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Geo-Disaster Report

Survey report on damage caused by 2019 Typhoon Hagibis in Marumori Town, Miyagi Prefecture, Japan

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Abstract

Typhoon Hagibis struck Japan on October 12–13, 2019. There was substantial damage over a wide area including the Tohoku region. In particular, Marumori Town, an urban area in Miyagi Prefecture that includes a town hall, was flooded due to heavy rain. The maximum cumulative rainfall and hourly rainfall measured in the town were over 600 and 70 mm, respectively. Heavy rain caused river flooding and landslides throughout the town, resulting in 10 deaths and one missing person. There was also substantial damage to the infrastructure, such as roads, railways, and river levees. The authors performed a field survey immediately after the disaster, and analyzed the observed data. Most levee breaches occurred due to overflow. A breached levee that failed in an unusual direction, namely, a failure which took place from the landside toward the waterside, was also observed. Landslides were not only caused by the amount of rainfall, but also by geological and topographical factors. Roads and railways were damaged by both river flooding and landslides. While both river flooding and landslides occurred in the Usudaira community, which is in the middle reaches of the Gofukuya River, there were no deaths or missing persons. This should be an important case for future disaster mitigation.

Keywords: Typhoon Hagibis; Marumori town; Field survey; River flooding; Landslide

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1. Introduction

Typhoon Hagibis struck Japan on October 12–13, 2019, causing substantial damage to the Tohoku, Kanto, Hokuriku, and Chubu regions. In the Tohoku region, damage occurred mainly in Iwate, Miyagi, and Fukushima Prefectures as the typhoon passed directly overhead. In particular, in Marumori Town, Miyagi Prefecture, there was serious damage due to heavy rain from the typhoon. Marumori Town is the southernmost town in Miyagi Prefecture (Fig. 1). It is a small town rich in natural beauty with a population of 12,453 (Miyagi Prefecture, 2020). This paper focuses on the damage to Marumori Town. The damage to other areas of Miyagi Prefecture has been reported by Kazama et al. (2021).

The large volume of rainfall is the primary reason for the damage to Marumori Town. Fig. 2 presents a distribution map of the cumulative rainfall observed from 15:00 on October 11 to 9:00 on October 12 in Miyagi Prefecture (Sendai Regional Headquarters and Japan Meteorological Agency JMA, 2019). Fig. 3 displays a distribution map of the cumulative rainfall observed in Marumori Town. The Radar-AMeDAS precipitation data provided by the Japan Meteorological Agency (JMA, 2020a) were used to create the maps. As shown in the figures, very high levels of cumulative rainfall were observed in Marumori Town. There are two automatic weather stations in the study area, namely, Marumori and Hippo (Fig. 3). The locations of these weather stations are given in Fig. 3. Fig. 4 shows a time series of the hourly and cumulative rainfall observed at the two weather stations (JMA, 2020b). At the Hippo weather station, the maximum hourly rainfall was over 70 mm, and the cumulative rainfall observed in one day was over 600 mm.

Marumori Town is located in the Abukuma Mountains. Many rivers, including the Abukuma River, a first-class river and the second longest river in the Tohoku region, flow through Marumori Town. The upper reaches of the rivers are in the northern or eastern parts of the mountainous areas and are widely distributed. An urban area, including a town hall, is located in the northeastern part of Marumori Town. Fig. 5 is an aerial photo of Marumori Town provided by Google Earth (Google). The rivers and the locations of the casualties are also indicated in this figure. The deaths due to flooding occurred in the basins of the Shin River, Gofukuya River, and Uchi River near the urban area, while the deaths due to landslides occurred in the Koya and Hippo areas. According to Miyagi Prefecture (2019), there were 10 deaths and one missing person. The casualties in Marumori Town comprise almost half of the total casualties in Miyagi Prefecture. There was also substantial structural damage. In total, 113 houses were completely destroyed and 870 houses were partially destroyed. All the casualties were elderly people. Although the difficulty of evacuating elderly people during disasters has been pointed out and studied (e.g., Nakanishi et al.,

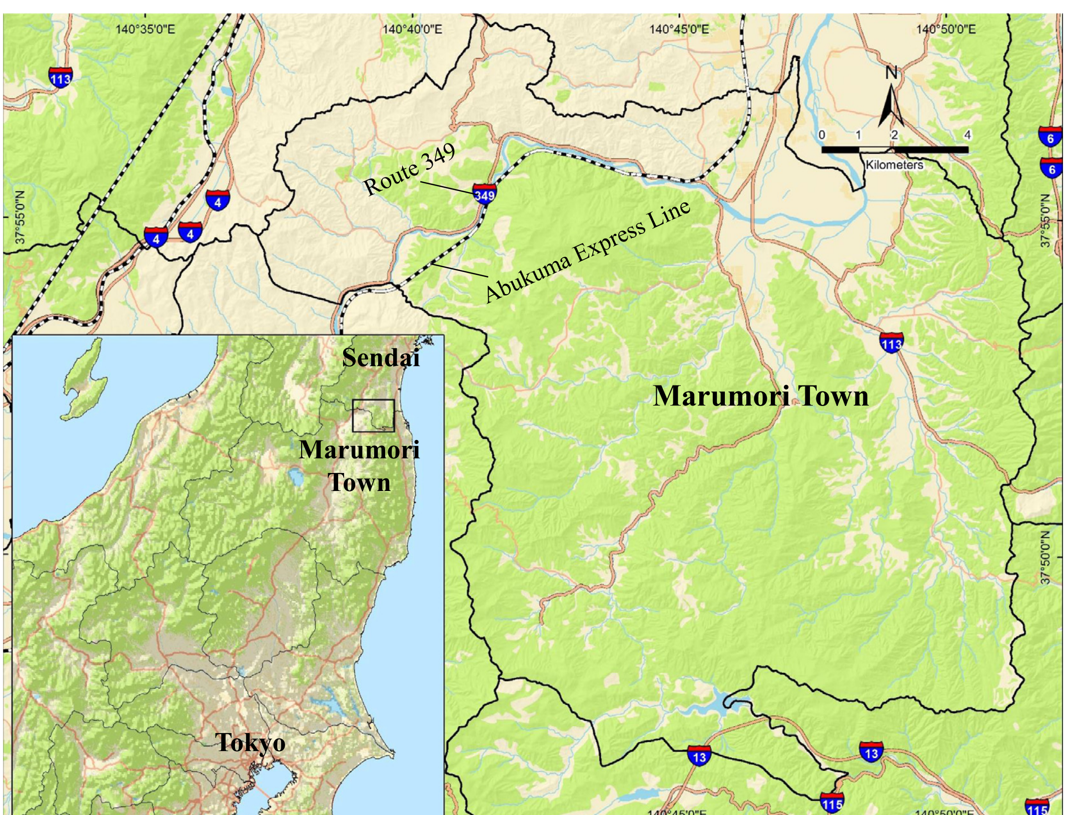

Fig. 1. Location of Marumori Town.

