INPUT PAPER

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EARLY WARNINSYSTEM FOR LAHAR IN MERAPI

Current and Future Development

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ABSTRACT

Early warning system (EWS) for lahar in Merapi Volcano has been developed since 1970s. For more than 40 years, there were several development changes in the system that has been implemented in order to enhance its technology. The changes were done to respond the current challenges and needs. This paper discusses and examines three sub topics related to EWS for lahar in Merapi volcano. The first is the history of the development process of EWS in Merapi volcano before the 2010 eruption, the second is the impact of the 2010 eruption to the existing EWS, and the last is the future challenges on the next Merapi volcano eruption. Through over-viewing those, it is found that in the future there will be more challenges in the efforts of disaster mitigation since the statistics show the increasing trend of disaster in magnitude and frequency. On the other hand, the population growth will be inevitable which means that more people will live in hazard area. EWS in Merapi Area will have important role in reducing disaster risk in the disaster area, especially in the condition that the disaster occurs beyond scientific prediction. Therefore, continuous improvement of EWS in Merapi volcano will strengthen the community preparedness. Finally, this paper proposes an integration system supported by multi-sectoral involvement for better EWS in Merapi volcano.

Keywords: lahar, Early Warning System (EWS), disaster, eruption, sediment, sabo dam.

Introduction

Mt. Merapi is one of the most active volcanoes in the world and the most active among 129 volcanoes in Indonesia. Since the year 1768 to 2010 it has 84 eruptions with a dormant period of 1 – 18 years and four years in average (Subandriyo, 2011).

Table 1 : Distribution of material due to 2010 eruption of Merapi Volcano.

River	Volume, millions m^3	River	Volume millions m^3
1. Pabelan	20.8	6. Krasak	10.8
2. Trising	3.8	7. Boyong	2.4
3. Senowo	4.4	8. Kuning	3.7
4. Blongkeng/Lamat	1.4	9. Gendol	24
5. Putih	8.2	10. Woro	7.3

Source: Subandriyo, 2010

The recent eruptions of Mt. Merapi has been recorded from 1969 to 2010. The geomorphologic condition of summit area which is characterized by strong Old Merapi formation on the Eastern, Southeastern and Northeastern parts of the volcano has made the volcanic activity always on the West, Southwest and South directions for several decades. However, due to the collapse of Geger Boyo hill on the eruption of 2006, the direction of activity changed to Southeastern part and in the eruption of 2010 the pyroclastic flow reached a distance of 17 km toward Gendol River (Figure 1). The latest catastrophic eruption of Merapi Volcano occured in November 2010. It started on October 26 and reached its peak on November 5, 2010. The longest distance of pyroclastic flow was 17 km from the crater to the direction of Gendol river. Centre for Volcanology and Geologic Disaster at that moment decided

the dangerous zone of Merapi were 20 km from crater for Sleman, Boyolali and Klaten. The number of persons killed updated on December 2, 2010 were 277 bodies and 273 persons were hospitalized. Besides, a lot of infra-structure were totally damaged that made the total lost to be 7.3 trillion rupiahs, Just after the pyroclastic flow occurred the condition of Gendol river was blocked by deposits and no lahar o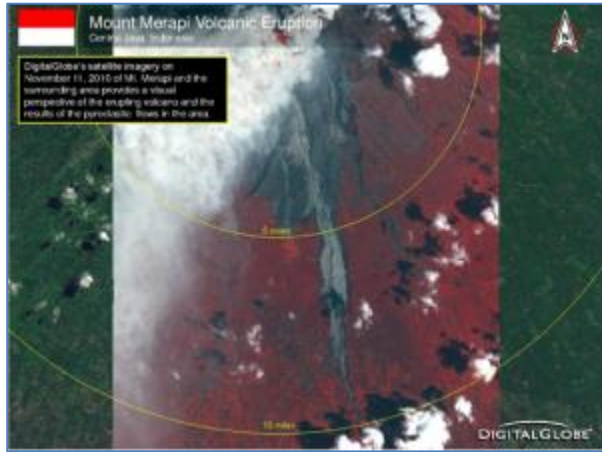ccurred at the moment. At the first rainy season 2010-2011, lahar that occurred in almost all river in the area of Merapi volcano destroyed a lot of public works infrastructures (bridges, sabo dams, irrigation dams, etc), residential area, agricultural area and many times buried the Jogja-Magelang national road at Jumoyo. Due to the dominant of wind during eruption was to the west direction, a great amount of ejected ash was deposited on the west slope of Mt. Merapi. The ash particles made the sediment easily flashed down and easily triggered lahar in Pabelan River. Consequently, the lahar in Pabelan River destroyed a lot of bridges along the river, one of them was Tlatar Bridge as shown on Figure 2 (left). An example lahar ini Boyong River is shown on Figure 2 (right).

