CONTROLLING EFFORT OF LAHAR FLOW IN SINABUNG VOLCANO

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ABSTRACT

The Sinabung Volcano that has been inactive for 400 years suddenly erupted on 29 August 2010. This activity kept going until November 2010. After being idle for a while, Sinabung was back to be active on 15 September 2013. The fluctuating activity was going on until November 2016. Recorded that from 2013 until 2016, there have been almost a thousand eruptions. For the Sinabung activity, people living around the dangerous area, such as West, South, Southeast, and East slopes, had been evacuated. The controlling effort of lahar flow by government of Karo Regency is still non-structural. One of them to forming observer volunteer team of river height, and installing ARR+ equipment with Balai Litbang Sabo Yogyakarta to support the lahar flow early warning systems based society. On the other hand, local goverment collaborates with BWS Sumatera II to implement the structural lahar flow control. In 2017, few sabodams are going to be built in Lau Bekerah 1 River, Perita, and Perbaji, as an effort to protect the settlement and agricultural land on West slope. Besides, to mitigate, adapt the threat of lahar flow, and to prevent casualties and loss, it has been proposed some recomendation.

Keywords: *Eruption, dome-collapse pyroclastic flow, lahar flow, the lahar flow early warning systems*

INTRODUCTION

Background

Sinabung Volcano which has strato shape and height 2.460 asl, geographically lies on 03° 10’ N and 98° 23.5’ E, in Karo Regency, North Sumatera. After 400 years has been inactive, this mountain suddenly erupted on 29 August 2010. This activity kept going until November 2010. After being idle for a while, Sinabung was back to be active on 15 September 2013. The fluctuating activity was going on until November 2016.

The activity from September 2013 until September 2016 has produced more than 50 million m^3 of volcanic material spewed to the South, Southeast, and East slopes. However, since the wind headed to random direction, some volcanic ash got the western slope while the wind was moving from the east to the west. The spread of the volcanic ash on the western slope and heavy rain triggered the occurrence of erosion and landslide on Western cliffs. Therefore, in rainy season, west, east, south-east, and south areas are potentially affected by the lava of Sinabung Volcano.

As an anticipation of casualties, government of Karo District, through Regional Disaster Management Agency (BPBD) evacuated people in the South, Southeast, East, and West slopes. Even, to prevent the return of the people to their houses, supplying electricity to the residential will be determined by local governments.

The increasing number of pyroclastic material from Sinabung Volcano eruption on several slopes, also many areas are eroded and got landslide on West slope, led the potentially affected of lahar wider.

Figure 1. *Location of Sinabung volcano on Sumatera Island, Indonesia*

Especially, since the erosion material fills the river, it's getting shallower. Shallower river could change lahar flow out off the track.One case occurred on 9 May 2016 in Western slope of Sinabung Volcano at around 15.45 WIB. Because there was a blockage in Lau Bekerah 1 River that goes to Desa Mardingding, the lahar flow was off the track and hit some houses and field in Kutambaru Village, Tiganderket Sub-District, Karo District. It caused three house were heavy damaged. (Magazine Tempo, Co, 2016).

Along with the increasing of world natural disaster, world countries have agreed to put natural disaster risk reduction on their development (United Nations Office for Disaster Risk Reduction, 2015). Different impact will be happened between country which is consequently applying the effort of disaster risk reduction and which is not.

Disaster vulnerability index of Indonesia reaches 52.8% (United Nations University, Environment and Human Security Institute, 2016). Therefore, facing natural disaster should not only focus on doing responsive action. It is now the time to carry out the result of Sendai Framework Disaster Risk Reduction, namely, emphasizing the disaster management agenda to change the concept of disaster risk reduction, mitigation and adaptation. Disaster mitigation is a series of effort to reduce the risk of natural disaster, either through physical construction or ability enhancement of facing the disaster threat (Government Regulation of Republic of Indonesia, 2008). Adaptation is an effort in many sectors to minimize the negative impacts of natural disaster.

