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Capacity Building for Hazmat Transport Emergency Preparedness: 'Hotspot Impact Zone' Mapping from Flammable and Toxic Releases

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Abstract**—**Hazardous Material transportation by road is coupled with inherent risk of accidents causing loss of lives, grievous injuries, property losses and environmental damages. The most common type of hazmat road accident happens to be the releases (78%) of hazardous substances, followed by fires (28%), explosions (14%) and vapour/ gas clouds (6 %.).

The paper is discussing initially the probable 'Impact Zones' likely to be caused by one flammable (LPG) and one toxic (ethylene oxide) chemicals being transported through a sizable segment of a State Highway connecting three notified Industrial zones in Surat district in Western India housing 26 MAH industrial units. Three 'hotspots' were identified along the highway segment depending on the particular chemical traffic and the population distribution within 500 meters on either sides. The thermal radiation and explosion overpressure have been calculated for LPG / Ethylene Oxide BLEVE scenarios along with toxic release scenario for ethylene oxide. Besides, the dispersion calculations for ethylene oxide toxic release have been made for each 'hotspot' location and the impact zones have been mapped for the LOC concentrations. Subsequently, the maximum Initial Isolation and the protective zones were calculated based on ERPG-3 and ERPG-2 values of ethylene oxide respectively which are estimated taking the worst case scenario under worst weather conditions. The data analysis will be helpful to the local administration in capacity building with respect to rescue / evacuation and medical preparedness and quantitative inputs to augment the District Offsite Emergency Plan document.

Keywords**—**Hotspot, Ethylene Oxide, LPG, MAH (Major Accident Hazard).

I. Introduction

HAZARDOUS Material transportation by road is a world-wide phenomenon coupled with inherent risk of accidents causing loss of lives, grievous injuries, property losses and environmental damages. It is an acceptable fact that road transportation of hazardous materials is very risky affair, but unavoidable. The situation is no different, rather more serious for India compounded by the lack of public awareness on the probable consequences. The number and the extent of losses that occurred in previous years in India are related to hazardous material transportation accidents.

According to the Eleventh five year plan on transportation in India report [1], Transportation sector accounts for 6.4% of GDP. Also, Road transport has emerged as the dominant segment in India's transportation sector with a share of 4.5 per cent in India's GDP in comparison to railways (source: National Accounts released by the Central Statistical Organization (CSO). Besides, the cost of road accidents is estimated in the range 1 to 3 per cent of GDP.

Occurrence of accidents and road fatalities is an outcome of interplay of a number of factors which among others include length of road network, vehicle population, human population and adherence/enforcement of road safety regulations. It has also been brought out that about two-thirds of the persons are killed in National Highways and State Highways.

An analysis of Major Hazard Incidents Data Service (MHIDAS) of HSE, UK on worldwide data from 1980-2004 on 1932 hazmat transportation related incidents revealed that 63% accidents happened on road of which highways constitutes to 81.4% of accidents. The most common type of hazmat road accident happens to be the releases (78%) of hazardous substances, followed by fires (28%), explosions (14%) and vapour/ gas clouds (6 %.) [2].

The paper intents to highlight a part of a study that is underway estimating initially the probable 'Impact Zones' likely to be caused by one flammable (LPG) and one toxic (ethylene oxide) chemicals being transported through a sizable segment of a State Highway (SH-6) connecting three notified Industrial zones in Surat district in Western India housing 26 MAH industrial units, for hazard zone mapping on three selected 'Hotspots' along the highway stretch. Based, on the quantitative values of 'Impact Distances' and the number of affected population, the District Emergency Plan is being augmented in terms of Capacity building for evacuation and medical preparedness.

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II. Study Area Description

The City of Surat is a District Headquarter having population of 4,996391 (2009 data) and spread over an area of 326.515 square kilometer. The city with a population density of 15300 per square kilometer has registered highest Gross Domestic Product (GDP) growth in India. Its industrial belt has three different zones housing a total of 26 Major Accident Hazard (MAH) industrial units, refer Fig.1. Two National Highways NH-6 and NH-8 pass through the outskirt of the city and are connected by State Highways SH-6 and SH-66.

