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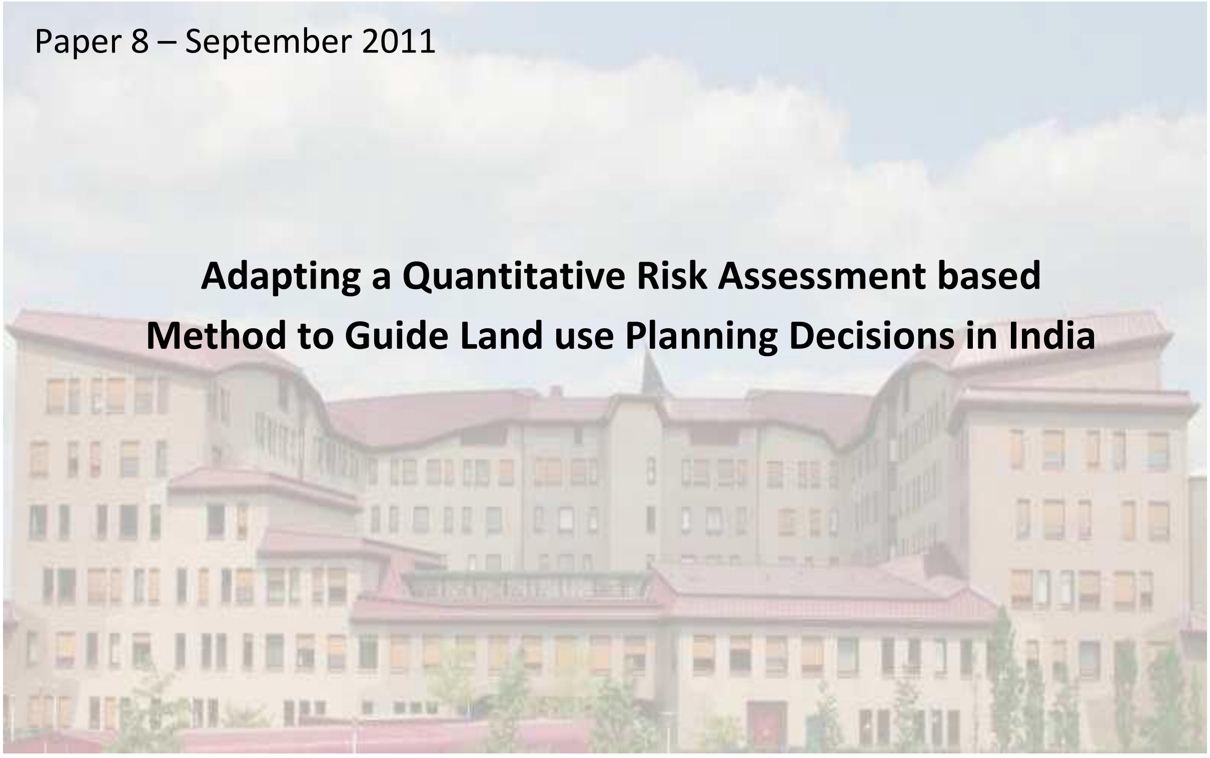

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Adapting a Quantitative Risk Assessment based Method to Guide Land use Planning Decisions in India

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Introduction:

India has been witness to the Bhopal industrial accident in 1984 which caused widespread damage in terms of lives and injuries. Since then, several other industrial accidents have occurred in hazardous industries causing damage and loss of lives in the surroundings. The intensity of such damages or the number of fatalities have been high because many of these hazardous industries often coexist with densely populated areas in industrial towns where proper land use planning or zoning is absent. At this time there are more than 2000 hazardous industries located predominantly in some 100 industrial clusters, across the country. The number of hazardous industries in such clusters is anticipated to go up significantly, with the current policy focus of the government to provide further impetus to growth of chemical industries.