Limitation

There are some limitations found in this research:

a) The ongoing activity of Sinabung Volcano since 2013 until now (2016) causes the growth of new lava dome which can lead to hot cloud avalanches towards the south slope, Southeast, and East.
b) The ongoing activity of Sinabung Volcano makes the spread of volcanic ash to the West slope cause the erosion and landslide on cliff. This triggers the lahar flow of going to the West slope.
c) The areas of South, Southeast, East, and West are still uninhabited for the ongoing activity of Sinabung Volcano.
d) Both survey on the dangerous area and lahar flow control effort are still postponed since the entry ban for the community to enter the dangerous areas of South, Southeast, East, and West is still valid.
e) There has not been found a thorough effort to reduce the lahar flow risk factors which potentially kill people and destroy properties.

Objectives

Based on the points of limitation, this research aims to do:

a) Vulnerabilities Analysis and Risk Assessment in the area of Sinabung Volcano.
b) Recommendation based on the concept of mitigation and adaptation of disaster risk reduction with priority scale tied to the basic direction of the local area.

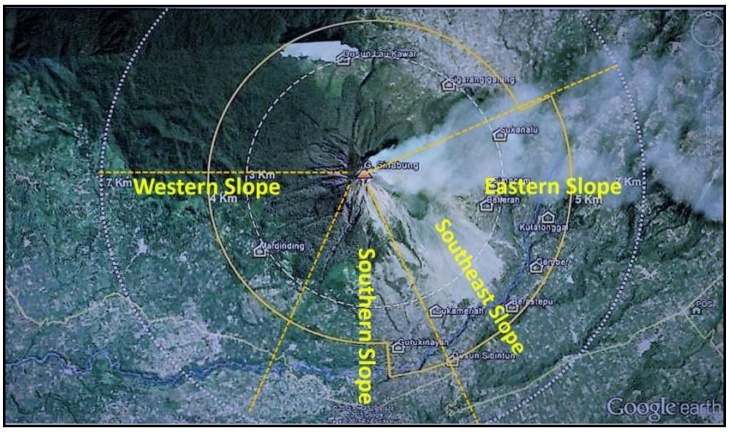

Figure 2. *Map of Sinabung Volcano Dangerous Area*

METHODS

Disaster risk factor reduction is done by planning a disaster prevention which is arranged on the basis of disaster risk analysis and the effort to prevent it. These are two things to note:

a) To determine the locations of lahar flow area and equipments required, the analysis method and interpretation of debris flow map.
b) To carry out the concept of disaster risk reduction by mitigation and adaptation, it is required to do the disaster risk reduction based on the priority scale which is tied with the local area development basis.

RESULTS AND DISCUSSION

The fluctuating and continuous activity of Sinabung Volcano (2013-September 2016) is magmatic. The volcano emits lahar flow, dome-collapse pyroclastic flow, and the emergence of new lava dome. The lava domes often collapse due to eruption, as shown in Table 1 (The national disaster management agency of Indonesia, BNPB, 2016).

Table 1. *The Number of events the collapse of the lava dome Sinabung 2013 ~ Sept. 2016*

No.	Formation date	Collapse date	Volume	Avalanches distance (m)
1	19 February 2015	5 March 2015	1.5 million m^3	4,700
2	March 2015	21 May 2015	2.8 million m3	4,000
3	May 2016	24 August 2016	2.6 million m^3	3,500

**) Data and information centre, BNPB, 2016.*

The volcanic activity of Sinabung Volcano until early October 2016 was still ongoing. This can be seen through the hybrid earthquake which was back to happen on August 31, 2016. It indicates that lava supply inside the Earth is going to reform a lava dome. The 2.6 million m^3 lava dome material which collapsed on August 24, 2016 is still left around 20%, and will get decreased day by day. The collapse of the lava dome would create an dome-collapse pyroclastic flow slide to the South and Southeast.

The result report of visually observation from Pos Pengamat Gunung Api (PGA) Sinabung in Ndokum Siroga Vilage, Simpang empat Regency, the growth of a lava dome on October 28, 2016 reached 2.4 million m^3. Therefore, in the coming time, the threat of dome-collapse pyroclastic flow on South, Southeast, and East Sinabung still remains risky.

