A REVIEW OF EARLY WARNING FOR DEBRIS FLOW IN JAPAN AND RECOMMENDATIONS FOR VIETNAM

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Abstract

Debris flow is one of the most common geohazards in some northern and central mountainous provinces of Vietnam, such as Lao Cai, Yen Bai, Ha Giang, Son La, Quang Tri, and Quang Nam. In general, debris flow often occurs suddenly and quickly with high kinetic energy. Thus, this geohazard not only caused a significant change in terrain and environment but also caused a huge loss of people and properties every year in Vietnam. There are different non-structural and structural countermeasures that can be applied to reduce and prevent the impacts of debris flow. In which, the monitoring and early warning of debris flow play an essential role in preventing and reducing the impacts of this geohazard. In Vietnam, some early warning systems have been built so far. However, the application and investment in the monitoring and early warning for debris flow in Vietnam are still limited. In the world, Japan is one of the countries that is severely affected by debris flow and related geohazards. In Japan, investigations of debris flow such as definition, monitoring, countermeasures, and early warning for debris flow have been started since the 1950s. Some criteria for monitoring and early warning have been proposed and applied in engineering practice. The warning systems have effectively prevented and minimized the impacts caused by debris flow in Japan. In this study, the early warning for debris flow applied in Japan will be reviewed throughout. Based on the overview, suitable criteria and early warning system for debris flow will be recommended for the conditions of Vietnam

Keywords: *debris flow; early warning; soil water index; critical line; RBFN.*

1. Introduction

Debris flow, along with flash floods and landslides, are the major types of natural disasters and are the most common geohazards in mountainous areas not only in Vietnam but also in many countries in the world, such as Japan, Taiwan, China… In Vietnam, these geohazards have caused significant damage to people and properties in the mountainous areas, especially in the North and Middle of Vietnam. According to statistics of the Ministry of Agriculture and Rural Development (MARD), there were 250 flash floods, debris flow, and landslides in Vietnam from 2000 to 2015 with an average of 16 times/year. In this period, these geohazards have caused 779 people died, 426 people injured, more than 100 000 houses flooded and damaged, and more than 75 000 hectares of rice and crop flooded and buried (MARD, 2019). In particular, in 2020, natural disasters such as floods, flash floods, debris flow, and landslides in some central provinces (Quang Binh, Quang Tri, Thua Thien Hue, Quang Nam) have caused 249 people died and missed, 1531 houses collapsed, more than 239 000 houses damaged, more than 473 000 houses flooded with an estimated economic loss of over 36 trillion VND (Thanh Chung, 2021).

In Vietnam, the main causes and triggering factors of debris flow are the high rainfall in a short time, the improper use of land, road construction, mining activities, changes in the hydrological regime, and slope failure. Among different geohazards in Vietnam, debris flow has been on the rise in recent years and is one of the geohazards causing the most huge loss of life and properties. Thus, the establishment of monitoring and early warning systems is essential for the prevention and mitigation of the impacts of debris flow. So far, the research, investment, and application of early warning systems for geohazards in general and debris flow in particular in Vietnam are still limited (Ngo et al., 2020). Some monitoring and early warning systems have been built for flash floods in river basins (MONRE, 2014; Pham, 2018; VAWR, 2018). In 2019, one of the first realtime early warning system for debris flow has been installed at the stream of Ban Khoang commune, Sapa. However, the criteria for monitoring and warning system for debris flow need to be further clarified.

In the world, Japan is one of the countries which is often severely affected by geohazards such as debris flow, flash floods, and landslides. In Japan, the recognition and investigation of debris flow have begun since the 1950s (Takahashi, 2009). So far, many monitoring and early warning systems for debris flow have been established and built in the whole of Japan. Japan has become an international leader in the research, development, and application of early warning systems for debris flow. In this study, a review of the early warning system for debris flow in Japan will be conducted. Based on the review, the criteria and early warning system will be recommended for the conditions of Vietnam.