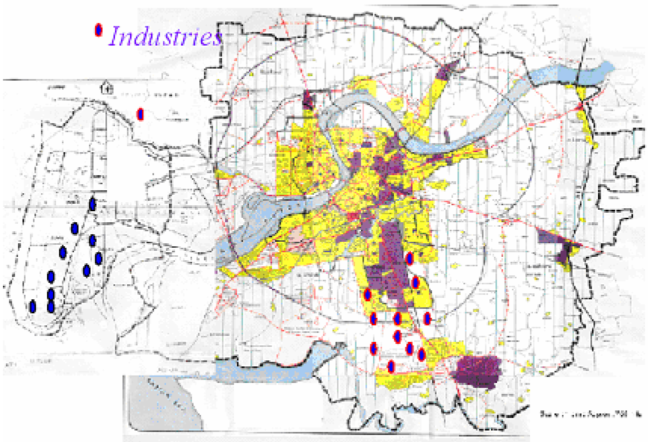

Fig. 1 The MAH Units in the Industrial District of Surat

As many as 30 hazardous chemicals (both raw materials and product) are being transported to and fro the three industrial areas through the State and National Highways. For the present study a 6.5 Km stretch of the State Highway SH-6 was taken and two UN Class-2 hazardous chemicals, LPG and Ethylene Oxide are selected. LPG is highly flammable and can cause fire and explosion, whereas ethylene oxide is both flammable as well as toxic.

The study area enjoys a tropical climate with average rainfall of 2500 mm a year.

III. Selecting 'Hotspots'

Three 'Hotspots' along the entire 6.5 Km length of the SH-6 was selected based on the following criteria:

a) Population of road transports passing through the road segment carrying the study chemicals.
b) Population density of the area within 500 meters on both sides of the road.
c) Accident proneness of the locations with respect to congestion due to human and vehicular traffics.
The hotspots are depicted on the Google-Earth map of the area as shown in Fig.2.

IV. Scenario Description

i) Fire & Explosion

Both the selected materials i.e. LPG and Ethylene Oxide are flammable and pose fire and explosion hazards. In the event of any accident to any of these two types of tankers the following scenarios could result (Fig.3):

Fig. 2 Depiction of Three 'Hotspots' on the 6.5 Km stretch of SH-6

a] A *BLEVE*, which occurs if the vapour side of a transport vessel is heated by a torch or pool fire. The effects of a BLEVE, generally identified by means of a physical BLEVE model (TNO) are; a fire ball and pressure wave effects resulting from the expansion of the vapour and the flash off and Cracking of the bullet, resulting in the formation of numerous fragments of the transport vessel.

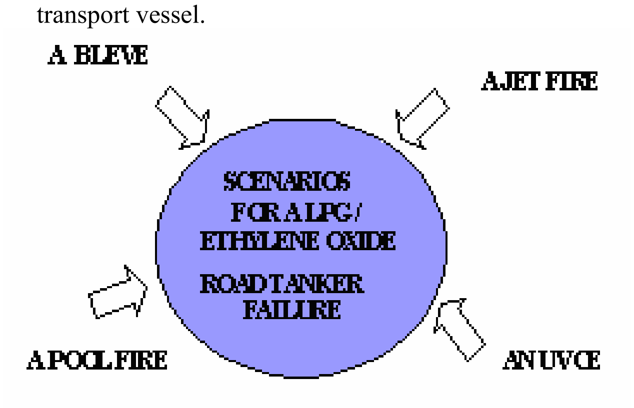

Fig. 3 F & E I Scenarios for LPG/Ethylene oxide road tanker failures

b] An *unconfined vapour cloud explosion* which can occur if the released material vapour is not ignited directly, but a late ignition takes place after the vapour cloud gets accumulated in the surrounding area with very little or no ventilation.

c] A *pool fire* causing heat radiation

From the BLEVE model (Fig.4), it is possible to calculate the radius of the fireball and thermal load. Similarly, peak overpressure caused due to expansion of vapour and flash-off can be estimated.

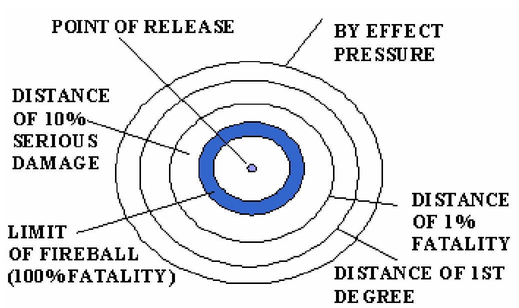

Fig. 4 Model for BLEVE Showing Effect Distance

ii) Toxic Release Scenarios

One of the two study material, Ethylene oxide is a toxic chemical too and could cause various acute health effects to population within the impact zone. The release scenario identified for the study is:

Catastrophic failure causing 'Total Rupture' of ethylene oxide tanker releasing major quantities of the content. The worst-case scenario has been considered under worst metrological conditions.

