Establishment of technology to support sediment disaster warning information and its policy development

1. Outline of Studies and Activities

Disaster	Major issues
June 29, 1999 Hiroshima Sediment Disaster	Method for setting the threshold rainfall
July 13, 2004 Heavy Rain in Niigata and Fukushima October 20, 2004 Typhoon No. 23	Nationwide deployment of the threshold rainfall information through collaboration between prefectural erosion control departments and the Japan Meteorological Agency
March 11, 2011 Tohoku-Pacific Ocean Earthquake (Great East Japan Earthquake)	Improved operations based on provisional post-earthquake standards
August 30 to September 5, 2011 Typhoon No. 12 Kii Peninsula Flood	Leveling of sediment disaster warning information (Utilization of various sensor information)
August 19-20, 2014 Hiroshima Heavy Rain Sediment Disaster	Legalization and mandatory communication
April 14-16, 2016 Kumamoto Earthquake August 26-31, 2016 Typhoon No. 10	Improved reliability of sediment disaster warning information
July 5-6, 2018 Heavy Rain Disaster in Western Japan	Reflection of topography and geology in operations

Research

<Related to Sediment Disaster Warning Information>

Research ① Method for setting the threshold rainfall (FY2003-2004)

- Study of short-term and long-term rainfall indices that will provide the highest accuracy for the CL (critical line)
- Study of applicability for actual operation using forecasted rainfall from JMA

Research ② Improvement of the method for setting the threshold rainfall (FY2005-2018)

- Development of a simple and accurate method for identifying parameters used in soil water indices based on known hydrological observation data

Research ③ Methodology for establishing provisional post-earthquake standards for sediment disaster warning information (FY2011-2012, FY2020)

- Quantitative verification of the appropriateness of setting provisional post-earthquake standards using rainfall data and sediment disaster occurrence data after the Great East Japan Earthquake

Research ④ Methodology for calculating the probability frequency of sediment disaster occurrence (FY2014-2019)

- Study of thematic maps on topographical and geological information that can be used as supplementary information for sediment disaster warning information

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

<Sediment Disaster Warning Information Manual, etc.>

[Manual for issuing sediment disaster warning information (including methods for setting the threshold rainfall)]

- ○"Report on the 2002 Sediment Disaster Warning Information and Future Policies" Study Committee on Sediment Disaster Warning Information, MLIT and JMA June 4, 2003
- ○"Draft Methodology for Establishing the Threshold Rainfall through Cooperation between the Sabo (Erosion and Sediment Control) Department of MLIT and the Forecast Department of JMA" Sabo Department of MLIT, Forecast Department of JMA and NILIM, June 2005
- ○"Guidelines for Prefectural Governments and JMA to Jointly Prepare and Release Sediment Disaster Warning Information (Revised Edition)" Sabo Planning Division, Sabo Department of MLIT, and Administration Division of JMA (First published June 2005, revised June 2019)
- ○"Revision of Criteria Used to Determine the Announcement of Sediment Disaster Warning Information" Sabo Department of MLIT, NILIM and Forecast Department of JMA, Office Communication June 11, 2017

[Manual on the Methodology for Verification of Operation Results of Sediment Disaster Warning Information]

- ○"Sediment Disaster Warning Information Verification Methodology" Sabo Department of MLIT, Forecast Department of JMA and Sabo Planning Division of NILIM, March 2008

[How to set provisional post-earthquake standards for sediment disaster warning information]

- ○"Establishment and Review of Provisional Post-Earthquake Standards for Sediment Disaster Warning Information" Sabo Planning Division, Sabo Department of MLIT, Sabo Planning Division of NILIM and Administration Division of JMA, Office Communication, revised on May 15, 2013

[Law and Manual on Sediment Disaster Warning and Evacuation, etc.]

