Establishment of emergency response methods in the event of a large-scale landslide disaster such as a river channel blockage

1. Outline of Research and Activities

Disaster	Number of river channel blockages	Disaster response
October 23, 2004 Niigata Chuetsu Earthquake	52	○Outline determination of the risk of river channel blockage failure ・Outline assessment of the risk of river channel closure for two large-scale blockages (Terano and Higashitakesawa) in the main Imogawa River
June 14, 2008 Iwate-Miyagi Nairiku Earthquake	15	○Numerical simulation of river channel closure risk assessment
August 30 - September 5, 2011 Typhoon No. 12 (Kii Peninsula Flood)	17	○Emergency survey based on the Landslide Prevention Act ・First emergency survey on river channel blockage after the revision of the law (simulation of mudslide inundation, etc., five locations) Notification and publication of emergency information on landslide disasters to relevant local governments ○Deciphering natural dams using satellite SAR images
September 6, 2018 Hokkaido Bold Eastern Earthquake	Large scale is 1	○Automatic decipherment of collapsed areas using satellite SAR images

Research

Research ① Publishing of technical guidelines for large-scale river channel blockage response (2005-2009)

・Compilation of technical guidelines for response to the 2004 Niigata Chuetsu Earthquake and the 2008 Iwate-Miyagi Nairiku Earthquake based on the actual response of natural dams during the earthquakes

Research ② Technical development and human resource development for emergency surveys based on the Landslide Prevention Act (2009-)

・Review of the Guidelines for Conducting Emergency Surveys Based on the Landslide Prevention Act (Landslide prevention measures for landslide dams) (2009-)

・Investigation of analysis methods for the period when damage may occur due to mudslides

・Concurrent training for Regional Development Bureau staff (2013-)

Research ③ Research on deep collapse countermeasures (normal and emergency)

・Enhancement of emergency response to large-scale sediment occurrence (2014-2016)

・Damage estimation method for landslides caused by deep failure (2014-2016)

Research ④ Establishment and research of the Technical Center for Large-Scale Landslide Countermeasures (2014-)

・Establishment of the Large-Scale Landslide Countermeasures Technology Center in Nachikatsuura-cho, Wakayama Prefecture in 2014 in collaboration with the Kinki Regional Development Bureau and others to promote research on deep collapses, etc.

Research ⑤ Survey method by satellite SAR observation (2007-2019)

・Erosion control watershed monitoring methodology by remote sensing (2007-2012)

・Large-scale landslide disaster monitoring methodology using remote sensing (2013-2019)

・Joint research with JAXA and “Sediment WG Meeting” with JAXA to promote research on satellite SAR image interpretation

Reflection of results (Manuals, etc. developed based on the study)

[Development of response manuals for channel blockage and deep channel failures]

[① Technical guidelines in response to the track record of natural dam response to earthquakes]

○Technical manual for natural dam monitoring (Draft), Public Works Research Institute, December 2008

○Manual for natural dam countermeasure works (Construction edition) (Draft), Study Group for Natural Dam Countermeasure Works (Erosion Control Department, Ministry of Land, Infrastructure, Transport and Tourism, Tohoku Regional Development Bureau), November 2010

○Basic approach to natural dam formation response (Draft), Sabo Planning Division, NILIM.

[②③ Manual on emergency survey methods based on the Landslide Prevention Act]

○Guidelines for conducting emergency investigation based on the Landslide Prevention Act (Landslide prevention measures due to river channel obstruction) and calculation program, Ministry of Land, Infrastructure, Transport and Tourism, Erosion Control Department, NILIM, Public Works Research Institute, Japan. April 22, 2011

○Same as above Guidelines were revised on March 31, 2016

[③④ Documents and manuals on deep collapse countermeasures]

○Technical guidelines for countermeasures against deep-seated catastrophic (rapid) landslides, NILIM Technical Note No. 807, 2014

○Assessment method for sediment disaster damage due to deep-seated catastrophic (rapid) landslides, NILIM Technical Note No. 983, 2017

[Crisis management]

○Recommendations on crisis management for large-scale landslide disasters, Large-Scale Landslide Disaster Crisis Management Review Committee, 2007.3

[Review and revision of laws]

○Legal system for warning and evacuation for special landslides (Proposal), Study Group on the Legal System for Warning and Evacuation for Special Landslides, etc. (in Japanese), December 2009

★Landslide Prevention Act
Amended on November 25, 2010
Enacted on May 1, 2011
(Emergency investigations and provision of emergency information on landslides and waterlogging caused by natural dams)

