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Towards measurable resilience: Mapping the vulnerability of at-risk community at Kelud Volcano, Indonesia

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ABSTRACT

This paper presents the application of Spatial Multi-Criteria Evaluation (SMCE) to assessing the vulnerability-resilience of at-risk communities alongside of the river channels on Kelud Volcano, East Java, Indonesia. The proposed method intends to bridge the gaps between the evaluations of resilience and vulnerability particularly since the former exists concomitantly in vulnerable groups in the aftermath of a natural disaster. These gaps emerge because vulnerability and resilience are analyzed separately using single weighting indicators but lacking spatiotemporal identifiers. Historically, Kelud Volcano erupted in 1000, 1586, 1901, 1919, 1951 1966, 1990, and 2014. The eruptions were generally short-lived and at a rapid speed. They produced Pyroclastic Density Currents (PDCs) and ashfalls, followed by dramatic lahars flowing through the river channels (Hidayati et al., 2009; Dibyosaputro et al., 2015; Nakashima et al., 2016). The hazard map of Kelud Volcano is currently available at the Center for Volcanology and Geological Hazard Mitigation (CVGHM), while the macro-scale risk map is accessible at the National Disaster Management Agency. Unfortunately, as yet the vulnerability map has not existed. Nevertheless, vulnerability information is integrated with hazard data as parts of disaster risk assessment and the production of macro-scale risk maps (UNISDR, 2015; UNISDR, 2017; Wilson et al., 2014). Whereas there are abundant scientific inquiries about volcanic hazard assessment, a few are about its vulnerability counterpart (Birkmann & Teichman, 2010; Jenkins et al., 2014; Hizbaron et al., 2015). The SMCE was thereby employed to 1) adjust the ill-structured theoretical foundation of vulnerability by allowing the use of abundant criteria, 2) generate the spatial characteristics of vulnerability along two different channels, i.e. Konto and Ngobo Rivers in Kediri Regency, and 3) combine the spatial and non-spatial data as the inputs of a balanced decision-making process that takes account of various plausible output scenarios. This research expressed vulnerability as the degree of potential damage or loss caused by potential disaster, which was scaled from 0 (no damage) to 1 (total damage). The results indicated that the SMCE delivered vulnerability as a function of social, economic, physical and hazard aspects that surrounded the at-risk communities. There were 34.48% out of the total 29 hamlets. Longside of Konto and Ngobo Rivers classified as highly vulnerable due to their physical aspects. Meanwhile, 54.17% out of the research area was subject to moderate vulnerability due to its social aspects, while 58.62% of it was subject to moderate vulnerability due to its economic aspects. As derived from the results, the social and economic criteria generated rather distinctive spatial characteristics. Reflecting these findings into the theoretical basis, the research expanded to the explorative possibility of vulnerability to be an indication of resilience. Resilience has been measured using various perspectives, including those that rely on the influence of social and economic aspects. Accordingly, this research argued that vulnerability assessment using SMCE, which emphasized on the combination of physical, social, and economic characteristics, might estimate the determinants of the resilience of at-risk community.

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1. Introduction

On February 18, 2014, 5 days after the wake of Kelud eruption, the subsequent lahars flowed through several channels, i.e. Konto River (Kediri and Malang Regencies), Ngobo River (Kediri Regency) and Bladak River (Blitar Regency). Exposed to massive lahar flood, the local people resided along these channels had bounced back to their normal conditions after 2 years. Kelud, a basaltic stratovolcano, has an explosive eruption followed by Pyroclastic Density Currents (PDCs), ashfalls, and lahars (Dibyosaputro et al., 2015; Hidayati et al., 2009; Nakashima et al., 2016; Thouret, Aburrachman, Bourdier, & Bronto, 1998; van Bergen, Bernard, Sumarti, Sriwana, & Sitorus, 2000). Historically, it erupted in 1000, 1586, 1901, 1919, 1951 1966, 1990, and 2014. These eruptions were generally short-lived (Dibyosaputro et al., 2015; Hidayati et al., 2009; Nakashima et al., 2016). In addition, history recorded that the 1919, 1951, 1966, and 2007 eruptions produced lahars that affected Konto River (Dibyosaputro et al., 2015). However, since the February 18, 2014 eruption, the lahars have inclined to occur repeatedly and spread wider onto different channels, namely Ngobo River and Konto River. At the same time, the areas adjacent to Konto and Ngobo Rivers have developed into densely populated areas with productive agricultural lands, which claim a greater potential loss caused by the destructive nature of lahars. The following Fig. 1 indicated location of Konto and Ngobo River towards Kelud Volcano.

Volcanic processes inherently leave damages over time and space. Their violent nature destroys both built-up and natural environments (Jenkins et al., 2014). Physically damaged buildings and reduced life-supporting functions, as well as insufficient in-time services from public infrastructures, are somewhat regular during volcanic eruptions. Often they co-occur with loss of productive agricultural assets, disturbance to produce sales, and other disruptions to local economic services. Moreover, a great number of at-risk communities have to evacuate to temporary shelters, which adds to the long list of volcanic destructive impacts (Mei et al., 2013).