2. Review of early warning system for debris flow in Japan

Early warning systems are one of the non-structural countermeasures which are important tools for the reduction of disaster risk as well as for achieving sustainable development and livelihoods (UNISDR, 2005). Early warning systems are also a major component of debris flow risk management. According to UNISDR (2006) (UNISDR, 2006), the aims of early warning systems are to enable individuals and communities threatened by natural disasters to mitigate the possibility of people injury, loss of lives and properties, and environmental damages. Generally, an early warning system is composed of four elements: risk knowledge, monitoring and warning devices, dissemination and communication, and respone capability.

Rain-induced debris flow is a common natural disaster that often occurs in mountainous terrains of Japan. The research and investigation of debris flow in Japan have been conducted since the 1950s. To reduce and prevent the impact of debris flow, numerous countermeasures including structural and non-structural measures have been developed and applied in Japan. In which, monitoring and early warning systems for debris flow are widely implemented at both territorial and regional levels. In Japan, there are two hypotheses for setting up early warning criteria. The first hypothesis is that mass movement can be forecasted using short-term and long-term rainfall indices. The second one is the area of mass movement occurrence and non-occurrence can be obtained by the plot of occurrence rainfall and non-occurrence rainfall. Since 1984, these two hypotheses have been used as the basic concept for establishing early warning systems in Japan. The various rainfall indices used by the Ministry of Land, Infrastructure, Transport, and Tourism (MLIT) are summarized in Table 1.

Table 1. Rainfall indices and methods of setting CL in Japan (Osanai et al., 2010)

Year	Short-term rainfall index	Long-term rainfall index	Method of fitting
1984	1-hour cumulative rainfall	AP (half time: 24 h)	By eye
1984	Effective rainfall	AP (half time: 24 h)	By eye
1993	AP (half time: 1,5h)	AP (half time: 72 h)	By eye
2005	1-hour cumulative rainfall	Soil-water index	Radial Basis Function Network

In 2001, the Radial Basis Function Network (RBFN) method was proposed by Kuramoto et al., (2001) (KURAMOTO et al., 2001) to set the non-linear Critical Line (CL) for sediment-related disasters with the 5-km mesh covering the whole of Japan. There are about 16,000 meshes in

Japan. The critical line CL can be linear, curved, or arbitrarily shaped, which depends on the fitting method and the distribution of rainfall (Figure 1). The proposed method of Kuramoto et al. (2001) (KURAMOTO et al., 2001) is based on the following concepts: (1) The main targets are debris flow and slope failure with high density, except for landslides; (2) Two rainfall indices are employed: a short-term rainfall index and a long-term rainfall index; (3) CL can be drawn using only non-occurrence rainfall with RBFN; (4) The shape of CL can be easily modified with new data.

In 2005, based on the RBFN method, a new nationwide early warning system for debris flow and slope failures has been established by the Japanese government and operated since 2007 (Osanai et al., 2010). This new system was developed based on two parameters: rainfall intensity (1-hour cumulative rainfall) and the Soil Water Index (SWI). One of the main advantages of this system is the ability to apply to areas without prior records of disasters. However, some engineering applications in Japan suggested that the new Japanese early-warning system can significantly reduce the impact of debris flow and slope failure if the CL is established based on many non-occurrence rainfalls and disaster records.

