Exposure Guidelines

ERPG - Emergency Response Planning Guidelines

IDLH - Immediately Dangerous to Life or Health

ABSTRACT

The accidental release of toxic, flammable and hazardous chemicals from chemical plants are causing serious threats to lives, properties and environment. The situation becomes more damaging if the plant is located in a densely populated area. Different chemicals are used for the production of variety of chemical products. Among all these, extreme use of chlorine gas in the manufacturing of chemicals and products possess great risk of chlorine gas leakage from storage tank. Chlorine gas is irritating to eyes and it cause respiratory problems on inhalation and being denser than air it remains on the ground for long time. During sudden release the gas will disperse in the atmosphere depending on the process and meteorological conditions prevailing at that time. In this paper with the help of ALOHA model the areas of Bhagwanpur (Uttarakhand) and Durgapur (West Bengal) which can be affected during the dispersion of chlorine gas have been calculated. It is mainly based on the principles of fluid dynamics. The methodology discussed in this paper is useful to predict the probable threat zones of chlorine gas dispersion for the concentrations 350 ppm, 125 ppm, and 15 ppm during summer, monsoon, post monsoon and winter season for the two areas. The rate of maximum indoor and outdoor concentration of chlorine gas in terms of time from the source at a distance of 2 km is also calculated. With the help probit analysis mortality rate for the three concentrations are calculated. The situation can be very critical during winter and post monsoon season. The mortality rate is also a matter of concern as it indicates 49.20 % of mortality rate for 350 ppm concentration for an exposure period of 15 minutes. The results from the scenarios are further analyzed and compared for the same and can be used in the analysis of consequences and risk assessments by the respective sectors in order to minimize the potential impact from such incident in future.

CHAPTER 1

INTRODUCTION

Industries plays a very important role in the development of economy and growth of a country especially for developing countries like India hence we can say that it is the most important part of today's as well as for our future civilization. There is a development of technology across the globe and with this advancement of science and technology different kinds of industries are developing across the world these industries may be pharmaceutical industries, chemical industries etc. Though these industries are contributing in the growth of economy, employment and social development of a country but at the same time it possess a threat of industrial disaster. There is no particular time and condition of a striking disaster but when it occurs it all the developments are lost and there remains a huge loss of human lives and environment. Not only that it also causes loss of valuable properties and its effect remains for a very long period of time.

A chemical industry deals with complex operation process where innumerable chemical substances are used in its different stages of production. The main hazards of chemical industries are fire, explosion and toxic gas release (Khan & Abbasi, 1999).These clusters of industries increases the probability of chain of accidents of domino effect in this a single accidents in one industry can trigger another accident in nearby industry and so on.

In chemical industries accidental release of toxic gases are caused due to leakage of the toxic substances if it is improperly handled or there is a failure in the processing system. This accidental release of gas could results the toxic gas to disperse into the surrounding air. In India, one of the most important examples of chemical disaster is the release of methyl isocyanate from the Factory of Union Carbide in Bhopal in the year 1984. It was the most catastrophic disaster in the history of not only India but also in the world. The effects of Bhopal gas tragedy can also be seen today in Bhopal as the effects of the disaster is passing from one generation to other (Renjith.V.R. et al., 2010).

After Bhopal gas tragedy of 1984 the Government of India formulated a plan called Sahara Plan and in 1986 The Environment Protection Act 1986 came into existence. It includes MSI rules (The Manufacturer Storage and Import of Hazardous Chemicals Rules) (Ruj Biswajit et al., 2012). This rule was a comprehensive attempt to regulate hazardous installations, consisting factories, storage of chemicals, pipelines etc.

In chemical hazards, the chemical accidents could occur under certain circumstances as it involves handling of toxic gases and substances like ammonia, chlorine etc. so there is a great need of proper attention in the improvement of plant safety, occupational safety, health safety and care must be taken in the process of storing and transporting the hazardous products (Dandrieux et al., 2002). Frequent transportation and use of chlorine for various processes has increased the chances of a potential accident. Accidents occurring in storage vessels can occur for different reasons, including transportation accidents; failure of human etc.

`When chlorine is suddenly releases from a storage tank it will vaporize and dispersed in the atmosphere. The dispersion of the gas depends on the process and meteorological parameters at that time of release. The area affected by the release of chlorine gas can be calculated using the fundamental principles of fluid dynamics. An accident involving chlorine can cause injuries, either severe or fatal (Dandrieux et al., 2002). The injuries caused due to a small release of chlorine can also become a fatal issue. It is very important to know the techniques of how to predict the release and their possible consequences to ensure the safety of the industries. Chlorine dispersion studies are mainly based on the evaluation of consequences which can be take place after the release of toxic gas. Simulation are done to estimate the release of chlorine, to study the effects of obstruction as well as various meteorological parameters on the gas cloud and the toxic effects of the gas on the population and the environment (Das D.B. et al., 1998).

With the help of risk analysis we can forecast the likelihood of accidents, assess the consequences and mitigation measures. A total risk assessment consists of all the steps from start to end and various techniques are available for this purpose (Khan and Abbasi, 1997). The potential of damage of an accident is mainly determined by the type of chemical substances, causes, and conditions of the operating system. The occurrence of accident is more destructive in high density area and can cause huge loss of lives and properties. The main points in the process of risk assessment of chemical industry which deals with hazardous substances are as follows.

1. It helps in the development of technical tools used to forecast an unwanted situation in the

chemical plant.

2. It analyses the consequences of likely accidents which fulfills two objectives one is to setting of the industries in such a way so that damage can be minimized and other is it provides a feedback which can be used to forecast and making of disaster management plan.

3. It also helps in development of strategies for emergency preparedness and damage minimization.

Risk analysis includes both qualitative and quantitative analysis of risks and its impact. It is basically a combination of hazard and the probability of occurrence of hazard. There are different techniques like HAZOP study, FTA, and FMEA etc. Maximum credible accident analysis is also a very good analysis it includes credible accidents scenario development using mathematical models (Khan & Abbasi, 1998).

1.1. SCENARIO OF CHEMICAL INDUSTRIES IN INDIA

Chemical industry is one of the main industries which have contributed in the development of Indian economy and employment. It provides products and services to improve the quality life of customers and communities. The production of products in the chemical industry uses raw materials like gas, coal, water and minerals to produce a variety of products. It is also major demand driver for other sectors such as energy, information technology, and environmental technology.

The nature of chemical industry is heterogeneous as it includes different sectors such as organic, inorganic, dyes, paints, pesticides and specialty chemicals. Specialty chemicals are produced in select countries with advanced technology and production skills. The chemical industry is basically energy intensive in its different manufacturing process.

The chemical industry is generally classified into the following three broad segments:

1. Basic chemicals: also known as commodity chemicals, it includes organic and inorganic chemicals, petrochemicals, other chemical intermediates, synthetic rubber, man-made fibers, dyes, printing inks.

2. Specialty chemicals: these are mainly are low volumes but of high-value compounds, it is also known as performance chemicals. These types of chemicals are derived from its basic chemicals and are sold according to their function. For example, paint, adhesives, electronic chemicals, oilfield chemicals, flavors and fragrances, paper additives, industrial cleaners and fine chemicals.

3. **Agricultural chemicals:** these are especially crop protection chemicals such as pesticides and herbicides. This sector of chemical is emerging as the major sector of chemical industries. Indian chemical industry is much diversified and it contains variety of products. The main important sectors of Indian chemical industries are comprised of these followings:

In India according to a study funded by the International Labour Office a survey was conducted to identify major accident hazards , it states that there are 586 MAH units and 75 hazardous chemicals. These MAH units are distributed across various states of India as presented in Table No.1 (Khan & Abbasi, 1999).It revealed that among all the states Gujarat and Maharashtra have the largest number of major hazardous units and also it handles largest number of hazardous chemicals.

Table 1.State-wise distribution of MAH units and hazardous substances

State	MAH units	Hazardous substances
Andhra Pradesh	35	24
Bihar	12	11
Delhi	19	8
Goa	8	9
Gujarat	112	32
Karnataka	26	14
Kerala	19	19
Maharashtra	97	24
Madhya Pradesh	33	10
Tamil Nadu	41	31
Uttar Pradesh	40	14
West Bengal	40	23
Assam	7	10
Haryana	7	4
Jammu Kashmir	7	4
Nagaland	1	1
Orissa	13	10
Pondicherry	3	3
Punjab	12	6
Rajasthan	54	17

(Source: National Chemical Management Profile for India prepared by Ministry of Environment and Forest and Central Pollution Control Board)

Chemical industries in India possess a major threat to property and population because of its magnitude. It will be very beneficial if we identify and categorize all the disasters and analyzed their results as it will be helpful to prevent their recurrence.

1.2. ACCIDENTS IN CHEMICAL PROCESS AND ANALYSIS OF CAUSES AND CONSEQUENCES:

1.2.1. Definition of accident:

An unexpected, unavoidable and unintended event is termed as accident (Suchman, 1961). These followings are characteristics of accident:

a) Degree of expectedness
b) Degree of avoidability
c) Degree of intention
d) Degree of warning
e) Degree of occurrence
f) Degree of negligence

1.2.3. Major hazardous process:

Fire, explosion and toxic release are the three major hazards of the chemical industry. Out of these fire is the most common but in terms of damage potential explosion is most significant. There is an estimation that about two-thirds of the losses are arising due to explosion. About 18% of fires are due to the overflow and release of toxic flammable gases. In comparison with fire explosion contributed about 75% of the total loss. Failure of controlling equipments and process system contribute 35% of the total number of accidents. The most susceptible area of the accident is the processing area.

1.2.4. Classification of accidents:

Accidents involving hazardous chemicals can be categorized into two main groups: fixed installation accidents and transportation accidents. The fixed installation accident includes all accidents occurring in industries during different stages of operation, while transportation accidents consider accidents occurring during transportation, loading or unloading of chemicals (Khan & Abbasi, 1999).The transportation accidents can be further categorized according to the different mode of transportation. Among various modes of transportation accidents rail has higher rate of failure and its damage potential is also high.

The classification of different modes of transportation accidents are as follows rail transport (37%), road transport (29%), marine transport (6%), pipeline transport (18%), inland waterways transport (4%) and rest are due to loading and unloading of toxic chemicals. According to sources major accidents are caused due to fixed installation accidents i.e. 54% fixed installation accidents, 41% are transportation accidents and 5% are miscellaneous accidents Fig 1. (Khan & Abbasi, 1999).

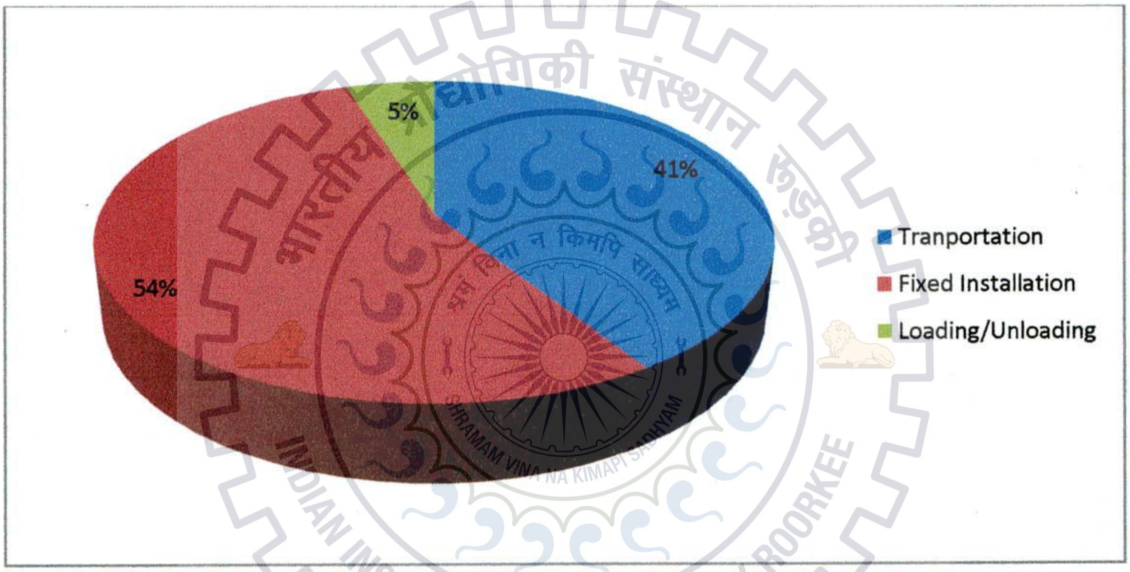


Fig 1.Classification of Accident

1.2.5. Causes of accidents:

The main cause of the accidents is the malfunctioning of the equipments and negligence during the processing stage or in the maintenance. Although there is a decrease in the number of accidents per year but the extent of damage has increased and it is true for developing countries like India. The impact of fire and explosion is limited to a lesser areas but the damage caused is very severe and can cause domino effect. In case of explosion the number of fatalities per accident is highest.

Among all the modes of transportation pipeline transportation is safe as compare to other modes and it does not pass through densely populated areas. As the density of industries in a particular complex is increasing the probability of accidents as well as domino effect are also increasing (Khan & Abbasi, 1999).

In Table No.2 there is a list of chemical accidents that have occurred in India due to sudden release of toxic gas and it also proves that if there was an early warning or prediction of the area likely to be affected by the release then a number of more lives could be saved (Tiwari Shashank et al., 2013).

Table 2.Major Chemical Accidents in India due to release of toxic gas

Place	Date	Deaths	Injuries	Cause
Ulhasnagar	17.03.1983	9	140	H_2S Gas
UCI Limited, Bhopal	3.12.1984	2800	50000	Methyl isocyanate gas
Bhatinda	17.01.1989	-	500	Ammonia gas
Lucknow	1990	-	200	Ammonia gas
Thane	1994	1	175	Chlorine gas
Thane	15.03.1995	2	-	Toxic Gas
Maharashtra	16.12.1995	1	160	Ammonia gas
Vishakhapatnam	14.09.1997	80	50	Vapor cloud explosion
Bhopal	21.01.1997	-	400	Ammonia gas
GACL,Vadodra	5.09.2002	4	20	Chlorine gas
BPT, Mumbai	14.06.2010	-	103	Chlorine gas
New Delhi	29.04.1992	43	20	Explosion
New Delhi	13.11.1994	-	500	Fire due to toxic cloud explosion
Kolkata	6.12.1991	-	200	Chlorine gas

1.3. MAJOR HAZARDS OF CHLORINE

1.3.1. Definition of hazard:

A hazard is a situation that posses a level of threat to life, health, property and environment whereas chemical hazards are systems where chemical accidents could occur under certain circumstances. Chemical substances like chlorine, ammonia, etc are used as starting materials in the production of any chemical compounds and both of the substances are very toxic and reactive that is why it can cause chemical accidents which can be fatal to human lives.

1.3.2. Hazards of chlorine

The major hazards of chlorine production industries are fire, explosion and toxic release. In terms of damage potential explosion is very significant than fire but among all the three toxic release has the greatest potential to kill large number of people and it can makes that area contaminated for a long period of time.

Explosion and Fire: Explosion can be initiated due to thermal stratification of the liquid and vapour or by shock waves. It occurs when gas phase chlorination operates either in flammable range or outside the flammable range where chlorine act as a controlling reactant. It includes chlorine evolution in the vapour state giving a flammable mixture with reactive solvent or mixture vapour (Saroha A.K, 2006). Explosions may be

a) Confined Vapour Cloud Explosion (CVCE)

b) Unconfined Vapour Cloud Explosion (UVCE)

c) Boiling Liquid Expanding Vapour Explosion (BLEVE)

Fires: may be triggered by ignition sources which can be an electric spark, atmospheric friction, momentary flame during a welding operation etc. the effects of fires are limited to those areas which are very close to the source like 200 meters radius. It can be classified as a) Pool fire b) Flask fire c) Fire ball. However, industrial fires can have a greater pervasive effect (Khan and Abbasi, 1997).

Toxic gas release and dispersion: Vapor clouds from industrial installations mainly arise from the accidental release of gases or evaporation of spilled liquids. The toxic vapour (gas) cloud is very dangerous even at much greater distance from the point of release than their flammable counterparts. It has the capacity to disperse easily in the air and comes in direct contact with the living system and environment (Khan & Abbasi, 1997).

Corrosion Hazard: Chlorine gas is highly corrosive in the presence of moisture. Wet chlorine is corrosive to most of metals and also to polyvinyl chloride pipelines. Chlorine reacts with water, weak solutions of hydrochloric acid and hypochlorous acid are formed which is highly corrosive in nature (Khan & Abbasi, 1997). All piping and equipment for handling liquid chlorine must be designed with an adequate corrosion allowance.

1.4. TOXICITY OF CHLORINE

Toxicity refers to the degree to which a substance can damage an organism and it can be in the form of chemical, biological or physical toxicants. The extent of injuries due to the accidental release of chlorines mainly depends on these followings factors:

i) The concentration of the chlorine gas.

ii) The time of exposure to the released gas.

iii) The presence of moisture in the exposed body tissue.

iv) The victim's inherent health condition during the time of release.

Chlorine is an irritating gas; its threshold limit value (TLV) is 1 ppm. The dangerous concentration of chlorine for a short term exposure is 35 ppm and for a few inhalations is 1000 ppm.

Chlorine can be detectable by odour and it cause irritation to eyes and throat. During a large and sudden release of chlorine it becomes very difficult to escape from the harmful effects of the gas. There are many cases in the past which proves that exposure to chlorine have resulted a large number of deaths and injuries.

The injurious effects of chlorine are due to the fact that chlorine is an oxidizing agent. It reacts with the body moisture and forms corrosive acid called hypochlorous acid which is very irritating to skin. It is mainly irritating to respiratory tract and its concentration above 3-5 ppm by volume in air can be detectable by normal person.

Chlorine is a notoriously gas and it can be lethal even in low doses (Saroha A.K, 2006).The effects of chlorine depend upon its concentration and duration of inhalation. The limiting values of chlorine are illustrated in Table 3. Whereas Table 4.shows different effects of chlorine depending upon its various concentrations (Saroha A.K, 2006):

Table 3.The Threshold Limiting Values of Chlorine

FATAL DOSE	1000 ppm
TLV-STEL (Short Term Exposure Limit)	1.0 ppm
TLV-TWA (Threshold Limit Value Time Weighted Average)	0.5 ppm

Table 4.Effects of Chlorine at Various Concentrations

Concentration of Chlorine (ppm)	Effects of exposure
1000	Cause death within a few minutes
430	Lethal over 30 min exposure
40-60	Pulmonary edema
30	Immediate chest pain with vomiting and cough
5-15	Cause irritation to the respiratory tract and eyes
1-3	Definite odour, cause irritation to mucous membrane
0.5-1	Slight odour

1.5. DISPERSION OF CHLORINE GAS

1.5.1. Dispersion Phenomenon:

Dispersion is a phenomenon which is influenced by many factors like meteorological, topographical etc. It is very complicated to model a dispersion of gas because during the release of gas various factors act on it and make it complex. For different types of gas the dispersion process varies in its mechanism. Gases are classified as dense gas, buoyant gas and neutrally buoyant gas. To understand the process of dispersion it is very important to know about the source of release. The source of release may be instantaneous or continuous one. It depends upon the type of process and its condition of operation. The accidental release of chlorine can be threat to human life even at a distance far away from the point of release.

