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Application of Population Dynamic Distribution Model in Hazardous Chemical Accident Risk Assessment

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Abstract. In order to cope with the rising tendency of Hazardous chemical accident in urban population accumulation area during the recent years,taking a petrochemical depots with a hypothesized leakage of LPG tanks as a sample, the urban local population dynamic estimation model was introduced, based on the comparative analysis of several potential accident consequence, to quantitatively estimate the individual risk index in affected area by BLEVE heat radiation. The results showed that the risk level by accident disaster is relevant to urban population spatial-temporal activity characteristics. The research work has important reference value for urban disaster emergency rescuing and planning of disaster reduction.

Key words. Hazardous chemical accident, population dynamic estimation model, BLEVE; individual Risk.

1. Introduction

As an important material of guaranteeing the normal operation of the national economy, the social demand of Hazardous chemical is ever-growing; but on the other hand, improper operation and leakage accident of Hazardous chemical in the process of storage and transportation can cause seriously hazardous events, which will harm public health. In the short term, it will lead to badconsequences including economic losses and casualties; in the longterm, it will cause ecological environment pollution in the region[1][2]. The risk grade of hazardous chemical accident mainly depends on the physical and chemical properties of the leak material, surrounding population density??geographical factors as well as weather conditions and so on.

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LPG??Liquefied Petroleum Gas??is a kind of clean fuel and important chemical material,which is convenientand High-calorific, but at the same time , it is also prone to accidents. The risk of accidents caused by LPG storage link has been gradually paid attention in China and abroad, from the historical experience and lessons of the accident, the emergent hazardous accident is unpredictable, but identifying in advance the potential risk caused by leakage storage facilities can significantly reduce the damage of life and property loss, and environmental destruction[2].

There are many related researches about the risk assessment to the hazard-affected body or area in the hazardous chemical accidents. Wu Zongzhi, etc. [3]established a risk evaluation model based on geographic grid, which has presented a quantitative evaluation result about the individual risk and social risk near the risk-source surrounding regions; When Zhang, Inanloo [4][5]etc. studied the hazardous material road transportation, they presented the risk quantitative evaluation that the surrounding crowd would need to bear by simulating the toxic gas diffusion range and combining individual risk calculation model; researches of Xu et al. [6] have established the chemical industrial park risk assessment model based on the information-diffusion principle, which can solve the evaluation uncertainty caused by lack of sample data; In the research of Cozzani, Renjith [7][8] et al., they referred to the land-use status of the accident surrounding area in order to enhance the rationality of the evaluation. The above all studies mostly embodied "population" factor , which was the main hazard-affected body, but the population data they used is large-scale, gridding and static, it did not realize the fact that the population distribution has the characteristics of dynamic state and spatial variation;Dynamic estimation method of population distribution and scientific assessment indicators system must be introduced in order to assess the risk indicator more accurate and objective; This paper attempts to establish population distribution model based on building scale, bring in the urban society activity characteristics and refine geographic information data in order to effectively identify the accident risk grade and scope, and provide a new view for the research of disaster assessment.

2. Study region and data source

Wuhu city is the important industrial and commercial center in Anhui section of Yangtze River, the urban population density is large, and the land-use concentration degree is relatively high. China's petrochemical and gas company's warehouse are founded on Tian-men Street, Jinghu district, where reserves a large number of liquefied petroleum gas. It is a risk source of formative high-potential safety hazard; while its safety protection distance is within the urban population accumulation area, the population of Tian-men community can reach 34000 people; this means once there is an hazardous chemical accident, it will lead to unpredictably serious consequences, so this area has certain representativeness, this study would select it as the case study region.

Relevant enterprises and hazardous substance data involved in the study are investigated and surveyed from the municipal department of safety supervision; statistical data used in population estimation include “the Sixth national census records statistical yearbook of Anhui province tatistical bulletin for national economic and social development of Wuhu city and so on; Building distribution vector data is drew on the ArcGIS platform based on the visual interpretation of the high resolution remote sensing image (high-resolution 5 satellite observation data) and the correction after the field observation.

