The Effect of Topographical changes on debris flow reduction at Mt. Unzen

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Introduction

Volcanic eruptions often induce long-term landscape change, leading to increased sediment discharge occurred by debris flows that continue after the cessation of the eruptions. To avoid damages from the debris flow and manage sediment in this area, it is essential to understand debris flow occurrence not only from rainfall data but also from topographical changes.

At Mt. Unzen, over 25-years have passed since the 1990-1995 eruption and, debris flows are still being observed in the Tansan-dani and Gokuraku-dani gullies, a tributary of the Mizunashi-gawa river. Although there are many studies that examine characteristics of debris flow in this area, they had focused on debris flow before 2000 when debris flow had been frequency occurred. Furthermore, some studies had considered debris flows since 2000, but an understanding of continuous and long-term topographic characteristics is insufficient.

The objective of this study was to verify the effect of topographical changes on debris flow occurrence in the Tansan-dani and Gokuraku-dani gullies since 2000. This would be important for prediction of debris flow occurrence and sediment management in this area.

Materials and Methods

The present study was conducted in the Tansan-dani and Gokuraku-dani gullies at Mt. Unzen (Fig. 1C). We focused on the period of 2000-2020. We installed more than four time-lapse cameras (TLC) and captured images at an interval of 1-minute in the rainy seasons (i.e., generally from June to October) during the period of 2016-2020.

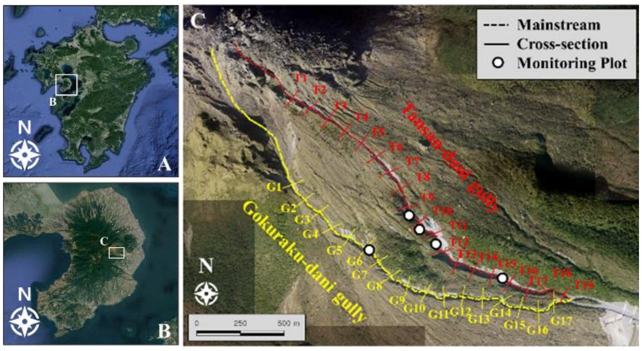

Figure 1. Location map of Mt. Unzen and research site

The captured images were defined as "debris flow" when the flow surges involving sediment entrainment and deposition were observed, and "surface runoff" was defined when runoff exceeding 30-minutes was observed. The rainfall data come from the JMA (Japan Meteorological Agency) Unzen-dake station, 4 km to the West of the Tansan-dani gully. The 10-minute rainfall data were used to identify and analyze the debris flow imaged from the TLC.

To analyze the topographical changes, we used 16 Digital Elevation Models (DEMs) and orthophotographs between 2003 and 2020 (Table 1). The DEMs and orthophotographs were developed based on the Aerial Laser Scanning (ALS) by Unzen Restoration Work Office directed by the Ministry of Land, Infrastructure, Transport and Tourism. The resolution of all DEMs was 1.0 m and orthophotographs between 0.125 and 0.250 m.

Table 1. List of DEMs and orthophotographs

Measurement of period	Grid size of Ems (m)	Resolution of orthophotographs (m/pixel)
August 19-23, 2003	1.0	0.250
October 6-16, 2005	1.0	0.125
December 28, 2006	1.0	0.200
August 6-8, 2010	1.0	0.200
January 17, 2012	1.0	None*
February 20-24, 2014	1.0	0.200
November 4, 2014	1.0	0.200
November 4-6, 2015	1.0	0.125
November 17-24, 2016	1.0	0.250
November 3, 2017	1.0	None*
August 8, 2018	1.0	0.250
November 23, 2018	1.0	0.250
September 18, 2019	1.0	0.250
November 16, 2019	1.0	0.250
August 19, 2020	1.0	0.250
December 4, 2020	1.0	0.250

None*: When constructed a planform, the slope raster map was used.

We calculated volume of sediment reduction, cross-section change, channel gradients, and effective shape index for 17 cross-sections for Gokuraku-dani gully and 19 cross-sections for Tansan-dani gully (Fig. 1C). We drew lines indicating a channel of the mainstream from the dome to the dam based on the DEM in 2020 and the channel network function of SAGA GIS. Cross-sections were set every 100 m of the line. Then, the planform was constructed between cross-sections using orthophotographs and slope raster maps (Table 1).

Based on the extracted planform, we calculated the difference of DEM (DoD) between the measured periods of DEM using Volume Calculation tool in QGIS. The DoD was totaled between the area of each cross-section. The cross-section change was calculated between the measured period of DEM, and channel slope between cross-sections was calculated based on the constructed mainstream. Both analyses were calculated using the terrain profile function of QGIS.

The effective shape index was developed for considering the lateral and vertical adjustment of gully [1]. A relatively high and low shape index indicates U-shaped and V-shaped cross-sections, respectively. The effective shape index was calculated measured cross-section area divided by the maximum rectangular area, that is, width of gully between bank and bank multiplied by maximum depth of gully.