Several risk management strategies have been adopted the world over to reduce the magnitude of risk from such hazardous industries to surrounding population. Land use planning decisions which involve restriction for developing land for certain uses in the vicinity of hazardous installations has become prevalent strategy implemented by a number of countries. In Europe, the Seveso Directive, which set the framework to control major accident hazards involving dangerous substances, specifically prescribes country states to implement land use planning measures that leads to reduction of risk to society in the areas surrounding major accident hazard facilities. In accordance with the Directive, many countries have drawn up detailed risk criteria which are taken into account by planners and decision makers when considering development of land in areas where such facilities are located. The methods adopted by such countries to guide land use planning is based on risk assessment approaches that are prevalent in the country and range from consequence based safety distance approach in Germany to risk based criteria arrived at through quantitative risk assessment (QRA) in the Netherlands and the UK.

Though India is a densely populated country where significant population migration to industrial growth centers in pursuit of economic opportunities has been noted, there is yet no regulatory or planning provision that provide guidance or lay down criteria for incorporating technological risk considerations into land use planning process of such industrial towns. Resultantly, the risk to population from such hazardous industries continue to rise, with the potential for significant damage in case a severe accident like a toxic release, fire or explosion occurs in a hazardous industry.

Objective:

The research presented here is a follow-up of the work carried out under the Environmental Risk Reporting and Information System (ERRIS) project implemented by the Indian Chamber of Commerce in the period 2004-06 in collaboration with European institutions. The key objective of this research was to adapt the contemporary methodology for Quantitative Risk Assessment (QRA) to estimate and spatially represent the cumulative risk originating from a cluster of hazardous industries for a study area in India. In trying to adapt

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the contemporary QRA method for mapping risk from multiple sources, an effort was made to gather insights and evaluate existing practice for risk analysis in India. This included a study of the criteria for selection of reference accident scenarios for maximum credible loss, use of accident frequency data, use of QRA techniques, associated theoretical models and software and finally risk acceptability criteria which could reliably convey levels of cumulative risk to planners and decision makers for use in the land use planning process.

Study Area:

The study was carried out in Haldia, one of the largest industrial areas of eastern India supported by a large port complex and other infrastructural facilities. Haldia is located at the southern tip of the state of West Bengal (Fig. 1). The area bounded by rivers from three sides is spread over an area of 326 km^2. Presently, there are 42 industrial units, out of which 17 are notified Major Accident Hazard (MAH) units as per regulatory criteria specified in Manufacture, Storage and Import of Hazardous Chemicals Rules. Several new industries including a chemical hub under PCPIR is being planned in the Haldia planning area. At the same time, the region is also witnessing a steady growth of population in the last few decades resulting in increase of potential (industrial) risk to communities with many people living in close proximity to hazardous installations.

