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An integrated methodology to develop a standard for landslide early warning system

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Abstract. Landslides are one of the commonly occurring natural disasters with worldwide susceptibility. Some distinct features of these disasters are that the affected area has a high density of population, low accessibility and the locals have low level of knowledge about disaster mitigation. Considering these conditions, it is necessary to establish a standard for an early warning system specific to landslide disaster risk reduction. This standard is expected to be the guidance system in conducting detection, prediction, interpretation, and response in landslide disasters. This new standard introduces the seven sub-systems for landslide early warning, starting with risk assessment and mapping, dissemination and communication, establishment of disaster preparedness and response team, development of evacuation map, standardized operating procedures, installation of monitoring and warning services, and building a local commitment to the operation and maintenance of the entire program. Since 2012, Indonesia has implemented a trial for the seven sub-systems in 20 landslide-prone provinces throughout the country. An example of the application of the proposed methodology in a local community in Central Java, Indonesia is also described.

1 Introduction

Landslides are one of the deadliest disasters according to their frequency of occurrence and potential fatalities. Landslide mitigation is always associated with the causing factors, i.e. precipitation, earthquake, and slope interference, among others (Ramesh, 2014; Senneset, 2001). There are two types of landslide mitigation efforts, which are structural and non-structural. An example of effective and adaptive methods of non-structural disaster risk mitigation is to increase the preparedness of the community with the implementation of an effective and reliable early warning system (Bednarczyk, 2014; Michoud et al., 2013).

Early warning is a timely and effective provision of information through appropriate institutions that enable exposed individuals to take precaution and effective response (UNEP, 2012). There are many definitions of early warning system (Medina-Cetina and Nadim, 2008), but common reference from UN-ISDR (2006) stated that a comprehensive and effective people-centered early warning system consists of four interrelated key elements, namely risk knowledge, monitoring and

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warning device, dissemination and communication, and response capability. One example of efforts to implement the system is the debris flow early warning system. Currently many countries already have debris flow early warning systems implemented in their watershed, including for water-induced sediment disasters in Indonesia (Apip et al., 2010). There is strong connection between debris flow and failure of the slope in some areas due to precipitation-induced as well as earthquake-induced failures (Collins, 2008; Baum and Godt, 2010). These disaster aversion systems would eventually evolve into the development of a landslide early warning system on its own (Intrieri et al., 2012).

However, cultural, economic, social, and demographic considerations are often left out compared to the other technical aspects in the currently developed early warning system. Furthermore, training on early warning systems and measures to be conducted as proper precautionary responses should be followed up not only by researchers and experts but also by the decision makers on the national and local level (Fathani and Karnawati, 2013; Fathani et al., 2014). Therefore, there is a necessity to create a universal standard for a landslide early warning system that puts more specific emphasis on the role of the community and social aspects in general. The development of the landslide early warning itself is a central alternative for landslide management (Barla and Antolini, 2016). Further criterion of landslide early warning system may be found in Wieckzorek and Glade (2005) and Guzzetti et al. (2008).

The Sendai Framework for Disaster Risk Reduction (SFDRR) 2015-2030 declared that national and community resilience against disaster is obtained through disaster prevention and risk reduction. Two of the components of the priority action are risk assessment and early warning in order to respond effectively to a disaster, by implementing a simple, low-cost early warning system and improving the dissemination of information at local and national levels. The need of the legal standard is important to exemplify the early warning capacity as well as community risk consciousness (Eidsvig et al., 2014). This standard development is aimed at empowering individuals and community at risk to act in sufficient time and with the right actions to reduce the number of the wounded, the loss of lives, and properties (UN-ISDR, 2006). This standard was composed by considering the limitations of local communities in socio-economic, culture, and education aspects hence it is essential for the standard to be simple and straightforward.

2 Methodology to Develop a Universal Standard

As the types and mechanisms of landslide early warning system vary, a universal standard should be developed so that uniformity in the implementation of an early warning system and improvement of community and stakeholders preparedness in landslide-prone areas can be obtained (WMO, 2010). The standard contains explanation on the glossary of technical terms and definitions, requirements and general phases in the implementation of landslide early warning systems. It also regulates the standardization of the commonly used monitoring equipment, warning criteria, the color of the lights and the sound of the sirens, the evacuation map, and types of disaster preparedness and response organization.

The proposed standard adopts a hybrid socio-technical approach in disaster risk reduction (Karnawati et al., 2011, 2013b). This approach needs inter-disciplinary roles to support disaster risk reduction in the context of community development. The technical approach plays a role in the risk assessment and installation of hazard monitoring and warning services. However, based on a long experience in implementing landslide early warning systems in Southeast Asian countries since 2008, focusing only on the technical approach would not guarantee the effectiveness and sustainability of the system (Fathani et al., 2014). In order to overcome this problem, a social approach plays a key role in the success of the program, particularly in terms of establishing the disaster preparedness protocol, developing the response team, evacuation map, a standard operating procedure, and enhancing local commitment. Both approaches are supported with continuing education and research. However, it should be noted that this hybrid technique should be made low cost with simple methods, approaches, and technology so that the community can understand, operate, and maintain it properly (Karnawati et al. 2013a).

Taking into account the four key elements of a people-centered early warning system (UN-ISDR, 2006) and the hybrid socio-technical approach for disaster risk reduction (Karnawati et al., 2013a, 2013b), a universal standard for landslide early warning system which comprises seven sub-systems is proposed as elaborated in Fig. 1. It can be clarified that monitoring and warning services that to date are considered as the core of early warning systems will remain an important part of the disaster management program that now needs to be supported with other equally important elements. In Asia, locals depend on hilly areas not only as their dwelling place, but also for agriculture and livestock farming (Arambepola and Basnayake, 2014). As the affected area of landslide is usually isolated, the implementation of the early warning system with seven sub-systems is expected to increase the capacity of the locals as first responders and eventually support the establishment of resilient villages/districts that will contribute to national resilience (Fathani et al., 2014; Karnawati et al., 2013b).

