Appropriate technology for landslide and debris flow mitigation in Thailand

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Abstract. Landslide causes the damage in property and life of the people. It can be mitigated using various factors i.e., relocation of population, warning and evacuation and various structural measures. In Thailand and various ASEAN countries, landownership and legal hindrances are major issues that has affected the relocation of the population but new laws have been proposed in Thailand to overcome this issue in future. Multiway warning system has been installed in various parts of Thailand using AP model based on statistical data of rainfall precipitation that had caused landslide in the past. Dynamic landslide hazard mapping along with AP model is used to produce landslide hazard map that can be changed with spatial rainfall data. Furthermore, community-based warning system can be used to estimate the landslide in local communities. The system along with the knowledge of landslide management needs to be transferred to local people.

Keywords: Landslide Mitigation, AP Model, Landslide Hazard Mapping, Early Warning System

1. Introduction

Extreme weather and climate events have increased in frequency and are projected to continue increasing in this century [1]. These events can impact humans and ecosystem extremely and include major destruction of assets, loss of human lives, and loss of and impacts on plants, animals and ecosystem services [2, 3]. Landslides are common geomorphic events on fragile, steep slopes of the mountains in Thailand. Recently, the frequency of rain-triggered landslides in Thailand has been increased and has gained momentum, coincident with the effects of climate change (

Fig. 1). The northern and southern part of Thailand is the most vulnerable part of the country subjected to landslide hazard [4, 5].

Fig. 1 Landslide at Nan Province, Thailand

Compared to other natural hazard (e.g., flood, earthquake, storms), the impact of landslides is often underestimated because the affected areas are mostly on a local scale [6]. Landslide hazard are expected to increase in the future through population growth, new settlements in landslide-prone areas, and climate change [7]. Although the occurrence of future landslides cannot be prevented, the magnitude of impact in terms of loss of life and destruction of property can be kept within reasonable bounds through preventive and mitigation measures.

2. Types of Landslide

A landslide is the movement of a mass of rock, earth or debris down a slope[8]. In landslide classification, there are great difficulties due to the fact that phenomena are not perfectly repeatable; usually being characterized by different causes, movements and morphology, and involving genetically different materials. For this reason, landslide classifications are based on different discriminating factors, sometimes very subjective[9]. However, depending on the size of slide mass and potential for loss of life, landslide has been classified in three categories:

2.1 Slope failure

Slope failure is a phenomenon that occurs due to weakened self-stability of the earth under the influence of various factors like rainfall or an earthquake. The sudden collapse of slope near the residential area results in loss of life and property. Mostly slope failure occurs from cut-slopes without an adequate protection (Fig. 2). The failure mass is limited and mostly slides down to replace the soil mass that has been cut (Fig. 3).

Fig. 2. Slope failure in cut slope

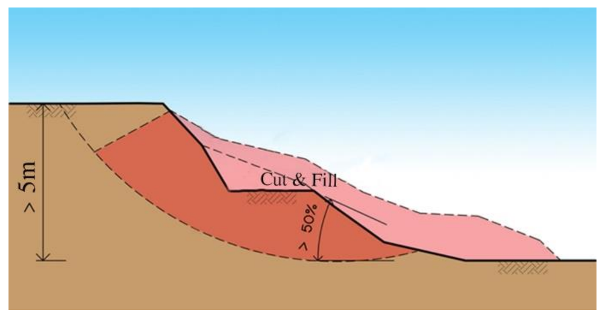

Fig. 3. Graphical representation of slope failure in cut slope

2.2 Landslide

Landslide involves a large area composed of several slope failure and movement. It affects the part or whole of the hill slope area. Most of the cases of landslide are related with the increase in ground water table from rainfall infiltration. Doi Chang village in the northern region of Thailand is a good example of landslide[10] where the whole village has been moving with slow rate resulting in the destruction of house and infrastructure (Fig. 4).

