Original Article

Temporal change in sediment yield from gully erosion on the flank of the Saido River basin on Mount Sakurajima

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Received Jun 24, 2006 / Accepted Oct 10, 2006

Summary

The flanks of Mount Sakurajima are widely and thickly covered with volcanic ash after a long period of volcanic activity. As a result, much sediment was generated from the flanks and flowed out due to debris flows and mud flows occurred in the rivers located around Mount Sakurajima. In this paper, we investigated the gully erosion process and the temporal change in sediment yield from gully erosion based on field surveys and interpretation of aerial photographs, as well as the effects of the temporal change in volcanic activity on sediment yield from gully erosion in the Saido River basin in Mount Sakurajima. The results are as follows:

(1) The gullies were extensively distributed on the slopes covered with volcanic ash in the Saido River basin. The density and scale of the gullies, as well as the proportion of gully erosion area in the basin area of the Saido River basin became considerably larger over time. The proportion of gully erosion area in the basin area reached about 50 % in 2000.

(2) The average annual sediment yield from gully erosion, average specific annual sediment yield from gully erosion, and average annual sediment yield from gully erosion divided by average annual rainfall reached a peak between 1984 and 1991, and subsequently declined with the temporal decrease in volcanic ash. The average annual sediment yield and average specific annual sediment yield between 1984 and 1991 were about 61,500 m^3 and about 43,000 m^3/km^2, the largest annual values for the period of 1978 to 2000.

Key Words: Mount Sakurajima, Saido River basin, volcanic activity, gully erosion process, sediment yield from gully erosion

1. Introduction

Mount Sakurajima has been continuously active with frequent and lively small scale ash eruptions since 1972. Over this long period of volcanic activity, the flanks of Mount Sakurajima have become widely and thickly covered with volcanic ash, and created a radical alteration of the hydrologic and erosion regime of the area. As a result, much sediment yielded from the flanks covered with volcanic ash, and debris flows and mud flows often occurred in the rivers located around Mount Sakurajima. Consequently, the topography of the basins located around Mount Sakurajima has shown substantive changes.

Additionally, the ebb and flow of volcanic activity has a great effect upon sediment yield and sediment discharge from the flanks of an active volcano. Regarding the flank of Mount Sakurajima, rainfall induced surface runoff and debris flow, the total runoff and the peak discharge of surface runoff and debris flow during heightened volcanic activity were found to be greater than during low activity (Jitousono & Shimokawa, 1989, 1991). Moreover, Teramoto et al. (2005a, 2005b) demonstrated that the yearly depth of the volcanic ash layer and the yearly erosion rate during heightened volcanic activity (between 1972 and 1992) were much greater than during low activity (between 1993 and 2003) on the northern flank of Mount Sakurajima.

The purpose of this study is to clarify the gully erosion process and the temporal change of sediment yield from gully erosion based on field surveys and interpretation of aerial photographs on the flank of the Saido River basin in Mount

Sakurajima. Moreover, we investigated the effects of temporal changes of volcanic activity on sediment yield from gully erosion.

2. Study area and methods

The study area is the Saido River basin located on the northern flank of Mount Sakurajima, as shown in **Fig. 1**. The basin area is 1.43 km^2 and at altitudes from 0 m to 1,117 m above sea level.

The slope inclination of the basin was calculated with a 50 m numeric map mesh from a Geographical Survey Institute publication. The basin was divided into areas of slope inclinations at 20 degree intervals using the slope inclination distribution chart. 25.8 % of the total area had an inclination of less than 20 degrees, and 61.8 % from 20 to 40 degrees. The area with an inclination of 40 degrees or more was 12.4 %. The average inclination of the basin was 29.0 degrees. The average longitudinal slope of the main stream was 17.0 degrees.

From 1978 onward, Kagoshima Prefecture measured the amount of volcanic ash fall at 30 m above sea level in the Saido River basin (Kagoshima Prefecture, 1978-2000). The rainfall data used in this paper was collected by the Kagoshima Regional meteorological observatory (Kagoshima Regional meteorological observatory, 1978-2000).

