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RESEARCH ARTICLE

A STUDY ON THE EFFECTS OF 10 KT YIELD NUCLEAR BLAST IN A HYPOTHETICAL CITY USING GIS

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ABSTRACT

A Nuclear bomb explosion within or immediately nearby a City or town can cause catastrophic damage on the building's, infrastructures, basic amenities, and shutting down of critical life-safety systems. Nuclear explosions produce immediate effects such as Blast, thermal radiation, prompt ionizing radiations and delayed destructive effects such as radioactive fallout and other possible environmental effects, cause damage over an extended period ranging from hours to years. In this present study a Simulated City with all basic amenities with an area of 125 Square Kilometers is developed using Satellite Data of different Cities and GIS. Data for existing City is not used in this study because of security reasons. Any how the City is planned and modeled as per second Master plan of Chennai Metropolitan Area. The Model City is detonated with a yield of 10 Kiloton of Nuclear explosions using openly available source Hotspot 2.07 as the surface blast at various locations. The ill effects are predicted and modeled using Arc GIS.

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INTRODUCTION

A disaster is a crisis situation that is triggered by either natural calamity or human induced accidents which out-strips the societal capability to cope with. The features of disaster are Unpredictability, Unfamiliarity, Speed, Urgency, Uncertainty, and Threat. The Detonation of a Single Nuclear Bomb or a single nuclear device exploded in any city either by accident, terrorism, or any other reason, it is likely to wipe out hundreds of thousands of people which may cause a Local Disaster on a Scale. That would cause the end of civilization in the countries concerned, and perhaps over the whole world, as well as radioactive contamination of whole continents, and terrible damage to the environment and ecology. Approximately 85 percent of the energy of a nuclear weapon produces Blast energy and Thermal energy (50% Blast energy + 35% Thermal energy). The remaining 15 percent of the energy is released as various type of nuclear radiation. Of this, 5 percent constitutes the initial nuclear radiation, defined as that produced within a minute or so of the explosion, are mostly gamma rays and neutrons. The final 10 percent of the total fission energy represents that of the residual (or delayed) nuclear radiation, which is emitted over a period of time. This is largely due to the radioactivity of the fission products present in the weapon residues, or debris, and fallout after the explosion. If a city of one million or two million would be struck by a single one megaton bomb around one third of inhabitants would be killed instantly or fatally injured, one third seriously injured and the rest uninjured or slightly injured. The two bombs that have been exploded over cities,

Hiroshima and Nagasaki in Japan in August 1945, were in the 10- to 20-kiloton range.. The magnitude of a nuclear explosion is quantified in terms of the amount of conventional explosive it would take to create the same blast effect. The amount of explosive power from a nuclear explosion, or the "yield," is measured relative to TNT, and is usually in the thousands of tons (kilotons, or KT) of TNT. A small nuclear device, for example, would be a 1 KT device, meaning it would produce an explosive yield equivalent to one thousand tons of TNT. Most nuclear weapons in the world today were designed to deliver less than 200 KT; but, some can deliver millions of tons (MT) of yield.

EFFECTS OF 10 KT NUCLEAR EXPLOSIONS IN A MODERN CITY

Blast and Thermal Effects of 10 KT yield Nuclear Explosion

A surface burst of a nominal 10-kiloton explosive in a densely populated modern city would be even more devastating. Because of the heavy local fallout of radioactive material associated with a ground burst, a ground level detonation would greatly increase the number of deaths and injuries from radiation. In addition, there would be a fallout spot, or plume, delayed by, perhaps, 30 minutes, at a distance of 5 to 20 kilometers (km) from the ground burst. Another new phenomenon would be a crater, which, on dry soil or dry soft rock, would have a diameter of about 75 m and a depth of about 17 m (Glasstone and Dolan, 1977). A blast of invisible nuclear radiation would be released within microseconds,