Fig. 4. Observed movement of house and infrastructure in Doi Chang village, Chaing Rai , Thailand

2.3 Debris flow

Lastly, the most fatal type is debris flow. They develop when hill slope is subjected to heavy rainfall and mostly in case of extreme precipitation events. Debris flow occurs when the flood debris flow down the flow channel and inundate the downhill area. In 2011, numerous villages were swept away by landslide and debris flow at Khao Phanom Benja National Park of Krabi Province in the southern part of Thailand (Fig. 5) [5, 11]

Fig. 5. Landslide and Debris Flow at Krabi Province, Thailand

3. General Landslide mitigation scheme

A hazard doesn't necessarily have to become a disaster, or can be minimized, if we are well prepared. Several mitigation measures have been proposed by various authors for landslide and debris flow [12]**.** These mitigation requires good information and tools such as hazard and risk map, rainfall prediction system, sensors and warning tools etc. A technology is deemed to be appropriate when it is consistent with the cultural, social, economic and political context of each society and country. Some of the effective landslide mitigation measures are listed below:

- Relocate the population living in the risk areas: This is the most effective and difficult mitigation scheme especially in the mountainous area where suitable location for settlement is hard to find. New legal regulations cannot be applied to the people who have been residing at those areas before the law was issued. Moreover, this mitigation is suitable for the area where land movement is active or where landslide and debris flow had happened in the past even in some geological period.

- Warning and evacuation: The sequential steps of the evacuation process would be detection, evaluation and prediction, decision and warning to bring population at risk out of the potential hazard area. However, evacuation drill needs to be carried out periodically for key success.

- Structural measures: These measures are mostly used for preventing slope failure by means of slope reinforcement or slope protection to reduce speed of debris flow by using check dam, debris flow net etc. This method, however, is not economically feasible for large area.

- Law, code and standard: Effective law, code and standards are essential part of a long-term strategy and sustainability but is normally time consuming. Law can enforce all three mitigation schemes mentioned above but its effectiveness depends on the authorized representative.

4. Country context that affects mitigation

4.1 Right of landowner

In Thailand and many southeast ASEAN countries, people living in landslide risk area cannot fully clarify the ownership of the land. This is because human settlement is mostly located near the hill slope or connecting area between mountain and flat area, which has easier access to woods for hunting and collecting timber products with some flat area for housing, agriculture or farmland. People living there for centuries get affected by the frequently occurring landslides and have adjusted their housing location accordingly. In later years, government has issued forestry conservation law to conserve the forest in the mountainous area. Village located inside the conservation area cannot verify if their village or houses have been there before or after the issuance of the law. This has created a conflict and dispute between the people and the government which has been trying to sort out this issue for years. The conflict worsens in case of landslide prone areas. People are expected to move out to the new safe area but as their landownership is not yet clear, government cannot issue a new land for them.

4.2 Law structure and Governance

The law in Thailand has different levels starting from constitution, act, ministerial regulations, ministry announcement, code and standard. Laws relating with the landslide are building code act, cut and fill of earth act, land development act, disaster reduction and prevention act, etc.

Department of Disaster Prevention and Mitigation (DDPM), established in 2002, is a central state agency created under Ministry of Interior (MOI) with the responsibility to oversee the administration of disaster management responsibilities in Thailand. The national disaster management system is made up of multiple agencies and committees to carry out disaster preparedness and response activities. The Disaster Management System based on the Disaster Prevention and Mitigation Act 2007 (DPM Act 2007), came into force on 6 Nov 2007 and implements Thailand's national Disaster Management (DM) Institutional arrangement. All disaster management activities are directed and controlled by the Commander/ Director at different levels; National, Provincial, District and Local[13].

In case of Thailand, flood is the most catastrophic disaster; therefore, most of the existing laws are developed to address this issue as compared to landslide. Since, severe landslides were observed in Thailand after the onset of development in late 1980s, proper guidelines for landslide mitigation has not been developed. Additionally, lack of guidance on how governmental agencies and other stakeholders should coordinate their work has been a major challenge to Thailand's disaster management system.

4.3 Economics

Economics has always been a major concern in mitigation itself because people from landslide prone areas always express their uncertainty about the cost and finances after the relocation. One of the best example would be Doi Chang village, Mae Suai District, Chiang Rai Province of Thailand. This village has been continuously moving for years and is constantly monitored by Geotechnical Engineering Research and Development Center (GERD), Kasetsart University. The area is a national reserved forest and residents there have no documentation to live or farm in the area. Because of the cool temperature and the area being 1,000 meters above sea level, the conditions are ideal for Arabica coffee plantation. This yields high quality aromatic coffee making it the number one choice for coffee drinkers around the world and the attraction place for tourist. People living there rely on coffee farming and therefore are not willing to relocate as economics and other insecurities after the relocation influences people's decision of moving to a new safe place.

