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Using Geographic Information Systems in and Constructions of LPG Installation: Case 1 Assessment Effects of Fire on Humans

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Abstract

The application of Geographical Information System (GIS) for controlling of risks from chemical installations handling hazardous substances is getting popular due to the advantage of being automated and allows powerful analytical techniques. The capability of GIS is to combine image map with the corresponding information at each level offering a new dimension to the management of industrial risk to the human health and the environment. Accidentally releases of flammable material like liquefied natural gas (LPG) can lead to hazardous events such as fire and explosion and poses an immediate effect to workers on-site and communities off-site as well as the potential to adversely affect the environment. Mathematical models are very useful tools to simulate consequence due to explosion of liquefied natural gas (LPG) hazards. The results from mathematical models can be incorporated with GIS maps technology to estimate graphically the probability risk to the human (injury or death) and the property (construction damage). This paper presents the effects of radiation to the people due to accident of LPG Installation which lead to BLEVE and fire.

Keywords: LPG tank; fire; Probit function; GIS; risk management.

Introduction

In recent years there has been a significant increase in public awareness of the potential dangers posed by the use of chemicals in modern society and their effects on both human beings and environment. Major industrial hazards are generally associated with the potential for fire and explosion or dispersion of toxic chemicals and usually involve the release of material from containment followed, in the case of volatile materials by its vaporization and dispersion. The consequence analysis addresses the impact and damage that the physical/chemical events may cause. The damage depends on the most important event or major release of "unconfined energy" during the accident sequence. The most important characteristic of major chemical industrial accidents is that they have off-site from their location. As a result the extent and severity of the accident may significantly affect the population of the adjacent area (Markatos *at. al*., 1999). The most common accident in the last century happened at Mexico City on 1984. At the time of the disaster the complete storage may have contained (11,000-12,000) m^3 of LPG. Approximately 500 people were killed and over 7,000 were seriously injured. The surrounding area was truly dramatic (Pietersen, 1988).

The development in geographic information system (GIS) technology has come a long way in the past decade. The precursors to current commercial GISs are those developed in the 1960s and 1970s. GIS can provide a comprehensive database of contaminated site conditions, tool for spatial and customized interface of risk assessment, and visual presentation of modelling results and site conditions. Especially, integration of the risk assessment results with spatial land-use information will be helpful for identifying and assessing hazard impacts on specific receptors through various exposure pathways, where map can be valuable for risk analysis.

This paper is an extension to the previous work of El-Harbawi *et. al*., (2004), whereby they have used the mathematical models with integration of GIS to evaluate the final events hazards, which are assumed, engulf with LPG tank.

LPG Hazards

The major hazards with which the chemical industry is concerned are explosions, fires and Toxic release. Of these three, fire is the most common but explosion is more significant in terms of its damage potential, often leading to fatalities and damage to property. Toxic release has perhaps the greatest potential to kill a large number of people (Faisal *et. al*., 1999). The flammable materials are those that can be ignited to give a number of possible hazardous effects, depending on the actual materials and conditions. Major hazards result is thermal radiation of combustion, over pressure and fragment generation. Other hazards could be suffocation caused by the smoke of combustion. Therefore, this work is considered the main effect of the radiation from thermal radiation from the BLEVE/fireball.

Thermal Radiation Hazards

Thermal radiation is the radiant energy (heat and light) that is emitted by the BLEVE/fireball. The radiation at fireball surface can be up to $200\left(kW/m^2\right)$ (TNO, 1990). Within the radius of the fireball there will be severe damage to process equipment and buildings. Beyond this, the danger is mainly for the people that may be affected by the radiation. Therefore, the fireball radius is defined as the domino effects radius. Thermal radiation travels at the speed of light and persists as long as the fireball is luminous. Thermal radiation can incapacitate exposed personnel by causing skin burns, flash blindness or retinal burns. It can cause burn injuries directly when the skin absorbs radiant energy. It can also cause burn injuries indirectly as a result of fires started by the radiation.

In order to estimate the consequences of an accident on people, a function relating the magnitude of the impact, usually, the method used is the Probit analysis, which relates the Probit (from "probability unit") variable to the probability. Probit analysis has been widely used to express injury relations.