2.1 Risk assessment and mapping

Risk assessment and mapping is carried out by technical, institutional, and socio-economic-cultural surveys within the vulnerable community. The survey is conducted by the local authority‒along with the local community and supported by researchers and experts. This assessment is an important first step to determine the strategy of the implementation of the system from various aspects. This systematic approach will serve to identify the hazardous and safe zones and to prioritize the location of hazard monitoring and warning devices installation (Michoud et al., 2013).

The technical survey is performed to understand the geological conditions in certain areas, especially to determine landslide susceptibility and stable zones (Collins, 2008). This survey is also conducted to gather information on the history of landslide movement, damaged infrastructures, and symptoms regarding mass movement such as crack, subsidence, appearance of spring water, fracture on structures, and tilting of poles and/or trees. During technical surveys, information on lithology and distribution of soil and rock formations should also be included. By examining the results of technical surveys, the authority and community could identify the potential instability of slopes, predict the impact, and determine the placement of the landslide monitoring and early warning instruments.

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The institutional survey is performed in order to understand whether an established institution or a local organization exists to monitor and mitigate landslide hazards. Meanwhile, the cultural-economic survey is conducted to gather information on community demographics, such as population (household), age, education, financial situation (vehicle and livestock ownership), and culture, so that it is easier to introduce the entire stages of early warning system implementation. Information on potential vulnerable inhabitants and infrastructures due to landslide is important to determine the risk level in a certain area.

The social survey is performed to understand the community's understanding of landslide hazards and address the social issues and gaps within the community. The community's eagerness and motivation to actively participate is prerequisite to regulate strategy of risk reduction programs that are suitable with the local socio-economic-cultural conditions. To increase people awareness, one of the empowerment programs is training and continuing education. This activity will give knowledge and increase people's capacity to be able to decide what needs to be done in order to prevent and protect themselves from landslides.

2.2 Dissemination and communication

Dissemination aims to provide comprehension and understanding to the community, particularly on landslide disaster and to understand the community's aspirations, including the risk consciousness of the community (Jaiswal and van Westen, 2013). Dissemination and communication process is equally important to assess the community risk consciousness and its efficiency (Eidsvig et al., 2014; Lateltin et al., 2005). Methods and materials of the dissemination are tailored based on the preliminary data of the risk assessment and mapping that have been performed. This understanding includes the definition, mechanisms of occurrence, controlling and triggering factors, the symptoms, and the mitigation of landslide which includes its early warning devices, warning levels and warning signs. The inclusion of risk knowledge is also important during the dissemination process (IEWP, 2008). The result of dissemination is that the people have a better understanding of landslide characteristics possibly threatening their area, causes and mechanism, and how to minimize risk. Furthermore, the dissemination and communication serves to identify the key people who have a strong commitment as forerunners in the establishment of the disaster preparedness team.

2.3 Establishment of disaster preparedness and response team

A disaster preparedness and response team is established based on the community consensus facilitated by the local authority or related agencies. Disaster preparedness and response team is related with a disaster prevention volunteer as explained by Chen and Wu (2015). The appointment of this team is based on the ability of each member in landslide preparedness, prevention, mitigation, emergency response and post-disaster management. The team consists of at least a chairperson, data and information division, refugee mobilization division, first aid division, logistics division, and security division. Other divisions included in the team may be added according to the needs of the community and must remain in accordance with the purpose of an early warning system. Each division consists of at least three people or in proportion to the number of population. In addition, it should be composed of permanent residents who live in the hazard prone area. The disaster preparedness team is tasked to conduct all preparedness and response activities, including mobilizing the community to support the technical system effectively. The team is in charge of determining landslide risk zones and evacuation routes that are verified by the local authority or experts and mobilizing people to evacuate before the landslide occurs. All members of the disaster preparedness team are required to participate in an "orientation and training program" then finally selected to be responsible in a particular section (Arambepola and Basnayake, 2014). The team is then responsible to disseminate all information mentioned in the evacuation map and to train the local community regularly to increase their awareness on how to implement the standard operating procedures for evacuation. This process of continuing education is essential because even in a community exposed to landslide risk, many of them are not aware of the risks they have (Calvello et al., 2016). It is emphasized that the community actively participate, because one of the indicators of preparedness of the community will be their own activism that will have a direct impact on the mortality rate after the disaster (Chen and Wu, 2014). In addition, the team is also responsible for operating and maintaining the installed monitoring devices, and conducting a regular evacuation drill at least once a year.

2.4 Development of evacuation map

An evacuation map that provides information on the unsafe zones and areas safe from landslide hazard includes secure evacuation routes, and strategic gathering locations (assembly points). The landslide risk zones and evacuation routes serve as operational guidelines for the disaster preparedness and response team and the vulnerable community to gather in an assembly point and subsequently to evacuate by following a predetermined route. The minimum information provided by the evacuation map, are (Karnawati et al., 2013c):

a. High-risk and low-risk (safe) zones;
b. Houses and important facilities: school, mosque, church, community health center, offices, and landmarks;
c. Alert post, assembly point(s) and evacuation shelter(s).
d. Installation point of early warning system;
e. Streets and alleys;
f. Evacuation route(s).

The evacuation map is very simple and easily understood by the local people even for those having a low education level. In this case, the applied village hazard map may not comply with all of the technical requirements in mapping but it contains all of the basic information to be a guidance system for the people when conducting evacuation (Karnawati et al., 2013c).