The geological composition of the study area consisted of a 1779 Anei pumice layer covered by a 1914 Taisho pumice layer, and a volcanic ash layer after a 1914 Taisho eruption of Mount Sakurajima.

Fig. 2 shows the change in annual amount of volcanic ash fall

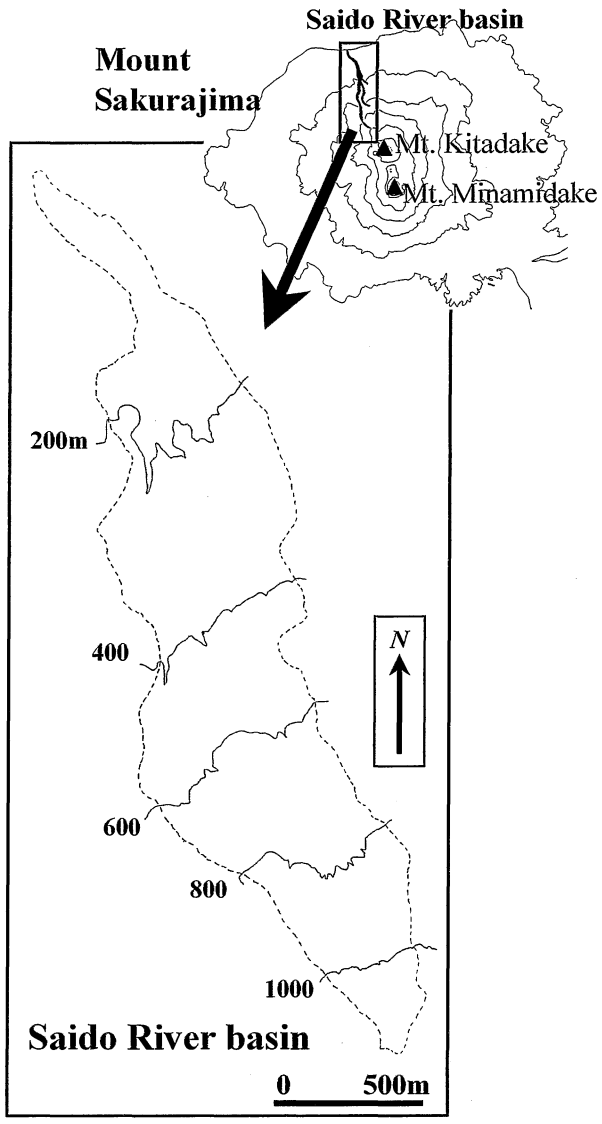

Fig. 1 Location of the study area.