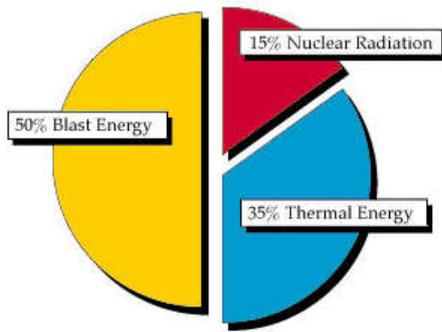


Fig. 1: Energy from a Nuclear Weapon

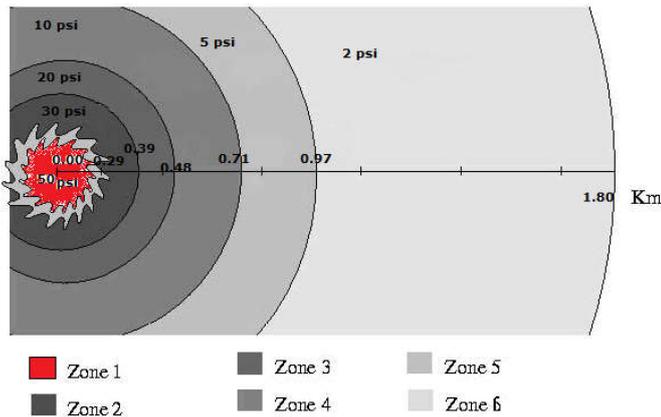


Fig. 2: Blast Effect- Buffer Zones of peak overpressure and distance for a 10 KT explosion (Not to Scale)

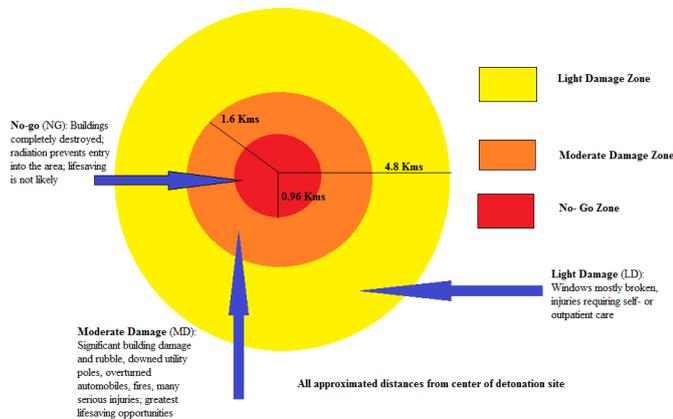


Fig. 3: Representative damage zones for 10 KT nuclear explosion (not to scale)
(Courtesy Homeland Security Council & Office of Science and Technology Policy, USA)

followed within milliseconds by thermal radiation from the surface of the expanding fireball. Winds and destructive overpressure would follow, knocking down buildings in the destroyed area, breaking windows out to a radius of 5.3 km (at 0.5 psi, overpressure from a surface burst of 10 kiloton yield), and converting people and objects into lethal missiles (Glasstone and Dolan, 1977). The damages due to the blast and Thermal Energy may be classified into three Zones as Light Damage Zone, Moderate Damage Zone and severe Damage Zone (Figure 3). There are no clear boundaries between damage zones resulting from a nuclear detonation, but generally, the light damage (LD) zone is characterized by broken windows and easily managed injuries; the moderate

(MD) zone by significant building damage, rubble, downed utility poles, overturned automobiles, fires, and serious injuries; and the no-go (NG) zone by completely destroyed infrastructure and radiation levels resulting in unlikely survival of victims.