[⑤Development of manuals for satellite SAR surveys]

○Method of emergency search for the location of landslide dams using high-resolution single-polarization SAR image interpretation, NILIM Technical Note No. 760, 2013

○Method of emergency search for the location of landslide dams and collapses using high-resolution dual-polarization SAR image interpretation, NILIM Technical Note No. 791, 2014

○Guidelines for the interpretation of sediment-related disasters by synthetic aperture radar (SAR) images, NILIM Technical Note No. 1110, April 2020

In 2004, 2008, and 2011, earthquakes and heavy rains caused a series of deep-seated landslides and natural dam disasters, strongly reaffirming the need for a response to such large-scale sediment disasters as well as crisis management.

The Sabo Department of NILIM dispatched erosion control researchers to the disaster sites to support local response, and has continuously engaged in the creation of manuals and technical development of knowledge obtained through response, intensive field-based research, and training of human resources capable of responding to natural dam disasters and other disasters.

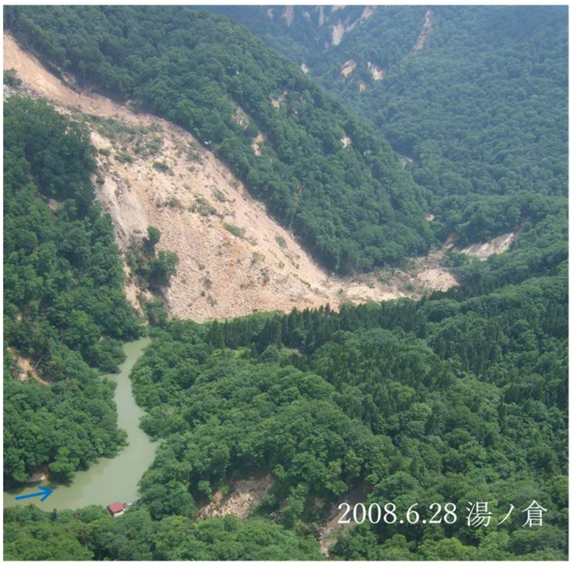

Figure-1 Yunokura river channel blockage caused by the 2008 Iwate-Miyagi Nairiku Earthquake (Natural dam)


Figure-2 Field survey of river channel blockage (natural dam) by the Landslide Research Department (Iwate-Miyagi Nairiku Earthquake in 2008)
Field survey of collapsed sediment accumulation and upstream waterlogging at a natural dam that formed a channel blockage

Research ① Preparation of technical guidelines for dealing with large-scale river channel blockages (2005-2009)

A large number of natural dams were formed by the Niigata Chuetsu Earthquake in October 2004 and the Iwate-Miyagi Nairiku Earthquake in June 2008 (Figure-1), and many researchers from the Sabo Department of NILIM and the Sediment Management Research Group of the Public Works Research Institute (PWRI) were dispatched to support the Regional Development Bureau (Figure-2). In March 2007, the "Large-Scale Landslide Crisis Management Review Committee" recommended the necessity of developing a crisis management system for large-scale landslides, and also pointed out two issues: how the government should provide support such as dispatching Sabo researchers from NILIM and PWRI, and the need to develop new equipment and materials. The 2008 Iwate-Miyagi Nairiku Earthquake highlighted specific issues related to the technology for dealing with large-scale landslides, while the PWRI Sediment Management Research Group's newly developed equipment and materials, such as the Doken drop-type water level observation buoys, were utilized.

Based on the issues identified, the Sabo Department of NILIM, together with the Tohoku Regional Development Bureau, the PWRI Sediment Management Research Group, and others, compiled the basic approach to natural dam response technology based on the knowledge accumulated through the response to recent earthquakes and other disasters. The "Basic Approach to the Response to Natural Dam Formation (Draft)," the "Technical Manual for Monitoring Natural Dams (Draft)," and the "Manual for Construction of Natural Dam Countermeasures (Construction Edition)" were compiled as technical guidelines for natural dam response that update the existing response manuals by establishing the basic approach to technology.