Figure 3. *The formation of new lava dome, photograped from Desa Sukanalu on July 21, 2016 and November 28, 2016.*

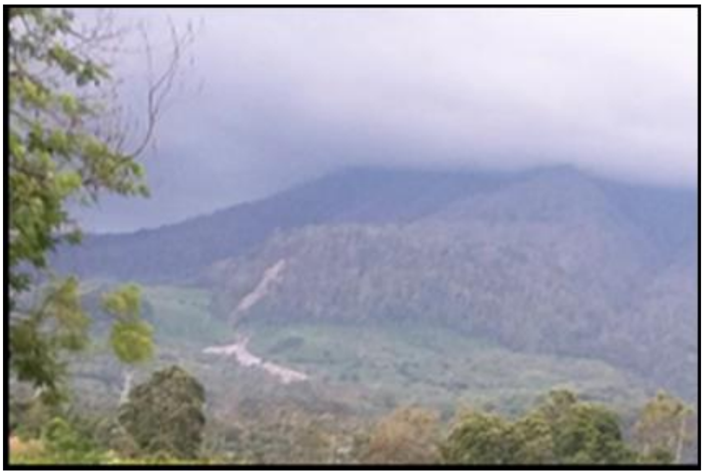

Figure 4*. Erosion and landslide on the Western of Sinabung Volcano*

The volcanic activity of Sinabung Volcano causes more than 50 million m^3 of volcanic material as a result from eruption spread to South, Southeast, and East slopes. The ash also spread by the wind to the West slope, which makes rain water cannot permeate into the ground, and "run-off" score is added to the area. That "run-off" on the steep slope areas causes the land cover material on the West slope from the past was revealed, and then brought by the flow to the downstream, causes erosion and landslide on some cliffs and slopes. The rain water flow that goes from steep slope to the foothill, form a water flow which has a big power to load sediments that is crossed. Lahars rapidly formed corridors on the distal slope of the volcano. (Edouard de Belizal, et. al, 2013).

That small scale debris flow gathered in the flow of tributary. When the tributary flow cannot hold debris flow any longer, there would be a debris flow runoff which comes out of the tributaries. Even when the rain was getting heavier, there would be more sand and stones with bigger diameter loaded. It causes the runoff flow get bigger as well. If the rain keeps going in a longer time, erosion and landslide could happen intensively both on the river bank and river bed.

Sedimentation process happens more in the middle of the river and downstream, with high sediment concentration. The combination of that process causes many river morphology changes on the proximal fasies zone (slope area) and distal (foothill area). The changes could be the shallowing and widening of river channel (Gilang Arya Dwipayana, et. al, 2013).

Disaster Planning and the Management

Essentially, natural disaster is something that cannot be separated from life. This gives direction that disaster should be managed thoroughly since before, at the occurrence, and after. Therefore the basic principle on the arrangement of disaster management is to apply the paradigm of holistic disaster risk management.

Figure 5. *River channel of Merdingding Village was full of material of Sinabung old eruption*

Lahar flow management in the area of Sinabung, Balai Wilayah Sungai (BWS) II is done by dividing three types of area based on the potency of lahar flow to make the execution easier to do (data from BWS Sumatera II). As shown in Figure 6, there are division of the types based on the volcanic material direction, potency of the occurrence of lahar flow, and victims also infrastructure damage.