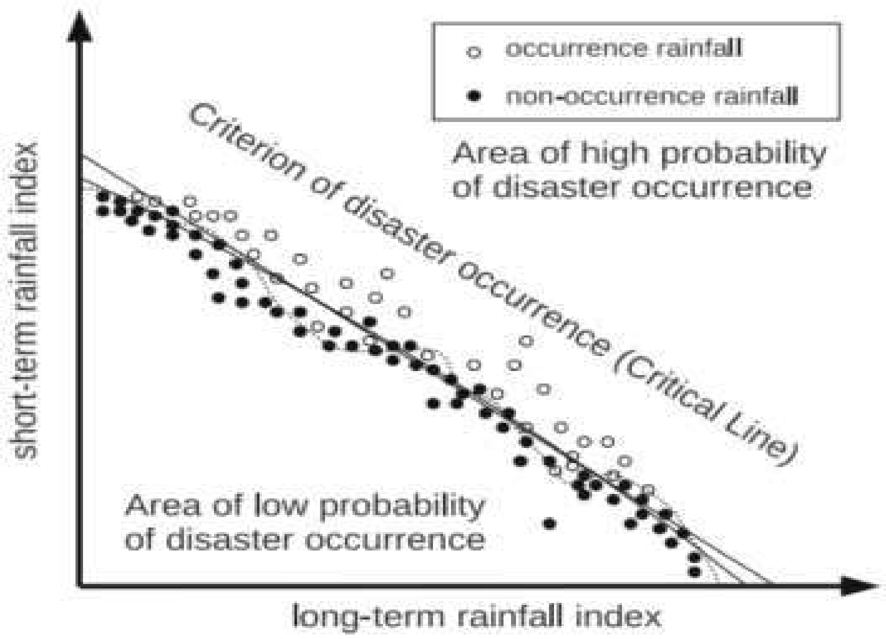

Figure 1. Critical line (CL) for predicting the occurrence of debris flow (Osanai et al., 2010).

*Soil-water index (SWI)

The SWI was proposed by Sugawara (1974)which represented the conceptual water stored in the soil and is calculated based on three layers (surface water infiltration, surface water runoff, and underground water runoff) of a physical runoff tank model. In the tank model, a part of the rainfall will be retained in the soil layers; a part will seep into the layers below, and a part will form the surface flow in the T1 and T2 tanks. This process is also repeated for T2 and T3 tanks. In each tank, there is an outflow and a seepage flow to a lower tank to describe both surface runoff and infiltration runoff. In the three-layer tank model, the water depth in each layer is known as soil moisture. The sum of water depths in the three tanks (surface, middle, and deeper soil layers) is called the Soil Water Index. The SWI has been adopted by Japan Meteorological Agency (JMA) as the conceptual soil water content affected by both antecedent and event rainfall. The SWI has been widely applied to establish the early warning criteria for landslides and debris flow not only in Japan but also in many countries in the world (Lin et al., 2020; Matsuyama et al., 2021; Osanai et al., 2010; Vasconcellos et al., 2020; Zhu et al., 2021).

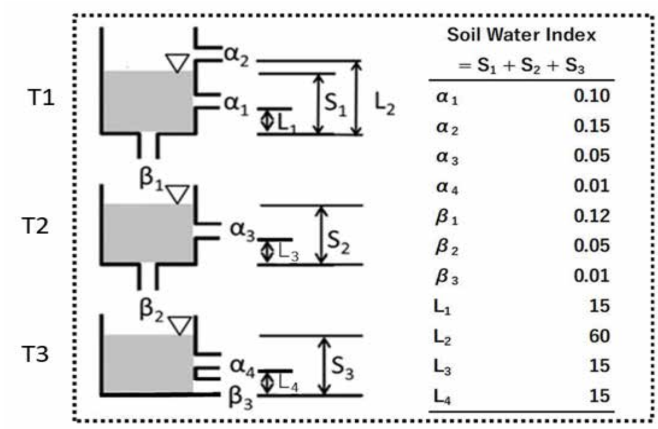

Figure 2. Three-layer tank model for calculating SWI (Matsuyama et al., 2021)

*Radial Basis Function Network (RBFN)

RBFN is one of the neural networks. This is an effective method to reasonably determine the CL in areas where the data of disaster is limited. RBFN can find a safe area where is no sediment disaster (Figure 3). The areas without sediment disasters are displayed as a three-dimensional chart. In which, the X-Y axis is the amount of water in soil (SWI) and the hourly rainfall, respectively. The Z-axis is the probability that a sediment disaster will not occur. The RBFN has some characteristics as follows: (1) Critical Line (CL) can be set in areas where the data related to past natural disasters are limited or unavailable; (2) CL can be set reasonably; (3) Reliability is improved by the sequential accumulation of data rainfall; 4) In monitoring, CL is represented as a contour line of a two-dimensional histogram that exhibits the probability of no rain.

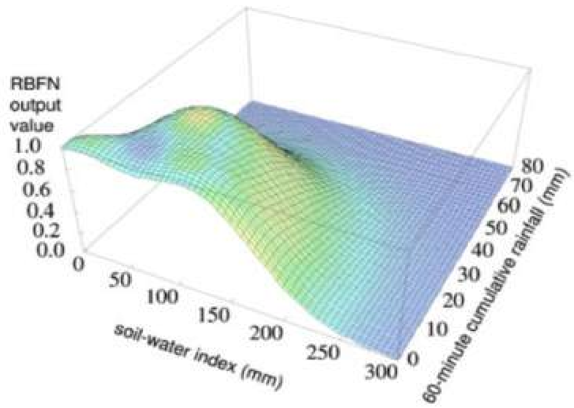

Figure 3. Output of RBFN using rainfall indices (Osanai et al., 2010).

