Health Risk Assessment and Management for Air Toxics in Indian Environment

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ABSTRACT

Toxic or hazardous substances pose two types of risks in the environment, namely 'short-term or acute risk' and 'long-term or chronic risk'. The short-term risk is associated with the one-time acute exposure to potentially hazardous substances accidentally released in the environment, whereas the long-term risk is resulted from continuous exposure to potentially harmful substances present in different environmental media. In this paper, appropriate modeling techniques are applied to estimate acute or short-term risk from accidental release of toxic materials in industries. Dense gas dispersion models developed for this purpose such as IITHG-I and II are used. The usage of this model is demonstrated with a case study for Chlorine storage in Indian environment. Nomograms are constructed for use during an industrial chemical accident by administrators for evacuation purposes where immediate modeling usages are not required. The nomograms are prepared for eight commonly used toxic chemicals in the Indian industries.

This paper also deals with the assessment of potential health risks related to certain carcinogens and non-carcinogens (e.g., Cadmium, Chromium and Nickel) present in different Indian states (regions). Appropriate dose-response models have been identified and used for this purpose with the assumptions and input data as per the Indian context. Individual and societal risks of extra cancer due to above toxics are estimated in different states of India. The hazard quotients and hazard index representing the non-carcinogenic chronic health effects caused by Chromium and Cadmium due to their long-term exposure through water and food have also been estimated. The risk results have been compared with the disease surveillance data where a satisfactory validation is observed.

An integrated approach for risk estimation is demonstrated with two case studies of chlorine industries in the country. The integrated risk estimation suggests a method to combine acute and chronic risks to provide risk contours, the severity of which can be assessed from a risk ranking matrix devised for this purpose. It is suggested that industrial siting and planning in the country shall consider adopting such concepts.

Finally, current status of Quantitative Risk Assessment (QRA) techniques is elaborated along-with the limitations of the same.

Keywords: Air toxics, Acute risk, Chronic risk, Health risk, Industrial siting, Dense gas sispersion, Quantitative Risk Assessment (QRA)

1. Introduction:

A number of accidents worldwide such as those at Flixborough (1974), Seveso (1976), Bhopal (1984), Pasadena (1989), etc. have led to growing concern about the potential hazards and risks involved in chemical process industries (Kim et al., 1995; Khan and Abbasi, 1998). Such industrial accidents may cause serious injury to people and/or severe damage to infrastructures within and beyond the immediate vicinity of the work place. Top ten industrial disasters based on fatality estimates, which occurred in between 1945-1990, are shown in Table 1 (UNEP, 2000).

In addition to accidental releases of extremely hazardous chemicals, the continuous release of toxic pollutants from major industrial facilities and other anthropogenic activities may also cause adverse effects on human health and the environment. There are various guidelines, acts, laws and regulations to reduce and control the risks in India. These aid in preparing and implementing the emergency response plans to respond in a catastrophic situation. For example, Manufacture, Storage and Import of Hazardous Chemicals (MSIHC) Rules, 1989 (later amended in 1994 and 1999), Hazardous Waste (Management and Handling) i.e. HW (M & H) Rules, 1989 (later amended in 1997 and 1999), and Public Liability Insurance (PLI) Act, 1991, etc. are amongst those used for regulatory applications. Despite so many rules and acts, the hazardous chemicals continue to be handled in an unsafe and environmentally unsound manner. This is reflected in a number of catastrophic accidents occurred in past decades such as at Bhopal (1984), Panipat (1993), Mumbai (1995), and Visakhapatnam (1997) as shown in Table 2.

Thus, there is also a substantial concern about the accidental release of hazardous materials as a result of growing awareness of the scale of tragedy that may accompany activities involving such materials. The development of appropriate regulatory measures requires the acceptable balance between economic benefit and potential harm accompanying such activities, which emphasizes a need for quantitative risk assessment of the accidental releases of hazardous materials into the environment.

In scientific term, risk is expressed as a combination of two factors, (i) the probability that an adverse event will occur, and, (ii) the consequences of the adverse event. More precisely, the risk is a combination of expected frequency and consequence of a single accident or group of accidents. This type of risk is associated with an emergency situation comprised of acute hazard (i.e., the potential for injury or damage to occur as a result of an instantaneous or short duration exposure) caused by an episodic event (i.e., an unplanned event of limited duration, usually associated with an accident). However, there is another type of risk known as chronic risk due to long term exposure for months, years or decades of toxic chemicals that manifest as chronic health problems. Risk from chronic exposure arises from activities associated with the production and use of food, energy, industrial and consumer goods, and from the waste produced through daily living. This paper presents in detail an account on the following studies encompassing both acute and chronic risks.

(a) Acute Risk: IITD Heavy Gas Model for dense gas dispersion of airborne toxic materials for estimating individual and societal risk and for the estimation of vulnerable zones and user oriented nomograms (Singh et al., 1991; Mohan et al., 1995).

(b) Chronic Risk: Potential health risks related to carcinogens in the atmospheric environment in India for Cadmium, Chromium and Nickel (Gurjar and Mohan, 2003).

(c) Integrated risk analysis using both acute and chronic risk: Case Studies (Gurjar et al., 1996).

2. Acute Risk [Mohan et al., 1994 and 1995]

Large number of chemical disasters in past emphasize that the accidental release of hazardous materials is a grave problem. This is especially the case when the release leads to the quasi-instantaneous formation of a large cloud. In many situations, such a cloud will have a density that is greater than the ambient air. The ground-hugging tendency of dense toxic cloud makes a large part of population vulnerable to the exposure of hazardous material. Hence, it is important to develop appropriate models for heavy gas dispersion or negatively buoyant cloud. In this context, it is worth mentioning that appropriate heavy gas models (IIT Heavy Gas Model I and II) have been developed for this purpose and verified against field trials. Mohan et al. (1994 and 1995) describes in detail the basics and application of the IITD Heavy Gas Model for dense gas dispersion of airborne toxic materials for estimating individual and societal risk and for the estimation of vulnerable zones and user oriented nomograms, which is given in brief as below.

(i) Model formulation and validation [Mohan et al., 1995]

IIT Heavy Gas Model is numerical box models where governing equations take into account the relevant physical processes such as gravitational slumping, entrainment of air, cloud heating, etc. Numerical solution of the equations evaluates the cloud characteristics viz., radius (length in the case of continuous release), height, density, temperature, amount of entrained air at each time step. Particular emphasis has been laid on model validation by comparing their performance against relevant field trial data (Thorney Island, Burro Series and Maplin Sands Trials) as well as with other models. On the basis of statistical evaluation, a good performance of the model has been established. The performance of the IIT Heavy Gas Model is close to the model showing the best performance amongst 11-14 other models developed in various countries. A detailed account on model formulation and validation is included in Mohan et al., 1995. Using the IIT Heavy Gas Model, the Safe distance/vulnerable zones can be easily estimated for different meteorological and release conditions for the storage of various hazardous chemicals.

(ii) Estimation of vulnerable zones [Singh et al., 1991]

A special feature of the IIT Heavy Gas model is to determine various zones in terms of concentration isopleths corresponding to IDLH (Immediately Dangerous to Life and Health), STEL (Short Term Exposure Limit) and TLV (Threshold Limit Value) on the city map for a given release and meteorological situation as illustrated in Figure 1. Thus, areas of potential impact could be easily identified and appropriate emergency preparedness measures could be undertaken in case of an industrial accident. Here, concentration isopleths are provided for 65 tonnes storage of chlorine at Shriram Foods and Fertilizers Industries (SFFI) in Delhi. The site and storage quantity is only for the demonstration purpose as it existed in the past. However, these do not confirm to the existing scenario. The meteorological scenario chosen for plotting the isopleths corresponds to stable atmospheric condition with low wind speed and it represents the case for which the maximum value of IDLH distance is obtained. Based on climatological data on wind frequencies, we have considered North - Westerly wind to plot the isopleths. Therefore, the areas of potential impact lie in the South-Easterly direction of the site.