5. Landslide and Debris Flow Mitigation in Thailand

5.1 Multiway warning system

Establishing an effective early warning system is a vital tool for mitigating the impacts of disaster. The more time we have, the safer people are. An effective warning system is based on high quality, real time data with parameters having higher accuracy. In case of landslide and debris flow, precipitation is the most important parameter that needs to be considered. Various landslide prediction models [14] can predict the amount of precipitation in advance for 3-4 days with some certain accuracy. These information can be used for advance warning. Multi-way warning system, which has been developed in Thailand, uses rainfall precipitation prediction to warn the village in case of heavy rainfall (Fig. 6). There are 54 provinces and more than 5000 villages prone to landslide and debris flow in Thailand. It is not possible to monitor all the villages by central government and there remains a requirement for early warning system. Multiway warning system can analyze 3-4 days landslide potential area in advance using Antecedent Precipitation Model (AP-model) [15-17]. This model analyzes rainfall threshold by using information of the precipitation that caused landslide in the past. Warning message will be given to the villages if there is probability of predicted rainfall exceeding the rainfall threshold. The accuracy of the warning from AP model, even though not high but is good enough to alert people in the prone area.

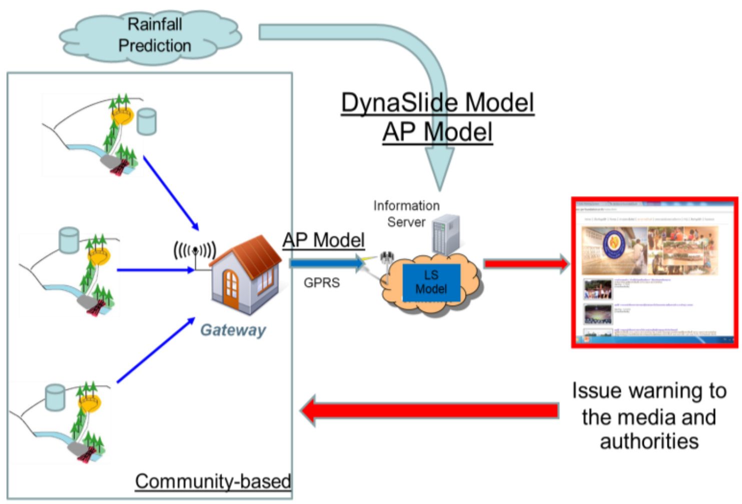

Fig. 6. Multi-way warning system using AP Model

It is necessary to establish community-based warning together with the early warning using AP model. Necessary tools, knowledge and evacuation plans are required for letting the people in the risk area respond accordingly. Once the warning is issued, people in the risk zone should record the accumulated rainfall precipitation from rain gauge and plan for the evacuation if rainfall exceeds the threshold. Fig. 7 shows the timeline before and after the occurrence of landslide. Different types of detection and warning system are placed based on this timeline. The accuracy of the warning message from prediction might be less but is enough for the preparation and evacuation while the accuracy of warning from direct measurement of land movement is high but the warning period is generally less. This concept has been used in Thailand for more than 10 years and has successfully saved many lives.