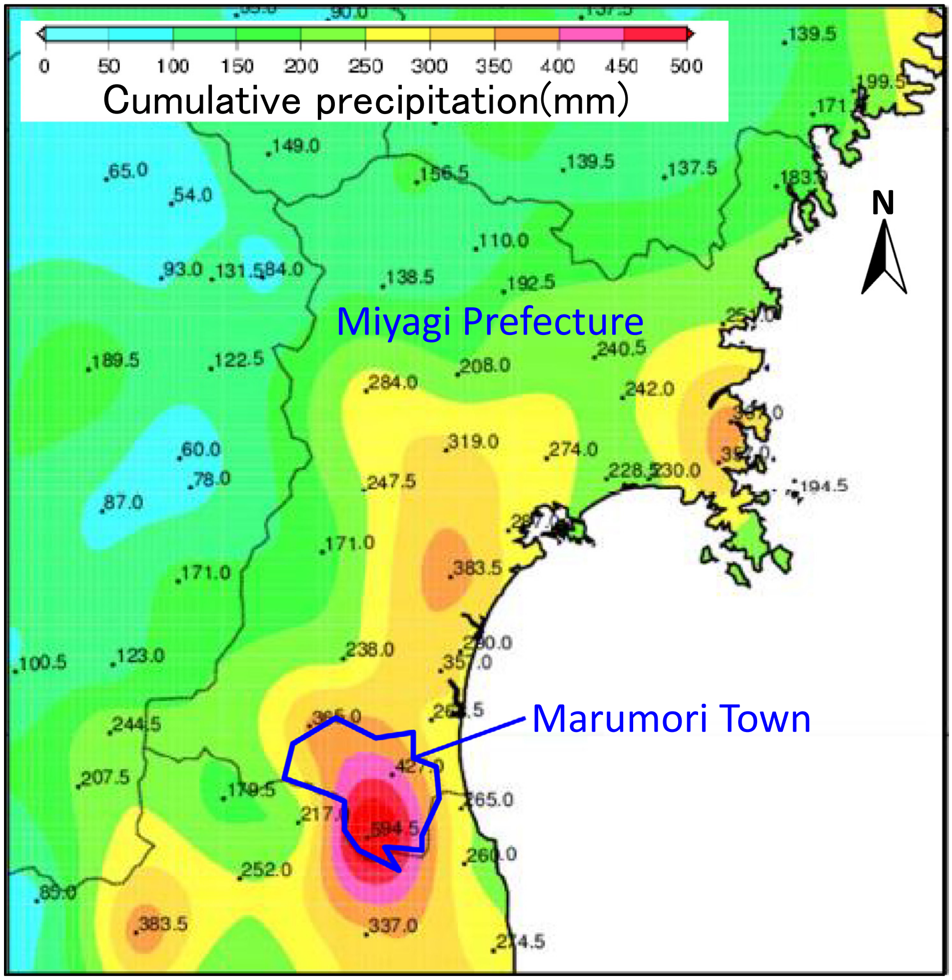

Fig. 2. Distribution map of cumulative precipitation in Miyagi Prefecture (After Sendai Regional Headquarters, JMA, 2019).

2019), the problem remains an unsolved issue in disaster management.

2. Damage from river flooding

2.1. River flooding in urban area

River flooding in the urban area located in the northeastern part of Marumori Town is described here in detail. As mentioned before, houses and buildings, including the Marumori Town Hall, are concentrated in this area. Houses and buildings were flooded due to inland flooding and the levee overflow of river water. Fig. 6 shows the flooded area and levee breach points around the urban area. This map was created from data provided by the Japanese government (Geospatial Information Authority of Japan, 2019; Ministry of Land, Infrastructure, Transport and Tourism, 2019). The Abukuma River and its tributaries, the Shin River, Gofukuya River, and Uchi River, flow through this area. Our field survey showed that there were no river breaches on the right levee of the Abukuma River or the left levee of the Shin River in the urban area. Here, the right and left orientations are viewed in the downstream direction. In addition, there were no traces of substantial overflow on the levees. It was concluded, therefore, that the inundation in the urban area was caused by inland flooding. On the other hand, there were many levee breaches on the right levee of the Shin River and the levees of the Gofukuya and Uchi Rivers. These levee breaches were caused by the rising water level of the rivers. As shown in Fig. 6, most levee breaches occurred near the river confluences. Soil sampling was performed (sampling points S1, S2, and S3 in Fig. 6) to investigate the sediment transported by the river flooding. A steel sampling tool, with a length of 1 m and a width of 0.1 m, was used for the sampling. Soil boring logs obtained at each sampling point are displayed in Fig. 7. As the samples were collected in active rice fields, the layers of cultivated soil indicate the surface layers before the river flooding. Silt and sand were transported by the river flooding; the river sediments covered the original surface with a thickness of approximately 40 cm. Ripple marks (Fig. 8) were observed on the ground surface at soil sampling point S3. This indicates that water, including a large amount of sediment, flowed over this area at a constant flow velocity.