(iii) User-oriented results

Based on this model certain user-oriented results have been provided which could be used by a layman for control and management in case of an emergency without really working on the complex mathematical simulation procedure on a computing machine. Figure 2 provides a nomogram for different storage quantities of chlorine under various meteorological situations which may be prevalent during the entire year and the same are represented by scenario numbers. Here, nomogram refers to a graph from which safe distances are determined due to accidental release of various quantities of a toxic material under different meteorological scenarios prevalent in the entire year. The meteorological conditions at the time of the accident could be easily correlated with the scenario number by knowing the time of the accident, cloud cover and observable wind effects in the surroundings. The details about the meteorological classification are given in Table 3 (Mohan et al., 1994) Thus, by knowing the meteorological scenario and the quantity of the toxic material released during an accident, the safe distance could be easily ascertained. This study has been performed for eight toxic chemicals (Chlorine, Ammonia, Ethylene oxide, Hydrogen fluoride, Carbon disulphide, Oleum, Phosgene and Hydrogen cyanide) at the behest of the Ministry of Environment and Forests, Govt. of India. Here, emphasis is laid on the presentation of the model output in a use-friendly manner such that in case of an emergency a non-technical person at the site can also use these. In this regard, the modeling approach to estimate the safe or threshold planning quantities (TPQ) by the industries using dispersion models is elaborated in (Mohan and Gurjar, 1995; Mohan and Gurjar, 2004).

3. Chronic Risk [Gurjar et al. 1996; Gurjar and Mohan, 2003]

Potential health risks related to carcinogens in the atmospheric environment in India for Cadmium, Chromium and Nickel have been estimated and published by authors in their following publications; Gurjar et al. (1996), and Gurjar and Mohan (2003). Urbanization, industrialization, increased vehicular traffic, and use of fertilizers and pesticides in agriculture have resulted in increased contamination of atmospheric environment by chemical pollutants.

India has developed many industries to meet its own demands as well as for export purposes. The development of metallurgical, heavy engineering, and various chemical industries in India has created new and complex potential health risks both for workers and for the community at large through exposure to toxic contaminants in air environment. Consequently, quantitative analysis of human health risks has become increasingly important as a means both of judging the degree of risk associated with chemical pollutants and for selecting control strategies that can reduce these risks to an acceptable level. This study assesses the individual and societal risks due to three carcinogenic metals, namely Cadmium (Cd), Chromium (Cr), and Nickel (Ni), present in the atmospheric environment of different states in India. The ambient air interim guidelines for these carcinogenic metals were also derived at the risk level of 10^{-5} .

The ambient air interim guidelines for cadmium, chromium, and nickel is derived at a risk level of $10^{-5.}$. The typical cancer rate is one in four, so in a group of 100,000 persons, 25,000 would likely to develop a tumor during their lifetime. If the same 100,000 persons breathe air contaminated with $5x10^{-3}$ $\mu g/m^3$ (ambient air interim guideline concentration) cadmium daily for their lifetime, no more than one additional person (i.e. 25,001) would get cancer (Sidhu, 1987).

Tables 4 and 5 show estimated individual (Figure 3) and societal risk (Figure 4) for cadmium, chromium and Nickel contamination in various states in India. The inference from these Tables and Figures are briefly described here.

Cadmium

It appears that cancer risk to humans from exposure to cadmium concentration in ambient air in various states of India as shown in Tables 4 and 5 is very minimal. In other words, the low concentration of cadmium in ambient air in different states of India may not lead to increased development of cancer in humans. The maximum individual carcinogenic risk is found for Uttar Pradesh, West Bengal and Rajasthan in equal measures.

Chromium

The highest individual risk estimate attributable to human exposure to Chromium was estimated for the residents of Chandigarh (Union Territory) followed by the risk to those living in the states of Orissa, Bihar, Haryana, Punjab, Uttar Pradesh, West Bengal, Himachal Pradesh, and Gujarat. The Union Territory of Chandigarh was a rural agricultural land prior to 1950, and therefore it is very surprising that the ambient concentration of Chromium is high at this location. It may be worth studying if the industrial plants, particularly those producing cement located only a few miles east of Chandigarh, are releasing hexavalent Chromium to the atmospheric environment. The cement producing plants are important potential sources of atmospheric Chromium. There was a huge cement plant located about 3 km east of Chandigarh (UT) during the period when these data were collected for MOEF, GOI. A large number of small-scale industries related to manufacture of fasteners and doing the job of electroplating may also be additional sources to contribute for high Chromium content in the atmosphere of Chandigarh. Chronic exposure (30 to 40 years) via inhalation of elevated levels of hexavalent Chromium increases the likelihood of development of lung cancer in humans.

Nickel

The highest individual risk estimate attributable to human exposure to Nickel appears to be to the residents of Chandigarh (Union Territory), followed by the risk to those living in Uttar Pradesh, Bihar, Haryana, and Punjab (Table 4). It may be worth studying if the high levels of Nickel in the ambient air and the increased risk estimates of lung and nasal cancers attributable to exposure to Nickel in some northern states of India (Union Territory of Chandigarh, Uttar Pradesh, Bihar, Haryana, and Punjab) are associated with the burning of coal. Burning of coal is one of the major sources of release of Nickel to the atmospheric environment (ATSDR, 1993).

It appears that the estimated cancer risk attributable to Chromium contamination of ambient air is relatively higher than that attributable to Nickel (Table 4). However, the true carcinogenic risk from chromium, as shown in Table 4, are less because estimates in Table 4 include total Chromium while only the hexavalent Chromium is carcinogenic in nature (USEPA, 1995).

Smoking contributes significantly to Cadmium intake. Depending on the brand of cigarette and the number of cigarettes smoked, daily intake of Cadmium may vary from 1 to 6 μg/day. When 10% of the intake of Cadmium is assumed to be absorbed in the lungs, it may cause about 3-19 times more risk to the smoker than the maximum risk that exists in Uttar Pradesh state (Pandya, 1978).

The societal risk is highest in Bihar for Chromium and in Uttar Pradesh for Nickel and Cadmium (Table 5). This is understandable because, with respect to the total population, Uttar Pradesh and Bihar are the top two states among the 14 states shown in this table. The societal risk and population (total and density) are important factors for decision-making processes for future industrial growth and location.

It is impossible to develop precise risk estimates due to various uncertainties included both in available data and in the models which are used to calculate potency factors and effective concentration (Fiksel, 1985). However, this type of average estimation of risk levels can be useful for planning purpose. The method adopted here is helpful in estimating carcinogenic risk attributable to carcinogens present in the atmospheric environment. However, there are some limitations as well. The assumption of average population, for example, implicitly assumes a homogeneous population distribution with identical background factors such as sensitive populations, age, and sex. These limitations narrow the scope of this method, which should be kept in mind when using this method in planning and decision-making activities.

4. Integrated risk analysis using both acute and chronic risk: Case Studies [Gurjar and Mohan[b], 2003]

The general practice to study various types of risk in isolation to each other could give erroneous conclusions. This is because in real life situations a person or community may encounter the different combinations of environmental risks posed by the surrounding. Keeping this view in mind an integrated approach of environmental risk analysis (ERA) has been proposed to explicitly consider and define a comprehensive tool, specifically for toxic risks, that is broadly reflective of real-life risk situations.