Radiation Effects due to 10 KT yield Nuclear Explosion

About six seconds later, the nearest potential survivors would feel an enormous blast and wind. The intensely bright fireball would be long gone by then and some fires would be burning, but more would later be ignited by broken gas mains and the ignition of combustible materials from buildings. The crater material would give off intense, but unfelt, radiation in the immediate area; a total dose of 4 Sieverts (4 Sv or 400 rem) would be lethal to at least 50 percent of the people exposed. The bomb debris, mixed with hundreds of thousands of tons of material from the crater, would rise in the prototypical mushroom cloud into the stratosphere from which coarse debris particles, along with much of the radioactive material, would fall out over a period of 30 minutes or so. With a nominal wind speed, there would be a fallout plume about 2 kilometers (km) wide to a downwind distance of about 20 km. The area affected by lethal fallout might be on the order of 20 km². An example of such a plume with boundaries at the dose rate of 10 rem/hr is shown in Figure 2.

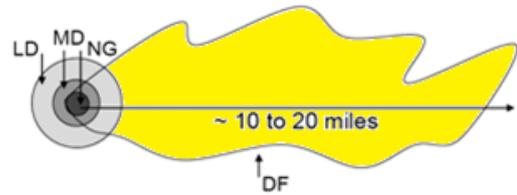


Fig. 4: Nominal fallout plume bounded by 10 rem/hr initial dose rate. DF = Dangerous fallout zone; LD = Light Damage; MD = Moderate Damage; and NG = "No Go."
(Source: Homeland Security Council, 2009 (Not to scale))

Role of GIS in analyzing the affected zones

The role of Geographical Information Technology is an essential tool used in various applications. As far as Nuclear Disasters are concerned, it is very essential to represent the extent of the devastation in the form of spatial format. A geographic information system (GIS) integrates hardware, software, and data for capturing, managing, analyzing, and displaying all forms of geographically referenced information in disaster preparedness, prediction, mitigation, response and Management. It was exhorted in Yokohama Declaration, 1994 that "Disaster Prevention, mitigation and preparedness are better than disaster response which alone is not sufficient, as it yields only temporary results at a very high cost. The information, knowledge and some of the technology necessary reduce the effects of disasters can be made available in many cases at low cost and should be applied." The availability of accurate and reliable data is an essential component of disaster preparedness. Such data bases can be compiled using Relational Data Base Management Systems (RDBMS) interfacing it with Geographic Information System (GIS) of the area. The database can form a valuable resource and can

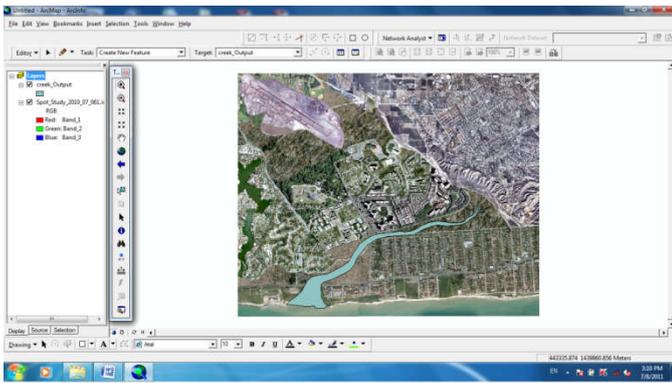


Fig.: 5 Raster Data of Hypothetical City (ARC GIS Edited Google Pro Imagery)

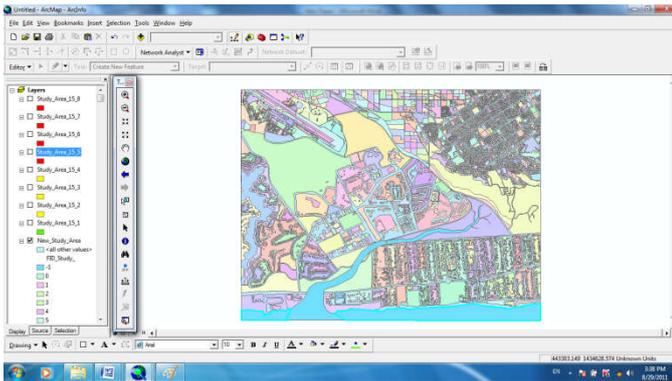


Fig. 6: Vector Data of Hypothetical City (Digitized using ARC GIS)