Research ② Technical development and human resource development for emergency surveys based on the Landslide Prevention Act (2009-)

The “Act Concerning the Promotion of Landslide Disaster Prevention Measures in Landslide Disaster Prevention Areas, etc.” (hereinafter referred to as the “Landslide Disaster Prevention Act”) was not designed with special landslide disasters in mind, such as river channel blockages that require advanced techniques to manage, and there were no provisions for the national government to support municipal mayors in appropriately issuing evacuation orders, etc., as pointed out by the “Study Group on the Legal System for Warning and Evacuation for Special Landslide Disasters.” Consequently, the Landslide Prevention Act was revised in 2010, and the government’s emergency investigation and emergency information on landslide disasters to support municipal mayors in the event of special landslide disasters such as river channel blockages were legally established. In response, the Erosion Control Department of the Ministry of Land, Infrastructure, Transport and Tourism, the Sabo Department of NILIM, and the PWRI Sediment Management Research Group prepared the guidelines for emergency sediment disaster investigation and a numerical calculation program to estimate the extent of damage caused by debris flows due to river channel blockages (natural dams) and other causes.

Figure-3 River channel blockage (natural dam) caused by heavy rainfall from Typhoon No. 12 in 2011 (Kumano River Basin, Gojo City Akaya, photographed by the Sediment Control Research Group, PWRI on September 6, 2011)

The guidelines and programs prepared by the Sabo Department of NILIM, and others were actually utilized when the government conducted an emergency survey based on the Landslide Disaster Prevention Act for the first time in Japan, targeting five large-scale river channel blockages in Akadani (Figure-3) and other areas after Typhoon No. 12 in September 2011 caused deep channel failures in the Kii Peninsula. In this disaster, the Sabo Department of NILIM and the PWRI Sediment Management Research Group dispatched a number of researchers to provide technical support for the Kinki Regional Development Bureau’s response (Figure-4).

Figure-4 Detailed survey of blocked river channel by the Landslide Research Department

On the other hand, it became clear that in the case of a disaster of a large scale, such as the occurrence of several large-scale natural dams, the number of staff members familiar with emergency surveys was not sufficient in the affected Regional Development Bureau alone. Therefore, the Sabo Department of NILIM, in cooperation with the PWRI Sediment Management Research Group, launched the “Support Program for Training Regional Bureau Officials for Advanced Landslide Countermeasures” in 2013 with the aim of supporting human resource development of the regional bureau staff members who are familiar with the contents and implementation methods of emergency surveys, based on knowledge gained through

Figure-5 Training support program for local development bureau staff members engaged in advanced landslide countermeasures
Measuring the height of a natural dam with a laser rangefinder from inside a helicopter.

past disaster responses (Figure-5). Under this program, staff members at the rank of section chief of the Regional Development Bureau are concurrently assigned to the Sediment Hazard Research Department of NILIM and PWRI from April to December to disseminate knowledge obtained by the Sabo Department of NILIM and the PWRI Sediment Management Research Group on how to respond to sediment-related disasters such as river channel blockages. By FY2020, a total of 65 people had participated in the program.

Research ③ Research on deep collapse countermeasures (normal and emergency) (2014-2016)

Natural dams often result from the occurrence of large-scale landslides known as deep-seated landslides, which occur less frequently than ordinary landslides, but can be very large in scale and cause extensive damage. Many disasters that formed natural dams due to deep-seated landslides caused by earthquakes or heavy rains have occurred in Japan and abroad in recent years, and the need for countermeasures, including emergency responses, has increased.

Therefore, the Sabo Department has been conducting research on countermeasures against deep-seated catastrophic (rapid) landslides, and NILIM Technical Note No. 807 "Technical guidelines for countermeasures against deep-seated catastrophic (rapid) landslides" was published in 2014. The guidelines include (1) hard countermeasures by improving facilities, (2) evacuation based on information on the imminence of deep-seated landslides, and (3) disaster prevention planning based on information on land hazards (hazard maps) related to damage caused by deep-seated landslides (e.g., appropriate locations for evacuation centers and disaster prevention sites), etc. The "Technical guidelines for disaster prevention planning" (Figure-6) covers the following three points.) On the other hand, after the development of the "Technical guidelines for countermeasures against deep-seated catastrophic (rapid) landslides," the Regional Development Bureau has been studying disaster scenarios related to deep-seated landslides. The Sabo Department of NILIM has also been conducting new studies on damage prediction due to deep-seated catastrophic failures, and based on these recent efforts, NILIM Technical Note No. 983 "Assessment method for sediment disaster damage due to deep-seated catastrophic (rapid) landslides" was published.