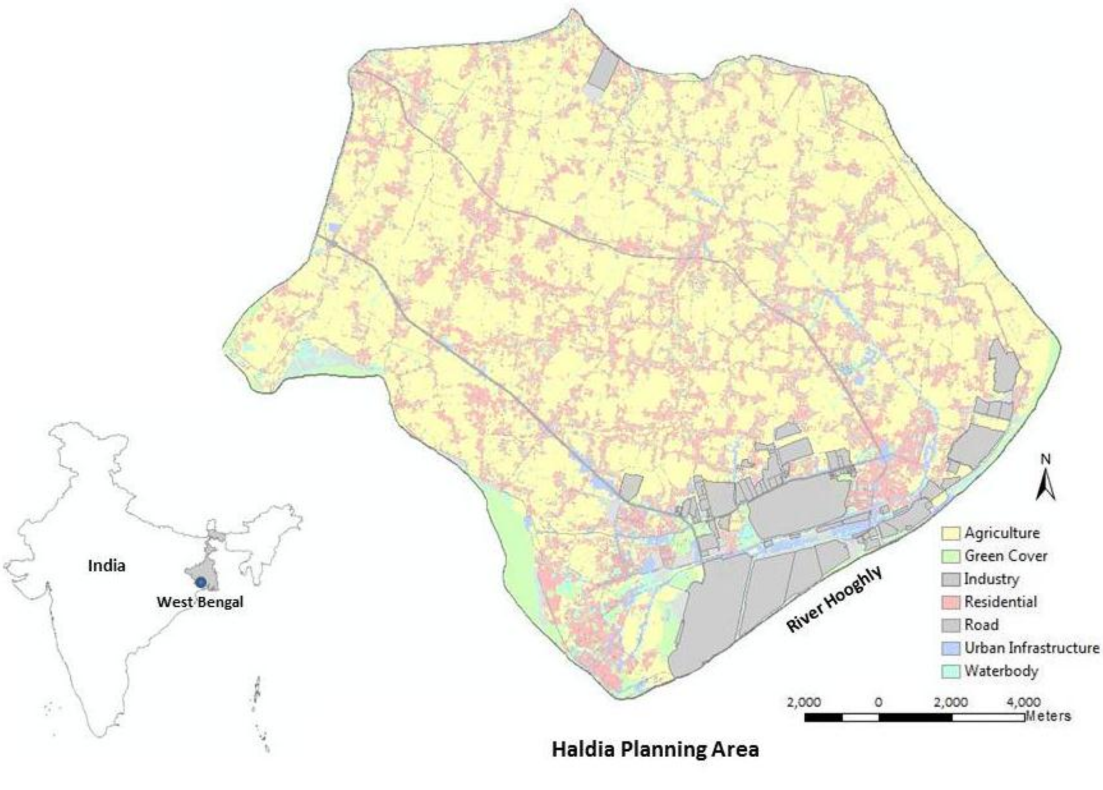

Figure 1: Location of Haldia Planning Area, India

Methodology:

In line with the objective, the study involves the application of the contemporary quantitative risk assessment (QRA) methodology, with certain simplifications, to calculate a measure of risk to communities and to assess the effectiveness of such a risk measure for guiding the land use planning or zoning decisions in the area. The availability of information on hazardous industries and the vulnerability of the surrounding residential areas are vital for undertaking a systematic QRA and utilizing the results for taking land use planning decision in an industrial area. In India, a first step in consolidating such information was taken through the ERRIS project. As a component of this project, a GIS-based risk information system was prepared for the Haldia area. Further research on upgrading the system capabilities of ERRIS is presently being pursued in parallel with the development of a robust and versatile platform called the RMIS (Risk Management Information System). The RMIS geo-database stores information on the location of the hazard sources, the nature of the hazardous chemicals and the conditions of storage, thereby facilitating the building of reference hazard scenarios for this research. In addition, the need for spatial information at sufficient scale has also been highlighted in order to map risk measures like societal risk. For the purposes of the study, a detailed land use map was prepared from a cadastral base map of the area on a scale of 1:4000. The population of entire area, as available from Census administrative units was interpolated into 100 X 100 m grids, through the application of a dasymetric modeling technique.

Eight reference scenarios from select MAH industries were selected for testing the methodology. It is assumed that when applied in practice, such a reference scenario would represent an accident causing maximum credible loss (MCL) to society based on effects in terms of exposure to toxic substances, radiation damage or overpressure from an explosion. Such scenarios is expected to be the outcome of an industry level risk assessment exercise, guided by a uniform method and harmonized set of criteria for facility level risk assessment.