To begin with, individual risk factors (IRF) and geo-societal risk factors (GSRF) have been estimated for two Indian industries that may cause acute risk due to an accidental release of chlorine in the atmosphere. Further, background risk factors (BRF) have been determined by converting the chances of extra cancer cases into mortality per year due to the presence of carcinogenic toxic elements present in the environment. The cumulative individual risk factors (CIRF) and cumulative geo-societal risk factors (CGSRF) have been calculated as the sum total of risks posed by acute and chronic toxic exposures for individual and societal risk respectively.

The methodology is demonstrated with Two industries located in Haryana state of India. These are i) M/s Ballarpur Industries Ltd., Yamuna Nagar and ii) M/s Advanced chemicals, Bahadurgarh (Haryana). The detailed methodology is covered in Gurjar and Mohan[b], 2003. The risk contours for the above two industries are demonstrated in Figures 5 and 6 respectively.

5 CURRENT STATUS AND LIMITATIONS OF RISK ASSESSMENT TECHNIQUES

It is a worldwide experience that quantitative risk assessment (QRA) is a valuable tool to improve the safety and efficiency level in chemical process industries (CPI). However, it is also a fact that this is a continuously evolving science, wanting further refining (Kim et al.,1998). This is why the views on the potential uses of risk analysis differ. For example, most experts and policy-makers agree that risk analysis is a valuable tool to inform decisions, but they disagree about the extent to which risk estimates are biased and should be allowed to influence public policies to protect health and the environment. Often, it is agreed that it should be used to target and address the worst risks to health and the environment first, to achieve risk reduction in more cost-effective and flexible ways that minimize overall economic impacts, and to ensure that risk reduction achieved by regulations is worth the cost. Critics also charge that quantitative methods cannot assess very long-term or newly discovered threats. They also believe that quantitative cost-benefit analyses undervalue environmental and health benefits, exaggerate costs, and focus on relatively widespread but individually small costs and risks rather than on much larger costs and risks to smaller (and often more vulnerable) groups.

The crucial parts of a quantitative risk assessment come before and after the actual risk analysis i.e., making the correct initial assumptions and then interpreting results. An assumption for one case may not be appropriate for another and in case it is used, it may give highly debatable results. In a study conducted in 1988, for example, 11 teams used QRA on a small ammonia plant and their results for one hazard varied from 1 in 400 to 1 in 10-million (Kim et al., 1978). Further, it has been observed that descriptions of the likelihood of adverse effects may range from qualitative judgments to quantitative probabilities. Although risk assessments may include quantitative risk estimates, quantification of risks may not always be possible. Thus it is better to convey conclusions (and associated uncertainties) qualitatively than to ignore them because they are not easily understood or estimated.

Another problem is that the models drastically simplify what happens in real nature. This is the reason that for the same set of data, different models are liable to give highly varied results depending on the basic premises and assumptions used in the development of models (Smith et al., 2000). This makes difficult to choose a model and reject the others. Further drawback to QRA is the need for accident and equipment failure data, which become scarcer, the safer plants become. Nevertheless, trends can be seen. One common cause of failure is "correlated failure", in which backing up one piece of equipment is assumed to increase safety. In an example of "external" correlated failure, an explosion would disable two generators located next to each other. An example of internal correlated failure would be when environmental factors damage the Teflon seals in two pumps of the same type, and a pressure surge takes them both out. Human error is also becoming a more-prominent factor in failures, as the trend to automated equipment continues.

Furthermore, the quality of risk analysis depends on adequacy of data and validity of method. Whereas, for environmental hazards and most health and ecological effects, there are few data, and methods are controversial. As a result, there is a growing perception that the risk analysis has not done a very good job predicting the ecological and health effects of many new technologies (Schierow and Linda-Jo, 2001).

Yet, despite various limitations of QRA as shown in Table 6 (CMA, 1987) and differences in attitudes toward risk analysis, ERA is becoming more important globally. Risk-based decisions, whatever the context, seem to be the soundest guides to ensuring adequate human health and environmental protection, while avoiding costly and unnecessarily stringent control on chemical exposures. It is expected that the use of risk analysis will increase in future because of its versatile application in cost effective management of chemical process industries in particular and to ensure safety and healthy environment to the public in general.

6. CONCLUSIONS

Use of dispersion modeling is demonstrated for the estimation of acute risk for estimating vulnerable zones. Nomograms from dispersion moodelling techniques are illustrated with case studies from Indian industry to be used for evacuation purposes at the time of an accidental toxic release from an industry.

Chronic risk estimates for certain air toxics is estimated from simple dose response models for different states in India and validated with the disease surveillance data. Finally integrated risk assessment approach is demonstrated with case studies for Indian industries with possible adaptation for industrial siting and planning. Lastly, it is recommended to use with caution the dispersion models and QRA techniques with due importance to assumptions and limitations implied therein.

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Table 1. Top ten industrial disasters based on fatality estimates (1945-1990)

Sl. No.	Year	Location	Type / Agent	Deaths[a]
1.	1984	Bhopal, India	Toxic vapor/methyl isocynate	2,750 - 3,849
2.	1982	Salang Pass, Afghanistan	Toxic vapor/carbon monoxide	1,550 - 2,700
3.	1956	Cali, Colombia	Explosion/ammunitions	1,200
4.	1958	Kyshtym, USSR	Radioactive leak	1,118[b]
5.	1947	Texas City, TX	Explosion / ammonium nitrate	576
6.	1989	Acha Ufa, USSR	Explosion / natural gas	500 – 574
7.	1984	Cubato, Brazil	Explosion / gasoline	508
8.	1984	St.Juan Ixhautepec, Mexico	Explosion / natural gas	478 – 503
9	1983	Nile River, Egypt	Explosion / natural gas	317
10.	1986	Chernobyl, USSR	Explosion / radioactivity	31 - 300[b]

a Estimates vary depending on the source(s) used, therefore ranges are provided where there are differences in the total.

b Total number of deaths are hard to gauge since the reported fatality figures only reflect immediate deaths, not the longer term deaths associated with radioactive exposure.

Source : Cutter (1999, 1993, 1991), and Glickman et al. (1992)

Table 2. Major accidents occurred in India during the last decade (Gurjar and Mohan, 2002)

Year	Date/ Month	Location	Origin of accident	Products involved	Number of	
					Deaths	Injured
1997	14.09	Wishakhaptnam	Refinery fire		34	31
1997	21.01	Bhopal	leakage (transport accident)	Ammonia		400
1995	12.03	Madras	Transport accident	Fuel	~100	23
1994	13.11	New Delhi	Fire at a chemical store	Toxic cloud (chemicals)		500
1994	4.1	Madhya-Pradesh	Explosion (storage)	Fire crackers	30	100
1994	January	Thane District	Transport accident	Chlorine gas	4	298
1992	25.1	Tharia	Explosion, Fire	Fireworks	>25	100
1992	29.04	New Delhi	Explosion (warehouse)	Chemicals	43	20
1991	December	Calcutta	Leakage from a pipeline	Chlorine		200
1991	November	Medran	Transport accident (leakage)	Inflammable liquid	93	25
1991	January	Lhudiana	Market	Fireworks	>40	
1991	January	New Bombay	Transport accident	Ammonia gas	1	150
1991	12.07	Meenampalti	Explosion (firework factory)	Fireworks	38	
1990	5.11	Nagothane	Leakage	Ethane and propane	32	22
1990	July	Lucknow	Leakage in an Ice Factory	Ammonia gas		200
1990	16.04	Near Patna	Leakage, transport accident	Gas	100	100
1990	15.04	Basti	Food poisoning	Sulplios	150	>150