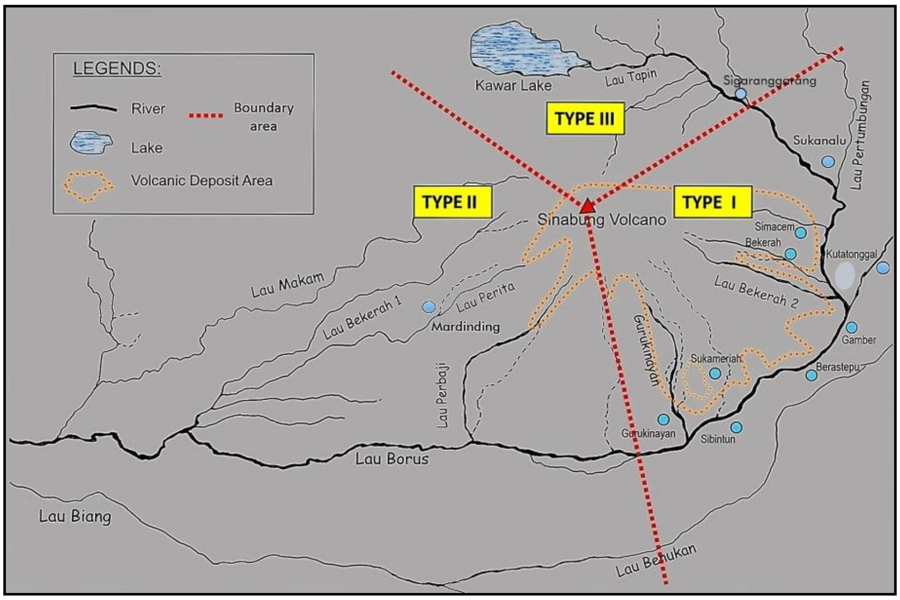

Figure 6. *Map of area types based on the lahar flow potency on Sinabung Volcano*

***Table 2.** The area classification around Sinabung*

Area	Remarks	Actions
Type I	Area where 1,250 Hectares pyroclastic depositions occupy the slope and riverbed. The people around should have been evacuated.	No action taken yet
Type II	This area is not an area of pyroclastic deposits but potentially lahar flow affected, that area covered the distribution of the volcanic ash which led to the occurrence of landslides and slope erosion and in the rainy season can be triggered a flood of lahar flow. Infrastructures are damaged, such as weir, irrigation channel, bridges, and roads.	The priority goes to protecting settle-ment and agricul-tural land
Type III	Area which is safe enough from the potency of lava flood as most consist of forest that is not affected by the activity of Sinabung, and no river flow comes from the top of Sinabung.	No action required

**) Source data from BWS Sumatera II*

According to the conference result of Frame Work Disaster Risk Reduction 2015-2030, the disaster management in Indonesia should be done in all the synergy with development plan. Disaster management, however, is a part of development plan. Disaster management plan is arranged based on the disaster risk analysis result. The efforts are explained on disaster management activity program and the detail of its budget. Every plan generated by this plan is a program related to the prevention, mitigation, and awareness which is arranged by the scale priority

Lahar Flow Threat in Sinabung

Lahar is a kind of post eruption disaster. It consists of volcanic material which is gathered on the top of mountain and it is not consolidated with rain water yet. Lahar flow to downstream with high speed and density. The density is so big that makes the move is controlled by the heavy gravity and topography around the area, and it leads to load huge stones up to great distance. Hence, lahar flow has enormous destructive power.

Based on the division of lahar flow potential area as shown on Figure 6, the disaster threat on Sinabung areas exists on West, South, Southeast, and East slopes (type I area).

Lahar flow on West Slope (Type II Area)

As a result of the Sinabung activity, there was a spread of volcanic ash blown to the west slope. Volcanic ash that covers the surface causes the soil cannot absorb water well. This adds "run-off" value to the area. "run-off" on steep slope makes the old land coverage material was peeled and brought by rain water to the foothills. It causes erosion and landslide on some cliffs and slopes. That mixture flow creates water flow which has great power to load the sediments it goes through. Lahar rapidly formed corridors on the distal slope of the volcano. (Edouard de Belizal, et. al, 2013).

When the rainfall goes to the surface of Sinabung West slope which is being covered by volcanic ash, mud flow covers the soil pores and this blocks rain water to permeate into the ground. That flow is the surface flow, called surface "run-off" that has rapid flow. This surface flow goes to downstream by making scours on soil and loading stones and other materials. The strokes are possible to enlarge. Those strokes will then form small grooves, later small trenches, and eventually change into a tributary that would form a river. The flow continues to converge and will meet in the river as a greater water flow where the runoff combine with subsurface flow and basic flow (Sari Anggriani SA, 2016).

