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Multi-factor evaluation indicator method for the risk assessment of atmospheric and oceanic hazard group due to the attack of tropical cyclones

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ABSTRACT

China's southeast coastal areas frequently suffer from storm surge due to the attack of tropical cyclones (TCs) every year. Hazards induced by TCs are complex, such as strong wind, huge waves, storm surge, heavy rain, floods, and so on. The atmospheric and oceanic hazards cause serious disasters and substantial economic losses. This paper, from the perspective of hazard group, sets up a multi-factor evaluation method for the risk assessment of TC hazards using historical extreme data of concerned atmospheric and oceanic elements. Based on the natural hazard dynamic process, the multi-factor indicator system is composed of nine natural hazard factors representing intensity and frequency, respectively. Contributing to the indicator system, in order of importance, are maximum wind speed by TCs, attack frequency of TCs, maximum surge height, maximum wave height, frequency of gusts ≥ Scale 8, rainstorm intensity, maximum tidal range, rainstorm frequency, then sea-level rising rate. The first four factors are the most important, whose weights exceed 10% in the indicator system. With normalization processing, all the single-hazard factors are superposed by multiplying their weights to generate a superposed TC hazard. The multi-factor evaluation indicator method was applied to the risk assessment of typhoon-induced atmospheric and oceanic hazard group in typhoon-prone southeast coastal cities of China.

1. Introduction

Tropical cyclones (TCs) are one of the most serious natural disasters in China. TCs sweep across China's southeast areas and east coast every year, where population is extremely dense, economy is highly developed, and social wealth is notably concentrated (Chan and Shi, 1996). The approaching and landing of TCs cause great disasters through chains of strong winds, huge waves, storm surge and heavy rain, which break out simultaneously and lead to a series of secondary disasters, flood, seawater intrusion and salt-alkalization of soil, landslides and so on (Fig. 1). As defined by UNISDR (2009) and IPCC (2012), hazard refers to the physical phenomenon that has the potential to cause damages and losses to human and natural systems (UNISDR, 2009; IPCC, 2012). Multi-hazard refers to hazardous events occurring at the same time or shortly following each other (Komendantova et al., 2014; Gallina et al., 2016). Shi (2009) distinguished the difference between loss assessment for multi-hazard overlaying and disaster chains. Strong wind, huge waves, storm surge and heavy rain, these extreme changes of local atmospheric and oceanic elements break out simultaneously. Here we see them as multiple hazards overlaying, forming an atmospheric and oceanic hazard group containing multiple factors. Development of a multi-factor evaluation method is the basis for the risk assessment of TC disaster losses and of significance for natural disaster prevention and mitigation in coastal areas.

Analysis of natural hazard risks generally includes several typical natural dynamic processes. Separate investigations of a single process only might lead to misjudgments of the general natural risks. To avoid this, natural risk assessments should not focus on a single hazard factor and process but on multiple factors and processes (Bell and Glade, 2004). Fleischhauer et al. (2005) developed an integrated risk assessment of multi-hazard approach for the European Spatial Planning Observation Network (ESPON) project "The spatial effects and management of natural and technological hazards in general and in relation to climate change". Grünthal et al. (2006) introduced a methodology for a multi-risk assessment of an urban area. The natural hazards they considered include windstorm, flooding and earthquake. They conducted hazard assessment, vulnerability assessment and estimation of losses for each peril. Shi (2009) proposed the concept of regional disaster system and discussed loss assessment for multi-hazard overlaying and established disaster risk science, which is composed of disaster science,

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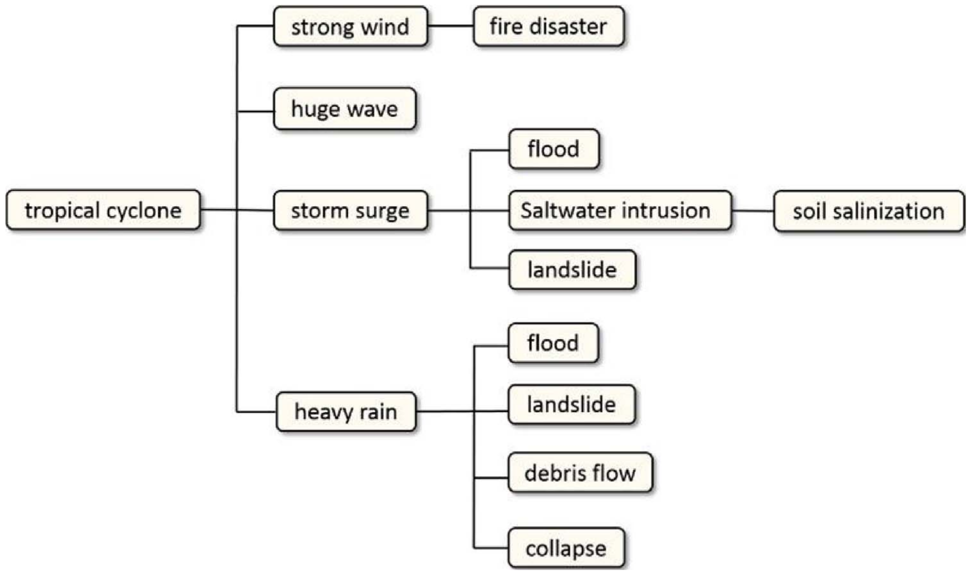