2.5 Establishment of standard operating procedure

The Standard Operating Procedures (SOP) serves as a guide for the disaster preparedness team and the community living in a hazard prone area when facing all hazard levels. The number of hazard levels are adjusted for the local conditions taking into account physical characteristics, geomorphological conditions, affected area, rate of movement, and accessibility to a safer area. The SOP contains the procedures for responses by the disaster preparedness team and the community to the alert. The SOP was prepared based on the discussions and agreements of each division under the direction of the local authority and relevant stakeholders. Table 1 shows typical standard operating procedures for evacuation.

The warning levels are determined based on the monitoring data that are verified by trained officers with visual ground check. The determination of Level 1 (Caution) is based on the results of rain gauge measurement. Level 2 (Warning) and Level 3 (Evacuate) are determined when the rain intensity exceeds the determined critical limit, along with the increase in groundwater, and the increase in landslide indications in terms of ground surface or slip surface deformation. The critical limit is determined by the experts after analyzing the monitoring data in the area or other areas with similar landslide conditions.

In Level 1 the disaster preparedness and response team should conduct community coordination and data collection from the local people. During data collection, the officers should inform the people on the increase in hazard level, appropriate preparation, evacuation route, the location of assembly point, and also ask them to monitor their environment. In Level 2, the information and data division should conduct visual ground check to the monitoring devices, and if the landslide indications had already been verified, they should evacuate the vulnerable group. Furthermore, in Level 3 all residents are evacuated based on the guidance in the evacuation map. The role of the local authority in each level is to receive reports from the head of the team, check the location, and provide emergency support to the evacuated residents. The establishment of SOP is important to clearly define the role and responsibilities of the disaster preparedness team and the community when dealing with specific landslide alert (Michoud et al., 2013). However it is important to find the type of communication system and overall operation procedure that will work best locally in a specific area.

2.6 Installation of hazard monitoring, warning services and implementation of evacuation drill

Landslide monitoring and warning devices can be in the form of conventional monitoring modules or radar monitoring modules. The common conventional monitoring modules involve the operations connected to the installation, data acquisition and processing of the in-situ geotechnical instrumentation (extensometer, tiltmeter, inclinometer, piezometers, etc.) and of further remote sensing equipment which can be adapted for landslide monitoring (i.e. terrestrial laser scanner, total stations, photogrammetric techniques, etc.) (Barla and Antolini, 2016). Based on previous experiences Michoud et al. (2013) stated that simplicity, long-term robustness, presence of multiple sensors, proper maintenance budget, and power and communication lines backups are among the important precursors of an effective and successful monitoring network.

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This proposed methodology focuses on the conventional monitoring module, since it is commonly used at the community level to produce a local and immediate warning communication. The conventional monitoring devices consist of the instruments to measure rainfall (rain gauge), to measure the ground movement (extensometer, tiltmeter, inclinometer, and pipe strain gauge), to measure the fluctuation of groundwater level and pore water pressure (piezometer), and survey stakes with or without a telemetry system (Yueping et al., 2010). Each device sends designated information concerning the hazard level. The mechanism of data transmission inter human-technical sensors is shown in Fig. 2. Each device is equipped with lights in different colors and sirens with different sounds to show the hazard levels namely CAUTION-WARNING-EVACUATE. Sirens sound off when the surface/ground movement or rainfall intensity, pore water pressure or groundwater exceeds the critical limit. The disaster experts should determine the threshold of rainfall intensity and pore pressure that may trigger potential landslides. The warning and monitoring networks are all equally important and will succeed in its purpose if all the components are installed correctly (Angeli et al., 2000).

An instrument to measure changes in slope inclination (tiltmeter) is installed in areas susceptible to slope inclination change. Disaster experts should determine the critical limit of soil movement in degree (°) minute^{-1} or hour^{-1}, in the X-Y direction (N–S and W–E). If the instrument indicates slope inclination change that exceeds the critical limit, then it triggers the warning mechanism. The instrument to measure soil crack (extensometer) is installed in areas susceptible to ground movement. This device has critical limits in mm/minutes or mm/hour, depending on the field condition. With the same method, inclinometer, pipe strain gauge, and multi-layer movement devices installed to detect movement on slip surface. Other devices to detect mass movement can be installed and integrated with this system to give timely and proper warning to the community.

In telemetry-based monitoring, every movement at the ground and slip surface, rainfall intensity-duration and groundwater fluctuation are being recorded by sensors and transmitted to an operations control center. The local server analyzes the data by taking into account the critical limit of ground movement and rainfall intensity-duration. Cautiousness is important in installing the early detection sensor in high-risk zones with a high number of people at risk. Determination of the installation location is based on zonation of landslide risk. The installation should be done together with the locals so that they develop greater sense of belonging and responsibility towards the devices and an entire system. The devices should be installed appropriately taking into account the geological condition, the existing symptoms, and landslide volume and potentially affected area. To realize a community-based landslide early warning system, the monitoring and early detection devices should use the most effective and adaptive technology (Fathani and Karnawati, 2013). Once the devices are installed, the teams are formed, the evacuation map and SOP are made available, and an evacuation drill is conducted to ensure the functionality of the devices and the community’s responses. This annual drill will embody the risk consciousness from the Jaiswal and van Westen (2013) study. Evacuation drills are carried out based on a scenario drawn up according to the SOP (Table 1). It serves to train vigilance, preparedness, and responsibility of the disaster preparedness team during the time that the early detection devices indicate potential landslide. In addition, the evacuation drill is also aimed to introduce and familiarize the local community with the sounds of the sirens from each stage of the early detection devices, and to train people on evacuation. The evacuation drill must be done at least once a year at the end of the dry season.

