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Reprint of: Spatial–temporal human exposure modeling based on land-use at a regional scale in China ☆

Qie Zijun *, Rong Lili

Institute of Systems Engineering, Dalian University of Technology, Dalian 116024, PR China

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ABSTRACT

Regional human exposure to the hazard is an important basis of decision support for more efficient and effective emergency management especially pre-event. Due to the diverse locations of human activities and the displacements they induce, the spatial distribution of population is inhomogeneous and strongly time-dependent. Hence, in the present work, land use pattern was introduced to reflect the distribution characteristics of human exposure in hazard affected regions both in daytime and nighttime. Human activities that contribute to spatial distribution variance were considered to establish the correlation between human types and land-use patterns at a regional scale. Furthermore, hypergraph was used to model the regional human exposure in order to benefit the analysis of spatial–temporal distribution characteristics of population, and variance algorithms for disaggregating different styles of human to the regional land were constructed. What's more, the model was applied to the analysis of potential human exposure in the built district of Dalian City. Results show that a great amount of area and population are beyond moderate exposure levels on urban construction land of Dalian City, and the population potentially exposed significantly increases from nighttime to daytime periods, especially in the zones with diverse human activities. The presented approach in this study can not only be of utmost importance for vulnerability assessment or risk evaluation, but also for regional and environmental planning as well as local development.

1. Introduction

China is one of the countries which are subject to a variety of disasters frequently. According to the statistics of Ministry of Civil Affairs of China (2015a), nature disaster (such as earthquake, flood, and hurricane) affected population has reached an annual average level of 0.36 billion person-time in recent five years. Besides, accidents in industry, transportation and public health have caused great losses of casualties and property as well, such as explosion and infectious disease.

Though the impacts caused by those disasters have a great difference whether in form, intensity, scope or frequency, the common threat to human life is the most significant risk to be addressed. As human is the major element at risk in regional disaster system, human life is undoubtedly the most important value for emergency response. For many hazards occurrences, especially those above certain intensity, human exposure is arguably the greatest determinant of vulnerability or risk and to some extent will forebode potential casualties. It is well-known that China is the world's most populous country, with a population of over 1.35 billion, which makes up approximately one fifth of the world population, while accounts for only 6.44% of the world's land. Along with a sustained growth of urbanization progress, the populations are increasingly concentrated in metropolitan areas, and due to diverse locations of human activities and the displacements they induce, the spatial distribution of population is inhomogeneous and strongly time-dependent, which have jointly resulted in tremendous difficulties and challenges to protect human life and property from those various hazards. Accurate and reliable information on about regional human exposure particularly in big cities is an urgent demand for vulnerability assessment and risk evaluation so as to derive corresponding emergency response policies: determination of severely affected area, deployment of rescue teams, scheduling of relief supplies and like that. However, it is usually a "black-box" at the early stage once an event occurs, the capability for real-time population distribution mapping is quite limited, typically like the great earthquake in Wenchuan that china have experienced in 2008. According to the analysis of pre-event

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* Corresponding author.
E-mail address: qiezj0723@163.com (Z. Qie).

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population distribution at the disaster affected areas, we can establish a base-line situation for human exposure to the hazard as an important basis for decision support to more efficient and effective emergency response.

The present work, therefore, is an attempt to propose a method for the assessment of human potential exposure with data sets that can be prepared ahead of time, which could be employed once a disaster occurs, and contribute to rapid and efficient emergency preparation and response.

2. Related works

Exposure reflects "who or what is at risk" in the framework of vulnerability assessment or risk evaluation (Adger, 2006; Cutter, 1996; Pelling, 2004). A system, subsystem, or system component is likely to experience harm due to exposure to a hazard (Birkmann, 2007; Turner et al., 2003). From an overall perspective, the exposure of an element characterized by certain vulnerabilities to the hazards is a major factor to cause risk. Therefore in the evaluation of the risk that a certain element might be affected by a hazard, the exposure of the element has to be evaluated (Schelhorn et al., 2014), which is unquestionably significant to reduce the casualties and property losses suffered from disasters.

Human exposure refers to the human occupancy of hazard zones (Cutter, 1996), which is generally reflected by population distribution. Knowing what the characteristics of human exposure are is critical for disaster consequence assessment, and significant for urban planning, emergency management, policy making and so on (Aubrecht et al., 2013; Deville et al., 2014; Freire et al., 2011). Therefore quantifying human exposure as a step for conducting vulnerability or risk assessment is an important issues of concern. Except for some conceptual analysis, the majority quantitative studies on human exposure were carried out from the perspective of population distribution reflected as the differences of population density (Aubrecht et al., 2011; Freire and Aubrecht, 2012).