This paper presents the application of Spatial Multi-Criteria Evaluation (SMCE) to assessing the vulnerability of at-risk communities alongside of the river channels on Kelud Volcano, East Java, Indonesia. The SMCE for Vulnerability was chosen among the diverse methods such as, SoVI (Social Vulnerability Index), SERV (Spatial-Explicit Resilience Vulnerability) and CVI (Composite Vulnerabilty Index) due to three main reasons, which were its abilities to: 1) adjust the ill-structured theoretical foundation of vulnerability by allowing the use of abundant criteria, 2) generate the spatial characteristics of vulnerability along two different channels, i.e. Konto and Ngobo Rivers in Kediri Regency, and 3) combine the spatial and non-spatial data as the inputs of a balanced decision-making process that takes account of various plausible output scenarios (Barros, Tavares, Santos, & Fonte, 2015; Frazier et al., 2013; Frazier, Thompson, & Dezzani, 2014; Hummell, Cutter, & Emrich, 2016; Tavares, Barros, & Santos, 2017). Although, the SMCE application was not new, however, the main thought of this research was to argue that vulnerability assessment using SMCE might provide an estimate of the determinants of the resilience of at-risk communities. The proposed method intends to bridge the gaps of evaluating resilience exist in vulnerable groups in the aftermath of a natural disaster.

1.1. Research rationale

Scholars have constantly scrutinized the ill-structured theoretical foundation of vulnerability. At the early stage of the development, vulnerability, perceived to be growing beyond multi-contextual theories, was actually concealed within hazard and risk assessments (Burton and Kates., 1964; Burton, Kates, & White, 1993; Cardona, 2003; Haque, 2003; Alexander, 2005). Natural scientists (e.g., geologists, hydrologists, etc.) articulated vulnerability merely as an impact of hazard itself, as denoted by the quantification of vulnerability to particular hazard at that time. Vulnerability was not yet fully understood. The focus of disaster-related analyses was more on the identification of at-risk elements and their potential damages or losses. At the next stage of its development, the idea of vulnerability proliferated. It was used for qualifying the inability of a process to survive a particular hazard (Blaikie, et al., 1994; Berke & Campanella, 2006; Birkmann & Teichman, 2010; Birkmann & Wisner, 2006; De Leon, 2006). Social sciences expressed a rather different approach on vulnerability. They highlighted the underlying factors of how a person became vulnerable. The approach was not limited to impact identification, but it expanded to the diverse social, economic, and political attributes of a person that influence his/her inability to survive a particular threat. This domain used the term “vulnerability” specifically for at-risk human. As for the other at-risk elements, it used criticality or fragility for identifying their potentials to be disrupted by hazard. Meanwhile, applied sciences promoted the idea of vulnerability as a combination of natural and built-up environments. Geographers, environmental experts, and planners principally relied on the interplay between humans and their surroundings, which underlay spatial unit diversity (Burton et al., 1993; Cutter, 1996; Tavares et al., 2017). For instance, Davis (1981) focused on anthropocentric effects (e.g., human, housing, etc.) that were assorted spatially due to an extreme event. Furthermore, Burton et al. (1993) noted that vulnerability stemmed from the precariousness of daily existence in a certain environment in addition to extreme events such as natural hazards. Cutter (1996)then proposed that the social fabric and the natural-physical existence of particular spatial unit exclusively defined vulnerability. In addition, a degree of vulnerability was defined later as the magnitude of the potential damages or losses experienced by at-risk elements, which were exposed to particular frequency and magnitude of hazards (Cutter, 2003; Hizbaron, Hadmoko, Samodra, Dalimunthe, & Sartohadi, 2010). Recently, Barros et al., 2015 proposed territorial vulnerability assessment, which argued that each territorial constructed from very unique characteristics of social, economic, environmental and land use transitions, and then shape their vulnerability.

Suffice to say that vulnerability has surpassed the idea of linking a mere impact of hazard to social and economic domains. It has also acknowledged the political and anthropological domains in a particular spatial unit. In addition, because the ill-structured theoretical basis for vulnerability frames the concept application, researchers have to firstly provide a clear definition of vulnerability as either a current state (i.e. disaster-affected condition) or an anthropocentric process that is susceptible to a particular hazard. This research defined vulnerability as current state, and employed both spatial and temporal units as important aspects to its quantification, which followed the perspective of applied sciences on vulnerability.

Even though vulnerability quantification requires a rigid methodological explanation to estimate the spatial and temporal potentials of disaster risks, the standardization of variable selections still receives a paucity of attention. The international vulnerability database generally presents the ratio or percentage of previous disaster-affected population to the total population exposed to potential hazard. For example, the Emergency Events Database EM-DAT presented the spatial and temporal trends of the aforementioned ratio from 1900 to 2016 using several variables, namely total deaths, affected people, damages (in value), and total damages (in US$). Meanwhile, the National Disaster Management Agency of Indonesia presented the information of vulnerability as related to the number of people at hazardous areas. The information interlinks with intercensal data that comprises demographic, social, economic, and educational variables, which defines the current states that contributes to the vulnerability level of a population.

This research defined vulnerability as the degree of potential impacts, damages, or losses whose scale ranged from 0 (no damage) to 1 (total damage) depending on the social, economic, and environmental conditions of a population during a particular hazard (Hizbaron et al., 2015). Vulnerability analysis ideally includes information on hazard or