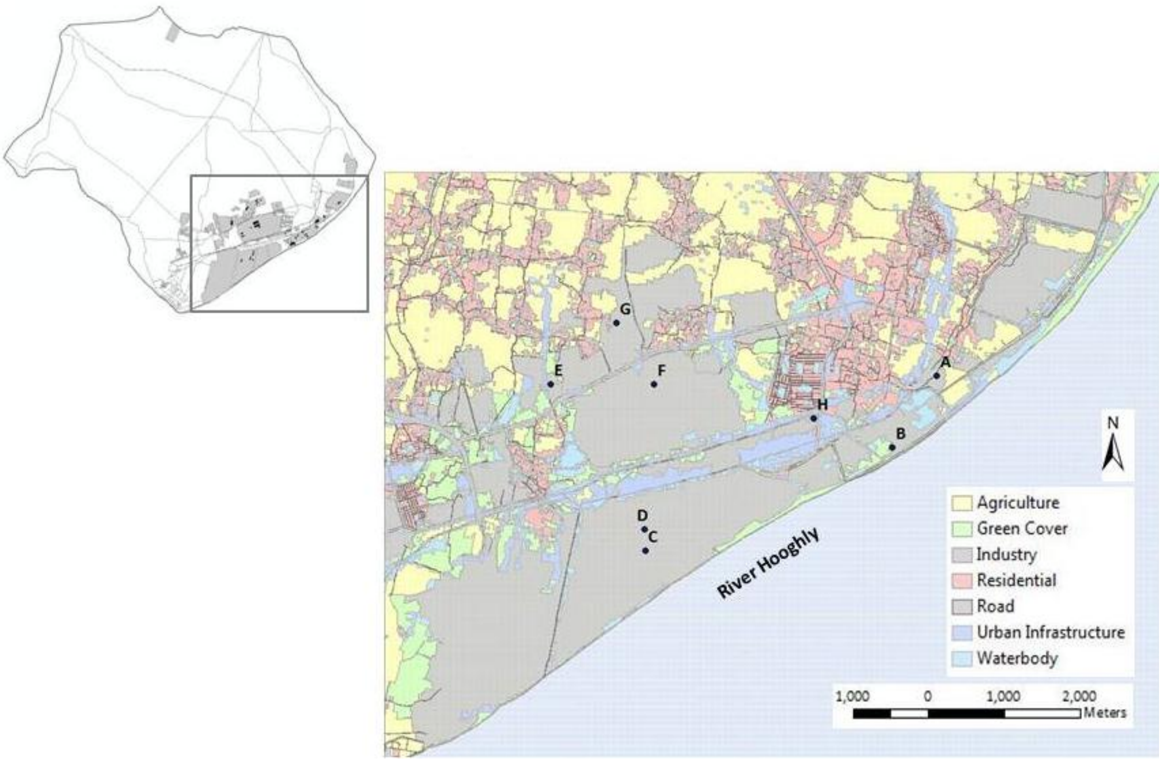

Figure 2: Location of the storages in MAH industries used for reference scenarios

A host of analytical approaches have been formulated and used by risk analysts to predict potential damage, in terms of injury or fatality, from an accident involving a toxic release, fire or explosion in a hazardous installation. Regulatory authorities have varying opinions on the outcome of consequence modeling. Some agencies like the US EPA stress on the use of simple consequence modeling equations for prediction of worst case damage distances to specific end-points whereas other agencies like RIVM in the Netherlands or the HSE in UK prescribe the use of specific tools like SAFETI and RISKAT respectively to be applied based on certain requirements and boundary conditions. Several independent evaluations undertaken in this regard however point to the need for adhering to agree upon benchmarks and prescribed calculation methods for undertaking such risk analysis. Adopting such methods would lead to a reliable and standardized estimate of risk or for judging severity of consequences which could subsequently be summed up to arriving at a measure of cumulative risk.

In the implementation of our methodology for estimation of risk, we have used an acceptable and commonly available tool called ALOHA to simulate spatial footprints representing hazard endpoints of toxic gas concentrations, radiation exposure or explosion overpressure based on threshold for fatality. The choice of ALOHA has been made taking into account the lesser complexity and manageable input requirements of the software. The threshold in terms of % fatality has been derived from Probit functions delineated in standard QRA documentation for different chemicals (for toxic gases) or nature of events (for fire and explosions). The physical effects resulting from the potential accident scenarios were calculated for 1, 5, 10, 20 and 50% fatalities respectively and the resulting effect distances for each scenario is shown below in Fig. 3.

Table 1: Reference Scenarios

Scenario ID	Installation	Containment	Frequency (y^{-1})	Total Capacity	Scenario Description
A	Atmospheric tank single walled	Motor Spirit (Gasoline)	5. 10^{-6} [1]	4200 MT	Catastrophic failure leading to VCE involving 1200 MT
B	Double walled dome roof tank	Ammonia	4. 10^{-4} [2]	10000 MT	Release of 50 MT of Ammonia
C	Atmospheric tank single walled	Motor Spirit (Gasoline)	2.5. 10^{-3} [1]	24150 MT	VCE involving 100 MT of released Motor Spirit
D	Tonner	Chlorine	4. 10^{-6} [3]	1MT	Catastrophic rupture releasing 1 MT Chlorine
E	Atmospheric tank	Motor Spirit (Gasoline)	1. 10^{-4} [1]		Major failure involving VCE of 400 MT of released Motor Sprit
F	LPG bullet	Propane (LPG)	5. 10^{-6} [4]	160 MT	Release of 80 MT of which ignites resulting in VCE
G	Horton Sphere	Butane (LPG)	9. 10^{-7} [5]	915 MT	Tank engulfed into fire and resulting in BLEVE
H	LPG bullet	Butane (LPG)	1. 10^{-5} [4]	30 MT	BLEVE involving 25 MT of LPG