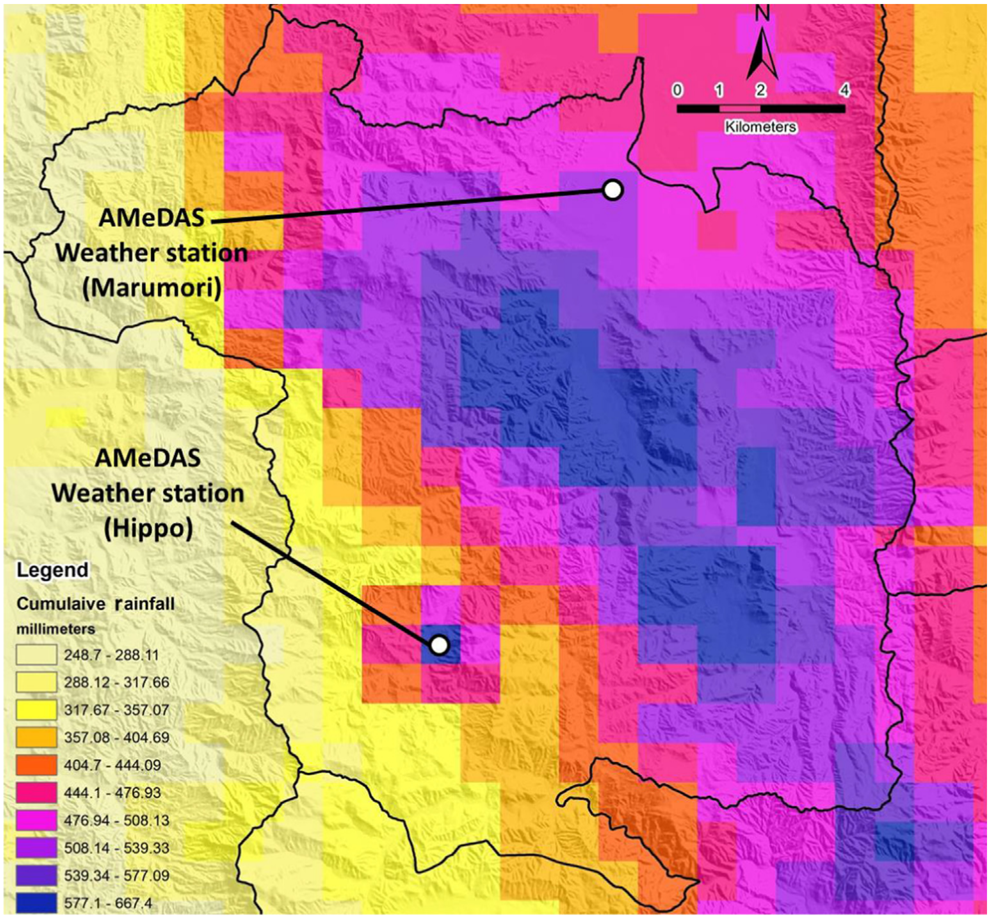

Fig. 3. Distribution map of cumulative precipitation in Marumori Town.

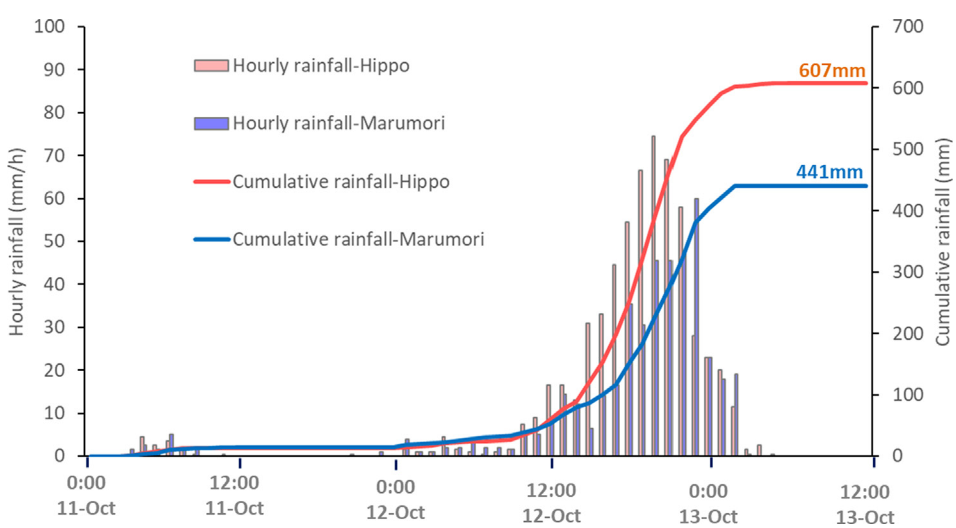

Fig. 4. Observed rainfall from 11 October 2019 01:00 am to 13 October 2019 12:00 am.

2.2. Typical cases of levee breaches

Fig. 9 shows a photograph of a levee breach that occurred on the right levee of the Shin River. The location of the levee breach is point A in Fig. 6. Photographs (a) and (b) in Fig. 9 were taken from the right and left levees, respectively. As shown in the figure, it was concluded that the levee failure developed from the landside toward the waterside. Levee failures generally occur from the waterside toward the landside, but this failure occurred in the opposite direction. This unusual levee breach was caused by rising water levels on the landside. It has been suggested

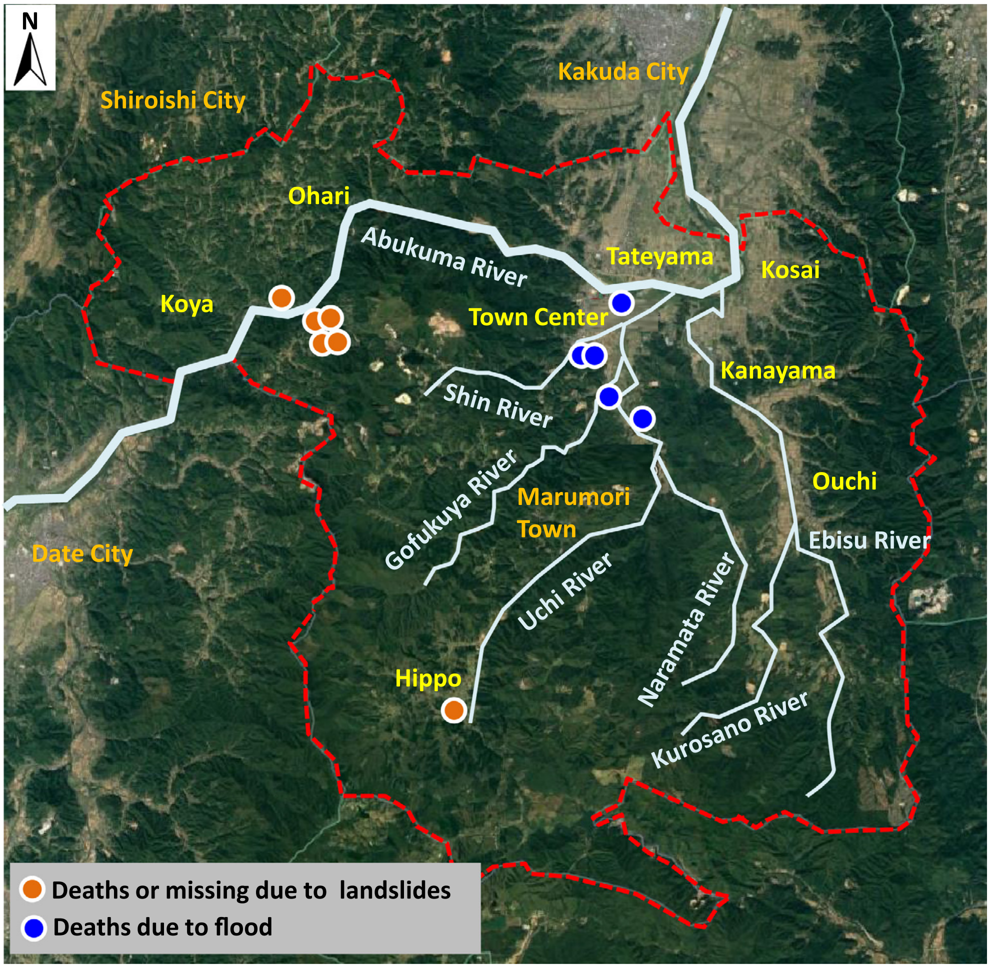

Fig. 5. River map and locations of deaths and missing person.

that the river water flowed out from the levee breach points of the Shin and Gofukuya Rivers, increasing the water level in the area between the rivers. As the area is surrounded by rivers and a mountain, the inland water drains poorly. The water content of the soil here remained high even two months after the disaster.