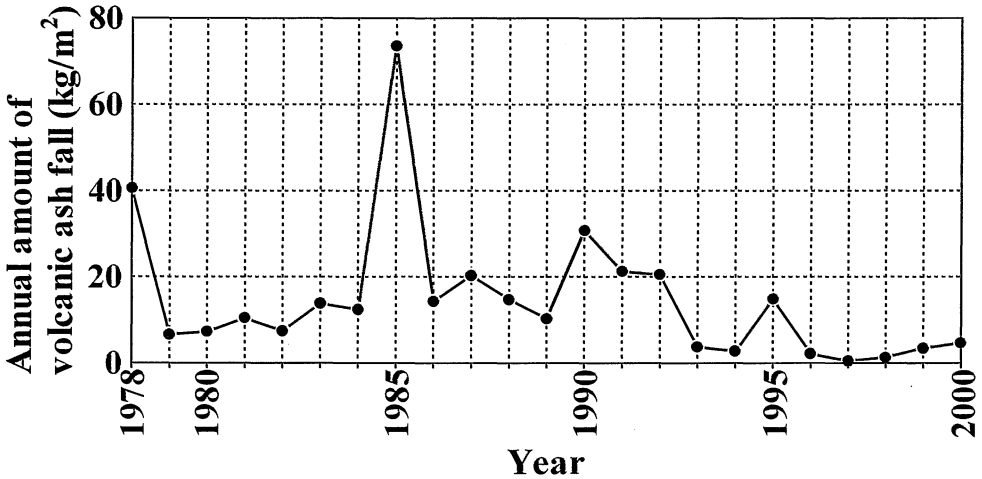

Fig. 2 Change in annual amount of volcanic ash fall at 30 m above sea level in the Saido River basin as measured by Kagoshima Prefecture between 1978 and 2000.

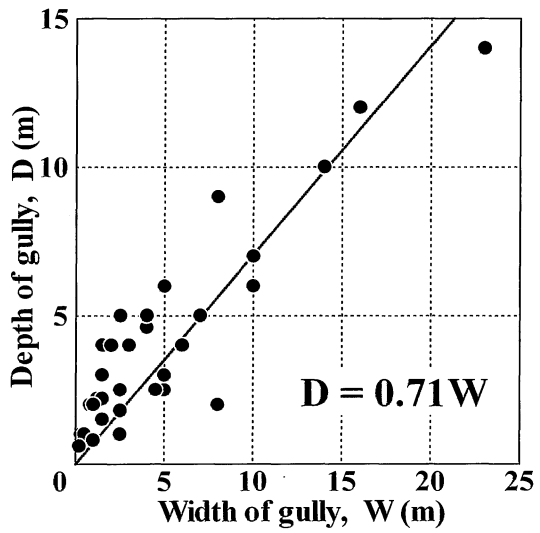

Fig. 3 Relationship between width and depth of gullies on the slopes covered by volcanic ash in the upper reaches of the Saido river basin.

at 30 m above sea level in the Saido River basin as measured by Kagoshima Prefecture between 1978 and 2000 (Kagoshima Prefecture, 1978-2000). The annual amount of volcanic ash fall between 1978 and 1992 was substantial. Moreover, the annual amount of volcanic ash fall in 1985 was about 73 kg/m^2, the largest annual value for the period of 1978 to 2000. Since 1993, the annual amount of volcanic ash fall has been decreasing remarkably, though there was an increase in 1995.

Aerial photograph was used to clarify the gully erosion process and temporal change of sediment yield from gully erosion in the Saido River basin, and a distribution chart of the gully erosion scar was made. Six pairs of aerial photographs taken in 1978, 1980, 1984, 1991, 1996 and 2000 were used for the analysis. The minimum width of gully erosion that is interpretable by aerial photograph is 3 m. To be able to produce a distribution chart of gully erosion scars of less than 3 m in width, squares of