Table 3: Classification of the Meteorological Scenarios of the entire year

S.No.	Season	Time(IST)	Winds*	Cloud Cover	Meteorological Conditions	Scenario No.
1.	Winter Summer	1200-1400 hrs 1100-1500 hrs	W_1	0-1/2 0-1/2	AS-A WSC-(0.6-1.78)ms^{-1}	1
2.	Winter Summer	1200-1400 hrs 1100-1500 hrs	W_2	0-1/2 0-1/2	AS-(A-B) WSC-(0.9-3.5)ms^{-1}	3
3.	Winter Summer	1200-1400 hrs 1100-1500 hrs	W_3	0-1/2 0-1/2	AS-B WSC-(3.5-5.2)ms^{-1}	6
4.	Winter Summer	1200-1400 hrs 1100-1500 hrs	W_4	0-1/2 0-1/2	AS-C WSC-(5.3-7.4)ms^{-1}	11
5.	Winter Summer	1200-1400 hrs 1100-1500 hrs	W_5	0-1/2 0-1/2	AS-C WSC-(7.5-9.8)ms^{-1}	12
6.	Winter	1200-1400 hrs -1000-1200 hrs & (1400-1600) hrs	W_1	>1/2 0-1/2	AS-(A-B) WSC-(0.6-1.78)ms^{-1}	2
	Summer	1100-1500 hrs 0900-1100 hrs & 1500-1700 hrs		>1/2 0-1/2		
7.	Winter	1200-1400 hrs 1000-1200 hrs & (1400-1600) hrs	W_2	>1/2 0-1/2	AS-B WSC-(1.9-3.5)ms^{-1}	5
	Summer	1100-1500 hrs 0900-1100 hrs & 1500-1700 hrs		>1/2 0-1/2		
8.	Winter	1200-1400 hrs 1000-1200 hrs & (1400-1600) hrs	W_3	>1/2 0-1/2	AS-(B-C) WSC-(3.5-5.2)ms^{-1}	7
	Summer	1100-1500 hrs 0900-1100 hrs & 1500-1700 hrs		>1/2 0-1/2		
9.	Winter	1200-1400 hrs 1000-1200 hrs & (1400-1600) hrs	W_4	>1/2 0-1/2	AS-(C-D) WSC-(5.3-7.4)ms^{-1}	13
	Summer	1100-1500 hrs 0900-1100 hrs & 1500-1700 hrs		>1/2 0-1/2		
10.	Winter	1200-1400 hrs 1000-1200 hrs & (1400-1600) hrs	W_5	>1/2 0-1/2	AS-D WSC-(7.5-9.8)ms^{-1}	15
	Summer	1100-1500 hrs 0900-1100 hrs & 1500-1700 hrs		>1/2 0-1/2		
11.	Winter	1000-1200 hrs 1400-1600 hrs & 2 hrs after sunrise to 1000 hrs and 1600 hrs to 1 hr before sunset.	W_1	>1/2 any amount but not overcast	AS-B WSC-(0.6-1.78)ms^{-1}	4
	Summer	0900-1100 hrs 1500-1700 hrs 1 hrs after sun-rise to 0900 hrs and 1700 hr to 1 hr before sunset.		>1/2 any amount but not overcast		
12.	Winter	1000-1200 hrs	W_1	>1/2	AS-B	9

		1400-1600 hrs & 2 hrs after sunrise to 1000 hrs and 1600 hrs to 1 hr before sunset.		any amount	WSC-(1.9-3.5)ms^{-1}	
	Summer	0900-1100 hrs 1500-1700 hrs 1 hrs after sun-rise to 0900 hrs and 1700 hr to 1 hr before sunset.		>1/2 any amount		
13.	Winter	1000-1200 hrs 1400-1600 hrs & 2 hrs after sunrise to 1000 hrs and 1600 hrs to 1 hr before sunset.	W_2	>1/2 any amount	ASC-C WSC-(3.5-5.2)ms^{-1}	10
	Summer	0900-1100 hrs 1500-1700 hrs 1 hrs after sun-rise to 0900 hrs and 1700 hr to 1 hr before sunset.		>1/2 any amount		
14.	Winter	1000-1200 hrs 1400-1600 hrs & 2 hrs after sunrise to 1000 hrs and 1600 hrs to 1 hr before sunset.	W_4	>1/2 any amount	AS-D WSC-(5.3-7.4)ms^{-1}	14
	Summer	0900-1100 hrs 1500-1700 hrs 1 hrs after sun-rise to 0900 hrs and 1700 hr to 1 hr before sunset.		>1/2 any amount		
15.	Winter	1000-1200 hrs 1400-1600 hrs & 2 hrs after sunrise to 1000 hrs and 1600 hrs to 1 hr before sunset.	W_4	>1/2 any amount	AS-D WSC-(7.5-9.8)ms^{-1}	15
	Summer	0900-1100 hrs 1500-1700 hrs 1 hrs after sun-rise to 0900 hrs and 1700 hr to 1 hr before sunset.		>1/2 any amount		

16.	Winter	Period between 1 hr after sunrise to 2 hrs after sunrise Within 1 hr before sunset	W_1	any amount any amount	AS-D WSC-(0.6-1.78)ms^{-1}	16
	Summer	Within 1 hrs before sunset or after sunrise		>1/2 any amount		
17.	Winter	Period between 1 hr after sunrise to 2 hrs after sunrise Within 1 hr before sunset	W_2	any amount any amount	AS-D WSC-(1.9-3.5)ms^{-1}	17
	Summer	Within 1 hrs before sunset or after sunrise		any amount		
18.	Winter	Period between 1 hr after sunrise to 2 hrs after sunrise Within 1 hr before sunset	W_3	any amount	AS-D WSC-(3.6-5.6)ms^{-1}	18
	Summer	Within 1 hrs before sunset or after sunrise		any amount		
19.	Winter	Period between 1 hr after sunrise to 2 hrs after sunrise Within 1 hr before sunset	W_4	any amount	AS-D WSC-(5.6-7.9)ms^{-1}	19
	Summer	Within 1 hrs before sunset or after sunrise		any amount		
20.	Winter	Period between 1 hr after sunrise to 2 hrs after sunrise Within 1 hr before sunset	W_5	any amount	AS-D WSC-(8.0-10.5)ms^{-1}	20
	Summer	Within 1 hrs before sunset or after sunrise		any amount		
21.	Winter	2 hr after sunrise to 2 hrs before sunset (during the day)	W_1	Overcast	AS-C WSC-(0.6-1.78)ms^{-1}	8
	Summer	Within 1 hrs before sunset (during the day)		Overcast		
22.	Winter	2 hr after sunrise to 2 hrs before (during the day)	W_2	Overcast	AS-C WSC-(1.9-3.5)ms^{-1}	9
	Summer	1 hrs after sunrise to 1 hour before sunset (during the day)		Overcast		