3. Simulation of accident injury zone

3.1. Analysis to the LPG hazardous substance and the potential consequences

LPG mostly contains propane and butane, accompanied by a small amount of propylene and butylene ,as well. Propylene is more dangerous than butane in terms of fire disaster and explosion danger. Besides, it has low-boiling point, strong volatile and large combustion heat value, so in this study, propane is selected as the simulation object. Propane is a kind of colorless and odorless gas under normal and standard condition, its boiling point is 42.09 ℃, after compressing, it will condense into colorless liquid; its ignition point is 450 ℃, when mixing with the air, it would form explosive mixture; When getting to open fire and heat source, it would have deflagration risk. The Commonhazardous chemical substance classification standard (GB 13690-92) defines it as class 2.1 flammable gas; The density of gaseous propane is larger than air's, so it can spread to the surrounding area distance from the nearer ground; because of its simple asphyxia and anesthetic effect, suffocation would happen when inhaling high-concentrations propane.

When the flammable, explosive and toxic chemical substance leaks into the atmosphere from the storage tank, the hierarchical relation of the consequences about the several potential accidents is shown in figure 2.

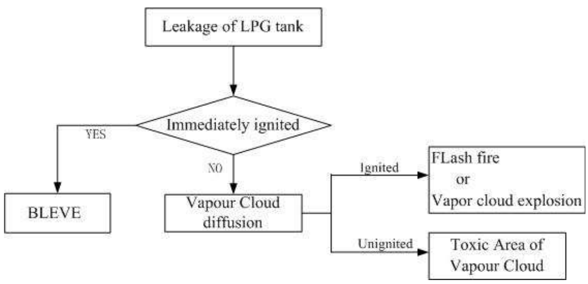

Fig. 1. The possibility analysis of LPG leakage accident consequences

3.2. Simulation and contrast to accident risky region

As for the different potential leakage results of LPG storage tank, ALOHA (Areal Locations of Hazardous Atmospheres), which is developed by Environmental Protection Agency (EPA) and Chemical Emergency Preparedness and Prevention Office (CEPPO), is used to respectively quantitatively simulate the results caused by these four kinds of disasters: toxic air mass diffusion, flash fire, vapor cloud explosion, and BLEVE(Boiling Liquid Expanding Vapor Explosion)fireballs The below figure present their Injury risk zoning contour lines :

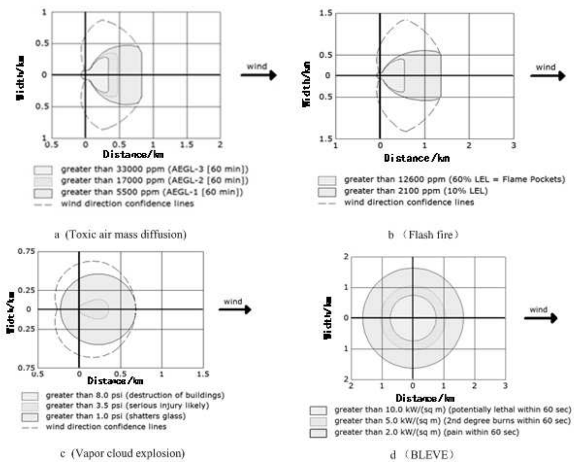

Fig. 2. Results Simulation of potential LPG leakage accident

It can be found that the injury degree brought by BLEVE is the highest after comprehensively comparing the potential accidents' harmful results and influence. Its influence area and the possibility of covering larger area in a short time are relatively large. The damage to the hazard-affected body is direct and hard to avoid effectively; At the same time, the explosion of a single storage tank will easily lead to cascading accidents between the peripheral storage tank. Based on the above factors, this paper selects the area influenced by the tank BLEVE accident as the object of risk evaluation.

Figure 3 (d) shows the simulation results of thermal radiation damage scope caused by BLEVE fireballs (duration time for 1 min), a radius of 743m away from the fire source is the lethal region; a radius of 743∼1020m is the serious injury region; a radius of 1020??1600m is the slight injury region.

4. Population Dynamic Distribution Model based on Building Scale

Since the accident damage scope is limited in a relatively small area of the city, the existing demographic data which takes 'km' as the unit cannot meet the requirement of evaluation accuracy; at the same time, The present population distribution estimation method is based on static premise, it does not have any changes or consider the effect of change of population space-time[9][14]. Therefore, we should firstly consider the accurate classification of buildings in the region and people's activities characteristics attached to all kinds of building and site within the region, and establish a precision calculation model aiming to the population size and dynamic distribution.