Result and Discussions

For the period 2016-2020, the debris flow and surface runoff were observed in three and 64 events, respectively (Fig. 2), with the first debris flow of 2016 being prior to the TLC installation. The debris flow that occurred in 2016 reached the check dam past the downstream in gullies. In contrast, debris flows in 2017 and 2018 stopped within the gullies. The maximum 1-hour rainfall intensity of debris flow triggered before 2016 was 35 mm but has changed to about 47mm since 2016. Moreover, although the 1-hour maximum rainfall of the three events in 2020 was over 60 mm, debris flows did not occur for the three events. The rainfall threshold that triggered debris flow in 2020 has become higher than threshold before 2019, and the occurrence of debris flow can be affected by topographical changes [2].

The volume of sediment in the gullies was decreased until 2016 (Fig. 3). Although debris flow occurred in 2017 and 2018 (Fig. 2), the volume of sediment was not changed dramatically after 2016. In 2015, Both Tansan-dani and Gokuraku-dani gullies had the lowest average of effective shape indices as 0.62 and 0.64, respectively (Figs. 4A and B). After large-scale debris flow occurred in 2016, the indices gradually increased. It means that after 2016 debris flow, the gully shape was changed to U-shape. As shown in Figs. 4C and D, the average cross-section change had a high value in both 2015 and 2016 for both gullies. The average of channel gradient also had a high value in 2015 (Figs. 4E and F). Based on the debris flow in 2016, The volume of sediment reduction was affected by topographical factors.

The debris flows significantly affect the shear velocity (i.e., friction velocity), which is proportional to the channel gradient, and it decreases with the flattening of the gradient. Moreover, if the cross-sectional area of the channel is sufficiently large, the debris flow movement stops within the channel [3]. Thus, topographical change (i.e., channel gradient, development of gully) can affect the process of debris flow reduction.

Acknowledgement

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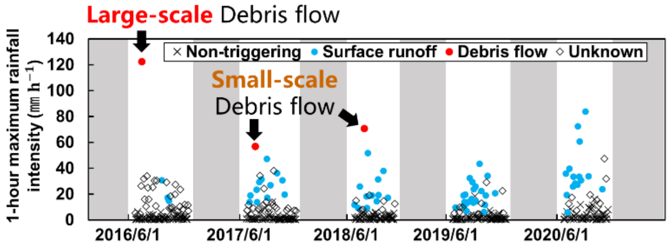

Figure 2. 1-hour maximum rainfall of rainfall events from 2016 to 2020. Large-scale: sediment observed in check dam, small-scale: debris flow stops in the gully.

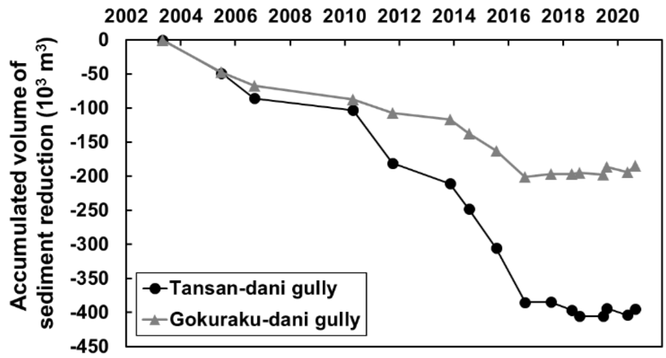

Figure 3. Accumulated volume of sediment in Tansan-dani and Gokuraku-dani gullies.

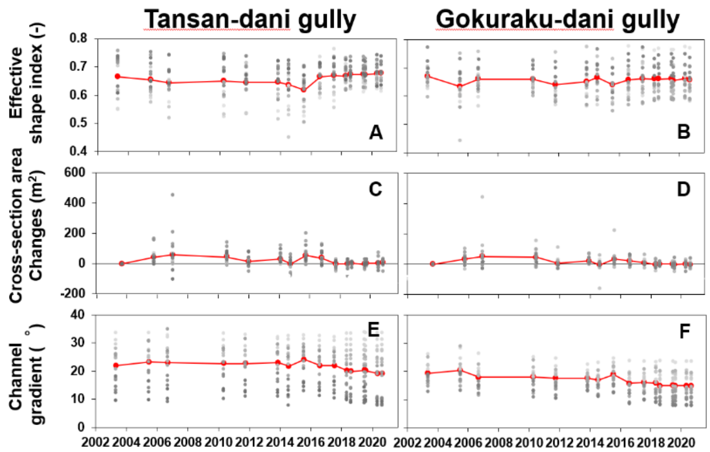

Figure 4. (A and B) The effective cross-sectional shape indies, (C and D) cross-section area changes, (E and F) channel slopes in Tansan-dani and Gokuraku-dani gullies between 2003 and 2020. The red line is the average of each value. Light gray to dark gray dots means upper-stream to downstream.

References

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