There are different methods for forecasting of rain-induced sediment disasters in Japan. These methods are summarized and presented in Table 2.

Table 2. Forecasting methods of rain-induced sediment disasters in Japan (JICA, 2021)

No.	Stage	Rainfall index	Method	Overview of the forecasting method
1	Stage 1	Total rainfall and rainfall intensity	Statistical method	Since heavy and prolonged rainfall can cause sediment disasters, past disaster data relating to the total rainfall and rainfall intensity are plotted on the X-Y axis. Rainfall data are valuable when a sediment disaster occurs and can therefore be used to establish rainfall thresholds. The collection and processing of rainfall data are very simple. In particular, past disaster data without rainfall data can also be used.

No.	Stage	Rainfall index	Method	Overview of the forecasting method
2a	Stage 2	Effective rainfall using semi-cycle (1984-1993)	Statistical method	In method 1, rainfall thresholds are established based on the actual rainfall data where semi-cycle effective rainfall is used to improve the occurrence and non-occurrence of sediment disasters. In this method, the rainfall indices in 1,5 hours and 72 hours are used.
2b		Soil Water Index (SWI)	Hydrology method	Using the analysis method based on the three-tank model, the total volume of three tanks is used as an indicator (SWI). The storage threshold for disaster is determined based on historical disaster data. In Japan, this threshold varied by region and is usually set from 120 to 200 mm.
3	Stage 3	Short-term rainfall	Statistical method	To evacuate before a disaster occurs, it is necessary to delay the time required to evacuate from the rainfall threshold and issue an alarm or warning. Since the amount of rainfall during the delay time greatly affects the accuracy of the warning, a decision on whether the rainfall threshold will be exceeded should be made 1-2hours before using the short-term rainfall forecast.
				RBFN was developed to determine the boundaries of the rainfall threshold using non-linear mathematics

In Japan, various devices such as wire sensors, accelerometers, optimal beams, geophones, and CCTV images have been used to establish early warning systems for debris flow. In which, since the price is cheap, wire sensors are commonly used in Japan. Wire sensors have been widely applied in field surveys of debris flow since 1980 (Okuda et al., 1980). The wire sensors are often used in combination with CCTV cameras. Wire sensors detect the occurrence of debris flow based on the disconnection of the wires and the magnitude is estimated based on the height of wire from the river bed. The height of the wire from the river bed is often 60, 120, and 180 cm (Kato et al., 2018). However, the wires need to be reconnected after each event of debris flow. To overcome the shortcoming of sensors, Kato et al., (2018) have developed the LVP (load, vibration, pressure) sensors in combination with wire sensors (Figure 4).