Materials produced by the water strokes on the slope enter to the valley, flow to downstream trough tributary with small and narrow capacity, form lahar flow in small scale. When the tributary groove cannot hold the lahar flow which consists of water, stones, and sand from the old Sinabung eruption, there would be a run-off that is off the track (out of the tributaries). When the rain is growing heavier, the runoff flow will get bigger and be able to load big amount of bigger diameter sand and stones. Besides, the bigger runoff flow causes the tributary grooves get wider, as well, as there would be erosion on both left and right side. In conclusion, rushing run-off flow on steep slope can load great scale sediment. This leads to the change of river morphology that is gone through. Therefore, high intensity and short-period rain or low intensity and long-period rain can trigger the occurrence of lahar flow.

Lahar flow on South, Southeast, and East Slopes (Type I Area)

The amount of material emitted by Sinabung Volcano since September 2013 until September 2016 reaches about 50 million m^3 on the South, Southeast, and East slopes. The pile of volcanic material in the form of ash and volcanic stones (*tehpra*) on valleys or rivers on South, Southeast, and East slopes potentially change into lava in different condition, depends on the size of volcanic particles, the thickness of material reserved, tilt of the slope where the material is located, and the intensity of rain. The more or thicker material on the steep slope, the faster, stronger, bigger, and more dangerous the lahar flow, when the rain is falling (Danang Sri Hadmoko, et. al, 2015).

Lahar flow Control Efforts Undertaken

Due to Sinabung Volcano activity, the Government of Karo District, through BPBD has evacuated people living around that volcano. Even, to prevent casualties, both people and visitors are not allowed to come to the settlement and agricultural land in those forbidden areas. Therefore, there is no sufficient and detail survey yet, and the effort of lahar flow control was done limited.

BPBD Karo District has placed volunteers to observe rivers which the upstreams are on west slope (Type II Area), such as Lau Perbaji, Lau Perita, and Lau Bekerah 1. The volunteers have a duty of observing the river surface, and they would report to BPBD as an early warning of lahar flow, if there is a water level increase in a determined level.

To intensify the effort of early warning that BPBD has undertaken, Balai Litbang Sabo and Pusat Litbang Sumber Daya Air initiated to install the equipment of "early warning system of lahar flow on community basis" in a form of rain measurer, equipped with rain data display and logger data equipment (ARR+: Automatic Rainfall Recorder plus). The location of the ARR+ installation is in Mardingding Village (West slope) and Sigaranggarang Village on East slope of Sinabung.

The location mentioned was chosen based on the regional representation, factor of equipment safety, and the difficulty level of how volunteers reading rain data. ARR+ is used for measuring the rainfall on the upstream of rivers on the West and North-east Sinabung Volcano. It is expected that with the rain data, observers of the volunteers team can report the intensity of the rainfall on the upstream to their coordinator, other volunteers, and local BPBD through Handy Talky. If there is a heavy rain and estimated that it is possible for lahar flow going after, BPBD can make a fast decision that evacuation should be done as soon as possible. Therefore, evacuation itself could be done in sufficient time, and it is expected to reduce the number of victims and loss. Table 3 shows the rain data that has to be reported by the observer volunteers of ARR+ to their coordinator, other volunteers, and BPBD.