Chlorine being a heavy gas its vapour density is 2.48(Dandrieux et al., 2002) it always remains on the ground and thus possesses more risk to the population and the environment. Vapor cloud of chlorine is toxic by inhalation therefore it is necessary to predict the pollutant concentration when it release in the air and its variation with time and position.

Dispersion phenomenon mainly depends upon the

a) Meteorological conditions like wind speed, wind direction, relative humidity, cloud cover etc.

b) The topography of the area such as elevation.

c) Physical and chemical properties of the released gas.

Ambient air movement is responsible for the process of advection and diffusion of chlorine gas and its movement is also affected by gravitational force and it can loft on the ground. For both dense and neutrally buoyant gas cloud, the ambient wind dominates both the advection and diffusion. Wind velocity and turbulence are the two parameters which characterize the movement of the air. The roughness of the ground produces a drag on the moving air which produces velocity gradient of zero speed and it increases with the height. The roughness of the ground surface also generates turbulence within the wind field. The velocity field and turbulence are also affected by the topography factor because due to this the wind moves around these structures. Thermal effect also plays a major role in generating the turbulence for example as the sun warms the ground surface it makes the surface air to rise up.

The air dispersion model requires the wind – speed profile and it varies according to the height near the surface. Dispersion is affected by the vertical wind shear in the along wind direction. The irregularity of the ground surface on which the wind blows also affects the wind profile. Presence of trees, buildings, grasses can also affect the vertical profile of the wind. The dispersion parameters mainly depend on the stability class and surface roughness along with the time associated for the measurements. There are two classes of surface roughness i.e. urban corresponds to a large ground roughness and rural to a small surface roughness. In order to predict the dispersion pattern of chlorine gas there are two models i) Gaussian model and ii) Heavy Gas Dispersion model. The primary assumption of Gaussian model is the random occurrence of atmospheric turbulence and normal distribution in both the vertical and horizontal planes in the downwind direction (Rhyme, 1994). It works well for the pollutants which are not directly affected by gravity.

Heavy Gas Dispersion model shows that the vertical standard deviation for a denser gas is one quarter for a neutral buoyant gas and the horizontal standard deviation is four times for neutral buoyant gas. This is appropriate for vapour cloud whose density is greater than the ambient air and affected by gravity. The parameters which characterized Gaussian model are mainly based on empirical measurements and actual distribution of concentration from a source can vary significantly from Gaussian at any time instant.

Chlorine dispersion studies are mainly based on the assessment of the consequences of an accident (Dandrieux et al., 2002) to simulate the dispersion of chlorine gas release in order to estimate the effects of obstructions on a gas cloud and the toxicity effects on the population.

1.5.2. A Case Study on Accidental Release of Chlorine Gas:

Chlorine leakage from valve bonnet in a chlorine bullet in West Bengal:

In Durgapur, West Bengal there is a chloro-alkali plant. Chlorine is stored in cylindrical shaped horizontal, thermo cool insulated storage tanks. There are four storage tanks which contain chlorine in the liquid state. The tanks are made up of steel sheet 21-mm in thickness and 12.55m in length the inside diameter of the tank is 2.74 m. There is one manhole cover on the top of the tank. In each tank there are six valves which serve different functions. These valves are fitted with proper connections of all the necessary pipelines. The functions of the valves are outlet and inlet of liquid chlorine, for safety purpose and for equalizer and pressurization of air. In addition to this a safety relief valve and one rapture disc are also provided in each of the four liquid chlorine storage tanks (Gangopadhyay R.K et al., 2005).

Events Leading to the Accidents: On 9th of June in the year 1987 at around 11 pm degassing of chlorine tank took place from a chloro alkali plant of Durgapur in the district of Burdwan in West Bengal (Gangopadhyay R.K et al., 2005).The leakage of chlorine gas was noticed around the plant after about one hour. At about 2 am, the workers of the plant noticed the gas leak and found that the chlorine is leaking from outlet valve of third chlorine liquid tank.

Rectification of the leakage was done by tightening the valve but due to the bolts was very tight and there was chlorine leakage at the working spot. In order to reduce the chlorine leakage the valve was immediately closed and on proper checking it was seen that the leakage was from the bonnet joint of the valve. One stud nut was freely rotating and it was already sheared. To prevent the failure of other studs the higher authority decided to clamp the bonnet. Then about 7.30 am the degassing operation was started through equalizer, it was of possible to degas the two tanks at the same time because of common degas line. At about 8.30 am the plant declared emergency and a siren was released around the area (Gangopadhyay R.K et al., 2005).

After the occurrence of accident: Spraying of water from hydrant points was started with the help of three fire service hoses and the strength of water curtaining was increased by providing five more connection of hoses. Attempts were made to transfer the first tank into the second tank but it was also a failure due to there were no possibility of inter transfer. At about 5.30 pm the hole was plugged and that the leakage had also decreased to some extent.

The wind direction was towards the north, and in that direction there was no densely populated locality. But after 1.30 pm, the wind diverted to the south and it caused panic in the nearby localities. The residents vacated their residences temporarily in search for a safer shelter.A heavy shower of rain for some time brought relief by restricting the spreading of gas. Later the wind again started to blew in the north direction (Gangopadhyay R.K et al., 2005).

Casualties: 72 persons were affected and 9 were admitted to the hospital. After 72 hours all were discharged from the hospital. There was no serious case and none of them died (Gangopadhyay R.K et al., 2005).

Probable causes of the accident: The gas nuisance was noticed at 12 O' clock at night on 09.06.87 and it was presumed the leak is from the gland. These followings are the probable cause of the accidents may be wrong assumption of the source of chlorine gas leakage.

Mechanical failure of the equipments like bolts were jammed the tank was damage due to the corrosion of the metals. Mitigation was done at very late stage. The leakage of chlorine around the tank makes the place intolerable for the workers to continue their repairing process. Sudden temperature difference of the equipments leads to the failure of studs.

A large part of the liquid chlorine gets evaporated immediately with large expansion in volumes whereas a huge portion of chlorine released at a high velocity and settle on the ground in the form of crystalline solid chlorine hydrate. The chlorine hydrate is acidic in nature so in this case neutralization was very important. The neutralization of chlorine gas can be done with the help of caustic soda. But it was very late to perform the neutralization process (Gangopadhyay R.K et al., 2005).

1.6. OBJECTIVES OF THE DISSERTATION

As we have seen earlier that occurrence of chemical disaster is an unwanted event which can take place anywhere at any time. The loss caused by accidental release of gases cannot be repair but if we can predict and analyze the consequences of the gas release then damage can be minimized. The industrial profile of both areas is vast and rich so occurrence of accidental release of toxic gases cannot be neglected. There is a need of analyzing the consequences of release of gas for the two areas. The study is mainly based on the dispersion phenomenon of chlorine and its impact on the surrounding area and population during its sudden release. The objectives of the study are as follows:

- Recognition and specification of risk to the public residing near the industrial area.
- Estimation of distance affected from the release of chlorine gas using toxicological and physical properties of the chlorine and by using real time conditions.
- Prediction of indoors and outdoors concentrations of chlorine during its emission.
- Calculation of threat zones for the release of chlorine during the four seasons for both areas.
- Estimation of threat zones for concentration 350 ppm, 125 ppm, and 15 ppm.
- Calculating dose – response for concentration 350 ppm, 125 ppm, and 15 ppm for 5 min, 10 min and 15 min.

CHAPTER 2

Literature Review

Khan and Abbasi, 1997, carried out a risk assessment of a chloro alkali plant in the southern state of India. The study was based on MCAA. In this study with the help of MAXCRED six different accidents scenario was developed. The most important was domino effect of accident and second was the continuous release of toxic chlorine gas.

It is concluded that amount of gas storage and the conditions under which the substances are stored determine the nature of accidents. It gives an idea of different types of accident and their conditions of occurrence. For the calculation of toxic effect it calculates toxic load and its lethality with the help of the probit equation as

$$Pr = a + b\ln(C * t)$$

C is the concentration of the gas in ppm and a, b are gas constants. It states that for non flammable chemical there is no heat load but it can cause toxic dispersion. Confined vapour cloud explosion and fire ball are more likely to occur in case of flammable gas. The output of the study is very beneficial in development of the mitigation measure as it provides a clear scenario of different modes of accidents.

Dandrieux Aurelia et al., 2002, performs an experiment to understand the dispersion phenomenon of chlorine gas of small plume size. The accidents of chlorine gas do not occur only at larger scale but even a bottle of chlorine gas can lead to toxic emission of chlorine.

In this experiment 24 kg of chlorine gas is used in a bottle of 6.77 m^3 capacity. There were facilities for distribution of sensors and measurements of sensors, several meteorological data were also noticed. There were two categories of atmospheric stability i.e. is A and B. It proves that for the validation of heavy gas dispersion large scale experiments are required. As the parameters chosen for the experiments are changed then there is a need of set of standard deviations. The concentration of chlorine gas is highest along the axis of plume centerline. ALOHA model is not appropriate in the prediction of toxic release for shorter distances i.e. distances less than 100 m. When chlorine is highly concentrated then gravity and nature of dense gas effect should be considered. If any gas has a tendency to soluble in the air then the initial mass of the gas cloud could be decreased by the solvation process. It is studied that in the presence of water or moisture the chlorine gas cloud gets deflected. In order to determine the rate of weak release of chlorine there is some effective dilution.

Reeves et al., 2001, studied the effect of terrain and buildings on the behavior of heavy gas dispersion. This work is mainly by ERM. The models which are available to predict the dispersion of gas are based on flat and unobstructed terrain. But for a real scenario this type of model does not work well and therefore errors in the results occur. It can cause error up to 90% and overestimation of hazard range by factor 5. So it is very important to consider the type of terrain to minimize the errors as these results are very useful in land use planning as well as for hazard analysis. It uses Richardson number of scaling for wind tunnel simulation the equation is as follows

$$L_m \Delta\rho_m / U^2_m = L_f \Delta\rho_f / U^2_f$$

L, u and Δ can be adjusted according to the limitations of wind tunnel.This works suggests the effect of complex terrain which are dense gas cloud gets diverse, along the valleys the cloud forms channels, some amount of gases are entrapped on the sides of hills covered with ice, the gas spreads laterally at the foot of the upslope. All these can reduce the hazards of the dense gas and it is clear that the movement of gas cloud responds to the surrounding local topographical features. This study gives the idea of chlorine gas dispersion in real scenario.

Renjith et.al, 2010, There are number of techniques and methods are available for the hazard analysis and risk assessment. In this paper the authors have used Fuzzy Fault Tree analysis and his works also explained the beneficial aspects of this technique. Here basically two dimensional fuzzy fault tree analysis have been done. This method determines different aspects of hazard identification both in quantitative and qualitative. One of the best parts of the FTA is that it goes very well according to the industrial scenario of India. The total fuzzy possible score are calculated and then it is transform into fuzzy failure probability.

Khan and Abbasi, 1999, There are two types of releases routine emission and accidental release. Routine emission is the continuous release from a chemical plant and it is a long term emission where the source strength is continuous and well defined. The accidental release is for limited time duration which may include immediate health effects. Here the source strength may not be well defined. For the two different release scenario different dispersion models are used. Studies on chlorine release illustrate these followings reasons for accidental release of chlorine gas:

i) Frequent transportation of chlorine through different modes of transportation like railways, chlorine tank car etc.

ii) Accidents in storage vessels due to mechanical or human failure, corrosion of the storage vessels.

iii) When several derived compounds are mixed or react it causes chlorine gas release.

Saroha A.K, 2006, The density of chlorine gas is greater than air and it is a heavy gas with vapor density 2.48. Being denser than air chlorine gas resides on the ground and can mix up with the surrounding air which can be more dangerous to people. Chlorine is very reactive member of halogen group in the periodic table and it is found that it does not exist freely. Large scale production of chlorine is done by chloro-alkali process. In chloro-alkali process chlorine, hydrogen and sodium hydroxide are formed out of these three chlorine is the main product. At normal conditions it is a greenish yellow gas, liquid chlorine is amber yellow in colour and solid chlorine exists as a pale of yellow crystals in the form of chlorides, chlorates and perchlorates. The properties of chlorine are given in the Table No.5. Chlorine reacts with almost all the metals, organic materials, chlorinated hydrocarbon etc.

Table 5.Physical Properties of Chlorine

Molecular formula	Cl_2
Molecular weight	70.906
Melting point	-101°C
Boiling point	-34.6°C
Solubility in Water	0.7g per 100g of water at 20°C
Vapour pressure	6.315 atm at 20°C and 1 atm
Vapour Density	2.49 at 0°C

(Source: Material Safety Data Sheet of Chlorine)

CHAPTER 3

STUDY AREA

The study is based on two industrial areas i.e. Bhagwanpur located in Haridwar district of Uttarakhand and Durgapur located in the district of Burdwan district in West Bengal. Both the areas are completely different from each other in terms of location, topography, geographical surroundings, weather conditions etc. but similar in terms of development of industrialization.

3.1. Bhagwanpur at a glance:

Bhagwanpur (30.06 °N and 77.83°E) is a tehsil located in Haridwar district of Uttarakhand at 264 m above mean sea level. The total population of the village is 187,481 comprises of 99,758 male and 87,723 female. It is surrounded by Saharanpur in the west, in the north-east by Dehradun, Pauri Garhwal in the east and Bijnor and Mujaffarnagar in the southern part.

Due to its nearness of Himalayas it has an extreme erratic and continental climate. Summers starts late in March and continues up to July with average temperature 28°C and monsoon starts in July and goes on till October whereas from October to late November post monsoon prevails and winters start in December and the annual rainfall is 2600 mm.

This area is very rich in natural resources due to the proximity of Himalayas and Ganga River. Minerals like sand, gypsum and stone are available in abundance. Rajaji National Park presents a Shiwalik eco system. It is covered by thick Sal forest and it provides shelter to tiger, Himalayan bear, hyena, civets, goral etc.

There are total 85 industrial units in Bhagwanpur out of which 7 are small scales. The industries are comprises of textile, food processing, pharmaceuticals, packaging, plastics etc. Devbhoomi industrial is one of the main industrial units and SIDCUL in Haridwar. The main exportable items are fabric, automobile parts, UPS, electronic meter, pharma products, personal care products etc. Industrialization in Bhagwanpur generates employment opportunities. But it also offers a threat of loss of biodiversity, environmental degradation, deforestation and disasters like Bhopal Gas tragedy.

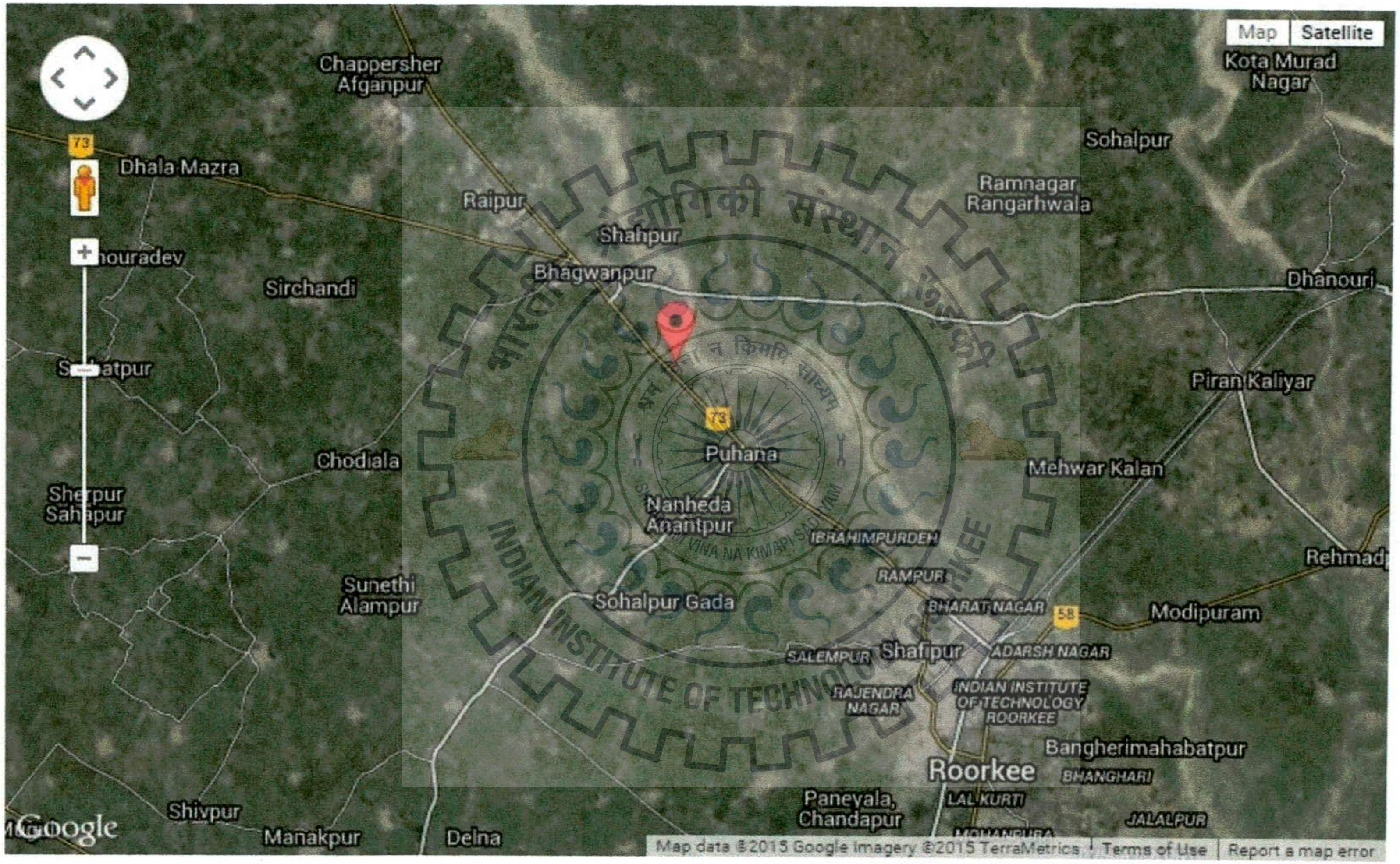


Fig 2. Satellite view of Bhagwanpur area

3.2. Durgapur at a glance:

Durgapur (23.48°N and 87.32°E) in Burdwan district of West Bengal is located on the banks of River Damodar and at a distance of 160 km from Kolkata city. It is situated at an altitude of 68.9 meters and its topography is undulating. It was mainly set up by Dr Bidhan Chandra Roy, the second chief minister of West Bengal. Durgapur is surrounded by Asansol in the west, in the east there is Bardhman Sadar subdivision, Bankura district lies in the south and in the north across River Ajay there is Birbhum district. According to 2011 census Durgapur had a population of 493,405 out of which 263,721 are males and 229,684 are females.