V. Consideration of Damage Criteria

The failure cases for fire & explosion and toxic release scenarios [3] will be as mentioned below:

A) Fire & Explosion

TABLE I SUGGESTED RUPTURE SIZES FOR DIFFERENT FAILURES

Typical failures:	Suggested failure sizes:
BLEVE (not buried case only)	Total rupture (ignited)
Rupture	Total rupture
Connection leak	100% pipe diameter and 20% pipe diameter

The BLEVE effects have been calculated using Effects-I software of TNO following the criteria given by the Technica, World Bank [3].

B) Toxic Release

For toxic release scenarios involving ethylene oxide, a two phase release scenario is taken and heavy gas dispersion model is chosen. One simplified approach is to specify a toxic concentration criterion above which it is assumed that individuals exposed to this value will be in danger. This approach has led to many criteria promulgated by several government agencies and private associations.

Emergency exposure guidance levels (ERPGs) is one such criteria which are prepared by an industry task force and are published by the American Industrial Hygiene Association (AIHA). Three concentration ranges are provided as a consequence of exposure to a specific substance:

i) ERPG-1 is the maximum airborne concentration below which it is believed nearly all individuals could be exposed for up to 1 hr without experiencing effects other than mild transient adverse health effects or perceiving a clearly defined objectionable odor.

ii) ERPG-2 is the maximum airborne concentration below which it is believed nearly all individuals could be exposed for up to 1 hr without experiencing or developing irreversible or other serious health effects or symptoms that could impair their abilities to take protective action.

iii) ERPG-3 is the maximum airborne concentration below which it is believed nearly all individuals could be exposed for up to 1 hr without experiencing or developing life-threatening health effects.

The dispersion calculations are based on ALOHA model (EPA, 2000) and the consequence distances are estimated for ERPG-2 and ERPG-3 [4].

In both the Fire & Explosion and Toxic release cases, the criteria of 'Alert zone' and 'Intervention Zone' criteria [5] have been applied which is put in Table-II.

TABLE II
ALERT AND INTERVENTION ZONE CRITERIA

Event scenario	Alert Zone adopted	APARICIO et al., 2006	Intervention Zone adopted	APARICIO et al., 2006
Thermal Radiation	4.0 kW/m^2	1.6 kW/m^2	12.5 kW/m^2	4 kW/m^2
Explosion Overpressure	0.03 bar	35 mbar	0.1 bar	170 mbar
Toxic effects	ERPG-2	ERPG-1	ERPG-3	ERPG-2

The above criteria both for 'Alert and Intervention zones' have been relaxed as against suggested by APARICIO et al., 2006 [5], as it warrants practicality and rationalization considering the population density and the logistics in Indian scenario.

Besides, Initial Isolation Zone based on the IDLH value and the Protective Action Zone based on the STEL concentration have been estimated (Fig. 5) which found usefulness in the emergency evacuation planning of the affected area. The Initial Isolation Zone defines an area SURROUNDING the incident in which persons may be exposed to dangerous (upwind) and life threatening (downwind) concentrations of material. The Protective Action Zone defines an area DOWNWIND from the incident in which persons may become incapacitated and unable to take protective action and/or incur serious or irreversible health effects [6].

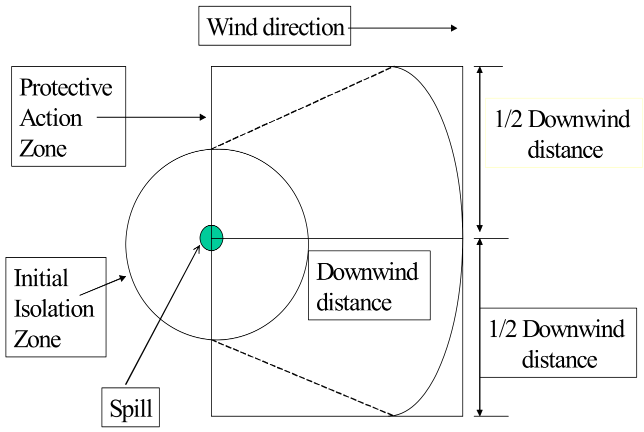

Fig. 5 Depiction of Initial Isolation and Protective Action Zones [6]

The District Crisis Group has augmented its responses to any emergency involving hazmat road tankers in the selected hotspots.

VI. RESULTS

As discussed earlier, two fire and explosion scenarios are considered:

i. BLEVE of LPG Road Tanker with worst case of total release of the tanker content. The estimated damage distances for Heat Radiation and the overpressure distances have been given in Table-III and Table-IV.

TABLE III
HEAT RADIATION FROM LPG BLEVE SITUATION

Ambient Temperature = 30 °C
Amount Of Gas = 10000 kg
Diameter Cloud = 129.3 m
Duration Of Fire Ball = 9.3 s
Intensity Of Radiation = 179.8 kW/m²
Relative Humidity = 70 %
The thermal load is calculated from the centre of the fire-ball.