Figure 1 : Satelite image of 2010 pyroclastic flow of Mt. Merapi .

The effect of 2010 eruption of Merapi volcano left a large amount of material laying on its upper slope. National Agency for Disaster Countermeasure "BNPB") said that the remaining pyroclastic material of 2010 eruption was estimated 80 million m^3 (Pikiran Rakyat Online, Dec. 13, 2012 at 19:51). The high intensity of rainfall concentrated on the area will be able to trigger the occurrence of lahar. The rivers potentially threatened by lahar are Woro River, Gendol/Opak River, Kuning River, Boyong/Code River, Krasak River, Putih River and Pabelan river covering the Regencies of Sleman, Klaten and Magelang.

Figure 2 : Pabelan bridge in Magelang was swept away by lahar (2011) (left); Lahar in Code River, Yogyakarta (2011) (right).

So far, an old paradigm of *living together with disaster* is still alive in Mt. Merapi and other volcanic area in Indonesia. In order to give warning to the residents in the dangerous zone, a warning system against lahar is quite necessary. Since 1976 a simple warning system has been conducted in Mt. Merapi area. Then in 1984 the system was modernized by installing real time

monitoring of rainfall, water level, lahar sensors and radar rainfall donated by Japan International Cooperation Agency (JICA). Renewal and additional new monitoring stations were conducted within the period of 1998-2005 to improve the system. In the year 2006-2010 before Mt. Merapi eruption, cellular based monitoring of rainfall and water level were installed to replace the old equipments since most of equipments were broken due to vandalism. When Mt. Merapi eruption reached its peak on November 5, 2010 some of monitoring stations were swept away by pyroclastic flow and others were totally damaged by to lahar. The latest revitalization was conducted in 2012 by renewal of monitoring system. A critical line for lahar has also been updated based on the historic data to forecast the occurrence of lahar. Now, a new radar rainfall has been installed to monitor the spatial rainfall in the area of Mt. Merapi and its surrounding.

However, the growing population density along river course would be a challenge in the future how to maintain the existing system and prevent from vandalism to get absolutely a reliable and sustainable Early Warning System against lahar disaster in Mt. Merapi area.

Debris Flows Forecasting and warning System

The debris flow forecasting system is an effort to predict the occurrence of debris flow. This system consists of a monitoring station in the field that consists of a set of data and voice communications equipment, data storage, and sensors and a master station that consists of a set of data and voice communications equipment as well as monitoring and storage of data from the gaunging stations. The location of gauging station and data monitoring station in the area Merapi, as shown in Figure 4.

Monitoring station that consists of the sensors to detect rainfall, water level and monitors debris flows occurence in the river course. Then the data will be sent to the master station in the Office of Experimental Station for Sabo (Balai Sabo), after the signals from several remote station are amplified by repeater station in Babadan Station. The master station is equipped with voice and data communications equipment to call and receive the data detected by sensors in the gauging stations. From the results of of data detection the occurrence of debris flow can be confirmed. Record of water level at a gauging station located before intering the residential area will give enough time to the residence to evacuate.

History of Forcasting and Warning System
The history of forcasting and warning system against debris flow in the area of Merapi volcano can be grouped into five periods.