- ★Soil and Sand Disaster Prevention Act revised on November 19, 2014, effective January 18, 2015, same as 1.18 Changes to the basic guidelines for soil and sand disaster prevention
- ○Revision of the "Guidelines for Preparation of Manuals for Determining and Communicating Evacuation Advisories, etc." (Revised as needed after September 2014), Cabinet Office (Disaster Management), 2014
- ○"Sediment Disaster Warning and Evacuation Guidelines" Sabo Department of MLIT, revised April 2015

[Sediment disaster risk estimation method for topography and geology]

- ○"Study on the estimation method of the risk of landslide disasters in Japan using topographic and geological thematic maps (June 2020)" Masayuki Matsuda and Hiroaki Nakatani, NILIM Technical Note No. 1120

Sediment Disaster Warning Information (Figure-1) is issued jointly by the prefectural governments and the Japan Meteorological Agency. The information is intended to help the mayors of cities, towns, and villages make decisions when issuing evacuation orders and to help residents make decisions on voluntary evacuation when the danger of sediment disaster increases due to rainfall.

The Sabo (Erosion and Sediment Control) Department of MLIT and the Administration Division of JMA collaborated to establish a "Study Committee on Sediment Disaster Warning Information" in 2002, with the Fire and Disaster Management Agency (FDMA) also participating. The Sediment Disaster Warning Information began being sequentially released in September 2005, and its rollout to all prefectures was completed in March 2008.

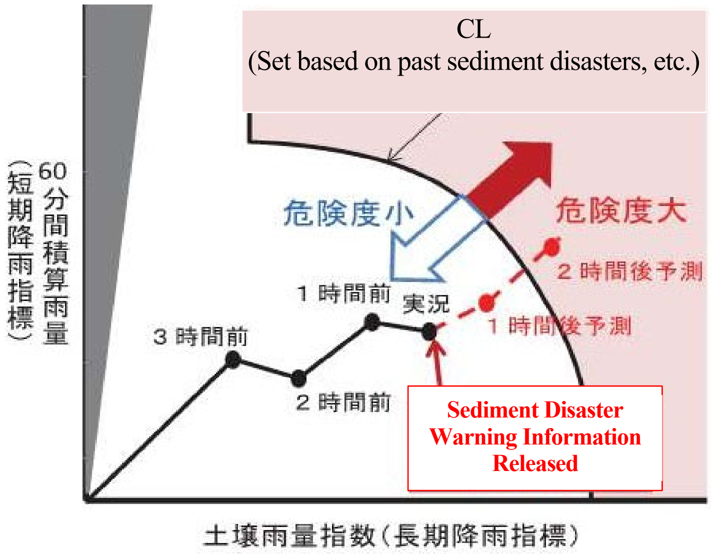

Figure-1 Threshold rainfall and sediment disaster warning information by CL

Source: MLIT website

https://www.mlit.go.jp/mizukokudo/sabo/sabo_ken_link.html

Since 2003, the Sabo Department of NILIM has continuously conducted research and prepared manuals on methods to improve the accuracy of sediment disaster warning information.

Research ① Methodology for setting the threshold rainfall (FY2003-2004)

To mitigate human suffering from sediment disasters, efforts have been made to evacuate people early by using the threshold rainfall based on the "CL."*1

The Sabo Department of NILIM examined "the combination of short-term and long-term rainfall indices that would provide the highest accuracy of CL" as well as "its applicability for actual operation using JMA forecast rainfall." Based on this, the Sabo Department of NILIM, together with the Sabo Department of MLIT and the Forecast Department of JMA, prepared the "Draft Methodology for Establishing the Threshold Rainfall through Cooperation between the Sabo Department of MLIT and the Forecast Department of JMA" in 2005.

At the same time, the Sabo Department of MLIT and JMA issued the "Guidelines for Prefectural Governments and JMA to Jointly Prepare and Release Sediment Disaster Warning Information" concerning the sediment disaster warning information (Figure-1) to be issued using the established CL.

*1 "CL" is the Critical Line, and is the boundary line between the announcement and non-announcement of the radial basis function network (RBFN) method for sediment disaster warning and evacuation. It is statistically defined in response to the occurrence or non-occurrence of past events.

