Original Article

Slope failures and movement of driftwoods caused by typhoon Nabi in the Nakamata River Basin in Kagoshima Prefecture, Tarumizu City, in September, 2005

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Summary

To clarify the characteristics of slope failures and the movement of driftwoods caused by typhoon Nabi in September, 2005 in the Nakamata River Basin in Kagoshima Prefecture, Tarumizu City, field surveys and the interpretation of aerial photographs were carried out. The results are as follows:

(1) Thirty slope failures in the Nakamata River Basin were identified as due to typhoon Nabi. The range of area of a slope failure was from 25 m^2 to 2,600 m^2 (average 467 m^2). The total amount of sediment yield due to slope failures was 4,456 m^3/km^2.

(2) The sediment yield due to slope failures in the Nakamata River Basin during the twenty years between 1986 and 2005 was found by determining the area and depth of slope failures by analysis of aerial photographs. The amount of sediment yield during these twenty years was calculated to be 20,309 m^3/km^2, giving a yearly average of 1,015 m^3/km^2. The amount of sediment discharge that had accumulated against the check dams was calculated based on a field survey. During the fifteen years from 1991 to 2005, the amount of sediment discharge that flowed out due to slope failures, debris and mud flows, and floods was 12,010 m^3/km^2. The yearly mean value was 800 m^3/km^2.

(3) Driftwoods resulted not only from slopes covered with conifers but also those covered with broadleafed trees. 227 m^3 of the total driftwoods of 630 m^3 yielded by slope failures was caught by the check dams, 176 m^3 was caught in the channel, and 198 m^3 flowed out to sea.

Key Words: Typhoon Nabi, Tarumizu City, Nakamata River Basin, slope failure, driftwood

1. Introduction

The sediment-related disaster of typhoon Nabi occurred over a wide range in Kyushu, Chugoku and Shikoku region from 6th to 7th September, 2005. As a result, five people died in Kagoshima Prefecture, Tarumizu City. In addition, considerable damage was caused to houses, engineering works, and agriculture, forestry, and fishing industries though it did not result in human damage (Taniguchi et al., 2005).

Sediment-related disasters have occurred frequently in Tarumizu City. For example, the sediment-related disaster caused by slope failures and debris and mud flows due to the heavy rainfall of typhoon No.11 in July, 1989 and the sediment-related disasters caused by heavy rainfall in 1992 and 1993 (Jitousono and Shimokawa, 1995).

The authors carried out a field investigation of the Nakamata River Basin in Tarumizu City to clarify slope failures and movement of driftwoods as a result of typhoon Nabi. Here we report on the results that were obtained.

2. Sediment-related disaster caused by typhoon Nabi in Kagoshima Prefecture, Tarumizu City

A total rainfall of 600 mm or more fell from 4th to 6th in September, 2005, resulting in slope failures and frequent debris and mud flows in Kagoshima Prefecture, Osumi peninsula. Five people died due to this sediment-related disaster, and considerable damage was caused to houses, engineering works and the agriculture, forestry and fishing industries in Kagoshima Prefecture, Tarumizu City. In addition, typhoon caused traffic on the national road passing through Tarumizu City to come to a complete stop due to the large amount of sediment, and a village was temporarily isolated (Taniguchi et al., 2005).

Rainfall data from September 4th to 6th, 2005 due to typhoon Nabi recorded by a Takatoge automated meteorological data acquisition system, showed the maximum hourly rainfall was 38 mm. Moreover, the total rainfall was 600 mm or more. Heavy rainfall due to typhoon Nabi continued for a comparatively long time (Takatoge automated meteorological data acquisition system, 2005).

3. Outline of the Nakamata River Basin

The investigation area was the Nakamata River Basin located on the north side of Tarumizu City (**Fig. 1**). The basin area is 3.11 km^2 and is located from 0 m to 580 m above sea level. The drainage density of the basin was calculated using a topographical 1/25,000 map. The drainage system was divided by Strahler's method. The drainage density of the basin is 9.7 km/km^2.