1) **Before 1976**

    The monitoring system of debris flow consisted of wire sensors that cross the perimeter of river at 1 meter height from river bed. The wire sensor were installed at several points on a river segment of about 500 meters and connected to the simple recorder that record the time of wire cutting. With known distance between wire sensor the velocity of debris flow could be calculated. Radio communication was used to send information to the residents.
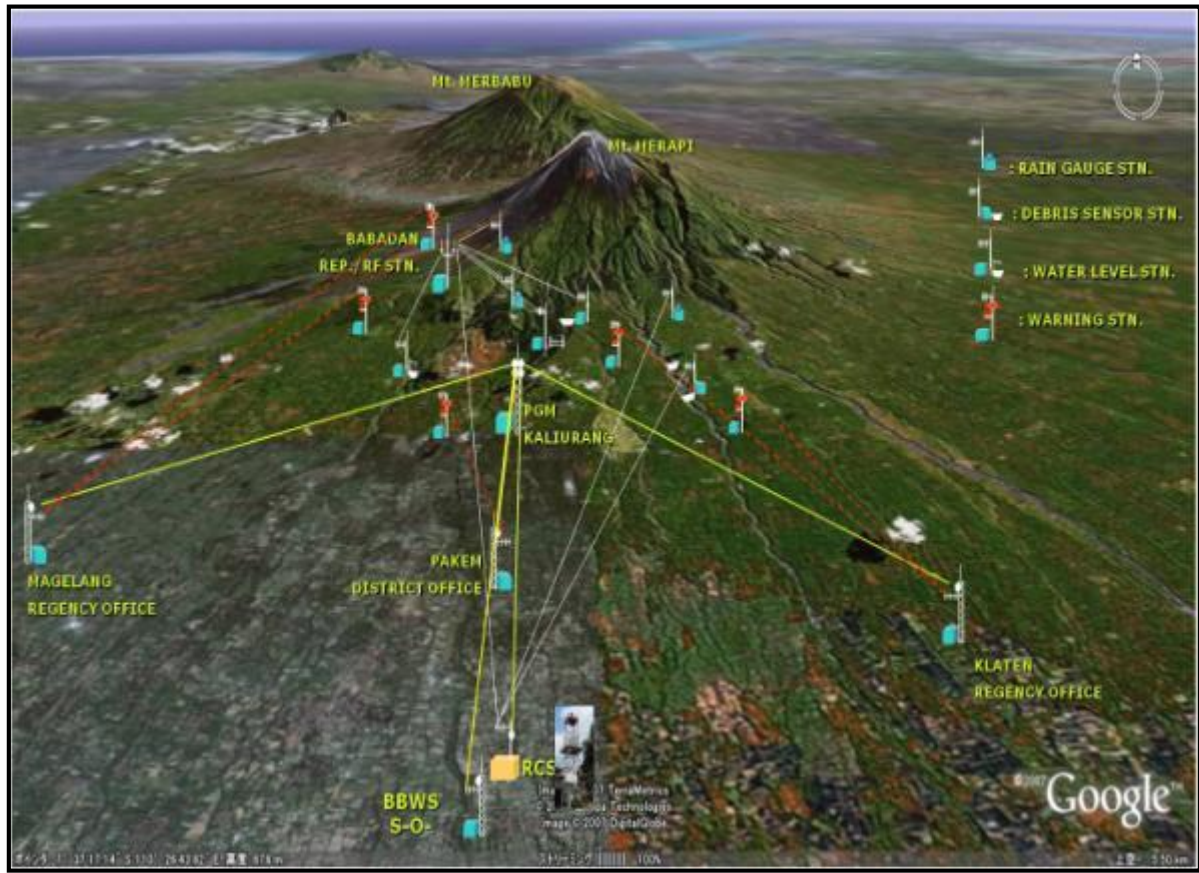
Figure 3 : The location of telemetry station and data monitors station in the Merapi volcano area

2) Period: 1977 - 1983

This system was still conducted by installing wire sensors that cross the river perimeter at 1 meter height from the the river bed. The arrangement of sensors was still the same as before. A movie camera conneted to the system was able to activate the camrea to record the debris flow. Radio communication was used to send information to the residents.

3) Period: 1984 - 1998

The system is implemented based on the Master Plan of debris flows prevention in regional Merapi volcano. In this period the radar raingauge and telemetry stastions were installed in the master stations of Balai Sabo, telemetry stations that consisted of raingauge, debris flows monitoring with vibration sensors and wires sensor and water level gauge of ultrasonic type (contactless measurement), mounted on an arm above the wing of sabodam. The system used radio telemetry equipment at a frequency 70 MHz. and analog data transmission. Monitoring station installed in River of Senowo, Putih, Bebeng, Krasak (Magelang Regency) and River Boyong (Sleman Regency).

4) Period: 1998-2005

Due to the life time of the radar rain gauge finished it was necessary to installed additional telemetry station. The new telemetry stations still used the radio system, but by using the

digital data transmission. In this system the width of the frequency used to transmit data was narrower than the analog system so the more number of monitoring stations could be controlled. Location of telemetry station were in River Senowo, Lamat, Putih, Blongkeng, Bebeng, Krasak (Magelang Regency) and River Boyong (Sleman Regency)

5) Period: 2006 - November 6, 2010 (Eruption)

There was increasing the number of telemetry stations on this period, since new telemetry stations were installed. The new telemetry stations used cellular systems and digital data transmission. The location of celullar telemetry station was in River Senowo, Lamat, Putih, Blongkeng, Bebeng, Krasak upstream (Magelang Regency) and Down stream of Krasak River, Boyong, Gendol (Sleman Regency) and K. Woro (Klaten Regency).

Before the eruption of Merapi volcano in the end of 2010, Balai Sabo operated 10 telemetry gauging stations located in the upstream of River Senowo, Lamat, Putih, Krasak, Boyong, Kuning, Gendol and Woro. Water level gauge stations of telemetry system as much as 16 stations, in River Senowo, Lamat, Putih, Krasak, Boyong, Kuning, Gendol and Woro. Debris flows monitoring station telemetry system as much as 6 stations, in River Senowo, Lamat, Putih, Krasak, Boyong.

