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Population Vulnerability Assessment around a LPG Storage and Distribution Facility near Cochin using ALOHA And GIS

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ABSTRACT: The growth of chemical industries has increased the hazard, risk and vulnerability of the population and the environment. Although accidents in major chemical industries are less frequent, they do pose severe hazard to life and can create havoc on the immediate environment depending on the toxicity of the materials involved, terrain features and meteorological conditions and demography. During a sudden release of hazardous chemicals from a storage tank due to accidents or improper handling, the chemicals may quickly evaporate and form a large cloud of gas which may remain in the planetary boundary layer (PBL). Liquefied Petroleum Gas (LPG), appearing in various hazardous substances lists, can pose a significant vapour hazard, which may cause spontaneous combustion and explosion. This study considers accidental release of LPG and associated risks imposed on society by modelling their dispersion using ALOHA (Areal Location of Hazardous Atmosphere) air dispersion model and human vulnerability assessment using GIS. ALOHA can approximately calculate the area that would be affected by chemical hazards. In this study, using ALOHA, the five possible hazardous outcomes of LPG release are assessed. Mapping of threat zones associated with the accidental release of LPG is done with the help of Arc GIS.

KEY WORDS: *Hazardous material, ALOHA, BLEVE, Arc GIS, Population vulnerability, LPG*

I. INTRODUCTION

Improper handling and accidental release of hazardous chemicals pose serious public health hazards. The intensity of such accidents depends on the nature of release, toxicity of the material, population density and meteorological factors. LPG is one of such chemicals, which can create a significant vapour hazard. The common LPGs in general use are commercial propane, comprising predominantly propane and/or propylene, and commercial butane [1]. There are several studies which focused on an estimation of risks posed by LPG and other hazardous materials during transportation by road [2, 3, 4]. Although the accident from a storage facility is extremely rare, the explosion in IPCL Gas Cracker Complex at Nagothane in Maharashtra, in 1990 [5] and Vapour Cloud Explosion of HPCL refinery at Vishakhapatanamin 1997 are unforgettable incidents [6]. Both the accidents caused the death of more than 50 people each. Previous accidents reveal that, since the accidents are unpredictable, advance identification of potential risks arising due to sudden release of hazardous chemicals from storage facility is essential for reducing loss of life and minimize damage to property and environment. This study is focused on assessing the risks and vulnerability of population around a hazardous material storage.

To assess the population vulnerability, suitable methodologies and tools are integrated in this study. Vulnerability has been defined in various ways such as the threat of exposure, the capacity to suffer harm and the degree to which different social groups are at risk [7, 8]. In this study, vulnerability is assessed by the population which is at risk during an accidental release of LPG. Zhang et al, [4] assessed the risk imposed on human population during the transportation of hazardous material using a two–step process of modeling their dispersion and combining its results with the population distribution. In this study, to assess the population which are at risk, various hazard scenarios created by accidental release of LPG from the storage facility was modeled using ALOHA and the most dangerous one among them is identified for detailed analysis in the study area. This result is used for the estimation of population in the vulnerable area around the facility. Li et al [9] developed a conceptual model of human vulnerability to chemical accidents and proposed a GIS (Geographical Information System) based methodology for mapping the human vulnerability. Cutter et al, [7] in their study, population density was used to reflect relative human vulnerability in an urban area. The knowledge of land use pattern surrounding the hazardous storage facilities as well as other relevant geographical details required for emergency management using GIS helps in rapidly identifying the area at risk at a glance, and is also very helpful for making effective response and decisions for administrators and emergency managers [10].

II. STUDY AREA

Ernakulam District is the industrial hub of Kerala State in south India, where a number of Major Accident Hazard (MAH) chemicals are handled regularly. The LPG bottling plant, operated and managed by Indian Oil Corporation, is located between 9^0 53’ 35” N latitude and 76^0 22’30” E longitude at Udayamperoor GramaPanchayat (Figure 1), which is a densely populated village. The adjoining Panchayath near to this installation is Mulanthuruthy which is also populated similarly. Total population of Udayamperoor and Mulanthuruthy Panchayaths is 29,523 and 19,417 respectively. A unique feature of the Kerala is that it is a continuously populated region with varying densities of population, which adds to the vulnerability during major hazards.