Distance (m)	Max. Thermal Load (kW/m²)
71.1	123.7
77.6	97.6
84.0	80.2
90.5	67.4
97.0	57.5
129.3	30.4
193.9	12.7
258.6	6.9
323.2	4.3
646.5	1.0
969.7	0.4
1292.9	0.2

TABLE IV
OVER PRESSURE DISTANCE

(Calculation model: Vapour cloud explosion-Butane(n-))
Amount of explosive material = 4336 m^3
Reactivity = medium explosive
Temperature = 30.0 °C

Damage Type	Distance to the Centre of the Cloud	
	Min (m)	Max. (m)
Heavy (0.3 Bar)	0	86
Repairable (0.1 Bar)	103	257
Damage of Glass (0.03 Bar)	343	858
Crack of Windows (0.01 Bar)	1029	2573

TABLE V
HEAT RADIATION FROM ETHYLENE OXIDE BLEVE SITUATION

Ambient temperature = 30 °C
Amount of gas = 4000 kg
Diameter cloud = 96.0 m
Duration of fire ball = 7.4 s
Intensity of radiation = 69.1 kW/m²
Relative humidity = 70 %
The thermal load is calculated from the centre of the fire-ball.

Distance (m)	Max. Thermal Load (kW/m²)
52.8	48.8
57.6	38.6
62.4	31.7
67.2	26.6
72.0	22.7
96.0	12.0
144.0	5.0
192.0	2.7
240.0	1.7
480.0	0.4
720.0	0.2
959.9	0.1

ii. BLEVE of Ethylene Oxide Road Tanker with worst case of total release of the tanker content. The estimated damage distances for Heat Radiation and the overpressure distances have been given in Table-V and Table-VI.

TABLE VI
OVER PRESSURE DISTANCE
(Calculation Model:Vapour Cloud Explosion----Ethylene Oxide)
Amount Of Explosive Material = 2288 m^3
Reacitivity = High Explosive
Temperature = 30.0 °C

Damage Type	Distance to the Centre of the Cloud	
	Min (m)	Max. (m)
Heavy (0.3 Bar)	51	142
Repairable (0.1 Bar)	154	302
Damage of Glass (0.03 Bar)	513	829
Crack of Windows (0.01 Bar)	1539	2320

iii) For Ethylene Oxide toxic dispersion without fire, the IDLH, ERPG-2 and ERPG-3 limits have been calculated using ALOHA dispersion software by taking catastrophic total rupture of ethylene oxide tanker under worst meteorological conditions i.e. in 1.5 m/sec of wind speed (4) and stability class of F, and the results are tabulated in Table -VII.

TABLE VII
THE OUTPUT OF THE ALOHA MODEL FOR THE ETHYLENE OXIDE RELEASE SCENARIO

Location	Surat
Chemical	Ethylene Oxide
Wind Speed	1.5 m/sec
Wind Direction	SW
Worst Release quantity	4000 Kg
Ambient Temp	30^0C
Stability Class	F
Rel. Humidity	75%
Model	Heavy Gas
Release Duration	1 min
IDLH (800 ppm) Distance	0.833 KM
ERPG-3 (500 ppm)	1.0 KM
ERPG-2 (50 ppm)	2.56 KM

The Initial Isolation zone i.e. the immediate danger zones and the Protective Action distances thus estimated have been provided in Table-VIII which show that the actual situation in the study area is likely to be worse if we take a worst case release scenario, as the conditions of meteorology and the population density would substantially differ from other parts of the world.

TABLE VIII
ESTIMATED INITIAL ISOLATION AND PROTECTIVE ACTION ZONES
(w.r.t. Ethylene oxide release)

Max Initial Isolation Zone (Irrespective of Day and Night)	Max. Protective Action Zone (Irrespective of Day and Night)
1.0 km (ERPG-3)	2.56 km (ERPG-2)

VII. HAZARD ZONE MAPPING

The estimated damage distances for each 'Hotspots' are mapped on the location map of the entire stretch of the State highway segment (6.5 Km) for various fire/ explosion scenarios e.g. Thermal radiation, Overpressure and also for toxic dispersion, refer Fig.6 (a & b), Fig.7 (a & b) and Fig.8 respectively.

Based on the estimated effect distances and the approximate number of populations that might be affected 'hotspot ranking is determined taking the year 2001 census data and the population density of the study area into consideration. The results are tabulated at Table-IX.

