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Study on Risk Zoning Technology of Major Environmental Risk Sources in Urban Scale and Its Application in Shanghai, China

Ya Yang , Junwei Ma*

Beijing Normal University ,State Key Joint Laboratory of Environmental Simulation and Pollution Control, School of Environment, Beijing, 100875, P. R. China

Abstract

Because of the inherent characteristics of the cities, such as high population density, complicated traffic, numerous pollution sources, etc., it has become very important to conduct environmental risk zoning in urban scale. Based on analyzing the current research situation of the regional environmental risk assessment and regional environmental risk zoning, this paper constructed the index system and the quantitative model of environmental risk zoning which are fit for urban scale, applies AHP to weight index and comprehensive evaluation method to calculate comprehensive risk index value. Then applying the method to Shanghai, and with the clustering function of SPSS and the visualization of GIS, the quantitative risk zoning map of Shanghai was obtained. The result can provide reference for environmental risk management of Shanghai.

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Keywords: urban scale; major environmental risk sources; quantitative zoning technology;Shanghai.

1. Introduction

With the fast development of social economy and the acceleration of urbanization, there are some common features in large cities of China(such as Beijing, Shanghai, Guangzhou and Tianjin): high population density; industrial agglomeration and a large number of petrochemical industries; developed transportation and many dangerous mobile sources; vulnerable urban public safety systems; a variety of potential risk and wide affecting range; requiring fast speed and accurate emergency response and emergency decision-making after the accident, etc. These features make the harms caused by the city-scale environmental risks have a "domino" effect. Therefore, it's very important to conduct quantitative environmental risk zoning in urban scale and provide decision-making criterion for managers

Existing environmental risk assessment researches were more concentrated in environmental risk of toxic and hazardous substances and single incident .While consideration of the environmental risk as a complex system composed of multiple factors from regional level, systematic studies on combined effects caused by regional

* Corresponding author .Junwei Ma. Tel.: 086-10-59893106; fax: 086-10-59893086
E-mail address: jwma@bnu.edu.cn

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environmental risks were few, as well as the causes and the inherent links of environmental risks from the macro level of human social and economic activities [1].

The word of risk zoning was first used in the field of natural disasters [2-6]. Environmental risk zoning was gradually developed with the economic growth and increasing frequency and hazards of sudden accidents of environmental pollution, which can reveal regional and interregional similarities and differences of environmental risks distribution. It was proposed as an effective measure of environmental risk management to prevent environmental pollution and harm[7].

Yang Jie and Bi Jun (2006) discussed the process, indicators and methods of environmental risk zoning. They took risk zoning of Yangtze River Basin (Jiangsu Part) as a case study. An index system for regional environmental risk zoning was developed and an integrated assessment model (IAM) was adopted to assess the regional environmental risk. Potential risk management countermeasures were suggested for decision-makings about risk management in this region. Yang Jie et al (2006) thought environmental risk zoning was a sequencing process of the relative size of the regional environmental risk. In accordance with the structures, functions and features of regional natural and social environment, the region can be divided into different ranks, and then the priority order of environmental risk management can be determined.

In China, there were two mainstreams about regional risk assessment: risk assessment based on personal risk and social risk and risk assessment based on risk compensation. Research achievements mainly concentrated in applying the principle of superposition and assigning a value to self-defined parameters based on experience to obtain the quantitative risk value of each point [8]. The methods such as environmental risk assessment based on sensitivity[9], environmental risk assessment based on reliability theory[10] and fuzzy comprehensive evaluation assessment all evaluate environmental risk from three aspects: the danger of risk sources, effectiveness of control mechanisms and vulnerability of receptors.

In general, the quantitative zoning system of the regional environmental risk is still very immature and needs further study. This paper, on the basis of regional environmental risk assessment and environmental risk zoning， constructs the index system and the quantitative model , applies AHP to weight index and comprehensive evaluation method to calculate comprehensive risk index value. This method has been successfully applied in the literature[11]. In this paper, based on the use of this method, with the clustering function of SPSS and the visualization of GIS, quantitative risk zoning map can be obtained.

