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Disaster Report

The July 2020 Rainfall-Induced Sediment Disasters in Kumamoto Prefecture, Japan

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On July 4, 2020, heavy rainfall was observed in the southern part of Kumamoto Prefecture and the northern part of Kagoshima Prefecture. Due to heavy rainfall, floods and sediment disasters such as collapses and debris flows occurred predominantly in the Kuma River basin of Kumamoto Prefecture. We conducted field investigations at four sites in Ashikita Town and Tsunagi Town, Kumamoto Prefecture, where collapses and debris flows caused deaths. We also conducted field investigations in the Kawauchi River branch of the Kuma River, where vast amounts of sediment discharge caused damage to houses. The objectives of these investigations were to clarify the situation and mechanism of the disasters and to propose procedures to recover from the disasters. This report briefly summarizes the results of these investigations.

Key words : heavy rainfall, collapse, debris flow, sediment disaster, Kumamoto Prefecture

1. INTRODUCTION

In the early hours of July 4, 2020, southern Kumamoto and northern Kagoshima Prefectures experienced record-breaking heavy rainfall that led to a rainfall emergency warning and resulted in extensive floods and sediment disasters. In Kumamoto Prefecture, in particular, 226 sediment disasters occurred and 12 people died. In this paper, we report the results of surveys on sediment disasters in Ashikita Town and Tsunagi Town, Kumamoto Prefecture, which caused severe human casualties, and in the Kawauchi River basin on the right branch of the Kuma River, where a large amount of sediment was discharged [*Jitousono et al*., 2020].

2. RAINFALL OVERVIEW

Figure 1 shows the temporal variation of the spatial distribution of rainfall intensity around the

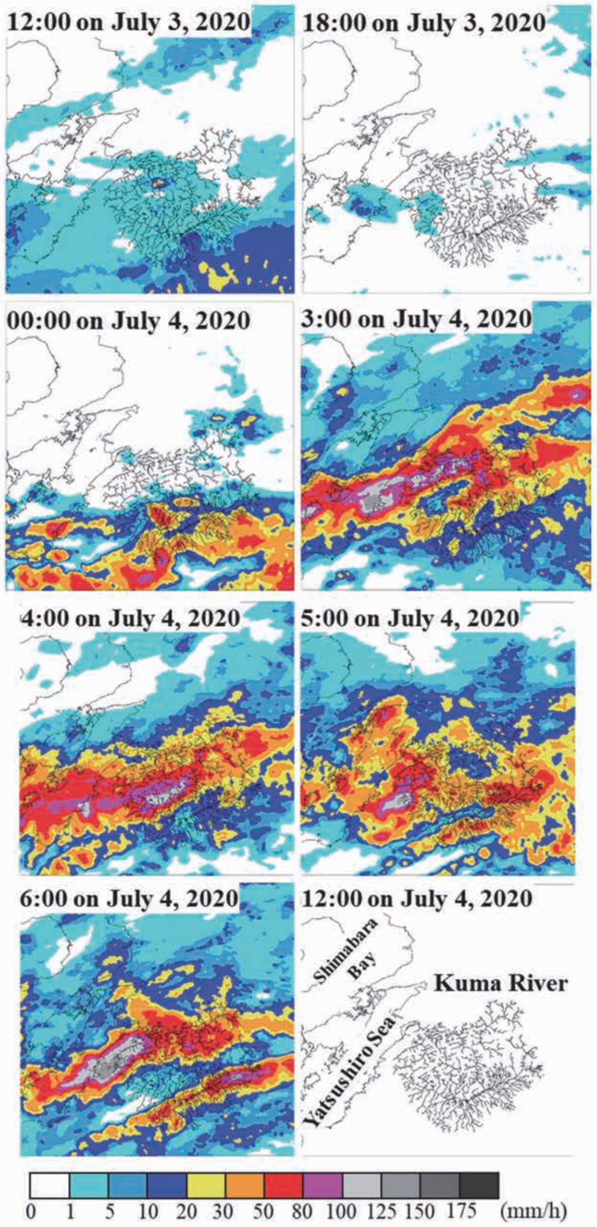

Fig.1 Temporal variation of spatial distribution of rainfall intensity obtained from XRAIN observation, which was provided by the Ministry of Land, Infrastructure, Transport, and Tourism

Kuma River basin. Rainfall began at approximately 23 : 00 on July 2 and continued intermittently until approximately 11 : 00 on July 4. Heavy rainfall was widespread in the east-west direction and concentrated in a narrow area in the north-south direction. The area where sediment disasters occurred was intermittently hit by rainfall of 80 mm/h or more between 2 : 00-6 : 00 on July 4, and a large amount of rainfall provided over half a day.