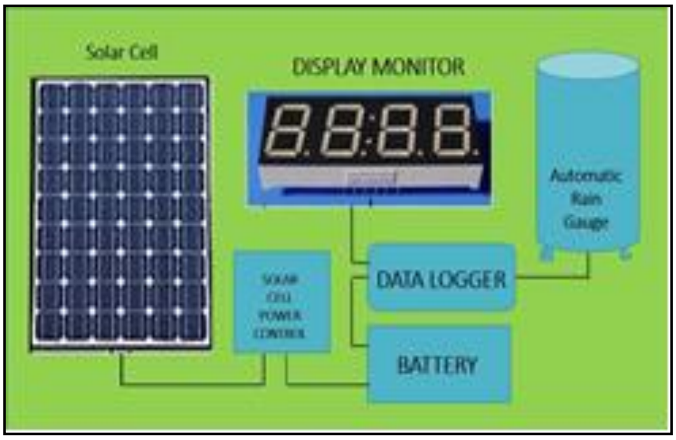

Figure 7. *System Configuration of automatic rainfall recorder plus*

Table 3. Reported rainfall intensity data

No.	Rain intensity reported
1.	approximately 20 mm/10 minutes
2.	approximately 30 mm/30 minutes
3.	approximately 60 mm/1 Hour

Area Condition affected by Sinabung Activity, Recently

Local governments of South, Southeast, East, and West have evacuated people there into some evacuation posts. However, regarding to the ongoing activity of Sinabung until the end of 2016, there were some of them feeling saturated living in the evacuation post. Later, it is known that some people came back to their house, even stay longer by reason of working their fields and taking after their livestock.

BWS Sumatera II, in 2017 is going to build some Sabo buildings on Lau Bekerah 1 river, Lau Perita, and Lau Perbaji as the priority of lava flood management on west slope of Sinabung Volcano. That area, especially in Mardinding Village, had been struck by lahar flow few times. It destroyed the infrastructures, like weir, irrigation channels, bridges, roads, and agricultural land. That policy was made as a management effort and lava control to protect the settlement areas and agricultural lands on West slope (type 2).

It will be required to add the number of humans and equipments to the Sabodam construction on the West of Sinabung Volcano. This leads to the increasing level of lava disaster risk. The quantitative estimation of risk may be determined by using the following formula Risk = Lahar flows Hazard (H) is probability x the vulnerability of the elements of risk (V) x the amounts of costs (A) of the elements at risk. (C.B. Sukaja et al., 2014).

Recommendation for Lahar Flow Control

BWS Sumatera II recently has prepared the effort to overcome lava flood in Sinabung area with Structural Sabo Technology. Therefore, in this opportunity, Non-structural Sabo Technology is proposed. Here are some of the explanations:

a) Estimation and Early Warning of Lava Flood with Telemetric System

This system was installed by using transmitters-radio 2 M Band. This system uses transmitters-radio as that area has no longer got electricity supply. The data acquisition on this system uses wave network of 2 M Band just as been

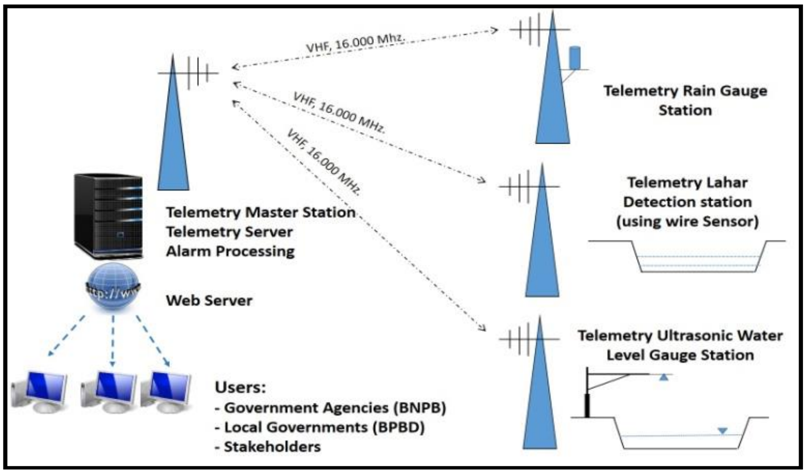

***Figure 8**. Early warning system for lahar flow by using transmitters-radio 2 M Band*

Used nowadays in the frequency of 16.000 MHz. (Very High Frequency). The choice of that frequency is was intended to speed up the plan, simplify the technology, the equipments can be found easily with inexpensive price, and the maintenance can be derived from domestic.

a) Early Warning System for Lahar Flow Based on Video and Lahar Arrival Time Forecasting

To equip the early warning system with telemetric system and for the research purpose and development, complementing it with the early warning system of lava flow based on video and lahar arrival time is recommended. This system can forecast when the lahar flow is coming on the location predicted. This system consists of Lahar Detection Station (Seismograph number 1); Lahar Detection System and CCTV Station (Seismograph number 2) and controller station. Station of Seismograph no.1 consists of broadband data acquisition equipments, vibration sensor, IP-based camera, monitor screen, data recording controller, data analyst, and power supply.