2. Methods

2.1. The establishment of index system

According to the principles of systematicness, consistency, dominance，dynamism and data availability, the index system of regional environmental risks can be established from three aspects: the danger of risk sources, effectiveness of control mechanisms and vulnerability of receptors. The index system consists of target, system, rule and index layers (Table 1).

Table 1. The index system of major environmental risk sources zoning in urban scale

Target Layer	System Layer	Rule Layer	Index Layer
Environmental risks	Risk sources		Leading industry type
		Stationary sources	The scale of major risk sources
			The intensity of risk sources
		Mobile sources	Characteristics of hazardous waste
			Emissions
			Transportation risk
	Control mechanisms	Control mechanisms	Frequency of man-made risks
			Present situation of environmental quality
	Risk receptors		Quantity and level of protected areas(schools、place of historical interest、hospitals)
		Degree of exposure	Residential density
			The level of drinking water source
			The level of per capita GDP
		Adaptability	The number of beds in million units
			Forewarning ability
			Per capita public green areas

According to the consideration that the greater danger of risk sources, the worse validity of control mechanisms, the higher exposure and the worse adaptability can cause the greater environmental risk, the urban environmental risks can sorted and then an environmental risk zoning map can be worked out.

For the urban scale, there are many chemical industries or risk sources of storing hazardous chemicals. The major risk sources can be selected as the risk sources of environmental risk zoning. It is defined in Technical Guidelines for Environmental Risk Assessment on Projects that the major hazard resource is the functional unit in which dangerous or hazardous substance is produced, processed, transported, stored for long-term or short-term， and quantity of hazardous substance is equal to or exceed the critical value. In this paper, major hazards are selected in accordance with the danger of toxic substances. In the functional unit, hazardous coefficient is calculated as follows:

$$I = \frac{q_1}{Q_1} + \frac{q_2}{Q_2} \cdots + \frac{q_n}{Q_n} \tag{1}$$

Where $q_1, q_2 \cdots, q_n$ is the actual storage of each kind of hazardous substance in the functional unit, t;

$Q_1, Q_2 \cdots, Q_n$ is the critical quantity of each kind of hazardous substance in the functional unit, t.

If the $I \geq 1$, the functional unit can be defined as the major risk source.

In this paper, danger of risk sources includes stationary sources and mobile sources in rule layer. Stationary sources are the risk sources whose positions are unchanged in the areas, such as factories and enterprises. Mobile sources are the new risk sources which are created by the transport of hazardous waste. Vulnerability of receptors include degree of exposure and adaptability. Degree of exposure is the number and area of sensitive targets exposed in the area where risks occurred, reflecting the extent that receptors suffered danger. Adaptability refers to the ability of system to return to raw condition that is the ability to adapt to the environment after the receptor subjected to external disturbances such as sudden pollution accidents. In the index layer, leading industry type reflects the situation of the regional major industries; the scale of major risk sources reflects the number of regional major risk sources; the intensity of risk sources is that the number of major hazards is divided by population density， reflecting the situation of the cascading and collective burst of risk sources; characteristics of hazardous waste reflects the danger of hazardous waste during the transportation; emissions reflect the number of hazardous waste; transportation risk represents the status of the transportation of hazardous waste. Control mechanisms reflect the impact of human factors on the possibility and harmful level of accidents. Present situation of environmental quality reflects the level of regional primary control mechanisms; the frequency of man-made risks reflects the level of regional secondary control mechanisms, including emergency input and the level of environmental management systems. Better control mechanisms lead to relatively small danger, because risky enterprises can predict and prevent accidents before they happened in order to reduce the possibility of accidents; on the other hand, risky enterprises can make a timely response measures to the accidents after they happened to reduce the hazards and losses on the environment and human health. The more protected areas, the greater residential density and the higher level of drinking water sources can lead to greater exposure and greater regional risk. The level of per capita GDP, the number of hospital beds in million units and per capita public green areas reflect respectively the economic strength to reduce the danger of risk sources, the level of urban medical aid and urban open space for emergency evacuation.