2.7 Commitment of the local authority and community

The commitment of the local government and the community is crucial in the operation and maintenance of the system so that all activity stages included in the SOP run well. This commitment is expected to provide constant communication among all related stakeholders to ensure the result of the system (Lacasse and Nadim, 2009). The duty and responsibility in terms of ownership, installation, operation, maintenance, and security of an early warning system are adjusted to the condition in each location and are agreed upon by the authority, the community, and the private sector. Based on experiences, sustainability of the system is assured with keen involvement of local government (Kafle and Murshed 2006). More advance effort is to include landslide early warning system as an extension to the local government work program. To ensure future improvement on disaster risk reduction, it is also important to conduct periodical analysis and audit on the community reception and involvement of the relevant authorities (Arambepola and Basnayake, 2014; Hernandez-Moreno and Alcantara-Ayala, 2016).

3 The Result of the Implementation of the Proposed Methodology

Since 2008, landslide monitoring and early warning systems have been implemented in Indonesia, starting with a manual monitoring device, paper-recorded device, utilization of data logger up to the real-time monitoring system (Fathani and Karnawati, 2013). Since 2012, the newly proposed standard has been in trial run in 50 districts throughout 20 provinces in Indonesia and Myanmar. Locations of the implementation of the universal standard are indicated in the landslide risk map of Indonesia (Fig. 3). According to Indonesian National Disaster Management Authority-BNPB (2011), out of 453 districts in Indonesia, 42 of them are classified as having high potential landslide risk, whereas 228 districts have medium potential landslide risk. In total, 41 million people are exposed to landslide hazard. Therefore, the management of landslide risk is the main priority in the National Plan of Disaster Management (BNPB, 2011).

As an example, the implementation of the proposed methodology in Banjarnegara District, Central Java Province, Indonesia is explained. Risk assessment was conducted by technical, institutional, and socio-economic-cultural survey of the community performed together with the community. The activity was started with the technical surveys to identify physical symptoms of the landslide hazard, such as cracks, depressions, or upheavals. The surveys were conducted with several key people whom the local authority and experts could directly train on the early symptoms of landslide, the mechanism of slope movement and its processes, and the preventive measures (Cruden and Varnes, 1996). Further, a socio-economic-cultural survey was also conducted with the local people through in-depth interviews or Focused Group Discussion. The results of the preliminary surveys were then discussed in a meeting to communicate and to disseminate the information and at the same

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time to establish the disaster preparedness team (Fig. 4). One of the important results from the socio-economic-cultural survey is a comprehensive and accurate community data collection, e.g. number of households, vulnerable groups, amount of vehicles and cattle.

Examples of an evacuation map developed at a village in Banjarnegara District of Central Java Province are shown in Fig. 5, which shows that the evacuation map is simple and straightforward so that it is easy for the local people to understand and follow. The map also contains information regarding low to high hazard zones, evacuation route and the location of the installed monitoring devices (rain gauge, extensometer, tiltmeter, inclinometer, and piezometer) and warning devices (sirens). Furthermore, the map also contains important landmarks in the area, and locations of each house with detailed information of the house number and the name of the head of the household. Evacuation routes are shown by arrows and forbidden zones are also shown.

The evacuation SOP is composed in compliance with the newly proposed standard in Table 1. The SOP is divided to three warning levels: CAUTION-WARNING-EVACUATE based on each location's characteristics. In each level, comprehensive explanation on what needs to be done, who is in charge, how to respond, etc. is provided. In level CAUTION, the main activity is the coordination of disaster preparedness team and data collection. The main activity in level WARNING is evacuation of vulnerable group (sick people, disabled, elderly, children, pregnant women) and officers have to conduct visual check on the devices and landslide hazard zone. The main activity in level EVACUATE is to evacuate all population in the area to the temporary shelter. Disaster preparedness team is also required to monitor the situation and close access to any high threat zones.

After all the steps above, the results of risk assessment are used to determine the location of landslide early detection devices. Usually, the number of devices is limited and not all can be installed in the high risk zone. Due caution and circumspection is essential to decide where the devices should be installed. Generally, the devices are installed at the most critical areas based on the ground symptoms that show rapid movement compared to other zones. Other factors that determine installation location are the number of exposed lives, accessibility, device security, land ownership, etc.

The final step of this methodology is to carry out an evacuation drill for each warning level. The disaster preparedness team conducts their tasks by referring to the task demarcation, existing SOP, and evacuation map. Facilitators from local authority, experts from university/research center, and NGOs observe the process and ultimately give an evaluation in the end of the drill. Unlike the evacuation system in tsunami, volcanic eruption, and flood with longer warning time, landslide is quite the opposite. The total time from the start of warning to actual landslide may be very short. The location of hazard zones may also be quite far and have difficult access. That is why community empowerment to enable the community to perform independent evacuation led by the disaster preparedness team is important and needs to be supported. Fig. 6 shows the process of evacuation drill. After the evacuation drill, in accordance with the seven sub-systems, local government signs a commitment memorandum containing the agreement to operate, sustain, and maintain the entire system.

4 Discussions

In the application of landslide early warning systems, the determination of hazard level and delivery of warning information is a very crucial part, as it determines the steps to be conducted by the disaster preparedness and response team and the local people. The application of appropriate Standard Operating Procedures for command and communication is key to the whole management system (Calvello et al., 2016). The process of determining the hazard level and delivery of warning information can be explained simply through a series of mechanisms and decisions as follows. The system gives warning when monitoring devices detect landslide symptoms. It then goes through two paths until final decision whether the evacuation should be carried out. The first path is information flow on the left side of Fig. 7. Field data logs created by monitoring devices are sent to the local server through a telemetry system (SMS, GSM, and radio frequency) to focal points (local leaders and trained key people). Trained local officers then conduct visual observation to each device and landslide-prone zones. The follow-up information is delivered to focal points, local authorities and the potentially impacted communities for "evacuation preparation". Generally monitoring the system can be conducted by different agencies/institutions, i.e. National Geological Survey, research center, and university. Ideally, data from these various monitoring agencies is well integrated so that both national and local authorities can make an immediate decision on evacuation.