MT = Metric Tons; VCE = Vapor Cloud Explosion; BLEVE = Boiling Liquid Vapor Cloud Explosion

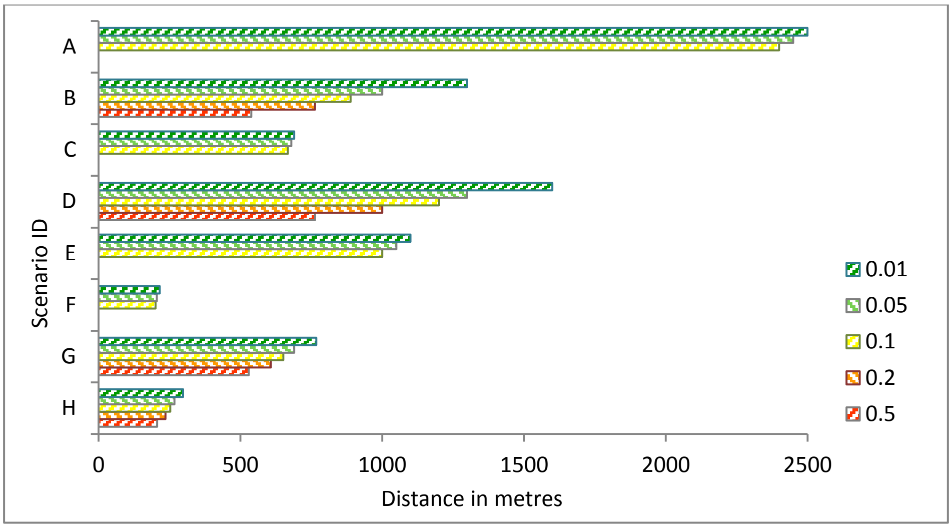

Figure 3: Estimated effect distances for each reference scenarios

These effect distances were then overlaid as concentric buffers from their point of origin using GIS, representing the extent of consequences spatially. Subsequently, using GIS analysis techniques, spatial consequence footprints were combined with the expected probability of occurrence for the accident (based on estimates from the UK HSE failure database) to arrive at a measure of Individual Risk (IR), which expressed as the probability of fatality to an unprotected person located at any location in the vicinity of such industries (unit being probability of death to a person in a grid / year). The IR is represented spatially using iso-risk contours and is presented in Fig. 4.

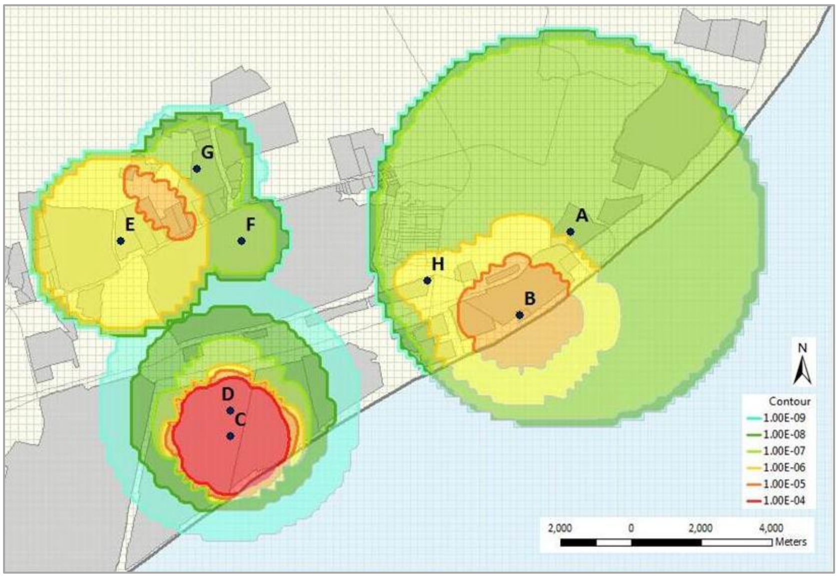

Figure 4: Iso-risk contours showing cumulative individual risk from reference scenarios

Finally, the societal risk in terms of the number of probable fatalities that may be caused, in area where the population resides, has been estimated using a Potential Loss of Life (PLL) function by combining the IR with the number of persons interpolated in each grid. The societal risk (unit being no. of people in each grid who can suffer fatalities/year) is presented in Fig. 5.