The Probit variable Y, is a measure of the percentage of a population submitted to effect with a given intensity (V) which will undergo certain damage. This variable follows a normal distribution, with an average value of 5 and a normal deviation of 1. The relationship between the Probit variable (Y) and the probability (P_r) is the following (Finney, 1971):

$$P_r = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{5} \exp\left(-\frac{V^2}{2}\right) dV \tag{1}$$

Eq. (6) provides a relationship between the probability P_r and the Probit variable Y. for spreadsheet computations a more useful expression for performing the conversion from Probits to percentage is given by (Crowl and Louvar, 2002):

$$P_r = 50\left[1 + \frac{Y-5}{|Y-5|} erf\left(\frac{|Y-5|}{\sqrt{2}}\right)\right] \tag{2}$$

where *erf* is the error function.

Abramowitz and Stegun (1965) have given a rational approximation for digital computation:

$$erf(x) \approx 1 - \left(a_1\phi + a_2\phi^2 + a_3\phi^3\right)\exp\left(-x^2\right) + \varepsilon \tag{3}$$

where:

$$\phi = \frac{1}{(1+\alpha x)} \; ; \; \alpha = 0.47047 \; ; \; a_1 = 0.34802;$$

$$a_2 = -0.09587 \; ; \; a_3 = 0.74785 \text{ and } \varepsilon \le 2.5 \times 10^{-5}$$

Most of the previous works about Probit analysis have been given by Finney, (1971); Eisenberg *et. al.*, (1975); TNO, (1990); Weber, *et. al.*, (1990); Schubach, (1995); Casal, *et. al.*, (1999) and Vílchez, *et. al.*, (2001). The following expression is normally used to calculate the value of Y:

$$Y = a + b \ln V \tag{4}$$

where Y is the Probit variable, a and b are constants which are experimentally determined from the information on accidents, or, in some cases, from experimentation with animals. V is a measure of intensity of the damaging effect; it can be just one parameter (for example, the overpressure in this case) or a combination of various parameters (for example, the concentration and time in toxic gas release).

$$Y = -23.8 + 2.92 \ln p_o \tag{5}$$

Estimation the Thermal Radiation Hazards

The thermal radiation can be results from; pool fire, jet fire, flash fire, vapour cloud fire and BLEVE/fireball. The major thermal radiation from these evens is result from the BLEVE/fireball. Therefore this paper has been considered only for the calculation of thermal radiation from BLEVE/fireball.

Fireball Size and Dynamics

The maximum of a fireball is governed primarily by the mass of the fuel released and vaporized. While the fireballs are rarely spherical, an equivalent spherical volume is widely used to characterize the size of a fireball (DiNenno, *et. al.*, 2002). The maximum fireball diameter is independent of the initial pressure of the fuel so long as the pressure and temperature are sufficient to vaporize the fuel. Hasegawa and Sato, (1977, 1978) suggest that for propane at or above normal ambient temperature ($20°C$) complete vaporization will occur. DiNenno, *et. al.*, (2002) indicated that the dynamic of the fireball are dependent upon the momentum of the release, which results from the flash evaporation of the fuel. El-Harbawi *et. al.*, (2004) have used work of Hardee and Lee, (1973), Roberts, (1982) and Pietersen, (1984) to calculate the physical parameters of BLEVE/fireball.

Point Source Model

One of the simplest practical models for evaluating fireball hazards is the point source model. This has been used to estimate the intensity of thermal radiation from the resulting fireball. This model estimates the emissive power as a function of the combustion mass (Papazoglou and Aneziris, 1999). Fireball composition occurs when volatile hydrocarbons are released and rapidly ignited. The calculations of the thermal radiation from the BLEVE/fireball have been done by number of authors; Thomas, (1963), Roberts, (1982), Pietersen and Huerta, (1984), TNO, (1992) and Lees, (1996).