2.2. *The establishment of quantitative model*

Quantify the various indicators according to the index system (Table 2).

Table 2. The quantitative model of major environmental risk sources zoning in urban scale

System Layer	Score Index		100 I	80 II	60 III	40 IV
The danger of risk sources	Stationary sources	Leading industry type	chemical industry, petrochemical industry	electroplating, pharmaceutical industry, non-ferrous metal smelting	machinery manufacture, storage of dangerous goods, construction, transportation	other
		The scale of major risk sources	high	middle	low	——
		The intensity of risk sources	high	middle	low	——
	Mobile sources	Characteristics of hazardous waste	3~4 dangerous substances of toxic, explosive, flammable and corrosive	2~3 dangerous substances of toxic, explosive, flammable and corrosive	1~2 dangerous substances of toxic, explosive, flammable and corrosive	0~1 dangerous substances of toxic, explosive, flammable and corrosive
		Emissions	high	middle	low	——
		Transportation Risk	high	middle	low	——
	Control mechanisms	Frequency of man-made risks	high	middle	low	——
		Present situation of environmental quality	failure	standard	good	excellent
	Degree of	Quantity and level of protected areas	huge numbers ;special protection areas	moderate quantity ;key protected areas	small numbers ;general protected areas	rare; potential protected areas

	Residential density	high	middle	low	——
	The level of drinking water source	municipal water intake	district water intake	town-level water intake	non-water intake
	The level of per capita GDP	low	middle	high	——
Adaptability	The number of beds in million units	few	middle	many	——
	Forewarning ability	low	middle	high	——
	Per capita public green areas	few	middle	many	——

1)Obtain regional data of the indicators and then carry on quantitative disposal according to the quantitative model. The fuzzy indicators were quantified by expert scoring, and the quantifiable indicators were collected directly from original data. Assign weight value by Using AHP and Delphi methods.

In the index system, leading industry type is a qualitative index. The score of the level of drinking water source in every district or county is calculated as：

$$G = \sum_{i=1}^{4} n_i t_i \tag{2}$$

Where：G——the score of the level of drinking water source in every district or county；

i——one of 4 types about the level of drinking water source;

n_i——the number of the i_{th} type of drinking water source in every district or county;

t_i——the score of the i_{th} type of drinking water source in every district or county.

This method can be used for indicators which are quantified by scoring.

2) Standardize the index of different dimension. After getting the original data of the index, uniform evaluation criteria (make each index value between 0 and 1). Standardize the original data of the index system by the extreme standardization method. Because the index system exists that the higher the index value the greater the risk is and the higher index value the lower the risk is, the reference[11]quantifies all indicators in accordance with the positive indicators (the higher the index value is, the greater the risk is) and reverse indicators (the higher index value is, the lower the risk is). Formula (3) and formula (4) respectively were applied for processing.

For the positive indicators:

$$M_{ij} = x_{ij} / \max(x_{ij}) \tag{3}$$

For the reverse indicators:

$$M_{ij} = \min(x_{ij}) / x_{ij} \tag{4}$$

Where: M_{ij}—standard value of the indicators;

x_{ij}—original value of the indicators;

$max(x_{ij})$—maximum value of the indicators;

$min(x_{ij})$—minimum value of the indicators.

3) Calculation of comprehensive risk index value. This paper uses comprehensive evaluation method was applied to calculate comprehensive risk index value. The formula is as follows:

$$M = \sum_{j=1}^{n} W_j M_j \tag{4}$$

Where: M—comprehensive risk index value;
W_j—the weight of the index layer;
M_j—the scores of the index layer;
n—the number of the index layer.

2.3. The hierarchy cluster of SPSS and the visualization of GIS

Comprehensive risk index value will be clustered in the SPSS and divided into 4 categories, which are major risk areas, higher risk areas, general risk areas and low risk areas.

Based on the clustering function of SPSS and the visualization of GIS, environmental risk areas of different categories can be represented intuitively.