Fig. 10 displays aerial photos of the confluence of the Gofukuya and Uchi Rivers taken before and after the disaster. The aerial photos were obtained from Google Earth (Google). The location is shown as point B in Fig. 6. Levee breaches occurred at four points around the river confluence. The largest breach was observed on the left levee of the Gofukuya River. A large landside ditch was also found near the levee breach (Fig. 11). Here, failure occurred in the normal direction, so this levee breach developed from the waterside to the landside. Our field survey team found driftwood remaining on top of other parts of the levee near the levee breach point. This indicates that overflow occurred around the levee breach point. In addition, although the team searched for traces of seepage failure in the levee, none were found around the levee breach point. It was therefore concluded that the levee breach had been induced by the erosion of the levee on the landside due to the overflow of river water.

The two above-described levee breaches were induced by the overflow of river water. Despite searching for traces of seepage failure along the levee breach and in other areas, no evidence of seepage was found. Although it is possible that the traces of seepage failure were washed away, it seems reasonable to suppose that most of the levee breaches occurred due to the overflow of river water.

3. Damage caused by landslides and river flooding in mountainous areas

3.1. Relationship between distribution of landslides and geology

Fig. 12 presents a geologic map of Marumori Town overlain by the distribution of landslides that occurred during the 2019 Typhoon Hagibis. Information on the distribution of landslides, shown in black in the figure, was obtained from the website of the Geospatial Information Authority of Japan (GIAJ). GIAJ created this landslide distribution map using satellite image data obtained immediately after the disaster. It should be noted that landslides were not detected in part of the western area. The geologic map was made using data provided by the National

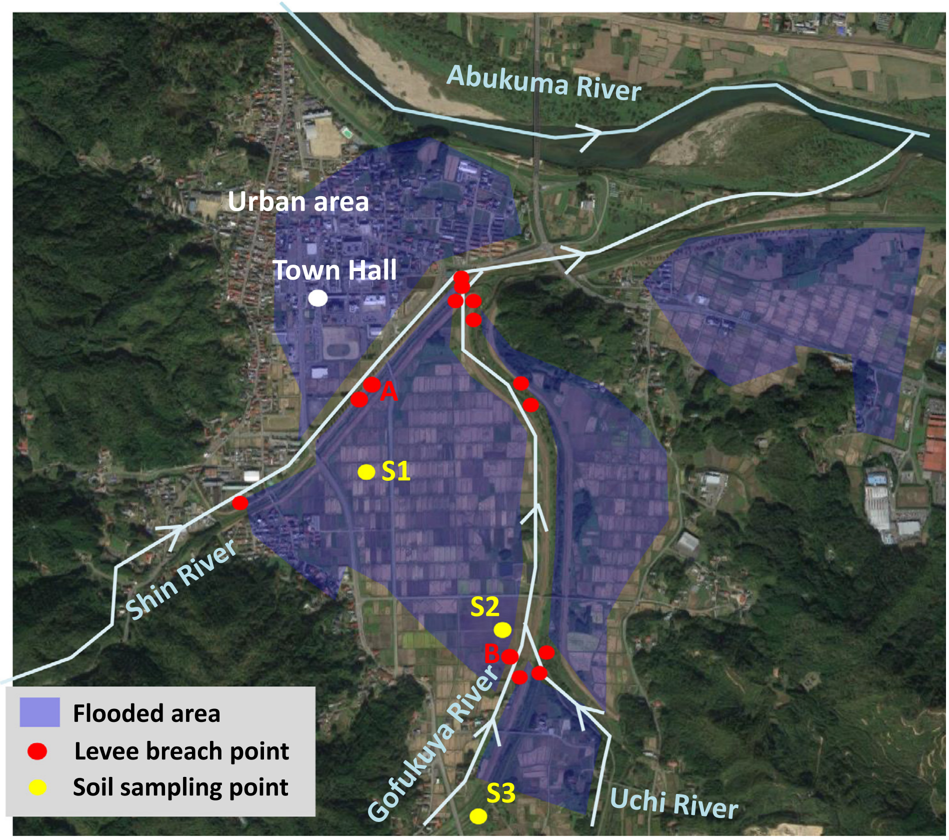

Fig. 6. Map of flooded area and levee breaches around urban area of Marumori Town.

Institute of Advanced Industrial Science and Technology (AIST, xxxx, AIST, xxxx). The geology of this area has been reported in detail by Kubo and Yamamoto (1990). As shown in Fig. 12, many landslides occurred in Marumori Town. The landslides mainly happened in the northwestern part and the middle reaches of the Shin, Gofukuya, and Uchi Rivers. Granitoids and granodiorite are widely distributed in these areas. Marumori Town is in the Abukuma Mountains. As granitoids and granodiorite are the main types of rock in the Abukuma Mountains, most parts of Marumori Town are underlain by these rocks. By comparing the distributions of landslides and rainfall (Fig. 3), a strong correlation can be found between them.

3.2. Debris flows in Mawarikura and Koyasu communities

The locations of the Mawarikura and Koyasu communities are labeled at point A in Fig. 12. Fig. 13 presents aerial photos (downloaded from Google Earth) that were taken before and after the disaster. The flow paths of the debris flows occurring in this area are shown as yellow lines. One of the debris flows, shown in the photo given in Fig. 14, caused three deaths and one missing person (Fig. 13). A geologic map of this area is displayed in Fig. 15. This area consists of mostly mid-Cretaceous granitoids and granodiorites, with basalt in areas of higher elevations. When exposed to weathering, the surfaces of granitoids and granodiorite generally change to granite soil. Granite soil was observed in our team's field survey. Granite soil has been recognized as a special soil, and some researchers have reported its properties (e.g., Kazama et al., 2003; Matsuo and Nishida, 1968, 1970). It has been reported that granite soil easily loses strength and flows under high water content conditions. Thus, it is well known that granite soil is at high risk for forming landslides. In fact, granite soil landslides and their risks have often been reported in recent disasters (Hashimoto et al., 2020; Nishimura et al., 2020). Although the debris flow that caused casualties occurred in the granodiorite rock areas, other landslides occurred in the granitoid rock areas. Some of them happened near the boundary between the granitoids and the basalt. It is estimated that the ground water located near the boundary was one of the causes of the debris flow.

