Investigation of lahars with rainfall intensity duration curves in Arimura river basin

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1. Introduction

The continuous ash deposition by volcanic eruptions and erosion due to lahars affect the topographical conditions of Sakurajima volcano. Compaction of volcanic ash deposits with small amount of raindrop impacts and chemical activities coupled with capillary forces form and impermeable crust. Therefore, the permeability of the ground changes with the effect of the change of the ash thickness on the surface.

The aim of this study is to develop rainfall intensity duration (ID) curves by evaluating the volcanic ash fall thicknesses, lahar types, minimum inter-event time and crater activities of Sakurajima volcano, which can be used as an early warning system against lahar occurrences. In this regard, 62 lahars were investigated in Arimura river basin occurred in between 2015 and 2020. Kinematic wave method is adopted to categorize lahars. X Band Multi-Parameter (XMP) radars were used to obtain rainfall data. Confusion matrices and receiver operating characteristic (ROC) were used to compare and optimize the ID curves.

2. Study Area and Methodology

Arimura river catchment basin is located at the southern slope of Sakurajima volcano in Kagoshima prefecture of Japan (Figure 1). The total area of catchment is around 2.8 km^2 which produces on average 10 lahars per year. Sakurajima volcano experienced 3113 eruptions in between 2015 and 2020. The average monthly ash fall thicknesses are about 0.089 and 0.094 cm when Showa and Minamidake craters were dominant, respectively. In between 2015 and 2020, 6.62 cm of ash fall thickness was measured in total. Kinematic wave method (KWM) is adopted to make the runoff analyses. Based on the hydrographs obtained from the model and measured data, the lahars were categorized into two as regular and irregular lahars. The lahars showing good agreement in terms of hydrograph shapes, peak discharge values and start and finish moments of the events are named as regular lahars (Figure 2a). Whereas, the hydrographs that could not be matched by the model with the measured data are named as irregular ones (Figure 2b).

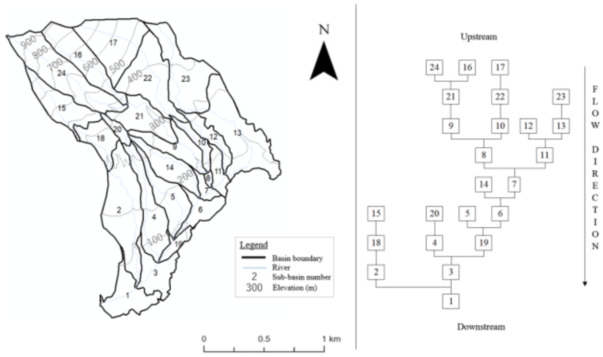

Figure 1 Sub-basins of Arimura River and flow relationship diagram

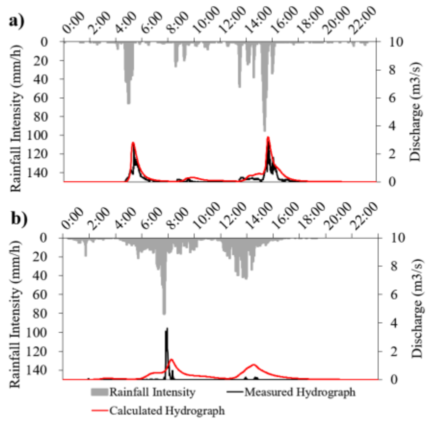

Figure 2 Examples of (a) regular and (b) irregular lahars

In this study, rainfall events are separated by minimum inter-event time (MIT) which indicates the minimum number of no rainfall hours creating an inter-event period. MIT values of 1, 3, 6 and 24 hours are set to be investigated for the rainfall events in Arimura River basin between 2015 and 2020. The rainfall intensity duration curves (ID) which are descripted as linear lines in log-log graph formation is defined as the equation of $I=\alpha D^{-\beta}$ where I is rainfall intensity and D is duration in terms of hours. Two parameters α and β are the intercept and slope of the threshold line, respectively. The "LR&TSS" method (Hirschberg et al, 2021), which is applied by first determining β on the log-log graph by the regression analysis of lahar triggering events and then assigning α by tuning the line, is used to maximize True Skill Statistic (TSS). Then, the highest values of accuracy and area under receiver operating characteristic curves (AUC) are considered to choose the best threshold value.