Research ② Improvement of the method for setting the threshold rainfall (FY2005-2018)

The threshold rainfall is set using two indices: the "60-minute total rainfall" provided by JMA and the "soil water index" using a three-stage tank model in series. Of these, the tank parameters used for the soil water index are those for a granite mountain watershed (Photo-1), and they are applied nationwide, but in order to improve the accuracy of the threshold rainfall, it is necessary to set parameters that reflect the regional characteristics for each target area. Since identification of such parameters requires much time and labor, the Sabo Department of NILIM developed a simple and accurate identification method based on known hydrologic observation data.

Using a highly reliable comprehensive rainfall database, the Sabo Department of NILIM developed a method for setting the threshold rainfall and CL, which were previously based on insufficient rainfall data and limited sediment disaster data. The methodology was developed based on the accumulation of individual case verifications, data, and sensitivity analysis by the Sabo Department of NILIM. Furthermore, in Study 2), we established an advanced setting method, "method for verifying sediment disaster warning information" and a "review of criteria used to determine when to issue sediment disaster warning information," etc., which includes the consideration of geological features and accumulated data. This method has improved the accountability and transparency, which are strongly requested by municipalities as the basis for specific evacuation actions.

Photo-1 Example of debris flow caused by heavy rain in a granite area
(Heavy rain in western Japan, July 10, 2018. Photo by the Sabo Department of NILIM, Hiroshima Prefecture, Japan)

Research ③ Methodology for establishing provisional post-earthquake standards (FY2011-2012)

It has been believed for a while that when a large-scale earthquake occurs, slopes collapse and crack, and collapse will occur even with less than normal rainfall. For this reason, the prefectural governments and local meteorological observatories jointly issue sediment disaster warning information in the event of heavy rainfall, and in consideration of slope instability caused by seismic motion from a large-scale earthquake, they apply a provisional standard, which is lower than usual based on empirical values. However, the mechanism of earthquake-induced slope failure is complex and not always clear. Therefore, the Sabo Department of NILIM has quantitatively verified the validity of the standard setting using rainfall data and sediment disaster occurrence data after the Great East Japan Earthquake, and has proposed measures to improve the operation of the sediment disaster warning information.

Research④ Methodology for calculating the probability frequency of sediment disasters (FY2014-2019)

Various proposals from a wide range of interdisciplinary fields have been made on the inherent risk of sediment disasters, and the geomorphic elements and factors to be focused on have not been narrowed down, yielding results that can be used in a unified manner throughout Japan. In addition, the topographic and geological data as prime factors are vector data such as analog decipherment maps and thematic maps, many of which have not been standardized in terms of legends, etc. Furthermore, the data used as the predisposition information to analyze the whole of Japan in a unified manner has not been sufficiently rasterized, making it difficult to directly utilize the primary topographical and geological data for GIS analysis of the whole of Japan. Therefore, the Sabo Department of NILIM examined thematic maps of topographic and geological information that could be used as supplementary information for landslide hazard warning information. Then, by organizing and examining various topographical and geological information and past disaster data held by MLIT, a combination of topographical and geological factors that have a strong correlation with disaster occurrence was compiled and published in academic journals, and an easy-to-understand risk map of factors was published in NILIM Technical Note No. 1120. The combination of geomorphological and geological factors that are strongly correlated with disaster occurrence was compiled and published in academic journals.

2. Main Research Results

◆Research ① Methodology for setting the threshold rainfall (FY2003-2004)

The Sediment Disaster Warning Information was created and disseminated on a trial basis in model prefectures in FY2002 through collaboration between the Sabo Department of MLIT, JMA, and FDMA in the "Study Committee on Sediment Disaster Warning Information." In this trial operation, the threshold rainfall and the historical ranking of the JMA soil water index were examined in parallel, and information was prepared and disseminated when both criteria indicated a high risk (AND condition) or when one of the two criteria indicated a high risk (OR condition). However, due to the complexity of operating the two criteria in parallel, it was deemed necessary to formulate a unified standard for the full operation of sediment disaster warning information.

Therefore, the Sabo Department of NILIM conducted a study to develop rainfall indices essential for the formulation of unified standards for the coordination, joint operation, and full-scale operation of landslide disaster warning information by prefectural Sabo departments and the Forecast Department of JMA.