The exposure time, t is assumed to be 30 seconds. For this time unprotected skin might severely be burned if it is exposed to a radiant flux of $5.0\, kW/m^2$ (Birk, 1995). Thermal radiation from hydrocarbon fires may pose significant hazards to both personnel and property. The fireball grows larger and moves upward continuously because of buoyancy. The duration of the fireball is small $(< 40\sec)$, but the radiation levels are intense and can be up to $(200\, kW/m^2)$ (TNO, 1990). Fireball can emit a large amount of radiant energy and is capable of causing injuries and damage over an area several times greater than the size of the fireball. Within the radius of the fireball there will be severe damage to environment and constructions. Beyond this radius, the danger is mainly for the people that may likely be affected by the radiation. Heat poses a significant physical danger to humans, environment and constructions. Moisture can be present in a fire environment as the result of natural humidity; therefore the effects of exposure to heated air are greatly augmented by the presence of air in the fire atmosphere. Thermal radiation effects can be estimated by probabilistic calculation methods based on experience about events that have occurred in the past.

The logic diagram for calculating BLEVE/fireball thermal intensity and thermal impact is shown in Figure (1).

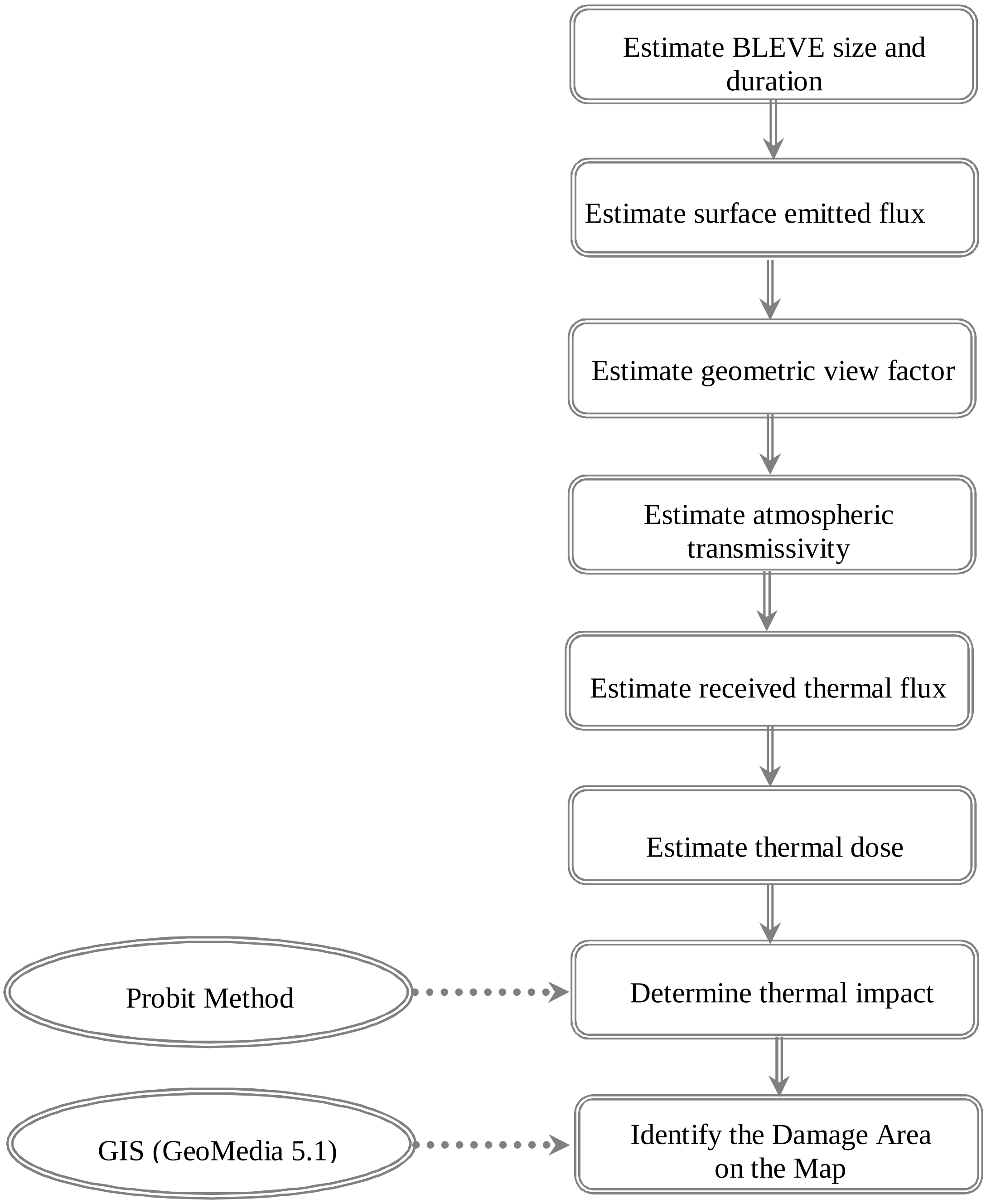

Figure 1: Logic diagram for the calculation BLEVE/fireball thermal intensity and thermal impact.