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 10 degree intervals using the slope inclination distribution chart. 7.5% of the total area had less than 10 degrees inclination 13.4 % from 10 to 20 degrees, 29.0 % from 20 to 30 degrees, and 45.7 % from 30 to 40 degrees. The area with an inclination of 40 degrees or more was 4.4 %. The average inclination of the basin was 27.2 degrees.

The geological composition of the investigation area is a sandstone and shale base covered with Ito pyroclastic flow deposits, volcanic ash and volcanic pumice.

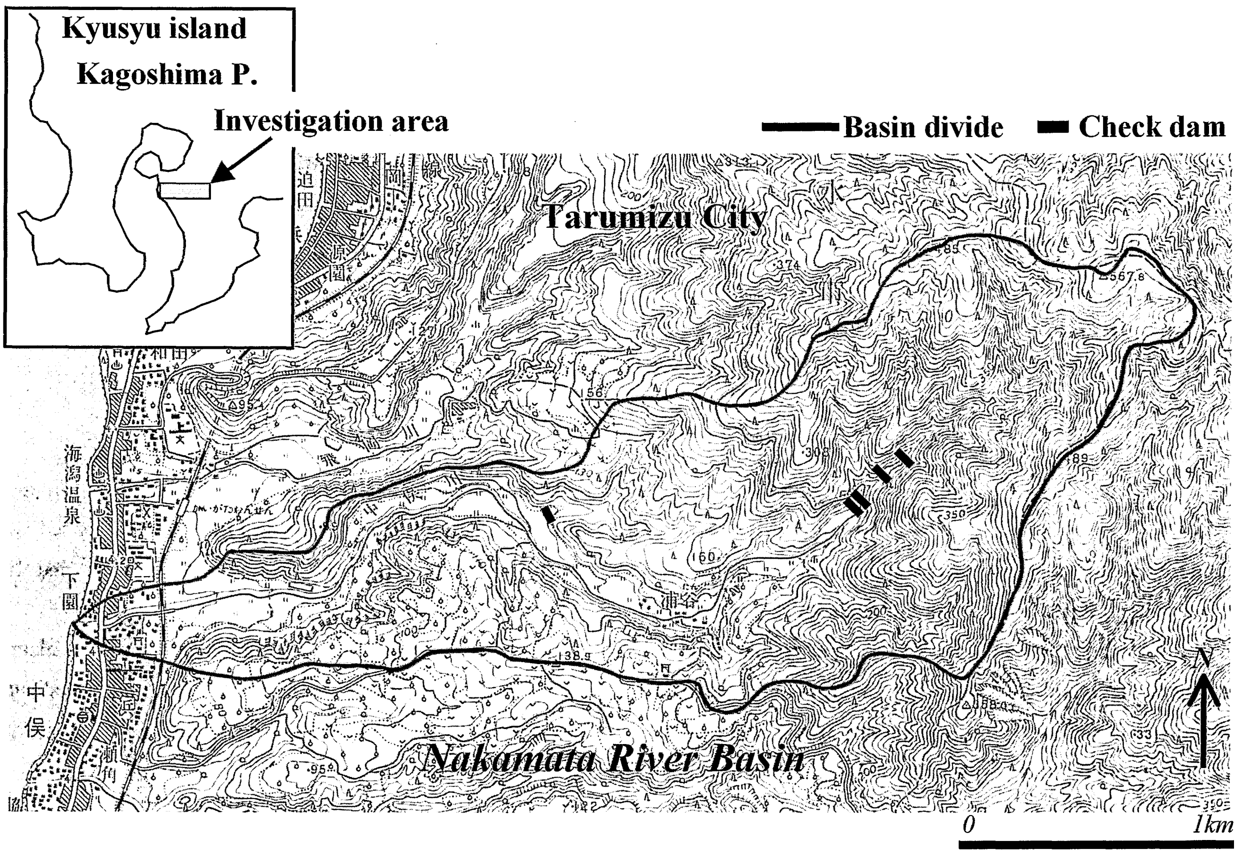

Fig. 1 Location of the study area.