6) November 6, 2010 – date

After eruption of Merapi 2010 all telemetry equipment could not be used due to damaged and some of them were swept away by pyroclastic flow. In order to make the system recovered, a revitalization has been conducted in 2011. A number hydrological monitoring stations and master station have been installed in the area of Mt. Merapi to replace the old one, some of them were just repaired by replacing the spareparts. In 2012 radar rain gauge of new generation has been installed to replace the old radar (made in 1984) which currently has been "expired".

Judgment Graph of Debris Flow

There are kinds of Judgment graph, the first is *Yano* method, the second is *risk judgment* method. In Yano method, computation of judgment graph of debris flow in the area of Merapi volcano uses the short duration of rainfall at the rain gauge located nearest to the sediment source. Data analysis was conducted through collecting serial rainfall, that are continuous rainfall proceeded and ended by 24 hour period of no rainfall, either occurrence or non occurrence rainfall. Variables used in the method are: (1) all serial rainfall of non occurrence having cumulative depth ≥ 80 millimeters or rainfall intensity ≥ 20 millimeter/10 minutes; (2) serial rainfall of significant occurrence debris flow; (3) antecedent rainfall for 14 days before as variable of saturation level in the deposit; (4) cumulative rainfall at maximum intensity; (5) maximum rainfall intensity; (6) cumulative rainfall at time of debris flow occurrence; (7) rainfall intensity at time of debris flow occurrence. The sum of variable (4) and (3) is called non occurrence working rainfall, while the sum of variable (6) and (3) is called occurrence working rainfall. Plotting non working rainfall against maximum rainfall intensity and occurrence rainfall against rainfall intensity at time of debris flow on the x-y axes, a straight line separating the occurrence and non occurrence plots can be drawn. The line is called judgment graph or critical rainfall. Figure 4 shows the display of judgment graph for Putih River, the area of Merapi volcano on the master station.
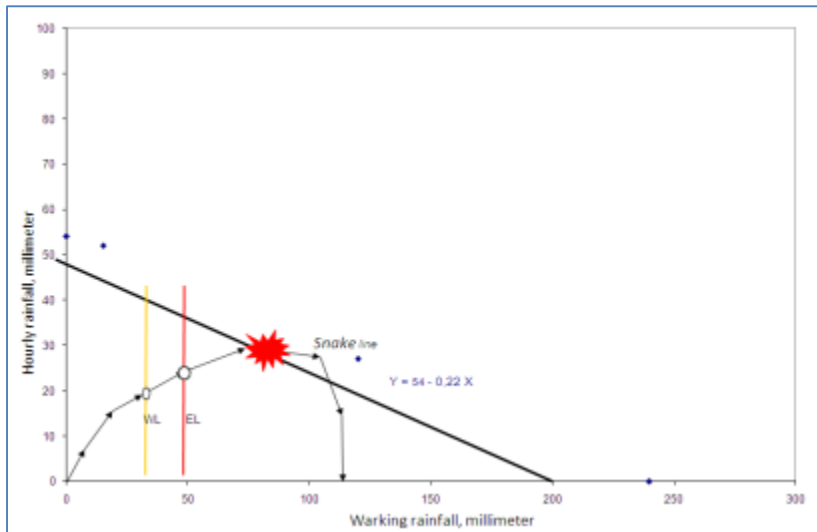
Figure 4 : Judgment graph of G. Maron rainfall station

After revitalization, additional software of forecasting method was provided. A new Risk Judgment Graph has been installed in master station. On 2D plane with the horizontal axis indicating working rainfall (half- life 24 hours) and the vertical axis indicating the depth of rainfall per hour, warning, evacuation, and landslide risk critical lines are drawn. Then, whether or not current status point indicated by snake line is determined. Figure 5 shows the New Risk Judgment graph of Putih River.
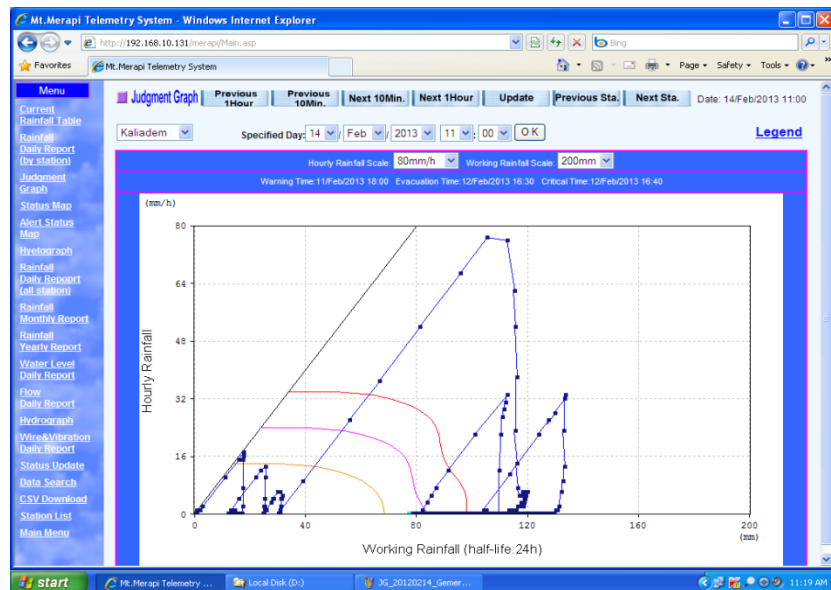