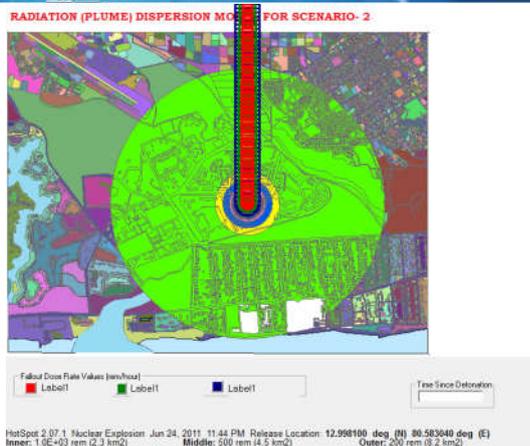
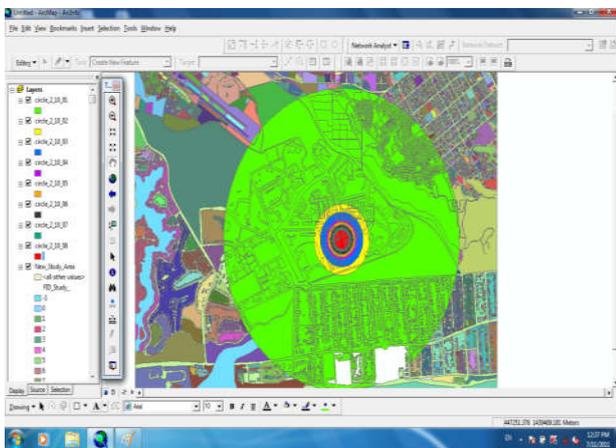


Fig. 8: Map showing the affected Zones and Fall Out patterns for the blast near SEZ

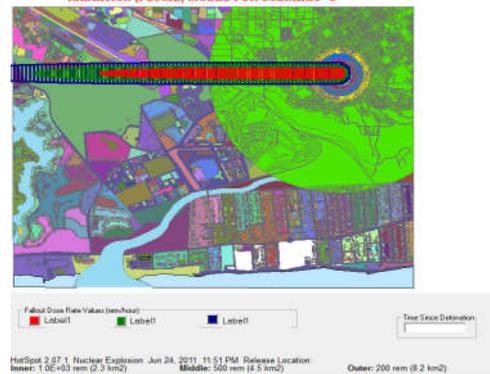
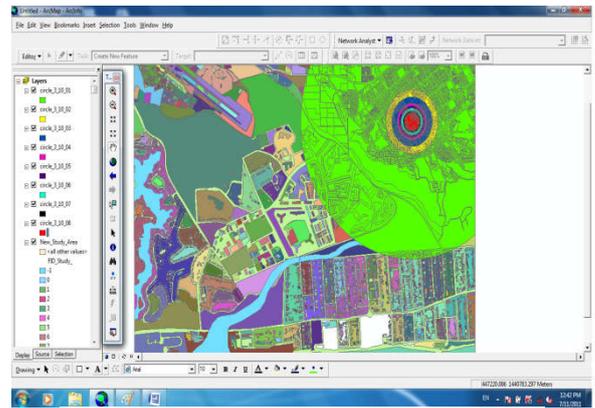


Fig. 9: Map showing the affected Zones and Fall Out patterns for the blast near Residential Area

be retrieved for specific purposes in decision making during disasters.

Need for present study

One of the most catastrophic incidents that could befall the India, causing enormous loss of life and property and severely damaging economic viability, is a nuclear detonation in an Indian city. It is incumbent upon all levels of government, as well as public and private parties within the country, to prepare for this incident through focused nuclear attack response planning. Nuclear explosions present substantial and immediate radiological threats to life and a severely damaged response infrastructure. Local and State community preparedness to respond to a nuclear detonation could result in life-saving on the order of tens of thousands of lives. The purpose of this study is to provide emergency planners with nuclear detonation-specific response recommendations to maximize the preservation of life in the event of an urban nuclear detonation. This paper addresses the unique effects and impacts of a nuclear detonation such as scale of destruction, blast effects and radiation dose plume path. The guidance is aimed at response activities in an environment with a severely compromised infrastructure for the first few days (i.e., 24–72 hours) when it is likely that many organizational resources will still be en route to the incident.