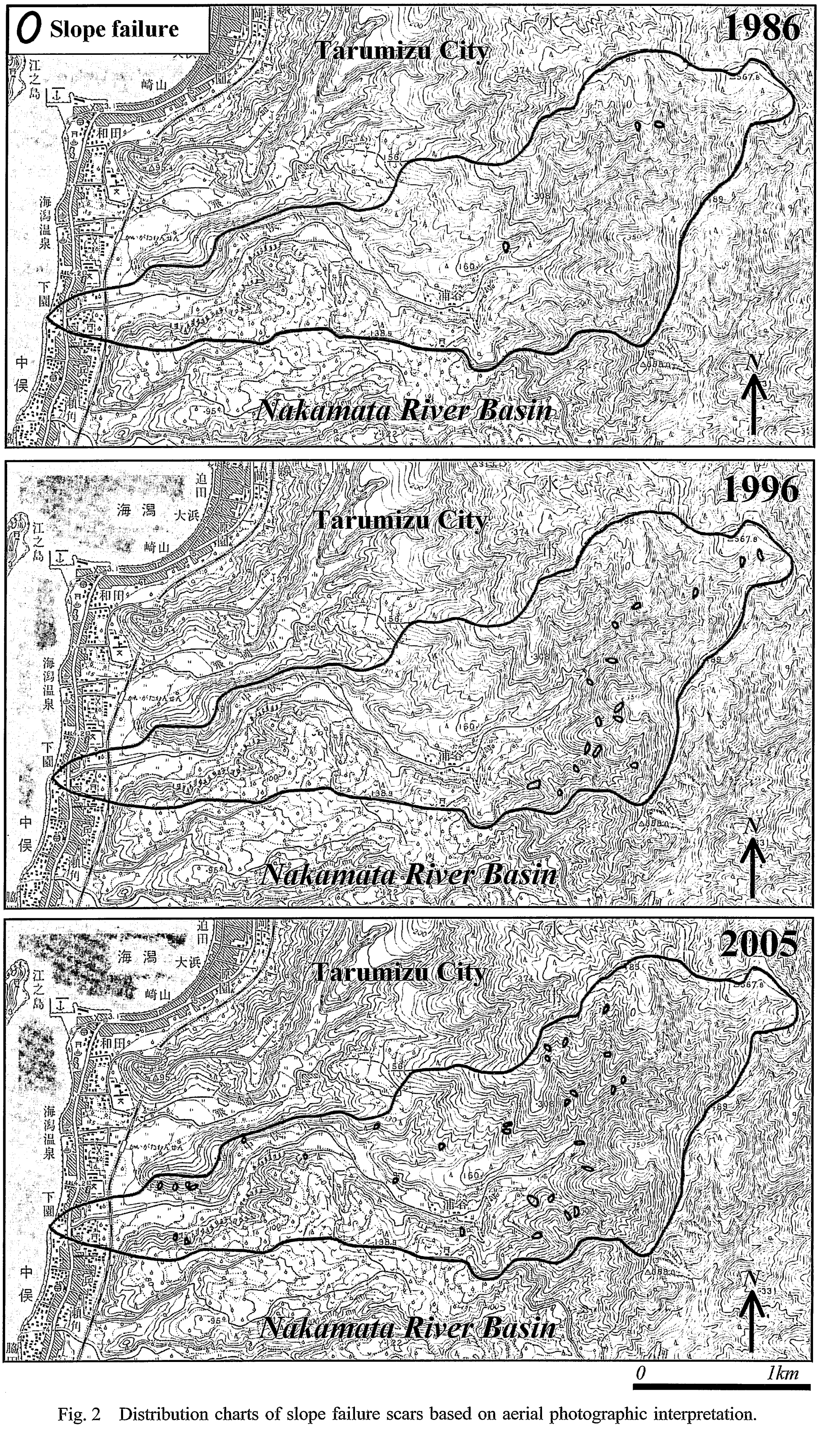

Fig. 2 Distribution charts of slope failure scars based on aerial photographic interpretation.