The second path is command flow, and it starts after information is received by the local authority. Local authority implements coordination with related stakeholders, e.g. local government, police/army, Red Cross, SAR, and emergency response unit. After the local authority officially declares the alert status, disaster preparedness teams then conduct SOP based on the status (Table 1). In WARNING status (Level 2) and EVACUATE (Level 3), results from monitoring devices can be directly conveyed by the local server to the community through sirens and signal warning lamps without local authority. Fig. 7 shows the information flow and command system to support landslide monitoring and the early warning system (Fathani et al., 2014). The proposed methodology of information flow and command flow has been quite effective and strategic to improve the community resilience at the landslide vulnerable village. It is also crucial that the system should be developed through community participation and the provision of simple and low cost technology up to real-time technology for early warning systems. This information flow and command system is a universal concept and adjustable to the conditions of each area or country.

5 Conclusions

Early warning systems are a vital part in disaster risk reduction. The main challenge for an early warning system is to implement it as a part of the community life. Therefore, in the landslide early warning system, an integrated methodology to develop a universal standard for community-based early warning systems is proposed. This universal standard accommodates one of the priorities of the Sendai Framework described in the four elements of people-centered early warning systems, which is then developed into seven sub-systems of the landslide early warning system. The hybrid socio-technical approach is carried out to support the implementation of a landslide early warning system in Indonesia where the trial of this proposed methodology was done. Both approaches (technical and social), supported with continuing education and research, are expected to be able to involve all of the related stakeholders, reduce the cost of system implementation and maintain its sustainability. The monitoring and warning service equipment that had been installed in various locations since 2012 is still in excellent condition until now by successfully implementing the newly proposed standards and maintenance methods.

It is important to know that landslides are common natural disasters in remote areas and therefore technical, institutional, and socio-economic-cultural characteristics of the community should be considered. This proposed methodology is used to establish a common standard, starting with risk assessment and mapping, dissemination and communication, establishment of disaster preparedness and response teams, development of evacuation map, implementation of Standard Operating Procedures, and installation of monitoring equipment. The standard is completed when the evacuation drill has been implemented and a commitment of the local authority and community on the operation and maintenance of an entire system is built. It emphasizes the role of central/local government and researchers/experts as facilitators to encourage the community to work independently on their preparedness and response capacities. Performing self-evacuation drills is important to be conducted periodically to keep the community's spirit and alertness, especially if conducted before the rainy season begins.

The primary issue that the adoption of this system addresses is that implementing the technical approach only is not effective to sustain disaster prevention. This failure often occurs when early warning system devices are installed by local authority/third party without local community involvement, so when the devices are triggered, the community lacks the ability to respond appropriately. The establishment and effective implementation of the seven sub-systems as a universal standard for landslide-prone countries would enhance current disaster risk reduction efforts. Also by increasing community involvement, the operation, maintenance, and sustainability of an entire disaster prevention system are secured early in the process.

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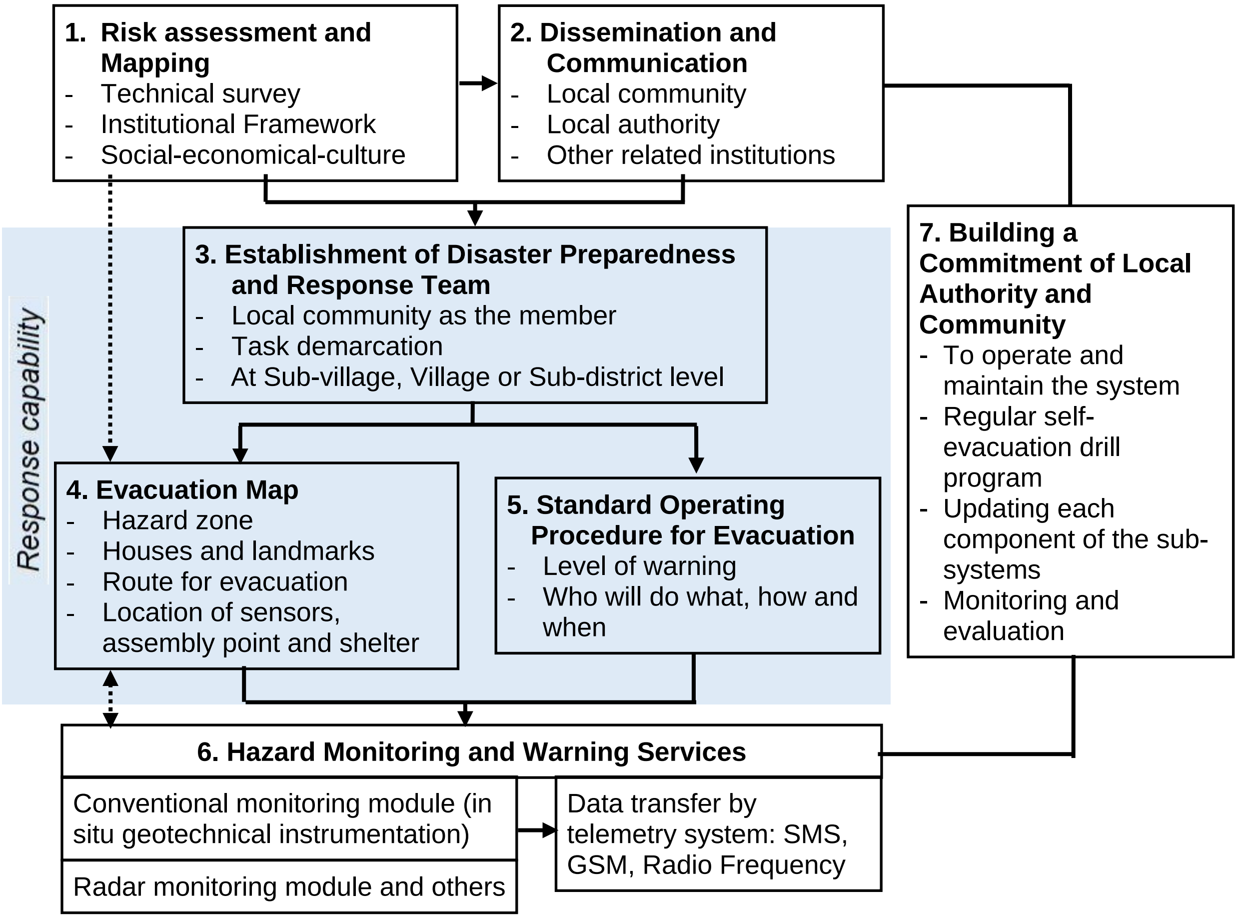

