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Integrated flood vulnerability assessment approach based on TOPSIS and Shannon entropy methods

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ABSTRACT

Flood vulnerability assessment is becoming increasingly important around the world. Nevertheless, the high-dimensional and non-linear relationship between various indices and flood vulnerability greatly hinders researchers from making a reasonable assessment. Thus, an integrated flood vulnerability assessment approach is proposed here by combining a multi-criteria decision making technique, the technique for order preference by similarity to ideal solution (TOPSIS), with the Shannon entropy method. The Shannon entropy method is used to account for the inhomogeneity in the indicator values. TOPSIS uses a multi-criteria system where hydrodynamic modeling is applied to obtain the values of exposure indicators. This approach is tested in a rural district of Hainan Province, China. The flood vulnerability at the town and administrative village scales is presented through a geographic information system. By considering the inhomogeneity of the internal attributes, the integrated assessment approach is eventually proven as a highly realistic approach for assessing flood vulnerability. The advantages of this approach become highly pronounced when the evaluation objects have more internal indicators and the internal inhomogeneity among the values of these indicators is high. The main driving factors of flood vulnerability in one district has also been successfully identified using the proposed integrated method. In sum, this integrated assessment method can provide decision makers with highly targeted decision making references to effectively reduce the flood vulnerability of the study area.

1. Introduction

Flood is one of the most important natural disasters that cause substantial human suffering and economic losses (Kind et al., 2017; Lian et al., 2017). Doocy et al. (2013) estimated that 19,000, 12,000, and 150,000 persons all over the world get killed, get injured, or lose their homes per year due to floods, respectively. Flood events are also predicted to rise in frequency and scale in the future (Chang, 2011; Hirabayashi et al., 2013). This case is particularly true for China, where the annual economic losses caused by floods account for approximately 3.5% of its gross national product (GNP). People in the rural areas of China suffer huge losses from flood disasters due to their relatively weak economic development, poor flood control standards, and low flood prevention awareness. Thus, the flood vulnerability of rural areas in China needs to be evaluated.

Vulnerability has become a central focus of global environmental change and sustainability science research communities in recent years (Chang and Huang, 2015; Karamouz and Zahmatkesh, 2017; McElwee et al., 2017; Rahman et al., 2016; Turner et al., 2003). A substantial amount of research on vulnerability has been published, and its concept has been given various definitions by different scholars. Turner et al. (2003) defined vulnerability as “the degree to which a system, subsystem, or system component is likely to experience harm due to exposure to a hazard, either a perturbation or stress/stressor.” Fell et al. (2008) viewed vulnerability as the degree of loss to an element at risk as a result of the impact of a hazard with a given frequency and magnitude. Adger (2006) argued that “vulnerability is the state of susceptibility to harm from exposure to stresses associated with environmental and social change and from the absence of capacity to adapt.” This definition indicates that vulnerability consists of three interrelated components, namely, (1) exposure to perturbation, (2) sensitivity of the system to perturbation, and (3) capacity of the system to adapt (Adger, 2006; Chang and Huang, 2015). Although many definitions of vulnerability exist, this study adopts Adger’s definition as it is more applicable to the objectives of the study.

A growing number of vulnerability evaluation methods and indicators are being constantly updated and improved (Brooks et al., 2005). Cutter et al. (2003) used principal component analysis to