4. Details of generation of slope failure

An aerial photograph was taken to clarify the history of slope failure in the Nakamata River Basin, and a distribution chart of the slope failure scars was made. Two pairs of aerial photographs taken in 1986 and 1996 were used for the analysis. Since no aerial photograph was taken after typhoon Nabi, a similar distribution chart was made from a field investigation.

Fig. 2 shows distribution charts of the slope failure scars. Since the slope failure scars which are common to each figure are plotted respectively not to be duplicate, these scars in the figure are proper ones in every period.

Table 1 shows the range of the areas of slope failures and the mean value of the area of slope failure calculated from the slope failure distribution charts and the field investigation.

We examined the features of the slope failure distributions generated for each period with the rainfall data obtained by the Takatoge automated meteorological data acquisition system in the vicinity of the investigation basin from 1986 to 2005 (Takatoge automated meteorological data acquisition system, 1986-2005).

(1) Distribution chart of slope failure in 1986

Three slope failures were detected. A slope failure is distributed in the middle reaches region and another in the upper stream region in the basin. All were shallow landslides. The area of slope failure ranged from 125 m^2 to 625 m^2, with an average of 313 m^2. The heavy rainfall immediately before 1986 when the aerial photograph was taken includes the heavy rainfall due to typhoon No.13 (maximum daily rainfall of 115 mm from August 25th to 26th 1984) and the heavy rainfall from August 30th-31st 1985 (maximum daily rainfall 186 mm).

(2) Distribution chart of slope failure in 1996

There were sixteen detected slope failures, generated over the course of eleven years from 1986 to 1996. These was generated in slopes consisting of Ito pyroclastic flow deposits and sandstone and shale in the basin, and most are shallow landslides. The areas of slope failure are in the range of 31 m^2 to 1,562 m^2, with an average of 407 m^2. The heavy rainfall period from 1986 to 1996 includes that due to typhoon No.11 (maximum daily rainfall was 202 mm from July 27th -28th, 1989) and the heavy rainfall due to typhoon No.20 (maximum daily rainfall 369 mm from September 28th -29th, 1990.) In the heavy rainfall caused by typhoon No.11 in 1989, slope failures, debris and mud flows and floods happened frequently and considerable damage such as death and injury to people, and the collapse and flooding of houses occurred in Tarumizu City. Moreover, from