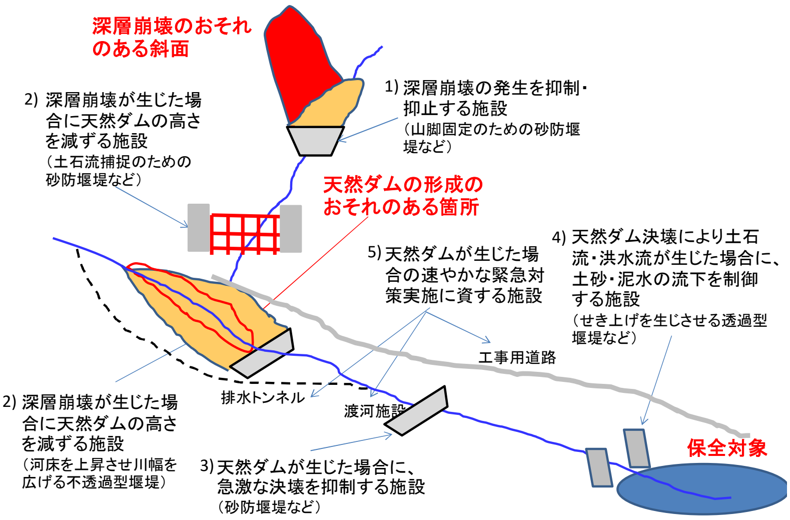

Figure-6 Image of hard countermeasures for natural dams

Based on these technical notes, regional development bureaus are now studying disaster scenarios in model areas set up in erosion control project zones under direct control throughout Japan.

Research ④ Establishment and research of the Technical Center for Large-Scale Landslide Countermeasures (2014-)

In 2011, Typhoon No. 12 caused deep collapses at 72 sites in the Kii Peninsula. Since then, the Kii Mountain Range Erosion Control Office has been carrying out erosion control works under severe conditions, such as slope recollapses and deformations at the river channel blockage points during the outflow season, which frequently require advanced judgment by researchers from the Sabo Department. In addition, deep failures, surface failures, and debris flows, and the sediment dynamics associated with them are not yet fully understood, and it is necessary to conduct in-depth and continuous topographic change measurements, hydrological observations of river flow, groundwater, spring water, etc., and an understanding of the sediment transport phenomena for each rainfall event.

For this purpose, the Kinki Regional Development Bureau established the Sediment Disaster Prevention Technical Center in Nachikatsuura-cho, Wakayama Prefecture in April 2014. Since 2017, the Sabo Department of NILIM has had one Sabo senior researcher on staff, who has been working on deep-seated landslides, and the department is promoting research on the mechanisms of shallow landslides and debris flow generation, etc.

Research ⑤ Research on survey methods using satellite SAR observations (2007-2019)

Since the launch of Japan's Advanced Land Observing Satellite "Daichi (ALOS)" in 2006, the Sabo Department of NILIM has conducted research on the utilization of observation data from Daichi (ALOS) and other satellites for erosion control watershed monitoring. Research on the utilization of satellite data has progressed, and in particular, synthetic aperture radar (SAR) data, which can be observed at night and in bad weather and includes phase information, has been used to monitor erosion control basins. In order to enable rapid initial response when a landslide is expected to occur, we conducted research and development on a method to identify landslide areas using SAR intensity images and interferograms from satellites such as Daichi-2 (ALOS-2), launched in 2014, and others.

In parallel, we made progress in our research on the use of satellite SAR images, etc. through joint research with JAXA (National Aerospace Exploration Agency (NAXA)), such as "Joint Research on the Development of Landslide Monitoring Methodology Using Satellite Daichi-2 (2017-2021)," and participation in the "Sediment WG Meeting" with JAXA.

2. Main Research Results

◆Research ① Publishing of technical guidelines for large-scale river channel blockage response (2005-2009)

The Sabo Department of NILIM, has compiled the “Draft Basic Approach to Natural Dam Formation Response,” which summarizes the basic concepts accumulated through the response to the October 2004 Niigata Chuetsu Earthquake and the June 2008 Iwate-Miyagi Nairiku Earthquake, with the aim of contributing to a prompt and effective response to natural dams, including “disaster response flow,” “initial response,” “investigation,” “risk assessment,” and “response during normal operation.” In order to quickly determine the risk level of a natural dam, a peak flow rate estimation method (simulation calculation method) was used at the time of a natural dam failure, taking into account the erosion process of the upstream slope using a two-layer flow model, etc. (Figure-7).