First, a comparative verification of the threshold rainfall was conducted based on a literature review of the "A/B Draft" by the Sabo Department of the Ministry of Construction following the 1982 Nagasaki heavy rain disaster, the "Proposed Draft" following the 1993 Kagoshima 8.6 (August 6) heavy rain disaster, and the historical ranking method using soil rainfall indices by the Forecast Department of JMA. The combined (AND/OR) method of MLIT (the Ministry of Construction) and method of JMA was organized as a decision flow to suit specific computer processing, and a concrete procedure was proposed based on trials in model prefectures. As a "collaboration proposal" between the Sabo Department of MLIT and JMA, we compared and examined candidates for short-term rainfall indicators on the vertical axis and long-term rainfall indicators on the horizontal axis, and confirmed the superiority of the 60-minute rainfall accumulation as a short-term rainfall index and the soil water index as a long-term rainfall index.

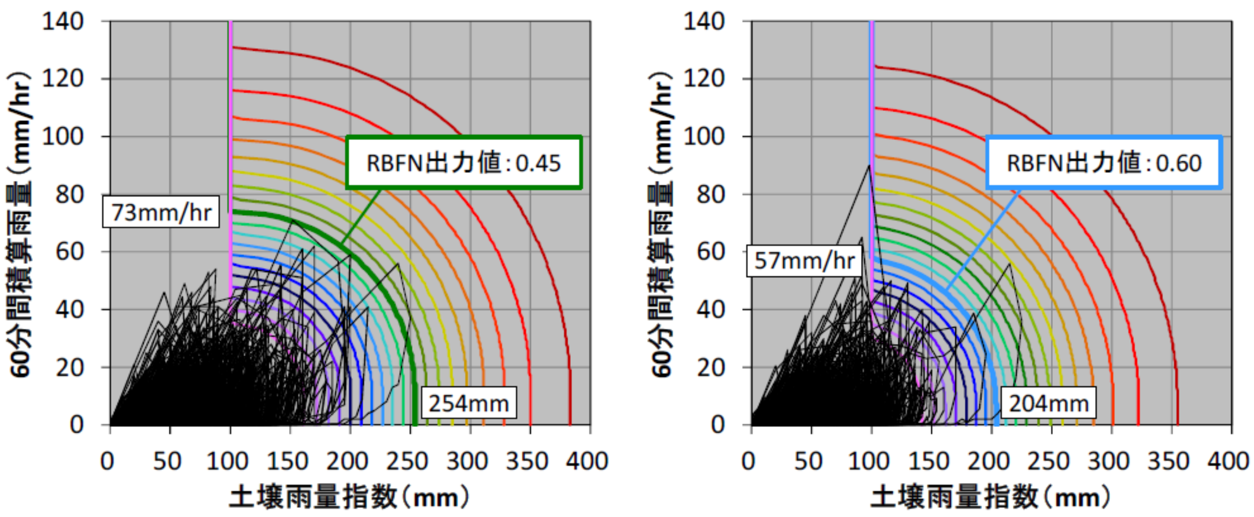

Figure-2 Snake line of actual rainfall vs. RBFN value

From the historical rainfall database, the horizontal axis (soil water index) and the vertical axis (60-minute total rainfall) are organized numerically as "likelihood" using a neural network and normalized with a maximum value of 1.0. The further outward the curve goes, the more "rare" the event is. For example, an RBFN contour of 0.1 indicates that an exceedance is likely to occur once every 3-4 years based on the historical data used.

Next, the Sabo Department of NILIM empirically investigated the radial basis function network (RBFN) method with the aid of machine learning techniques to process two-dimensional values in an integrated manner, and confirmed its suitability in the model area. Using the RBFN output values, multiple CLs based on rainfall of non-occurrence rainfall were set up (Figure-2), and the appropriate*2 rate, swing*3 rate, and missed*4 rate for disaster occurrence and non-occurrence rainfall in each CL were compared and examined. Comparisons were made for long-term rainfall indicators only and combinations of short-term and long-term rainfall indicators. The results also showed that the combination of a 10-minute rainfall and the soil water index had the highest accuracy for the short-term and long-term rainfall indices, respectively.