Durgapur experiences a transitional climate between tropical wet and dry climate. Summers starts from March and ends in the middle of June with an average temperature 32°C. Summers are followed by monsoons with low temperature and heavy precipitation. Durgapur receives annual rainfall of 52 inches and monsoons are followed by mild and dry winter from November to January with average temperature 20 °C. At the end of October there is autumn and in February there is spring season with a temperature of 25 °C.

Durgapur is one of the most industrialized cities in Eastern India and it is designed by Joseph Allen Stein and Benjamin Polk. Due to the proximity of coal mines areas of Asansol and Ranigunj there is a plenty supply of resources for the industries. The presence of NH 60 provides an excellent connectivity with the neighboring states. Damodar Valley Corporation, Durgapur Thermal Power Station, Durgapur Steel Plant, Hindustan Fertilizer Corporation, Durgapur Chemicals, Alloy Steels Plants Limited, Durgapur Cement Limited and many other large and small industries contributed a huge to the development of Durgapur City. Inspite of this development there is a threat to lives and properties as numerous chemical industries are situated in the closer proximity of residential areas. There is a high risk of chemical disaster and a lot of irreparable damage can occur due to a minor negligence. Many of these industries are comprised of heavy works like steel, cement electrical etc so the risks of accidents are also higher and more damaging than any other industries. It also possesses risk to the surrounding environment due to the presence of blast furnaces, big and small chimneys of various industries. So along with industrialization there is a necessity of focus on industrial safety, occupational safety and health safety.

Fig 3. Satellite view of Durgapur area

CHAPTER 4

METHODOLOGY

Dispersion of gas is a function of atmospheric conditions like wind speed and direction. Average of 5 years meteorological data of Durgapur and Bhagwanpur are provided in Table 5 and 7 for the simulation using ALOHA. The data are further classified into four seasons of the year summer, monsoon, post monsoon and winter as shown in Table 6 and 8. The source of meteorological data is Agricultural Meteorological Division of India under India Meteorological Department.

The industrial data is same for both the areas and it is basically industrial data of a chloro-alkali plant of Durgapur. In 1987 chlorine release took place in that plant and using the same source strength a dispersion model is developed for the present situation for the two areas. Then after the completion of the simulation a comparative study is done.

Material safety data sheet of chlorine provides all the information about the properties of chlorine both physical and toxicological.

For the simulation of chlorine dispersion ALOHA software is used. With the help of this software four scenarios of accidental release of chlorine gas are developed for the two areas. ALOHA also helps to predict the maximum indoor and outdoor concentration of chlorine for both the areas.

The calculations of threat zone are first done by ALOHA then with the help of Google earth the areas of the threat zones are drawn.

The probit analysis is done for the three concentrations of chlorine for three time period of exposure. After the analysis of probit variables, mortality % for all the three concentrations is calculated with the help of statistical tool.

4.1. ALOHA (Areal Location of Hazardous Atmosphere) model of dispersion of gas: There are many types of software available for risk and consequences analysis like PHAST, FMEA etc. But these softwares are costly and complex to operate. As for our present study time period is short and due to unavailability of some data working on these softwares would be very difficult.

To overcome this problem we have choose ALOHA model of dispersion of gas. It is very easy to operate and require less input data but provide important outputs which are beneficial for our research purpose. It was developed by the USEPA, CEPPO and NOAA. It gives an estimation of the spatial extent affected by the accidental release of volatile and flammable gases or chemicals. It mainly deals with health hazards of humans due to the inhalation of toxic chemical vapors, thermal radiation from chemical fires etc. In this study the latest version of ALOHA model 5.4.1 (published in February 2007) is used and it is freely available to the users by NOAA of the United States and EPA (Environmental Protection Agency).ALOHA model of dispersion proves to be an important and useful tool for the toxic gas cloud assessment and in recognizing the threat zones (I, Y.P, et al,. 2009).

4.1.1. DESIGN CRITERIA AND LIMITATIONS: The ALOHA model of dispersion is built upon the principles of Gaussian dispersion model of continuous and buoyant air pollution flumes (Tseng J.M et al., 2012). It requires data on local atmospheric conditions, chemical identity and details about the accident scenario. It provides a close upper bound to the distance of threat associated with the toxic chemicals. It is very easy and can be used during a spill event and results are graphically represented. ALOHA also provides estimation of the gas release and volatilization rate of chemicals for different accident scenarios. It can be run quickly on computers and easily transportable. ALOHA is designed to predict spill event for the threat zone in the range of 10^2 to 10^5 with a time limit of 1 hour. It does not account for the effect of terrain and buildings. It uses a wind field which varies with elevation but does not with time and horizontal position. It cannot be used for very low wind speeds or calm conditions. It is applicable only where wind speed is greater than 1 meter per second.

4.1.2. HEAVY GAS MODEL FOE DENSE GASES: ALOHA used heavy gas dispersion model based on the DEGADIS model (Havens and Spicer, 1985). There are some simplifications which makes ALOHA different from DEGADIS model. ALOHA –DEGADIS is limited for the release at the ground level and it does not account for the initial momentum from the jet release. Aloha used ambient air pressure which is independent of position and time. It assumes that the pollutant and air are behaving as non-interacting ideal gases. ALOHA is designed to model time dependent releases of gases. ALOHA-DEGADIS model predict longer distances for steady state and continuous releases. It also uses the principles of Gaussian models. The correlation between the estimated maximum concentrations by the two models is 0.994%. ALOHA-DEGADIS model is slightly conservative than DEGADIS model. If the user is not confirmed which model should be used for a particular scenario then in this case ALOHA can make the decision easily and thus it saves time of the user.

4.1.3. TOXICOLOGICAL DATA: ALOHA mainly uses levels of concerns (LOC) to determine the impact of toxic gas release on human populations. LOC can predict the response of general public to a short term gas release and it is specific to chemicals for toxic inhalation hazards. In the database of ALOHA it also includes AEGLs, ERPGs, PACs and IDLH. It includes 60 minutes AEGLs and 60 minutes ERPGs exposure time limit. IDLH limits are available to the users in the list of LOCs. It was developed for making decisions in case of respiratory use. Only single IDLH value is defined for applicable chemicals.

4.1.4. CHEMICAL RELEASED FROM GAS TANK: ALOHA mainly estimates the amount of chemical substances that release into the air due to the rupture of a tank. It only deals with the tank containing single chemical. When the gas release from the tank ALOHA reevaluates the conditions of the tank and it can modify the release rate calculation as required. The release rate of the chemical substance depends upon the phase of release, the driving pressure and the nature of rupture. ALOHA can modeled two types of rupture a hole in the wall of the tank and release of gas through a short pipe or valve. The tanks which contain the liquid, the rupture can takes place above the level of the liquid or below the level of the liquid or at the liquid level. It predicts that when a gas is released into the atmosphere it immediately dispersed downwind and can ignite to form a jet fire.

4.1.5. CHARACTERIZATION OF WIND FIELD AND TURBULENCE: The impact of atmospheric turbulence on the rate of dispersion is very major. Stability is the tendency of the atmosphere which can resist or enhance the vertical motion and turbulence. There are three types of atmosphere i.e. stable atmosphere which inhibits the vertical mixing; neutral atmosphere does not play any role in the mixing with the air and an unstable atmosphere which enhances the vertical mixing and turbulence. In case of atmospheric stability solar radiation plays a very vital role. With the increase and decrease of temperature of the air the vertical mixing and turbulence is affected. In ALOHA model stability classification is a central factor. According to Pasquill

(Pasquill, 1961) there are six classes of atmospheric stability which is now known as Pasquill-Gifford-Turner stability classes. Stability class A, B and C defined unstable condition where D represents neutral stability and E and F represents stable atmospheric conditions.

4.1.6. THREAT ZONE: The threat zone in ALOHA mainly represents the area within which the ground level gas concentration exceeds the concern level at any time. The pollutant concentration is a function of both time and location. ALOHA calculates the peak concentration for all the points in the space and generates a threat zone. The concentrations which are predicted by ALOHA are time – averaged over different interval of time and it depends upon the type of dispersion model employed. The contours for threat zone can be drawn through the maximum concentration where it equals to LOC. The maximum concentration exceeds the LOC at the points within the threat zone. With the help of the confidence lines the uncertainties in the average wind direction can be represented. The threat zone axis is rotated through an angle on either side of the wind and then the rotated threat zone contour is drawn.

With the help of export threat zones command the threat zones can be transferred to Google earth and satellite view of the affected area is generated. It is a very interesting feature of ALOHA because the satellite view of the threat zone clearly explains the particular places which are likely to be affected by the accidental release of chlorine gas.

4.1.7. INDOOR AIR CONCENTRATION: Indoor air concentration is that a well insulated building provides an excellent protection against a toxic gas cloud of a finite time period. Air behaves completely different inside of a building than outside. Inside of a building there are obstruction like walls and ceilings. Not only has that heating up process also affected indoor air concentration. Therefore it is very difficult to know the exact indoor air concentration.

The wind creates a pressure difference which drives the infiltration and exfiltration depending upon the pressure gradient direction. In this case the temperature difference creates a pressure gradient which enhances the infiltration process. This is simplified with the help of ALOHA. It is assumed that the inside and outside concentration of the toxic gas are uniform and environmental conditions are also stationary in time.

4.2.CALCULATION OF DOSE–RESPONSE WITH THE HELP OF PROBIT ANALYSIS

There are many cases of accidental release of toxic gas in many parts of the world and these accidents demonstrate that analysis of acute exposure threat of the individual due to the contact of released toxic gas is very important. It mainly depends upon two factors namely concentration of the toxic substance and time of exposure.

Toxicity is defined as the ability of a substance that can produced an undesirable effect when the substance has reached a sufficient concentration at a particular site in the living body (Zang & Guo-ming, 2010). It can be chemical toxicant, biological toxicant or physical toxicant. Chemical toxicant mainly includes inorganic substances like lead, mercury, cadmium etc. Biological toxicant are comprises of bacteria, viruses which can induced diseases in human. Physical toxicant interferes with the living body and disturbs the biological processes eg.coal dust, silicon fibers, asbestos etc.

On the basis of dose – response function toxicological considerations are done and for this purpose probit equations are available. This equation is available for variety of toxic materials and their exposure to the population. It is a type of regression which can be used to determine binomial response variable. Probit analysis mainly transforms the sigmoid curve of dose-response into a straight line which can be analyzed further by regression either by least square method or by maximum likelihood. It can be done by three methods

i) By using the table to determine the probits and finding the relationship by eye

ii) By manually calculating the probits , regression coefficient and confidence interval.

iii) With the help of statistical package like SPSS.

The probit variable Y can be expressed by the equation (1)

$$\boldsymbol{Y = A + B \ln(V)} \qquad (1)$$

In eq (1) A and B are toxic gas constants and V represents the amount of toxic dose. The values of A and B are different for various toxicants and it can be found from the table no 6 given by (Zang & Guo-ming, 2010)

Table 6.Toxic Gas Constant

	A	B
Ammonia	-35.9	1.85
Carbon Monoxide	-37.98	3.7
Chlorine	-8.29	0.92
Hydrogen Chloride	-16.85	2.00
Hydrogen Cyanide	-29.42	3.008
Nitrogen Dioxide	-13.79	1.4
Phosgene	-19.27	3.686
Sulfur Dioxide	-15.67	2.10
Hydrogen Sulfide	-31.42	3.008

The probit variable can be converted into % of mortality (P) with the help of the equation (2) where erf is error function and also by Finney's Table (Finney, 1952) by determining the probit to the corresponding % responded.

$$P = 50\left[1 + \frac{Y-5}{|Y-5|}\,\mathrm{erf}\left(\frac{|Y-5|}{\sqrt{2}}\right)\right] \quad \text{.............................} (2)$$

Transformation of Probits to % of Mortality

%	0	1	2	3	4	5	6	7	8	9
0	--	2.67	2.95	3.12	3.25	3.36	3.45	3.52	3.59	3.66
10	3.72	3.77	3.82	3.87	3.92	3.96	4.01	4.05	4.08	4.12
20	4.16	4.19	4.23	4.26	4.29	4.33	4.36	4.39	4.42	4.45
30	4.48	4.50	4.53	4.56	4.59	4.61	4.64	4.67	4.69	4.72
40	4.75	4.77	4.80	4.82	4.85	4.87	4.90	4.92	4.95	4.97
50	5.00	5.03	5.05	5.08	5.10	5.13	5.15	5.18	5.20	5.23
60	5.25	5.28	5.31	5.33	5.36	5.39	5.41	5.44	5.47	5.50
70	5.52	5.55	5.58	5.61	5.64	5.67	5.71	5.74	5.77	5.81
80	5.84	5.88	5.92	5.95	5.99	6.04	6.08	6.13	6.18	6.23
90	6.28	6.34	6.41	6.48	6.55	6.64	6.75	6.88	7.05	7.33
--	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
99	7.33	7.37	7.41	7.46	7.51	7.58	7.65	7.75	7.88	8.09

Table 7.AVERAGE OF METEOROLOGICAL DATA OF BHAGWANPUR AREA FROM 2010 TO 2014

	Month of the year											
PARAMETERS	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Rainfall (mm)	1.88	10.99	2.69	1.88	16.75	156.39	211.49	178.45	111.06	1.67	0.06	0.47
Max temperature (°C)	17.76	19.43	24.52	31.12	34.55	38.25	35.15	31.00	33.16	30.01	25.61	23.85
Min temperature (°C)	5.22	8.11	10.56	16.66	19.87	24.13	24.14	24.12	22.72	16.64	12.98	7.64
Total cloud cover (octa)	1.31	2.42	2.44	4.33	1.73	1.01	4.72	5.86	1.98	0.88	22.72	0.63
Max relative humidity (%)	71.59	78.38	69.68	68.33	59.88	46.60	72.45	91.76	79.18	75.87	83.72	71.48
Min relative humidity (%)	31.81	41.65	35.13	33.28	27.94	21.71	40.85	63.14	53.07	42.72	44.75	34.03
Wind speed (kmph)	5.80	6.51	7.036	7.25	7.01	8.07	5.62	4.95	5.49	4.84	5.74	5.46
Wind direction (°)	206.14	179.08	160.98	184.6	185.21	171.26	202.60	123.68	104.37	173.00	267.54	186.57

(Source; Agricultural Meteorological Division of India under India Meteorological Department.)

Table 8.AVERAGE OF METEOROLOGICAL DATA OF BHAGWANPUR AREA FROM 2010 TO 2014 (SEASON WISE)

Seasons of the year				
PARAMETERS	**Summer (Mar-May)**	**Monsoon (Jun-Sep)**	**Post monsoon (Oct-Nov)**	**Winter (Dec-Feb)**
Rainfall (mm)	7.12	164.35	0.86	4.45
Max temperature (°C)	30.07	34.39	27.81	20.34
Min temperature (°C)	15.79	23.77	14.83	6.99
Total cloud cover (octa)	2.83	3.39	11.81	1.45
Max relative humidity (%)	65.97	72.51	79.81	73.81
Min relative humidity (%)	32.12	44.69	43.74	35.83
Wind speed (kmph)	7.11	6.03	5.29	5.92
Wind direction (°)	176.93	150.48	220.27	190.59

Table 9.AVERAGE OF METEOROLOGICAL DATA OF DURGAPUR FROM 2010 TO 2014

	Month of the year											
PARAMETERS	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Rainfall (mm)	80	0.66	0	0	2.46	3.3	11.85	11.86	6.85	7.34	0	0
Max temperature (°C)	25.4	28.93	32.06	38.26	38.86	37.05	33.8	33.36	33.44	32.31	29.76	26.7
Min temperature (°C)	12.71	16.33	18.73	26.26	26.86	26.55	26.15	25.66	25.58	23.68	17.6	12.07
Total cloud cover (octa)	0.77	2.06	1.6	0.8	3.26	5.4	6.5	5.73	4.58	3.08	0.9	2.3
Max relative humidity (%)	55.6	55.93	57.4	75.93	71.14	77.75	88.95	93.86	91.29	92.08	69.53	54.6
Min relative humidity (%)	30.54	29.13	22.8	18.8	28.06	38.7	60.65	66.53	61.73	67.57	43.06	31.5
Wind speed (kmph)	8.42	7.93	6.73	9.8	13.46	14.4	9.05	8.76	6	4.34	6.6	7.35
Wind direction (°)	204.74	133.06	211.86	182.33	192.13	176.05	143.8	163.5	168.79	191.65	195.53	120.27

(Source; Agricultural Meteorological Division of India under India Meteorological Department.)

Table 10.AVERAGE OF METEOROLOGICAL DATA OF DURGAPUR FROM 2010 TO 2014 (SEASON WISE)

Seasons of the year				
PARAMETERS	**Summer (Mar-May)**	**Monsoon (Jun-Sep)**	**Post monsoon (Oct-Nov)**	**Winter (Dec-Feb)**
Rainfall (mm)	0.82	8.46	3.67	0.22
Max temperature (°C)	36.39	34.41	31.03	27.01
Min temperature (°C)	23.85	25.98	20.64	13.52
Total cloud cover (octa)	1.88	5.55	1.99	1.71
Max relative Humidity (%)	68.15	87.96	80.82	55.37
Min relative Humidity (%)	23.22	56.90	55.31	30.39
Wind speed (kmph)	10.24	9.55	5.47	7.90
Wind direction (°)	195.44	163.03	193.59	152.69

4.3 Modeling of Dispersion of Chlorine Gas Release in Bhagwanpur and Durgapur

4.3.1. Input Data:

Input data are mainly meteorological data and industrial data i.e. data of chlorine storage tank.