VIII. RANKING THE 'HOTSPOTS'

The selected 'Hotspots' have been ranked based on the consequence estimates of accidental BLEVE cases involving both the selected chemicals and also the toxic effect distances.

i) Accordingly, the study finds that the 'Hotspot-3' is having highest consequence risk in terms of number of people likely to be generally affected within the estimated impact zones, both from fire & explosion as well as from toxic effects point of view, based on the population of the area.

ii) The 'Hotspot-2' is basically surrounded by industries and the damage distances goes deep into their boundary areas which may cause any subsequent fire and explosion cases, escalating the emergency. However, the protection and preparedness of the area is much superior compared to other isolated hotspots thereby situations could be brought under control quickly.

iii) The 'Hotspot-1' is a four -road junction with residential colonies and recreational complexes (Fig.2) and any incident of BLEVE and Toxic release will be of great consequences, as the administrative services are at considerable distance away. The preparedness has to be of high order in this location.

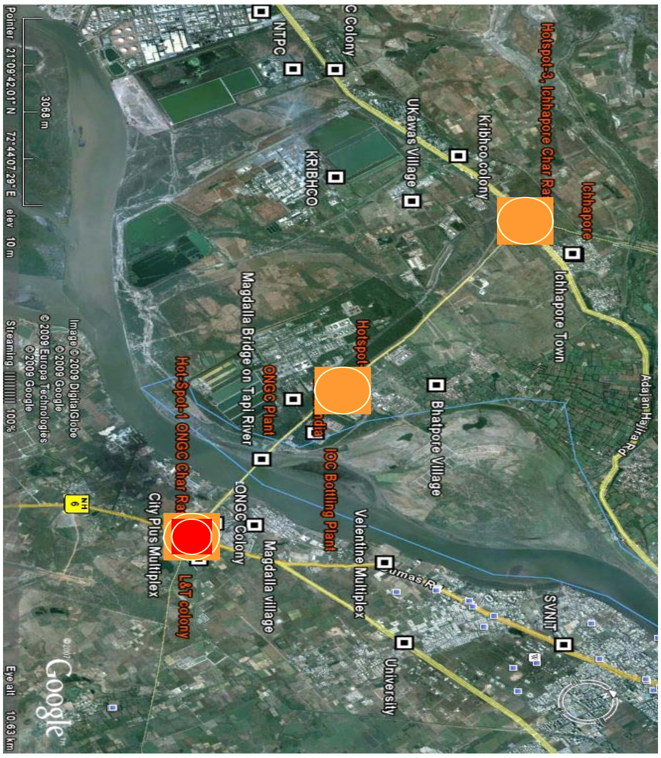

Fig. 6(a) Alert and Intervention Levels for LPG - Thermal Radiation Effects in three ‘Hotspots’

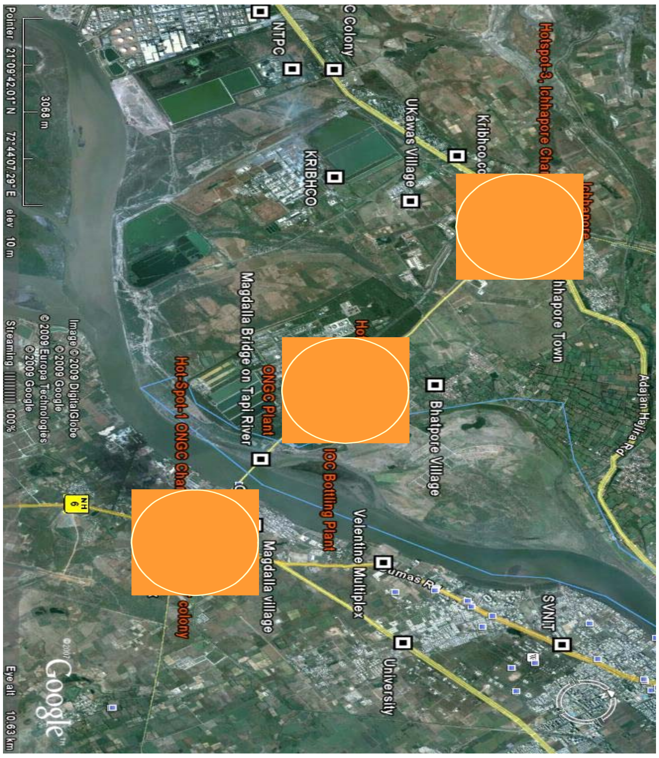

Fig. 7(a) Alert and Intervention Levels for LPG –Explosion Overpressure Effects in Three ‘Hotspots’