23.	Winter	2 hr after sunrise to 1 hrs before sunset (during the day)	W_3	Overcast	AS-C WSC-(3.5-5.2)ms^{-1}	10
	Summer	1 hrs after sunrise to 1 hr before sunset (during the day)		Overcast		
24.	Winter	2 hr after sunrise to 1 hrs before sunset (during the day)	W_4	Overcast	AS-D WSC-(5.3-7.4)ms^{-1}	14
	Summer	1 hrs after sunrise to 1 hr before sunset (during the day)		Overcast		
25.	Winter	2 hr after sunrise to 1 hrs before sunset (during the day)	W_5	Overcast	AS-D WSC-(7.5-9.8)ms^{-1}	15
	Summer	1 hrs after sunrise to 1 hr before sunset (during the day)		Overcast		
26.	Winter	Night + 1 hr after sunrise	W_1	Overcast	AS-D WSC-(0.6-1.78) ms^{-1}	16
	Summer	Night				
27.	Winter	Night + 1 hr after sunrise	W_2	Overcast	AS-D WSC-(1.9-3.5) ms^{-1}	17
	Summer	Night				
28.	Winter	Night + 1 hr after sunrise	W_3	Overcast	AS-D WSC-(3.6-5.6) ms^{-1}	18
	Summer	Night				
29.	Winter	Night + 1 hr after sunrise	W_4	Overcast	AS-D WSC-(5.6-7.9) ms^{-1}	19
	Summer	Night				
30.	Winter	Night + 1 hr after sunrise	W_4	Overcast	AS-D WSC-(8.0-10.5) ms^{-1}	20
	Summer	Night				
31.	Winter	Night + 1 hr after sunrise	W_1	Any amount but not overcast	AS-F WSC-(0.7-2.0) ms^{-1}	23
32.	Winter	Night + 1 hr after sunrise	W_2	$< ½$	AS-F WSC-(2.0-3.6) ms^{-1}	24
33.	Winter	Night + 1 hr after sunrise	W_2	$> ½$	AS-E WSC-(2.0-3.6) ms^{-1}	21
34.	Winter	Night + 1 hr after sunrise	W_3	$< ½$	AS-E WSC-(3.4-5.7) ms^{-1}	22
35.	Winter	Night + 1 hr after sunrise	W_3	$> ½$	AS-D WSC-(3.6-5.6) ms^{-1}	18
36.	Winter	Night + 1 hr after sunrise	W_4	Any amount	AS-D WSC-(5.6-7.9) ms^{-1}	19
37.	Winter	Night + 1 hr after sunrise	W_5	Any amount	AS-D WSC-(8.0-10.5) ms^{-1}	20

38.	Summer	Night	W_1	Any amount	AS-D WSC-(0.6-1.78) ms^{-1}	16
39.	Summer	Night	W_2	Any amount	AS-D WSC-(1.9-3.5) ms^{-1}	17
40.	Summer	Night	W_3	Any amount	AS-D WSC-(3.6-5.6) ms^{-1}	18
41.	Summer	Night	W_4	Any amount	AS-D WSC-(5.6-7.9) ms^{-1}	14
42.	Summer	Night	W_5	Any amount	AS-D WSC-(8-10.5) ms^{-1}	15

W_1 Light Air: Wind is not felt on the face, Leaves do not move, though drift could be noticed in the smoke plume.
W_2 Slight Breeze: Wind could be felt on the face, leaves rustle.
W_3 Gentle Breeze: Leaves and twigs in constant motion, wind extends light flags.
W_4 Moderate: Breeze Dust, loose paper and small branches are moved.
W_5 Strong Breeze: Small trees and leaves begin to sway and/or large branches in motion and whistling from the telegraph wires could be heard.

Note:

Night timings are from sunset to sunrise

Winter conditions (in the plains) are assumed to prevail if the mean temperature (average of daily maximum and minimum temperatures) at any station persists at 20 C or below for five consecutive days. Rest of the period corresponds to summer conditions.

For monsoon season, when sky is clear, the same conditions as for summers are applied.
For overcast sky, cases with varying winos have been included in these scenarios.

For raining period, classification corresponding to overcast sky may be considered.

During foggy conditions, scenario number 23 should be considered.

During hazy conditions, scenario number 16 should be considered.

Table 4: Incremental Individual Cancer risk from Cadmium, Chromium and Nickel contamination in certain atmospheric environments in India (Conservative estimates for mixed population)

Input Data: Inhalation rate = 0.6 m^3/hr, Exposure time = 24 hrs/day Exposure frequency = 350 days/year Exposure duration = 60 years, Absorption fraction = 1, Body weight = 60 kg, Averaging time period = 60 x 365 days Potency factors = 6.1 (Cd), 41 (Cr) and 1.19 (Ni)			
	Incremental Individual Cancer Risk (10^{-5})		
State	**Cadmium**	**Chromium**	**Nickel**
Andhra Pradesh	2	30	2
Bihar	2	125	6
Chandigarh (UT)	1	195	7
Gujarat	2	48	1
Haryana	1	85	4
Himachal Pradesh	1	60	2
Karnataka	0	16	1
Kerala	1	17	1
Orissa	1	134	2
Punjab	1	77	3
Rajasthan	3	15	2
Tamil Nadu	1	16	1
Uttar Pradesh	3	67	6
West Bengal	3	63	2
· Actual Chromium risk will be less because risk estimates included total Chromium while only hexavalent Chromium is carcinogenic in nature.			

Table 5: Incremental societal Cancer risk from Cadmium, Chromium and Nickel contamination in certain Atmospheric Environments in India

State	Population* (million)	Incremental Societal Cancer Risk**		
		Cadmium	Chromium[+]	Nickel
Andhra Pradesh	66.30	1,326	19,890	1,326
Bihar	86.34	1,727	1,07,925	5,180
Chandigarh (UT)	0.64	6	1,248	45
Gujarat	41.17	823	19,762	412
Haryana	16.32	163	13,872	653
Himachal Pradesh	5.11	51	3,066	102
Karnataka	44.82	63	7,171	448
Kerala	29.01	290	4,932	290
Orissa	31.51	315	42,223	630
Punjab	20.19	202	15,546	606
Rajasthan	43.88	1,316	6,582	878
Tamil Nadu	55.64	556	8,902	556
Uttar Pradesh	138.76	4,163	92,969	8,326
West Bengal	67.98	2,039	52,827	1,360

* Mahendra, 1991

** Incremental Societal Cancer Risk = Incremental Individual Cancer Risk (from Table 1) x Population.

[+] Actual chromium risk will be less because risk estimates included total Chromium while only hexavalent chromium is carcinogenic in nature.

Table 6. Classical Limitations of QRA (Hanna, 1991)

Five of the most global limitations of QRA are:	
Issue	**Description**
Completeness	There can never be a guarantee that all accident situations, causes, and effects have been considered.
Model Validity	Probabilistic failure models cannot be verified. Physical phenomena are observed in experiments and used in model correlations, but models are, at best, approximations of specific accident conditions
Accuracy/ Uncertainty	The lack of specific data on component failure characteristics, chemical and physical properties, and phenomena severely limit accuracy and can produce large uncertainties.
Reproducibility	Various aspects of QRA are highly subjective thus the results are very sensitive to the analyst's assumptions. Using identical data for a problem models may generate widely varying answers when analyzed by different experts.
Inscrutability	The inherent nature of QRA makes the results difficult to understand and use.