The vibration sensor mentioned earlier which is installed in Seismograph Station no.1 is sending signal to the Seismograph Station no.2, CCTV, and to controller station to switch on the camera and video data recorder in controller station. Sensors on both Station no.1 and 2 which are put on a certain distance could be used to calculate the speed of lahar flow. This information (speed of lava flow, Sabo buildings distance, and public facility along the observed river) enables to estimate when the lava flow comes (travelling time) on areas potentially affected.

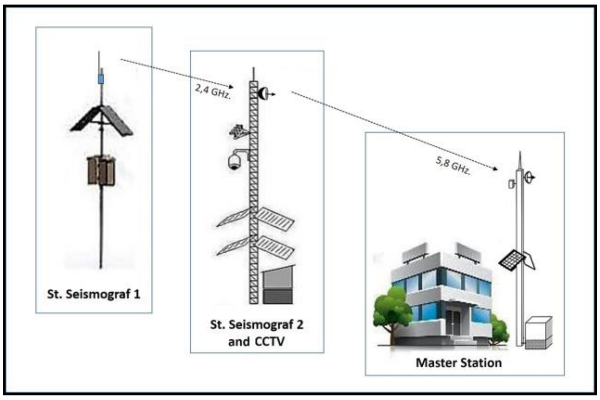

Figure 9. *Configuration of lava flow early warning system based on video*

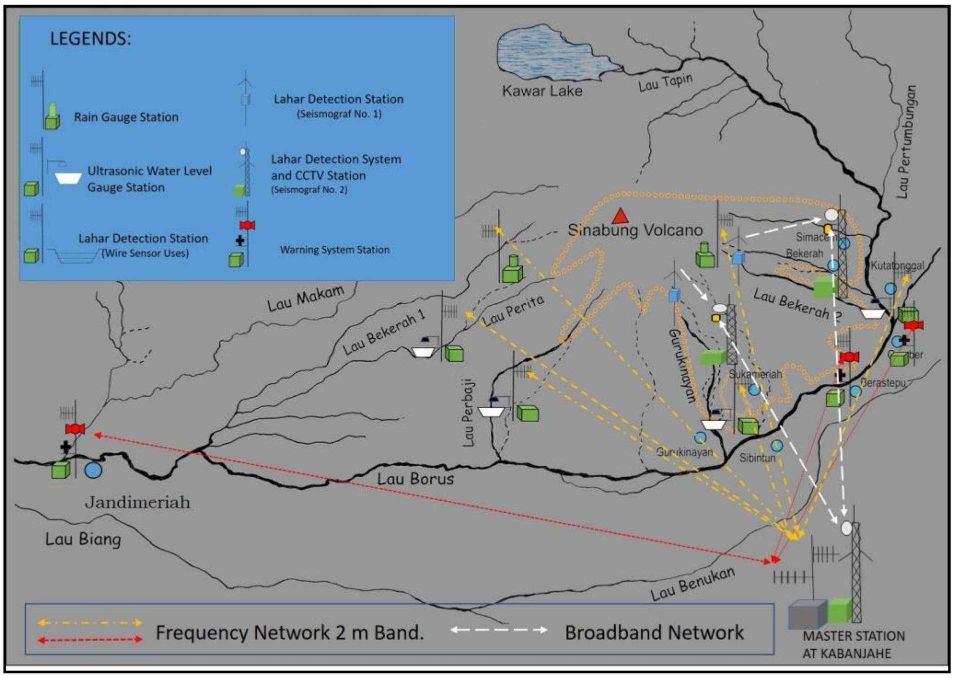

Figure 10. *Plan of lava flow early warning system system network*

b) Weather Radar

The analysis of rain spread in narrow Sinabung Volcano area shows that the rainfall moves around. Therefore, ideally, accurate rainfall data can be obtained in plenty number of rain measurer station. This is going to be hard as Sinabung activity is still ongoing fluctuativaly. Besides, the installment, maintenance, operator and equipment safety should be put on consideration as well. There are limited maintenance staff numbers, anyway.