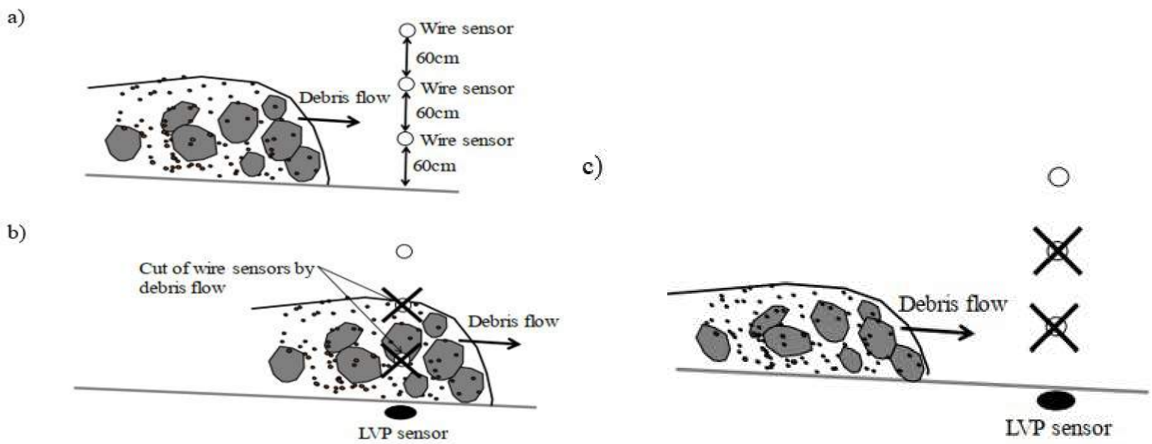

Figure 4. LVP systems in combination with wire sensors. a) Occurrence of debris flow without LVP; b) LVP and wire sensors work together; c) Only LVP operating (Kato et al., 2018).

LVP sensors consist of a load cell, accelerometer, and pressure meter, and all are installed below the river bed to detect the debris flow directly. One of the main advantages of LVP sensors is that they are not destroyed by debris flow and can be used for the next event of debris flow. Along the longitudinal bed of the river, different LVP sensors can be installed at different positions. In addition to LVP sensors, several types of sensors were installed along the river bed such as rainfall gauges, CCTV cameras, wire sensors, velocity meters, and ultrasonic sensors.

3. Early warning system for debris flow in Vietnam

In Vietnam, rain-induced disasters such as flash floods, debris flow, and landslides are becoming increasingly complicated and unpredictable. Recently, rain-induced disasters are increasing in scale, intensity and scope, causing a lot of damage to people, property, and construction work. These disasters. often suddenly occur with high speed and intensity, so forecasting and early warning play an important role in preventing and avoiding damages. Establishing early warning systems is one of the most proactive solutions to reduce disaster risk. In Vietnam, the Vietnam Disaster Management Authority has issued forecast bulletins to the district level, regularly updating the situation of natural disasters. Besides, early warning systems have been developed and set up in some places. Some projects have been carried out to build monitoring and warning systems for flash floods based on rainfall, river water level, and flow rate (MONRE, 2014; Pham, 2018; VAWR, 2018). However, these systems did not work for warning debris flow. Many research works related to debris flow investigation at different ministries, sectors, and universities have been conducted. Nevertheless, the research and application of early warning systems for debris flow are still limited. Additionally, there are no standards or guidelines for survey, classification, design, and installation of the structural and non-structural countermeasures to prevent, mitigate and control the risks of debris flow, flash floods, and landslides. In general, there seem to be no effective solutions to stop or mitigate the impact and damage caused by rain-induced disasters in Vietnam.

Some reasons affect the application and effectiveness of early warning systems for natural disasters in general and debris flow in particular in Vietnam. Due to the complex terrain, scattered population, and limited funding, the investment and installation of early warning systems are only focused on key locations. In which, lack of funding is one of the most difficult things in building, operating, and maintaining early warning systems. For example, according to the Deputy Director of the Sub-Department of Irrigation of Cao Bang province, the Provincial People's Committee needs to provide additional support of about 90 million VND/year to operate and maintain the monitoring stations for disaster warning tasks (Government of Vietnam, 2021). Besides the financial problems, the shortage and unprofessionalism of prevention and control forces for natural disasters also cause difficulties in operating and maintaining the warning systems. In many localities, most staff have not been trained in disaster mitigation and control. Thus, this leads to difficulty in coordination between all levels and sectors.

4. Recommendation of criteria and system for debris flow early warning in Vietnam

The early warning systems for natural disaster in general and debris flow in particular in Vietnam is very urgent. However, the research and application of early warning systems for debris flow are still limited. Thus, it is needed to learn from other countries to propose the criteria and systems for debris flow in the conditions of Vietnam. In the world, Japan is a country that has much experience in the prevention and mitigation of the impacts of debris flow. Different criteria and systems for early debris flow warning have been developed and applied in engineering practice. Based on the above review of debris flow early warning in Japan, the Soil Water Index (SWI) and hourly rainfall are proposed for Vietnam. These indices were combined using the Radial Basis Function Network (RBFN) to predict debris flow. In Vietnam, the data of short-term rainfall (hourly rainfall) is limited, so the current hourly rainfall is expected to continue to occur over the next hour. To accurately forecast the occurrence of debris flow, it is needed to have the data of hourly rainfall. In Japan, the rainfall data in the grid of 5km is measured by radar with a correlation coefficient of 80%. Thus, in Vietnam, rain gauge stations should also be installed considering the correlation coefficient of rainfall. Nevertheless, ground-based rainfall measurement stations within 5km grid are costly, so it is recommended to use radar to measure rainfall.