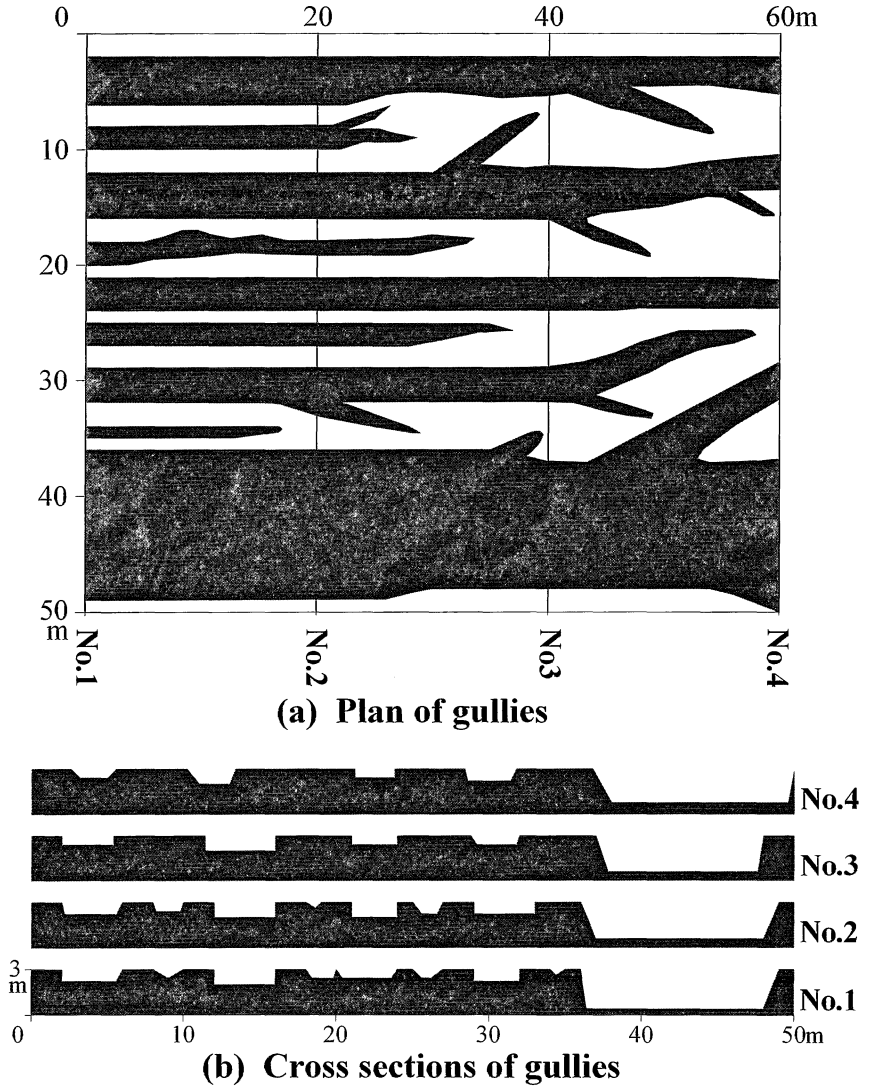

Fig. 4 Plan and cross sections of gullies in a square in the upper reaches of the Saido river basin.

60 m long and 50 m wide were established on the flank of the upper reaches of the Saido River basin. The position, width and depth of gully erosion in a square were surveyed, and a distribution chart of gully erosion scars of less than 3 m in width was made. The area of gully erosion and sediment yield from gully erosion were calculated using a distribution chart of gully erosion scars produced by the field survey and interpretation of aerial photographs.

The total amount of sediment yield from gully erosion was calculated in the basin, as shown below: The shape of a gully cross section is an inverted trapezoid in which the side-wall of the gully is 70 degrees in inclination on the basis of the field survey. The width of a gully at the top was directly measured at 20 m intervals along each gully on a distribution chart produced after interpretation of the aerial photographs. The depth of a gully was calculated by the width-depth relationship of gullies, which was plotted from the result of the field survey, as shown in **Fig. 3**. The area of a gully cross section which is given by multiplying the depth of gully by the width of gully, was obtained at 20 m intervals, and following this the unit sediment yield between two gully cross sections was calculated. The sediment yield from gully erosion in gullies less than 3 m in width,