As shown in Fig. 14, many large boulders were deposited along the paths of the debris flows. The large boulders were detached from the granitoid and granodiorite bedrock. Although granitoids and granodiorite weather to granite soil, the subsurface parts usually do not weather because they are not exposed to air. As a result, large boulders remain on the slopes. In the debris flow described here, it is estimated that granite soil flowed as a result of heavy

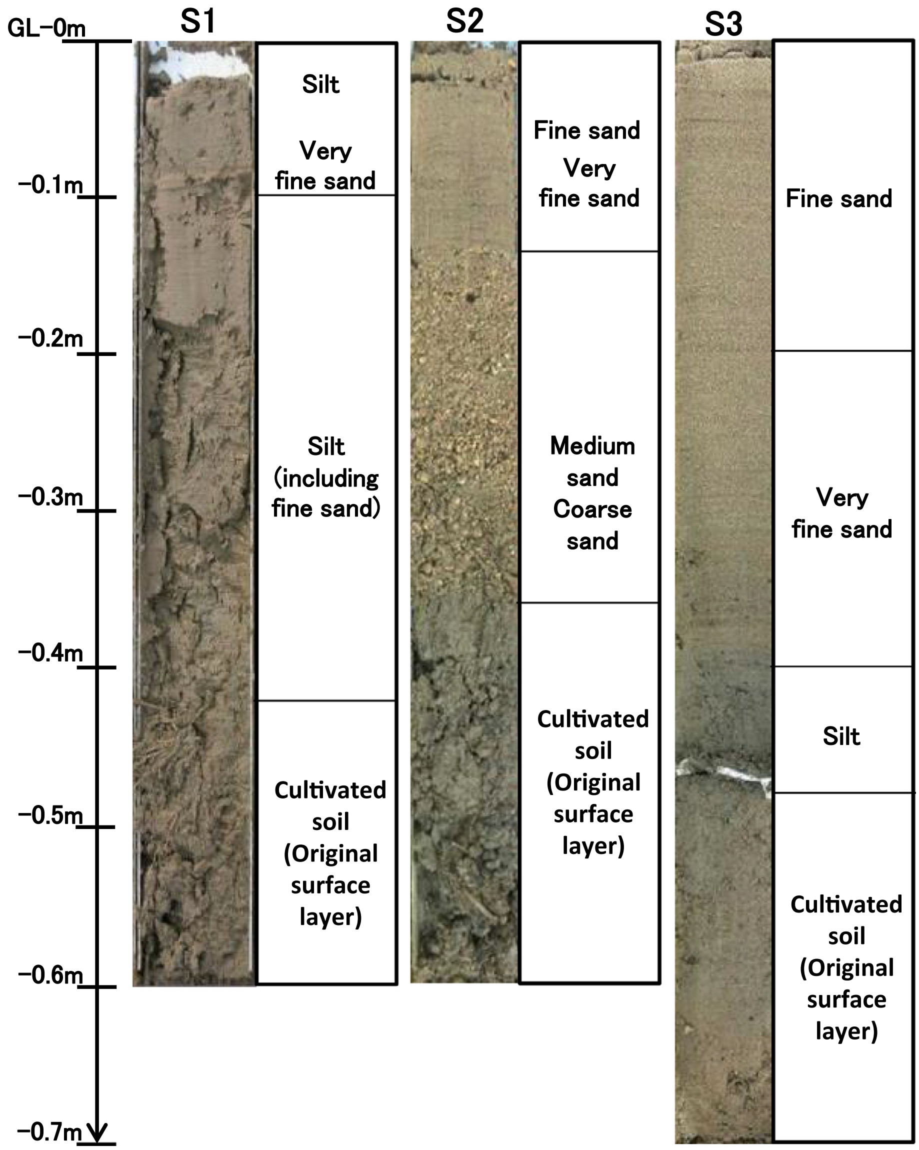

Fig. 7. Soil boring logs.

rain and destabilized pieces of in situ bedrock, which were then picked up and carried along with the debris flow. The impact force of the debris flow was thus extremely large. The risks associated with debris flows, including large boulders, have also been pointed out in survey reports of recent disasters (e.g., Hashimoto et al., 2020).

The low slope angle of the flow path of the debris flows should be noted. Fig. 16 is a distribution map of slope angles in the area. The debris flow that caused the casualties had a slope angle of 30 degrees or more near its source, but most of the parts of the flow path had a slope angle of approximately 20 degrees or less. It would be difficult to predict that such a relatively low-angle slope would produce such a large-scale, far-traveling debris flow. Although the slope angle is mainly used to evaluate the risk of slope disasters, the underlying geology should also be carefully taken into account in risk assessments.

3.3. Debris flows and river flooding in middle reaches of Gofukuya River

A great deal of serious damage occurred in the middle reaches of the Gofukuya River area. Washouts of bridges and roads from river flooding (Figs. 17 and 18) were observed. Fig. 19 is a geologic map of the middle reaches of the Gofukuya River area, overlain by a distribution map of landslides. Many landslides occurred on the slopes along the Gofukuya River. The middle basin of the Gofukuya River is a narrow valley, and the bedrock consists mainly of granite and granodiorite. This area is at high risk for landslides because of both its topography and geology. In addition, the cumulative rainfall in the middle reaches of the Gofukuya River was particularly large (Figs. 3 and 5). In other words, in the middle reaches of the Gofukuya River, landslides occurred abundantly because of topography, geology, and heavy rainfall.

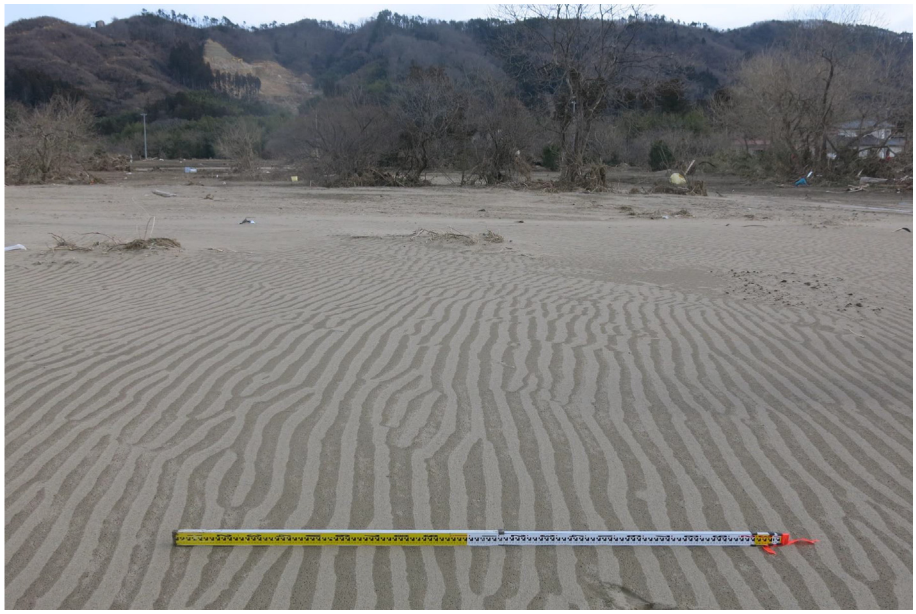

Fig. 8. Ripple marks observed at S3.