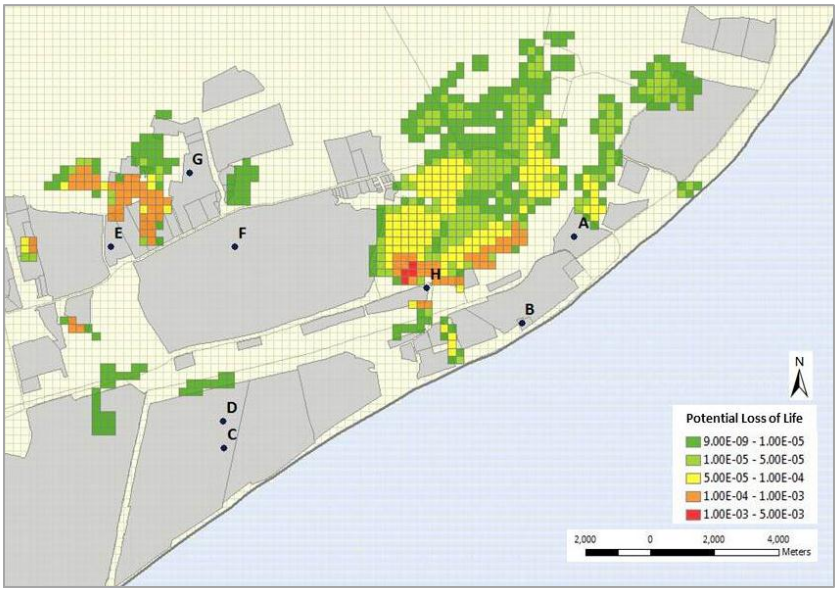

Figure 5: Estimated PLL from all reference scenarios

There can be several uncertainties that can be associated with the application of this adapted QRA method for calculation of individual and societal risk metrics. Some of the key variables or techniques can give rise to such uncertainties and on which the sensitivity of the results may vary. They have been identified and analyzed as a part of the study to stimulate discussion with QRA professionals and planners who may intend to apply this methodology:

- The choice of maximum credible loss scenario, which stands for the probable scenario that can cause maximum offsite-consequences, is dependent on the methodology adopted for facility level risk assessment, which analyses the hazards associated with the process and is based on a number of assumptions made during the exercise and then presented through a safety report. This will bring in inherent uncertainties in QRA study, involving multiple facilities. In addition, the estimation of failure frequency for QRA is generally done based on analysis of historical accident data, which is documented in generic failure frequency databases like TNO's Purple Book and HSE's Failure Rate and Event Database (FRED) and whether these level of failure frequency will hold for Indian MAH installations has to be discussed and agreed upon. The alteration of risk contribution from different scenarios have been studied, based on variation of scenario probabilities and a comparison between assumed probabilities as compared to an intrinsic frequency for all scenarios is presented in Table 2 below.

Table 2: Comparison of societal risk contribution (in percentage)

Scenario ID	Varying frequency	Intrinsic frequency
A	39.72	75.08
B	9.17	0.22
C	0.00	0.00
D	0.25	0.59
E	28.52	2.70
F	0.00	0.00
G	0.43	4.58
H	21.90	16.83

- Consequence assessment models based on data-driven deterministic techniques have considerable levels of uncertainty in predicting end-points based on analytical construct of algorithms for modeling complex chemical release behavior combined with atmospheric phenomena and assumptions made on input parameters. However, for attaining consistency of results and transparency in the application, it is important to use a standardized method which has good traceability in terms of source algorithms – the selection of ALOHA has been made accounting for these aspects.