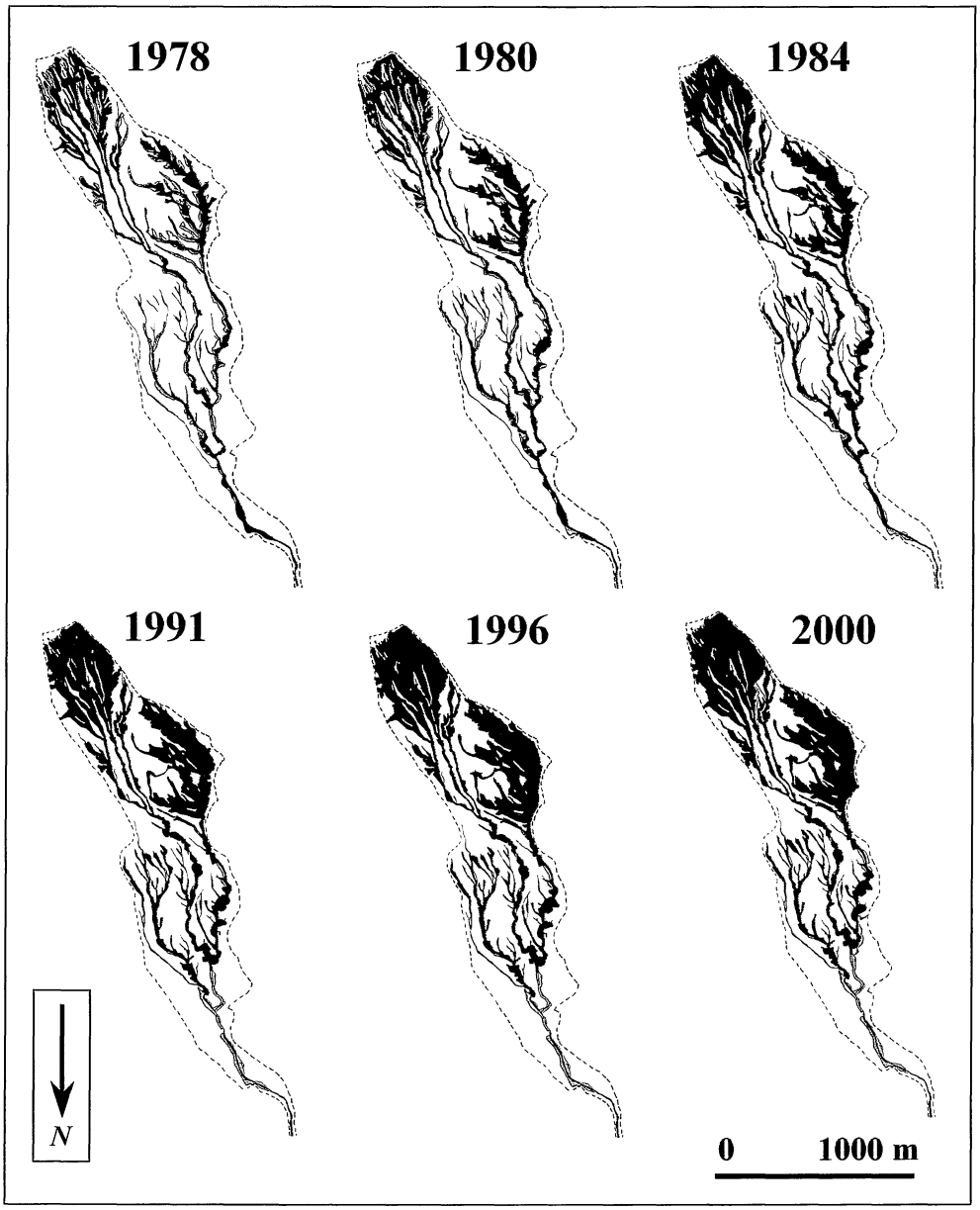

Fig. 5 Distribution charts of gully erosion scars produced by the interpretation of aerial photographs taken in 1978, 1980, 1984, 1991, 1996, and 2000 in the Saido River basin.

calculated using a distribution chart of the gully erosion scar in a square (**Fig. 4**). The sediment yield from the square was calculated by adding the sediment yield of each unit between two gully cross sections of 5 m intervals facing each other along the gully and converted into the specific sediment yield. The totaling of each unit volume along all the gullies provides the total amount of sediment yield from gully erosion in the Saido River basin.

3. Gully erosion process and the temporal change of sediment yield from gully erosion in the Saido River basin in Mount Sakurajima

Fig. 5 shows distribution charts of gully erosion scars produced by the interpretation of aerial photographs taken in 1978, 1980, 1984, 1991, 1996, and 2000 at the Saido River basin. Gullies which are more than 3 m in width were extensively distributed on the slopes covered with volcanic ash fall. The density and scale of the gullies which were more than 3 m in wide became considerably larger over time.