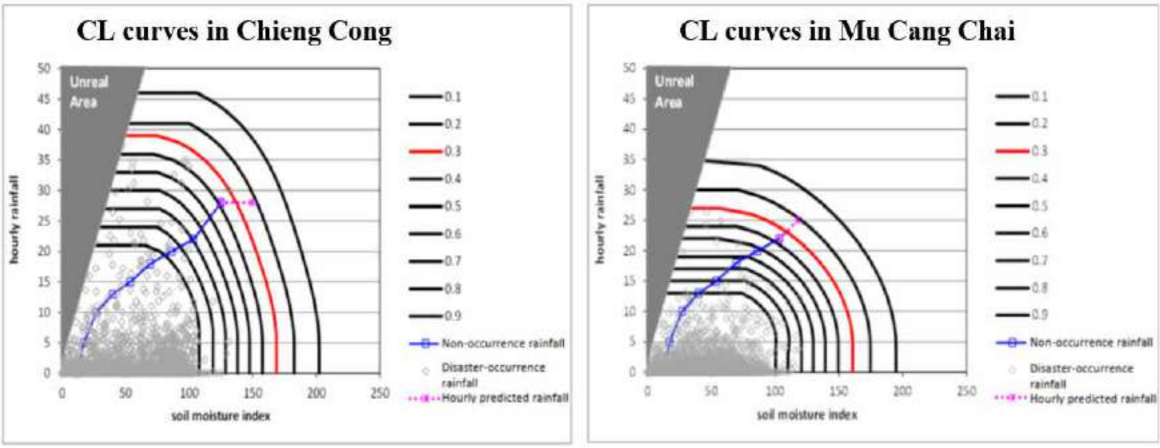

Figure 5. Relationship between hourly rainfall and SWI in Chieng Cong commune and Mu Cang Chai town (JICA, 2021).

The SWI in Chieng Cong commune and Mu Cang Chai town was generated based on hourly rainfall data from 2018 to 2020 and is presented in Figure 5. As shown in this figure, the red line is recommended as the rain threshold line for the warning (JICA, 2021)

Regarding the early warning system, as experienced in Japan, besides the use of wire sensors, CCTV cameras, rainfall gauges, ultrasonic sensors, and velocity sensors, the LVP (load, vibration, pressure) sensors should be installed below the river bed to identify debris flow.

To improve and increase the effectiveness of early warning for debris flow, there are some solutions should be conducted as follows:

1) improve the capacity of forecasting and responding to natural disasters for local authorities and armed forces;

2) develop a real-time disaster warning system based on continuous monitoring data;

3) establishing early warning system associated with an online map of zoning risks of debris flow;

4) promoting education and communication training the local people (hamlets, villages, communes) on the use of risk maps and early warning systems;

5) building the rainfall measurement stations using radar in the whole country, especially in mountainous areas;

6) authorities and government should provide the mechanisms and policies related to the establishment of early warning systems.

5. Conclusions

Based on the review of early warning for debris flow in Japan, some main conclusions are drawn as follows:

In Japan, the research and investigation of debris flow have been carried out since the 1950s. Soil Water Index (SWI) and hourly rainfall data have been widely used to determine the rainfall threshold for debris flow prediction. The relationship between SWI and hourly rainfall data is established based on Radial Basis Function Network (RBFN) method and is presented in a three-dimensional chart. Regarding the early warning system, the LVP (load, vibration, pressure) sensors in combination with wire sensors were widely used in Japan to directly detect debris flow.

In Vietnam, the research and application of early warning systems for debris flow are still limited. Thus, learning from other countries such as Japan is necessary. Based on the review of debris flow in Japan, it is proposed that SWI, hourly rainfall data, and the RBFN method should be used to determine the threshold of rainfall for the occurrence of debris flow. The early warning systems of LVP and wire sensors are recommended to use to detect the debris flow.

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References

Government of Vietnam, 2021. Early warning of flash floods and landslides (https://reliefweb.int/report/viet-nam/early-warning-flash-floods-and-landslides).

