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Reprint of: Regional risk assessment for urban major hazards based on GIS geoprocessing to improve public safety ☆

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ABSTRACT

Regional risk assessment for urban major hazards is significant for environment protection and public safety. In practice, repeating geoprocessing steps required in risk mapping process is quite timeconsuming, and it has been a challenge for both researchers and managers. In this study, we designed and implemented a tool for facilitating the process of urban regional risk assessment. Geoprocessing workflow models are built for severity calculation, vulnerability evaluation and risk mapping respectively. We then integrate these models into an automatic GIS tool, and apply it in a typical urban district of north China to demonstrate its functionalities and utility. The risk map successfully obtained shows that it has potential to be a useful decision support tool for guiding emergency management and urban planning. This work offers new insights and valuable demonstration on promoting future risk assessment with the use of emerging GIS geoprocessing technology in the Big Geo-Data age.

1. Introduction

China has experienced rapid urbanization during the last three decades (Xiang et al., 2011). Its urban population increased from 17.6% in 1978 to 54.8% in 2014 (Pan and Wei, 2015). Urbanization is recognized as an "engine" of economic growth, and "accelerating urbanization" has been set as a national policy for years to come in China (13th Five-Year Plan, 2015). It is predicted that the urban population will increase to about 70% by 2030, implying that the trend of rapid urbanization is expected to continue (Pan and Wei, 2015). With the prosperity brought by urbanization, however, emerging issues pertaining to urban public safety have yet to receive essential attention they deserve (Xiang et al., 2011; Zhao and Chen, 2014, 2015).

In recent years, major accidents occurred frequently in urban areas in China, implying that the negative consequences of industrialization in densely populated regions become increasingly serious. Following rapid industrialization, lots of industrial plants have been set up in the vicinity of urban areas in China due to its convenient transportation system and abundant human resources (Zhao and Chen, 2015). But at the same time, more and more public infrastructures have been built around these plants accompanied by the rapid urbanization. Some plants are even surrounded by densely populated residential areas. Moreover, the lack of scientific urban planning also leads to concentration of hazardous chemical industry clusters in some cities, which are with high risk level (Huang et al., 2011). In these plants, hazardous materials (e.g., toxic, flammable or explosive substances) are unavoidably involved in the manufacturing process, which can lead to potential dangerous accidents (e.g., chemical leakage, fire, explosion, or toxic proliferation) (Zhou and Liu, 2012; Zhao and Chen, 2015). The impact of these hazardous accidents often spreads to the adjacent urban areas, causing catastrophic effects and leaving heavy casualties (Georgiadou et al., 2010; Li et al., 2010; Huang et al., 2011; Fan, 2014). Therefore, evaluating the potential hazards of urban major hazardous installations to adjacent urban areas is significant for public safety and environment protection.

Regional risk assessment of urban major hazards (RRAUMH) in a quantitative and spatial framework is essential for urban public safety (Zhao and Chen, 2014, 2015). A quantitative framework for RRAUMH is consistent with the standard notions of risk in actuarial principles, and it enables cost-effectiveness analysis as a basis for evaluating risk mitigation options. A spatial framework recognizes that risk of urban major hazards is a geospatial process with significant spatial variation in environmental factors driving the likelihood and intensity of dangerous phenomenon, as well as the human and asset vulnerability (Salvi and Debray, 2006). Quantita-

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tive and spatial framework for RRAUMH is increasingly being applied, with growing sophistication, to inform risk management in China and elsewhere (Zhao and Chen, 2014).

In urban areas, the hazard of industrial installations to adjacent areas is essentially geospatial issues, and it inevitably refers to the spatial pattern and natural geographical condition of urban system (Zhao and Chen, 2015). With the improvements of geospatial data in temporal and spatial resolutions, risk calculation and mapping for RRAUMH have grown significantly in volume. This is particularly true in case of large-scale urban areas, which unavoidably involves huge sets of spatial meshes in risk calculation, implying that an effective and efficient technology for geospatial information processing is required.

Spatial information technology known as geographic information system (GIS) is regarded as a powerful tool for managing, displaying, and analyzing data related to geospatial information. GIS has increasingly played an important role in geospatial information process in many special fields over the past years. GIS is thus a useful solution to handle the vast geospatial data sets and evaluate the regional risk of large-scale urban areas (Martín-Gómez et al., 2015). In recent years, GIS has become a key component of the RRAUMH framework, and it has been successfully demonstrated in performing regional risk assessment (Delvosalle et al., 2006; Matějíček et al., 2006; Planas et al., 2006; Tixier et al., 2006; Li et al., 2010, 2014; Sebos et al., 2010; Herrero-Corral et al., 2012; Zhou and Liu, 2012; La Rosa and Martinico, 2013; Liu et al., 2013; Tena-Chollet et al., 2013; Meng, 2015; Thompson et al., 2015).