Figure 1: The newly proposed seven sub-systems for landslide early warning system.

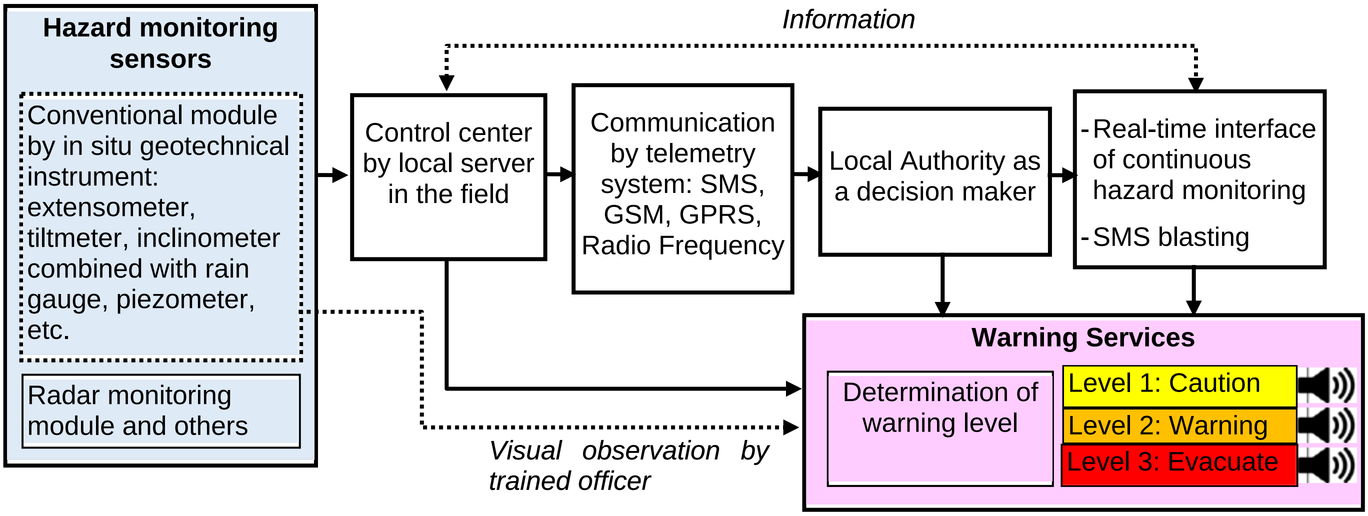

Figure 2: Mechanism of data transmission among landslide monitoring and warning devices.