Study area

A hypothetical City has been developed with all basic amenities and infra structures without selecting any existing Indian Cities due to security reasons. The City was planned as per the norms of second master plan for Chennai metropolitan area consists of Residential buildings, Commercial buildings,

Table 1: Relation of wind speeds to peak overpressure and distance for a 10 KT explosion (Glasstone and Dolan 1977)

Overpressure (psi)	Over pressure KN/m ²	Approximate Distance from Ground Zero (miles) [km]	Maximum Wind Speed (mph) [km/h]
50	344.825	0.18 [0.29]	934 [1503]
30	206.875	0.24 [0.39]	669 [1077]
20	137.93	0.30 [0.48]	502 [808]
10	68.965	0.44 [0.71]	294 [473]
5	34.482	0.6 [0.97]	163 [262]
2	13.793	1.1 [1.8]	70 [113]

Table 2: Area Details and % of land used for Amenities & infrastructures in Hypothetical City

Details of Infra structures	Chennai City		Study Area	
	Extent in Sq.Km.	%	Extent in Sq.Km.	%
Residential	95.23	54.25	55.10	43.93
Commercial	12.45	7.09	8.00	6.39
Industrial	9.08	5.17	7.00	5.59
Institutional	32.43	18.48	22.8	17.57
Open Space & Recreation	3.66	2.09	3.85	3.08
Agricultural	0.99	0.57	1.2	0.96
Non Urban	0.82	0.47	0.7	0.56
Others (Vacant, Forest, Hills, Low lying, Water bodies etc.,)	20.87	11.89	26.54	21.20

Table 3. Damage Zones with Peak over Pressure and Radius (source- HOT SPOT)

Damage Zones	Blast Overpressure (psi)	Distance from Ground Zero [km]
Severe Damage (SD) or No-Go Zone	75	0.27
	50	0.32
	30	0.40
	20	0.48
	15	0.54
Moderate Damage (MD) Zone:	08	0.74
	05	0.96
Light Damage (LD) Zone	0.5	4.09

Table 4. Damages to the structures and injuries to human bodies due to peak over pressure of 10 KT yield Nuclear Detonation (Glasstone and Dolan 1977)

Peak Overpressure (psi)	Type of Structure	Degree of Damage
0.15 – 0.22	Typical window glass breakage	Moderate
0.5 – 1.1	Minor damage to some buildings	Moderate
1.1 – 1.8	Panels of sheet metal buckled	Moderate (broken)
1.8 – 2.9	Failure of concrete block walls	Severe
Over 5.0	Collapse of wood framed buildings	Severe
4 – 7	Serious damage to steel framed buildings	Severe
6 – 9	Severe damage to reinforced concrete structures	Moderate
10 – 12	Probable total destruction of most buildings	Severe (collapse)
Peak Overpressure (psi)	Type of Injury to People in the Open	
5	Threshold for eardrum rupture	
15	Threshold for serious lung damage	
50	50% incidence of fatal lung damage	

Table 5: Example dose rate decay from early fallout tracked as a function of time after a nuclear explosion; adapted from Glasstone and Dolan

Time (hours)	Dose Rate (R/h)	Time (hours)	Dose Rate (R/h)
1	1,000	36	15
1.5	610	48 (2 days)	10
2	400	72 (3 days)	6.2
3	230	100 (~ 4days)	4.0
5	130	200 (~ 8 days)	1.7
6	100	400 (~ 17 days)	0.69
10	63	600 (~ 25 days)	0.40
15	40	800 (~ 33 days)	0.31
24	23	1,000 (~ 42 days)	0.24

Industrial buildings, Institutional buildings, Recreational buildings, etc. The Residential buildings are assumed to be RCC structures with single storey to multi storied buildings. The roads are planned with a widening of 10 m to 30 m. Google Pro was used to collect the raster images of existing

cities all over the world and the features such as buildings and other infrastructures were edited and merged using the GIS software ARC GIS(Fig. 5). Around 125 square kilometers of the raster data was also digitized using the GIS software (Fig 6).