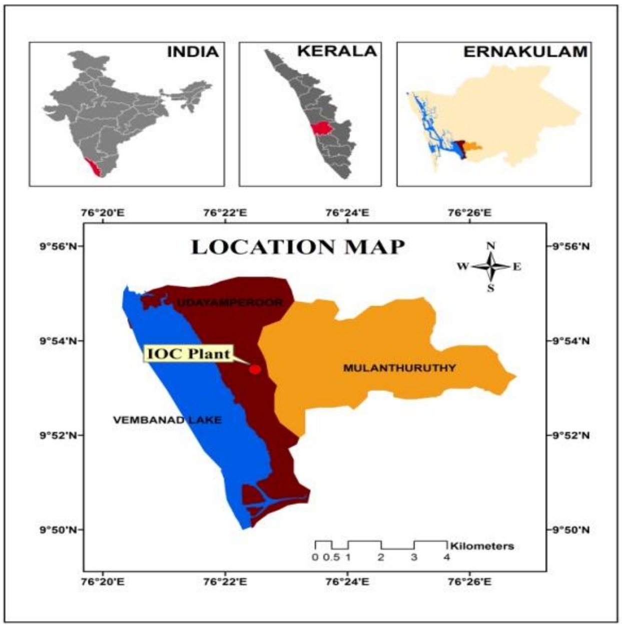

Figure 1: Study area map

III. MATERIALS AND METHODS

Information about the storage facilities and possibilities of LPG leaks was collected from the plant administrators as well as concerned Government departments. Other secondary data regarding the distribution of population was collected from Panchayat authorities. Land use pattern and regional boundaries were determined from toposheets as well as Google Earth. For assessing the risk imposed on population by an accidental release of LPG from a storage facility, the following methodologies were adopted:-

1. Analysis of various hazardous outcomes of an accidental LPG release using ALOHA; The threat zone distance, gas concentration and thermal radiation due to an accidental LPG release is modelled for five possible hazardous outcome scenarios. The most dangerous scenario among them is identified and its threat zone distance was overlaid on the actual location map given by Google Earth.
2. Assessment of vulnerable area within the threat zone using Arc GIS 9.3 software; Populated areas coming under the threat zone was demarcated using GIS. The geostatistical analyst tool in GIS provides necessary information about the population distribution pattern of the area surrounding the plant.

3.1. Areal Location of Hazardous Atmosphere (ALOHA)

ALOHA dispersion model is a Gaussian Plume model, which was developed and is supported by the Emergency Response Division (ERD) within the National Oceanic and Atmospheric Administration (NOAA) in collaboration with the Office of Emergency Management of the U. S. Environmental Protection Agency (EPA). It is a part of the CAMEO software suite, a system of software applications used widely to plan for and respond to chemical emergencies. ALOHA employs Levels of Concern (LOC) to address the impact of toxic air plume, fires and explosion on human population. LOCs for toxic inhalation hazards are specific to the chemicals. Thresholds for inhalation toxicity are extracted from CAMEO chemicals. Acute Exposure Guideline Levels (AEGLs) are public exposure guidelines, which are developed for accidental chemical release events, are stored within the data files integrated into ALOHA. ALOHA’s threat zone represents the area within which the ground level gas concentration exceeds the level of concern at any time [11]). There are several studies focusing on the consequences of accidental release of LPG using ALOHA [12, 13].

3.1.1. Hazard and Scenario Analysis by ALOHA

Basic data fed into the ALOHA model and the assumptions taken for predicting the damage potential of LPG are the following.