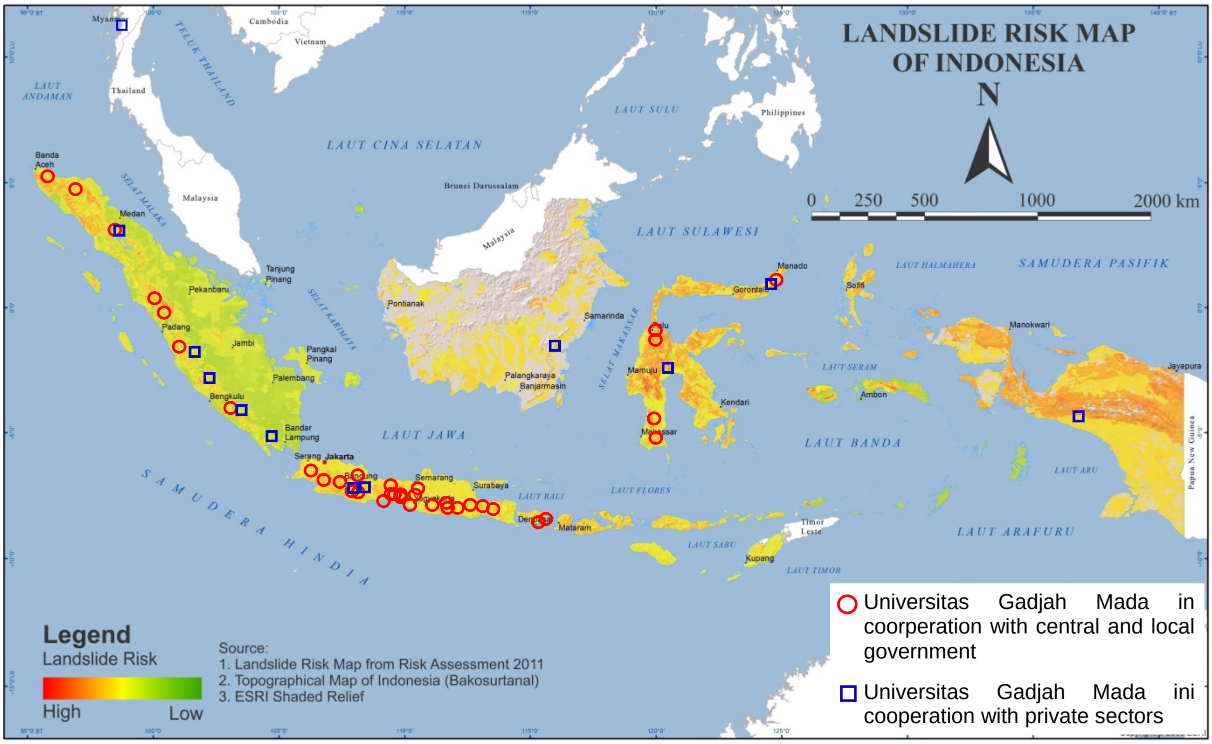

Figure 3: The implementation of the new standard plotted on Indonesian Landslide Risk Map (BNPB, 2010).

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Figure 4: Communication and dissemination process with local community: (a) The disaster preparedness and response team draw a community hazard map; (b) the newly developed community map; (c) team coordinator is explaining the map to the community; and (d) students read the evacuation map.

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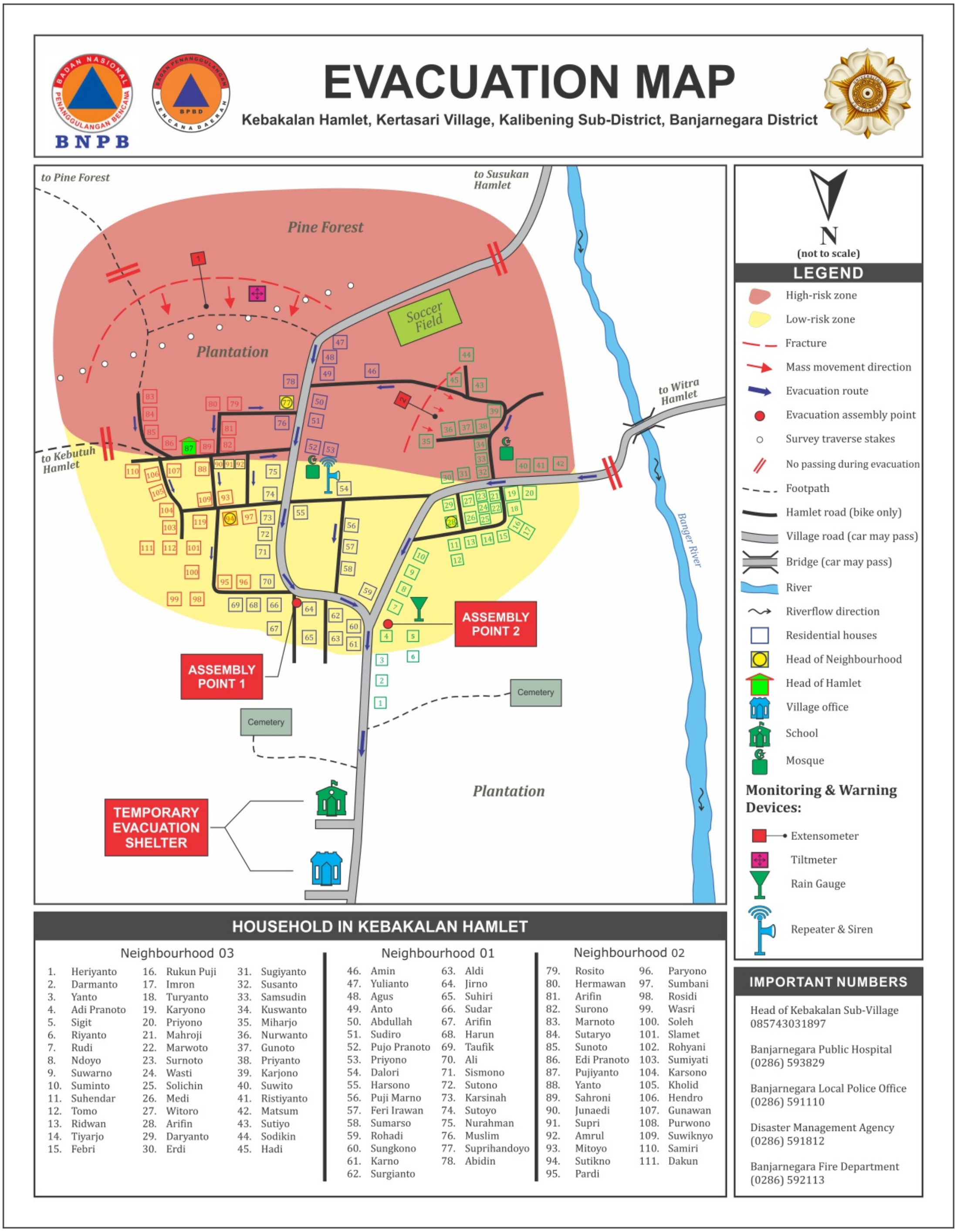

Figure 5: Example of evacuation map.

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Figure 6: Evacuation drill process: (a) coordination among the disaster preparedness and response team; (b) evacuation to the temporary shelter.