Based on these results, the Sabo Department of NILIM conducted a study on the applicability of the JMA rainfall forecast for actual operation, compiled a CL setting method (Figure-3), and together with MLIT and JMA, prepared in 2005 the “Draft Methodology for Establishing the Threshold Rainfall through Cooperation between the Sabo Department of MLIT and Forecast Department of JMA.” We also provided technical advice to prefectures when they set their own CL.

Figure-3 CL setup flow

The division of roles in setting the threshold rainfall is as follows: The Sabo Department of NILIM determines the method for setting the CL. MLIT provides technical advice to prefectures, which are responsible for setting and operating the CL. The Sabo Risk-Management Division of NILIM participates in the review committee for CL establishment held by prefectural erosion control departments and local meteorological observatories, and provides detailed technical guidance according to local conditions and the occurrence of disasters. The CL determined through this process is used as the basis for the overall judgment criteria, including JMA’s disaster prevention weather information (special warnings and mesh hazard distribution on the website).

*2 The term “appropriate” refers to warnings, etc. that are accompanied by an event when they are announced.

*3 A “strikeout” is a warning that was not confirmed to be accompanied by an event when it was announced.

*4 “Missed” refers to an event that was not accompanied by an announcement of an alert.

◆Research ② Improvement of the method for setting the threshold rainfall (FY2005-2018)

The Sabo Department of NILIM analyzed the characteristics of rainfall and the relevant indices using accumulated data in order to improve the operation of the threshold rainfall set by prefectural erosion control departments based on the radar and AMeDAS rainfall analysis and soil water indices calculated by the Forecast Department of JMA. The three-stage tank model calibrated using the observation results in watersheds composed mainly of granite and andesite, which is the basis of the soil water index, was used as a representative model to summarize issues in applying the model to various regions in Japan, and ways to improve the model were discussed. In addition, sediment disaster reports from each prefecture were carefully reviewed, and improved methods for extracting data on debris flows, slope failures, and other disasters for use in setting the threshold rainfall were also examined.

In model areas such as Hiroshima City and Kagoshima City, we studied the improvement of the threshold rainfall using the above two indices, and analyzed the trends of each index. In addition, for the development of more advanced indicators, we verified the parameter sets of the tank model for the above two indicators using hydrological observation data from eight locations by geological features. Based on the research results, we made presentations at academic conferences and provided the relevant prefectures with technical advice based on our findings.

Furthermore, we continued our efforts to improve the accuracy of sediment disaster warning information thereafter.

◆Research ③ Methodology for establishing provisional post-earthquake standards (FY2011-2012)

Based on the results of individual studies on post-earthquake sediment disasters, the provisional post-earthquake standard was empirically lowered for a certain period of time after the earthquake in a probationary manner. Based on these results, the Sabo Planning Division, Sabo Department of MLIT, Sabo Planning Division of NILIM, and Forecast Division of JMA formulated an operational proposal in FY2013. Subsequently, in FY2020, another five years of landslide occurrence data was added, and based on a total of 149 cases, the shaking (seismic intensity), geographic coverage, duration, and lowering rate that should be covered were empirically examined (Nakatani et al., 2020).

As a result, the following cases were identified as cases where there is little need to lower the long-term rainfall index for the threshold rainfall.

① Southwest Japan region, ② In the case of few strong aftershocks, and ③ In the case of 191 days or more of aftershocks with a maximum intensity of 5 or higher.

Conversely, the following cases were identified as cases where the long-term rainfall index needs to be lowered to 70-80%, even if only empirically.

The following cases were considered: ① Cases of frequent aftershocks, ②Cases of loose sedimentary layers, and ③Cases of groundwater-rich areas located at the boundaries of mixed volcanic and pyroclastic rocks and sedimentary terraces (however, since the findings in each case are based on limited data, detailed investigation of the relationship between the geology and groundwater is a requirement for each individual case).