The effects of thermal radiation on structures depends on whether they are combustible or not, and the nature and duration of the exposure. All structural materials classified as combustible or non combustible, inherently possess a degree of fire resistance. Wooden materials will fail due to combustion, whereas steel will fail due to thermal lowering of the yield stress. The degree of damage may vary with the basic material and building configuration. The building materials and the design of the details of construction have always played an important role in building fire safety. The vicinity of the tank are close to several buildings and hence the effects of the thermal radiation to adjacent buildings can cause danger effects on the steel beams and columns, concrete slabs, wooden beams and columns, and wood-frame walls and floors. Buildings with solid walls can provide complete protection from thermal radiation provided that the fire is no longer in line-of-sight. High radiation from fires, such as BLEVE fireballs may rise a considerable distance above the ground and this makes them relatively difficult to protected from. Table 1 gives the effects of thermal radiation on construction (Crowl and Louvar, 2002).

Table 1: Effect of thermal radiation on construction.

Thermal radiation (kW/m^2)	**Effect**	**Distance** (m)
37.5	Spontaneous ignition of wood after long exposure. Unprotected steel will reach thermal stress temperatures which can cause failures.	286
23-25	Non-piloted ignition of wood occurs.	346-360
25	Cable insulation degrades.	346
18-20	Piloted ignition of wood occurs.	385-405
12.5	Thermal stress level high enough to cause structural failure.	481
12.6	Minimum energy required for piloted ignition of wood, melting of plastic tubing.	488
12	Plastic melts.	491

Case Study

Location

Show Figure location

GIS For Risk Assessment

An important element is the preparation of topical maps, using local GIS data around the accident site. Maps, as a familiar format, are an effective basis for the communication of complex information by providing a familiar context. The most restrictive definition insists that a GIS must have a spatial data structure with topology, with geographic features linked to a relational database management system. Spatial analysis is the strength of GIS as is its ability to manipulate spatial data. With the facilities of handling large quantities of spatially referenced data and properly structured database, the GIS is able to manage, analyze, and display large multidisciplinary data sets for various applications with their geographical-related information. The role of the GIS, therefore, is to allow a modeller to visualize development changes to the landscape and to produce resultant input values for the individual models and create a map of a target source

Developing of GIS System for LPG Cause Study

GIS is a systematic integration of Computer Hardware, Software and Spatial Data, for capturing, storing, displaying, updating manipulating and analyzing, in order to solve complex management problems (rediff.com, 2004). GIS is used as a tool to provide geographical information of the potential affected areas in order to evaluate the consequences or impact of the disaster. The functionality of GIS enables the integrated model to handle the data management, computational aspects and the integrated needs as emphasized in the hazards approach. The data used in the creation of a GIS database include a location map of the LPG tank. The map module is prepared for storing various types of GIS-related maps, such as the buildings, roads, stations, lakes and etc. The techniques allow the identification of areas that are affected by accidents. Building a database consists of three major steps: (a) identifying the geographic features, attributes, and required data layers; (b) defining the storage parameters for each attribute; and (c) ensure co-ordinate registration. The collection of cartographic data can be achieved by any of the alternative procedures: extent maps through digitizing, scanning, photogrammetric procedures or terrestrial surveying measurements. The results from the mathematical models can be linked with GIS software to create the hazard vulnerability maps. Figure 2 is shown the building of the database into GIS to get the graphical results.