Table 7: Damage Assessment for 10 KT Nuclear Explosion near Special Buildings Zone
Nuclear Yield = 10 KT Wind Speed = 5.0 m/sec Wind Direction= 90° (East to West)

Damage Details (Including Buildings & Human lives)	Damages due to Blast Effects								Total Damages
	Affected Zones Vs Peak over Pressure (Psi)								
	I	II	III	IV	V	VI	VII	VIII	
	75	50	30	20	15	8	5	0.5	
Distance from Ground zero	0.27	0.32	0.40	0.48	0.54	0.74	0.96	4.09	-
Area Affected (Km ²)	0.057	0.023	0.046	0.055	0.048	0.201	0.294	12.42	13.144
Residential Buildings	11	13	15	15	13	23	20	2190	2300
Commercial Buildings	2	4	4	5	4	5	3	202	229
Industrial Buildings	-	-	-	-	-	-	1	49	50
Institutional Buildings	1	1	2	3	4	7	7	161	186
Open space & Recreation	3	3	4	4	4	5	8	55	86
Others	-	-	-	-	-	-	2	38	40
Population Affected (Approximate)	4883	2863	5108	5921	3965	22781	21007	939113	1005641

Casualties Details: Human Loss (Zone I, II, III & IV) = 18775. Severe Injuries (Zone V, VI & VII) = 47753. Light Injuries (Zone VIII) = 939113.

Table 8: Damage Assessment for 10 KT Nuclear Explosion near Residential Zone
Nuclear Yield = 10 KT Wind Speed = 5.0 m/sec Wind Direction= 0° (North to South)

Damage Details (Including Buildings & Human lives)	Damages due to Blast Effects								Total Damages
	Affected Zones Vs Peak over Pressure (Psi)								
	I	II	III	IV	V	VI	VII	VIII	
	75	50	30	20	15	8	5	0.5	
Distance from Ground zero	0.27	0.32	0.40	0.48	0.54	0.74	0.96	4.09	-
Area Affected (Km ²)	0.057	0.023	0.046	0.055	0.048	0.201	0.294	12.42	13.144
Residential Buildings	92	1	119	122	114	332	534	3797	5111
Commercial Buildings	1	5	9	12	9	28	43	277	384
Institutional Buildings	4	4	6	11	11	12	10	227	273
Open space & Recreation	3	1	2	2	3	5	4	46	66
Others	-	79	1	1	1	1	-	54	137
Population Affected (Approximate)	26333	12105	25043	25387	23654	103561	150214	1240953	1583550

Casualties Details: Human Loss (Zone I, II, III & IV) = 65168. Severe Injuries (Zone V, VI & VII) = 277429. Light Injuries (Zone VIII) = 1240953.

Related works

Alan F. Phillips from his study indicates that the Detonation of a Single Nuclear Bomb or "Warhead" Would Cause a Local Disaster on a Scale That Few People in the World have seen and survived. The nuclear bombs available to the great military powers of the world range in power from several megatons down to a few kilotons. A "megaton" is the explosive power of one million tons of TNT. A "kiloton" is the power of one thousand tons of TNT. Bombs likely to be available to terrorist organizations or governments other than the great military powers would be in the 10- to 100-kiloton range. *Steinmeyer. K.P.*, has studied that an atomic bomb explosion results in a great amount of damage due to blast and fire, followed by the highly radioactive fallout. At Chernobyl there was no nuclear detonation so the initial local damage was limited to the Unit 3 Reactor Building and adjacent structures. However, the amount of radioactive material released during the accident was far more than would have resulted from a nuclear explosion. *Abdul Mannan*, in his study expressed that although an act of nuclear terrorism is of very remote probability in Pakistan, nevertheless, an attempt has been made to review the pre and post 9/11 threat of nuclear terrorism and its impact on Pakistan. *Vamanu. D et al*, in their paper indicates that it was confirmed in a consensual manner by the various authorities and technical expert parties present and participating in the exercise that RODOS is indeed a viable and functional decision support system, worth implementation in the National Emergency Center, and a commitment was publicly expressed to this effect. It became