Location

Udayamperoor
Latitude $9^0$53' 35"N Longitude 76^0 22'30" E

Chemical data

Name; Propane
Molecular weight; 44.10 g/mol
Ambient boiling point; -42.0 ^{0}C
Vapour pressure at Ambient Temperature; greater than 1 atm

Atmospheric data

Wind; 2 m/s from west-south west (WSW) at 10 meters height during day time
Ground roughness; open country
Stability class: B (slightly unstable)
No inversion height
Relative humidity: 75%

Source strength

In the present case, a leak from a hole of 10 cm in diameter is considered. An accidental tank explosion, which is highly unlikely, will be considerably more hazardous.

Tank diameter: 3.5 meter
Tank volume : 312 cubic meters
Chemical mass in tank: 150 tons
Internal temperature: 29^0 C
Tank contains liquid
Tank is 85% full

3.2. Geographical Information System (GIS)

GIS is an effective tool to deal with spatial data. In this study, Arc.GIS 9.3 software is used to display the threat zone over the spatial land use pattern. The geostatistical analyst in spatial analyst toolbox of Arc.GIS 9.3 provides tools for viewing the population distribution pattern in the threat zone area.

The combined use of GIS and ALOHA is used for vulnerability assessment. The information provided by both the software, like the hazard consequence area (affected area), the populated area within this threat zone etc are considered for vulnerability assessment. The density of population in the area is also taken into account.

IV. RESULT AND DISCUSSION

There are 10 LPG bullet tanks installed in this plant (7 tanks with 150 MT capacity each and 3 tanks with 100 MT capacity each) with a combined capacity of 1,350 metric tons. Usually, the tanks are filled about80% to 85 % making the total storage more than 1,000 MT at any point of time. The LPG contained in only one tank (150 MT) is considered for the prediction of hazard in the ALOHA model.

If a flammable and toxic chemical is released, but does not immediately catch fire, a vapour cloud will form and multiple hazards are likely to occur depending on the meteorological conditions, release pattern of the chemical etc. The leak of LPG from a storage tank can be a jet fire (if the hole is only a puncture), flash fire (when the vapour cloud catches fire), vapour cloud explosion (when the cloud explodes) or Boiling Liquid Expanding Vapour Explosion (BLEVE) [8]. LPG, even though slightly toxic, is not poisonous in vapour phase, but can however, suffocate when in large concentration due to the fact that it displaces oxygen [14].

4.1. Scenario Analysis using ALOHA

Depending on the nature of LPG release, five possible hazardous outcomes mentioned above are graphically represented below predicted using ALOHA.