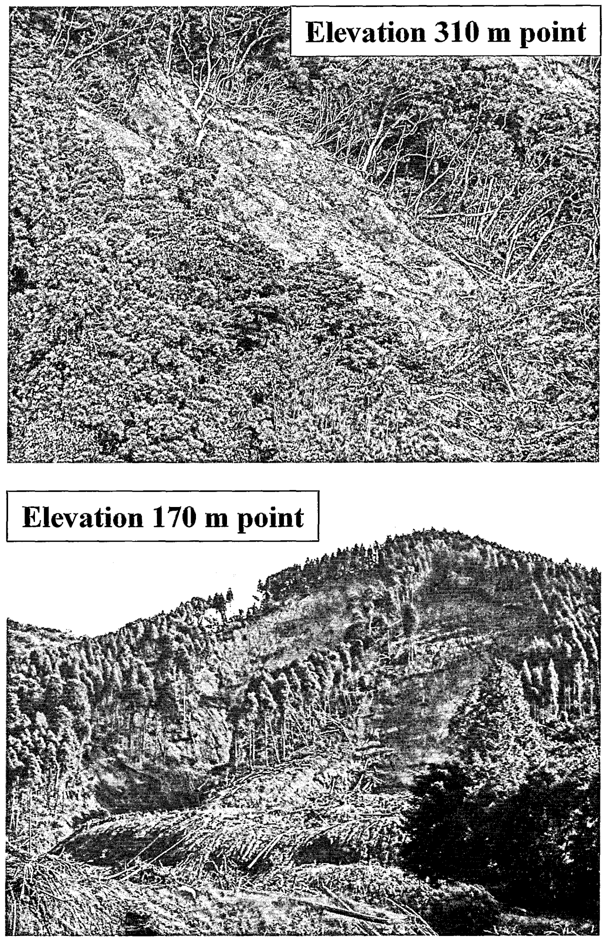

Fig. 3 Slope failures caused by typhoon Nabi.

Table 1 Areas of slope failures in the Nakamata River Basin.

Term	Number of slope failures	Area of slope failures (m^2)	
		Range	Average
− 1986	3	125 - 625	313
1986 − 1996	16	31 - 1,562	407
1996 − 2005	30	25 - 2,600	467

1991 to 1992, a large amount of sediment flowed out to the national road (Jitousono and Shimokawa, 1995). As a result, traffic movement became temporarily suspended because of the sediment that flowed out. In addition, a lot of slope failures were generated by the heavy rainfall (daily rainfall on August 6th was 169 mm, and on August 9th, 238 mm.) that had been suffered on countless occasions in 1993 (Shimokawa et al., 1994).

(3) Distribution chart of slope failure in 2005

The number of slope failures generated by typhoon Nabi was confirmed by the field investigation to be thirty. Slope failures were generated on slopes consisting of Ito pyroclastic flow deposits and a sandstone and shale from the upper stream to downstream region in the basin. All were shallow landslides (**Fig. 3**). The area of slope failure ranged from 25 m^2 to 2,600 m^2, with an average of 467 m^2. The maximum daily rainfall was 34 mm, and the total rainfall was about 630 mm from 4th to 6th September, 2005 (Takatoge automated meteorological data acquisition system, 1986-2005).

5. Sediment yield and sediment discharge in the Nakamata river basin

The area of a slope failure due to individual slope failures from the distribution charts of three slope failure scars in 1986, 1996 and 2005 was calculated (Table 1). For an average slope inclination of 45 degrees, the sediment yield of the slope failure is given by multiplying the effective depth of the slope failure by its area. i.e.

$$\text{Sediment yield} = \text{The area of a slope failure} \times \text{Effective depth of failure} \times \frac{1}{\sqrt{2}}$$

Table 2 gives the sediment yield by slope failure totaled for each period. The amount of sediment yield during the 20 years from 1986 through 2005 was 20,309 m^3/km^2. The yearly mean value was 1,015 m^3/km^2.

In addition, the amount of sediment that accumulated against the check dams (Fig. 1, **Fig. 4**) constructed after the sediment-related disaster in 1991, that is, the sediment discharge was calculated, is based on the result of field surveying executed in November, 2005. During the 15 years from 1991 to 2005, the amount of sediment discharge that flowed out due to slope failures, debris and mud flows and floods was 12,010 m^3/km^2. The yearly mean value was 800 m^3/km^2. The sediment discharge of the remainder is thought to have accumulated in the channels