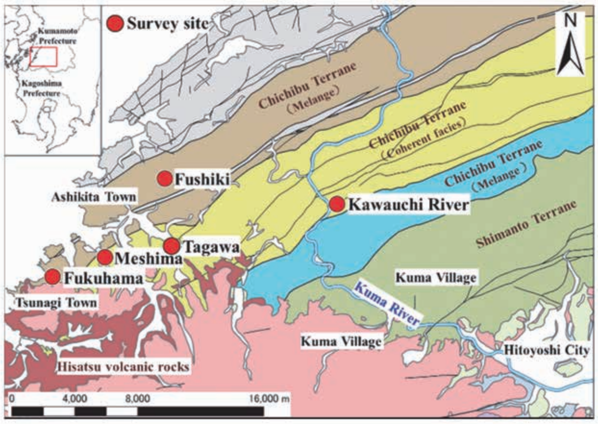

Fig.2 Geological map of the study area created from *Saito et al*. [2010]

3. TOPOGRAPHY AND GEOLOGY

The study area is located at the southwestern edge of the Kyushu Mountains and has steep mountainous terrain, few plains, and a complex coastline. The Kuma River passes the Hitoyoshi Basin, where the flooding occurred, and meanders through the center of the study area.

Figure 2 shows a geological map of the study area [*Saito et al*., 2010]. Ashikita Town and Tsunagi Town and their surroundings consist of Mesozoic accretionary complexes named the Chichibu Terrane. The Fukuhama area in Tsunagi Town and the Fushiki area in Ashikita Town are composed of an accretionary melange, with interbedded mudstone, sandstone, chert, limestone, and volcaniclastic rocks. Meshima, Tagawa, and the Kawauchi River basin in Ashikita Town are composed of coherent accretionary facies and strata consisting of sandstone, mudstone, and chert. Hisatsu volcanic rocks formed after the Late Miocene are distributed in the southern part of the study area.

4. REPRESENTATIVE SEDIMENT DISASTERS

4.1 Tagawa, Ashikita Town

In Tagawa, Ashikita Town, a collapse occurred after 04 : 00 on July 4, killing three people (**Fig. 3**). According to rainfall data from near the disaster area (Ashikita observation station, Kumamoto Prefecture), 79 mm was recorded at 03 : 00-04 : 00 and 82 mm at 04 : 00-05 : 00 on July 4. Total rainfall from 04 : 00 on July 3, when the rainfall event began, to 05 : 00 on July 4, was 384 mm (**Fig. 4**).

The collapse occurred at a slope angle of approximately 30° at an elevation of 60-100 m and collapsed sediment was deposited in a wide area at the foot of the slope with an angle of approximately 10° (**Fig. 5**). The slope length of the collapse and the

Fig.3 Panoramic view of the disaster area in Tagawa, Ashikita Town
Courtesy of Asia Air Survey Co., Ltd., and Aero Asahi Corporation ; taken on July 4, 2020

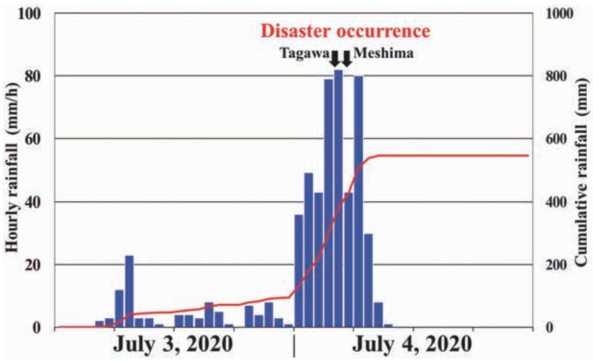

Fig.4 Rainfall on July 3-4 (Ashikita observation station, Kumamoto Prefecture)