(a) A photograph taken on the right levee

(b) A photograph taken on the left levee

Fig. 9. Levee breach occurring on right levee (Shin River).

The Usudaira community is located in the middle reaches of the Gofukuya River, as shown by the dotted white line in Fig. 19. Fig. 20 shows aerial photos taken before and after the disaster. It can be seen from the figure that houses were destroyed by landslides and that the width of the river expanded greatly in the flood stage. Figs. 21 and 22 show damage to houses caused by landslides and river flooding. As landslides and flooding occurred at the same time, there was serious damage in the Usudaira community. Part of the debris flow path was previously designated as a sediment disaster hazard area, called a ‘‘yellow zone”, but in this event, a debris flow flowed beyond the designated zone. However, there were no casualties in this area, which is amazing considering the level of damage. One of the reasons for this result is that great efforts were made by the local residents to ensure strong mutual assistance. By sharing information among the residents and evacuating before the disaster, lives were protected in this area.

A terrace with a relative height of 5 to 7 m from the riverbed was exposed on the right levee of the Gofukuya River in the Usudaira community. The terrace is composed of boulders and sediments. Silt, including humus soil, is on the upstream side. This indicates that the Gofukuya River was dammed up in a previous debris flow that occurred in the past, forming a dammed lake. Hence, it is evident that debris flows have occurred in these areas many times throughout history.

3.4. Damage to Route 349 and Abukuma railway

Route 349 and the Abukuma Express Line run through the northern part of Marumori Town (see Fig. 1). These are parts of the important transportation infrastructure for residents. As many sections of the road and railway run parallel to the Abukuma River, substantial damage was caused by landslides and erosion resulting from the rising water levels. The road and railway were unusable after the disaster.

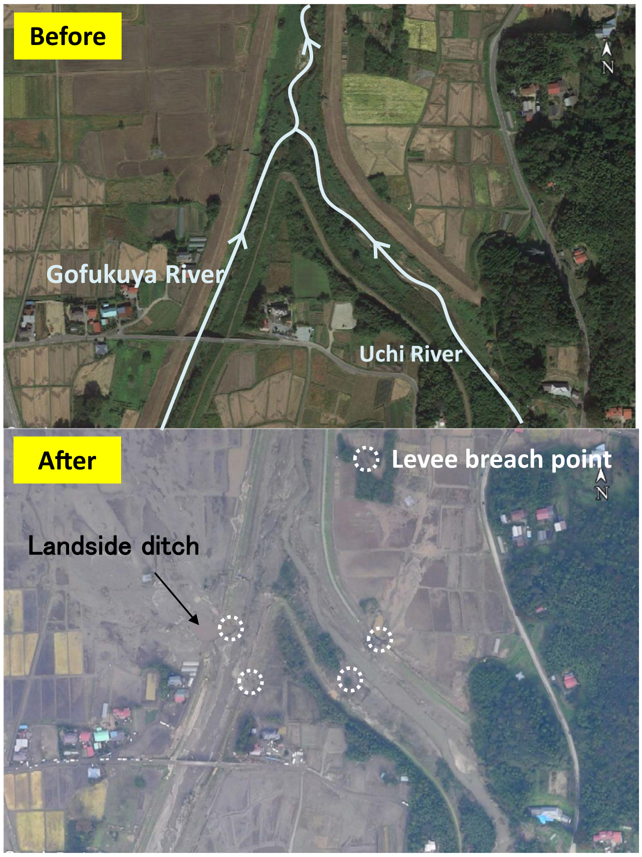

Fig. 10. Aerial photos of levee breach points (Gofukuya River).

Fig. 23 shows an example of damage to Route 349. Erosion caused washouts to road shoulders and river banks. Although half of the road remained at this location, many road sections were completely washed out or were cut off by landslides.

Fig. 24 displays aerial photos of Abukuma Station taken before and after the disaster. Debris flow and river flooding occurred at the same time near the station. The debris flow hit the platform of the station directly. In the same area, slightly farther from the platform, soil at the bottom of the railway track was washed out, and the track was floating in air. Figs. 25 and 26 show the damage caused by debris flows and river flooding, respectively. A small river flows perpendicular to both the road and the railway of the Abukuma Express Line. The two rivers merge just before an intersection, and then the river passes under the road and the railway through a box culvert. It can be estimated that the water volume increased sharply near the intersection with the influx of storm water and overflowed outside the box culvert, washing out the road and railway embankments.

4. Conclusion

This paper has summarized the damage caused by Typhoon Hagibis in 2019 in Marumori Town based on the results of our team's field survey. The characteristics of the damage are given below.

1) Many houses were inundated by river flooding around the urban area in the northeastern part of Marumori Town. As the levees adjacent to the urban area did not fail, the inundation in the urban area is thought to have resulted from inland flooding. On the other hand, in the area surrounded by the Shin, Gofukuya, and Uchi Rivers, many levee breaches occurred. In addition, some of these levee breaches developed in the direction from the landside toward the waterside. Most of the levee breaches occurred due to erosion induced by the overflow of river water.
2) Both landslides and river flooding occurred in mountainous areas. The landslides occurred mainly in granodiorite and granitoid areas. Granite soil is widely distributed on the surface and is underlain by weathered rock and corestones of granodiorite and granitoids in the subsurface. The combination of weathered granite soil and large boulders increases the risk of slope disasters.

(a) Cross-section of levee breach point (b) Landside ditch

Fig. 11. Levee breach occurring on left levee (Gofukuya River).