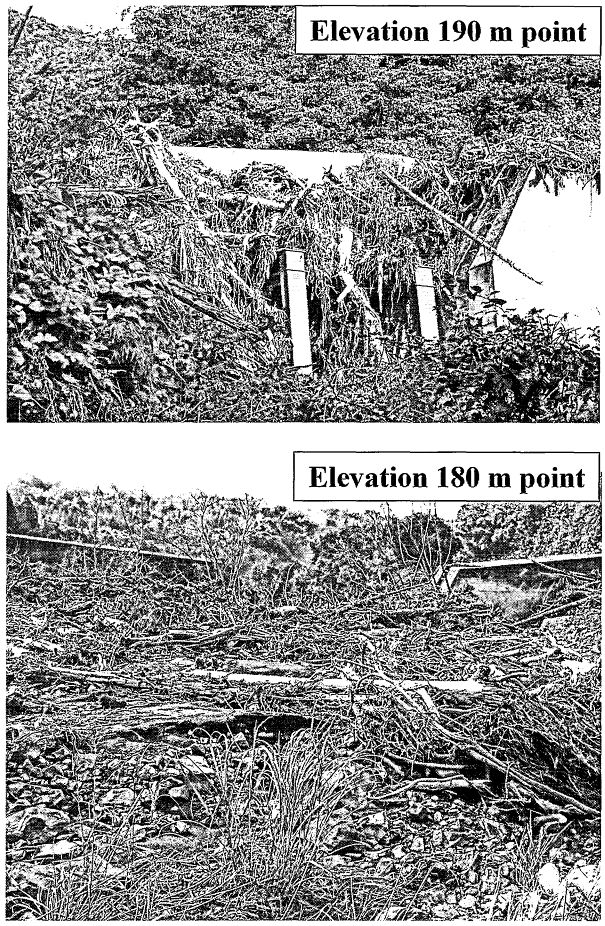

Fig. 4 Sediment that accumulated against the check dams and driftwoods caught by slope failures in the check dams.

Table 2 Sediment yield by slope failure in the Nakamata River Basin.

Term	Number of slope failures	Total area of slope failures (m^2)	Sediment yield by slope failures (m^3)	Specific sediment yield (m^3/km^2)
- 1986	3	938	929	299
1986 - 1996	16	6,515	6,450	2,074
1996 - 2005	30	14,000	13,859	4,456

upstream and to have flowed out downstream of the check dams.

6. The movement of driftwood caused by typhoon Nabi

Vegetation with which the slopes in the Nakamata River Basin were covered was destroyed by the slope failures generated by the heavy rainfall of typhoon Nabi. The destroyed trees flowed downstream along with other debris and mud flows in the floods. Driftwoods flowed out to sea after the check dams and channel were partially supplemented (**Fig. 5**). The basin was badly damaged by these driftwoods.

Field investigation of the movement and volume of driftwood caused by the slope failures generated by typhoon Nabi, caught in the channel, where it caused flooding, before flowing out to the sea, was carried out for the Nakamata River Basin.

The volume of this driftwood was estimated. The density and species (conifer or broadleaf tree) of driftwood vegetation was estimated by investigating the slope failure scar, the density of vegetation adjacent to the slope failure scar, and interpretation of aerial photographs taken in 1986 and 1996. The volume of the trees was calculated using a volume-of-tree conversion table (Kagoshima Prefecture Forestry and Fishery, 1995) from the species, height, and diameter of the trees.

Fig. 6 shows the main distribution of the driftwoods flowing out of the Nakamata River Basin. Fig. 6 shows the situation, at the same time, of the check dams constructed after the sediment-related disaster in 1991 and the distribution of slope failures caused by typhoon Nabi. **Table 3** shows the total volume of driftwoods yielded by slope failures and flowing out of the Nakamata River Basin. Most of the driftwoods yielded by the slope failures generated in stream above the check dams, was supplemented by the check dams (Fig. 4).

The majority of the driftwoods (Fig. 5) that were caught in the channel in the middle reaches region and the downstream region and which flowed out to the sea, came from the slope failures generated downstream of the check dams. Driftwood as produced by slope failures came not only from slopes covered with conifer but also slopes well-covered with broadleafed trees.