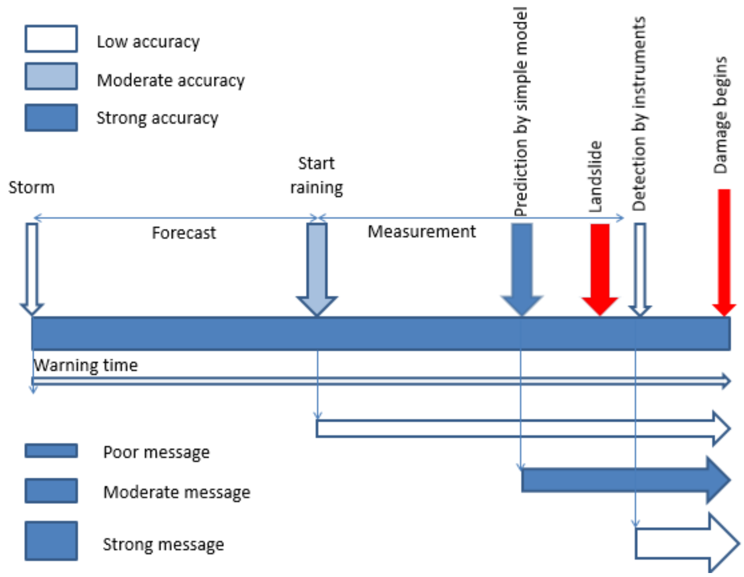

Fig. 7. Timeline of landslide and warning

5.2 Rainfall threshold

AP model is used for landslide forecasting and is based on statistical data of rainfall precipitation that had caused landslide in the past but rainfall threshold is based on different zones of Thailand as shown in Fig. 9. Verification of critical API value [5] [18]. Landslide threshold can be estimated based on the plot between rainfall intensity (mm/day) and accumulated precipitation as shown in Fig. 9. The plot shows the cumulative rainfall for 3 days obtained from various stations of Thailand and rainfall intensity. It has been found that 3 days accumulation period of precipitation is appropriate for making landslide threshold. Initially, this model was used for local warning based on data from local rain gauge and was effective for warning 24 hour prior to the landslide. Later, 3-4 days precipitation forecasting data was used for early warning of the landslide using AP model (Fig. 10). The accuracy of this model is further being improved using ROC method and comparing statistical landslide data in landslide susceptible areas. However, besides the limitation of the accuracy in forecasting precipitation, the grid size of rainfall data is 4x4 km, which may post some limited accuracy in terms of warning area.

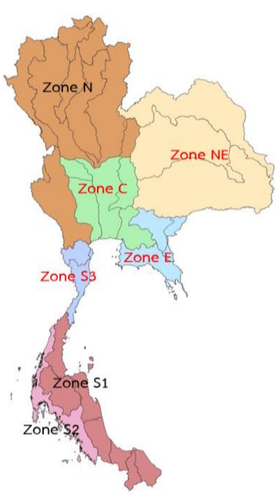

Fig. 8. Rainfall threshold for different zones in Thailand

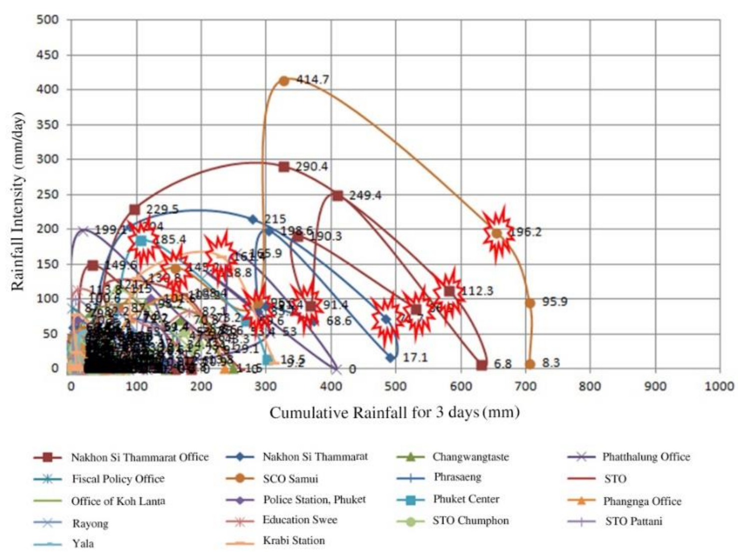

Fig. 9. Verification of critical API value [5]