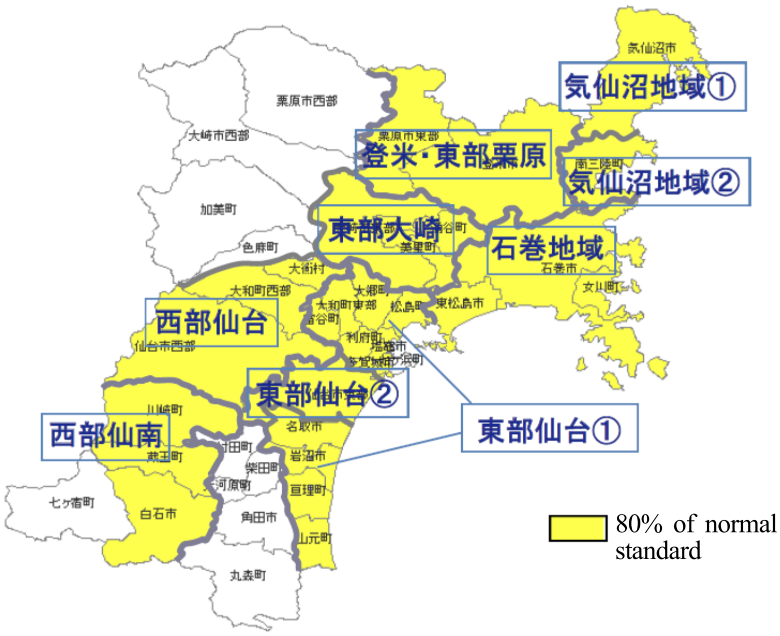

Figure-4 Study area and areas subject to provisional standards for the Great East Japan Earthquake

The Sabo Department of NILIM has been working to improve the operation of sediment disaster warning information by presenting these results to the relevant academic societies and disseminating and implementing the improved methods in the form of technical books and technical advice for prefectural governments.

◆Research ④ Methodology for calculating the probability frequency of sediment disasters (FY2014-2019)

The Sabo Department of NILIM compiled a combination of topographic and geologic factors strongly correlated with sediment disaster occurrence using various topographic and geologic information and past sediment disaster data owned by MLIT for use as supplementary information for sediment disaster warning information.

Specifically, among the survey data containing topographic and geological characteristics, three representative maps covering the entire country (sediment disaster warning areas, deep-seated landslide estimation maps, and landslide maps) were rasterized using a common method with the tertiary mesh of the NDLC as the basic unit so that they are suitable for GIS analysis. By comparing the rasterized mesh factors with the past 23 years of sediment disaster occurrences, a combination of factors that are most compatible with the occurrence of sediment disasters was identified.

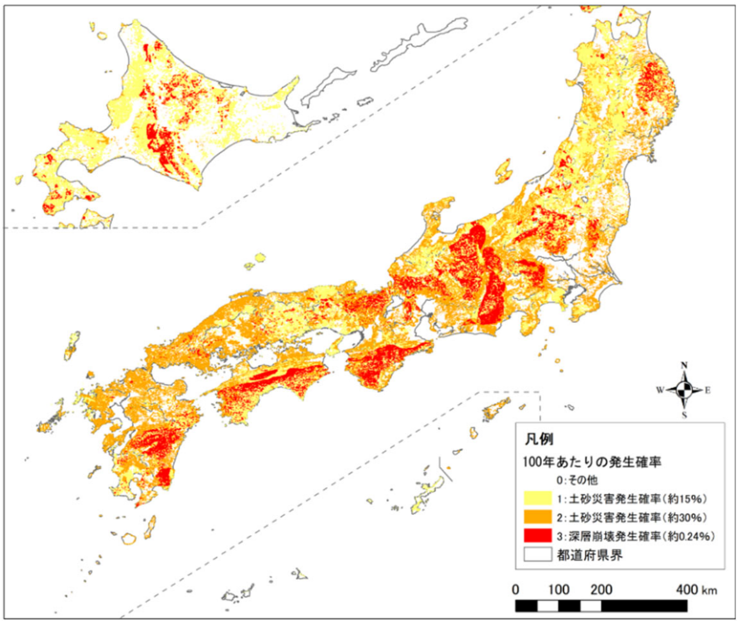

Figure-5 Sediment disaster occurrence probability map based on topographic and geologic factors (Draft)

Based on the most compatible factors (topography and geology based on thematic maps) and their combinations, a sediment disaster occurrence probability map (draft) (Figure-5) was created. Specifically, the following three categories were introduced.