- The results of consequence predictions can vary to a significant extent based on input weather factors like wind speed, direction, stability class. The variance that may result in risk levels due to consideration of actual wind direction data recorded by a weather station, when compared to assumption of equal probability, averaged across eight wind directions, is shown in Fig. 6 below.

Figure 6: Variation in IR levels accounting for wind direction probability (from wind rose)

- The societal risk results are also sensitive to the grid size defined and the level of detail at which land use is captured for population interpolation. A comparison of the societal risk levels between a 100X100 m and 50X50 m grid is shown in Fig. 7 below.

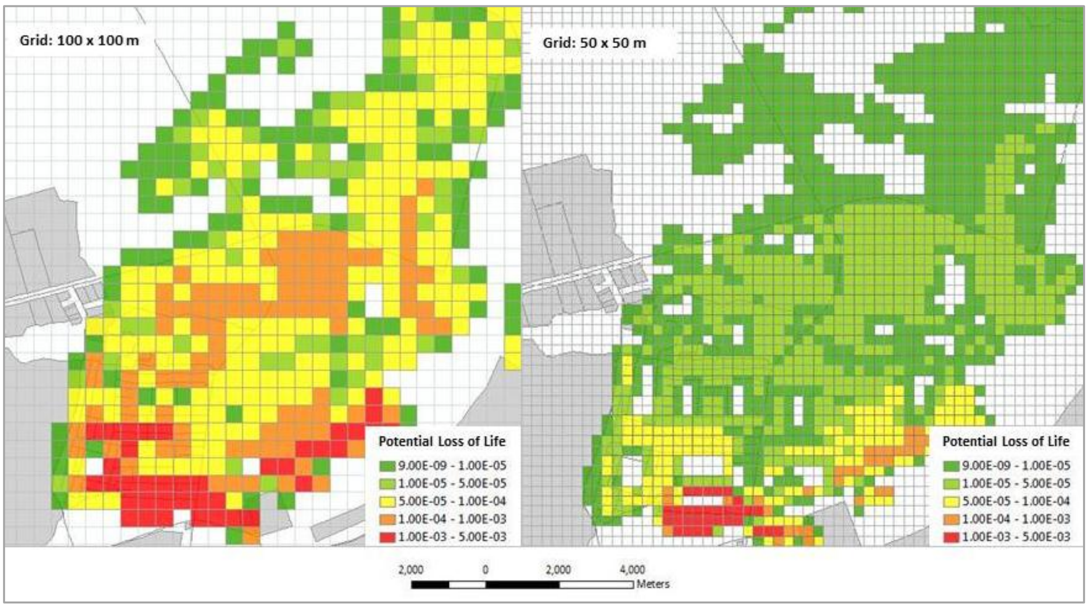

Figure 7: Changes in the level of risk at different resolution

Discussion & Conclusion:

We have demonstrated that a simplified, but reliable methodology for QRA can be adapted for estimating spatial measures of risk originating from a number of hazardous facilities using MCL reference scenarios. On one side, outcome of the research can lead to possible backward linkage towards harmonization of technological risk assessment methods based on standards and criteria acceptable to risk management actors. It has been noted that in the absence of standard criteria for risk endpoints, sufficient guidance on model input conditions and variables, risk or hazard analysis undertaken for MAH industries in the past exhibit substantial variations in results of the consequence scenarios from similar events. Standardization of the risk/hazard analysis procedure may lead to the generation of uniform risk scenarios using a accepted tool, which could be summed using this method to obtain a measure of cumulative individual or societal risk prevailing in an industrial cluster.

On another side, there is scope for exploration of forward linkage towards adoption of risk informed use planning or zoning strategies based on agreement on levels of acceptable risk at the societal level. The adaptation of QRA methodology for purpose of providing inputs to the land use planning process has attached due importance to the use of instrumentarium taking into account the constraints and limitations in India. For example, land use planners in fast growing industrial areas can consider various risk based scenarios and spatially overlaying them on present land use, to be able to allocate future land for industrial and residential development. Figure 8 illustrates the change in risk levels on underlying land use types based on two cases – scenarios with varying frequency and scenarios with frequency intrinsically considered.