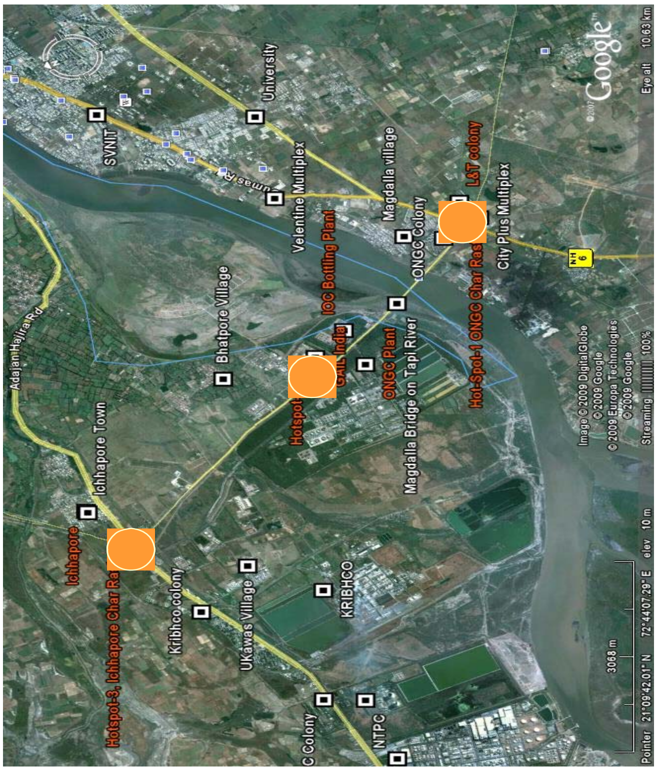

Fig. 6(b) Alert and Intervention Levels for Ethylene Oxide – Thermal Radiation Effects in three ‘Hotspots’

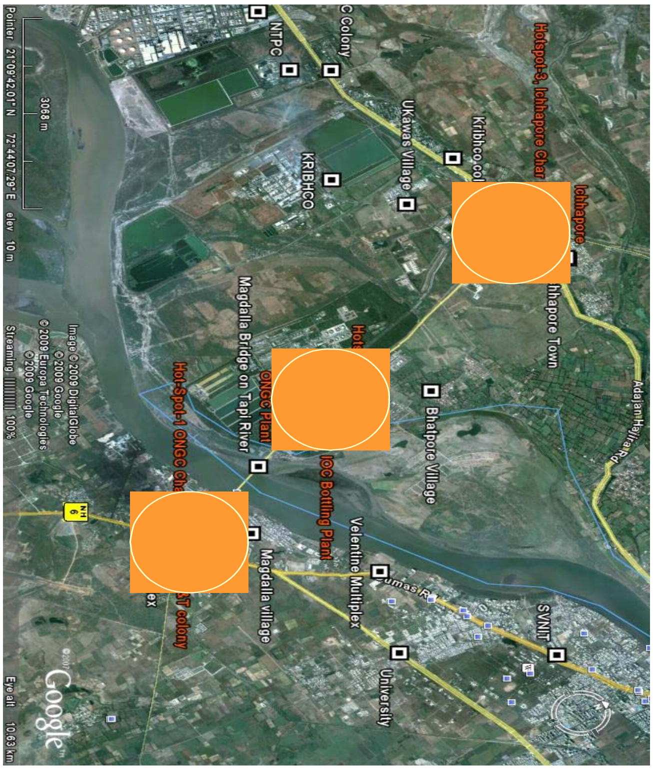

Fig. 7(b) Alert and Intervention Levels for ethylene oxide– Explosion Overpressure Effects in Three ‘Hotspots’