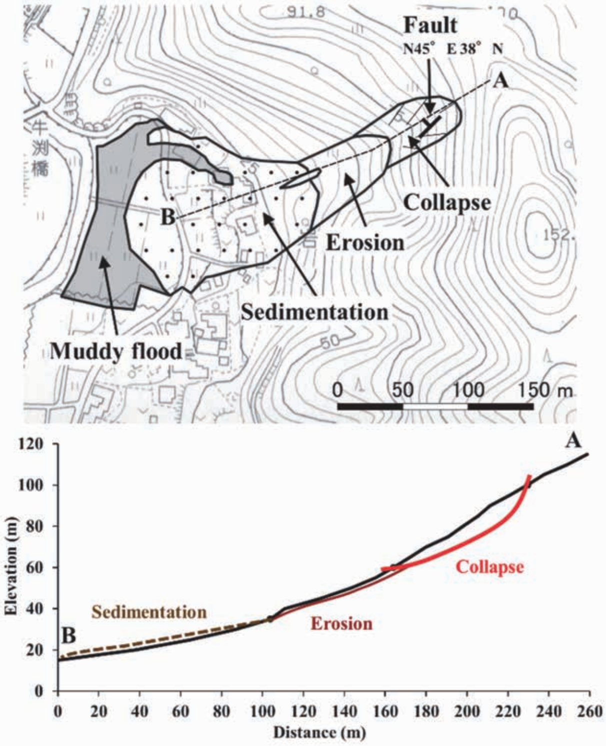

Fig.5 Plan and longitudinal section of the collapsed slope

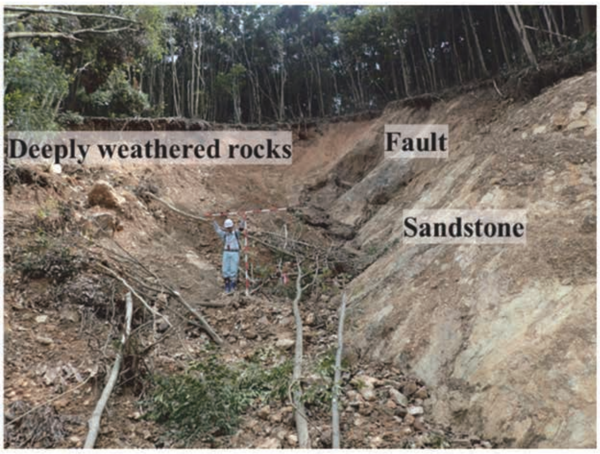

Fig.6 Head of the collapse in Tagawa, Ashikita Town (photo taken on August 1, 2020)

maximum width were approximately 80 m and 40 m, respectively. The maximum depth was approximately 10 m. The volume of the collapsed sediment was calculated to be 8,400 m^3 based on the length of 80 m, with an average width of 35 m and an average depth of 3 m of the collapse. If the volume of erosion in the area through which the sediment moved is included, it is estimated that approximately 10,000 m^3 of sediment was produced. A talus cone had developed at the foot of the collapsed slope, indicating that this is a place where sediment transport has repeatedly occurred.

The head of the collapsed area has a V-shaped transverse form with a depth of 8 m. A fault is identified by sandstone outcropping on the right side toward the collapse (**Fig. 6**). On the fault surface, there is a thin clay layer and slickenside, and fracture zones consisting of angular gravel are distributed along the fault plane. The left side toward the collapse is the upper part of the fault plane, and the rocks are deeply weathered. The collapse is considered to have occurred due to the infiltration of large amounts of rainwater into the fractured and weathered strata.

4.2 Meshima, Ashikita Town

In Meshima, Ashikita Town, a collapse occurred after 05 : 00 on July 4, killing two people, and a debris flow occurred in the Kosaki River near the collapse site, damaging houses (**Fig. 7**). Rainfall conditions at the time of the disaster are shown in **Fig. 4**.