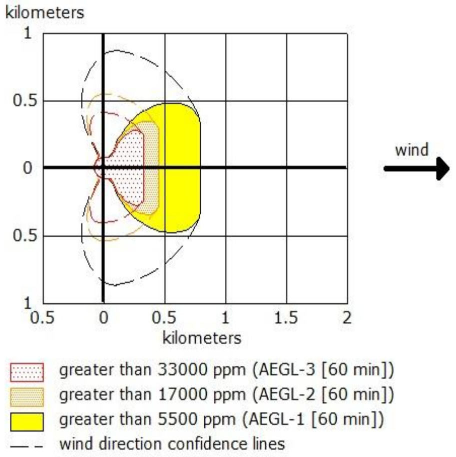

Figure 2: Toxic Area of Vapour Cloud

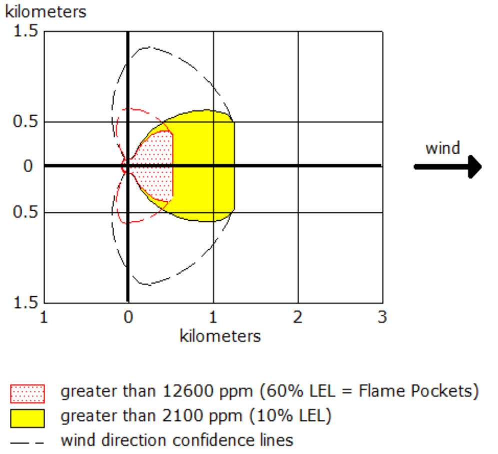

Figure 3: Flammable area of vapour cloud

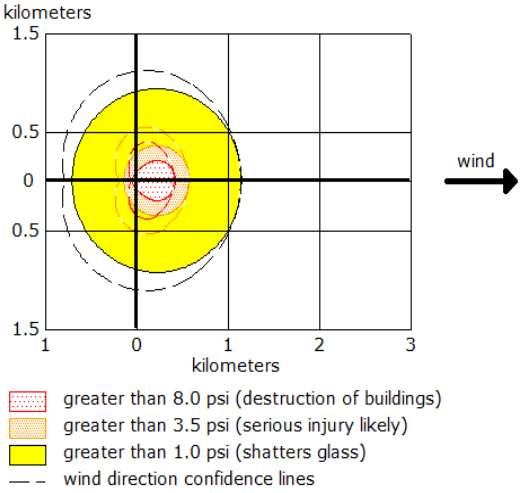

Figure 4: Blast Area of Vapour Cloud

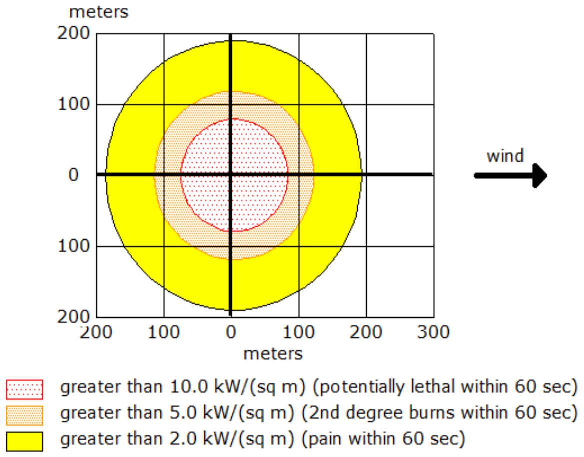

Figure 5: Thermal radiation threat zone(jet fire)

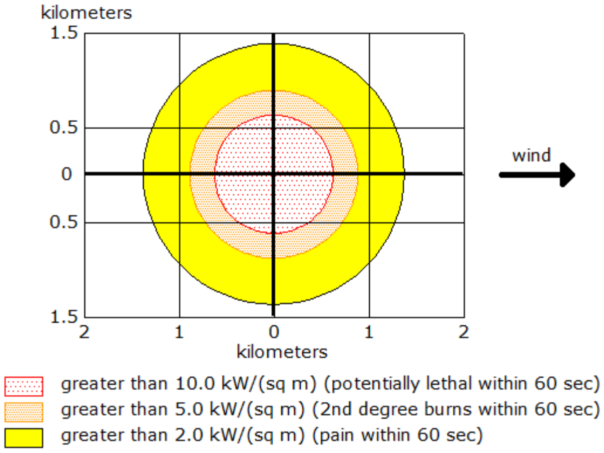

Figure 6:. Thermal radiation threat zone (BLEVE)

4.1.1. Toxic Area of Vapour Cloud:

Toxic Area of Vapour Cloud predicts the area where the ground level vapour concentration may be hazardous. Figure 2 depicts the threat zones of a vapour cloud persisting for 60 minutes in which shades of red, orange, and yellow are shown depending on the ground level gas concentration exceeding the Level of Concern (LOC). Red threat zone indicates that the concentration of the chemical is very high (>33000 ppm) up to a distance of 250 m from the source of leakage and at a distance of 250 to 495 m the concentration may be >17000 ppm. More than 5500 ppm of pollutant concentration may be experienced in the area at a distance of 495 to 760 m depending on the wind direction.

4.1.2 Flammable Area of the Vapour Cloud:

Figure 3 shows the area where flash fire could occur. Here, the red and yellow threat zones represents the concentration of LPG in the air and when it come into contact with any ignition source it will burn. In the red threat zone, the concentration of chemical vapour is >12600 ppm up to a distance of 500 m and it is >2100 ppm in yellow threat zone at a distance of 500 to 1150 m according to the wind direction.

4.1.3. Blast force:

If a vapour cloud formed in the air burns quickly, it will create an explosive force. Figure 4 represents the blast area of a vapour cloud. A blast force of 8 psi may be experienced at a distance of 400m from the point of leakage, 3.5 psi at a distance of 400 to 450 m, and 1.0 psi at a distance of 450 to 1050 m.