Figure 1

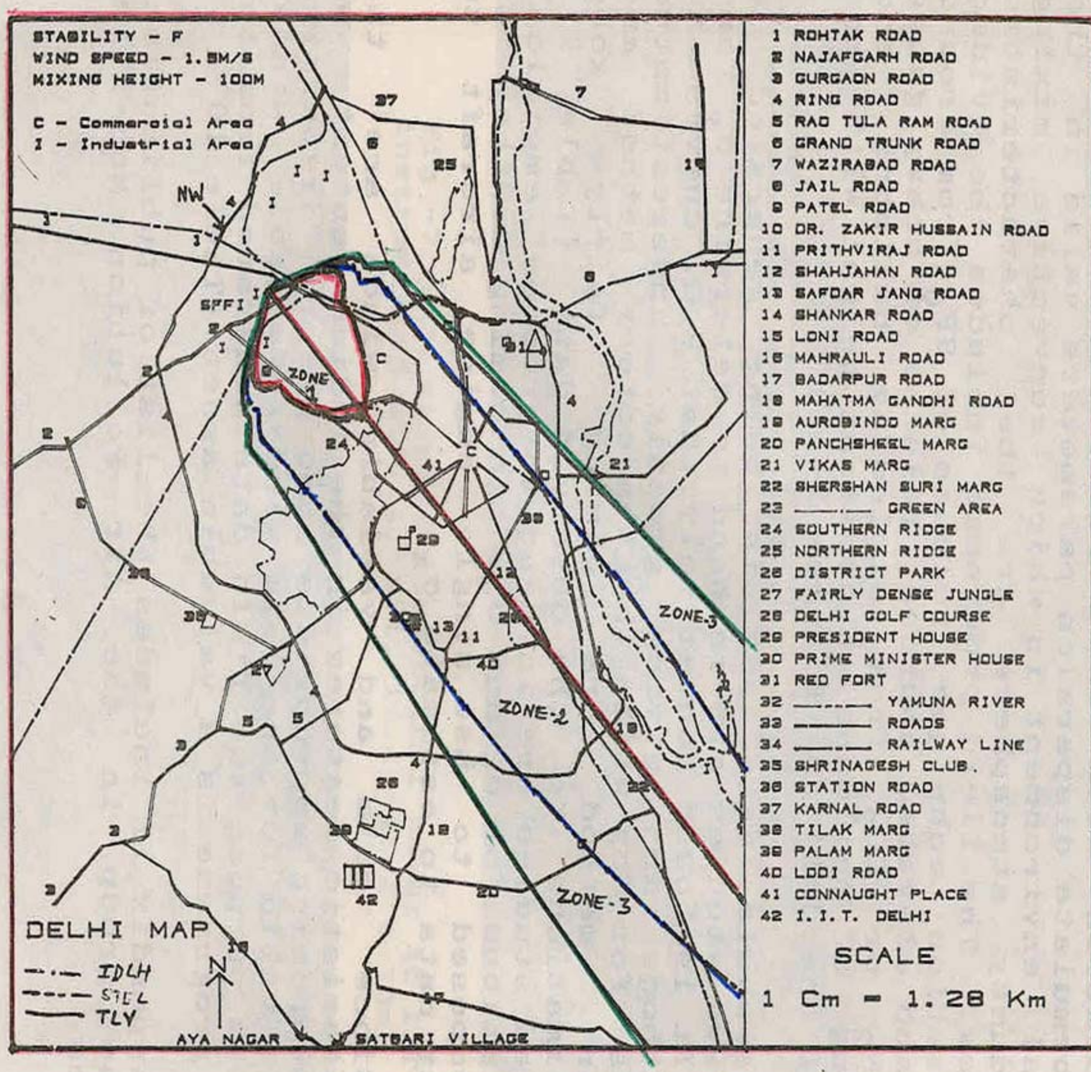
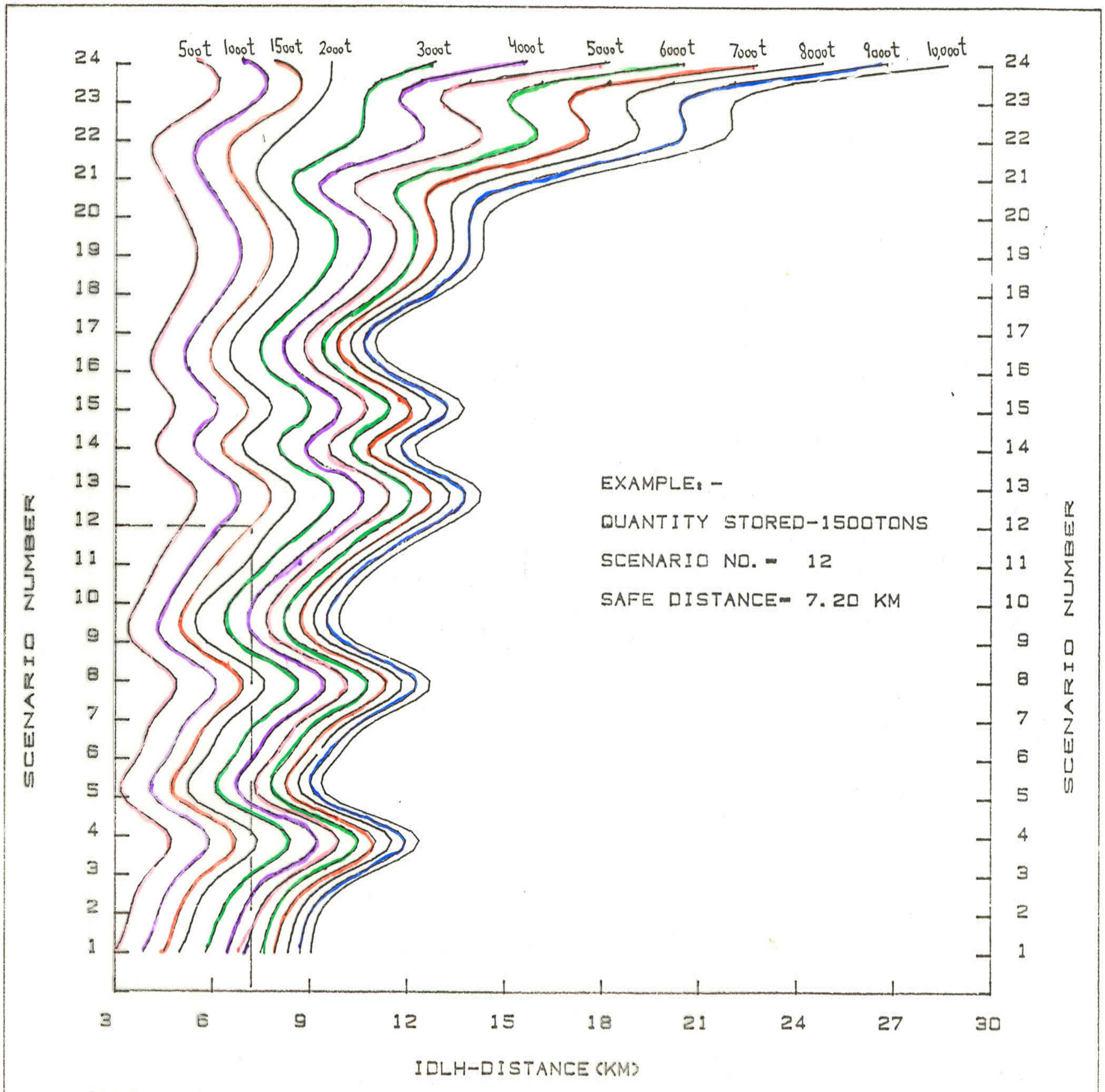


