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Policy Improvement on Evacuation Zone Designation from Ashfall Hazards during Large Eruptions

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Japan is home to 10% of the world's active volcanoes and has suffered many volcanic disasters in the past. Japan Meteorological Agency (JMA) listed 47 active volcanoes in Japan likely to erupt within 100 years. Apart from the direct impact of an eruption such as earthquake swarms, poisonous gases and lahar mudflows, Japan also suffered from massive ashfalls when the large eruption occurred. Volcanic ashes emitted from a large eruption could travel far away and disturb socio-economic activities, from damaging critical infrastructures and buildings, disrupting airline transportations, to even causing health problems.

Deposited ashes on the roof have chances to collapse buildings and short-circuit the electricity in power generation stations and transmission stations when considerable amounts of wet ashes penetrate inside. Settled volcanic ashes are directly affecting life and livelihoods, such as: destroying vegetation, crops, and pastures, clogging drainage systems and contaminating water supplies; also disrupting the traffic and damaging the vehicles on roads. Furthermore, despite shallow thickness accumulation, ashfall strongly affects the transportation fields, forcing airports, ports, and roads to be closed, amplifying the network disturbance.

A vivid illustration of how catastrophic the ashfall hazards is when Mt. Sakurajima in Kyushu erupts. The latest large eruption (VEI 4) in Mt. Sakurajima, the *Taisho* (1914 AD) eruption, is considered the biggest eruption in Japan during the 20th century. The *Taisho* eruption caused enormous damage to its surroundings by releasing eruptive substances of about 2 km^3 ejecta in total and claimed 56 lives.

Three days after the eruption started, the ashfall appeared at Kyushu, Shikoku, western Japan, and Sendai in northern Japan. Another important notion is the report of heavy ash fallout at Ogasawara, around 1222 km from the vent. Those pieces of evidence reflect that the impacts from enormous ashfalls dispersed during large eruptions can be further worsened by the wind condition that can bring ashfall to further and wider spaces. Accordingly, the damage caused by ashfall hazards will depend on the total amount of discharged ashfall during an eruption and the wind condition at the time of the eruption.

Unfortunately, the precursory phenomena preceding the *Taisho* eruption now reappears in Mt. Sakurajima, indicating that there will be another similar-scale eruption 130 years after the last large eruption. Consequently, the Sakurajima volcano has a significant probability of erupting with *Taisho*-scale eruption approximately within the next couple of decades. The present densely populated and modernised cities require comprehensive volcanic risk reduction strategies, especially for inhabitants who live close to the actively erupting volcano.

The rareness of explosive volcanic eruption as a natural phenomenon brings discrepancies between the recorded impacts in the past and the upcoming effects in the future. As the time intervals between eruptions mostly exceed human life spans, the current built environment is vastly different from when the last eruption occurred. There are also increasing vulnerabilities, and far greater impacts can be foreseen when the eruptions with similar or stronger scales happen shortly.

Addressing such an urgent issue, Kagoshima city municipal government has been preparing the risk management and evacuation plan by providing an updated Sakurajima volcano hazard map. The hazard map contains necessary information about the impacts of historical eruptions, volcanic alerts and warnings, and guidelines on evacuation directions and procedures. Furthermore, the Osumi Office of the Rivers and National Highways produced maps for the potential ash deposition from a large eruption case in municipalities surrounding the Sakurajima volcano.

However, the current solution only employed one scenario based on the *Bunmei* eruption (1471 AD), the largest eruption of Mt. Sakurajima in written history, as a worst-case scenario. This designation only sets static boundaries without considering various wind characteristics that greatly influence the ashfall trajectory. The latest researches indicate that the ashfall deposition patterns from a large eruption depend on the direction of the wind during its explosive phase. Further, the seasonal differences show that the static boundaries will produce more casualties (people at risk did not get alert to evacuate) and distrust to the emergency procedures (people in safe areas got alert to evacuate). Hence, due to uncertainty lies in both the direction and velocity of the winds, static boundaries can no longer be implemented, and dynamic designation of evacuation zones should be adapted.

The JMA already has a state-of-the-art forecast system for detecting volcanic ashfall when an eruption occurs called Volcanic Ash Fall Forecast (VAFF) system. The VAFF system relies on the wind forecast results from the Grid Point Values (GPV) dataset. Such a system can produce dynamic prediction results to designate an evacuation zone before the eruption occurs.

Nonetheless, due to the error residing in the prediction results and the lack of a recent large explosive eruption in Mt. Sakurajima, the accuracy of the VAFF system still cannot be confirmed completely. We propose adding a safety margin to the forecast results to alleviate such issues.

To fully utilise the ashfall forecast results for a more effective evacuation procedure, overcoming the errors of the prediction system can be achieved by introducing a safety margin. The municipal government can establish criteria for assigning evacuation zone and orders effectively by having a safety margin. The requirements for a successful countermeasure mechanism against ashfall hazards are: (1) informing all people at risk to reduce the casualties and (2) keeping unnecessary warnings to unthreatened locations to a minimum. Lastly, applying a safety margin also allows the government to have dynamic decision supports from ashfall hazards during a large explosive eruption event.

Here in this study, we assess the reliability of the ashfall forecast and try to improve the policy on evacuation zone designation by finding the most effective and efficient safety margin values, taking the *Taisho* eruption as a case study. We simulate the ashfall dispersal patterns using a high-quality volcanic dispersal model with predictive and historical wind data. We examine the differences between the simulation results from those different inputs. The study found the optimum values range for the safety margin in terms of enlarging safety boundaries, reducing the damage threshold for roof collapse, and minimum tilting degrees for rotating prediction results. Furthermore, this study analyses the underlying pattern that causes a disturbance on the ashfall forecast and suggests the improvement for the evacuation zone designation from ashfall hazards.