Fig. 6 shows the temporal changes in the cumulative annual amount of volcanic ash fall measured at 30 m above sea level in the Saido River basin (a), and the proportion of the gully erosion area in the basin area of the Saido River basin based on the field survey and interpretation of aerial photographs (b). The proportion of gully erosion area in the basin area reached about 25 % in 1978, but reached about 50 % in 2000. The rate of temporal changes in gully erosion area is in agreement with the rate of temporal changes of cumulative annual amount of volcanic ash fall.

Fig. 7 shows the temporal changes in average annual rainfall (a), average annual amount of volcanic ash fall (b), average annual sediment yield from gully erosion (c), average specific annual sediment yield from gully erosion (d), and average annual sediment yield from gully erosion divided by average annual rainfall (e). The average annual rainfall collected by the Kagoshima Regional meteorological observatory showed values ranging between about 2,000 mm and 2,500 mm. Due to the effect of a short-term ebb and flow of volcanic activity, the average annual amount of volcanic ash fall between 1978 and 1991

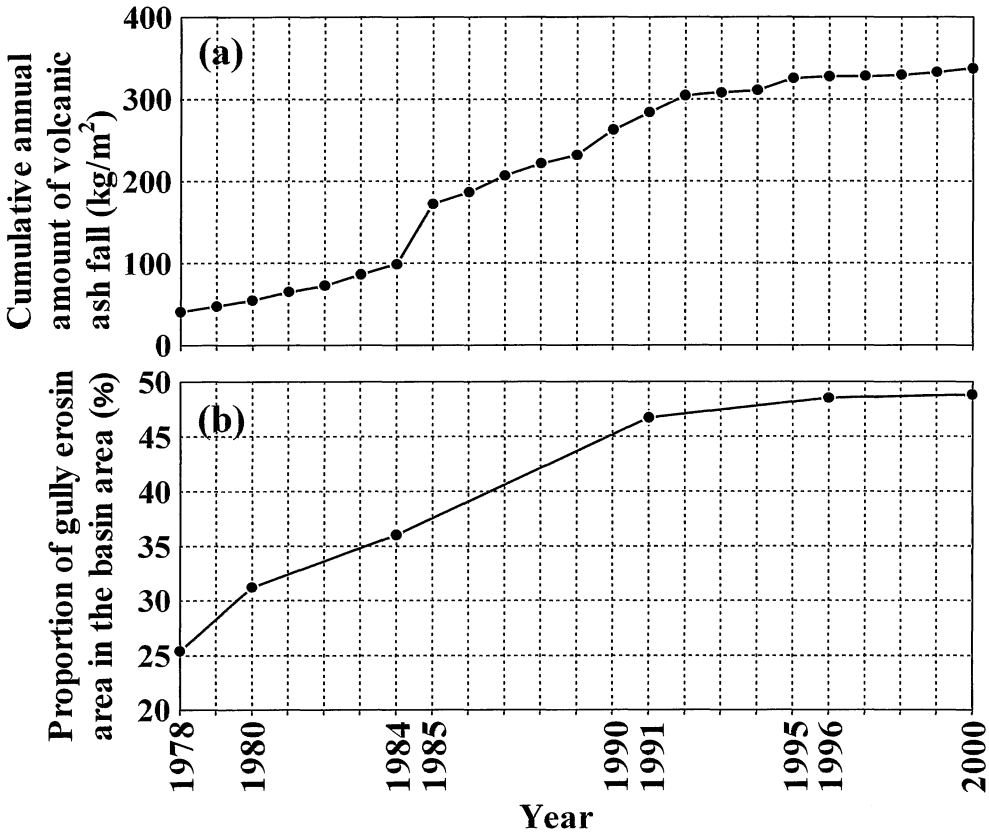

Fig. 6 Temporal changes in cumulative annual amount of volcanic ash fall measured at 30 m above sea level in the Saido River basin (a), and the proportion of gully erosion area in the basin area of the Saido River basin based on field surveys and interpretation of aerial photographs (b).