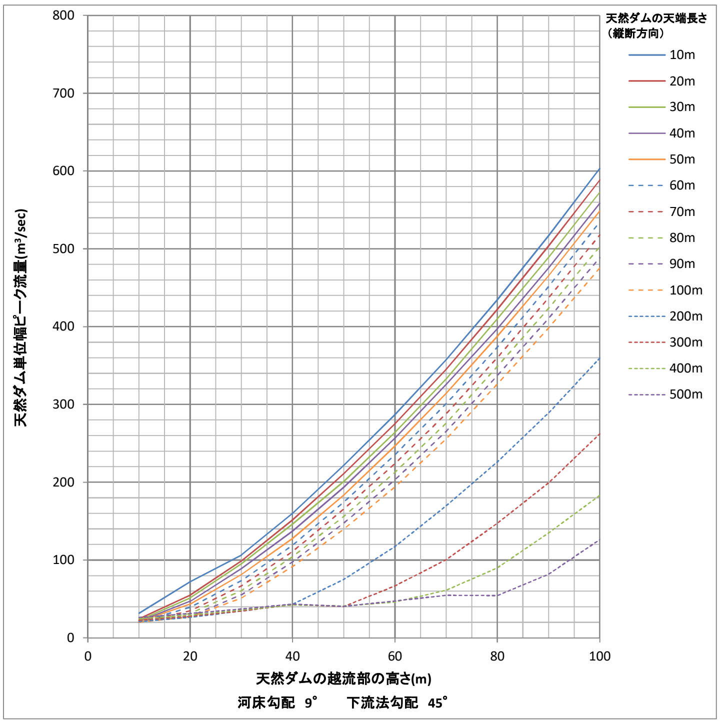

Figure-7 Example of a quick-response diagram of peak flow overtopping a natural dam

◆Research ② Technical development for emergency investigation based on the Landslide Prevention Act (2009-)

The Sabo Department of the Ministry of Land, Infrastructure, Transport and Tourism, the Sabo Department of NILIM, and the PWRI Sediment Management Research Group jointly prepared guidelines and a numerical calculation program to organize the minimum contents of the national emergency survey to be conducted under the Landslide Prevention Act from the decision to start the survey to its completion, mainly to ensure a certain level of accuracy and to produce results in less time.

Based on the guidelines prepared here, the first emergency survey after the enforcement of the revised Landslide Disaster Prevention Act was conducted for five natural dams in the Kii Mountain Range caused by torrential rains associated with Typhoon No. 12 in September 2011 (Figure-8). In addition, the Sabo Department of NILIM, and others, later compiled operational considerations based on their experience in conducting emergency surveys in this disaster, and revised the guidelines.

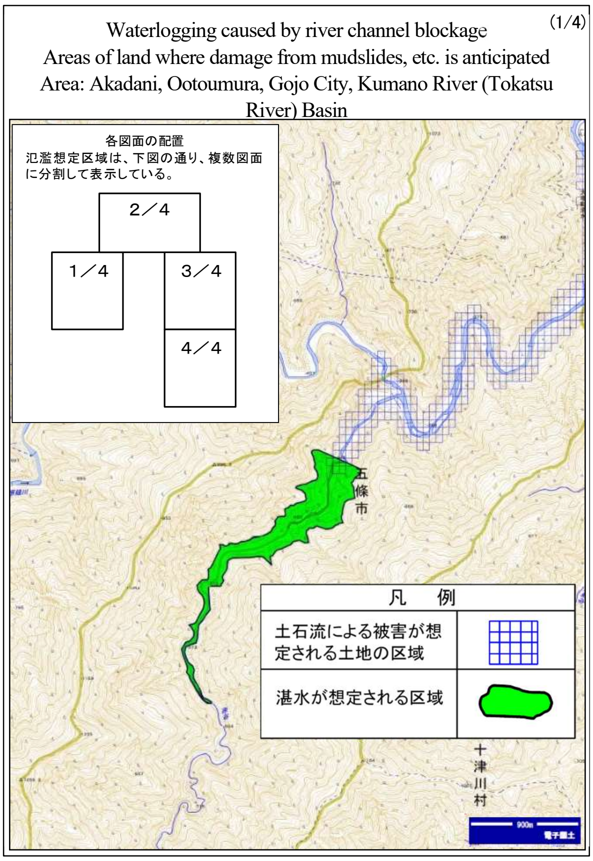

Figure-8 Areas of land that may be affected by mudslides, etc. caused by waterlogging due to channel blockage
(Example of Akadani, Gojo City, Kumano River Basin, September 2011)