At present, several key advances have been made to research on the global distribution of population. One is developed by Center for International Earth Science Information Network (CIESIN) of Columbia University called the Gridded Population of the World (GPW) dataset which experiences three versions (Balk and Yetman, 2004; Deichmann et al., 2001; Tobler et al., 1997). GPW is a gridded, or raster, data product which presents the distribution of human population by combining census data with satellite data. Another is established by the United Nations Environment Program (UNEP) named the Global Resource Information Database (GRID) especially the Sioux Falls. GRID Sioux Falls provides the population distribution data sets of Africa, Asia, Latin America, etc. (2015b, 2015c; Hyman et al., 2004). The results are computed from a gridding approach with transportation network and urban centers considered. And the most famous is the LandScan Population Distribution Database developed by Oak Ridge National Laboratory (ORNL) including LandScan Global and LandScan USA (Bhaduri et al., 2007; McKee et al., 2015). It is a raster image, or grid, of population counts, which provides federal, state and international organizations with a gridded population database. In general, the advances above have been achieved on the basis of comprehensive census data as well as mature technologies of spatial databases. But they are mostly on global or national scale, which are too macroscopic for detail emergency decision making.

Moreover, a variety of methods for population distribution have been developed in recent decades. Such as population density model in urban geography proposed by Clark (1951), which is a negative exponential model of population density according to the reality that population density tends to decrease with the increase of the distance to the city center. Further, Cubic Spline Model considering the phenomenon of city hollowing out and Switching Regression model considering land use and building distributions were developed (Li and Nakamura, 2006). Nearly these kinds of population density models are descriptions of general rules of urban population distribution rather than practical applications. Grid transformation models of population data are the mainstreams approaches in this field, like areal weighting (Deichmann et al., 2001), pycnophylactic interpolation (Tobler et al., 1997), dasymetric modeling (Mennis, 2009), surface modeling (Yue et al., 2005), multiple source data fusion technology (Liao and Sun, 2003) and so on (Bo et al., 2013). These methods translated administrative population census to girds or raster with a certain resolution to reflect spatial distribution and variation of population, which were usually accomplished combining with GIS and related spatial datasets. In addition, some use regression analysis to analyze the relationship between population distribution and the affected factors such as cultivated land, forest land, settlement, traffic, and infrastructure facilities (Meng and Jia, 1993; J. Zhang et al., 2013). And over time, refinement of the dasymetric mapping techniques have been used to refine the allocated population distribution instead of population count data from censuses, such as using mobile phone data (Deville et al., 2014). However, current distributions of population in this way are of limited use in long-term socioeconomic planning (McKee et al., 2015).

It is noteworthy that the majority of the research above took land use/land cover as important information which is accessible. And land use/land cover information is significant for improving population distribution model accuracies, particularly in countries where only coarse resolution census data are available (Linard et al., 2011). Land use or land cover categories can indicate the weight to present the likelihood of population distribution. Aubrecht et al. (2011) modeled the population exposure with high resolution satellite imagery and airborne Laser scanning data to move from land cover detection to land use assessment, which enabled modeling of vulnerability and damage potential patterns. Linard et al. (2011) use global land cover data to guide population distribution modeling combining with detailed settlement extents across large areas. Qi et al. (2013) established a relationship model among urban population, time (daytime or nighttime) and types of land-use, and also conducts an empirical study on the Haidian District in Beijing. Tian et al. (2004) argued that there is a close spatial relation between land use and population distribution, and built a model based on land use to simulate the population density in 1 km square grid-cells of China. Therefore, we can arrive at the conclusion that Land use/land cover is the best indicator and most prolific to distribute population from source zones (i.e., census regions) to more precise target zones (e.g., grid cells) (Aubrecht et al., 2013; Bhaduri et al., 2007; Dobson et al., 2000; McKee et al., 2015; Zandbergen and Ignizio, 2010).

This paper presents a guideline to construct spatial–temporal regional human exposure model on basis of land-use. The rest of the paper is organized as follows. In Section 3, the methodology of human exposure modeling was proposed corresponding to the human exposure characteristics which were analyzed from both spatial and temporal dimensions. In Section 4, a case study of Dalian City was conducted with the model we proposed. While Section 5 was closed by proposing some further considerations related to possible future developments and drawing some conclusions.

3. Methodology

3.1. Characteristics of spatial–temporal human exposure

Regional disaster risk evaluation will not be fully characterized without taking into account the exposure of regional human. The