- Probability of Occurrence Category 1: Areas that fall under one of the Sediment Disaster Warning Areas (WY), Deep-Seated Landslide Estimation Maps (DAB), and Landslide Maps (S), and have topographical and geological predispositions that require attention for landslide disasters. In each mesh, the probability of one or more disasters occurring in 100 years was about 15%.
- Probability of Occurrence Category 2: This probability category is an area that falls under the Sediment Disaster Special Warning Area (WR) and where there is a high probability that wooden houses will collapse or otherwise be damaged if a sediment disaster occurs due to rainfall. In each mesh, the probability of one or more sediment disasters occurring in 100 years was approximately 30%.
- Probability of Occurrence Category 3: This probability category corresponds to both the Deep-Seated Landslide Estimation Maps (DAB) and Landslide Maps (S), and is an area with a high probability of occurrence of a large-scale collapse such as a deep failure. In each mesh, the probability of one or more large-scale collapses occurring in 100 years was about 0.24%.

The results of this research are beginning to be used as materials for establishing regional divisions of the criteria for issuing sediment disaster warning information (at the juncture of the holding of the committee meeting to review the criteria, a switch is underway from the traditional administrative divisions and divisions by forecast area).

3. List of Related Reports and Technical Documents

(1) Research reports and materials

1) Matsuda, M. and Nakaya, H.: Study on the estimation method of the risk of landslide disasters in Japan using topographic and geological thematic maps, NILIM Technical Note No. 1120, June 2020

2) Nakaya H, Takiguchi S, Kishimoto Y, Yamada T, Ikeda H: Statistical analysis of rainfall-induced sediment-related disaster events after earthquakes, Journal of Japan Society of Erosion Control Engineering, Vol. 73, No. 4, pp. 35-40, 2020

(2) Manuals published and in operation (jointly with the Sabo Department of MLIT, etc.)

1) Sabo Department of MLIT, Forecast Department of JMA, and NILIM: Draft Methodology for Establishing the Threshold Rainfall through Cooperation between the Sabo Department of MLIT and Forecast Department of JMA, June 2005 https://www.mlit.go.jp/river/shishin_guideline/sabo/dsk_tebiki_h1706.pdf

2) Sabo Planning Division, Sabo Department of MLIT, and Administration Division of JMA: Guidance for Prefectural Governments and JMA to Jointly Prepare and Release Sediment Disaster Warning Information (Revised Edition), revised June 2019 (First published in June 2005, revised in February 2015)
https://www.mlit.go.jp/river/sabo/seisaku/tebiki_r106.pdf

3) Sabo Department of MLIT, Forecast Department of JMA, and Sabo Planning Division of NILIM: Sediment Disaster Warning Information Verification Methodology, March 2008
https://www.mlit.go.jp/river/sabo/pdf/kensho_080304.pdf

4. Future Outlook

The development of criteria for the release of sediment disaster warning information for all prefectures in Japan is based on the research conducted by the Sabo Department of NILIM. The results of this research form the basis of various data provided by JMA to society at large, including products related to heavy rainfall warnings for sediment disasters in cooperation with JMA. In addition, JMA has a system in place to provide seamless support to practitioners by providing national guidelines for the operation of provisional post-earthquake standards and regional division methods, as well as technical guidance for individual cases. This is a built-in element essential for disaster prevention and mitigation against weather-related disasters.

In the future, the following research will be conducted with emphasis on improving sediment disaster forecasting technology, taking into account the recent sediment disaster occurrence situation and the trends in policies related to erosion control, where severe damage has frequently occurred due to sediment disasters caused by heavy rainfall.

・ Study of analysis and evaluation methods based on a combination of predisposing characteristics (geology, topography, etc.) and triggering characteristics (rainfall) to provide more reliable sediment disaster risk information.

・ Development of a sediment disaster assessment system to improve the preliminary report of the imminence of a sediment disaster, such as by quickly identifying the occurrence of a line-shaped rainfall system, etc.

・ Development of threshold rainfall combined with various changes in the rainfall half-life to reduce the lack of sediment disaster warning information.