The collapse occurred at a steep-sloped of 36° at an elevation of 50 m. The collapse was 55 m in length, 20 -25 m in width, and 3-5 m in depth. It occurred on a

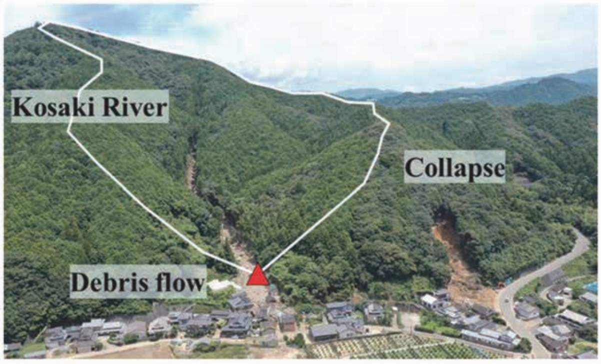

Fig.7 Panoramic view of the disaster site in Meshima, Ashikita Town (photo taken on August 1, 2020)

Fig.8 Collapse and damage in Meshima, Ashikita Town (photo taken on August 1, 2020)

concave slope. A boundary between hard and soft bedrocks was observed in the head scarp (**Fig. 8**). Hard sandstone was distributed on the left side toward the collapse site, and deeply weathered sandstone was distributed on the right side. The collapse is considered to have been caused by an increase in pore water pressure due to rainwater infiltrating the soft sandstone, leading to the foot collapsing, followed by the collapse of the hard sandstone from above.

Figure 9 shows the distribution of sediment transport in the Kosaki River (basin area : 0.1 km^2). A 17-25 m wide, 30-40 m long, and 3-5 m deep collapse occurred at the head of the Kosaki River at an elevation of 200-220 m. Most of the collapsed sediment was deposited at the foot of the collapse site. Downstream, 2 m wide and 0.8-1.4 m deep gully erosion occurred in a 150-m-long zero-order valley with a 30° riverbed angle. Further downstream, 2-5 m wide and 1-2 m deep channel erosion occurred in a 230-m-long first-order channel with a 15° riverbed angle. The volume of this eroded sediment was estimated to be 1,500 m^3, which was discharged downstream with eroded trees. In the downstream

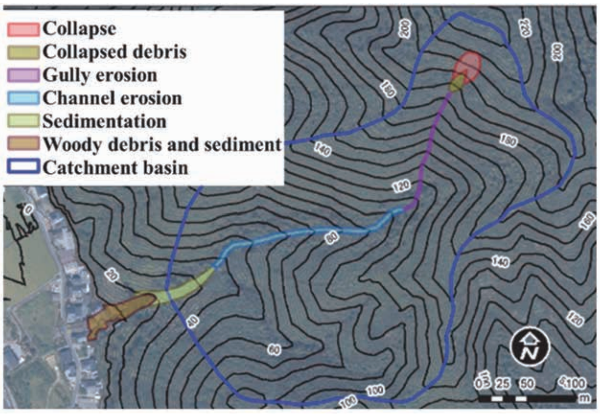

Fig.9 Distribution of sediment transport in the Kosaki River

Fig.10 Damage downstream of the Kosaki River (photo taken on August 1, 2020)

sedimentation area, approximately 1,200 m^3 of sediment accumulated with a width of 5-10 m and thickness of 2 m. In addition, the remaining sediment and large woody debris caused damage to houses downstream (**Fig. 10**).

4.3 Fushiki, Ashikita Town

In Fushiki, Ashikita Town, a collapse occurred at approximately 05 : 00 on July 4, killing one person (**Fig. 11**). According to the rainfall data from near the disaster area (Tanoura observation station, Kumamoto Prefecture), 129 mm was recorded at 03 : 00-04 : 00 and 97 mm at 04 : 00-05 : 00 on July 4. There was cumulative rainfall of 492 mm from 04 : 00 on July 3, when the rainfall events began, to 05 : 00 on July 4 (**Fig. 12**).