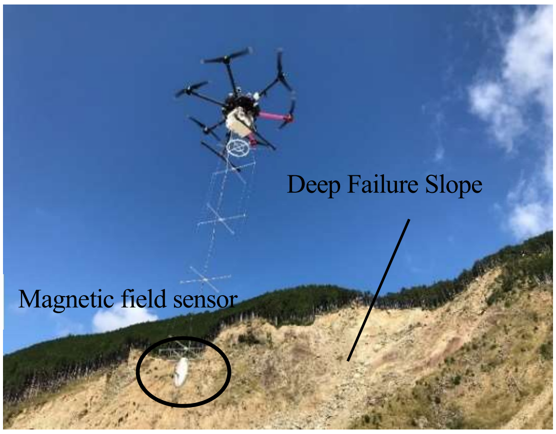

Figure-9 Drone airborne electromagnetic survey
An electric current is applied to a cable laid on the ground surface to generate a magnetic field, and a magnetic field sensor suspended from a drone measures the vertical component of the magnetic field in the subsurface.

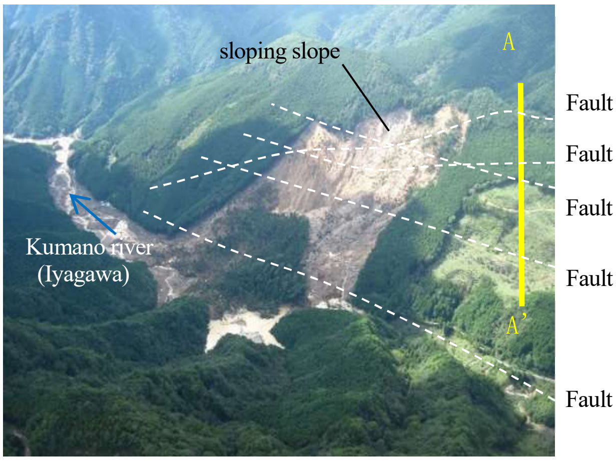

Figure-10 Kumano area, Tanabe City, Wakayama Prefecture, immediately after the disaster (September 5, 2011, photo by Landslide Disaster Research Department, NILIM)
Solid yellow lines indicate drone survey lines, and white dashed lines indicate the surface survey and fault zone.

◆Research ③ Establishment and research of the Technical Center for Large-Scale Landslide Countermeasures (2014-)

The mechanism of the deep-seated landslide in the Kii Mountains has been studied from various angles, including the topography, geology, and hydrology. It has been pointed out that the fault zone may have induced and dammed groundwater, which destabilized the slope and caused the deep-seated landslide.

In recent years, the development of airborne electromagnetic exploration using drones has enabled inexpensive, safe, and speedy investigation of groundwater behavior during heavy rainfall. Therefore, the Landslide Research Department of the National Institute of Land and Infrastructure Management (NILIM) conducted an aerial electromagnetic survey using a drone, which is the latest technology, for deep-seated landslides (Figure-9).

The drone airborne electromagnetic survey line spanned several faults, and a resistivity survey (depth of about 200 m) was conducted on the same line during two periods: immediately after Typhoon No. 14 (October 2020) and during the dry season (December 2020), to estimate the groundwater behavior during Typhoon No. 14 (Figure-10).

As a result, it was estimated that faults 1, 3, and 4 dammed groundwater, while fault 2 induced groundwater from the surrounding area (Figure-11). Thus, it was clarified that fault rupture zones influence the groundwater behavior and the induction and damming of groundwater by fault rupture zones strongly contribute to the occurrence of deep-seated landslides.

In the Kii mountain area, it was found that the deep-seated landslide risk can be accurately evaluated as a risk assessment method by investigating the planar distribution of the fault rupture zones and groundwater behavior during heavy rainfall by drone exploration (Figure-12).