Table 11.Meteorological data of Bhagwanpur and Durgapur for scenario I

Summer Season

	Bhagwanpur	Durgapur
Wind Direction	176.93°	195.44°
Wind Speed	1.975 m/s	2.86 m/s
Temperature	22.93 °C	30.17 °C
Cloud Cover	3 tenths	2 tenths
Relative Humidity	49 %	46 %
Atmospheric Stability	C	C

Table 12.Meteorological data of Bhagwanpur and Durgapur for scenario II

Monsoon Season

	Bhagwanpur	Durgapur
Wind Direction	150.48°	163.03°
Wind Speed	1.67 m/s	2.67 m/s
Temperature	29.08 °C	30.19 °C
Cloud Cover	4 tenths	6 tenths
Relative Humidity	59 %	73 %
Atmospheric Stability	C	C

Table 13.Meteorological data of Bhagwanpur and Durgapur for scenario III

Post Monsoon Season

	Bhagwanpur	Durgapur
Wind Direction	220.27°	193.59°
Wind Speed	1.47 m/s	1.52 m/s
Temperature	21.32 °C	25.85 °C
Cloud Cover	10 tenths	2 tenths
Relative Humidity	62 %	68 %
Atmospheric Stability	C	C

Table 14.Meteorological data of Bhagwanpur and Durgapur for scenario IV

Winter Season

	Bhagwanpur	Durgapur
Wind Direction	190.59°	152.69°
Wind Speed	1.64 m/s	2.21 m/s
Temperature	13.66 °C	20.35 °C
Cloud Cover	2 tenths	2 tenths
Relative Humidity	53 %	43 %
Atmospheric Stability	C	C

4.3.2. Local Information

Location: Bhagwanpur and Durgapur

Building Air Exchange Per Hour: 0.23 (sheltered double storied)

Time: January 5, 2015 1737 hours ST.

4.3.3. Chemical Information

Chemical Name: Chlorine

Molecular Weight: 70.91g/mol

AEGL-1 (60 min): 0.5 ppm

AEGL-2 (60 min): 2 ppm

AEGL-3 (60 min): 20 ppm

IDLH: 10 PPM

Ambient Boiling Point: -34.7°C

Vapour Pressure at Ambient Temperature: greater than 1 atm

Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

4.3.4. Source Strength:

Leak from short pipe or valve in horizontal cylindrical tank

Non-flammable chemical is escaping from tank

Duration of release is 1 minute

Table 15.Parameters of Chlorine storage tank

Diameter	2.74 m
Length	12.55 m
Volume of tank	74.0 m^3
Internal Temperature of tank	-10 °C
Amount of Chemical Mass stored	61.3 tons
Opening Diameter of tank	1.5 m
Distance of Opening from the tank bottom	10 inches
% of liquid in the tank	50 %

CHAPTER 5

RESULT AND DISCUSSION

In order to determine the dispersion pattern of chlorine gas release in Bhagwanpur and Durgapur total number of eight simulations are performed. Each simulation gives distinct and comparable results. These results were sufficient to know the concentration of chlorine gas which can affect the area, the area of threat zones and maximum indoor and outdoor concentration of chlorine gas. The area in red colour signifies 350 ppm, orange colour is for 125 ppm and green colour describes 15 ppm. The main important features of results are as follows:

5.1 Scenario I dispersion of chlorine gas during summer season

5.1.1 Distances affected by the gas release: In Bhagwanpur during summer season the distances affected due to the chlorine gas release for the concentration of 350 ppm, 125 ppm and 15 ppm are 2.6 km, 3.6 km and 7.2 km respectively. But for Durgapur the distances are smaller in comparison with Bhagwanpur.

In Durgapur 350 ppm travels up to 1.9 km 2.7 km for 125 ppm and 6.0 km for 15 ppm. For the three concentrations the differences in distance between both areas are 700 m, 900 m and 800 m. The differences in distances may be due to various factors mainly weather parameters and topographical conditions. Because for both the areas the source strength is same so there is no possibility of differences in release condition of the chlorine gas.

5.1.2 Threat zones: In Bhagwanpur the area which can be affected by 350 ppm concentration is Telpura and its nearby area. Aurangzebpur can be affected by 125 ppm and the area of Biharigarh, Nanakgarh and Thappel Islampur by 15 ppm concentration of chlorine.

In Durgapur Netaji Colony, Khudiram Colony, Kadamtal, Netaji Subhas Pally can be affected by the chlorine gas of 350 ppm concentration. The area of Sagarbhanga can shows the toxic effects of 125 ppm of chlorine gas concentration. On the other hand the areas and parts of Durgapur like Bidhan Nagar, DPL Coke Oven Colony and Kaliganj can be affected by 15 ppm concentration.

5.1.3 Maximum outdoor and indoor concentration: For Bhagwanpur the maximum outdoor concentration is 451 ppm and indoor concentration is 9.7 ppm. The maximum outdoor concentration is greater than 350 ppm and indoor concentration is less than 15 ppm. It means that the area can be affected by maximum of 451 ppm.

The outdoor concentration of Durgapur is 0.61 ppm which is very less in comparison with 350 ppm it may be due to the plant is located in an open space without any obstruction. It can dilute the large concentration of chlorine in the surrounding area. The maximum indoor concentration is 0.02 ppm under this concentration of chlorine there is no harmful effects on health. It implies that the people inside the buildings are safe under this level of chlorine concentration. The outdoor concentration In comparison with Bhagwanpur, the area of Durgapur possesses less threat of chlorine release and its effects.

5.2 Scenario II dispersion of chlorine gas during monsoon season

5.2.1 Distances affected by the gas release: In Bhagwanpur during monsoon season the distances affected due to the chlorine gas release for the concentration of 350 ppm, 125 ppm and 15 ppm are 2.1 km, 2.9 km and 5.8 km respectively. But for Durgapur the distances are smaller in comparison with Bhagwanpur.

In Durgapur 350 ppm travels up to 1.8 km, 2.7 km for 125 ppm and 6.0 km for 15 ppm. For the three concentrations the differences in distance between both areas are 300 m, 200 m and 200 m. The difference in distances with respect to summer season is less. It may be due to the fact that there is not a huge difference in meteorological parameters for monsoon season.

5.2.2 Threat zones: In Bhagwanpur the area which can be affected by 350 ppm concentration is Telpura and its nearby area. Aurangzebpur can be affected by 125 ppm and the area of Biharigarh, Nanakgarh, Kheri, Meerpur and Thappel Islampur by 15 ppm concentration of chlorine.

In Durgapur Netaji Colony, Sukumar Nagar, Adibedi and Khejurtala can be affected by the chlorine gas of 350 ppm concentration. The area of DPL Coke Oven Colony, Birbhanpur and Nepali Para can shows the toxic effects of 125 ppm of chlorine gas concentration. On the other hand the areas and parts of Durgapur like Sagarbhanga, Bidhan Nagar, Fuljhore, Asishnagar and Kalipur can be affected by 15 ppm concentration.

5.2.3 Maximum outdoor and indoor concentration: For Bhagwanpur the maximum outdoor concentration is 304 ppm and indoor concentration is 10.5 ppm. Both maximum outdoor concentration is less than 350 ppm and indoor concentration is less than 15 ppm. It means that the area can be affected by maximum of 304 ppm.

The outdoor concentration of Durgapur is 2.02 ppm which is very much less in comparison with 350 ppm it may be due to the plant is located in an open space without any obstruction. It can dilute the large concentration of chlorine in the surrounding area. The maximum indoor concentration is 0.06 ppm under this concentration of chlorine there is no harmful effects on health. It implies that the people inside the buildings are safe under this level of chlorine concentration.

5.3 Scenario III dispersion of chlorine gas during post monsoon season

5.3.1 Distances affected by the gas release: In Bhagwanpur during monsoon season the distances affected due to the chlorine gas release for the concentration of 350 ppm, 125 ppm and 15 ppm are 2.2 km, 2.7 km and 5.8 km respectively. But for Durgapur the distances are smaller in comparison with Bhagwanpur.

In Durgapur 350 ppm travels up to 2.1 km, 2.9 km for 125 ppm and 5.8 km for 15 ppm. For the three concentrations the differences in distance between both areas are 100 m, 200 m and 0 m. The difference in distances with respect to summer and monsoon season is less. It may be due to the fact that there is not a huge difference in meteorological parameters for monsoon season. The temperatures and relative humidity of both the places are more or less same. And among all the four seasons, the distance travelled by 350 ppm concentration in Durgapur is greatest.

5.3.2 Threat zones: In Bhagwanpur the area which can be affected by 350 ppm concentration is Tanda Hasongarh and its nearby area. Telpur can be affected by 125 ppm and the area of Biharigarh, Tanda Deshral, Kutubpur Grunt and Thappel Islampur by 15 ppm concentration of chlorine.

In Durgapur DPL Coke Oven Colony, Sagarbhanga and Kadamtal can be affected by the chlorine gas of 350 ppm concentration. The area of Adibedi, Muchipara, and Kalipur can shows the toxic effects of 125 ppm of chlorine gas concentration. On the other hand the areas and parts of Durgapur like, Dhunaraplot, Bamunara, Gopalpur, Kaliganj and City centre are affected by 15 ppm concentration.

5.3.3 Maximum outdoor and indoor concentration: For Bhagwanpur the maximum outdoor concentration is 428 ppm and indoor concentration is 10.6 ppm. Both maximum outdoor concentration is greater than 350 ppm and indoor concentration is less than 15 ppm. It means that the area can be affected by maximum of 428 ppm.

The outdoor concentration of Durgapur is 399 ppm which is more in comparison with 350 ppm. The maximum indoor concentration is 12.9 ppm under this concentration of chlorine it can cause harmful effects on health like respiratory mucous membrane irritation. It implies that the people inside the buildings are not safe under this level of chlorine concentration during post monsoon season. This is because of the fact large amounts of moisture is present which entraps chlorine gas and make uneasy for the surrounding people.

5.4 Scenario IV dispersion of chlorine gas during winter season

5.4.1 Distances affected by the gas release: In Bhagwanpur during monsoon season the distances affected due to the chlorine gas release for the concentration of 350 ppm, 125 ppm and 15 ppm are 2.7 km, 3.7 km and 7.3 km respectively. But for Durgapur the distances are smaller in comparison with Bhagwanpur.

In Durgapur 350 ppm travels up to 1.7 km, 2.5 km for 125 ppm and 5.7 km for 15 ppm. For the three concentrations the differences in distance between both areas are 1000 m, 1200 m and 1600 m. The difference in distances of threat zone for the two areas is maximum with respect to other season. It may be due to the fact that there is a huge difference in meteorological parameters for monsoon season.

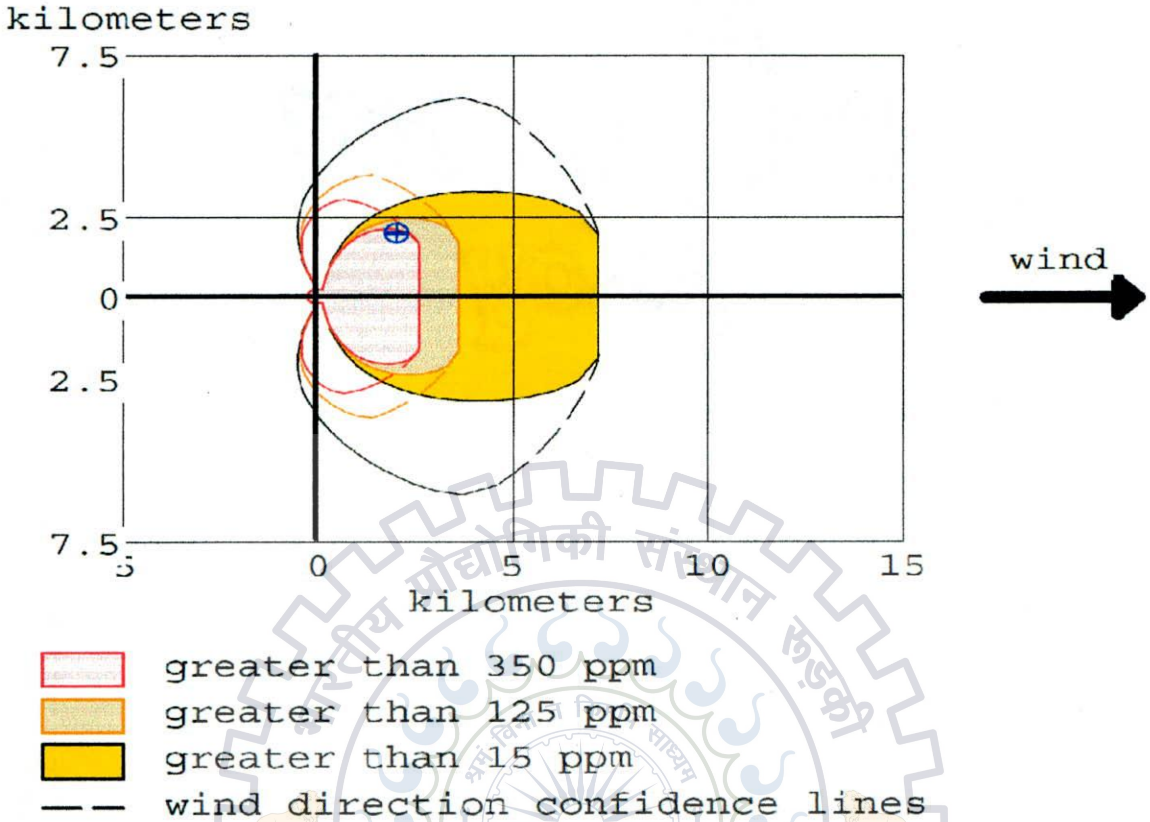
In case of Bhagwanpur the area can be greatly affected during winter season than any other season due to the presence of fog and mist. On the other side in winter season the area of Durgapur is less likely to damage. In winter season the threat zone of chlorine ga sin Durgapur is the minimum.

5.4.2 Threat zones: In Bhagwanpur the area which can be affected by 350 ppm concentration is Aurangzebpur, Hasiawala, Ganja, Telpur and its nearby area. The area of Biharigarh, Nanakgarh, Budhwa Shahid and Gokulwala can be affected by 125 ppm and Tanda Deshral, Banjarewal, Lodiwal and Thappel Islampur by 15 ppm concentration of chlorine.

In Durgapur Adibedi, Khejurtala, Birbhanpur and School para can be affected by the chlorine gas of 350 ppm concentration. The area of DPL Coke Oven Colony, Nepalipara and Asishnagar can shows the toxic effects of 125 ppm of chlorine gas concentration. On the other hand the areas and parts of Durgapur like, Sagarbhanga, Kalipur, Bamunara and City centre are affected by 15 ppm concentration.

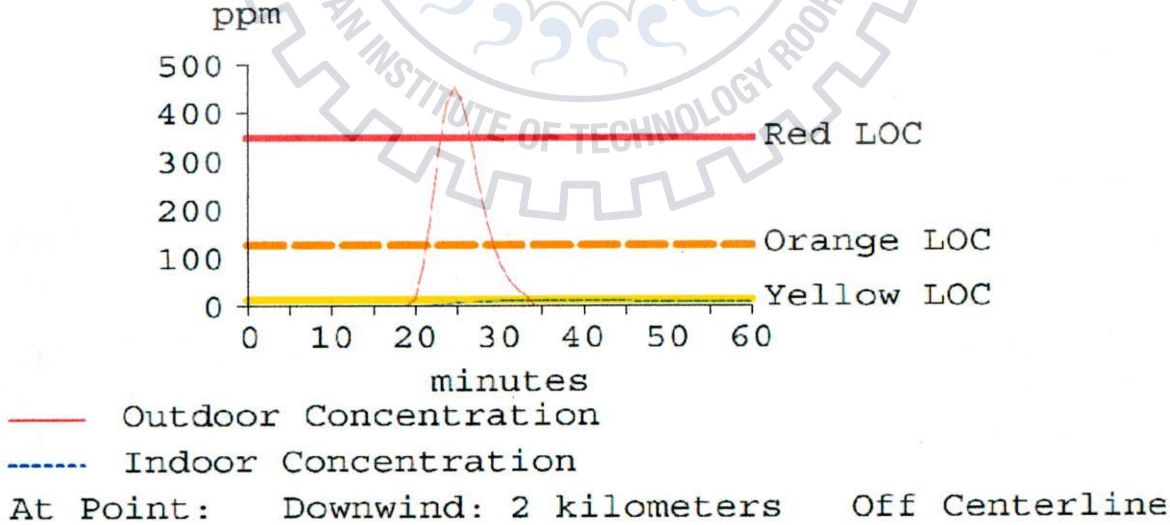
5.4.3 Maximum outdoor and indoor concentration: For Bhagwanpur the maximum outdoor concentration is 979 ppm and indoor concentration is 26.3 ppm. Both maximum outdoor concentration is greater than 350 ppm and indoor concentration is greater than 15 ppm. It means that the area can be affected by maximum of 979 ppm.

The outdoor concentration of Durgapur is 22.9 ppm which is less in comparison with 350 ppm. The maximum indoor concentration is 0.52 ppm under this concentration of chlorine does not cause harmful effects on health. It implies that the people inside the buildings are safe under this level of chlorine concentration during winter season. This is because of the fact that large distance is travelled by the chlorine gas which does not allow the accumulation of toxic chlorine.