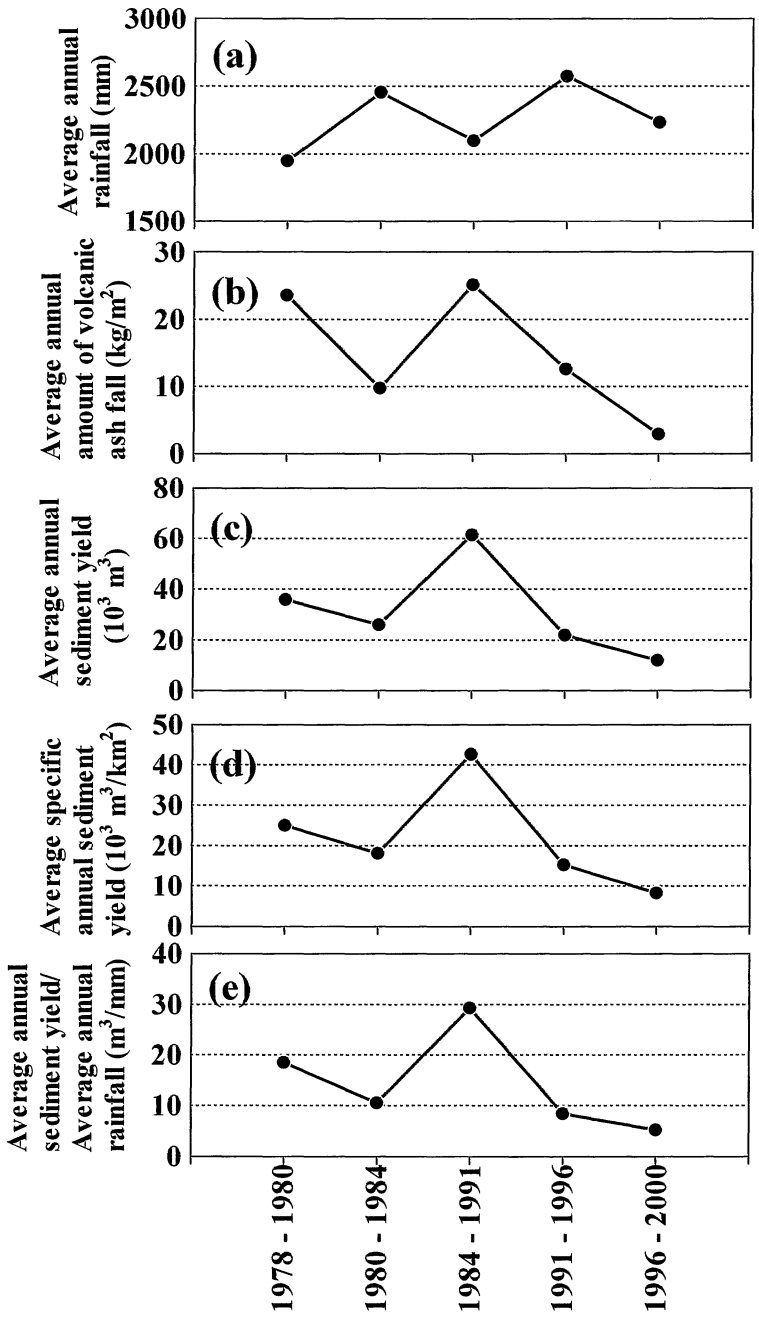

Fig. 7 Temporal changes in average annual rainfall (a), average annual amount of volcanic ash fall (b), average annual sediment yield from gully erosion (c), average specific annual sediment yield from gully erosion (d), and average annual sediment yield from gully erosion divided by average annual rainfall (e).