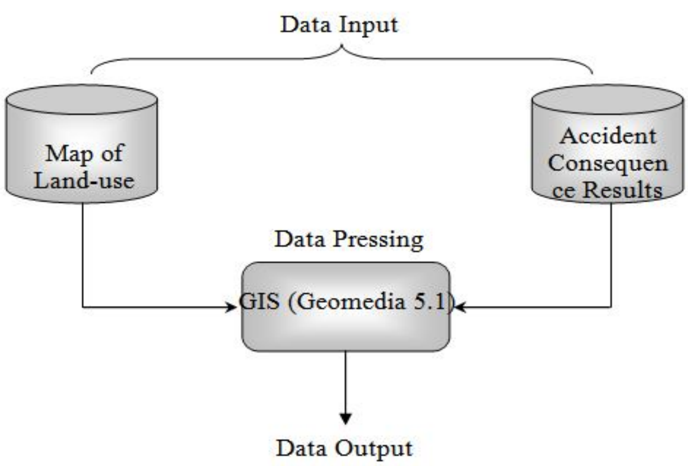

Figure 2: Simplified architecture of GIS.

Results and Discussions

The paper discusses the expected consequences and the actions proposed to be taken in order to evaluate the probable effects to human and environment in the surrounding area of LPG

Thermal radiation from BLEVE can cause severe harm and damage to human and construction in the vicinity area around the LPG tank. Its expected consequences and the actions proposed to be taken in order to evaluate the probable effects to human and environment in the surrounding area. The effect of the thermal radiation on structures depend on whether they are combustible or not, and the nature and duration of the exposure. Thus, wooden structures may be ignited if the radiant heat density at the structure's location exceeds the threshold value for ignition of wood, whereas steel will fail due to thermal lowering of the yield stress. Table (1) indicate to the thermal radiation effects on structure. The results for fireball characteristics are showing in Table (2). Most of the heat radiation will appear in the fireball radius. Within this radius, there will be severe damage to buildings and harm to humans. The intensity of thermal radiation from resulting fireball has been estimated from point source model. Baker *et al.,* (1983) have described a flux of 21 kW/m^2 can be sustained by a human for 2 s before pain is experienced. After this, continued exposure will lead to severe burns. As indicated by eai, (1989), personnel should be evacuated if sufficient shelter is not available from areas where the radiant heat exceeds 5 kW/m^2 for exposed more than 30 s.

Table 2: Results of BLEVE/fireball physical parameters.

m (kg)	$D_{\max}$ (m)	t_{BLEVE} (s)	$t_{liftoff}$ (s)	H_{BLEVE} (s)	D_{intial} (m)
60,000	231.46	14.41	6.88	173.59	300.89

The probabilities for human casualty or construction damage were calculated using Probit functions. The results from are shown in Tables 3 and Figures 6 to10 respectively. The likely probabilities were drowned as buffer zones for 10, 50, and 90 % likelihood to evaluate the exact geographical region where the consequences are most intense for the population. Table 3 indicated several consequences to human from thermal radiation. Figures 3 and 4 illustrate the effect on human skin which is protection and unprotection by clothes. Figures 5 and 6 are indicated to the probability of buffer zones for $1^{st.}$ and $2^{nd.}$ degrees respectively of human skin burn. The acceptable level of thermal radiation is 5 kW/m^2 for bare skin if the exposure time is <40 second. Figure 10 is illustrates to the probability of human fatality from exposure to thermal radiation. The 90 % likelihood of human death can happened with the thermal radiation 38.75 kW/m^2 and cover 59,828 m^2 of area.

Table 3: Probability consequences of thermal dose on humans.

r, (m)	Q_R, (kW/m^2)	I, $\left[(kW/m^2)^{4/3} \times s\right]$	t_p, (s)	P_r, (%)
Probability for persons protected by clothing from thermal dose				
639	6.65	3736894	9.10	10
538	9.54	6054166	5.63	50
453	13.71	9808688	3.48	90
Probability for persons unprotected by clothing from thermal dose				
535	9.64	6133788	5.56	10
450	13.90	9993315	3.42	50
378	20.06	16302139	2.09	90
Probability of non-fatal injury from thermal dose (1st. degree burns)				
824	3.89	1829497	18.57	10
708	5.35	2797853	12.16	50
609	7.35	4270065	7.97	90
Probability of non-fatal injury from thermal dose (2 nd. degree burns)				
557	8.85	8362225	6.23	10
479	12.16	12801171	4.08	50
412	16.74	12757664	2.67	90
Probability of fatality from thermal dose				
395	18.29	14408430	2.37	10
330	26.62	23765044	1.44	50
276	38.75	39201728	0.87	90