4.1.4. Jet Fire:

If a flammable gas sprays through an opening of a tank and gets ignited, it is likely to form a jet fire. The threat zones in the figure 5 represents the area which is affected by thermal radiation. A distance up to 80 m radius from the source is potentially lethal within 60 s. People coming under a radial distance of 80 to 110 m may experience 2nd degree burns and 110 to 198 m of radial distance may experience pain within 60 s of exposure.

4.1.5 Boiling Liquid Expanding Vapour Explosion (BLEVE)

When a tank containing a liquefied gas fails completely, a BLEVE can occur. The radiation effect up to 500 m radial distance from the source is potentially lethal. People living under a distance of 500 to 950 m may experience 2nd degree burns, and those living within a distance of 950 to 1300 m may experience severe pain. The hazard distance and thermal radiation effect is depicted in figure 6.

Table I: Hazard distance and effect of different possible outcomes of LPG release

LPG release scenarios	*Potential hazards and its effect*		*Threat zone distance in each scenario.*
Chemical is not burning immediately, but formation of a vapour cloud	Toxic vapour concentration	> 33000 ppm	250m (from the source)
		> 17000 ppm	250-495m
		> 5500 ppm	495-760m
	Ground level vapour concentration	>12600 ppm	500m (from the source)
		>2100 ppm	500-1150m
	Blast force (over pressure from the explosion)	> 8.0 psi	400m (from the source)
		> 3.5 psi	400-450m
		>1.0 psi	450-1050m
Chemical is burning as a jet fire	Thermal radiation	>10.0 kw/(sq m)	80m (from the source)
		>5.0 kw/(sq m)	80-110m
		>2.0 kw/(sq m)	110-198m
Tank explodes and chemical burns in a fire ball	Thermal radiation	>10 kw/(sq m)	500m (from the source)
		>5.0 kw/(sq m)	500-950m
		>2.0 kw/(sq m)	950-1300m

Table I shows the result of scenario analysis and its potential hazard distance. The result shows that the thermal radiation effect by BLEVE of LPG is very hazardous. Compared to other scenarios BLEVE is the most effective and dangerous hazard associated with failure of LPG storage tank as it has thermal radiation effect even on short exposure in a short duration. Besides, the area that would be affected by BLEVE is comparatively large and within a short span of time it has the potential to destroy large area. The explosion in one storage tank may trigger a secondary accident in a nearby tank, which in turn may lead to a tertiary accident, and so on. Hence, the probability of such chain of reactions (domino effect) is to be considered for hazard management. The area that would be affected by BLEVE from only one tank (150 MT) is only considered in this study for the estimation of vulnerable population. The domino effect has to be considered separately.

4.3 Assessment of Population Vulnerability

Figure 7 shows the thermal radiation threat zone created by BLEVE which is overlaid with the actual location given in the Google Earth. The maximum societal risk estimated up to a distance of 1300 m from the point of leakage is plotted in the figure.