3. Case-study

By the end of 2007, Shanghai included 18 districts and 1 county. In the May of 2009, the State Council approved "a requesting instruction on the revocation of Nanhui district and that it will be incorporated into Pudong ". In the paper, because the collected information and related data is from 2000 to 2008，Pudong and Nanhui are still considered as two districts.

Shanghai is the large city which has the following character: particularly dense population which can enlarge the accidents; dense river networks and open water sources; fragile ecological environment, intermix of residential area and old industrial area, high environment risk; well-developed logistics, high rate of environmental accidents caused by traffic accidents; developed storage industry, many large-scale cold storages and high risks of ammonia leakage etc.. It was estimated that every year a variety of natural and man-made disasters in Shanghai caused more than 2,100 people were killed and the direct economic losses were at least 4 billion RMB[12].

Every district and county of Shanghai is considered as a zoning unit in order to facilitate the collection of data. Data is collected through various channels, such as field researches, statistical yearbook, and network resources. The data processing platforms include Arcgis8.3, MATLAB7.0, Spss16.0 and Excell2003.

By screening more than 1,000 enterprises which product, process, transport, use or store dangerous substances in Shanghai in 2006，the results show there are more than 400 enterprises being judged to be the major risk sources. For the difficulty in collecting the data and investigation, according to the score of hazardous coefficient, the top 100 major hazardous enterprises are selected as our research object (Fig.1). The location of water intake at all levels in Shanghai is showed in Fig.2. The main drinking water sources in Shanghai include Yangtze River, Suzhou Creek, Huangpu River, Pudong canal, Punan Canal, Dianpu River, Dazhi River and Chuan Yang River.

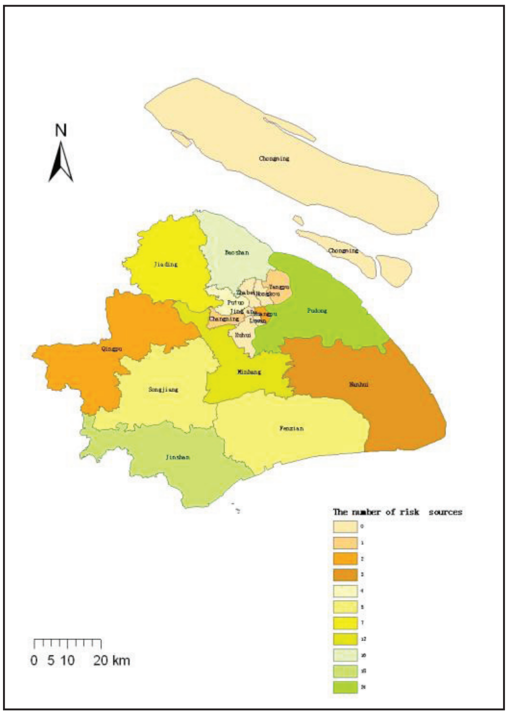

Fig. 1.Distribution map of 100 major risk sources

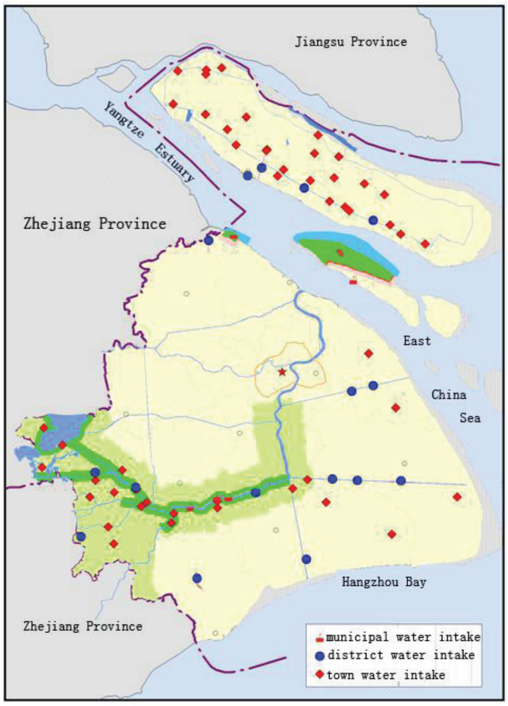

Fig. 2. Location of water intake in Shanghai

In accordance with the index system and quantitative model, comprehensive risk index values of major environmental risk sources in all districts and counties of Shanghai can be calculated (Table 3).