RED : 2.6 Km ----- (350 ppm) ORANGE : 3.6 Km-----(125 ppm) YELLOW : 7.2 Km-----(15 ppm)

Fig 4.Threat zones of Bhagwanpur during summer season in terms of distance



MAX CONCENTRATION ---------- OUTDOOR: 451 ppm INDOOR: 9.73 ppm

Fig 5.Concentration in terms of time from the source in 2 km downstream and 2 km out of the centerline

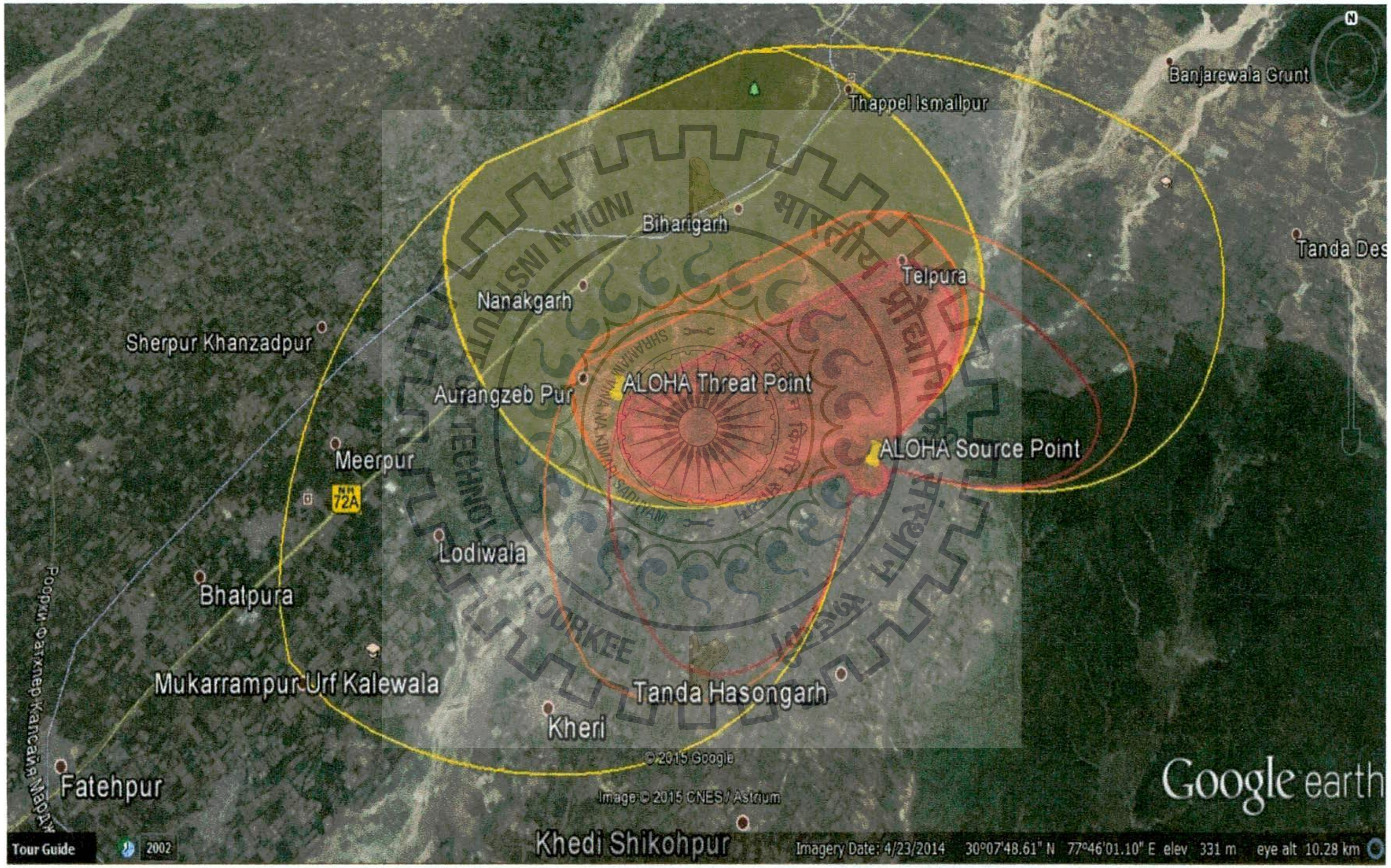
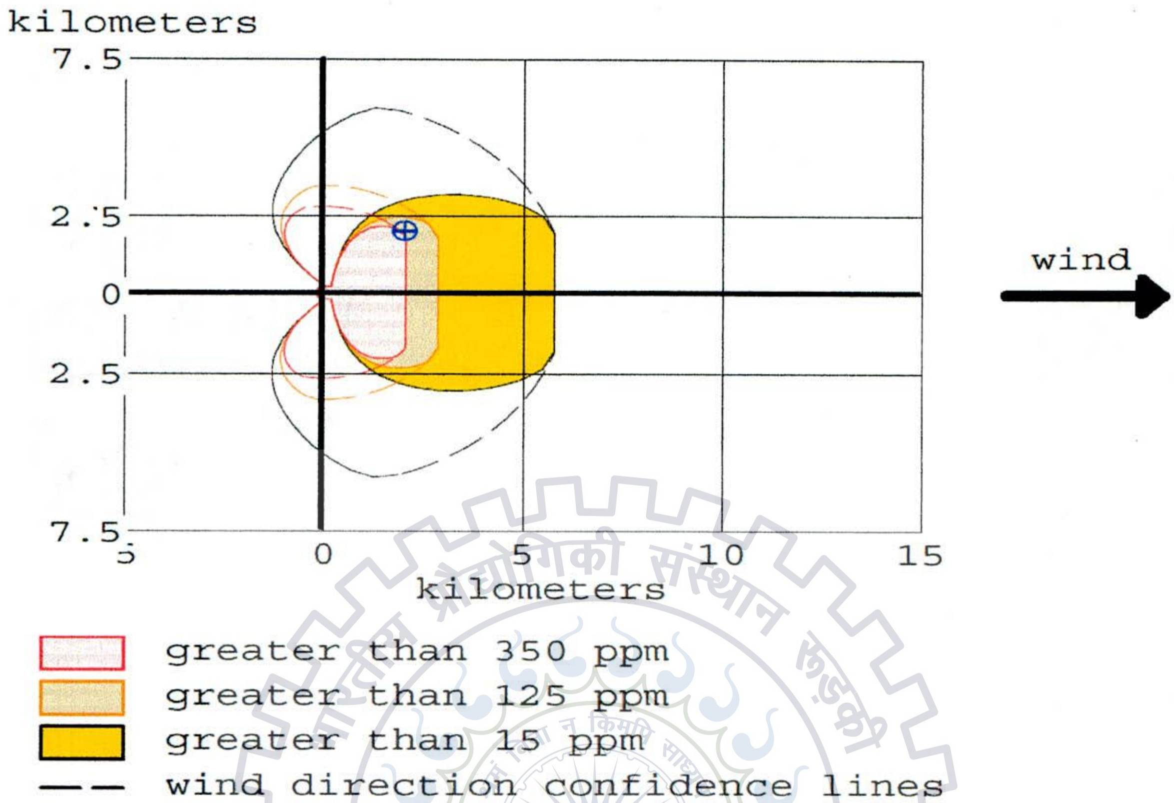
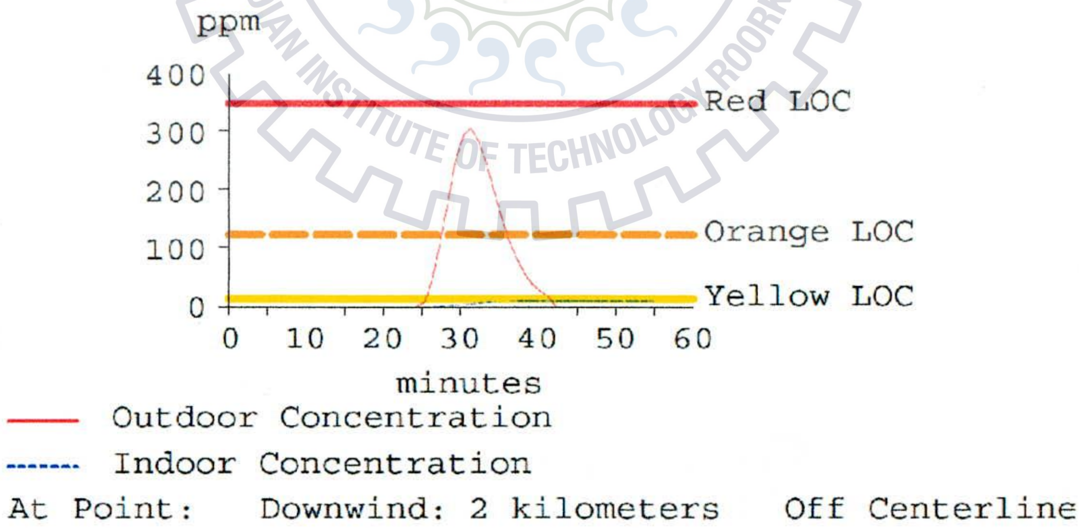


Fig 6.Threat zones of Bhagwanpur during summer season



RED : 2.1 Km ----- (350 ppm) ORANGE : 2.9 Km-----(125 ppm) YELLOW : 5.8 Km-----(15 ppm)

Fig 7. Threat zones of Bhagwanpur during monsoon season in terms of distance



MAX CONCENTRATION ---------- OUTDOOR: 304 ppm INDOOR: 10.5 ppm

Fig 8.Concentration in terms of time from the source in 2 km downstream and 2 km out of the centerline

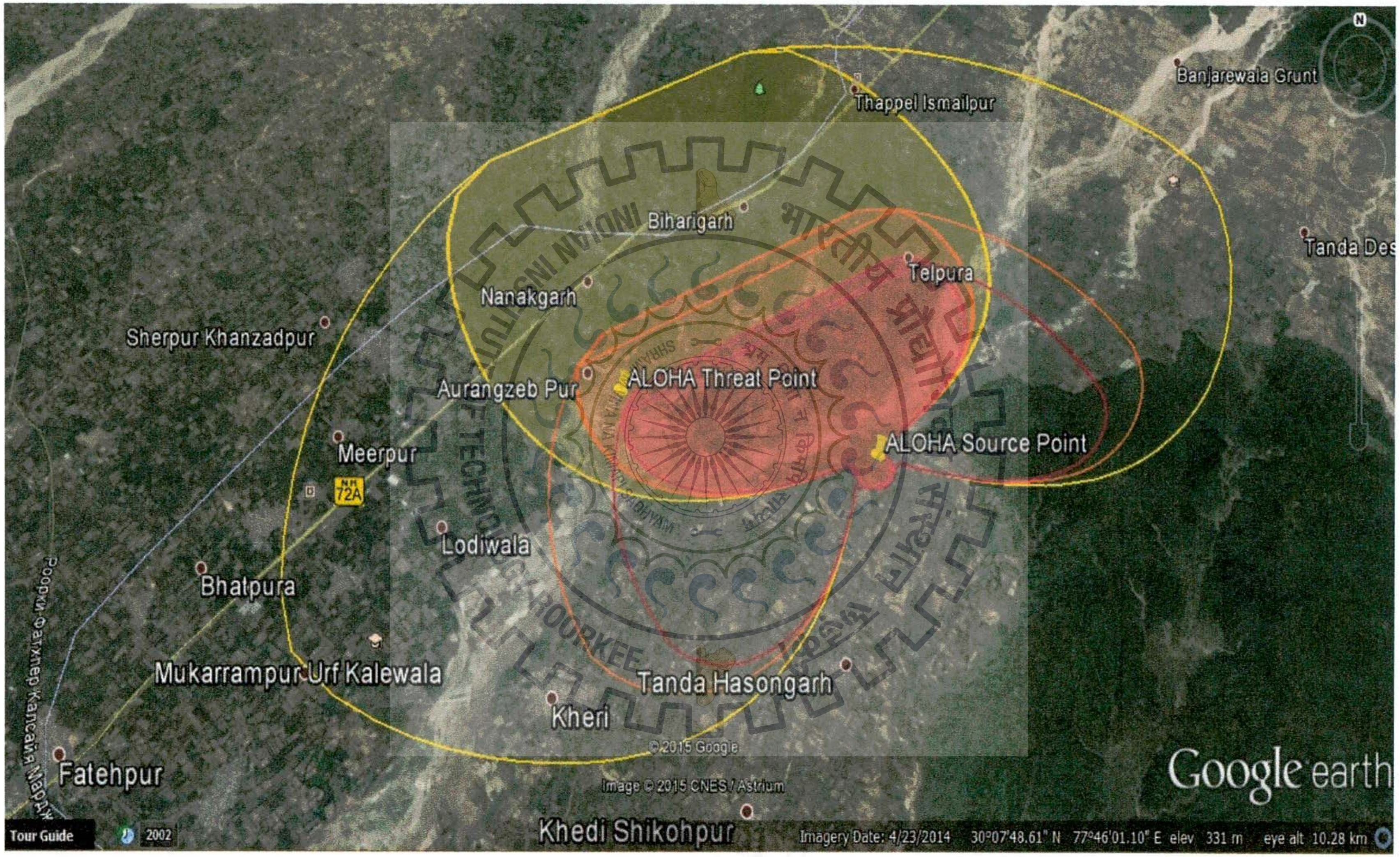
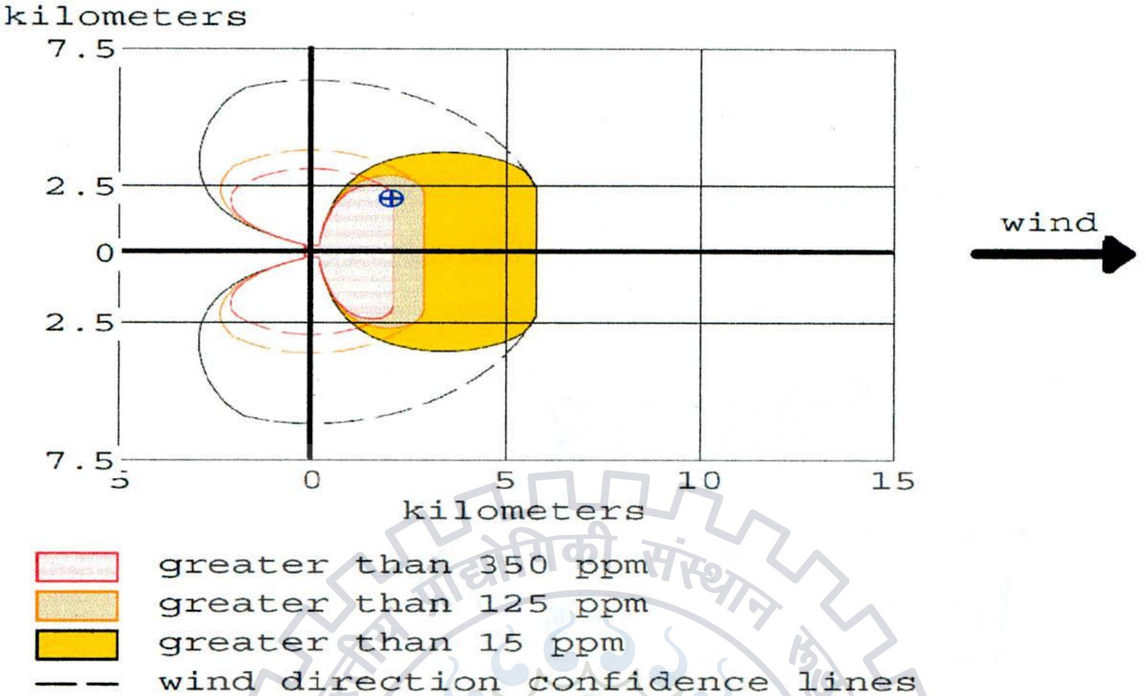
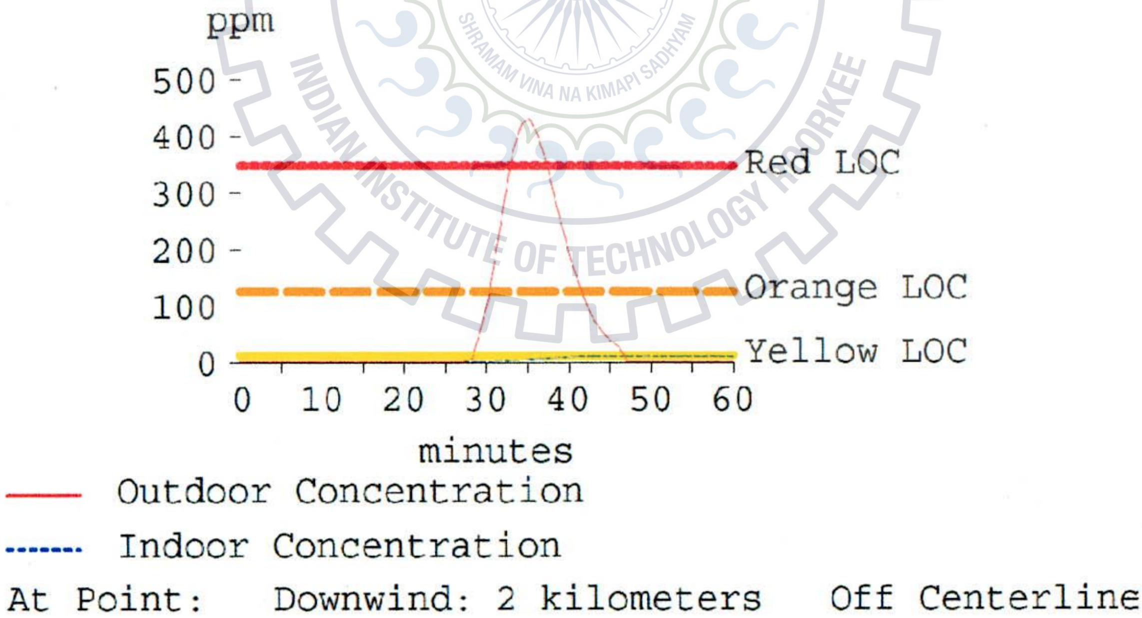


Fig 9.Threat zones of Bhagwanpur during monsoon season



RED : 2.2 Km ----- (350 ppm) ORANGE : 2.7 Km-----(125 ppm) YELLOW : 5.8 Km-----(15 ppm)

Fig 10.Threat zones of Bhagwanpur during post monsoon season in terms of distance



MAX CONCENTRATION ---------- OUTDOOR: 428 ppm INDOOR: 10.6 ppm

Fig 11.Concentration in terms of time from the source in 2 km downstream & 2 km out of the centerline