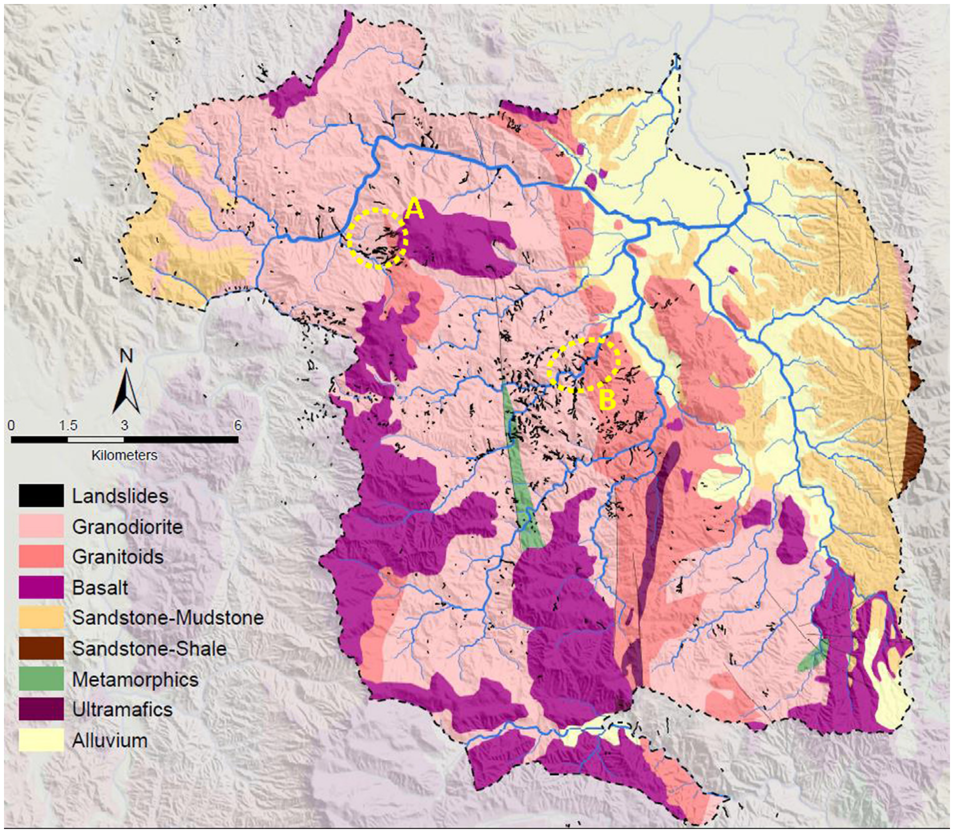

Fig. 12. Map showing distribution of surficial geology.

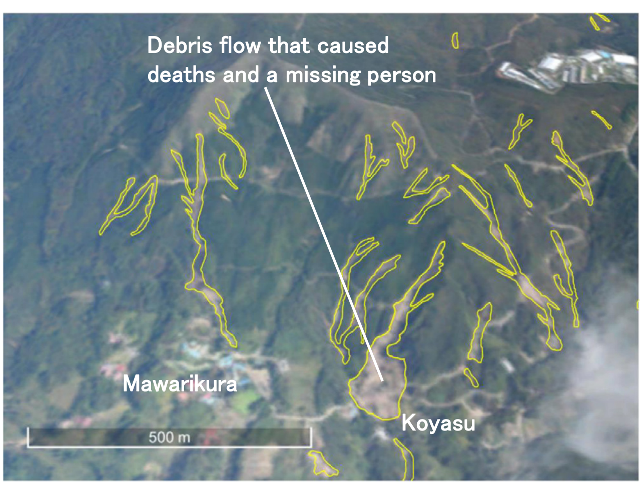

Fig. 13. Aerial photograph with outlines of landslides in Mawarikura and Koyasu communities.

Fig. 14. Photograph of debris flow occurring in Koyasu community.

3) In the middle reaches of the Gofukuya River area, landslides occurred at many places because of the large amount of rainfall, compounded by the presence of steep topography and granitic bedrock. In the Usudaira community, river flooding and debris flows occurred concurrently. However, there were no casualties in this area. This should be an important case for future disaster mitigation.

Reconstruction issues are summarized below.

A) Damage to levees occurred widely, especially along small- and medium-sized rivers managed by the prefecture. Countermeasures are required for future disasters, but for communities with small- and medium-sized rivers, there are many situations where a suffi-

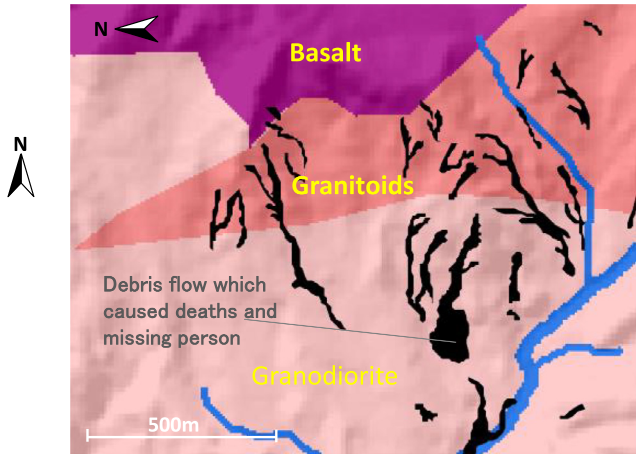

Fig. 15. Schematic geologic map of Mawarikura and Koyasu communities.

Fig. 18. Debris flow-induced road washout in middle reaches of Gofukuya River.

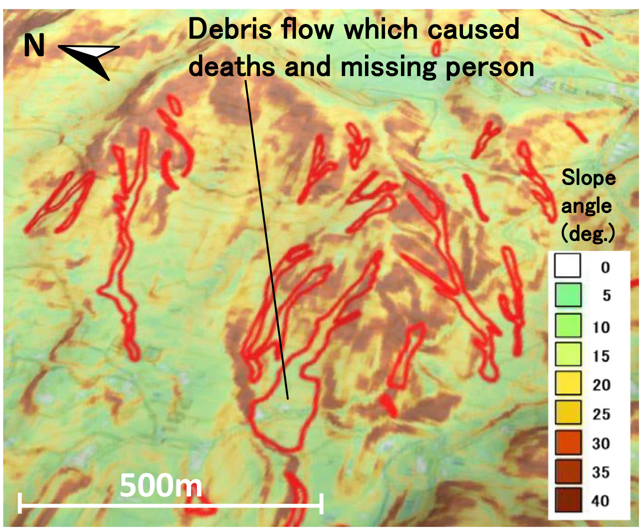

Fig. 16. Distribution of slope angles in Mawarikura and Koyasu communities.

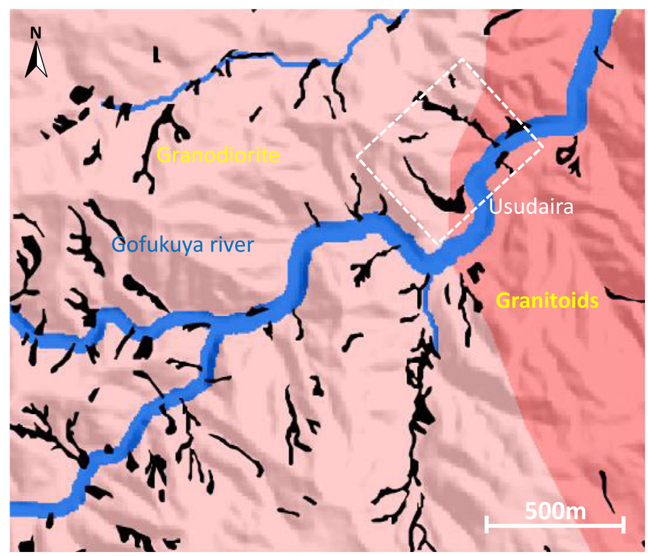

Fig. 19. Map showing distribution of landslides overlain on surficial geology in middle reaches of Gofukuya River.