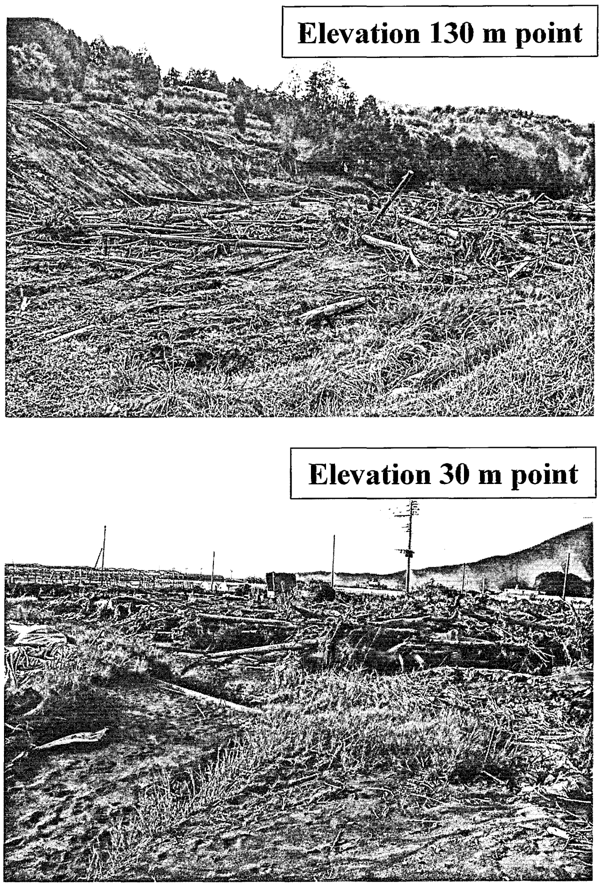

Fig. 5 Driftwoods caught the channel in the middle reaches region and around the downstream region.

Table 3 Total volume of driftwood yielded by slope failures and flowing out of the Nakamata River Basin.

		Conifer	Broadleaf tree	Total
Driftwood yielded by slope failures (m^3)		465.6	164.5	630.1
Driftwood flowed out to the downstream (m^3)	**Driftwoods caught by the check dams (m^3)**	152.2	75.1	227.3
	Driftwoods caught around in the channel (m^3)	146.0	29.7	175.7
	Driftwoods flowed out to the sea (m^3)	158.0	40.0	198.0