Table 3. Comprehensive index values of major environmental risk sources in all districts and counties of Shanghai

The name of districts and counties	Stationary sources	Mobile sources	Control mechanisms	Degree of exposure	Adaptability	Comprehensive risk index values
Pudong	0.2215754	0.0223796	0.438575	0.0151558	0.02621357	0.723899356
Huangpu	0.0591057	0.0010859	0.076058	0.080052	0.034407942	0.250709592
Luwan	0.0147686	0.0004525	0.0584287	0.064236	0.04018096	0.178066721
Xuhui	0.0204712	0.0025574	0.1347386	0.0344621	0.027440321	0.219669582
Changning	0.0426714	0.0020919	0.1699973	0.0310429	0.042370363	0.288173878
Jing'an	0.0147686	0.000362	0.0936874	0.0670718	0.041571386	0.217461163
Putuo	0.0968468	0.0034196	0.2325395	0.0301273	0.047749942	0.410683093
Zhabei	0.0147686	0.0016289	0.2518478	0.0419837	0.054825456	0.365054447
Hongkou	0.0147686	0.0018099	0.1091341	0.0582897	0.037449923	0.221452184
Yangpu	0.0574354	0.0026128	0.1813304	0.034479	0.043630311	0.31948802
Baoshan	0.1617285	0.0147374	0.6909025	0.0098221	0.055474104	0.932664682
Minhang	0.1462171	0.0111867	0.408833	0.0114249	0.036261715	0.61392343
Jiading	0.0962338	0.0103098	0.3404983	0.0048746	0.067440299	0.519356753
Jinshan	0.1974844	0.0787307	0.3223652	0.0057743	0.063853572	0.668208183
Songjiang	0.0919013	0.011564	0.3581276	0.0163398	0.057279542	0.535212203
Qingpu	0.0505532	0.009057	0.1699973	0.0095189	0.085704414	0.324830731
Nanhui	0.0635324	0.0072485	0.1620221	0.0080518	0.067389662	0.308244495
Fengxian	0.0648074	0.0084097	0.2934027	0.0079326	0.071746074	0.44629852
Chongming	0.0147686	0.0044343	0.110813	0.0350891	0.085775908	0.250880893

These results in Table 3 will be clustered by using SPSS method and divided into 4 categories. The clustering approach taken is Between-groups linkage and the distance measure method taken is Squared Euclidean distance. We can get the distribution maps of each district of the danger of stationary sources and mobile sources, effectiveness of control mechanisms, the degree of exposure and the size of adaptability, respectively shown in figure 3，4，5，6 and 7. From 1-4，the danger and degree of exposure gradually reduce, but the index values of control mechanisms and adaptability gradually increase. Because control mechanisms and adaptability are reverse indicators, in the calculation of the index values they have been reversely operated, therefore the greater the index values of control mechanisms and the adaptability are, the greater the risks are. Thus, after superposition, the level of risks gradually increases from 1-4.

Fig.3 shows that the danger of stationary sources in Pudong and Jinshan District is the greatest, followed by Minhang District and Baoshan District. The smaller is in Xuhui，Luwan，Jing'an，Zhabei，Hongkou and Chongming.

Fig.4 shows that the danger of mobile sources in Jinshan District is the greatest, followed by Pudong. The danger in Xuhui，Luwan，Jing'an，Zhabei，Hongkou，Changning，Huangpu，Putuo，Yangpu and Chongming are smaller, which is related with their storage and transport of hazardous materials. Large quantities and strong toxicity of toxic substances in Jinshan result in the greatest danger of its mobile sources. Xuhui, Luwan, Jing'an, Zhabei, Hongkou, Changning, Huangpu, Putuo and Yangpu are urban areas of Shanghai and store less toxic materials. What's more, urban environment management measures are better than suburbs. Urban areas are mainly densely populated and there are no large-scale chemical industries.