Figure 5 : Display of Risk Judgment graph of Kaliadem rainfall Station

on February 14, 2013

Weather Radar in Balai Sabo

The reflection of the electromagnetic wave emitted by radar antenna will detect objects in the atmosphere. The weather radar is *doppler* type and belongs to X band. Doppler radar detects

precipitation and their movements or objects by emitting and receiving electromagnetic waves back. Radar type X band (9.345 GHz frequency work on) has a wave length of 3 cm with short-range distance so it is appropriate for the observation of objects. With its sensitivity the radar does not only to detect rain, but also detect the very small particles like clouds, fog or snow.
The main component of radar includes:

- Transmitter unit: to transmit and amplify the signal frequency of radar.
- The antenna unit, to focus and radiate a signal which has been amplified by transmitter.
- Receiver: to receive the signals sent back by an object in the atmosphere through an antenna, then clarify and turn it into an image signal.
- Data acquisition unit, to receive the image signal and converts it into a signal numbers.
- Data Processing Unit, to process the signal numbers.
- Control Unit, to control the process so that the result is as you see fit.

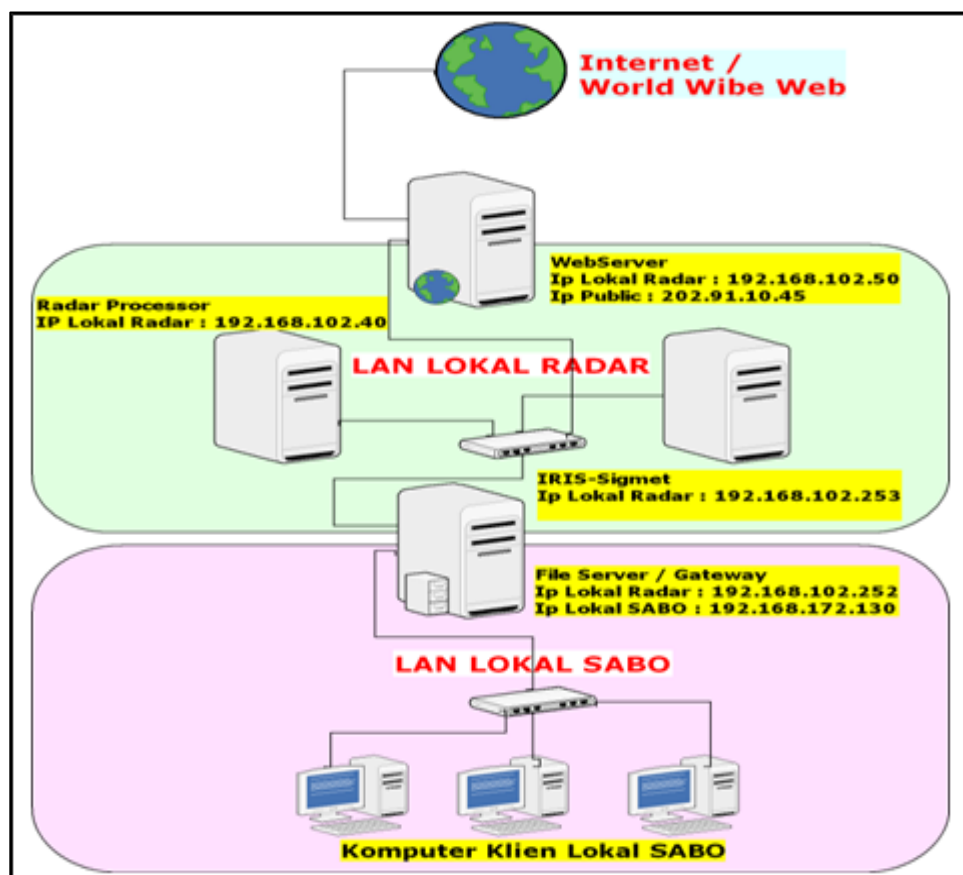The component of weather radar is shown on Figure 6.

