Relationship between debris flow discharge coefficient and monthly ashfall in Arimura river basin

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1. Introduction

During the volcanic activities, the ash erupted from the crater, deposits on the foothills of the mountain and in the near vicinity. Volcanic ash and other debris accumulated on the slopes diminish the infiltration capacity of the ground as it thickens. Subsequently, even light rainfall may form surface flow and eventually increase the risk of lahar occurrence. Rapid movement of lahars can cause serious hazards proximal to distal areas of volcanoes. Therefore, emergency countermeasures against them need to be implemented in order to prevent any harm.

The purpose of this study is to find a relationship between lahar occurrence and surficial properties of catchment basins like temporal changes of ash thickness on the ground. In this study, rainfall induced lahars are investigated at Arimura River basin at Sakurajima volcano, Japan. Kinematic wave model is adopted to calculate discharge values of lahars. Since ash thickness on the ground is reversely proportional to infiltration capacity and eventually controls the formation of surface flow, the temporal change of ash thickness is estimated with a conceptual model that considers the surface runoff erosion.

2. Study Area and Methodology

The study area of this research is Arimura River basin on Sakurajima volcano in Kagoshima prefecture, Japan (Figure 1). The catchment area is around 2.8 km^2 which is divided into 24 sub-basins to obtain accurate results by using kinematic wave model. Lahars occurred between 2015 and 2020 are examined.

Kinematic wave model is adopted to calculate discharge values. The ratio of surface runoff to total rainfall amount of a lahar event is named as discharge coefficient (dc):

dc = surface runoff / total rainfall (1)

The ultimate dc values were determined by the correspondence of the waveforms of the calculated and measured hydrographs by trial and error.

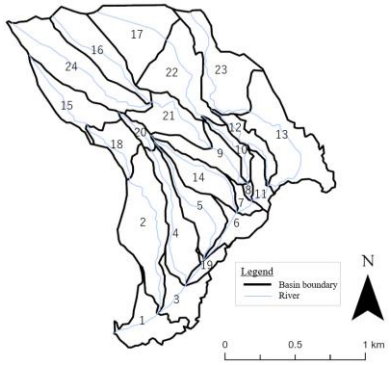

Figure 1 Arimura River basin

It is observed that discharge coefficients (dc) change in each lahar event. Since infiltration ratio is related with surface runoff, the average ash thickness on the drainage area is better to be known in order to assign correct dc values to each lahar event. The ashfall amount due to continuous eruption of Sakurajima is already known. On the other hand, a certain amount of erosion takes place by surface runoff due to precipitation. The temporal change of ash thickness is then calculated by using the difference between monthly ashfall and erosion on the surface. Therefore, a conceptual model is created to determine the erosion rate at the drainage area. A simplified equation is developed to estimate the erosion rate:

$E = \alpha * Q/A$ (2)

where, E is erosion rate at the drainage area [m/s], α is rate of change of erosion rate and Q is measured discharge at the upstream of Daiichi Arimura Bridge [m^3/s], A is drainage area [m^2].

3. Results

106 lahars have been investigated between 2015 and 2020. Here, lahars are divided into two as regular (67/106) and irregular lahars (39/106). Hydrographs of regular lahars match with the calculated ones in terms of peak discharge

and waveform. Irregular lahars, on the other hand, reveal very sharp increase and their peak discharges are not coherent with calculated hydrographs.

The change of ash thickness is calculated by subtracting erosion on the ground due to surface flow evaluated by Eq.2 from monthly ash fall between 2015 and 2020. Two different approaches are adopted in the conceptual model. Firstly, a constant value (0.0001) is assigned to the rate of change of erosion rate (α) between 2015 and 2020 (Figure 2). Secondly, α value i.e. the capability of erosion is changed. Simple regression analyses have been applied to find the relationship between dc and ash thickness. Results show that the relationship between dc and ash thickness is very low if constant α value (0.0001) is adopted. On the other hand, better relations are obtained when the α value is decreased once from 0.0007 to 0.0001 at the end of 2016. Best pair of results seem to be 2015 and 2016-2020 with correlation coefficients of 0.7 and 0.36, respectively.

Regressions reveal better correlations when dc values obtained from calculated discharges are considered instead of the measured ones. Likewise, more accurate results are obtained when irregular lahars are excluded from the analyses (Figure 3). Results reveal that conceptual model can predict discharge coefficient based on ash thickness to some extent. However, a more realistic physical model including other parameters like critical shear strength against erosion, characteristics of ash and rain loss effect may present better results.

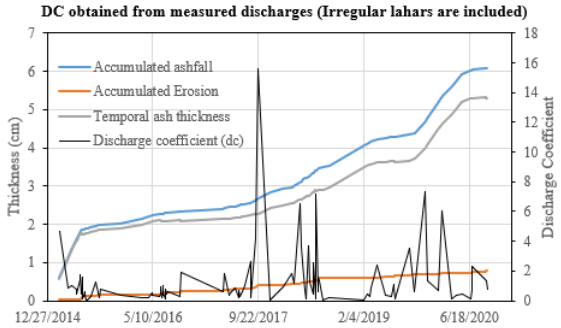

Figure 2 Temporal change of ash thickness with constant α

Better results which are obtained by considering the years separately show that other parameters like ash particle size, material content or accumulation / transportation of other debris could affect the infiltration ratio, accordingly, the discharge coefficient. Furthermore, it is thought that the change in the α value (decreased from 0.0007 to 0.0001) is due to the fact that after the loose material easily eroded by the end of 2016, the stiffer material appeared, making erosion more difficult. This result seems to be coherent with Tetsuka et al (2021).

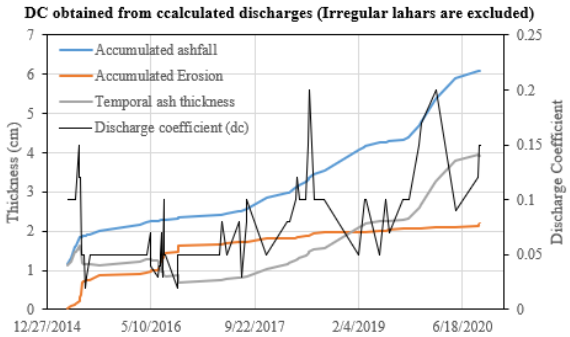

Figure 3 Temporal change of ash thickness with varying α

4. Conclusion

In this study, the lahar occurrence in Arimura river basin on Sakurajima volcano is investigated by using kinematic wave model. Regular and irregular lahars are distinguished in terms of waveforms and peak discharges. A conceptual model is developed to perform the erosion effect due to surface flow. Consequently, the relationship between discharge coefficient and ash thickness is examined. Results show that dc values are changing depending on ash thickness up to a certain point considering the erosion by surface flow. In the future, it is planned to consider rain loss effect to obtain more coherent results between measured and calculated waveforms. In addition, it is aimed to develop a physical model from the conceptual model created.

5. References

Tetsuka S, Hayashi S, Ishii Y, 2021. Changes in slope erosion and sedimentation rates and its relations with the amount of ash fall and debris flow occurrence based on Lidar data from 2010 to 2018 in the Arimura River basin of Sakurajima Volcano, Japan. Journal of the Japan Society of Erosion Control Engineering, 74, 4, pp 32-41.