apparent that the application of RODOS is a demanding endeavor in several respects, including, inter alia, the need of having the system implemented and fully operational in the Situation Room, wherever it may be, to avoid forbidding telecommunication stopgaps that may get aggravated in a real crisis.

Jan Beyenal and Maureen Hatch, have studied that Geographic modeling of individual exposures using air pollution modeling techniques can help in both the design of environmental epidemiologic studies and in the assignment of measures that delineate regions that receive the highest exposure in space and time. *Hemant B. Kaushik and Sudhir K. Jain* investigate the possibilities to improve the Dutch nuclear emergency management system, a pilot study was carried out on a data assimilation method for our atmospheric dispersion model. By means of the data assimilation method, the prediction of potentially contaminated areas in the early and late phases of a nuclear accident can significantly be improved. *Zakharov et al*, in their paper expressed that; Accident at the Chernobyl nuclear power plant (NPP) in April 1986 appeared to be one of most serious ecological catastrophes. It led to the nuclear pollution of vast surrounding territories and had severe global ecological consequences. *El-Harbawi et al* have studied about the air pollution problem which received more attention during the last decades whereby there has been a significant increase in public awareness of the potential dangers caused by chemical pollutants and their effects on both human beings and the environment. *DeeleshMandloi and Rajiv Gupta*, in their paper presents a method by which the accident-prone

locations on roads, commonly termed as accident black spots, can be identified. The methodology incorporates a model which implements prioritization of roads for accident occurrence, followed by analysis using a Geographic Information System (GIS).

Thomas J. Cova and Richard L. Church, have studied in their paper that a classification of this nature offers a unique approach to assessing community vulnerability in regions subject to fast-moving hazards of uncertain spatial impact. The approach is founded on an integer programming (IP) model called the critical cluster model (CCM). A heuristic algorithm is described which is capable of producing efficient, high-quality solutions to this model in a GIS context. *Lu Li-zhen et al.*, in their paper through analysis of remote sensing technology's application in the investigation and appraisal of geological hazard, in view of the application of remote sensing interpretation about debris flow geological hazard in small basin area, presented the remote sensing interpretation method (RSVH) based on virtual GIS and hydrology spatial analysis.

METHODOLOGY

Design of Hypothetical City

Due to the security reasons a simulated city is used in this present study instead of using Chennai City. Total area of the Model City is around 125 square kilometers. Roughly around 2.5 million (25 lakhs) is assumed to be the population of the hypothetical city. The infrastructures and the basic amenities are planned according to the second master plan of development for Chennai Metropolitan Area. Table given below is the details of the simulated city.

Analysis of Effects due to detonation 10 KT yields Nuclear Explosion using GIS

Blast Effects

The entire Hypothetical City of 125 square kilometers was divided into following three Zones (scenarios) to study the effects of Nuclear Explosion. The yield for the nuclear explosion is 10 KT and the speed of the wind is 5 meter per second (m/sec). The explosion was made as surface blast in day time. The peak over pressure for this blast was calculated from the HOT SPOT model. The following were the three scenarios developed to model the blast effects and radioactive fallouts (plume path)

- | | |
|-------------|---|
| Scenario 1: | Special Buildings Zone (IT offices, Commercial buildings, Administrative offices) |
| Scenario 2: | Residential Zone (Residential, Mixed Residential, Recreational, etc.) |