Fig. 1. Tropical cyclone disaster chain containing multiple hazards overlaying and secondary disasters.

emergency technology and risk management. Li et al. (2009) developed a systematic methodology to assess and rank the risks from multiple hazards in a small community. It is an interdisciplinary study that includes probabilistic risk assessment, decision analysis, and expert judgment. Introducing the methods of fuzzy information granulation and fuzzy transformation function, Xue et al. (2012) built a soft hierarchical model of integrated risk assessment for multi-hazard. Based on probabilistic approach, Ordaz (2015) developed a simple model for multiple hazards with different origins, which in some cases may be related, by combining the losses arising from several hazards that are triggered simultaneously by the same event. Pilkington and Mahmoud (2017) utilize a hurricane impact level (HIL) model to predict a range of economic damage from tropical cyclone events during the 2015 and 2016 United States hurricane season. The HIL model is a multi-hazard prediction model utilizing machine-learning techniques (artificial neural networks) to establish complex connections between all meteorological factors (wind, pressure, storm surge, and precipitation resulting in inland flooding) of a tropical cyclone and how those interact with the location of landfall to produce a certain level of economic damage.

It is clear that risk assessments have a spatial component. A geographic information system (GIS) is mapping software that provides spatial information by linking locations with information about that location. Zerger (2002) presented a technique for flood risk modelling using GIS and digital elevation models to map relative risk in urban communities. Based on GIS and contributing weight model, Wu et al. (2013) achieved geological disaster risk zoning by integrating the results of vulnerability and hazard which results from composing the intra-weight and inter-weight of assessment factors. Utilizing powerful spatial data analysis and processing functions of software ArcGIS combined with Analytic Hierarchy Process (AHP) as the evaluation method, Yang et al. (2016) obtained geological disaster risk prediction and evaluation zoning map of the study area .

Global warming due to continuously increasing greenhouse gases has the potential to enhance the risk of storm surge hazard through the strengthening of the TC system and sea level rise. Mcinnes et al. (2003) combined a statistical model for cyclone occurrence with a state-of-the-art storm surge inundation model to generate a synthetic record of extreme sea-level events, then evaluated storm tide (the combination of a storm surge and tide) return periods under present and enhanced greenhouse conditions. Sea level rise threatens to increase the impacts of future storms and hurricanes on coastal communities. Shepard et al. (2012) applied a GIS-based approach to quantify potential changes in storm surge risk due to sea level rise on Long Island, New York, and suggested that sea level rise will likely increase risk in many coastal areas and will potentially create risk where it was not before. However, through survey of tide gauge and satellite data carefully, Burton (2012) found that the rate of sea level rise has not increased significantly in response to the last 3/4 century of CO_2 emissions [see Burton's comments on Shepard et al. (2012)]. With global warming, not only does sea level rise, but also landing TCs intensity increases. In recent 40 years, the annual-averaged landfalling typhoon intensity increased from 34 m/s to 40 m/s, corresponding to a 63% increase in destructive potential (Guan et al., 2018).

This paper aims to develop a multi-factor evaluation method for the risk assessment of atmospheric and oceanic hazard group due to the attack of TCs. Firstly, the application of the improved Analytic Hierarchy Process (AHP) method to establish a multi-factor evaluation indicator system for TC induced atmospheric and oceanic hazard group is presented. To this end, an improvement of the AHP was made with cluster. In addition, indicator selection, historical data collection and indicator weighted allocation were conducted. Based on historical extreme data of concerned atmospheric and oceanic elements, a multi-factor evaluation method for the risk assessment of TC hazard group was developed. It is a multi-factor overlaying method. With normalization processing, all the single hazard factors are superposed by multiplying their weights to generate a superposed hazard. In the final sections, the multi-factor evaluation method was applied to the risk assessment of typhoon-induced atmospheric and oceanic hazard group in typhoon-prone southeast coastal cities of China.

2. Methodology

2.1. Multi-factor risk assessment model

The approaching and landing of TCs cause extremes of local atmospheric and oceanic elements, hazards of strong winds, huge waves, storm surge and rainstorm break out simultaneously. This atmospheric and oceanic hazard group is clearly a multi-factor hazard system, whose evaluation indicator system contains multiple hazards. With normalization processing, all the single-hazard factors can be superposed by multiplying their weights to generate a superposed hazard (Gai et al., 2011).

$$R=\sum_{i=1}^{n}(F_i\cdot W_i),\quad i=1,\ 2,\ 3,\ \ldots,n, \tag{1}$$