A Review on Approaches to Regional Environmental Risk Assessment

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Abstract. In recent years, economy grows rapidly in China accompanied by corresponding environmental risks in regional scale. This article reviews several approaches that researchers have developed related to identification, assessment of regional environmental risk and land use planning for further management according to the assessment. On the base of the literature review, further researches prospect for dynamic, comprehensive environmental risk assessment is proposed. In addition, adequate data with higher quality is required by the method combining geographic information system and remote sensing to achieve a better assessment and regional planning.

1. Introduction

With the progress of industrialization and urbanization in China, the number of chemical factories increases rapidly. At the same time, the environmental risk of sudden accidents draws certain concern of government. From 1998-2006, there were 14742 severe sudden accidents in China[1, 2], which lead to a heavy damage to human health and economic loss of more than 1.2 billion RMB. In addition, the oil pipeline explosion in Dalian in 2010 has caused crude oil pollution to the Yellow Sea in over 50 km^2 surface area. It was also a disaster that in 2015, the explosion of hazardous chemical warehouse in Tianjin Binhai new district resulted in over 800 casualties, 304 building destructions and several days of air pollution. The main reasons for these accidents are fire, and leakage caused by hazardous chemicals which resulted in explosion and casualties. Compared with construction and maintenance of factories, accidents during productions happened more. It is probably due to unprofessional operation and lack of safety regulations in many factories[3]. These severe accidents in China lead to a certain concern on environmental risk assessment. Environmental risks refer to the probability and result of accidents, natural events, and deliberate assaults, causing pollution or other health problem of human. Environmental risks are often described as the product of frequency, intensity and vulnerability. In order to identify, limit, and hopefully prevent these situations, environmental risk assessment and management places a strong emphasis on targeting the problems that could arise and implements a system of metrics that help with prevention. At present, relevant results can be divided into genetic risk assessment, individual health risk assessment, construction project environmental risk assessment and regional environmental risk assessment[4].

Regional environmental risk assessment (R-ERA) developed from regional-scale environmental impact assessment (R-EIA). Researchers conduct various approaches on the measurement of environmental impact risk, such as source analysis, accident probability estimation and information diffusion. Mathematical approaches along with toxicological approaches are used to predict and to make a risk spatial distribution map to help environmental protection[5, 6]. In the research area, human activities

should be considered where multiple risk factors may interact with each other. Therefore, it is crucial to measure environmental risk in the regional scale with comprehensive approaches. This article makes a literature review on studies of regional environmental risk assessment. On the base of the studies, this article puts forward relevant suggestions for further research. The following part is divided into three sections. Firstly, a review of methods to environmental risk assessment is given. Secondly, a short review of land use optimization with regard to methods of determining safety distance is given. After reviewing the approaches, conclusions and suggestions to further research are given in the final section.

2. Approaches to Regional Environmental Risk Assessment

Generally, regional environmental risk results from joint interaction of potential risk source, risk receptor and transmission of pollutants. In different area or period, status of receptors, pollutant emission, terrain and meteorological conditions are different. To identify, quantify and respond to environmental risk, various principles and methods have been used in previous works.

Identification of environmental risk is the first work in environmental risk assessment. Fault Tree Analysis (FTA), Event Tree Analysis (ETA) and Bow-Tie Analysis (BTA) are three widely-used methods. Fault tree analysis was developed by Watson in 1965 for qualitative and quantitative analysis. Accident type was identified to analyze direct reasons, and then resolve them into minimum cut set of reasons[7]. Event tree analysis is the technique used to define potential accident sequences associated with a particular initiating event or set of initiating events. Event trees consist of nodes and branches on which numbers, percentages or probability values are entered to describes the logical connection between the potential successes and failures of defined safety systems or safety functions as they respond to the initiating event and the sequence of events. The event tree evaluation can be qualitative or quantitative or both, which is similar to the fault tree evaluation. Two general methods or approaches exist for the event tree linking process with the fault tree analysis. The small event tree and large fault tree approach are mostly used in nuclear industry in probabilistic safety assessment of nuclear power plants[8]. For instance, Doytchin and Szwillus carried out a case study at a Bulgarian Hydro power plant using fault tree analysis and task analysis in 2009. They established a four-hierarchy fault tree to analyze the error modes of an operator's behaviour[9]. Celik applied a fuzzy extended fault tree analysis on shipping accident investigation, illustrating that technical failures, operational misapplications, and legislative shortages were main reasons of the shipping accidents[10].

The bow-tie analysis assimilates accident scenarios to a succession of events. The bow-tie is centered on the critical event, which is generally defined as a Loss Of Containment (LOC) for fluids or a Loss of Physical Integrity (LPI) for solids. The left part of the bow-tie, named fault tree, identifies the possible causes of a critical event while the right part of the bow-tie, named event tree, identifies the possible consequences of a critical event. The critical event, such as a pipe failure, leads to secondary critical events, which leads to tertiary critical events, which in turn leads to dangerous phenomena such as fire, explosion and dispersion of a toxic cloud. Major events are defined as the exposition of targets to a significant effect due to the identified dangerous phenomena[11]. It was an important tool in ARAMIS methodology, which was developed in an European project co-funded in the fifth Framework Program of the European Commission. The methodology is divided into the following major steps: identification of major accident hazards, identification of the safety barriers and assessment of their performances, evaluation of safety management efficiency to barrier reliability, identification of reference accident scenarios, assessment and mapping of the risk severity of reference scenarios and of the vulnerability of the plant surroundings[12]. It offers an alternative to purely deterministic and probabilistic approaches to risk assessment of process plants, land use or emergency planning.