The detonation of 10 KT Nuclear blast has produced both immediate and delayed destructive effects such as Blast, thermal radiation, and prompt ionizing radiation causing significant destruction within seconds or minutes of a nuclear detonation. Each of these effects is calculated from the point of detonation. The power of over pressure indicated in terms of psi (Pounds per square inch) will reduce with the increase in distance. The relationship between over pressure, distance and wind speeds (Table-3) and the effects of the over pressure

on the buildings and infrastructures (Table -4) are listed in the following tables.

Radiation Effects

Radiation casualties may be caused by prompt nuclear radiation or by radioactive fallout. Prompt ionizing radiation consists of x rays, gamma rays, and neutrons produced in the first minute following the nuclear explosion. Unprotected individuals could receive in excess of the prompt ionizing radiation dose required for 50% lethality (within weeks), out to a distance of 1.4 km (0.88 miles) The delayed ionizing radiation is produced by fission products and neutron-induced radionuclide's in surrounding materials (soil, air, structures, nuclear device debris). These radioactive products will be dispersed downwind with the fireball/debris cloud. As the cloud travels downwind, the radioactive material that has fallen and settled on the ground creates a footprint of deposited material (fallout). The exposure to the fallout is the dominant source of radiation exposure for locations beyond the prompt effects of the nuclear detonation. The dose received depends upon the time an individual remains in the contaminated area. Unprotected individuals remaining in the contamination zone for the first hour following the nuclear explosion could receive in excess of the fallout dose required for 50% lethality (within weeks), out to a distance of about 7 km (5 miles). The idealized maximum width of the fallout footprint (actual width could be larger or smaller) is about 0.32 km (0.20 miles). The downwind extent of the 50% lethality contour increases to approximately 15 km (10 miles) and the 50% lethality contour width increases to about 0.81 km (0.50 miles). Fallout record tracked after a nuclear explosion was shown in the table (Table 5).

RESULTS AND DISCUSSION

Model of 10 KT Nuclear Explosion near Special Buildings Zone of Hypothetical City

In this scenario, a 10 Kilo ton nuclear explosion was detonated near the special buildings and IT corridor zone. The motivation is to collapse the economy of the City or country. The blast effects fall out patterns and radiation dispersion of the affected area were shown in the map given below (Figure-8). The details of yield, Wind speed and direction and the damage assessment (both structural and human) of the affected area were also given in the Table 7.

Model of 10 KT Nuclear Explosion in the Residential Area of Hypothetical City

In this scenario a 10 Kiloton nuclear blast was detonated near the Residential zone. The motivation is to create more damage to the human and assets in the City or country. The blast effects fall out patterns and radiation dispersion of the affected area were shown in the map given below (Figure 9). The details of yield, Wind effect and Direction and the damage assessment (both structural and human) of the affected area were also given in the Table 8.

Conclusions

The greatest damage and lethality from a nuclear explosion in a hypothetical city would result from radioactive fallout that

might expose people in a 20 square kilometers area to radiation levels that would cause 50 percent mortality. From the above study it is observed that

- In the detonation which took place near the air port, around 10,000 people will be killed directly and 30,000 will be injured apart from structural damages and damages on other assets.
- In the second case of explosion near the special economy zone around 12000 people killed and 32,000 injured apart from other collateral injuries.
- In the third case of explosion near the residential area nearly 21,000 people killed and 140,000 people may be lightly and severely injured apart from several buildings collapse.
- In the fourth case of explosion near coastal zone around 15000 people killed and 25000 people may get injure apart from structural damages.

Although not everyone in such an attack can be saved, it is the government's responsibility to do the analysis, planning, simulation, and communication that might be needed for an attack on any one of 20 or more target cities. It would fall to local governments to prepare regulations that would facilitate the temporary sheltering of people, within tens of minutes, in office space to which they do not normally have access.

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