Figure 6 : Unit of weather radar in Balai Sabo

Hazard Mapping Against Debris Flow Disaster

In order to mitigate the risk of lahar, a structural measure should be provided by constructing sabo facilities that consist of check dams, dykes, sand pocket. The structural measures are designed to retain the lahar remains on the river course so it will not be dangerous to the residents. However, how strong the structure will be, it still has a risk of failure. Therefore, EWS should be provided in line with the structural measure. How the residents understand that their houses will be threatened by lahar or not, hazard mapping is quite needed. It will show to the residents the hazard status of their residence, where they should evacuate and which route(s) should they take when lahar comes to their residence. The following are summary of guideline on hazard mapping .

Summarry of Guidelines on hazard mapping of debris flow

The first guideline for hazard mapping against debris flow was officially published by Ministry of Public Works of the Republic of Indonesia in 2004.

Data and information

 1) River bed gradient.

   Relation between lahar occurrence and river bed gradient are as follow:

   $0 \leq \theta < 3°$: deposition area of hyper-concentrated flow

   $3° \leq \theta < 10°$: deposition area of debris flow

   $10° \leq \theta < 15°$: deposition area and occurrence area of debris flow or hyper-concentrated flow

   $\theta \geq 15°$: occurrence area of debris flow.

 2) Availability of material source on the river bed and on bank.
 3) Cross sectional area at the river bends, apex point and at the change of slope suspected as overflow points
 4) Geological condition, past landslide or lahar disaster and the existence of cracks on the catchment area,

 5) Peak discharge of debris flow is computed using Ashida Equation as follow:

$$Q_1 = \frac{2}{36}\left[f_2 A_2 + f_1 \frac{c_d}{c_* - c_d} A_1 \right] I_{30} \quad ....(1)$$

where, Q_t is peak discharge (m³/s), f_1 is run off coefficient in debris flow catchment area, f_2 is run off coefficient of other catchment, and f_2 are run off coefficient, A_1 is catchment area of debris flow area km²), A_2 is catchment area of others, I30 is 30 minutes rainfall intensity (mm) and C_d is sediment concentration of debris flow.

Volume of sediment

The sediment volume transported in one debris flow event can be estimated by Mizuyama Equation (1988) as follow:

$$V_{ec} = \frac{R_{24}A.10^3}{1-\lambda}\left[\frac{c_d}{1-c_d}\right]f_r \quad \text{................(2)}$$

Where, λ is void ratio $(\pm 0,40)$, *Fr* is run off coefficient (if no data it is assumed = 1, *A* is catchment area (km^2), V_{ec} is sediment volume transported in one debris flow event, C_d is sediment concentration in debris flow, R_{24} is 24 hour rainfall (mm)

Type of flow
Whether the type of flow belongs to debris flow or hyperconcentrated flow, it can be distinguished based on the river bed gradient and relatif water level.
1) Debris flow occurs when the river bed gradient is equal or greater than the critical gradient (tg θ ≥ tg θ_d), it can be computed by Takahashi Equation (Takahashi, et al., 1988)

$$tg\theta_d = \frac{C_*(\rho_s - \rho_w)}{C_*(\rho_s - \rho_w) + \rho_w(1+\frac{1}{k})}tg\varphi \quad \text{................(3)}$$

Where, ρ_s is mass densitiy of sediment (ton/ms), ρ_s is mass density of water, k is experiment coefficient *(0.85-1)*, φ is static internal friction angle (^{o}), C_* *is sediment concentration on the river bed (=0.6)*

2) Hyper-concentrated flow occurs when the river bed gradient is smaller than critical gradient for debris flow and greater or equal to critical gradient for hyper-concentrated flow.

$$tg\theta_h = \frac{C_*(\rho_s - \rho_w)}{C_*(\rho_s - \rho_w) + \rho_w\left[1+\frac{h_0}{d}\right]}tg\varphi \quad \text{................(4)}$$

Where, *ho* is water depth (m), *d* is grain size of bed material and *C** is sediment concentration at the river bed (=0.6). In case of debris flow the collective movement of particle is assumed to be uniform through the entire flow depth, so sediment concentration is also assumed to be uniform through the entire depth. The the sediment concentration can be computed by Takahashi equation (Takahashi, et al., 1988)

$$C_d = \frac{\rho_w tg\theta}{[\rho_s - \rho_w][tg\varphi - tg\theta]} \quad \text{................(5)}$$

Where, *tg θ* is river bed gradient (^{o}), C_* is sediment concentration at the river bed (=0.6).
If the result of C_d is greater than 0.9C*, it should be taken 0.9C* and if C_d is smaller than 0.3, it should be taken 0.3.