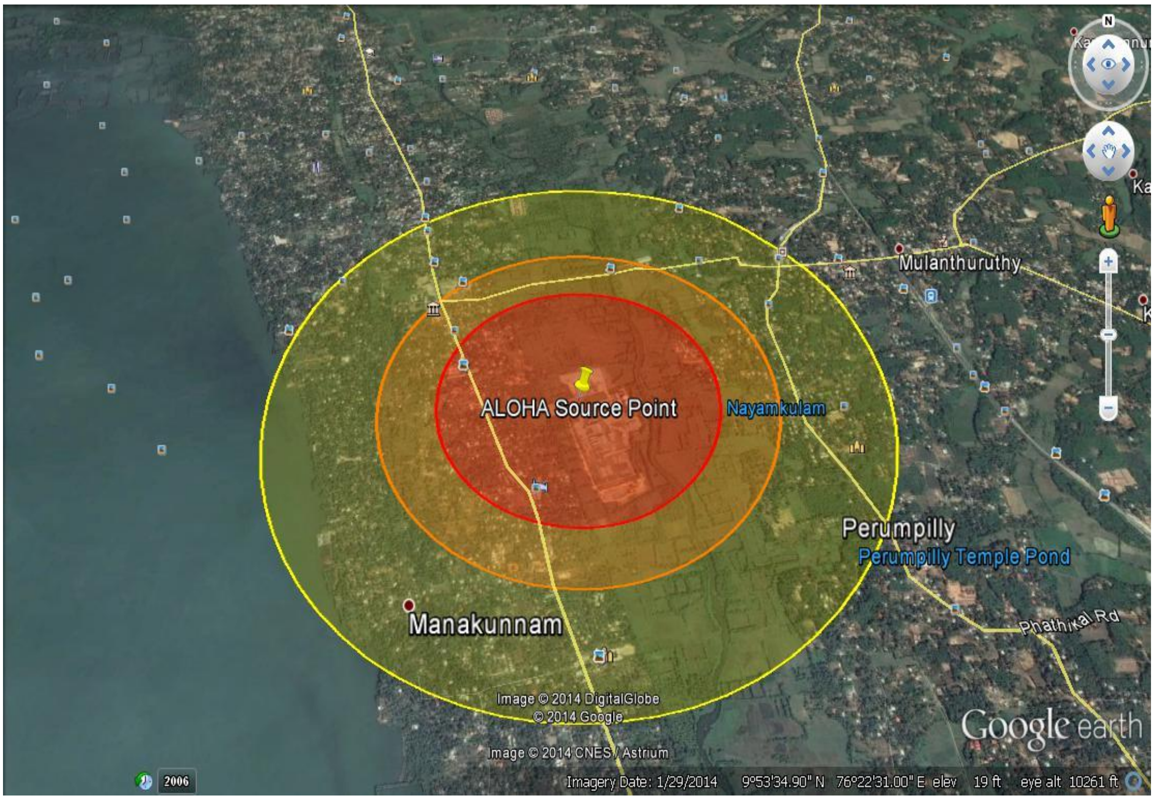

Figure 7: Threat zone overlaid on Google Earth Map

Considering the location of the industry and the threat zone distance, it is clear that the most seriously affected region at the time of accident will be the area coming under Udayamperoor and Mulanthuruthy panchayaths. Hence, the entire area coming under these two panchayaths is taken for the vulnerability study. Both the panchayaths together has a combined area of 50.32 km^2. From the land use classification of the area (figure 8) it is clear that out of the total area of the panchayaths, settlements cover 23.678 km^2 and the remaining portion is comprised of water body and various vegetations including agriculture.