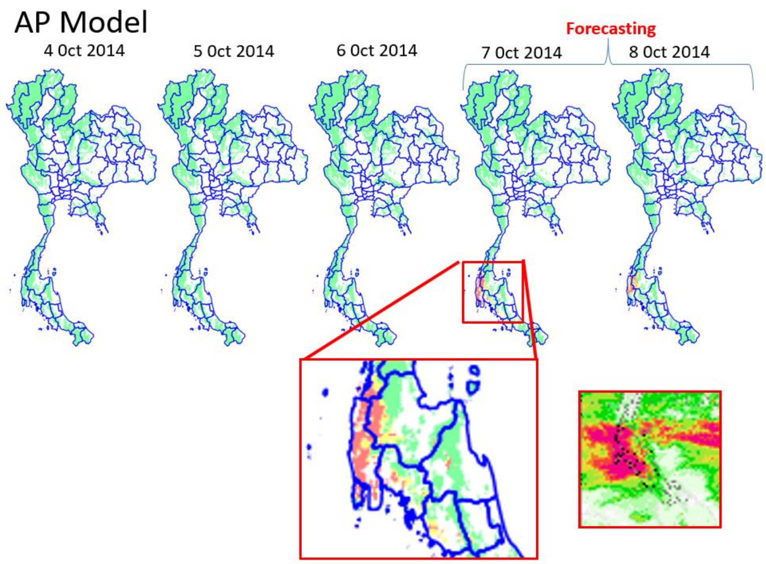

Fig. 10. Early Warning system using AP model

5.3 Dynamic landslide hazard mapping

In order to warn people accurately in time with the appropriate warning area, a geotechnical model, DynaSlide, was established based on infinite slope analysis. The model can produce landslide hazard map that can be changed according to the spatial rainfall data. The analysis is coupled between infiltration analysis through unsaturated soil and infinite slope stability analysis (Fig. 11). Infinite slope stability analysis is performed based on effective stress analysis. The analysis is based on more than 500 undisturbed soil samples, which were collected in the period of 15 years throughout Thailand. Analysis are performed through GIS with data grid cell of 30x30 m. Rainfall forecasting is used as a input data and the factor of safety of slope of each grid cell (30x30m) will be calculated based on this parameter. Even though, this model is more accurate, it takes much of a computer time while processing the larger area at one time. Therefore, this model is used together with AP model. AP model gives a potential area of landslide with limited accuracy and DynaSlide will analyze the particular area with finer grid for more accuracy.

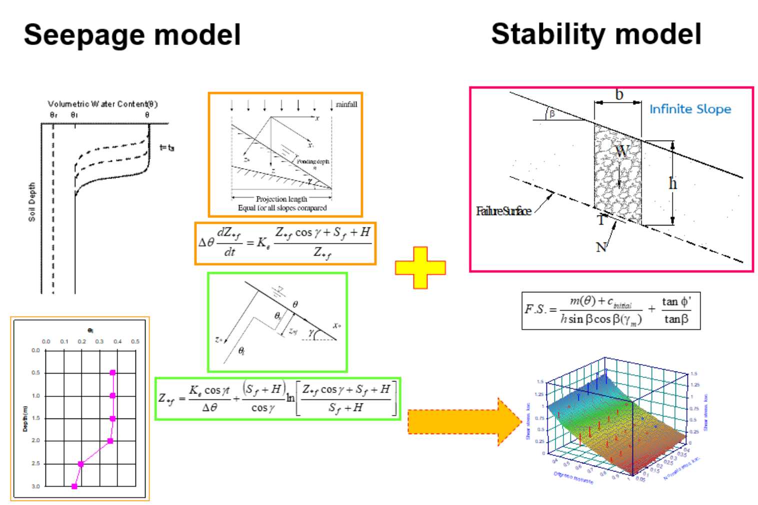

Fig. 11. Infiltration and Slope stability Analysis[19]

5.4 Community-based landslide warning

Important key of landslide and debris flow warning in Thailand is the potential victim themselves. As mentioned earlier, there are more than 5000 villages in Thailand located within landslide prone areas and single command operation alone cannot keep eyes on every villages. Instead, people living in the prone areas should be trained for early warning. Three key components for community-based landslide warning are:

5.4.1 Knowledge

Set of knowledge about landslide management should be transferred to the local people. On the other hand, local information, knowledge, wisdom and experience needs to be combined to come up with the specific landslide management of that village. Regular training is necessary to keep up through all generation in the village. Fig. 12 shows the training conducted in Khao Phanom District, Krabi Province to transfer the knowledge regarding the early warning system installed in the village. The system has now been handed over to the local community and is being operated by local government with constant supervision from Geotechnical Engineering Research and Development Center.

5.4.2 Tools

Appropriate tools that are easy to operate and maintain but relevant for warning is needed to be provided to local people. At least two types of sensors i.e., rain gauge and debris flow detection system should be installed on the mountain where landslide and debris flow tend to occur (Fig. 13). The signal from sensor will be sent through radio system because mobile phone system cannot be relied on during heavy storm. The receiver or master station will receive information from sensors and analyze if the warning needs to be issued or not. Precipitation data from rain gauge will be analyzed according to AP model and indicate the possibility of landslide using various shades of green, yellow and red. The shade color indicates that people can make their own decision while solid light indicates that people should consider the signal seriously and evacuate the area (Fig. 14). It is also important for people in the risk area to consider the surrounding information such as color of water in stream etc. to make their own decision.