In practical work, however, a number of significant process limitations became apparent. First, a potential bottleneck of calculating integrated risk indexes is that large numbers of geoprocessing steps are required, in particular the intersections of accident's consequence intensity with occurrence probability and calculations of vulnerability index to each mesh. In practice, one key lesson learned from our experience is that these steps are repeated many times dependent on the total number of meshes, and it is therefore quite a tedious and time-consuming process which is easy to involve human error. The computational time required for RRAUMH using standard GIS software packages can take days to complete, making it difficult to use the assessment results in a real-time workshop setting, or to quickly regenerate results if changes are warranted. Especially in the Big Data age, the volume of geospatial data is big, the variety of geospatial data is diverse, and the updating rate of geospatial data should be fast. In the urban planning or risk management community, researchers and managers may not be willing to wait for days or longer to process geospatial data streams repeatedly. Moreover, the essential of RRAUMH is geospatial calculation issue, which presents another challenge for individual decision maker who seek to obtain the risk spatial pattern of urban systems. The risk assessing process is computationally intensive, and this task is particularly difficult to perform for users from different discipline backgrounds, as some of them may have few concept and skill of the general GIS software system. Therefore, a standardized and streamlined risk calculation tool is needed to assist decision makers in facilitating the process of risk calculation as well as risk mapping. Unfortunately, given the large variety of tools used in urban planning and risk management community or software development reported in the literature, to date, there are relatively few special-purpose tools available that can automate these complicated geospatial tasks in solving urban regional risk assessment issues.

In order to address the limitations above, we developed a tool called RiskUMH (risk of urban major hazards) in this study by using GIS geoprocessing technology. RiskUMH is customized and designed to perform rapid risk calculations suitable for regional-scale risk analysis in urban areas. RiskUMH is a flexible tool capable of providing decision support to managers who are seeking to mitigate potential risk of urban major hazards. The main contribution of this study is two-folds: First, it presents the design and implementation of workflow models based on GIS geoprocessing technology for facilitating RRAUMH. Second, it provides valuable demonstrations about how to efficiently integrate emerging GIS geoprocessing technology and risk assessment method into a uniform toolbox to improve risk management research.

The rest of the paper is organized as follows. In Section 2, we introduce some relevant work about urban regional risk assessment and GIS geoprocessing technology to help understand the challenges involved in present research. In Section 3, the description of the design and implement of RiskUMH is presented. This is followed by a case study for demonstrating its workflow and functionalities in Section 4. We then discuss the results of risk mapping in Section 5, and conclude the paper with future research directions in Section 6.

2. Related work

In this section, we briefly point to related work and background material.

2.1. Regional risk assessment of urban major hazards (RRAUMH)

In recent years, different methods have been developed and applied to evaluate the potential hazard of urban major hazardous installations from different perspectives and levels. In European countries, theories and methodologies for hazards evaluation have been established to fulfill the requirements of SEVESO II directive (Salvi and Debray, 2006). In general, three kinds of potential hazards evaluation methodologies are usually applied in urban planning: the approach of generic separation distances, the consequence-based approach and the risk-based approach (Christou and Mattarelli, 2000; Kontić and Kontić, 2009; Sebos et al., 2010; Pasman and Reniers, 2014). Compared to the other two, risk-based approach is more comprehensive and efficient in quantifying the potential hazard of environmental accidents to adjacent areas, and it has been successfully demonstrated in guiding some kinds of urban planning problems, such as land-use planning (Bottelberghs, 2000; Christou and Mattarelli, 2000; Ale, 2002; Cozzani et al., 2006; Basta et al., 2007; Kontić and Kontić, 2009; Sebos et al., 2010; Zhou and Liu, 2012; Pasman and Reniers, 2014). Risk-based approach focuses on the assessment of both consequences of potential accidents and expected occurrence probability of possible accident scenarios (CPR18E, 1999). Risk is defined as the probability that an unprotected person, permanently presents at a fixed location, is killed due to an accident resulting from a hazardous activity (Bottelberghs, 2000; Jonkman et al., 2003). Risk is thus a property of the place, and it does not consider whether or not the individual is actually present (Jonkman et al., 2003; Zhou and Liu, 2012).

Quantitative Risk Assessment (QRA), or also sometimes called Probabilistic Risk Analysis (PRA), is a typical risk-based approach and well-known throughout the world. QRA is widely used in many organizations and authorities, and it has been successfully demonstrated in fulfilling a number of risk assessment problems, such as workplace's hazards evaluation, transportation of hazardous materials, regional land use planning, urban public safety and emergency management, etc. (Pasman and Reniers, 2014). QRA focuses on evaluating both accident's consequences and expected occurrence frequency or probability of possible accident scenarios. The results of QRA are represented as individual risk and/or societal risk (expressed as individual risk contours and societal risk (F–N) curves), and then the risk levels are determined