The collapsed slope angle was 36-38° and convex or rectilinear in the longitudinal direction and ridge-shaped in the transverse direction. The geology was clay-slate, including hard chert and basalt rocks of several tens of centimeters to several meters in size. It was strongly weathered with reddening from the surface to a depth of approximately 5 m. The collapsed length was 56 m, with a maximum width of 20 m, maximum depth of 5 m, and a volume of sediment of

Fig.11 Collapse (upper) and damage (lower) in Fushiki, Ashikita Town (photos taken on August 1, 2020)

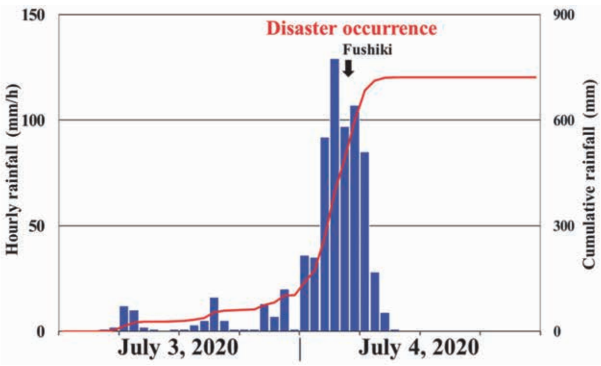

Fig.12 Rainfall on July 3-4 (Tanoura observation station, Kumamoto Prefecture)

1,500 m^3. The collapsed sediment, which contained hard rocks several meters in diameter, reached 40 m away from the slope.

4.4 Fukuhama, Tsunagi Town

A debris flow occurred at 5 : 40 on July 4 at Otsubo River 1 in Fukuhama, Tsunagi Town, killing three people (**Fig. 13**). **Figure 14** is a topographic map and

Fig.13 Disaster area in Fukuhama, Tsunagi Town (photo taken on July 13, 2020, courtesy of Kyushu Regional Development Bureau, Ministry of Land, Infrastructure, and Transport)

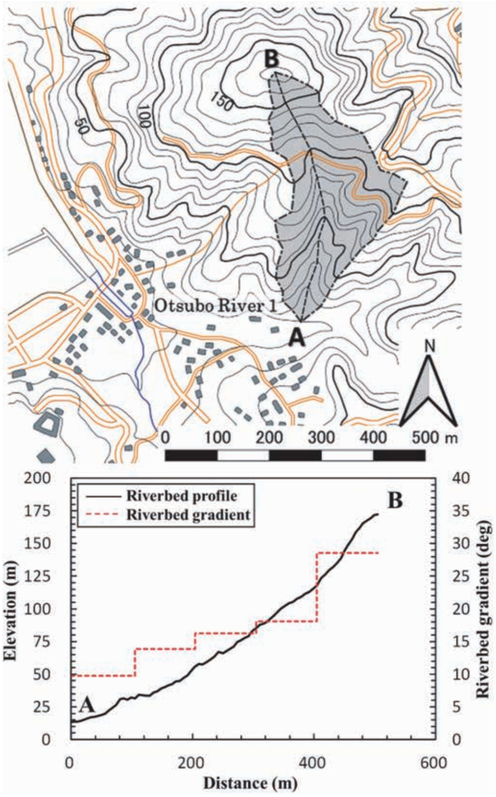

Fig.14 Topographic map and longitudinal section of Otsubo River 1

longitudinal section of Otsubo River 1 (basin area 0.068 km^2). The slope of the riverbed was approximately 10° at point A and became steeper upstream, reaching 28° at point B.

According to rainfall data from near the disaster area (Minamata observation station of Japan Meteorological Agency), hourly rainfall began to increase around midnight on July 4, with three peaks : 76 mm at 01 : 00-02 : 00, 63 mm at 04 : 00-05 : 00, and 54 mm at 07 : 00-08 : 00 on July 4 (**Fig. 15**). The

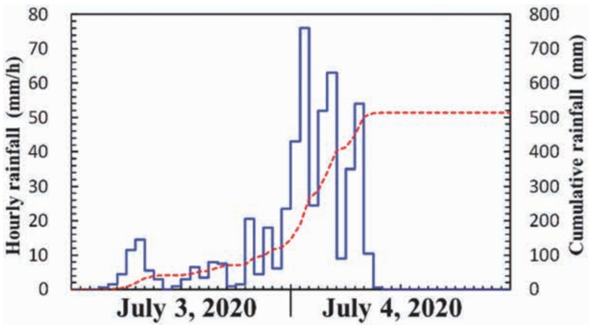

Fig.15 Rainfall on July 3-4 (Minamata observation station)