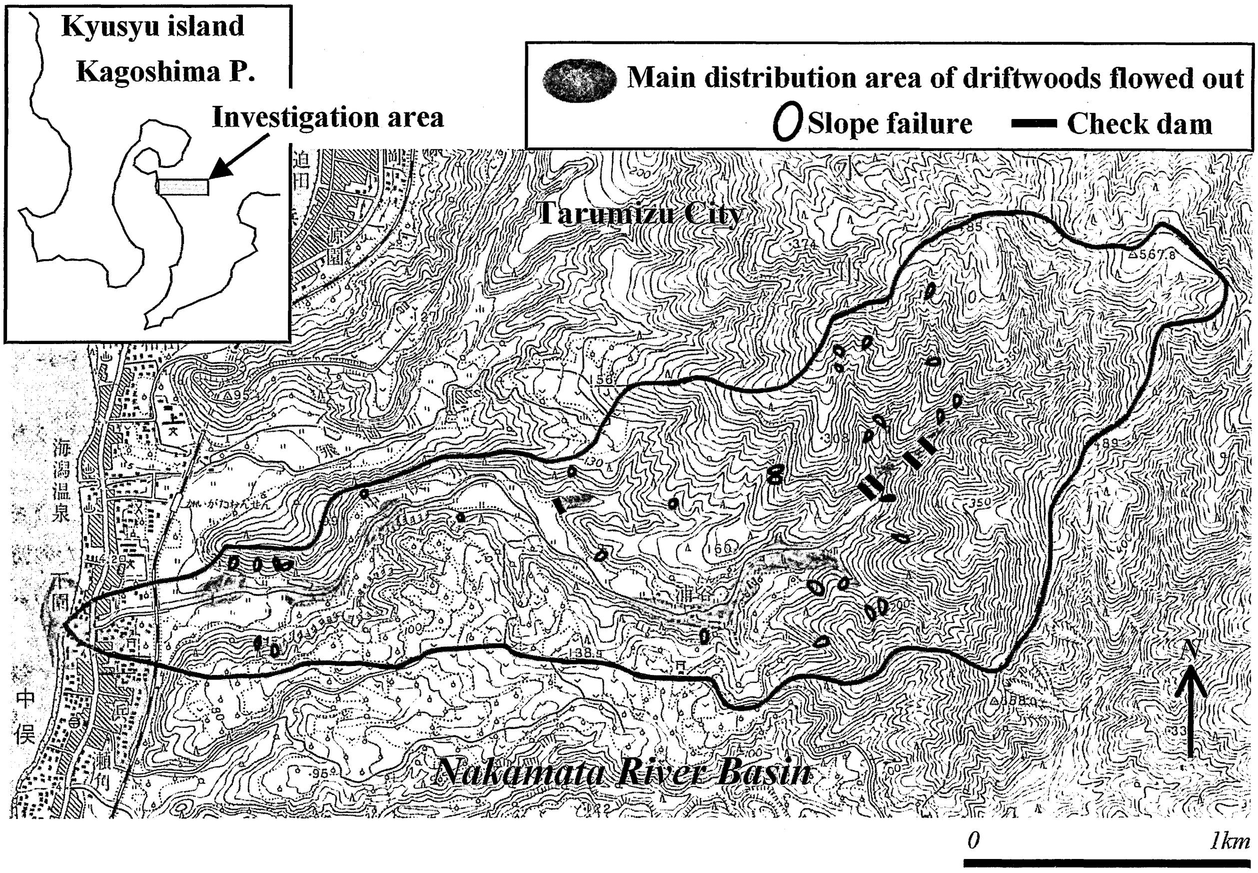

Fig. 6 The main distribution chart of driftwoods flowing out of the Nakamata River Basin based on a field investigation.

On the other hand, driftwoods other than that caught by the check dams, flowed out to the downstream region. The driftwood budget shows that 227 m^3 was caught by the check dams from a total driftwood yield of 630 m^3. In addition, 176 m^3 was caught in the channel and 198 m^3 flowed out to sea.

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垂水市中俣川流域において2005年９月の台風14号に伴い発生した斜面崩壊と流木の動態

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要　旨

鹿児島県垂水市中俣川流域において，2005年９月の台風14号に伴い発生した斜面崩壊の特徴と流木の動態を明らかにするため，現地調査および空中写真判読を行った。得られた結果は以下の通りである。

(1) 台風14号に伴い中俣川流域では30個の斜面崩壊が発生した。斜面崩壊の面積は25～2,600m^{2}の範囲（平均467m^2）であった。台風14号に伴って発生した斜面崩壊による比生産土砂量は4,456m^3/km^{2}であった。

(2) 中俣川流域において1986～2005年の20年間に発生した斜面崩壊による比生産土砂量を，空中写真判読および現地調査の結果に基づき求めた結果，20,309m^3/km^2（年平均では1,015m^3/km^2）であった。また，中俣川流域内に設置された砂防ダムに堆積した流出土砂量についても調査した。その結果，1991～2005年の15年間における斜面崩壊，土石流・泥流および洪水による比流出土砂量は，12,010m^3/km^2（年平均では800m^3/km^2）であった。

(3) 現地調査の結果，流木は針葉樹林で覆われた斜面からだけでなく，広葉樹林で覆われた斜面からも発生していた。斜面崩壊に伴って生産された630m^{3}の流木のうち，227m^{3}が砂防ダムによって捕捉，176m^{3}が河道内に捕捉，198m^{3}が海に流出した。

キーワード：2005年９月の台風14号，鹿児島県垂水市，中俣川流域，斜面崩壊，流木