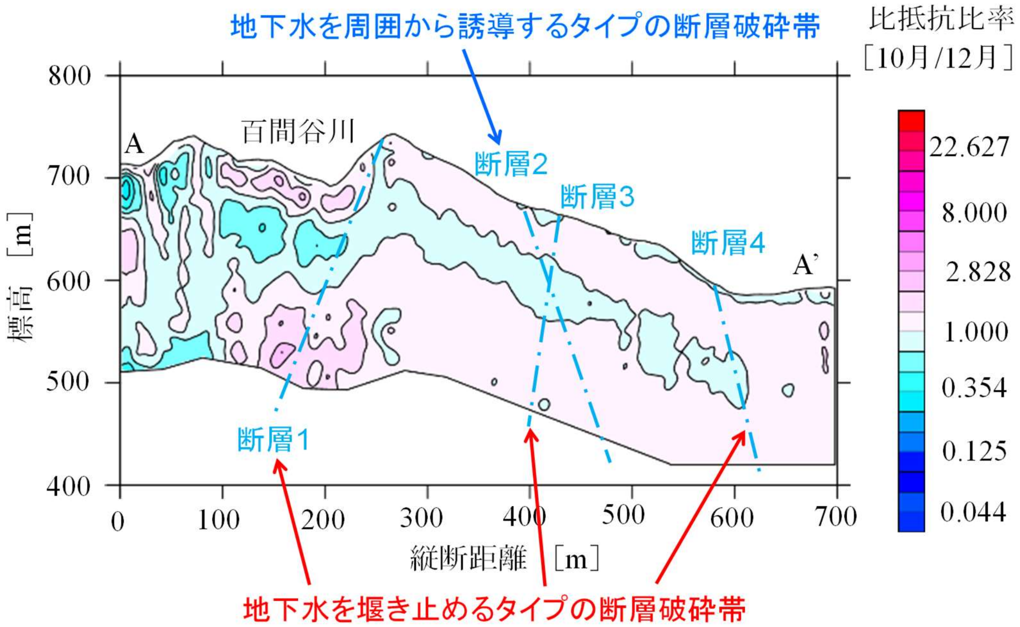

Figure-11 Longitudinal distribution of resistivity values obtained by dividing the resistivity values three days after the end of the rainfall caused by Typhoon No. 14 in 2020 by the resistivity values during the dry season (December 2, 2020) at the A-A' measuring line (Kumano area, Tanabe City, Wakayama Prefecture)

◆**Research ④ Research on survey methods using satellite SAR observations (2007-2019)**

When sediment accumulates in a river channel due to a large-scale or deep-seated landslide, it can block the river and create a waterlogged area. Sediment that blocks the river channel is often unstable, and if the waterlogged area expands rapidly, it may result in a collapse and cause extensive damage to the downstream area. It is also important to quickly identify the location and extent of concentrated slope and surface failures, so that emergency measures can be initiated as soon as possible.

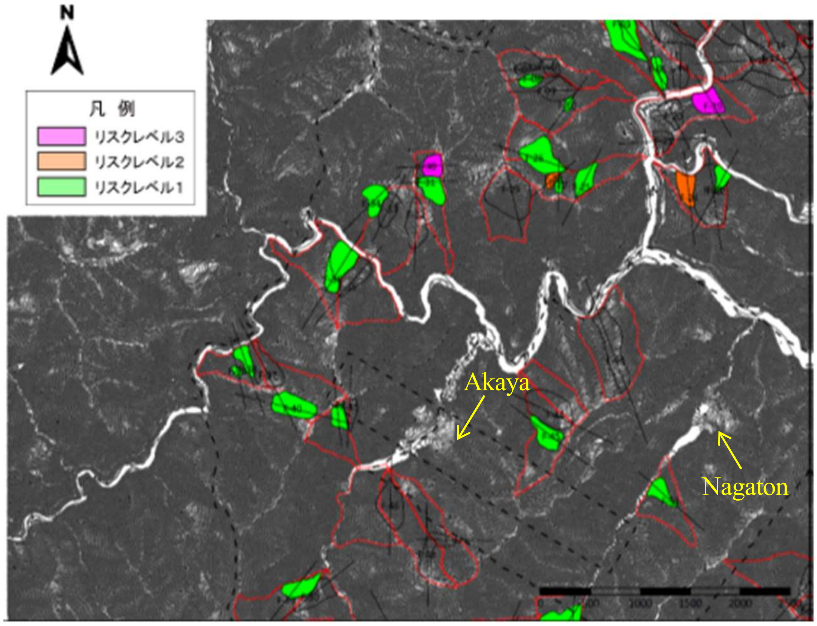

Figure-12 Example of deep collapse risk assessment map in the Kii Mountains (Near Akaya, Gojo City, Kumano River Basin)

For this reason, the Landslide Disaster Research Division of (NILIM) focused on the use of satellite SAR images, which can be observed day and night and in all weather conditions, and first studied a method to quickly identify river channel blockage points using single or multiple polarization images.

Furthermore, in recent years, the Landslide Disaster Research Division of (NILIM) has applied a method (Figure-13) for deciphering landslide damage using SAR intensity images before and after a disaster, utilizing data accumulated through regular observations. As a result, it was found that not only large-scale slope failures but also smaller failures, landforms, and land cover changes can be extracted, and that it is possible to assess the damage in a short time for landslides where slope failures occur in high density over a wide area.