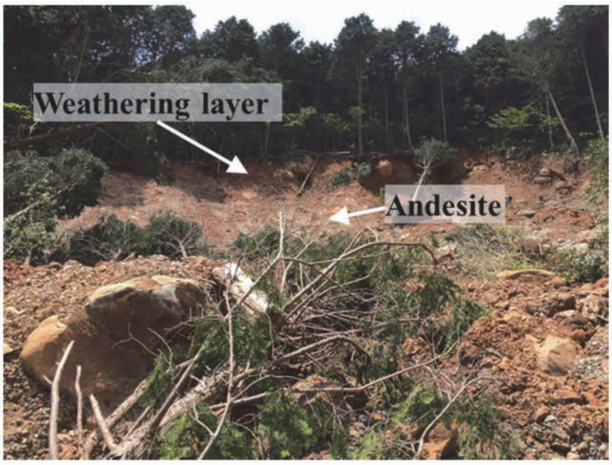

Fig.16 Head of the collapse in Otsubo River 1 basin (photo taken on August 1, 2020)

Fig.17 Erosion by debris flow in Otsubo River 1 (photo taken on August 1, 2020)

sediment disaster is estimated to have occurred during the second peak of rainfall.

Figure 16 shows the head scarp and sliding surface of the collapse. The collapse depth was 3-4 m, and the width was 40 m. The slope of the sliding surface was approximately 45°, and the slope of the surface of the collapsed sediment remaining in the collapse area was 35°. The collapsed slope consisted of Hisatsu volcanic andesite and subordinate siltstone.

Water came out from the boundary between them. A white clay layer was observed at the stratum boundary, indicating the possibility of a fault plane. In addition, mixed rocks consisting of mudstone and sandstone were distributed in the lower part of the collapsed slope, and gravels such as chert and limestone were also observed.

The collapsed sediment became a debris flow and flowed downstream while eroding the stream bank and bed (**Fig. 17**).

Fig.18 Sediment and flood damage in the Kawauchi River basin (photo taken on July 4, 2020, courtesy of Kyushu Regional Development Bureau, Ministry of Land, Infrastructure, and Transport)

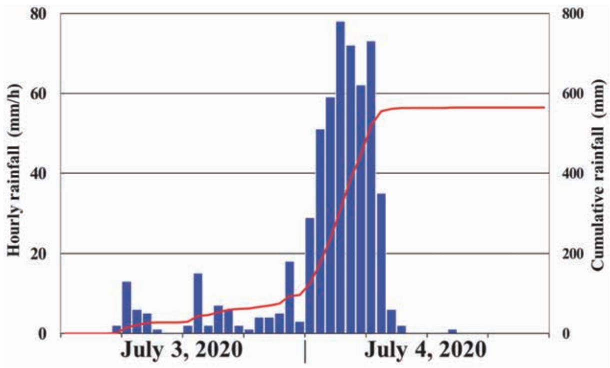

Fig.19 Rainfall on July 3-4 (Ministry of Land, Infrastructure, and Transport Kounose rainfall station)

4.5 Basin of Kawauchi River, a tributary of Kuma River

A sediment and flood damage occurred in the downstream area in the Kawauchi River (**Fig. 18**). The residents evacuated beforehand and there were no human casualties; however, many houses were destroyed, and sediment was deposited on floors. According to rainfall data from the Kounose rainfall station installed by the Ministry of Land, Infrastructure, Transport, and Tourism, MLIT, a maximum hourly rainfall of 78 mm and cumulative rainfall of 564 mm were recorded on July 3-4 (**Fig. 19**).

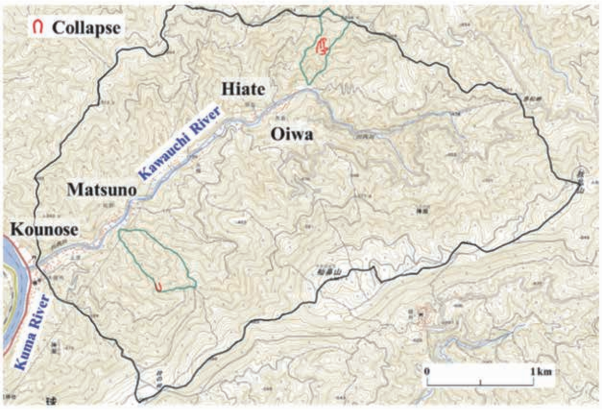

Fig.20 Topography of the Kawauchi River basin (using a Geospatial Information Authority of Japan map)