This paper consults the relevant research results in Human Geography[15] about population distribution and calculation method and combines the actual situation of Wuhu to establish the model[16].The population size in each building in a specific period of time can be calculated by equation (1) :

In equation(1), Parameter $PN_b$is the population size that the building can accommodate; $b_a$is the building‘s floor space, which is obtained by vector layer(in m^2); $b_f$is the average story number of the building; $h_a$is local per-capita housing area(in m^2 /person); a is the specific value of the population size that the building can accommodate and the benchmark of population size that the building(as the residential area)can accommodate; b refers to the attractive trend of some functional buildings or sites in a particular time period it can also be interpreted to the probability that the population would head for some building or site. The correction coefficient of the building‘s function a and its attractive rate b all need to accord to theparameter set by the actual situation of the region these parameters are often affected by the region's geographical location, urban function division, economic development status, and the characteristics of urban commuting etc. [15]. Due to the limited space, this paper will not detail the constructive process of each parameter. Table 2 shows the some building types correction coefficient of function and attractive rates in Wuhu The two lines in the table are about the attractive rate data, which respectively represent the buildings attractive rate on workdays and weekends :

Table 1. Correction coefficient and attraction rate of some Building types in Wuhu city

Building type Coefficient	Correction coefficient of building function (α)	Attractive rate in each period (β)						
		07:00- 08:00	08:00- 12:00	12:00- 13:30	13:00- 17:30	17:30- 18:30	18:30- 21:30	21:30- 07:00
Dwelling	1.0	0.61	0.22	0.7	0.25	0.21	0.78	1.0
		1.0	0.6	0.7	0.6	0.6	0.7	1.0
Commercial	10.13	0.0	0.3	0.2	0.3	0.2	0.5	0.0
		0.0	0.7	0.5	0.7	0.7	0.7	0.0
Office	1.79	0.5	1.0	0.5	1.0	0.3	0.0	0.0
		0.0	0.0	0.0	0.0	0.0	0.0	0.0
Education	6.9	0.1	1.0	1.0	1.0	1.0	0.3	0.0
		0.0	0.0	0.0	0.0	0.0	0.0	0.0

We have extracted all the buildings from the intersection region between the vector data layer and the dangerous area, and then used equation(1)to successively calculate the contained population size of each building. The next step is to summate the data,so the total population size in the dangerous area can be gained :in equation

Parameter n is the number of building intersecting with the dangerous area; $k_b$is the proportion of the building area in dangerous area with the total building area. The value of k_b in this article would be 1, considering the consequence of thermal radiation accident.

5. Individual risk assessments in accident area

5.1. Assessment index establishment of individual risk

Individual risk refers to the frequency of specific hazards caused by hazardous chemicals production, storage of various potential fire and explosion, and toxic gas leakage accident in some location or place in this paper, building is used to represent the 'location or place . Its equation is as follows:[16], where 'IR' is the individual risk value, 'f' is the probability of hazard accidents,' v' is the individual death probability in the location or place :

$IR=f\times v$ (3)

The individual death probability 'v' in these three kinds of injury zones is defined respectively based on the calculation result gained from thermal radiation damage degree zoning in section 3.2 and combines the burn medical literature statistics; meanwhile, LPG tank accidents occurrence probability 'f' is gained according to the historical data of Wuhu's deflagration accident analysis, table 2 shows the values of the above indexes and the individual risk in injury grade zones.(Note the unit of individual risk value is p a^{-1}).