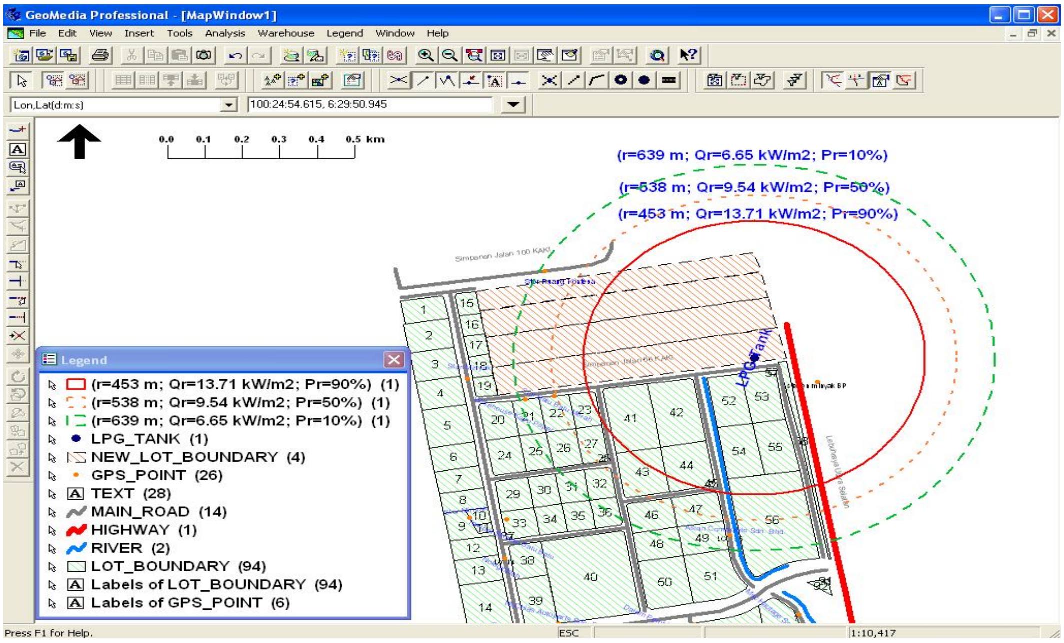

Figure 3: Buffer zones for probability of human protected by clothes from thermal radiation around LPG tank.

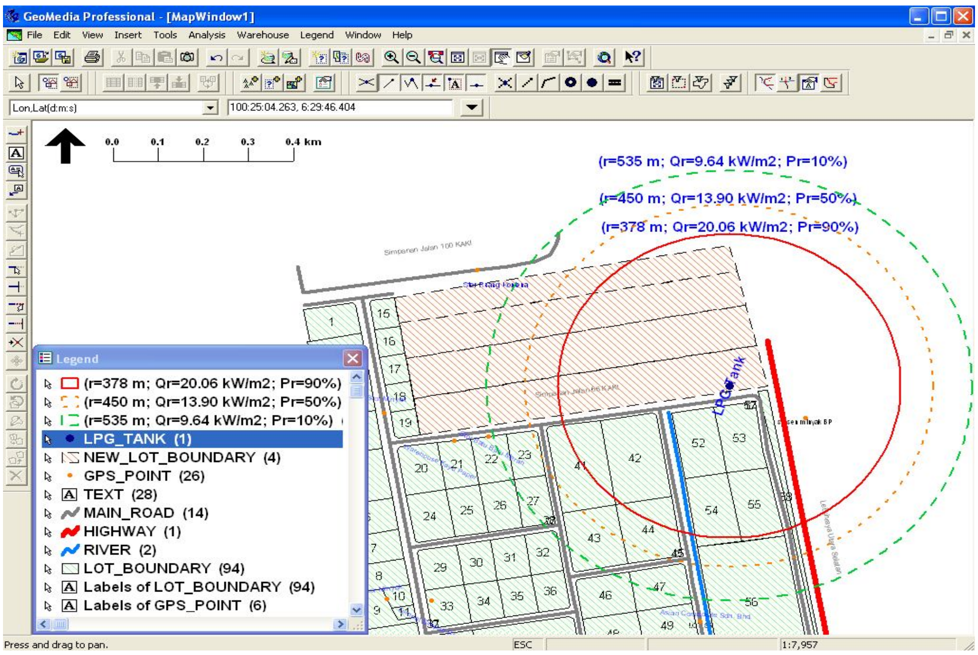

Figure 4: Buffer zones for probability of human unprotected by clothes from thermal radiation around LPG tank.

