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Mapping the expected annual fatality risk of volcano on a global scale

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ABSTRACT

According to The Centre for Research on the Epidemiology of Disasters (CRED) Disaster Events Database (EM-DAT 2013), during 1900–2012, volcanoes killed nearly one hundred thousand people worldwide and affected 5 million people [12]. Analysing global volcanic risk can provide a better understanding of the spatial pattern and hot spots of volcanic risk. This paper quantitatively maps the fatality risk of volcano on a global scale by calculating the annual eruption frequency of volcanoes of each Volcanic Explosivity Index (VEI) and building the global vulnerability curve of fatality. This study approved the global volcanic risk assessment method in three aspects: 1) The expected annual eruption frequency of each VEI scale of each volcano is analysed as hazard; 2) The vulnerability curve is fitted by the historical average fatality of each VEI provided by National Oceanic and Atmospheric Administration (NOAA). 3) Physical exposure is calculated using global 1×1 km resolution population distribution data of 2010 from Oak Ridge National Laboratory. The exposed regions that have a potential fatality risk are calculated according to several former studies by analysing the largest lethal radius of pyroclastic flow, lahar, and tephra. The results are exhibited at grid, national and comparable-geographic level to provide as much information about volcanic risk as possible in different dimensions. The results show that: 1) Global distribution pattern of expected annual fatality risk due to volcanic hazards is consistent with that of hazards, while local distribution of risks is related to distribution of vulnerability and exposure. 2) Most high risk areas are along the plate boundary, especially the Pacific Rim. 3) The top 10% high risk countries are Indonesia, Russia, United States, Papua New Guinea, Japan and Philippines.

1. Introduction

Volcanic eruption has a potential threat to life and traffic and it can also make significant changes in its surrounding landscape [6]. Volcanic eruptions present a particularly uncertain hazard environment, so Doyle et al. [11] took volcanic eruption as an example to assess the relationship between uncertainty and decision making, finding out that the description of uncertainty is of great importance for decision making. Volcanic disaster which is difficult to forecast for long-term poses a great threat to human life and property. The Eyjafjallajokull eruption in 2010 had a huge impact on airlines [3], and accompanied by secondary disasters such as landslides and floods; the same year, Merapi eruption killed more than 300 people, many as a result of pyroclastic flows [41].

Related volcanic disaster research has mainly focused on the description and summarisation of the happened volcanic disasters [9,15]. Although since the year 2000 many researches have been conducted about volcanic risk assessment [10,26,27], the number of researches on volcanic risk assessment is less than those dedicated to volcanic hazard assessment because of the difficulties to collect risk data. Moreover, previous volcanic risk assessment has typically explored the risk from a single volcano [2,23,27,28]. Many regional studies of volcanic hazard or risk have been attempted, including that of Jenkins et al. [20], who outlined a probabilistic framework for assessing ash fall hazard on a regional scale and applied to the Asia–Pacific region. Diefenbach et al. [9] described some overall characteristics of the volcanic activities in The United States from 1980 to 2008. Hoblitt et al. [15] assessed the hazards that could result from future eruptions of these volcanoes of Washington, Oregon, and California in the Cascade

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Range. Small and Naumann [34] quantified the spatial relationship between the global distribution of human population and recent volcanism, concluding that higher population densities in Southeast Asia and Central America lie in closer proximity to volcanoes than in other volcanic regions. Volcanic risk analysis at the global scale is limited by the availability and quality of data. Existing data can only support semi-quantitative risk assessment and derive relative risk level. The first global volcanic mortality risk map was developed by the World Bank 'Natural Disaster Hotspots' programme [10]. It applied an empirical method to depict global volcanic hazard and vulnerability using the historical death record of volcano from EM-DAT (1981–2000) and then integrated these two parts to rank the risk level. It assessed the risks of mortality and economic losses, with a spatial resolution of $2.5' \times 2.5'$.

Compared to the existing results, the present study considers both frequency and the Volcanic Explosivity Index (VEI) of historical volcanic eruption events. It also uses longer series of volcanic fatality data since 1600s, a certain time after which there is an improvement in recording volcanic activity especially for eruptions of lower magnitude as suggested by Furlan [13]. When identifying the exposure for each eruption event, area of particular radius for each hazard is generated instead of using administrative regions, an attempt actually suggested by Dilley et al. [10]. Therefore, this study intends to provide a more integrated risk assessment than previous studies, including a systematic analysis of hazard, exposure, vulnerability and fatality risk. Risk assessment results are provided at grid, comparable-geographic (a new assessment and cartographic unit introduced by this study, see 3.3) and national level, in order to provide risk information from different aspects for various applications of global volcanic disaster risk reduction action.

2. Data and method

2.1. Datasets

Four global databases were used in this study. Global historic volcanic eruption data provided by Global Volcanism Program (GVP) was used as hazard intensity index because of its complete record of volcanic eruptions in both time and space. Global database on large magnitude explosive volcanic eruptions (LaMEVE) provided by Volcanic Global Risk Identification and Analysis Project (VOGRIPA) was used to calculate the influence area because of its more detailed description of volcanic eruptions, such as tephra fall deposit volume and max column height. Besides, it has an evaluation of data quality (high, low, medium quality, no information, not entered). The disadvantage is that it does not record volcanic eruptions with VEI under 3. A global archive of historical volcano events and death toll from National Oceanic and Atmospheric Administration (NOAA) was used to build the vulnerability curve of volcanic eruptions because it has death toll records of corresponding volcanic eruptions. This database was also used by the 'Natural Disaster Hotspots' [10] to calculate mortality of volcanic eruptions. The 2010 global $30'' \times 30''$ (about 1×1 km) grid population distribution data from Oak Ridge National Laboratory [21] was used as exposure of volcanic eruptions because of its high resolution. A relatively older version (LandScan 2005) of this database was used by Jenkins et al. [19] to calculate the population influenced by ash fall. In addition, Simpson et al. [33] used LandScan 2004 to determine population within particular distances to volcanoes in the Asia–Pacific region. A detailed description of all of these databases is provided in Table 1.

Table 1
Sources and descriptions of the databases used in this study.

Category	Data	Data source	Period	Data description
Hazard	Volcanoes of the World 4.0	Global Volcanism Program (GVP) http://www.volcano.si.edu	The Holocene	*Volcanoes of the World* is a database describing the physical characteristics of Holocene volcanoes and their eruptions. Volcano name, VEI, and the location (Latitude and Longitude) were used in this study.
	Global database on large magnitude explosive volcanic eruptions (LaMEVE)	Volcanic Global Risk Identification and Analysis Project (VOGRIPA) http://www.bgs.ac.uk/vogripa	The Quaternary	The LaMEVE database contains the nearly 3000 Quaternary volcanoes catalogued by GVP. The Tephra fall deposit volume, Maximum Column height and VEI were used in this study [6].
Exposure	Global Population Density Data	LandScan 2010 Global Population Project of Oak Ridge National Laboratory (ORNL) http://web.ornl.gov/sci/landscan/	2010	The global 1×1 km resolution population distribution data are derived using an innovative approach with GIS and Remote Sensing.
Disaster	Global Large volcano Events Inventory	National Oceanic and Atmospheric Administration (NOAA) http://www.ngdc.noaa.gov/hazard/volcano.shtml	4360 B.C.–2012 A.D.	654 Significant Volcanic Events where all records returned. This study uses the dataset of death number and descriptor.

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