Fig.5 shows that the effectiveness of control mechanisms in Baoshan is the worst. According to statistics from the survey, the frequency of man-made risks is the highest. Baoshan accounted for 13 in 93 sudden pollution accidents in 2008. The effectiveness of control mechanisms in Chongming,, Xuhui, Luwan, Huangpu, Jing'an and Hongkou are better.

Fig.6 shows the degree of exposure in all districts and counties of Shanghai varies greatly, in space, main expression is that the central cities and the surrounding regions are higher than other regions. The highest is in Huangpu, Luwan, Jing'an and Hongkou, followed by Chongming. Population distribution in Shanghai is uneven and most people are gathered in downtown Puxi(including Huangpu, Luwan, Jing'an and Hongkou, etc.). Currently, population density in Puxi is about 4 million /square km, where high population density and large number of protected areas make the risk of exposure higher than other regions when facing sudden environmental incidents. Therefore, compared with the central cities, the degree of exposure is low in suburbs. Chongming as an important water source leads to its high degree of exposure.

Fig.7 shows the adaptability is greatest in Pudong and Xuhui. The level of per capita GDP, medical services and public green area per capita in these two areas are high, which makes them a better emergency response capability to sudden pollution incidents. As health services are relatively backward in Qingpu and Chongming, after the accident, emergency rescue is relatively weak, so the adaptability is lower.