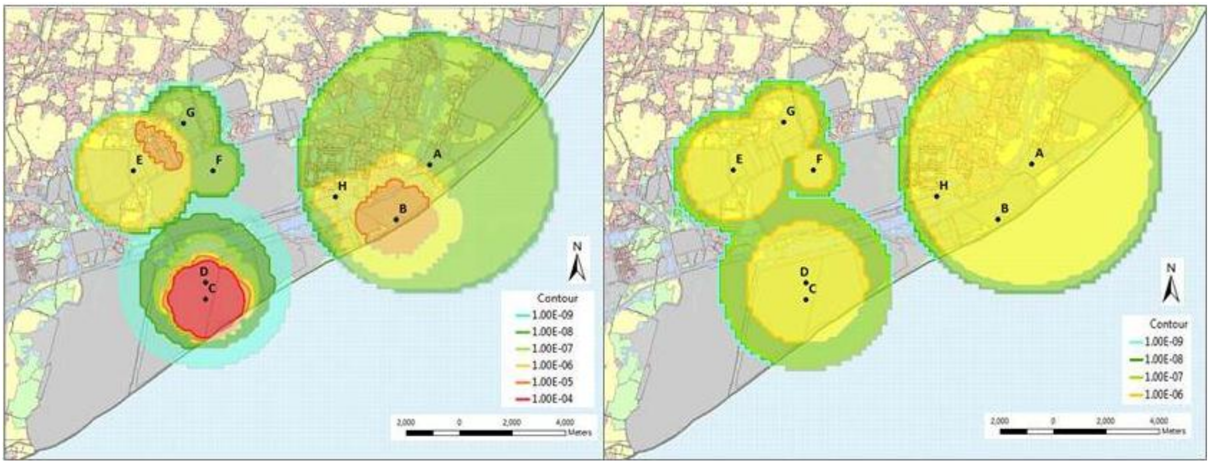

Figure 8: Application of two approaches in the study area

Table 3: Comparison of total area-affected in both approaches

Iso-risk contour value	Scenarios varying frequency		Scenarios with intrinsic frequency	
	Area (sq. km)	(%)	Area (sq. km)	(%)
Within 10^{-4}	1.67	5.92	0.00	0.00
Bet. 10^{-4} & 10^{-5}	1.84	6.53	0.00	0.00
Bet. 10^{-5} & 10^{-6}	5.48	19.44	20.60	72.51
Bet. 10^{-6} & 10^{-7}	12.70	45.05	5.66	19.92
Bet. 10^{-7} & 10^{-8}	3.58	12.70	1.83	6.44
Bet. 10^{-8} & 10^{-9}	2.92	10.36	0.32	1.13

Table 4: Percentage of affected area in different land use category in both approaches

Iso-risk contour value	Scenarios varying frequency				Scenarios with intrinsic frequency			
	Agriculture	Green Cover	Industry	Residential	Agriculture	Green Cover	Industry	Residential
Within 10^{-4}	0.00	0.00	5.93	0.00	0.00	0.00	0.00	0.00
Bet. 10^{-4} & 10^{-5}	0.25	0.50	4.18	0.46	0.00	0.00	0.00	0.00
Bet. 10^{-5} & 10^{-6}	3.00	2.11	7.29	2.32	10.07	4.29	30.21	12.96
Bet. 10^{-6} & 10^{-7}	8.46	1.82	13.43	11.39	0.25	1.50	10.75	1.93
Bet. 10^{-7} & 10^{-8}	5.75	0.93	2.07	0.93	1.36	0.43	2.79	1.00
Bet. 10^{-8} & 10^{-9}	0.82	0.86	6.07	0.93	0.21	0.07	0.46	0.21

One of the key aspects of the methodology formulated for estimation of risk measures in a spatial context is that no complex or proprietary software tool has been used in realizing the method. Therefore, the methodology aligns with the accepted frame set by many countries like the Netherlands and the US that technological risk analysis should not be a preserve of risk analysts, but a decision maker or planner should be able to apply it, following a standardized methodology after receiving basic training to acquire knowledge for its application. In addition, in proposing a risk based approach, in comparison to a consequence based approach, the methodology assigns due weightage to the issue of optimal use of scarce land resources for planning purposes in the Indian context. The methodology also illustrates a novel method for interpolation of population based on which grid based societal risk is estimated.

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