showed values ranging between about 10 kg/m^2 and 20 kg/m^2. The average annual amount of volcanic ash fall between 1984 and 1991 showed the largest annual value for the period of 1978 to 2000, and subsequently declined with the reduction of volcanic activity of Mount Sakurajima. The changes of average annual sediment yield from gully erosion, average specific annual sediment yield from gully erosion, and average annual sediment yield from gully erosion divided by average annual rainfall showed the same tendency as the change in average annual amount of volcanic ash fall. The average annual sediment yield, average specific annual sediment yield from gully erosion, and average annual sediment yield from gully erosion divided by average annual rainfall reached a peak between 1984 and 1991, and then declined with the temporal decrease in the amount of volcanic ash fall. The average annual sediment yield and average specific annual sediment yield between 1984 and 1991 were

about 61,500 m^3 and about 43,000 m^3/km^2, the largest annual value for the period of 1978 to 2000. Teramoto et al. (2005a, 2005b) demonstrated that the yearly depth of the volcanic ash layer and the yearly erosion rate during heightened volcanic activity (between 1972 and 1992) were much greater than during low activity (between 1993 and 2003) on the northern flank of Mount Sakurajima. These results are in harmony with the results of the current study.

Sediment yield from gully erosion was assumed to decrease with the reduction in volcanic activity of Mount Sakurajima due to the washing out of fine volcaniclastic materials by sheet erosion and gully erosion. As a result, an increase in slope roughness will occur, as well as the recovery of infiltration rates, a decrease in the area contributing to occurrence of Hortonian overland flow, and a decrease of Hortonian overland flow in frequency and magnitude.

Teramoto et al. (2006) conducted a field experiment on a bare land slope by artificially adding a spreading of volcanic ash fall on Mount Sakurajima. Their results showed that the ash-covering caused a decrease in rainfall loss and Manning's coefficient of roughness, and an increase in the area contributing to the occurrence of Hortonian overland flow, surface runoff, and sediment discharge. Additionally, the rainfall loss and Manning's coefficient of roughness increased over time through erosion of the surface volcanic ash layer and as a result, the area contributing to the occurrence of Hortonian overland flow, surface runoff, and sediment discharge also decreased. These results are similar with the results of the current study.

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桜島の西道川流域の火山灰被覆斜面における ガリー侵食による生産土砂量の経年変化

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要　旨

桜島の山腹斜面は，長期にわたる噴火活動の影響を受けて，火山灰に広く，分厚く覆われている。この結果，桜島の山腹斜面からは侵食によって多量の土砂が生産され，土石流・泥流によって多量の土砂が流出している。本論では，桜島の北側に位置する西道川流域を対象として，現地調査および空中写真判読の結果に基づき，ガリー侵食過程およびガリー侵食による生産土砂量の経年変化について検討した。さらに，噴火活動の経年変化がガリー侵食による生産土砂量のそれに及ぼす影響についても検討した。得られた結果は以下の通りである。

(1) 西道川流域の火山灰に厚く被覆された斜面では，広範囲にガリーが刻まれていた。ガリーの密度および規模だけでなく，流域面積に占めるガリー面積の割合も経年的に非常に大きな増加を示した。流域面積に占めるガリー面積の割合は，2000年時点で約50%に達した。

(2) ガリー侵食による年平均での生産土砂量および比生産土砂量，さらに雨量1mmあたりのガリー侵食による年平均での生産土砂量は，1984～1991年の期間に最大となり，その後噴火活動の衰退に伴って経年的に減少した。本論で解析対象とした1978～2000年の期間において，生産土砂量の最大値を示した1984～1991年の期間のガリー侵食による年平均での生産土砂量および比生産土砂量は，それぞれ約61,500m^3，約43,000m^3/km^2であった。

キーワード：桜島，西道川流域，噴火活動，ガリー侵食過程，ガリー侵食による生産土砂量