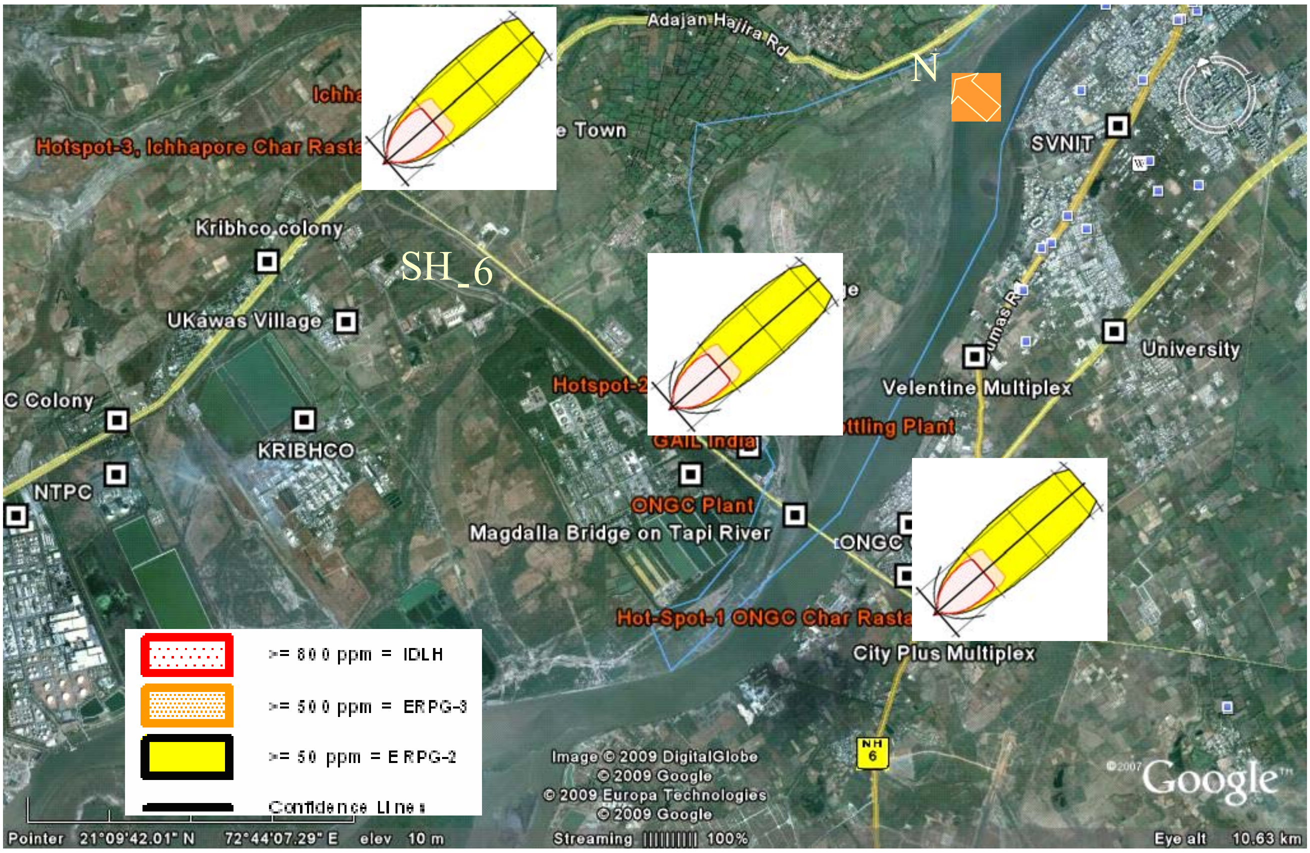

Fig. 8 Alert and Intervention Levels for Toxic Ethylene Oxide Effects in Three Hotspots

TABLE IX
RANKING OF HOTSPOTS

Hotspot	Chemical involved	Event Scenario	Estimated Impact Zone		Approx. estimate of likely Affected Population as per 2001 Census
			Alert Zone	Intervention Zone	
Hotspot-1	LPG	Thermal radiation	320 m	190 m	50 -200
		Explosion Overpressure	858 m (max)	257 m (max)	130 - 1500
		Toxic effect	-	-	
	Ethylene oxide	Thermal radiation	150	90 m	15 - 50
		Explosion Overpressure	829 m (max)	302 m (max)	150 - 1400
		Toxic effect	2.56 km (ERPG-2)	1.0 km (ERPG-3)	2500 - 8000
Hotspot-2	LPG	Thermal Radiation	320 m	190 m	50 – 150
		Overpressure	858 m (max)	257 m (max)	100 - 1200
		Toxic effects	-	-	
	Ethylene Oxide	Thermal Radiation	150	90 m	15 -40
		Overpressure	829 m (max)	302 m (max)	150 - 850
		Toxic effects	2.56 km (ERPG-2)	1.0 km (ERPG-3)	3500 - 7000
Hotspot-3	LPG	Thermal Radiation	320 m	190 m	74 – 209
		Overpressure	858 m (max)	257 m (max)	135 -1508
		Toxic effects	-	-	
	Ethylene oxide	Thermal Radiation	150	90 m	17 - 46
		Overpressure	829 m (max)	302 m (max)	187 - 1409
		Toxic effects	2.56 km (ERPG-2)	1.0 km (ERPG-3)	3000 -12000

IX. Evacuation and Medical Preparedness

Based on the results of the study, it has been proposed to the Local Administration to locate its emergency evacuation centers in meteorologically safer places. The proposed evacuation centers are indicated in Fig.9.

The likely damage distances thus estimated through well-known software models for three selected 'Hotspots' along the 6.5 Km State Highway segment have been used to rank the "Hotspots" which would help developing the appropriate emergency preparedness on the part of both industries and local administration.