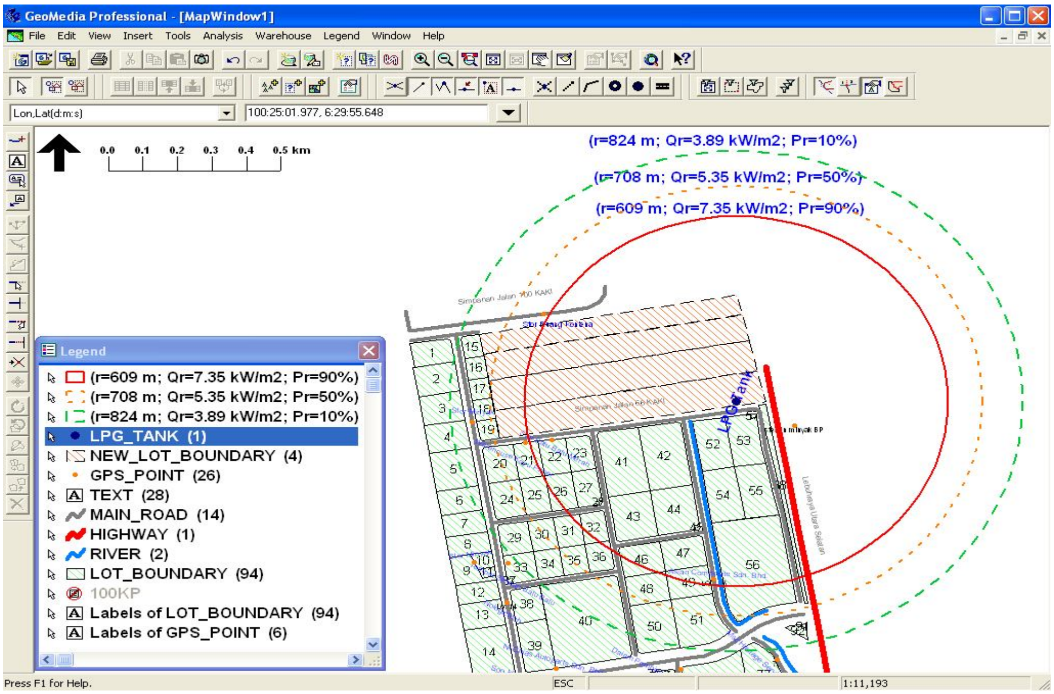

Figure 8: Buffer zones for probability of 1st. degree of burn.