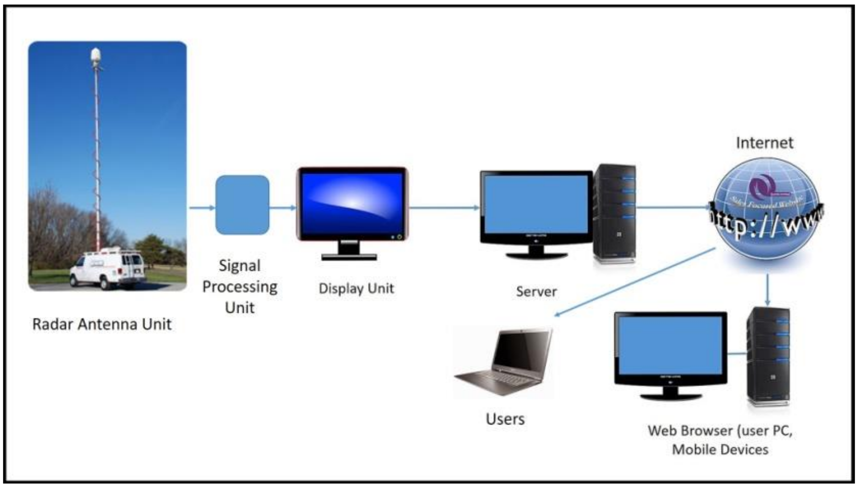

Figure 11. *System Configuration of Weather Radar X Band Dual Polarimetric Doppler*

In conclusion, it is recommended to install Weather Radar X Band Dual Polarimetric Doppler to observe rainfall (to forecast lahar flow) in the area of Sinabung Volcano. This weather radar has dome antenna with only 1 meter diameter, 68 kilograms weight, only 650 watt electrical power, and monitoring range 30-50 km. By installing one unit of weather radar at BPBD Kabanjahe office, the rainfall around Sinabung area can be monitored.

The rain data that occurred in the Sinabung volcano on the results of Weather Radar observations can be used to forecast the lahar flow. The radar data also can predict any disasters that triggered with rainfall intensity.

The installation of the Weather Radar in the office BPBD, Karo district which is located quite far from Sinabung Volcano, it's safe from the disaster caused by eruption and easy for maintenance. And Weather Radar X Band that have small size, light, and easily removable to reinstalled in the another volcanic areas.

CONCLUSION

1) Sinabung Volcano's activities in the form of eruption and lava dome growth until the end of 2016 are still going, so that the threat of lahar flow still exists on the west, south, south-east, and east (areas of type 1 and 2)
2) Construction plan of some Sabo buildings in the area of West Sinabung is creating many activities on the location of lahar danger. In consequence, lahar flow threat risk is increasing.
3) BPBD has role of utilizing simple EWS equipment, namely, ARR Plus which is very useful to reduce the lahar flow risk, especially on the construction area of Sabo building in Lau Bekerah 2, Lau Perita, and Lau Perbaji River.
4) Documented rainfall data of Sinabung Volcano upstream in ARR Plus which is equipped with Logger data, is very useful in the effort of designing and controlling the next lahar flow.

5) Due to the action of reducing risk of lahar flow in Sinabung area, the installment of lahar flow early warning system has to be undertaken as how it has been recommended before.
6) Future Sabo buildings and the lava flow early warning system equipments in Sinabung Volcano area are causing the sense of safety to the people there.

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