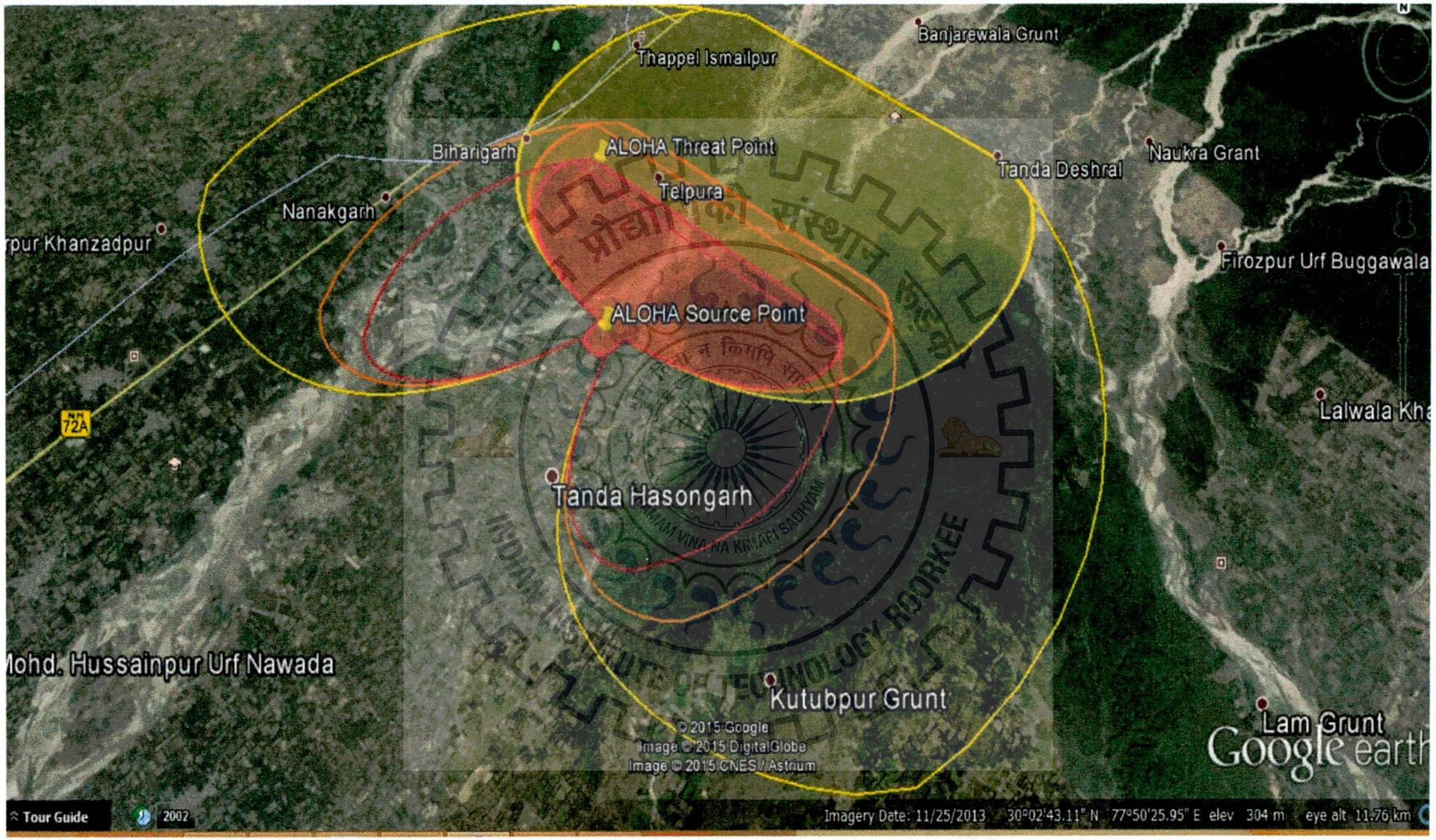
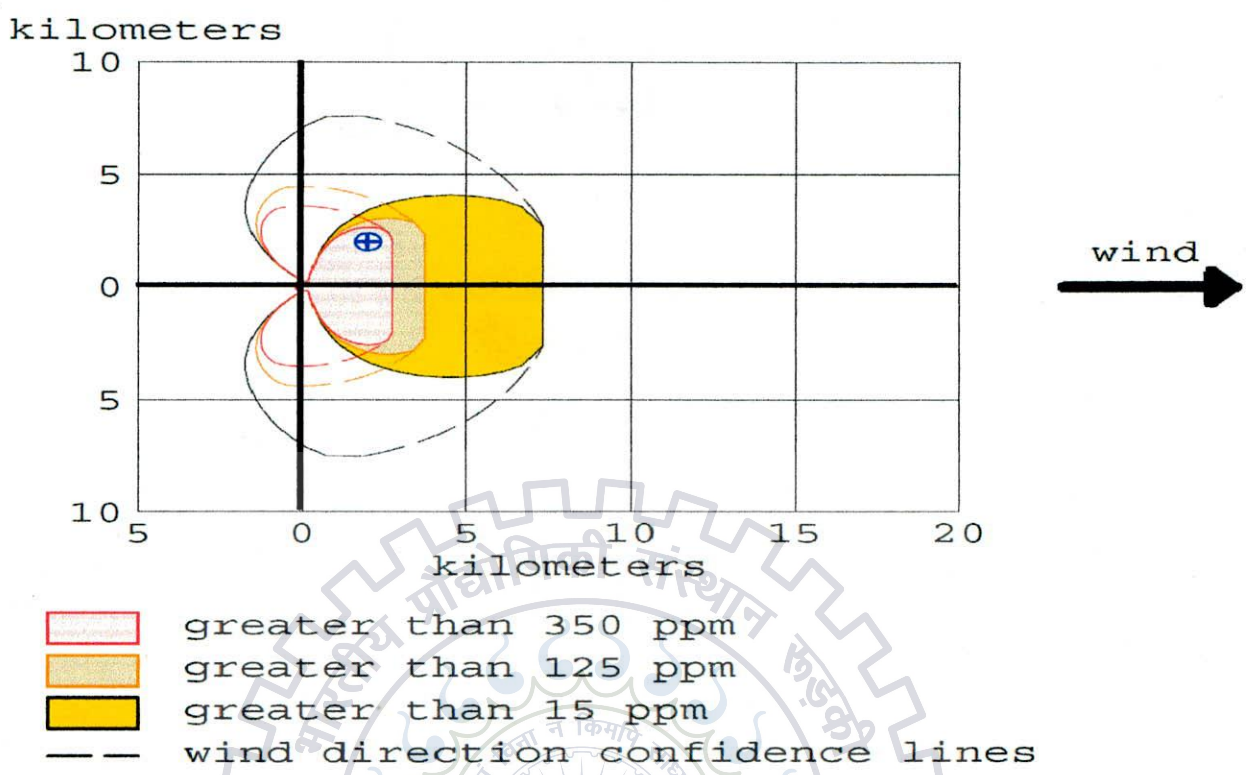
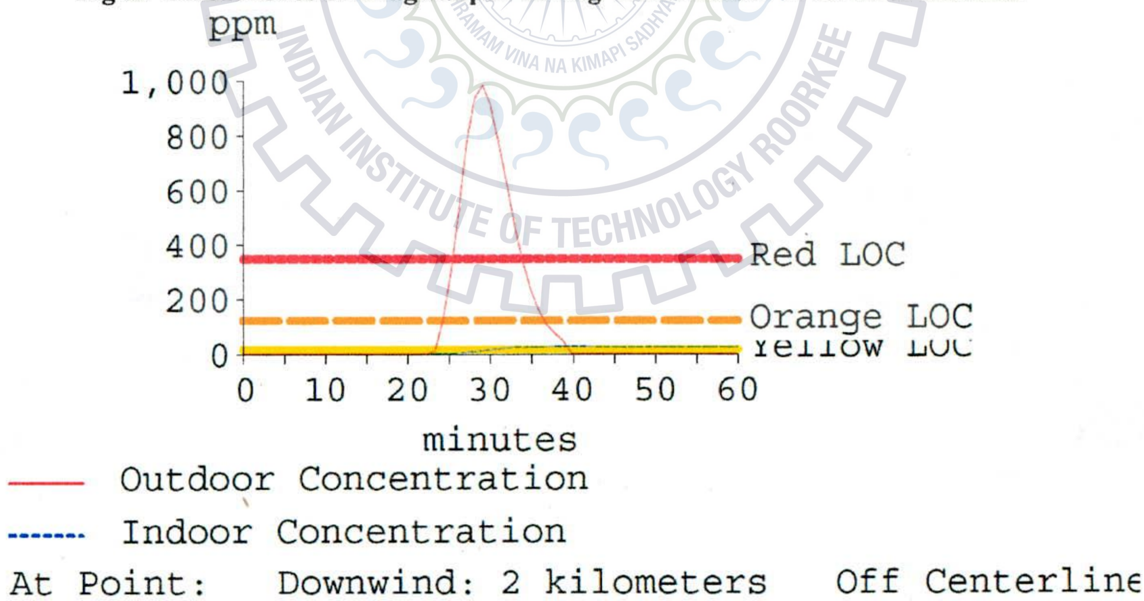


Fig 12.Threat zones of Bhagwanpur during post monsoon season



RED : 2.7 Km ----- (350 ppm) ORANGE : 3.7 Km-----(125 ppm) YELLOW : 7.3 Km-----(15 ppm)

Fig 13 Threat zones of Bhagwanpur during winter season in terms of distance



MAX CONCENTRATION ---------- OUTDOOR: 979 ppm INDOOR: 26.3 ppm

Fig 14.Concentration in terms of time from the source in 2 km downstream & 2 km out of the centerline

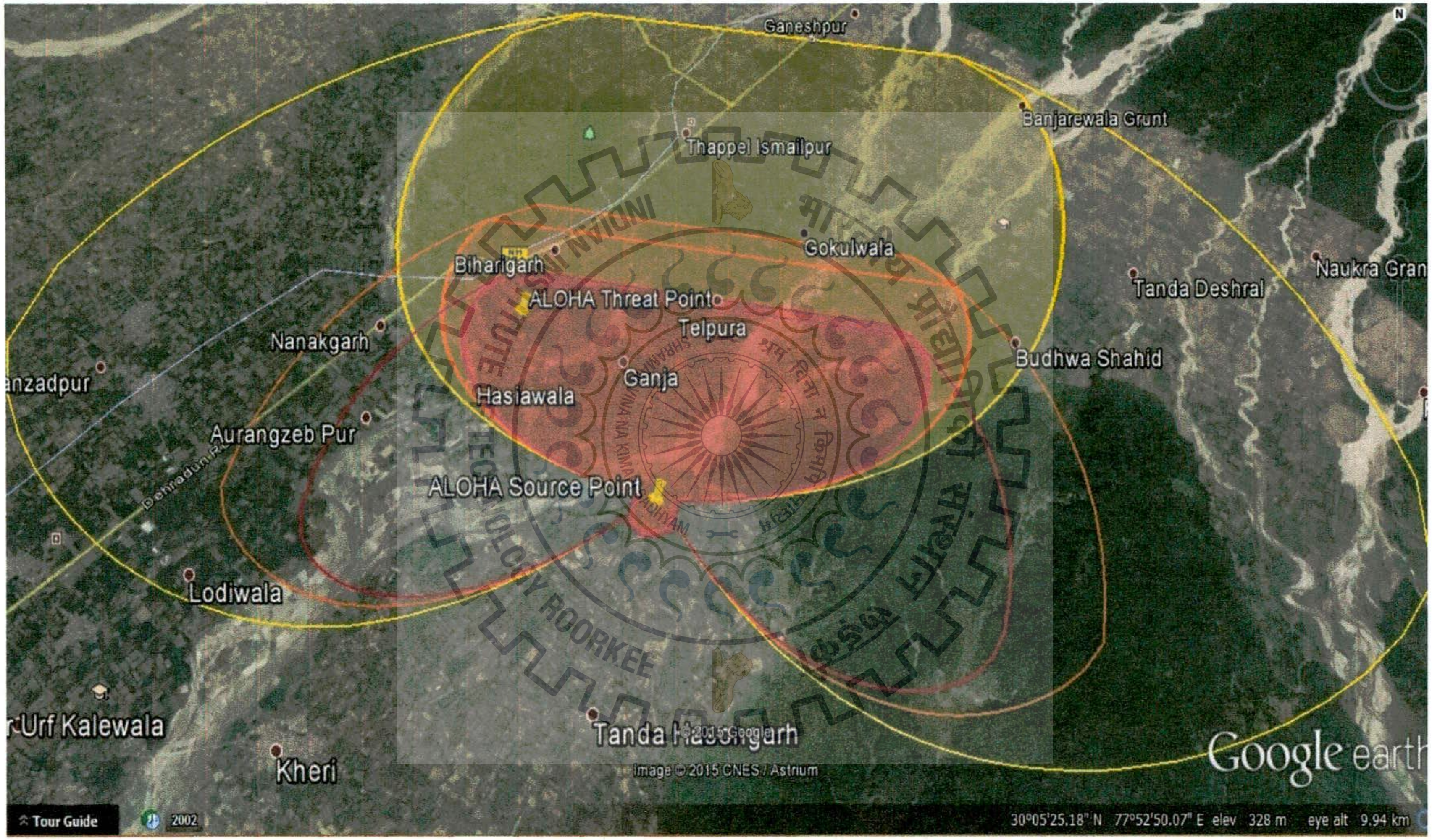
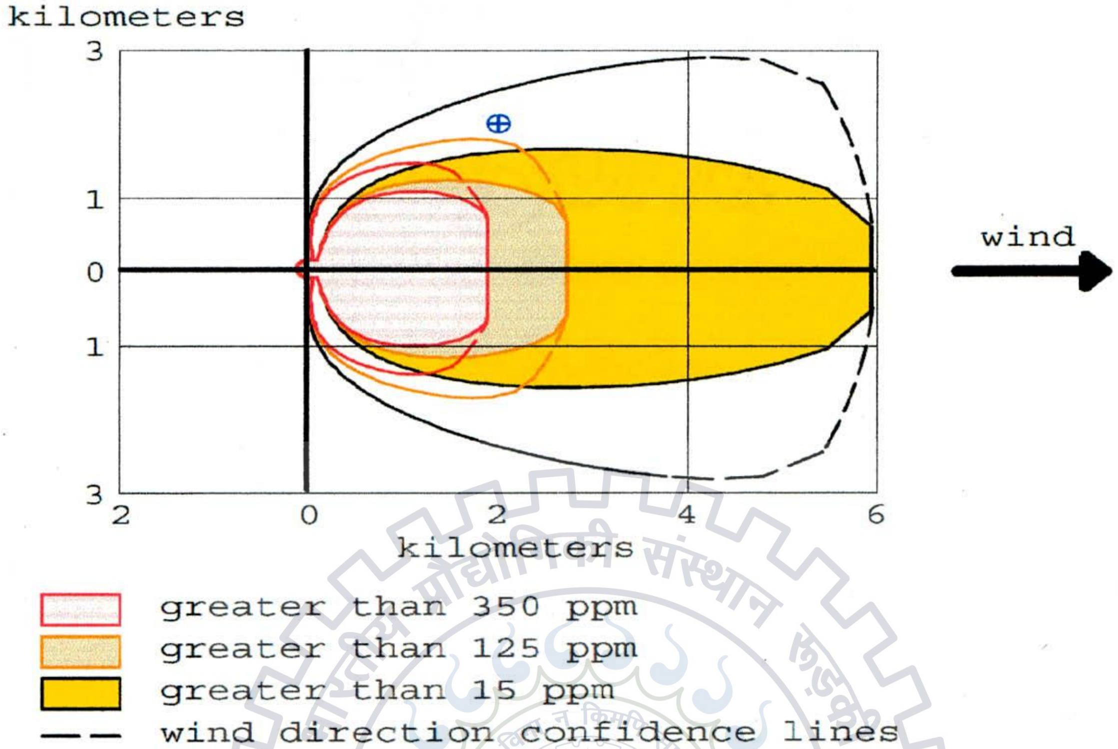
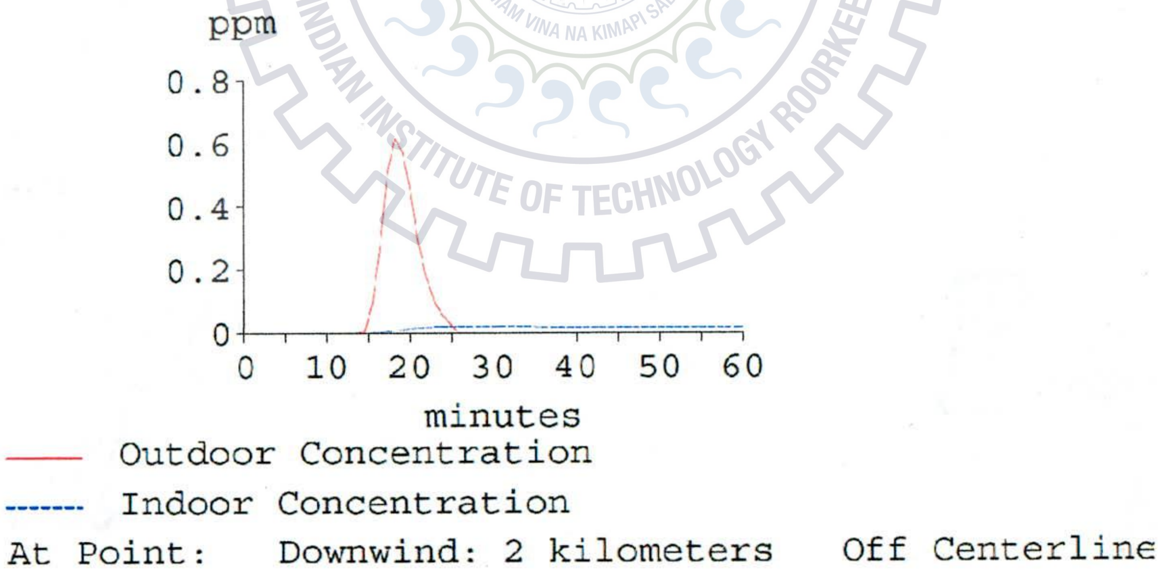


Fig 15.Threat zones of Bhagwanpur during winter season



RED : 1.9 Km ----- (350 ppm) ORANGE : 2.7 Km-----(125 ppm) YELLOW : 6.0 Km-----(15 ppm)

Fig 16. Threat zones of Durgapur during summer season in terms of distance



MAX CONCENTRATION ---------- OUTDOOR: 0.611 ppm INDOOR: 0.0173 ppm

Fig 17.Concentration in terms of time from the source in 2 Km downstream & 2 Km out of the centerline