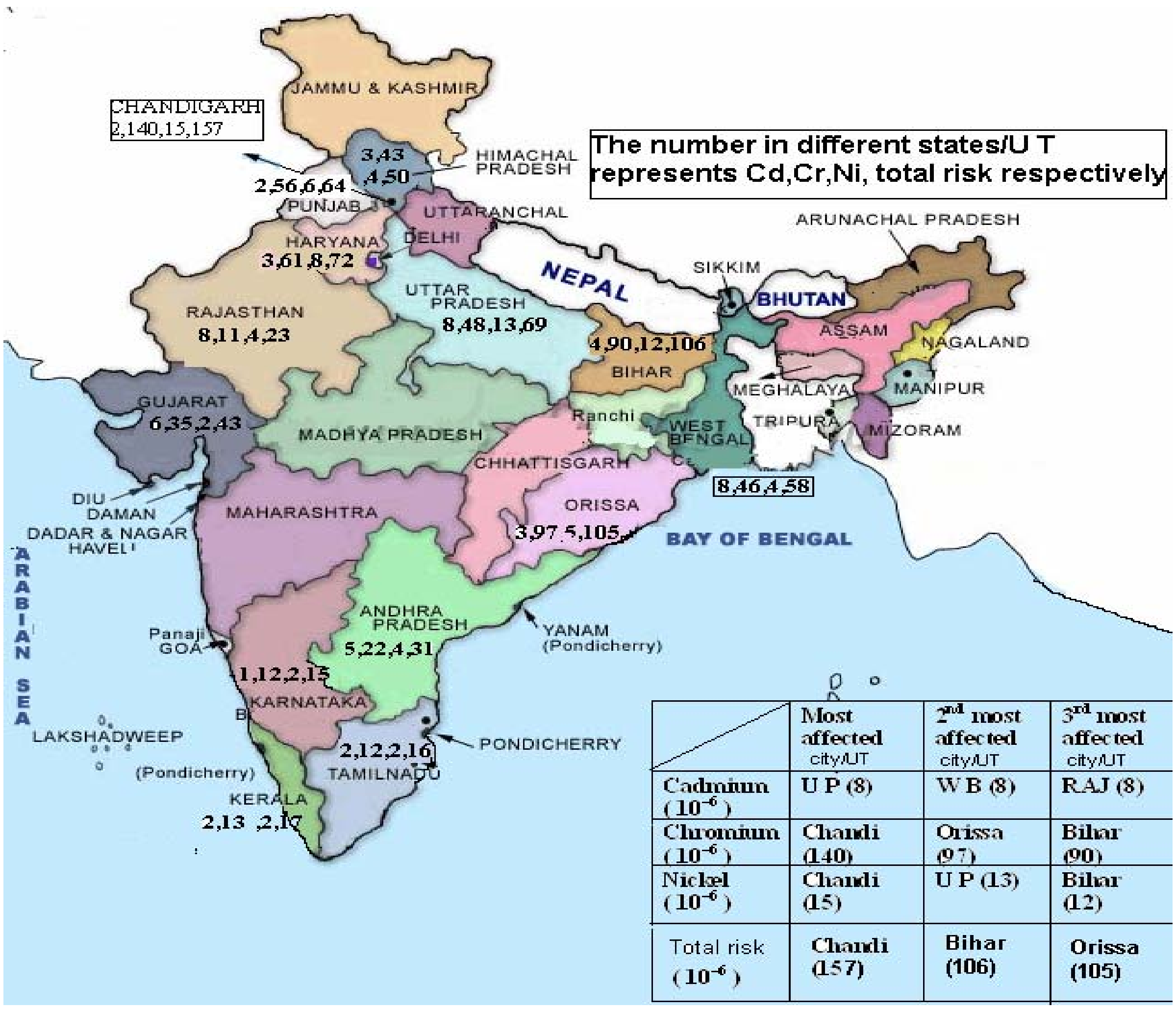
Fig.: Zone of influence due to storage of chlorine (65 t) at SFFI, Delhi.

Figure 2



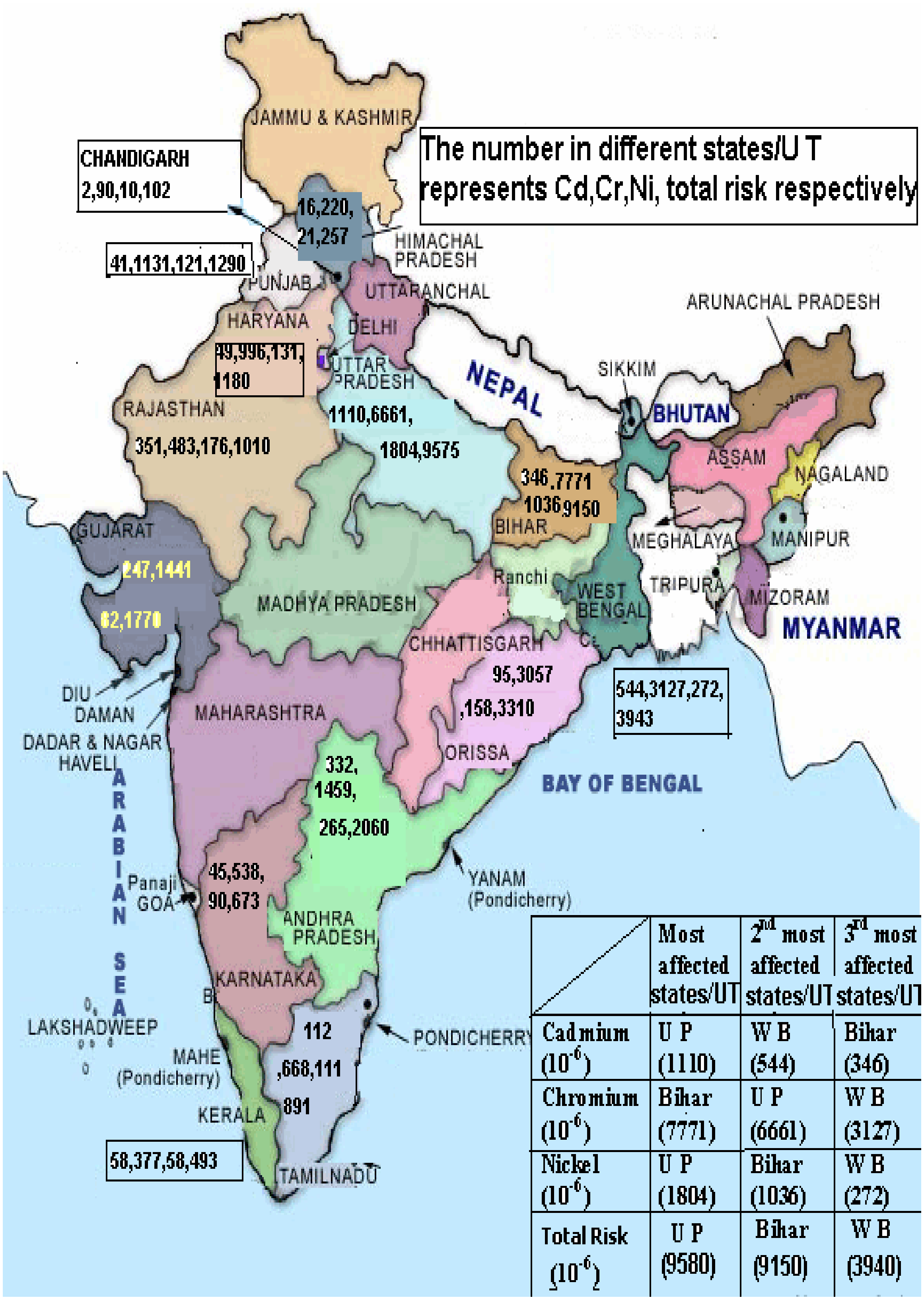
ISOTONS FOR THE ESTIMATION OF SAFE DISTANCE DUE TO STORAGE OF VARIOUS QUANTITIES (500TONS-10000TONS) OF AMMONIA FOR 24 METEOROLIGICAL SCENARIOS BASED ON PREVALENT WEATHER CONDITIONS IN A YEAR