In the hyper-concentrated flow the collective movement of particles do not occur through entire depth but it occurs only in part of the depth so the sediment concentration (Cd) will be different at each flow depth. The sediment concentration is governed by river bed gradient (tgθ) and therefore,it can be calculated by Mizuyama equation (1988).

$$C_d = \frac{11.85 tg^2\theta}{1+11.85 tg^2\theta} \quad\text{.......(6)}$$

Channel Capacity

In order to check whether there will be overflow or not, the capacity of cross sectional area using the following formula:

$$Q_t = Bhu \quad\text{.......(7)}$$

$$h = \frac{Q_t}{Bu} \quad\text{.......(8)}$$

where, Q_t is peak discharge (m³/s), B is river width (m), u is flow velocity (m/s)

Prediction of Overflow length.

Debris flow velocity can be computed by Takahashi equation as follow.

$$u = \frac{2}{5d}\left\{\left(\frac{g\sin\theta}{a\sin\alpha}\right)\left(C_d + (1-cd)\frac{\rho_w}{\rho_s}\right)\right\}^{\frac{1}{2}}\left\{\left(\frac{C_*}{C_d}\right)^{\frac{1}{3}}-1\right\}h^{\frac{3}{2}} \quad\text{.......(9)}$$

Where, d is grain diameter, g is gravity (m/s²), θ is river bed gradient, ρ_w is mass density of water (ton/m²), ρs is mass density of sediment (ton/m²) and a is dynamic internal friction angle of debris flow.

In case of hyper-concentrated flow the velocity can be computed by empirical formula as follow:

.

$$u = 0.4\frac{h}{d_{50}}u_* \quad\text{.......(10)}$$

The length of over flow can be calculated using the equation (11) as follow:

$$X_1 = \frac{u^2}{\left(\dfrac{(\rho_s-\rho_w)g.Cd.\cos\theta.tg\alpha}{(\rho_s-\rho_w)C_d+\rho_w}\right)-g\sin\theta} \quad\text{.......(11)}$$

Where, X1 is diameter of circle where debris flow concentrates.

Drawing of hazard map

a) Decide starting point and direction of overflow on the topographical map.
b) Draw the reach of overflow with a distance X1 on the line of overflow.
c) Make a circle with a radius of 1/2X through the starting point and centered on the line of overflow.

Hazard mapping by simulation model in Merapi Volcano.

Method of hazard mapping for debris flow has been developed through 2 D simulation model of debris flow using SIMLAR. It is a mathematical model based on hydrologic, hydraulic process developed by The Experimental for Sabo, Research Center for Water Resources, Ministry of Public Works collaborating with Gadjah Mada University Yogyakarta. This model is applicable for estimation of hazard area due to debris flow initiated by dam break or not. It can also be applied to predict the progress of movement of debris flow for warning purpose.

a) The data needed in this method of hazard mapping are:
  o Input data of debris flow simulation: topographical data can be topographical map, or satellite image (recommended), occurrence rainfall from the nearest station to the sediment source, hydrograph of past debris flow, characteristic of catchment area and sediment characteristics.
  o Supporting data of simulation: Historic data of past debris flow and its threatened area, satellite image before and after disaster.
b) Equipment:
  o Software: Satellite image and GIS processor ArcGIS, Debris flow simulation application (SIMLAR) and operating system (Windows XP or WIndows 7 with 32 bit.
  o Hardware: computer unit with processor "core I five" (minimal) with RAM capacity 4 GB, handheld GPS.
c) Process of mapping:
  1) Processing of satellite image or topographical map to become DEM (Digital Elevation Model);
     DEM can be extracted from elevation points, contour map and raster data (image) from other format (Geo Tiff) need conversion using Arch GIS.

  2) Validation of DEM to the actual field condition.
     When the morphological condition of river course changes significantly in a relatively short time it is quite recommended to conduct a cross section measurement at some suspected points and compare with DEM.

  3) Mapping of hazard area based on past disaster
     The mapping can use the existing satellite image at a condition before and after disaster, if satellite image is not available a field survey in the disaster area is recommended.

  4) Debris flow simulation using SIMLAR.
     Simulation should be conducted through the following steps:
     (1) Installation of SIMLAR following the instruction manual on the program.
     (2) Preparation of inflow data through onscreen menu.
     (3) Input parameter through onscreen menu: DEM, coefficient of Regime Formula, inflow point, mass density of debris flow, mass density of sediment, angle of side bank, internal friction angle, sediment concentration, sediment cohesion, coefficient of x- y direction, grain size distribution of transported sediment, grain size distribution of river bed material, minimum depth of stopping simulation.
     (4) Execution of SIMLAR.

        SIMLAR can be executed in four conditions:

        • Hydrograph inflow and sediment are available, no dam break
        • Effective rainfall and synthetic hydrograph are available, no dam break.