Table 2. Calculation of individual risk value in different injury grade zones

Injury grade	**Individual death probability(v)**	**Accident occurrence probability (f)**	**Individual risk value (IR)**
Lethal zone	0.5 (Individual death probability 50%)	8.37×10^{-5}	4.15×10^{-5}
4 Serious injury zone	0.15 (Individual injury probability 50%×probability of second-degree burn to death)		1.255×10^{-5}
4 Slight injury zone	0.05 (Individual injury probability 50%× probability of first-degree burn to death)		4.185×10^{-6}

The <individual and social acceptable risk criteria of hazardous chemicals production and storage devices (for trial implement)> formulated by Chinese State Administration of Work Safety indicates that the buildings and sites surrounding the hazardous source can be divided into three types: low-density, high-density and special high-density according to the crowd density and the evacuating complexity. Therefore, individual acceptable risk value can be formulated correspondingly. This paper describes three kinds of individual acceptable risk by consulting the above classification criteria and combining the actual situation in study area. The division basis is only the crowd density, details can be seen in table 3.In order to assess whether the individual risk value of every buildings and sites in the area is in a safe and reasonable range, this paper will divide the buildings locating in different injury grade zones into three types accordance with the classification requirements of table 3, IR_irepresents individual risk value for buildings in different injury grade zones the subscript i could be 1 3, respectively meaning lethal, serious injury, slight injury ,e.g. if one building or site locate in lethal zone, its IR value should be 4.15×10^{-5}; while CR_j j could be 1 3, respectively meaning low-density, high-density and special high-density buildings?? represents the individual acceptable risk value; CE is the risk exceeding degree coefficient of the building, the IR_i of each building should be separately compare with the corresponding CR_j according to the population size to be accommodated, so as to get the value of CE, the equation of calculating CE is equation 4 the coefficient value could be 3 0 , respectively meaning exceeded seriously exceeded relatively exceeded generally and zero exceeded??.

Table 3. Individual risk acceptable criteria for various types of buildings and sites

Classification Individual acceptable risk criteria	Low-density site (population size<30)	High-density site (30≤ population size<100)	Special high-density site (population size≥100)
In-service equipment	3×10^{-5}	1×10^{-5}	3×10^{-6}

5.2. Risk assessment and analysis

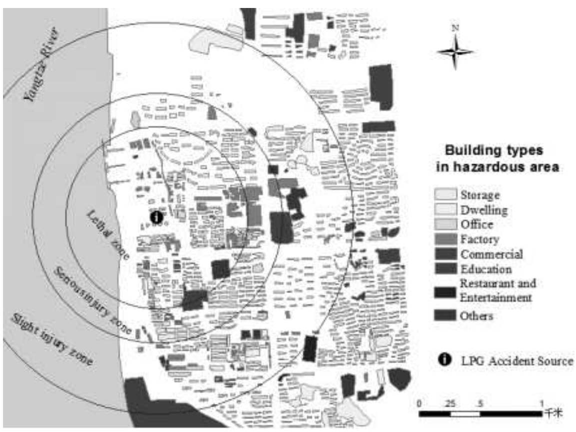

Fig. 3. Distribution of building type in hazardous area

Fine-scale vector data of the building distribution in this area has been drew in ArcGIS 10.1 by on-the-spot investigation and visual-interpreting to high resolution remote sensing image, which includes the type, structure, layer number, floor area and other detailed information of every building. By calculating, ALOHA has got three-layer annular region, Figure 4 shows the overlay result of area influenced by BLEVE thermal radiation and the building distribution layer. In this figure, they respectively represent lethal, serious injury, slight injury, different types of buildings and sites use different color lumps; If the LPG tank leakage accident respectively happens at 09 o 'clock and 22 o 'clock on workday, then with the help of ArcGIS 10.1 spatial overlay analysis tools and geographic statistical tools , the population size influenced by the accident in different period of each building can be gained based on the above population estimation model. After summary and analogy, the population proportion that some types of buildings and sites can accommodate is gained, the result is shown in figure 5; It can be clearly seen from the figure that the accumulation features in different periods (workdays) have changed. In the daytime, people go out to work or school from the habitable area, population activity tends to occur in places such as offices, schools and commercial facilities, during nights rest, the trend is basically opposite.