Fig. 17. Washout of backfill at bridge abutment in middle reaches of Gofukuya River.

cient budget for levee–improving measures cannot be secured. Therefore, it is necessary to accurately identify the most critical parts of levees for disaster prevention and develop technology that can provide countermeasures at a low cost. Additionally, as revealed by the damage done to levees and roads from erosion induced by rising water levels in rivers, the process of erosion is quite a complex phenomenon that is based on the interaction between geomaterials and fluids. Therefore, it is necessary to develop technologies that can realize a higher level of cooperation between geotechnical engineering and river engineering.

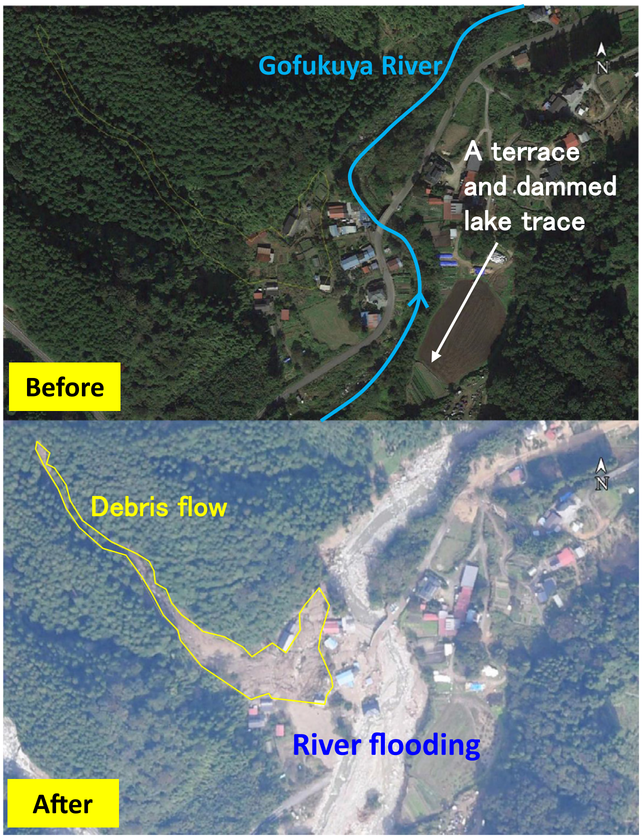

Fig. 20. Damage caused by debris flow and river flooding in Usudaira community.

Fig. 21. Damage to houses caused by debris flow in Usudaira community.

B) Regarding the damage caused by landslides, there is a strong correlation between landslides and the geology and geological boundaries. In addition, there are cases where landslides occurred even on relatively low-angle slopes, such as the debris flows in the Mawarikura and Koyasu communities. In

Fig. 22. Damage to house caused by river flooding in Usudaira community.

Fig. 23. Failure of road shoulder on Route 349.

the current risk assessment of slope disasters, the factors that are most often used are the topographical characteristics, slope angles, and disaster records, but techniques should be developed that can quantitatively consider the effects of geology and the degree of weathering.

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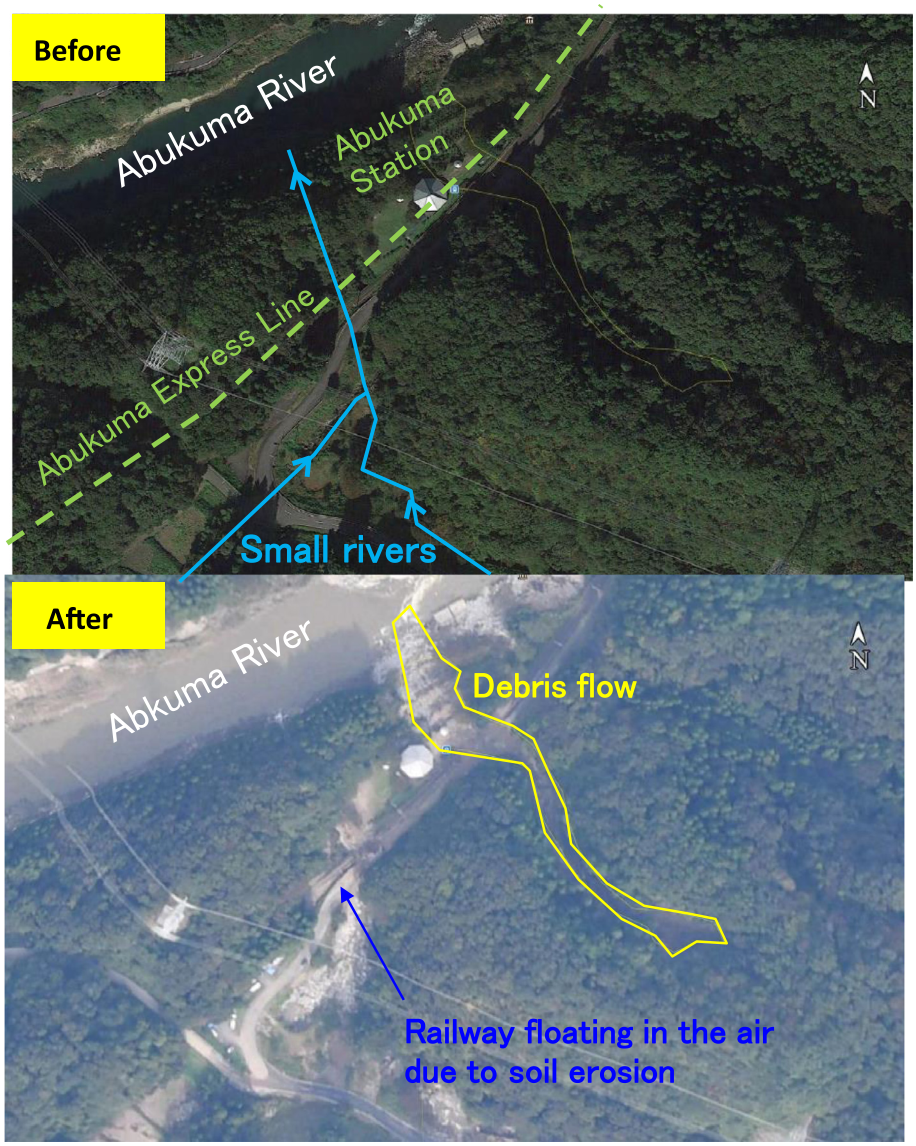

Fig. 24. Aerial photographs of Marumori Station.

Fig. 25. Damage caused by debris flow at Abukuma Station.

Fig. 26. Railway floating in air due to soil erosion.

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