Figure 3



	Most affected city/UT	2^{nd} most affected city/UT	3^{rd} most affected city/UT
Cadmium (10^{-6})	U P (8)	W B (8)	RAJ (8)
Chromium (10^{-6})	Chandi (140)	Orissa (97)	Bihar (90)
Nickel (10^{-6})	Chandi (15)	U P (13)	Bihar (12)
Total risk (10^{-6})	Chandi (157)	Bihar (106)	Orissa (105)

Figure 4:



	Most affected states/UT	2^{nd} most affected states/UT	3^{rd} most affected states/UT
Cadmium (10^{-6})	U P (1110)	W B (544)	Bihar (346)
Chromium (10^{-6})	Bihar (7771)	U P (6661)	W B (3127)
Nickel (10^{-6})	U P (1804)	Bihar (1036)	W B (272)
Total Risk (10^{-6})	U P (9580)	Bihar (9150)	W B (3940)

Figure 5

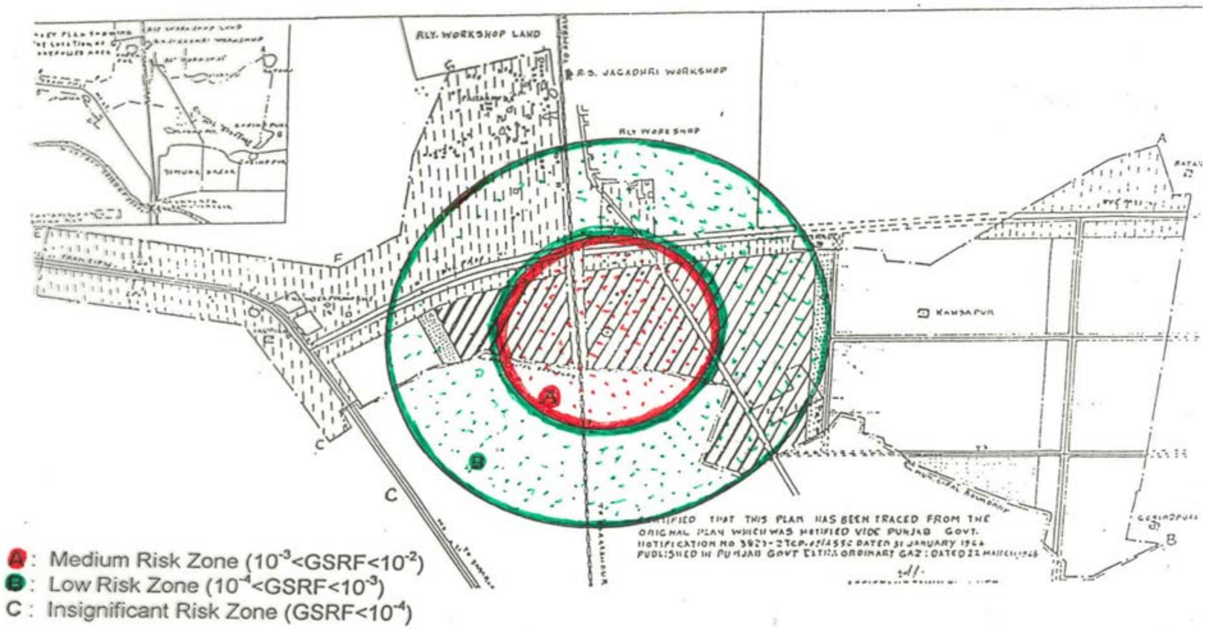


Fig. 6.6 Risk contours pertaining to a hypothetical catastrophic release of Chlorine from M/S Ballarpur Industries Ltd., Yamuna Nagar (Haryana) (Scale : 1 cm = 0.754 km)

Figure 6

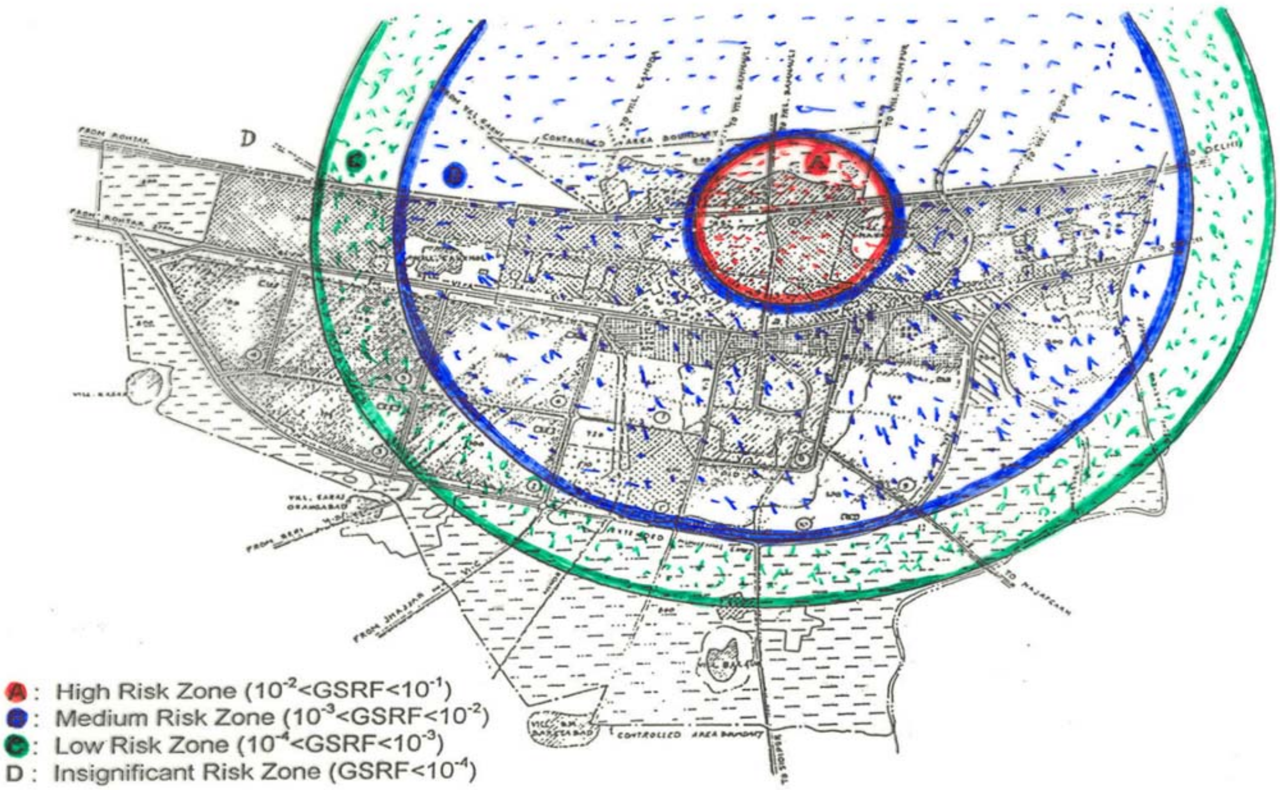


Fig. 6.5 Risk contours pertaining to a hypothetical catastrophic release of Chlorine from M/S Advanced Chemicals, Bahadurgarh (Haryana)
(Scale : 1 cm = 0.445 km)