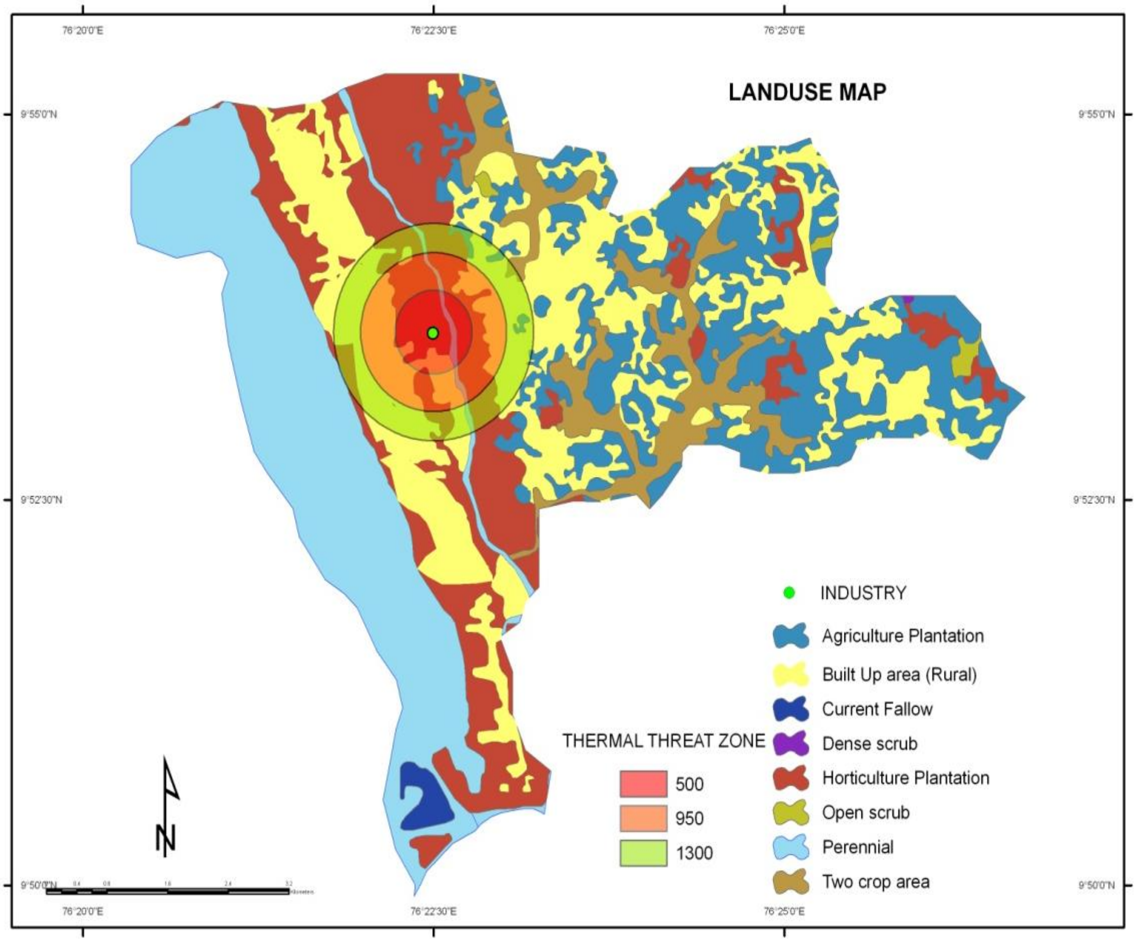

Figure 8: Land use classification map

When the area of settlements is taken in to account, the population density in total built up area is estimated to be 2039 per km^2. The estimated population coming under each threat zone based on population density is given in table II. People coming under the red threat zone (0.785 km^{2}surrounding the plant), may experience thermal radiation of 10 kw/m^2. It is potentially lethal. Orange threat zone covering 2.04885 km^2 and thermal radiation effect is 5.0 kw/m^2 which can cause 2nd degree burns. In the yellow threat zone (2.47275 km^2) people may experience severe pain due to thermal radiation effect of 2.0 kw/m^2.

Table II: Estimated population at each threat zone

Threat Zone	***Estimated area of settlements in each zone (km^2)***	***Population in the Threat zone***	***Health effect***
Red	0.083136	169	Potentially lethal
Orange	0.801252	1633	2nd degree burn
Green	0.951252	1939	Pain

The spatial illustration of the hazardous area can provide the responders essential information such as the definite location of chemical plant and its surrounding land use pattern which will be helpful for identifying the areas which must be evacuated urgently in case of a hazard. Information such as the hazard distance, its effect at each zone etc. can be linked to population distribution pattern (Figure 9). Also, it helps the planners in keeping a buffer zone around the plant without human inhabitation.