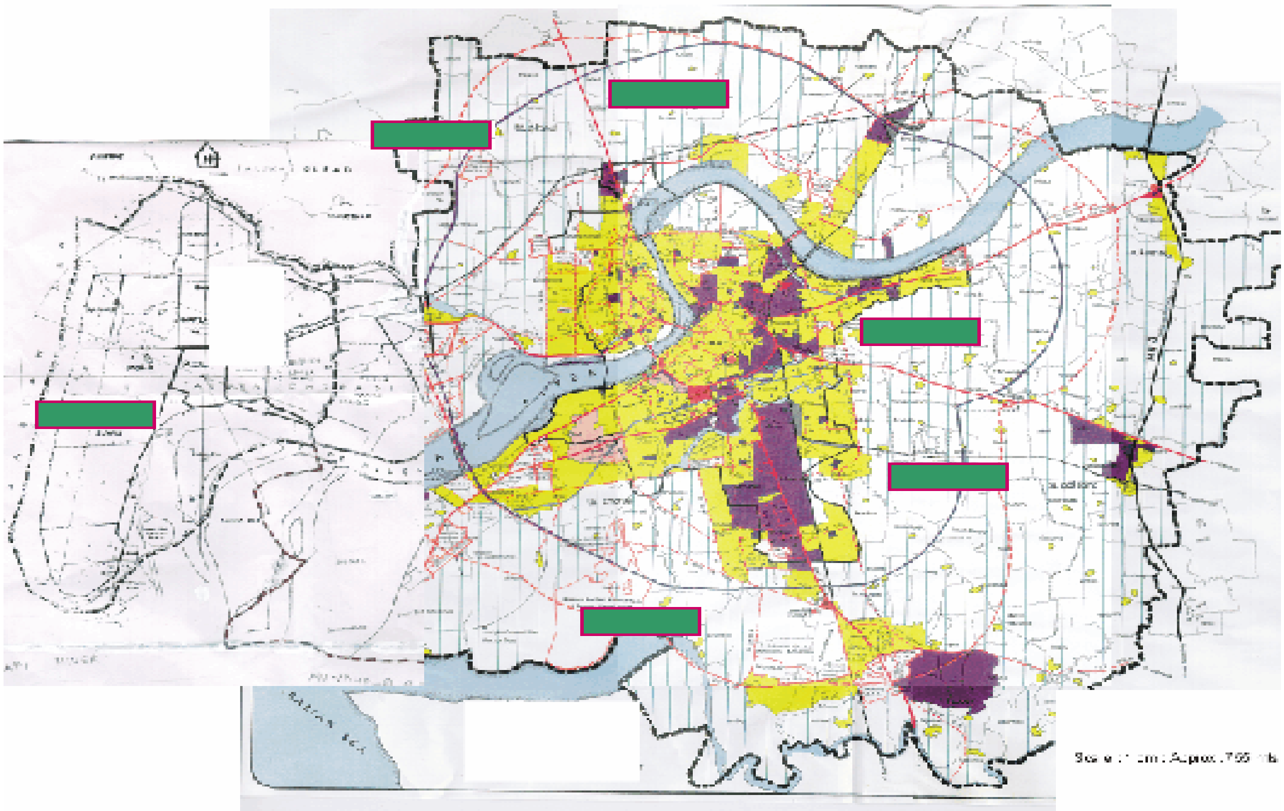

Fig. 9 The Depiction of Evacuation Centers over the plot plan of study area

Ethylene oxide in low concentrations inhaled will cause delayed nausea. Inhalation of high concentrations results in a narcotic and possible neurotoxic effect -- possibly followed by coughing, vomiting, and irritation to the respiratory passages which will eventually lead to emphysema, bronchitis, and pulmonary edema. Ethylene oxide is a suspected human carcinogen. Exposure may cause toxicity to the human reproductive system including spontaneous abortions.

Prompt medical attention is mandatory in all cases of overexposure. Rescue personnel should be equipped with self-contained breathing apparatus and be Cognizant of extreme fire and explosion hazard.

X. Conclusion

In the context of risk arising out of Hazmat Transportation on highway segments passing through the industrial business houses, the paper discussed the consequence analysis results based on the various accident scenarios involving one each of LPG and ethylene oxide road tankers on a State Highway segment (SH-6) at Surat in western India.

Although, emergency preparedness at the local level is formulated according to The Chemical Accidents (Emergency Planning, Preparedness and Response) Rules, 1996 of India (7), based on the principle of APELL (Awareness and Preparedness for emergency at Local Level), developed by UNEP to identify and create awareness of societal risk among the local community apart from developing preparedness of risk reduction and mitigation, the risks arising out of hazmat transportation through the population centers have not been quantifiably addressed. Hence, the outcome of the present study certainly would give valuable inputs to the Local Administration to augment its District Emergency Plan as far as the hazmat transportation risk is concerned.

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