Fig. 12. Training to local community regarding landslide warning system in Krabi, Thailand

5.4.3 Corporation and communication

Corporation and communication among local people, local officers, and central command unit is essential for proper implementation of community based landslide warning system. The best way is to organize evacuation drill to review emergency preparedness and action plan (EAP and EPP) which also initiates the communication inside the village for better preparation. EAP and EPP shall consist of a clear definition of the overall structure with specific responsibilities of all the key personnel and all the units should continuously coordinate with each other.

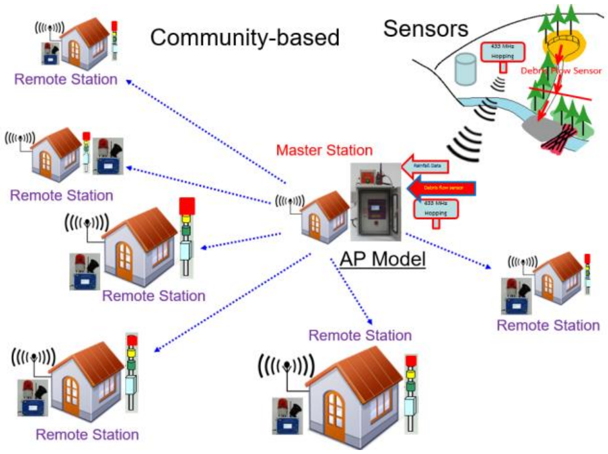

Fig. 13. Community based landslide warning system

Fig. 14.Siren for landslide warning

6. Triangle of success

Knowledge, Society acceptance and Policy maker represents the three most important ingredients to ensure success. This is a framework proposed for conceptualizing the relationship between the factors that influence the efficiency of disaster management system. Triangle of success represents the policy for proper installation, maintenance and effectiveness of landslide management system as shown in Fig 15.

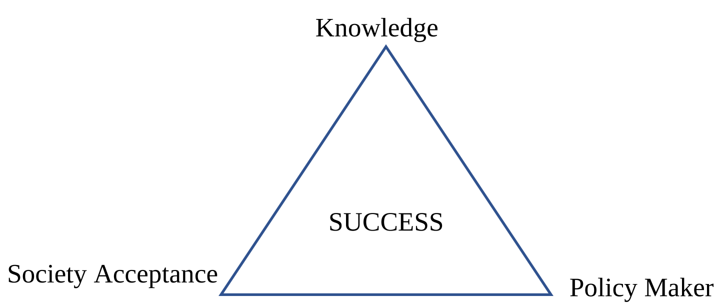

Fig. 15. Triangle of success for Landslide Management System

a. *Knowledge:* Disaster management system requires knowledge for decision making and coordinated action. Knowledge of people in risk area and government agencies along with other stakeholders must be shared for the successful planning.
b. *Society acceptance:* People in risk area and government agencies along with other stakeholders need to have discussion before making any decisions such as issuing a regulation or standard of practice.
c. *Policy maker:* The formulation and implementation of a national policy involves information from different fields at different levels, with the active participation of each and every stakeholder. If it is to be performed effectively, the efforts from all concerned groups must be coordinated.

7. Conclusions

Landslide mitigation is an arduous task but various mitigation measures have been developed in Thailand to minimize the loss of life and property from landslide. It is one of the most difficult tasks to relocate the people from risk zone due to legal hindrances in Thailand but new laws are now being formulated to overcome these issues in future by coordinating with various government and non-governmental agencies for disaster mitigation. Likewise, the accuracy of Antecedent Precipitation Model (AP-model) is also being improved for effective multiway warning system. This will help in improving the accuracy of landslide early warning system of Thailand. The new landslide and precipitation data are also constantly being monitored and recorded to further improve its accuracy in future. Community based landslide warning system has been installed in various parts of Thailand and has been handed over to the local community. Various training programs are being conducted for transferring the knowledge to the people and community living in landslide prone areas. Emergency Action Plan (EAP) and Emergency Preparedness Plan (EPP) has been conducted in local community for preparation in case of emergency. The installation and monitoring of community-based landslide warning system will be done in various parts of Thailand in future as well.

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