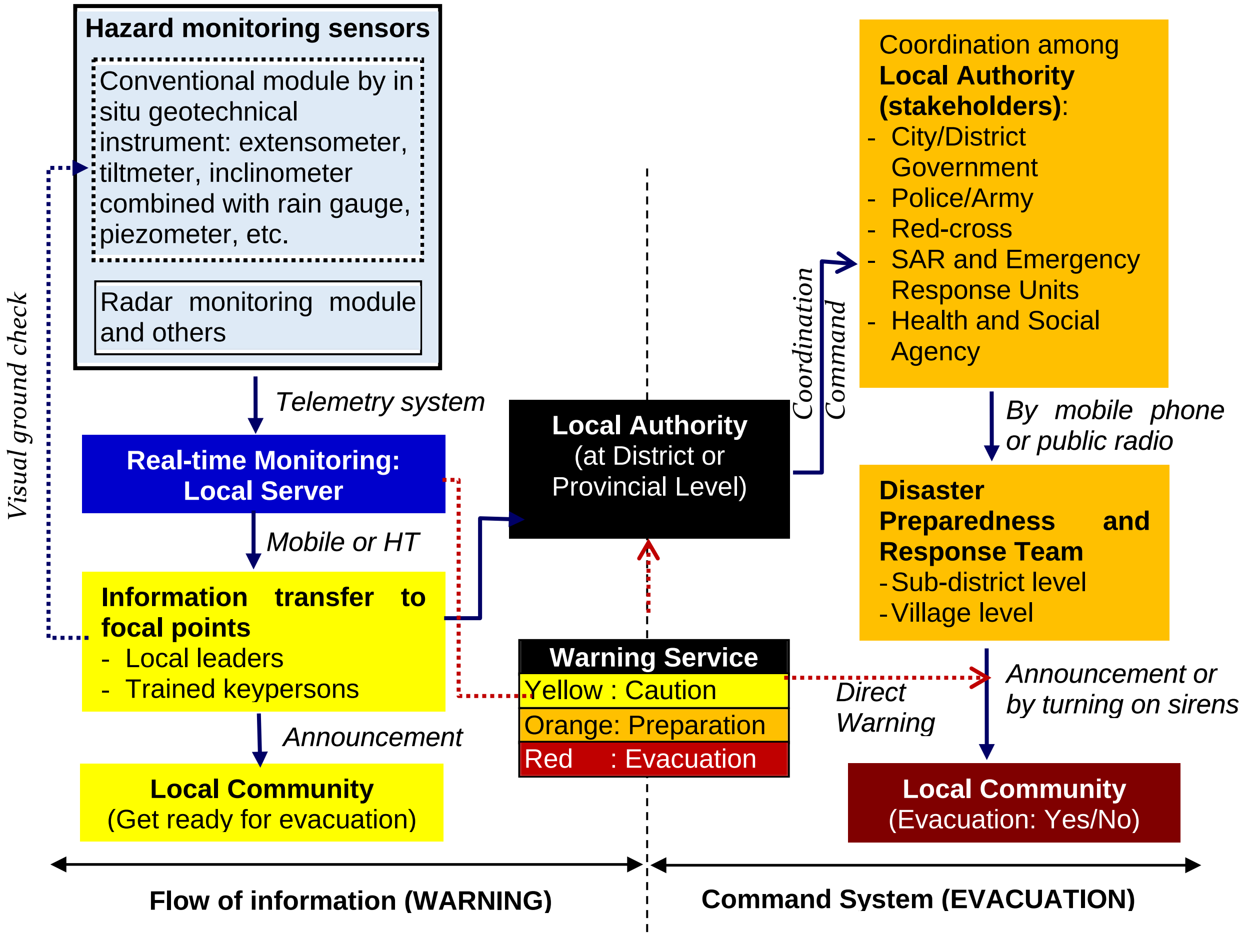

Figure 7: Flow of information and command system for landslide early warning system (after Fathani et al., 2014).

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Table 1: Typical evacuation SOP to support a landslide early warning system

Status/alert level	Criteria/ Sign	Action/response by the community	Action by the local authority
CAUTION (Level 1)	**Criteria**: determined by rainfall measurement (precipitation rate) **Sign**: "blue" lamps and/or siren that sounds "caution, high rainfall" or other sound signs that show the lowest threat level or depending on the local conditions	• The team leader coordinates with the Disaster Preparedness Team. • The data and information division checks the condition of the monitoring equipment and collects data of the community, and informs the alert level and encourages preparing essential items to bring. • The Disaster Response Team provides periodic reports to the team leader.	• Receives report from the disaster preparedness team leader • Checks the condition in the field and maintains coordination with the disaster preparedness team
WARNING (Level 2)	**Criteria**: determined by increased rainfall or groundwater, increased landslide indications in terms of ground surface or slip surface deformation **Sign**: "orange" lamps and siren that sounds "warning, evacuate the vulnerable people" or other sound signs that show the increase of threat level to "warning" or depending on the local conditions	• The data and information division re-checks the condition of landslide and the monitoring equipment, and collects data of the community • The team leader gives the vulnerable group an order to evacuate to the assembly point, with the help of the refugee mobilization division. • The data section collects data of the vulnerable group in order to ensure that they have been evacuated. • The security division is in charge of ensuring the security of the affected area.	• Receives report from the disaster preparedness team leader • Checks the condition in the field and maintains coordination with the disaster preparedness team • Provides support to the evacuated vulnerable group
EVACUATE (Level 3)	**Criteria**: determined by increased rainfall or groundwater, increased landslide indications in terms of ground surface or slip surface deformation **Sign**: "red" lamps and siren that sounds "evacuate" or other sound signs that show the highest threat level or depending on the local conditions	• The team leader gives all residents an order to evacuate to the assembly point, with the help of the refugee mobilization division. • The data and information section checks the monitoring devices and collects data of the residents in the refugee camp.	• Receives report from the disaster preparedness team leader • Checks the condition in the field and maintains coordination with the disaster preparedness team • Provides emergency support to the evacuated residents