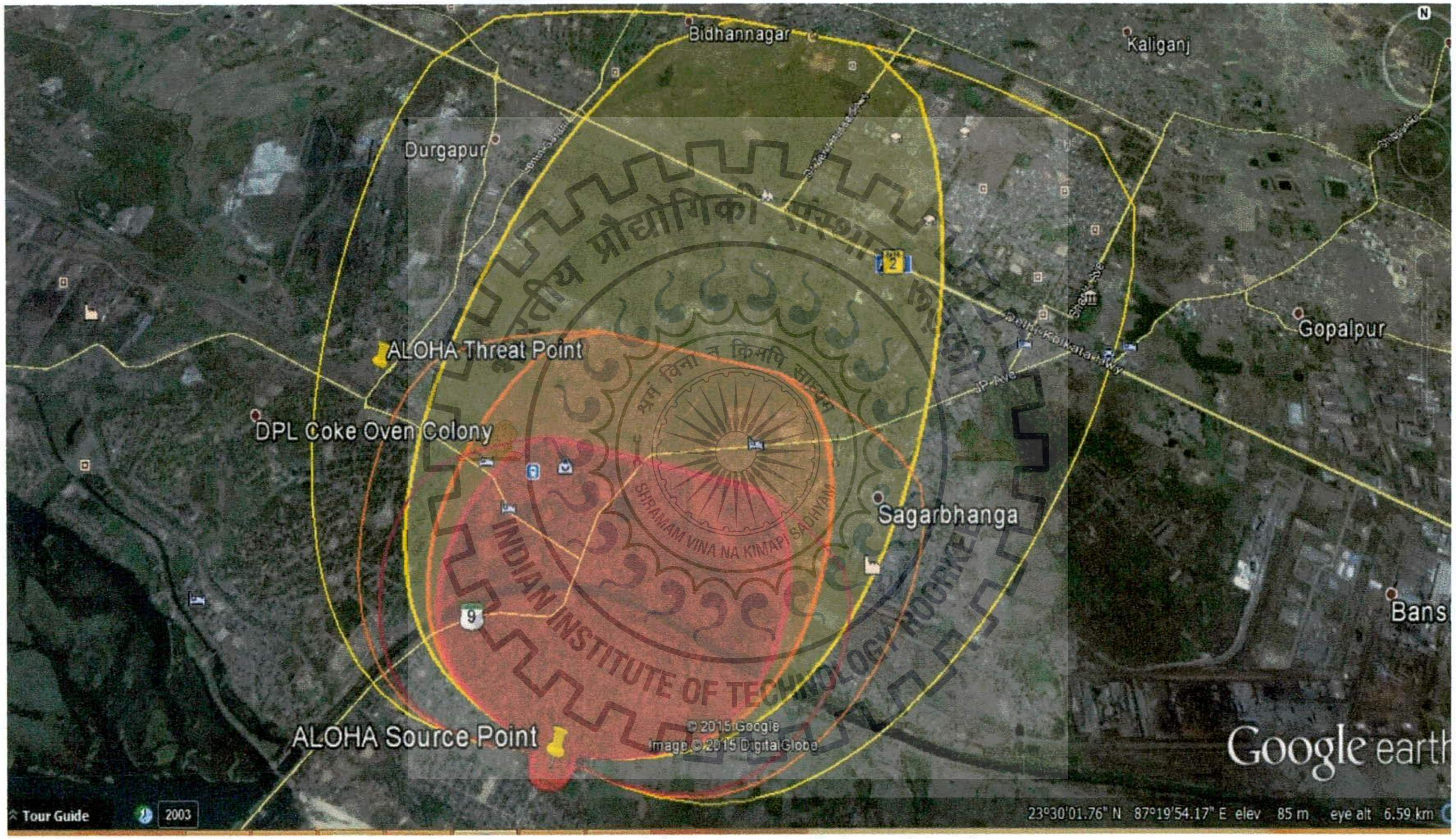
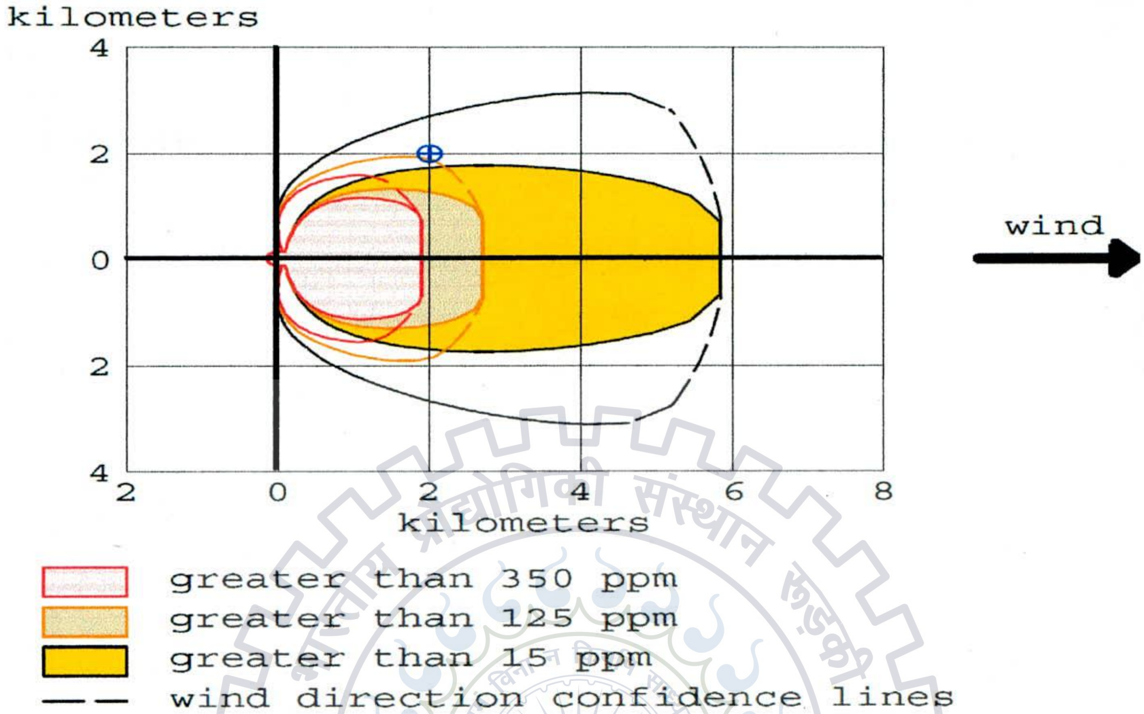
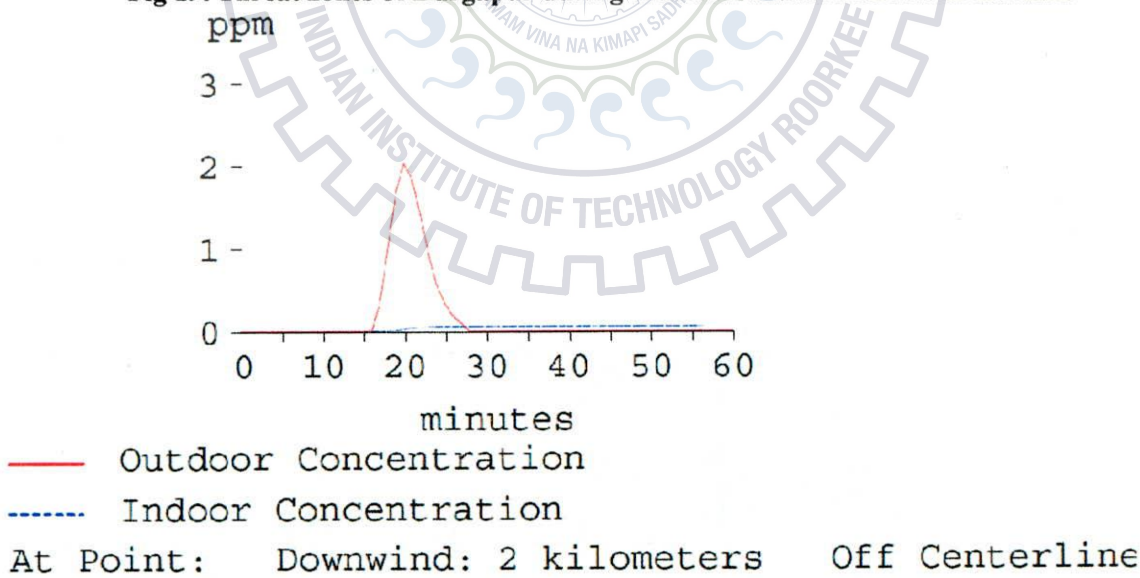


Fig 18.Threat zones of Durgapur during summer season



RED : 1.8 Km ----- (350 ppm) ORANGE : 2.7 Km-----(125 ppm) YELLOW : 6.0 Km-----(15 ppm)

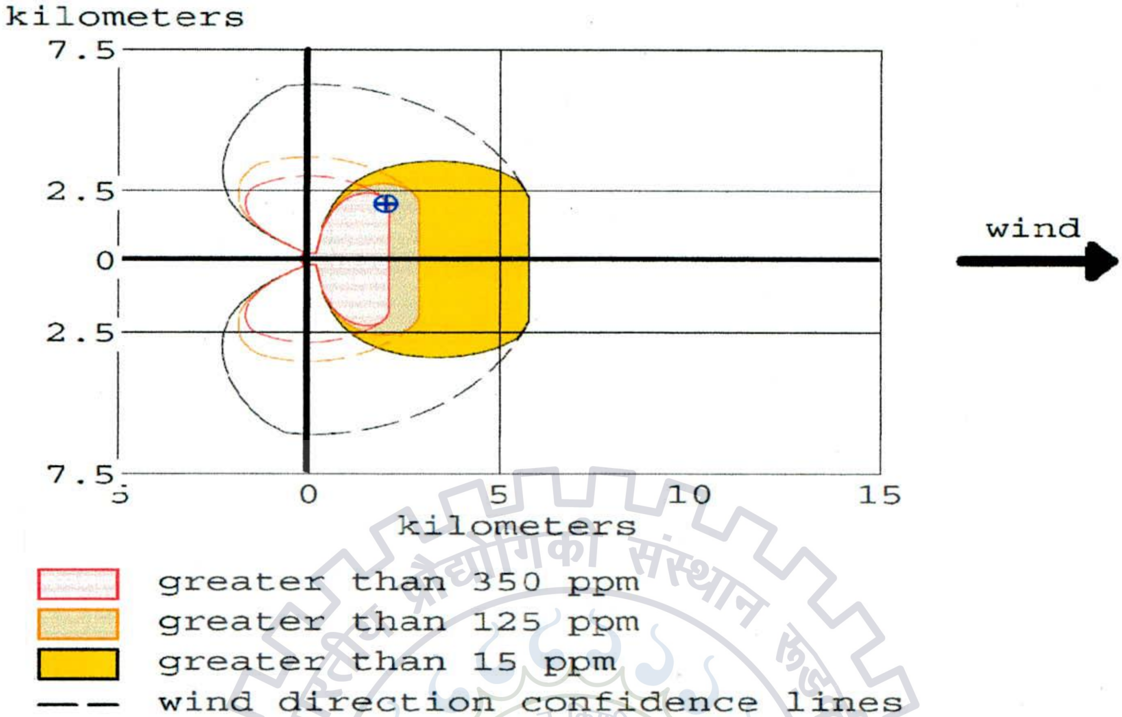
Fig 19. Threat zones of Durgapur during monsoon season in terms of distance



MAX CONCENTRATION ---------- OUTDOOR: 2.02 ppm INDOOR: 0.0588 ppm

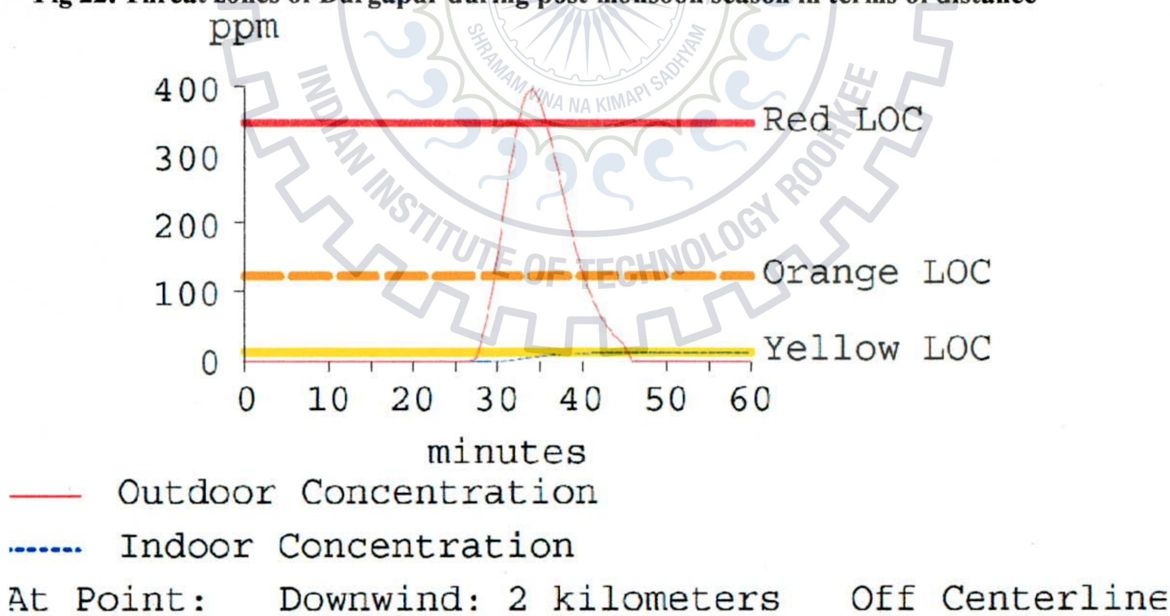
Fig 20.Concentration in terms of time from the source in 2 km downstream & 2 km out of the centerline

Fig 21.Threat zones of Durgapur during monsoon season



RED : 2.1 Km ----- (350 ppm) ORANGE : 2.9 Km-----(125 ppm) YELLOW : 5.8 Km-----(15 ppm)

Fig 22. Threat zones of Durgapur during post monsoon season in terms of distance



MAX CONCENTRATION ---------- OUTDOOR: 399 ppm INDOOR: 12.9 ppm

Fig 23.Concentration in terms of time from the source in 2 km downstream & 2 km out of the centerline

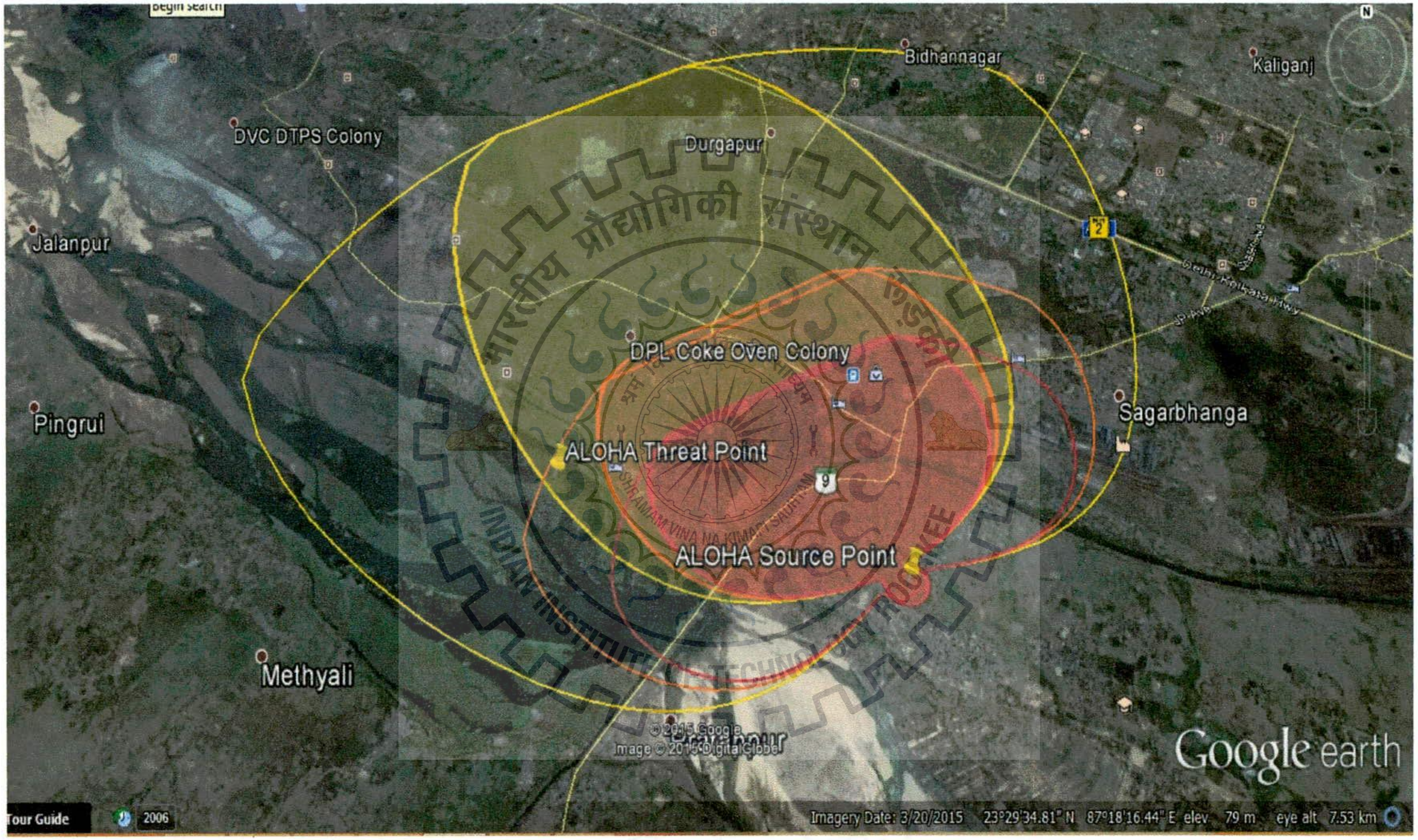
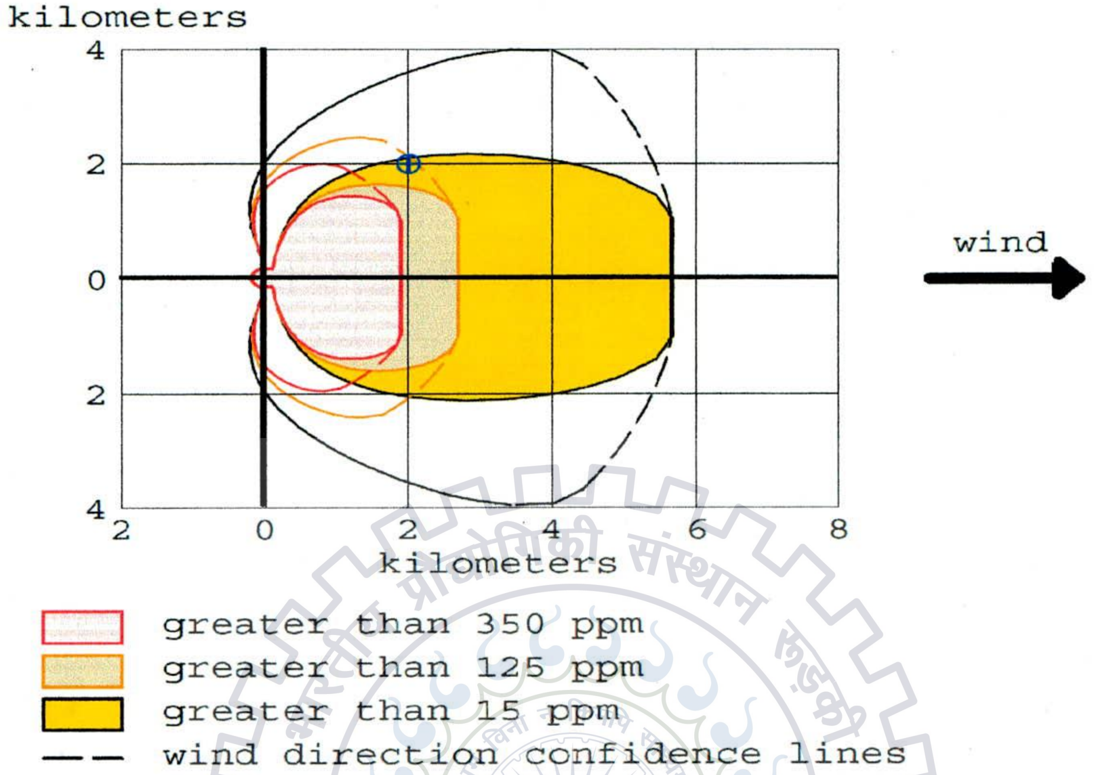
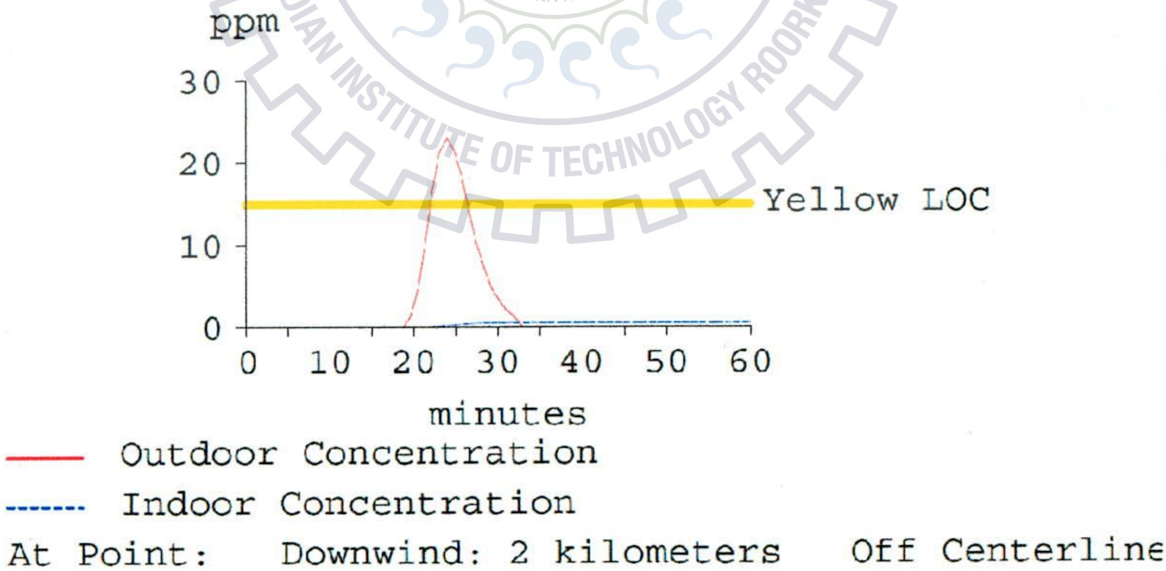