JICA, 2021. Báo cáo tóm tắt giữa kỳ "Khảo sát thu thập dữ liệu về các giải pháp phòng chống lũ quét và sạt lở đất tại khu vực miền núi phía Bắc của Việt Nam".

Kato, H., NODA, N., HASHI, K., TAGATA, S., ITOH, T., MIZUYAMA, T., 2018. Debris Flow Detection Using LVP Sensors in Japan.

KURAMOTO, K., TETSUGA, H., HIGASHI, N., ARAKAWA, M., NAKAYAMA, H., FURUKAWA, K., 2001. A study on a method for determining non-linear critical line of slope failures during heavy rainfall based on RBF network. Doboku Gakkai Ronbunshu 2001, 117-132.

Lin, G.-W., Kuo, H.-L., Chen, C.-W., Wei, L.-W., Zhang, J.-M., 2020. Using a tank model to determine hydro-meteorological thresholds for large-scale landslides in Taiwan. Water 12, 253.

MARD, (Ministry of Agriculture and Rural Development), 2019. Flash flood and landslide in Vietnam.

Matsuyama, H., Saito, H., Zemtsov, V., 2021. Application of Soil Water Index to landslide prediction in snowy regions: sensitivity analysis in Japan and preliminary results from Tomsk, Russia. *Progress in Earth and Planetary Science* 8, 1-13.

MONRE, (Ministry of Natural Resources and Environment), 2014. Report on the results of project: Survey, zoning and warning of the possibility of flash floods in mountainous areas of Vietnam-Phase I 2006-2009 in 14 mountainous provinces in the North.

Ngo, T.T.H., Vu, B.T., Nguyen, T.K., 2020. Early warning systems for flash floods and debris flows in Vietnam: A review. *Geotechnics for Sustainable Infrastructure Development* 1233-1240.

Okuda, S., Suwa, H., Okunishi, K., Yokoyama, K., Nakano, M., 1980. Observations on the motion of a debris flow and its geomorphological effects. Zeitschrift fur Geomorphology, Suppl.-Bd.35 142-163.

Osanai, N., Mizuno, H., Mizuyama, T., 2010. Design standard of control structures against debris flow in Japan. *Journal of Disaster Research* 5, 307-314.

Pham, V.Q., 2018. Introduction of real-time flood warning system structure. V*ietnam Academy for Water Resources*.

Sugawara, M., 1974. Tank model and its application to Bird Creek, Wollombi Brook, Bikin River, Kitsu River, Sanaga River and Nam Mune. *Research Notes of the National Research Center for Disaster Prevention* 11, 1-64.

Takahashi, T., 2009. A review of Japanese debris flow research. *International Journal of Erosion Control Engineering* 2, 1-14.

Thanh Chung, 2021. Bão, lũ năm 2020 khiến miền Trung thiệt hại hơn 36.000 tỉ đồng (https://laodong.vn/xa-hoi/bao-lu-nam-2020-khien-mien-trung-thiet-hai-hon-36000-ti-dong-978153.ldo#:~:text=N).

UNISDR, 2006. Developing early warning systems: a checklist, in: Third International Conference on Early Warning (EWC III). United Nation/International Strategy for Disaster Reduction (UN/ISDR).

UNISDR, (United Nations Inter-Agency Secretariat of the International Strategy for Disaster), 2005. Hyogo Framework for Action 2005-2015: Building the resilience of nations and communities to disasters, Extract from the final report of the Wold Conference on Disaster Reduction (A/CONF.206/6) p 22.

Vasconcellos, S.M., Kobiyama, M., de Almeida Mota, A., 2020. Evaluation of Soil Water Index of distributed Tank Model in a small basin with field data. *Hydrology and Earth System Sciences* Discussions 1-30.

VAWR, (Vietnam Academy for Water Resources), 2018. Construction of forecasting and warning system for disaster risk reduction in Vietnam. Joint research project between VAWR and NDMI (South Korea).

Zhu, Y., Ishikawa, T., Subramanian, S.S., Luo, B., 2021. Early warning system for rainfall-and snowmelt-induced slope failure in seasonally cold regions. *Soils and Foundations* 61, 198-217.