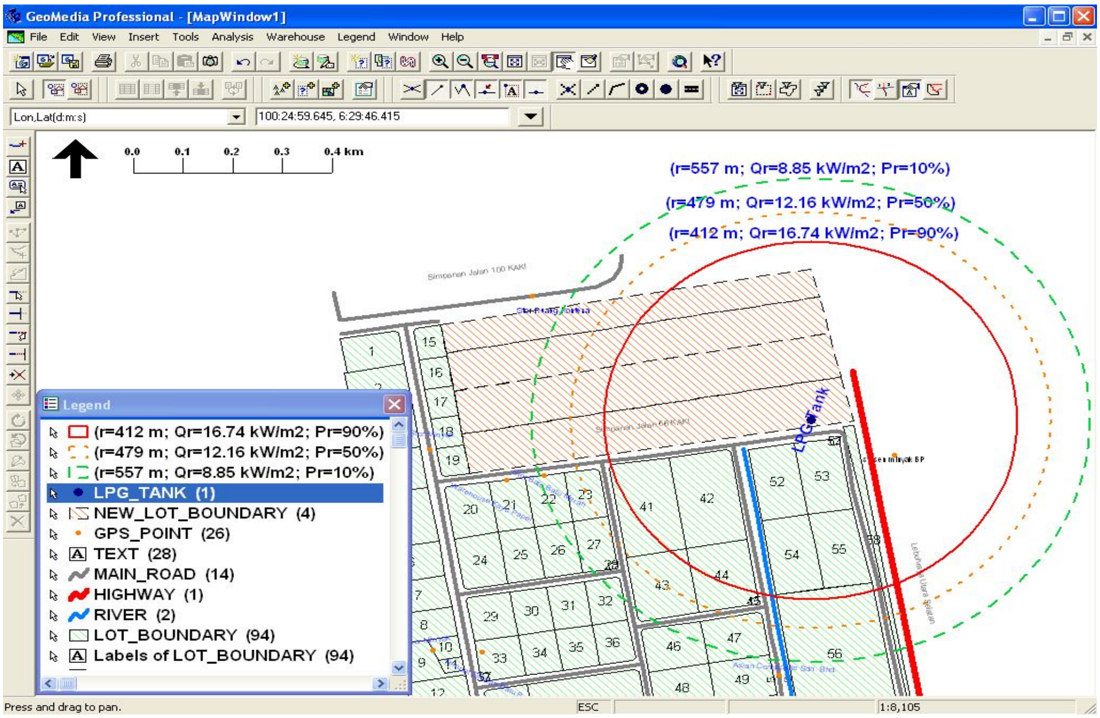

Figure 5: Buffer zones for probability of 2nd. degree of burn.

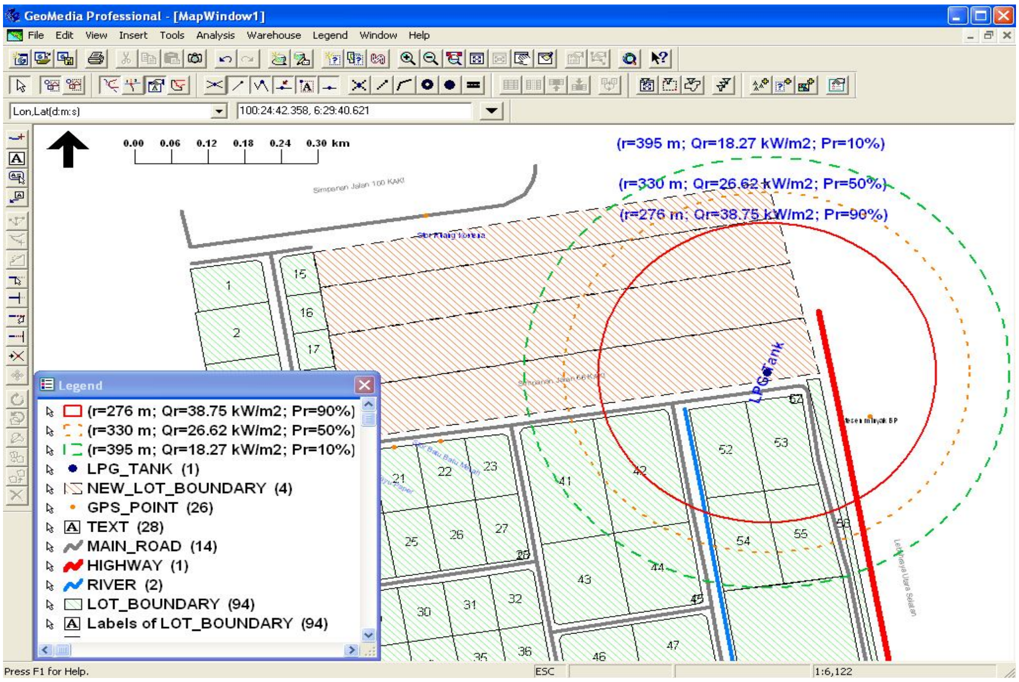

Figure 6: Buffer zones for probability of human fatality from thermal radiation around LPG tank.

Conclusion

Mapping, the visual display of information, is an extremely powerful tool for understanding and managing risk. Risk inherently involves a geographical component. It occurs at locations in space where receptors (human or environment) and hazards come together. GIS powerful tools can pinpoint all the chemical hazards events and mapping of environmental and risk area. It is a good estimation for the safety distance that can be known by utilising of GIS, which can be seen clearly on the maps. Several zones and probabilities for casualty have been classified on the location map. Based on the estimation probability, consequences and on the information retrieved by the available databases and GIS, the thermal radiation may risk people who exposed to fire within 1 km in radius.

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