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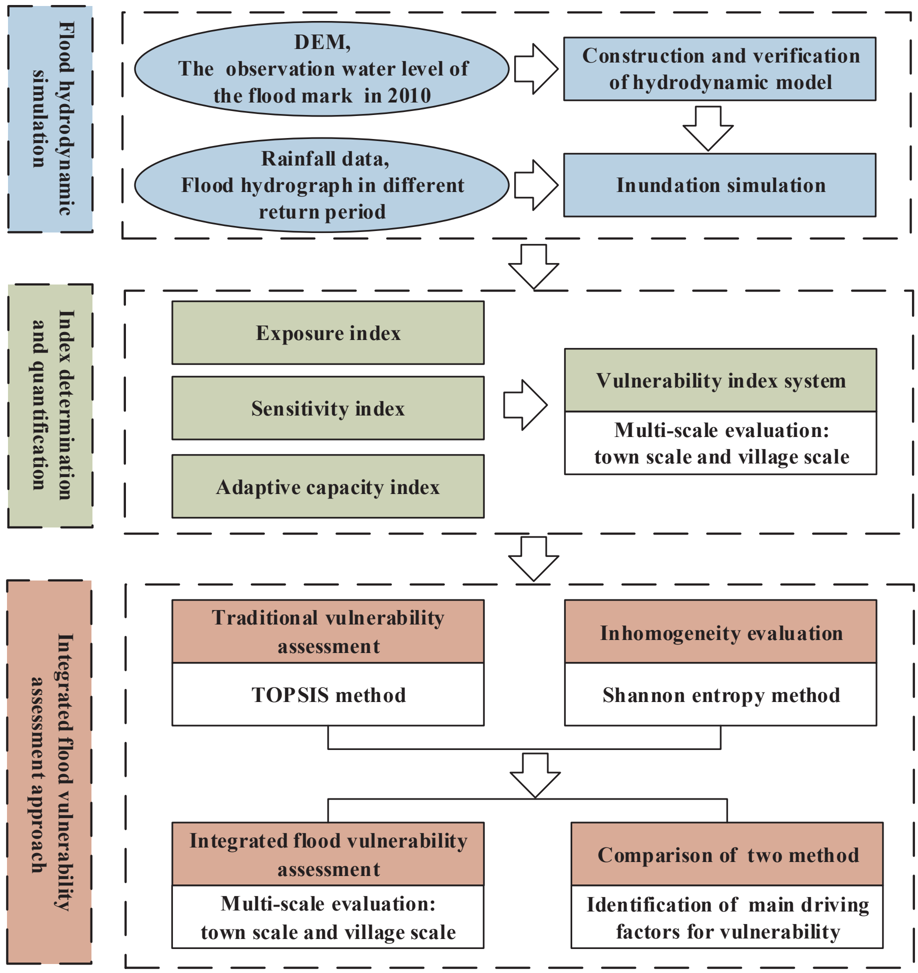

Fig. 1. Stepwise framework for flood vulnerability assessment.

aggregate county-level socio-economic data to assess the social vulnerability of different municipalities in the US. Ouma and Tateishi (2014) used the analytical hierarchy process to assign weights to decision making parameters and presented a flood vulnerability diagram. Metzger et al. (2006) proposed 12 social and economic indicators, including awareness, ability, and action. Szlafsztein and Sterr, (2007) proposed a comprehensive vulnerability index containing 16 related natural and socio-economic conditions. Chung et al. (2017) used the technique for order preference by similarity to ideal solution (TOPSIS), a ranking method for choosing alternatives that simultaneously have the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution, and coupled this technique with objective and subjective weights to assess the vulnerability of spatial robust water resources. TOPSIS has several advantages over other multi-criteria decision analysis methods, such as allowing explicit trade-offs and interactions among attributes (Govindan et al., 2013). Given its availability and scientific nature, TOPSIS has been verified and applied by many experts from various fields (Chen et al., 2016; Deb et al., 2016; Peng et al., 2017; Rosić et al., 2017). Unfortunately, only few reports have utilized TOPSIS for assessing flood vulnerability and for generating decision support options. Accordingly, our work tries to apply TOPSIS to flood vulnerability assessment.

The flood vulnerability assessments for global countries/cities as well for the cities/regions of China have been gradually increasing in number. Karmakar et al. (2010) performed a flood risk vulnerability analysis while considering the four components of such vulnerability (e.g., physical, economic, infrastructure, and social vulnerability) in a geographic information system environment. Kablan et al. (2017) proposed the improvement of vulnerability assessment in Europe framework to assess the major factors involved in social vulnerability to urban flooding and to understand the spatial distribution of areas that are vulnerable to urban flooding. Huang et al., (2012) developed models for assessing multidimensional flood vulnerability based on the data envelopment analysis method and measured the multidimensional flood vulnerability (e.g., population, death, agriculture, and economy) at the provincial scale in China. Lian et al. (2017) presented a material flow assessment framework to evaluate the flash flood vulnerability of small catchments in Wuzhishan County of Hainan Province, China, while taking into account the relationship among the three elements of vulnerability (e.g., exposure, sensitivity, and adaptive capacity).

Nevertheless, the extant flood vulnerability evaluation methods only focus on the final score of different evaluation objects and do not reflect the inhomogeneity among the attributes of these objects. According to wooden bucket theory, if the adaptive capacity indicators of two evaluation objects take values of [1, 2, 3] and [2, 2, 2], then the former object has a relatively weaker adaptive capacity than the latter although they have the same total scores. Thus, the quantitative inhomogeneity among multiple attributes of evaluation objects can influence flood vulnerability assessment and warrants consideration. In this study, the Shannon entropy method is employed to evaluate the inhomogeneity among indicators. This method has been traditionally applied to determine the weight of each criterion (Chung et al., 2017; Mao et al., 2016) and has rarely been employed for evaluating inhomogeneity and for generating decision making support options. Accordingly, this research utilizes the Shannon entropy method to evaluate the inhomogeneity among the attributes of one evaluation object.