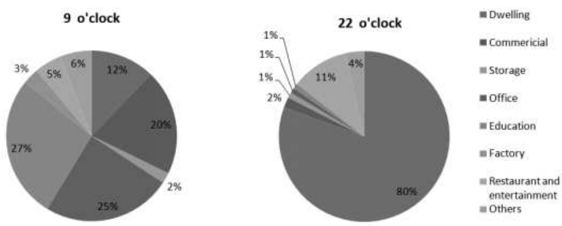

Fig. 4. The population proportion in various types of building of the danger zone in different

Using equation 4 to evaluate individual risk excessive degree of three types of buildings and sites with different risk exceeding degree, figure 6 and figure 7 show the classification according to the assessment results with the help of ArcGIS, in these two pictures, the periods that may happen accident are 09 o 'clock and 22 o 'clock. Compared with figure 4, it can be seen that the individual risk excess focus on buildings and places like offices, schools and commercial facilities in the daytime, while at night, the individual risk excess mostly focus on residential area, this change is consistent with the ratio characteristics presented in figure 4. Thus, the temporal and spatial dynamic distribution of urban population and the change of population size in various types of buildings in different periods lead to the dynamic change of the accident risk degree.

6. Conclusion

As for LPG tank accidents happened in the case study region, we uses ALOHA to respectively simulate several potential accident situations, and chosethe regionaffected by BLEVE deflagration accident, which has comprehensively higher hazard degree, as the dangerousregionto establish dynamic estimation model based on the urban population, and then calculated and evaluated the population size covered

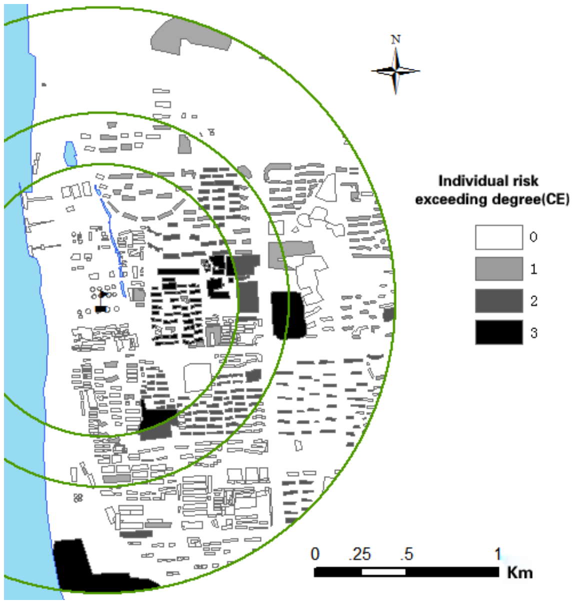

Fig. 5. The classification of regional individual risk exceeding degree

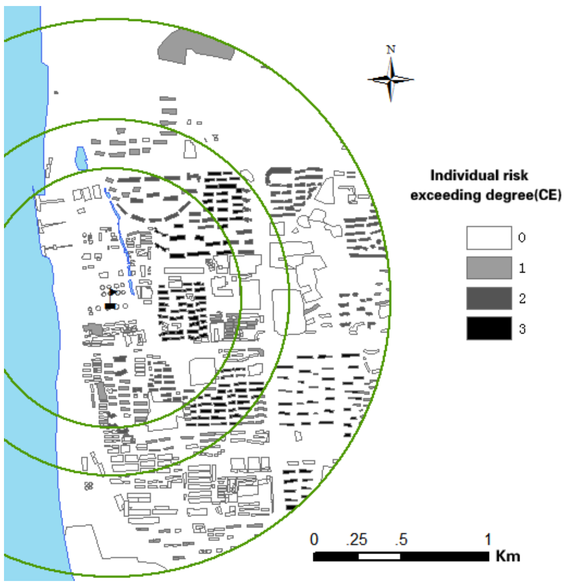

Fig. 6. The classification of regional individual risk exceeding

in the dangerous regionand the regional change characteristics of individual risk degreein different period of time.

The research results show that there is a strong relevance between the risk caused by hazardous chemical accidents and the temporal and spatial activities of people.

Dynamic and fine population distribution data plays an important supporting role in the risk evaluation of hazardous chemical accidents; the research achievements of the temporal and spatial dynamic distribution of hazard-affected bodies can provide a new angle of view and technical support for the accident emergency rescue, regional disaster prevention plan and the analysis of risk management.

If the population distribution data can better reflect their distribution difference in terms of holiday, day and night and season, this will greatly promote application value of the related methods and data in the management of accident research. there are many subjective factors in this paper when using calculation method to analyze the population dynamic distribution adopted, it can be considered to use a kind of simulation method based on big data and Individual space-time tag of cell tower in future research in order to improve the objectivity and accuracy of the results.

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