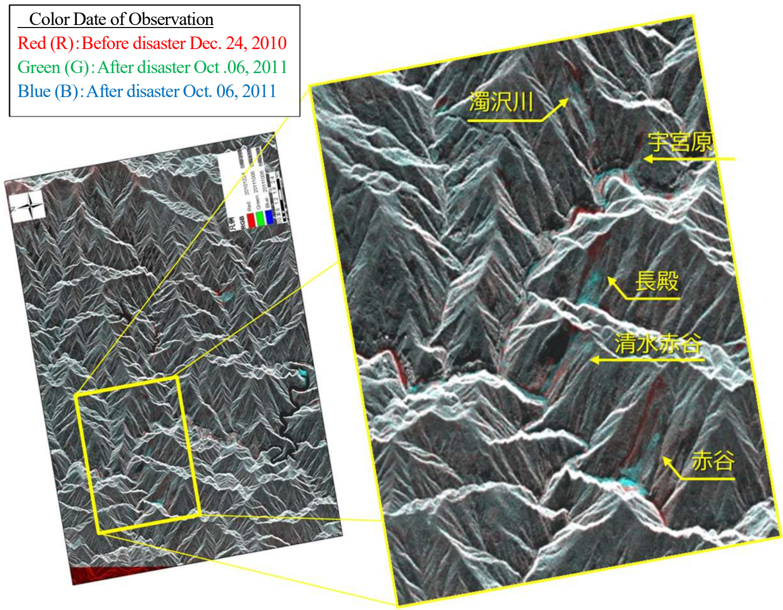

Figure-13 Stacked satellite SAR intensity images before and after the disaster (2011 Typhoon No. 12, Akadani, Gojo City, Kumano River Basin, near Nagadono, Totsukawa Village)

The results of this research are described in NILIM Technical Notes Nos. 760, 791, 1110, which explain the method of deciphering landslides using satellite SAR images, and summarize the applicable conditions and points to be noted.

3. List of related reports and technical documents

(1) Research reports and materials

1) Sabo Department, NILIM・Public Works Research Institute: Report on Investigations into Disasters in Kii Peninsula Caused by Typhoon Talas in 2011, NILIM Technical Note No. 728, March 2013

(2) Published manuals

1) Volcano and Debris Flow Research Team, PWRI: Technical Manual for Natural Dam Monitoring (Draft), Public Works Research Institute Document No. 4121, December 2008
2) Jun'ichi KAMBARA Taro UCHIDA: Technical guidelines for countermeasures against deep-seated catastrophic (rapid) landslides, NILIM Technical Note No. 807, 2014
3) Taro UCHIDA, Wataru SAKURAI, Kiyotaka SUZUKI, Masaaki MANTOKU: Assessment method for sediment disaster damage due to deep-seated catastrophic (rapid) landslides, NILIM Technical Note No. 983, 2017
4) Masaki MIZUNO, Joko KAMIYAMA, Masafumi EKAWA, Takumi SATOU, Junichi KANBARA, Shin-ichiro HAYASHI: Method of emergency search for the location of landslide dams using high-resolution single-polarization SAR image interpretation, NILIM Technical Note No. 760, 2013
5) Masaki MIZUNO, Joko KAMIYAMA, Masafumi EKAWA, Takumi SATOU, Junichi KANBARA: Method of emergency search for the location of landslide dams and collapses using high-resolution dual-polarization SAR image interpretation, NILIM Technical Note No. 791, 2014
6) SUZUKI Yamato, MATSUDA Masayuki, TAKIGUCHI Shigetaka, NOMURA Yasuhiro, YAMASHITA Kumiko, NAKAYA Hiroaki: Guidelines for the interpretation of sediment-related disasters by synthetic aperture radar (SAR) images, NILIM Technical Note No. 1110, 2020
7) SUZUKI Yamato, MATSUDA Masayuki, NAKAYA Hiroaki: Expository casebook of scattering changes in synthetic aperture radar (SAR) in times of disaster, NILIM Technical Note No. 1159, 2021

4. Future Outlook

The Sabo Department of NILIM continues to support human resource development for emergency response to large-scale sediment disasters such as landslide dams, and also to study methods for developing erosion control plans based on the risk assessment of deep-seated failures, which are feared to occur frequently due to climate change. In view of the increasing urgency of a major Nankai Trough earthquake, etc., we will also examine methods for evaluating the risk of slope failure due to earthquakes, including large-scale collapses, for early identification of the occurrence of collapse and rapid emergency response, and automatic extraction methods of sediment movement points to speed up satellite SAR deciphering work conducted by regional development bureaus in emergency situations.