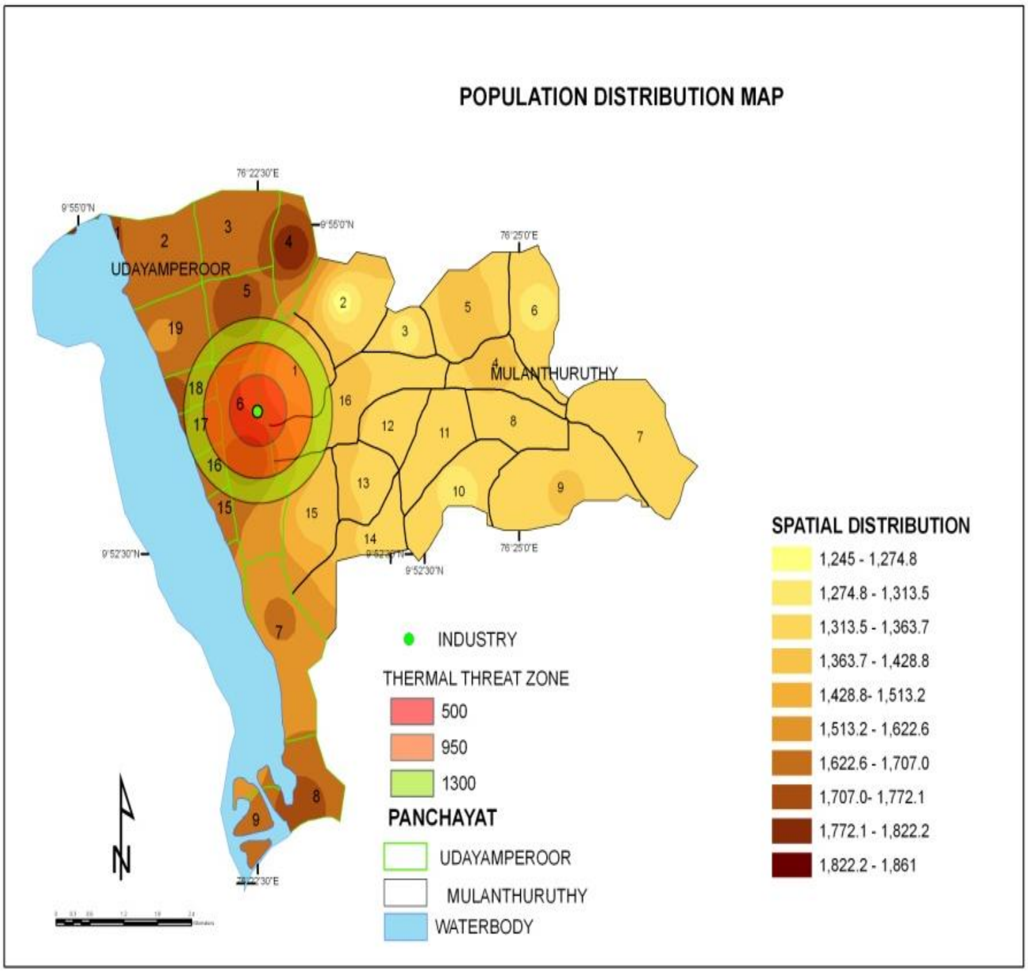

Figure 9: Population distribution pattern

In this study, application of GIS is utilized for illustrating the population vulnerability. For the effective management of a chemical emergency, the responders need to know enough geographical information.

V. CONCLUSION

In this study, two conceptual models (ALOHA and GIS) are overlaid to understand the vulnerability of neighbouring population in case of an accidental release of LPG are presented. ALOHA predicts the area that can become hazardous due to different hazard scenarios created by the accidental release of LPG. Comparing the five possible outcomes of LPG release, it can be concluded that BLEVE is the most dangerous one among them. Secondly, using the tools provided by GIS helps in assessing the spatial extent and land use pattern of the area under threat. Combing these two approaches, the specific population that are likely to be affected are identified. Such an integrated approach will be an essential and useful tool for assessing the vulnerable area around hazardous industries for the response team including industrialists, risk experts, District Crisis Groups (DCG) etc. to manage an emergency situation including timely evacuation of people. This system is helpful not only during actual emergency situation but also during pre-emergency state for planning and mock trials of major chemical emergencies so that the number of causalities can be minimized. At present, formulation of prevention and mitigation strategies and mock drills to face chemical disasters are confined within the industries with strict regulations and safety audits. People living outside the industries are usually unaware of the occurrence of the accident as has happened in the case of Bhopal Gas Tragedy. And the resulting panic also causes avoidable injuries and death. Since the accidents are unpredictable and sudden, it is very important to maintain a sufficient buffer zone around all hazardous chemical industries without any human inhabitation.

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