Fig.21 Collapse of a right bank stream upstream of the Oiwa area of the Kawauchi River (photo taken on August 11, 2020)

The Kawauchi River has a basin area of approximately 11 km^2 and flows in a straight line in a northeast-southwest direction to the confluence of the Kuma River in the last 3 km section. Villages are scattered along this section (**Fig. 20**). The riverbed slope is 2° near the confluence with the Kuma River and 4° near the uppermost village. The geology of the basin consists of sandstone and shale, and fracture zones caused by faults are distributed in the basin.

In the Kawauchi River basin, various sediment transport phenomena occurred, such as collapses, bed and bank erosion, and debris flows, and a large amount of sediment was produced. In the right bank stream upstream of the Oiwa area, five collapses occurred on a steep slope of more than 40°, one of which was due to a fractured weathering layer (**Fig. 21**). The total volume of collapsed sediment was estimated to be approximately 20,000 m^3, and the sediment flowed downstream into the Kawauchi River while eroding the stream bank and bed. As the sediment flowed through a narrow channel 6 m wide, it is assumed that the five collapses did not co-occur. The resulting sediment flowed down from each collapse separately. In addition, approximately 13,000 m^3 of sediment was estimated to discharge into the Kawauchi River due to the collapse from the crushed weathering layer and the accompanying debris flow in the stream on the left bank of the Matsuno area (**Fig. 22**).

Fig.22 Collapse of a left bank stream in the Matsuno area of the Kawauchi River (photo taken on July 18, 2020, courtesy of Kyushu Regional Development Bureau, Ministry of Land, Infrastructure, and Transport)

Sediment and flood damage occurred mainly at about 1.0 km between Kounose and Matsuno districts and about 0.5 km between Hiate and Oiwa districts. The main cause of sediment and flood damage may have been that sediment and floodwaters were not easily discharged into the Kuma River due to the backwater effect and were deposited in large quantities in the section of the Kawauchi River mentioned above (**Fig. 23**).

5. DISCUSSION

According to the *Fukuoka District Meteorological*

Fig.23 Flood retention in the Kawauchi River due to backwater effect from the Kuma River (photo taken on July 4, 2020, courtesy of Kyushu Regional Development Bureau, Ministry of Land, Infrastructure, and Transport)

Observatory [2020], this torrential rain set new records for 3, 6, and 12 h rainfall at many rainfall observation points across Ashikita Town and the Kuma River basin. In other words, it was the top rainfall event on record for this region in terms of heavy downpours lasting from three hours to half a day. Moreover, it was observed that it was difficult to evacuate after the torrential rains began, as information about a record-breaking deluge in a short period and emergency warning for heavy rainfall were issued at 03 : 00 and 04 : 00 on July 4.

All the collapse sites investigated in this study have a fragile ground (e.g., strongly weathered substratum, fracture zones, and concealed faults) extending deep underground, and the collapse depths are large. The combination of heavy rainfall lasting for several hours and the ground conditions in this area has potentially caused the deep collapses. As a result, the amount of collapsed sediment was much larger than that of general surface collapses, resulting in severe damage.

In Japan, the recovery and growth of forests, and the maturity of planted forests, have led to an increase in the ability of the tree root system to control surface collapse, making it more difficult for general surface collapses to occur in surface soils 1-2 m deep. The collapses investigated in this study occurred at a depth of approximately 5 m, which is much deeper than the depth of the tree root system. They are considered to have been influenced by the hydrogeological structure deep underground, such as groundwater flow along a fault plane and deeply weathered layers subjected to fracturing. Considering the extremes of heavy rainfall associated with climate change, it is possible that many similar collapses with large collapse depths influenced by deep underground hydrogeological structures will occur in the future. Slopes at risk of collapse should therefore be screened from such a perspective.

In future, it will be necessary to study physical characteristics that are more effective for predicting the location of a collapse with a large depth, which is determined by the deep underground hydrogeological structure, and to develop a detection method for accurately narrowing down the dangerous sections in a wide area.

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