To give a quantitative assessment of an area, researchers use information diffusion as an available integrated assessment method based on fuzzy sets which are formed by fuzzy numbers. This method can diffuse a single-value sample to a multi-value sample. The information diffusion method for R-ERA can be divided into five parts: the spatially distributed grid, risk information matrix, data correction, risk accumulation, and partition map. The research region should first be divided into many grids. These grids must be the same size (square) using equal step size, illustrated with a matrix, in which each

element represents the information of the corresponding square with the value of the center point. The greater risk the target grid is under, the greater the element in the matrix is. After the accumulation of risk values, result can be illustrated by a space figure with Geographic Information System (GIS) and Remote Sensing (RS) technology[5]. Xiaojie Meng applied this method to assess regional risk of Nanjing Chemical Industry Park in China, clustering the area according to a certain classification criteria and depicted using a spatial partitioning map[13]. Furthermore, Analytic Hierarchy Process (AHP) and Catastrophe Progression Method are useful in risk value determination and criteria decision[14].

After assessment of environmental risk, it is vital to carry out managements. It is considerable to adjust distance between risk source and receptor, to minimize the risk and to optimize the land use planning of the region.

3. Approaches to optimize land use planning

There are three widely-used approaches to optimize regional land use and determine of safety distance, including the experience-based approach, the consequence-based approach and the risk-based approach. Experience-based approach relies on historical data and cases. It is easy to handle but may lead to an imprecise result. Consequence-based approach relies on appropriate assumption about consequence of accidents, which is usually applied on site selection of newly developed land or factories. However, it overestimates safety distance, since the worst situation is selected as the consequence of accidents. Risk-based approach is also called probabilistic approach. This method relies on probability theory and reliability trial to quantify environmental risk, and then calculate safety distance. In consideration of overall situations of accidents, risk-based approach needs enough data and complex models to calculate.

Researches of experience-based approach initiated from 1860s. Governments evaluated accident result according to distance between factories and important facilities, such as hospital, central business district, school and housing area[15]. After Flixborough explosion in the United Kingdom (UK) in 1974 and LDK cable chemical pollution accident in Italy in 1976, researchers settled to apply consequence-based approach. Early in 1974, Rasmussen first applied this method on nuclear power plant risk assessment[16]. UK government established Advisory Committee on Major Hazards (ACMH) to present a proposal to nearby area of major hazard facilities. ACMH first estimates toxic effect on nearby human, then select acceptable location and safety distance to place hazards warehouse and transport vehicles. Notably, UK used GIS to map hazardous locations and allowed public notice on the Internet. In 2004, US stipulated that calculation of safety distance should consider environmental impact on susceptible group based on risk assessment[17]. France government applied consequence-based approach to measure the lethal distance and the adverse reaction distance for land use planning.

In China, relevant works have been done with quantitative methods. LI developed a method using accident scenarios analysis for the quantitative assessment on liquefied chlorine and identified the scenarios with the highest risk. It was processed for detail consequence analysis in typical scene, and the damage radius of median lethal concentration (LC_{50}) was calculated[18]. QU-Dan-dan used Bernoulli equation and the evaporation expressions to calculate the intensity of substances leakage. She also used the smog mode to simulate and calculate its effects on the environment and to forecast its effect degree under different distance and time[19]. ZHU Xiao-xuan applied Monte Carlo method combined with Gaussian diffusion simulation to assess the effects of four risk variables, including wind direction, wind speed, temperature and stability, on simulated leakage accidents. The results were compared with Protective Action Criteria (PACs) to determine safety distance around chemical factories[20]. In recent researches, Genetic Algorithm is also used in multi-objective optimization, linear optimization and nonlinear optimization to achieve better management[21].

4. Conclusion

This article introduces several approaches to environmental risk assessment including qualitative and quantitative methods. Fault tree, event tree and bow-tie analysis are useful tools to identify and assess the reason and result of an environmental accident. Then, information diffusion is available to set up a risk information matrix and output a partition map, with certain criteria and weight determined by AHP,

CPM or other approaches. To carry out feasible risk management, it is considerable to adjust safety distance between risk sources and receptors. Optimization of land use planning according to environmental risk has also been put into practice in different countries.

There are also some points to be improved in further studies. Firstly, further data collection of emergency monitoring is needed to deal with problems of uncertainty. Data mining approaches in risk assessment can be applied if enough data is acquired, which may give rise to the accuracy of assessment. Secondly, dynamic risk assessment approaches can be developed, combining GIS, RS and other technologies, to match the needs of visualization in regional management. Finally, a systematic assessment of financial, social, environmental risk needs further research to help with decision-making. Therefore, approaches to environmental risk assessment and management need more researchers that have the passion and enthusiasm to bring this field to the next level.

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