3. Results

In this study, 23 lahars show good agreement between measured data and KWM, which are named as regular lahars. The rest 39 lahars are named as irregular lahars since the measured data could not be matched with KWM in terms of either waveforms, event start/end time or peak discharge values.

The method applied to determine the best possible threshold is based on considering MIT values, lahar type (irregular or regular), monthly ash fall thickness and crater activity. The best possible pairs of TSS, accuracy and AUC are obtained when the monthly ash fall thicknesses are divided as thicker than or equal to 0.1 cm, between 0.1 and 0.05 cm, and thinner than or equal to 0.05 cm. Among the alternative MIT values, the highest performance metrics were obtained for 3 hours. Based on the best possible pairs of performance metrics considering lahar types, ash fall thicknesses and crater activities ID curves are developed (Figure 3). Considering the 3-hours MIT the total missed lahars cover only 9% of all lahars occurred between 2015 and 2020. The total false alarms are 26% in a total of 249 events with and without lahars. The ID equations (Table 1) show that slope of the curves (β) are nearly the same, changing between -0.392 and -0.318; however, the intercepts (α) dramatically decrease when the monthly ash fall thicknesses are thicker than or equal to 0.1 cm. Dramatic decrease of the thresholds from Showa crater (2015-2017) to Minamidake crater (2018-2020) is observed since the volcanic ash thicknesses increased from the beginning of 2018.

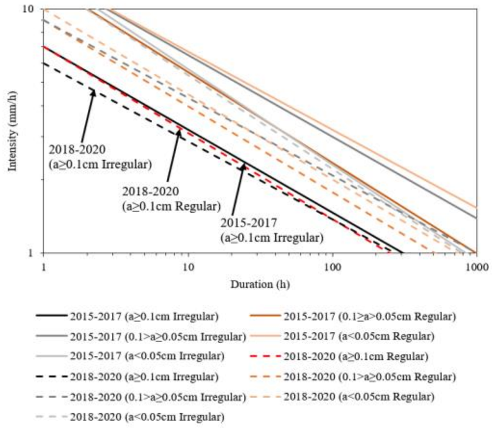

Figure 3 ID curves of 3-hours MIT on a single plot

Table 1 ID equations obtained from 3-hours MIT

	Regular lahars		
	a≥0.1cm	0.1>a≥0.05cm	a<0.05cm
2015-2017	-	$I=13*D^{-0.372}$	$I=14*D^{-0.321}$
2018-2020	$I=7*D^{-0.353}$	$I=9*D^{-0.353}$	$I=10*D^{-0.349}$

	Irregular lahars		
	a≥0.1cm	0.1>a≥0.05cm	a<0.05cm
2015-2017	$I=7*D^{-0.340}$	$I=14*D^{-0.335}$	$I=14*D^{-0.392}$
2018-2020	$I=6*D^{-0.320}$	$I=9*D^{-0.318}$	$I=13*D^{-0.385}$

4. Conclusion

In this study, 62 lahars were investigated in Arimura river basin of Sakurajima volcano between 2015 and 2020. In order to find ID thresholds, different MIT, monthly ash fall thickness, crater activities and lahar types are considered. It is found that volcanic activities and ash fall thicknesses have a certain control on the triggering factors on different kind of lahars. It has been clearly demonstrated that the volcanic ash thickness and threshold values are inversely proportional.

5. References

Hirschberg, J., Badoux, A., McArdell, B., Leonarduzzi, E., Molnar, P. (2021). Evaluating methods for debris-flow prediction based on rainfall in an Alpine catchment. Natural Hazards and Earth System Sciences, 21(9)