Fig 24.Threat zones of Durgapur during post monsoon season



RED : 1.7 Km ----- (350 ppm) ORANGE : 2.5 Km-----(125 ppm) YELLOW : 5.7 Km-----(15 ppm)

Fig 25. Threat zones of Durgapur during winter season in terms of distance



MAX CONCENTRATION ---------- OUTDOOR: 22.9 ppm **INDOOR**: 0.522 ppm

Fig 26.Concentration in terms of time from the source in 2 km downstream & 2 km out of the centerline

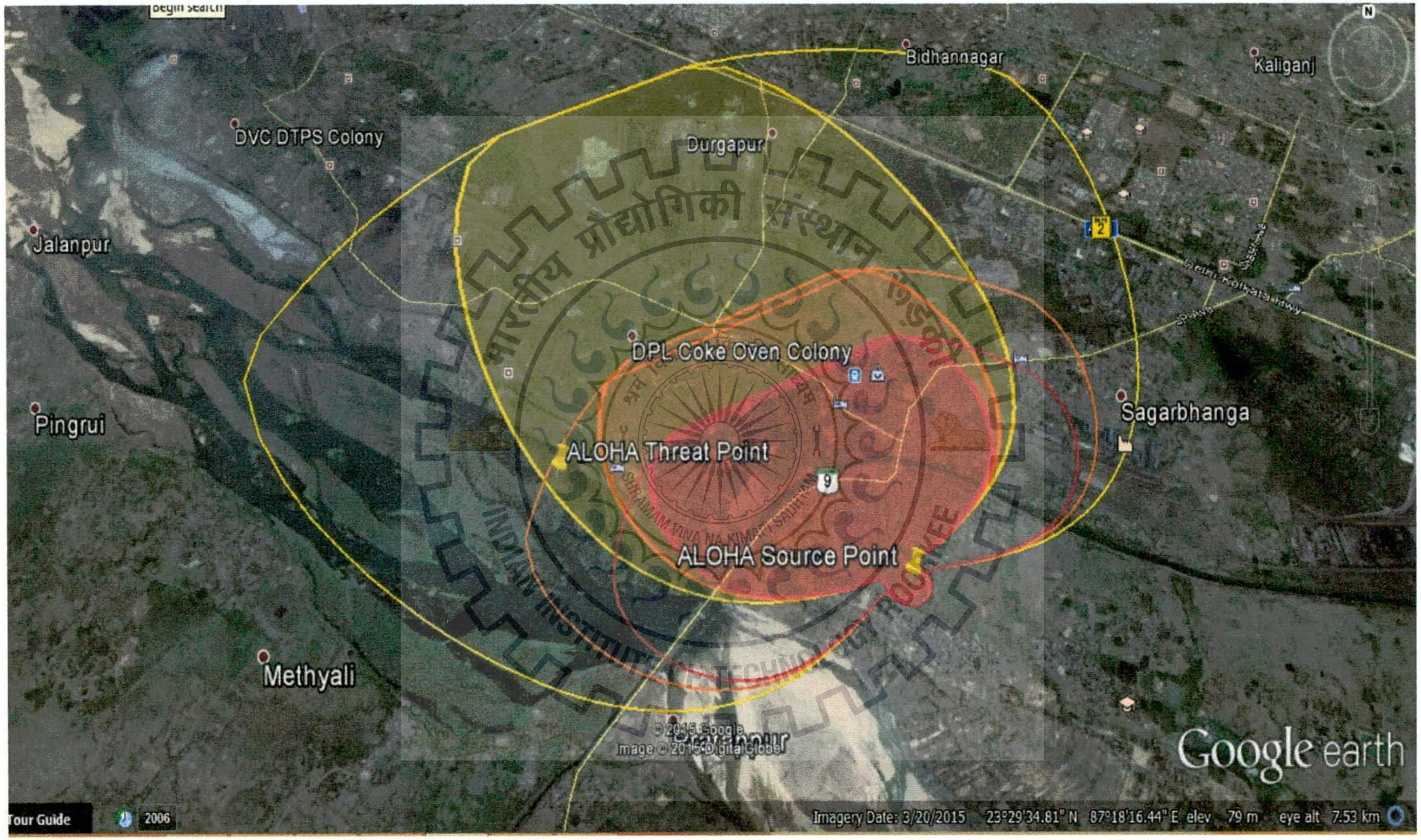


Fig 27.Threat zones of Durgapur during winter season

5.5 OUTPUT OF THE SIMULATION:

Table 16.Threat zones of chlorine release at Bhagwanpur and Durgapur as computed in the ALOHA simulation

	Concentration of Chlorine	Bhagwanpur	Durgapur
Scenario I Threat zone in summer	350 ppm	2.6 km	1.9 km
	125 ppm	3.6 km	2.7 km
	15 ppm	7.2 km	6.0 km
Scenario II Threat zone in monsoon	350 ppm	2.1 km	1.8 km
	125 ppm	2.9 km	2.7 km
	15 ppm	5.8 km	6.0 km
Scenario III Threat zone in post monsoon	350 ppm	2.2 km	2.1 km
	125 ppm	2.7 km	2.9 km
	15 ppm	5.8 km	5.8 km
Scenario IV Threat zone in winter	350 ppm	2.7 km	1.7 km
	125 ppm	3.7 km	2.5 km
	15 ppm	7.3 km	5.7 km

Table 17.Concentration Rate in terms of time from the source in 2 Km downstream, 2 Km out of the centreline

	BHAGWANPUR		DURGAPUR	
SEASON	**Outdoor concentration (ppm)**	**Indoor concentration (ppm)**	**Outdoor concentration (ppm)**	**Indoor concentration (ppm)**
Summer	451	9.7	0.61	0.02
Monsoon	304	10.5	2.02	0.06
Post monsoon	428	10.6	399	12.9
Winter	979	26.3	22.9	0.52

For both the areas as source strength is same therefore

Maximum Average Sustained Release Rate: 921 kilograms/sec.

Total Amount Released: 55,240 kilograms.

5.6 Values of probit variable

The probit variables for the concentrations 350 ppm, 125 ppm and 15 ppm of chlorine gas for the exposure time period of 5 min, 10 min and 15 min can be obtained from eq (1)

$$Y = -8.29 + 0.92 \ln(C^2 \times T) \text{.......................................eq (1)}$$

Equation (1) is the probit equation for chlorine fatalities where Y is probit variable C is concentration in ppm and T is exposure time in minutes. The values of probit variables obtained from eq (1) is given in the table 18

Table 18.Values of probit variables

Concentration of chlorine (ppm)	Exposure Time		
	5 min	10 min	15 min
350	3.96	4.60	4.98
125	2.07	2.71	3.08
15	-1.82	-1.18	-0.81

The probit variable can be converted into % of mortality (P) with the help of the equation (2) where erf is the error function.

$$P = 50\left[1 + \frac{Y-5}{|Y-5|} \operatorname{erf}\left(\frac{|Y-5|}{\sqrt{2}}\right)\right] \text{...................................eq (2).}$$

The values of % of mortality (P) obtained from eq (2) are shown in table 19

Table 19.Values of % of mortality

Concentration of chlorine	Time (min)	% of Mortality
350 ppm	5	14.92 %
	10	34.46 %
	15	49.20 %
125 ppm	5	0.15 %
	10	1.10 %
	15	2.74 %
15 ppm	5	0 %
	10	0.5 %
	15	.005 %

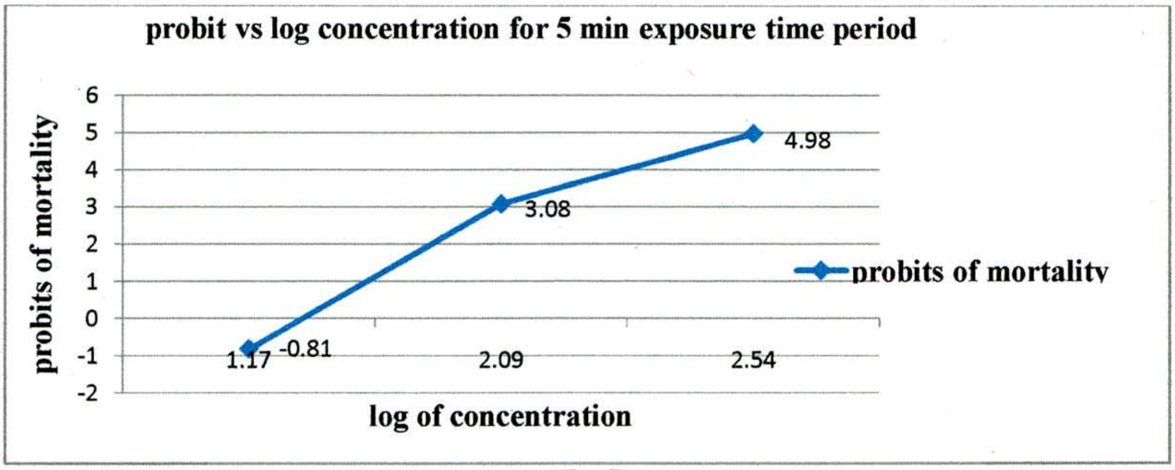


Fig 28.Probit vs concentration for 5 min exposure time period

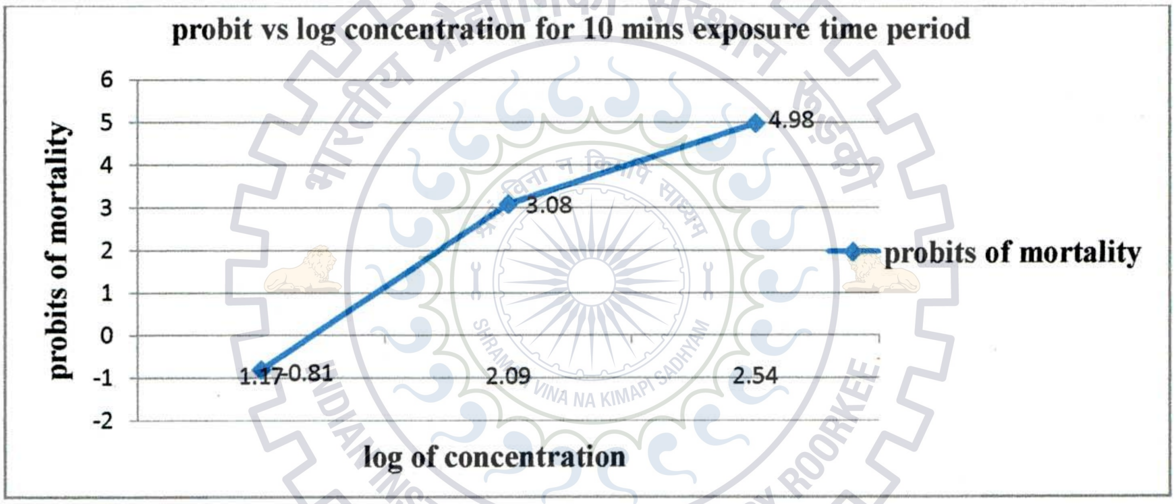


Fig 29.Probit vs concentration for 10 min exposure time period

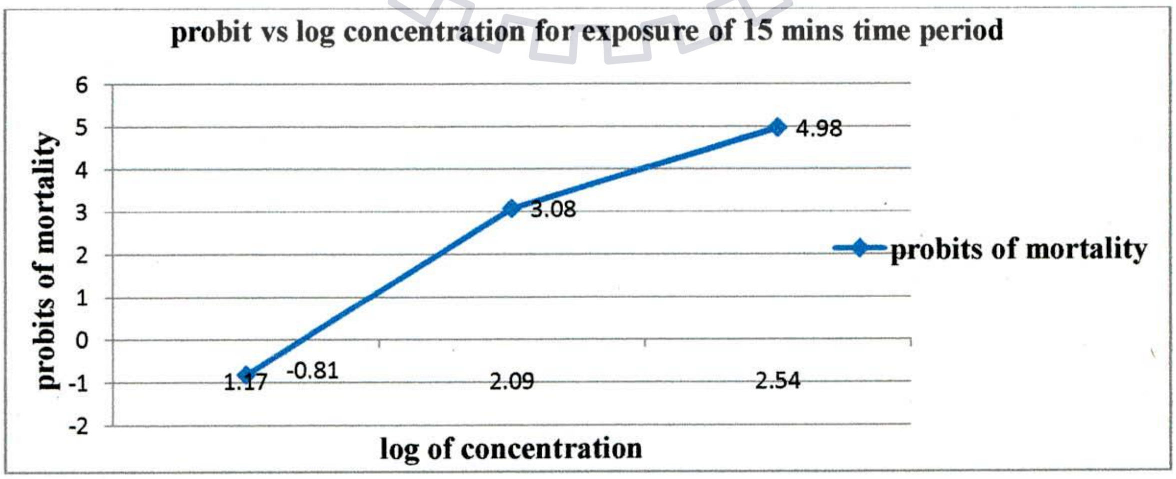


Fig 30.Probit vs concentration for 15 min exposure time

CHAPTER 6
SCOPE AND LIMITATION

6.1 Scope of the work

The scope of the study is that it can be further carried on for the analysis of risk and consequence evaluation of other toxic gases like ammonia, hydrogen sulfide etc. with the help of the data individual risk and societal risk can be calculated. This study is also beneficial for the transportation accidents of gases. The effect of chlorine on water bodies and its toxicological effect on the surrounding flora and fauna can be estimated with the help of hazard foot print.

With the help of the evaluation of consequences a proper disaster management plan can be prepared for that particular industry.

6.2 Limitations of the study

There are some limitations of the study like there are many dense and hazardous gases but this study has been carried out only for chlorine gas. The study is limited only for fixed installation accidents. It does not include the effects of transportation accident of chlorine gas. The study is concerned only for three concentration of chlorine 350 ppm, 125 ppm and 15 ppm. In addition to this there are several limitations of the model ALOHA like:

a) It does not account for the following:

- terrain effects or building effects
- radioactive materials or particulates
- chemical mixtures
- deposition rates
- releases into water bodies

b) Duration limited to 1 hour

c) Release area limited to 10 km.

d) Minimum distance to source is 100 m.

CHAPTER 7

CONCLUSION

From the simulation performed by ALOHA, it is proved that the meteorological parameters like wind speed, wind direction, humidity, temperature difference are very important for the dispersion of toxic vapour cloud of chlorine. The pattern of dispersion of gas cloud changes with season for both the place.

The study shows that there is a high risk of damage due to chlorine gas dispersion during monsoon season and winter season for both the areas. The maximum distances affected by the dispersion of chlorine gas is 7.3 km for Bhagwanpur and 6.0 km for Durgapur. The is a risk of inhalation of toxic gas inside as well as outside the building as the maximum indoor concentration for Bhagwanpur area is 26.3 ppm and for Durgapur it is 12.9 ppm. In case of outdoor concentration the maximum concentration for Bhagwanpur is 979 ppm and 399 ppm for Durgapur.

After comparing the results of both the areas it is found that Bhagwanpur possess a high risk than Durgapur. This may be due to the presence of complex terrain of Bhagwanpur where as Durgapur is situated on a flat surface. The mortality rate is also high i.e. 49.20% for 15 minute exposure of 350 ppm concentration of chlorine gas.

The results from the study can be used as a tool for effect analysis and risk assessments. It also integrates various aspects of industrial safety and if a proper assessment of risk can be done at the initial stage of installation of chemical plants then it will prevent chemical disasters in the future. The results of simulation will serve as a useful reference in the future and it will also notify the surrounding residents in the affected zones to take necessary precaution for the safety of their lives and properties.

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