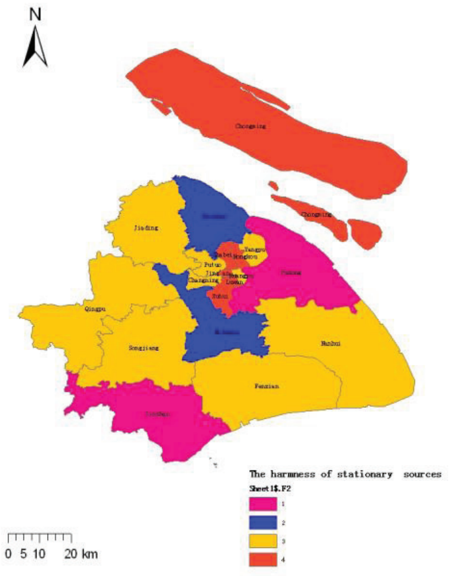

Fig.3.The danger of stationary sources

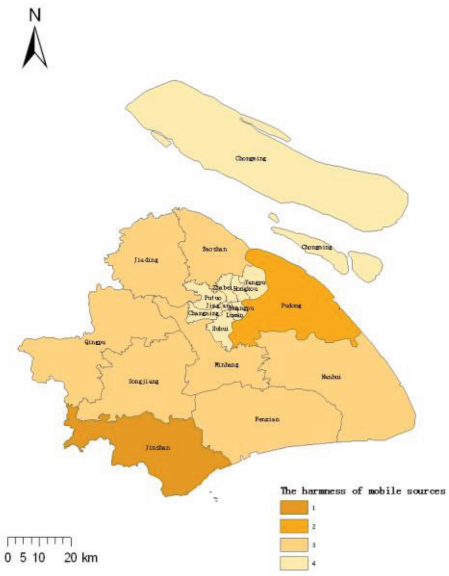

Fig.4. The danger of mobile sources

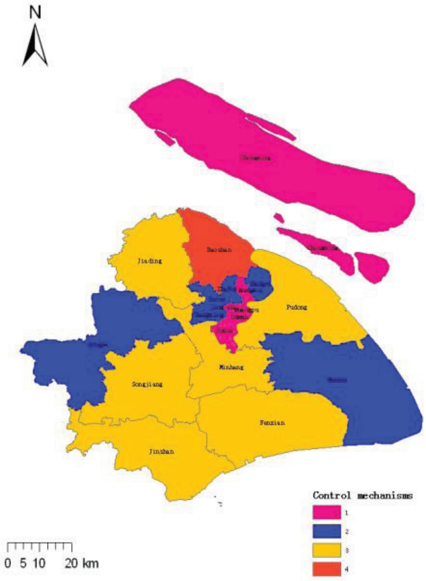

Fig.5. Effectiveness of control mechanisms

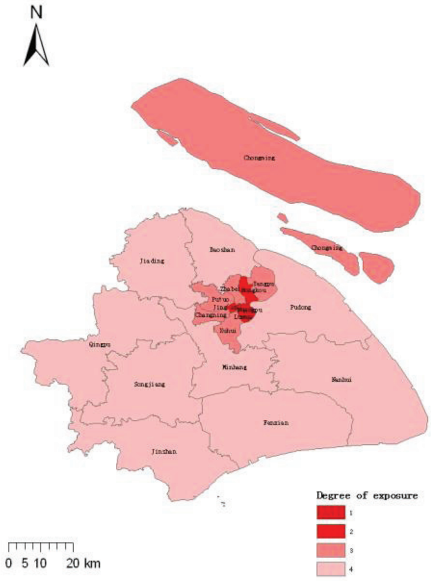

Fig.6. The degree of exposure

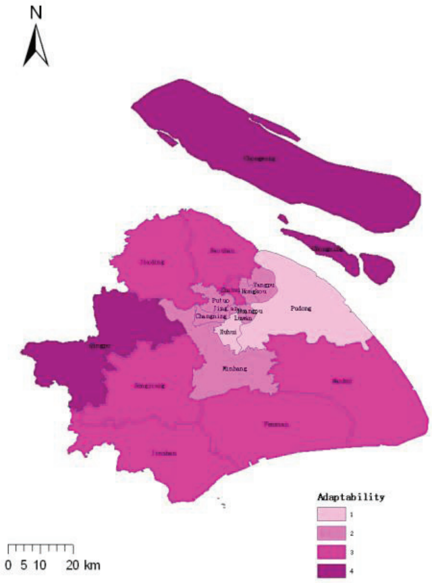

Fig.7. The size of adaptability

Similarly, comprehensive index values in all districts and counties of Shanghai will also be clustered in the SPSS, clustering results are shown in Fig.8:

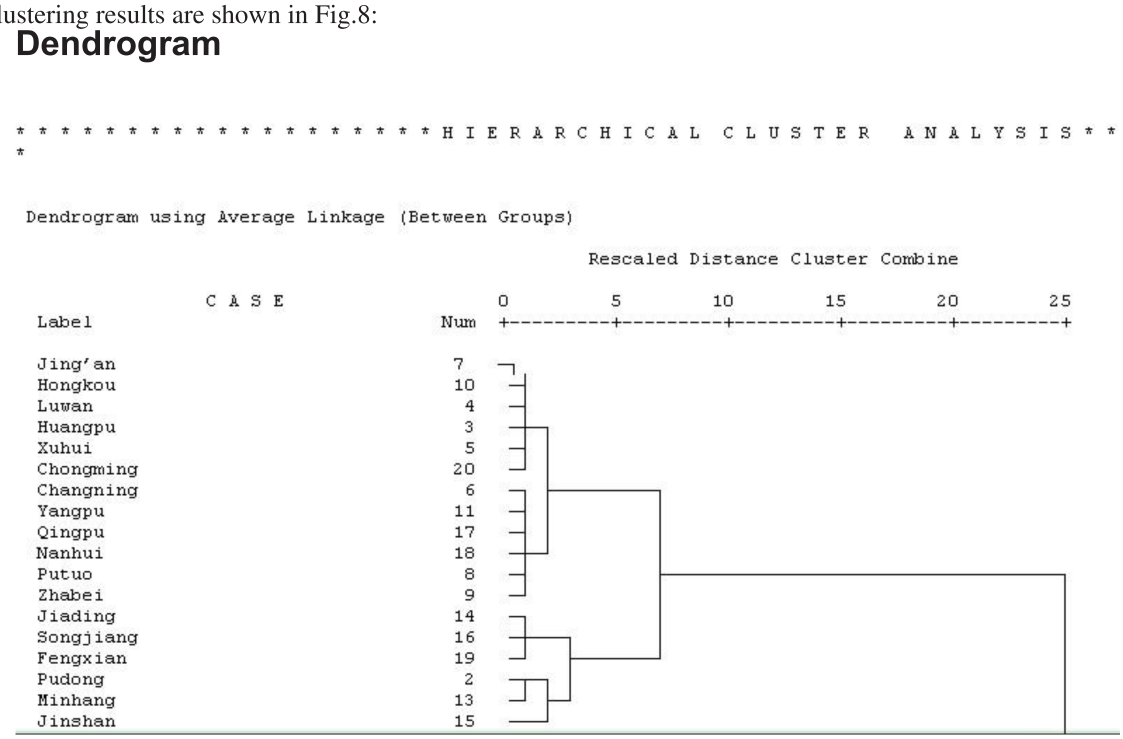

Fig.8. Clustering Histogram

Fig.8 shows that in the 19 districts and counties of Shanghai, Baoshan belongs to a category, the three areas of Pudong, Jinshan and Minhang belong to a category, the three areas of Jiading, Songjiang and Fengxian belong to a category, and the rest is a category. According to the data of Table 3 and the above classification result, it is obvious to draw that in Shanghai Baoshan belongs to the major risk area, the three areas of Pudong, Jinshan and Minhang belong to higher risk areas, the three areas of Jiading, Songjiang and Fengxian belong to general risk areas and the rest are low risk areas.

A quantitative zoning map of major environmental risk sources in all districts and counties of Shanghai can be obtained by using GIS operating software (Fig.9).

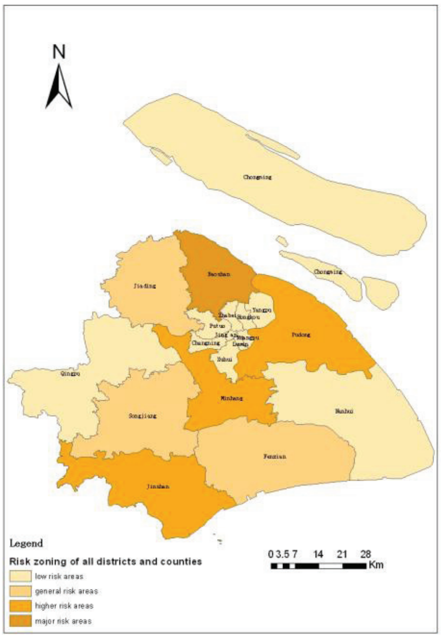

Fig.9. Quantitative zoning map of major environmental risk sources in all districts and counties of Shanghai

Some conclusions can be drawn from figure 9. Firstly, the integrated environmental risk index in different districts or counties of Shanghai are different clearly, the key management measures for key zones should be taken. Secondly, because of improper distribution of industries, the key risk zones of Shanghai (including Wujing industrial zone, Shanghai chemical zone, Gaoqiao petrochemical zone, Jinshan industrial zone, the second Jinshan industrial zone, Taopu industrial zone and so on) distributed in seven districts or counties such as Jinshan, Minhang, Pudong, Baoshan, Songjiang and so on. Thirdly, the integrated risk index of key risk zones is related to traffic accidents which can cause leakage of toxic and hazardous substances and then increase the risk of mobile sources. Fourth, there is a large difference among the level of control mechanisms of each district. This may due to the differences in supervision level, emergency investment, environmental management system, production technology level and some other factors.

4. Conclusion

This paper constructs the index system and the quantitative model of environmental risk zoning, which is fit for urban scale. And with the clustering function of SPSS and the visualization of GIS, the quantitative risk zoning map of Shanghai is obtained. The result shows that Baoshan District is the major risk area, Pudong District , Jinshan District and Minhang District is higher risk areas, Jiading District, Songjiang District and Fengxian District is general risk areas and the rest Districts are low risk areas. The results of this article can be seen more consistent with the actual situation in Shanghai, so the exploratory method in this paper is reasonable. The results have some practical value and provide decision-making basis for environmental risk management and spatially optimal distribution of Shanghai.

Acknowledgment.

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