- Effective rainfall and synthetic hydrograph are available, dam break occurs.
- Hydrograph inflow and sediment are available, dam break occurs.

Output of execution:

- Map of hazard area and progress of debris flow movement.

Figure 7 shows the result of debris flow simulation in Putih River, the area of Merapi volcano.

(5) Survey of evacuation routes and places.
(6) Drawing of hazard area based on the result of simulation.
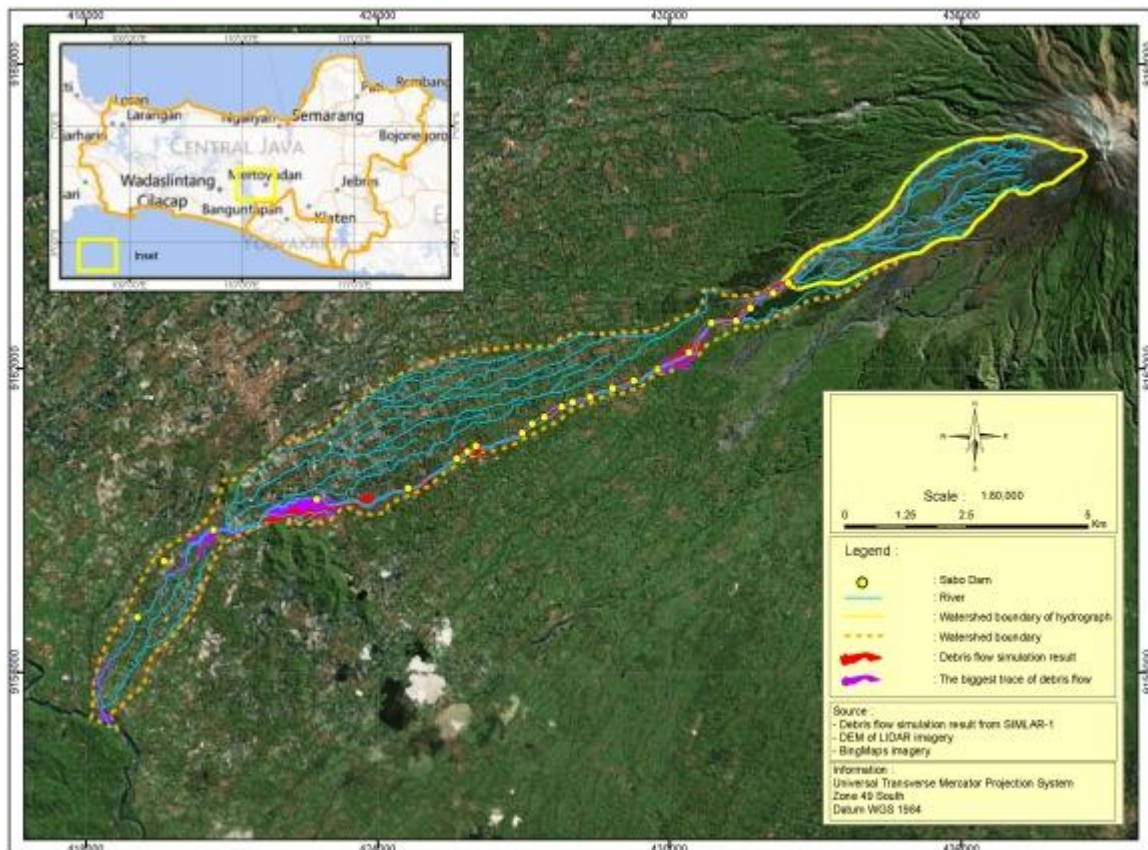(7) Validation of hazard map by comparing to the one based on the past disaster.

Figure 7 : Result of debris flow simulation in Putih River, Central Java, Indonesia

Dissemination of Information on Debris Flow Occurrence

According to the Explaination of the Law of Disaster Mitigation No. 24/2007, in the chapter-General:

> « *Penyelenggaraan penanggulangan bencana merupakan tanggungjawab dan wewenang Pemerintah dan pemerintah daerah, yang dilaksanakan secara terencana, terpadu, terkoordinasi dan menyeluruh.*»

> « *Disaster countermeasures are the responsibility and authority of Central and Local Government, conducted in a planned, integrated, coordinated and comprehensive manner.*»

It mentions "...planned, integrated, coordinated and comprehensive.", which means that although Government has the authority and responsibility, however the effort of disaster mitigation requires the involvement of other stakeholders across sectoral. Therefore, in the scheme of early warning system in Merapi the information related to the occurrence of lahar has to follow a particular stages of development before it is released to the community as the disaster information. In every stages, the type of data or information is different at which one or some institutions are incharged to proceed or issue it. The flow of the disaster information is illustrated in Figure 8.
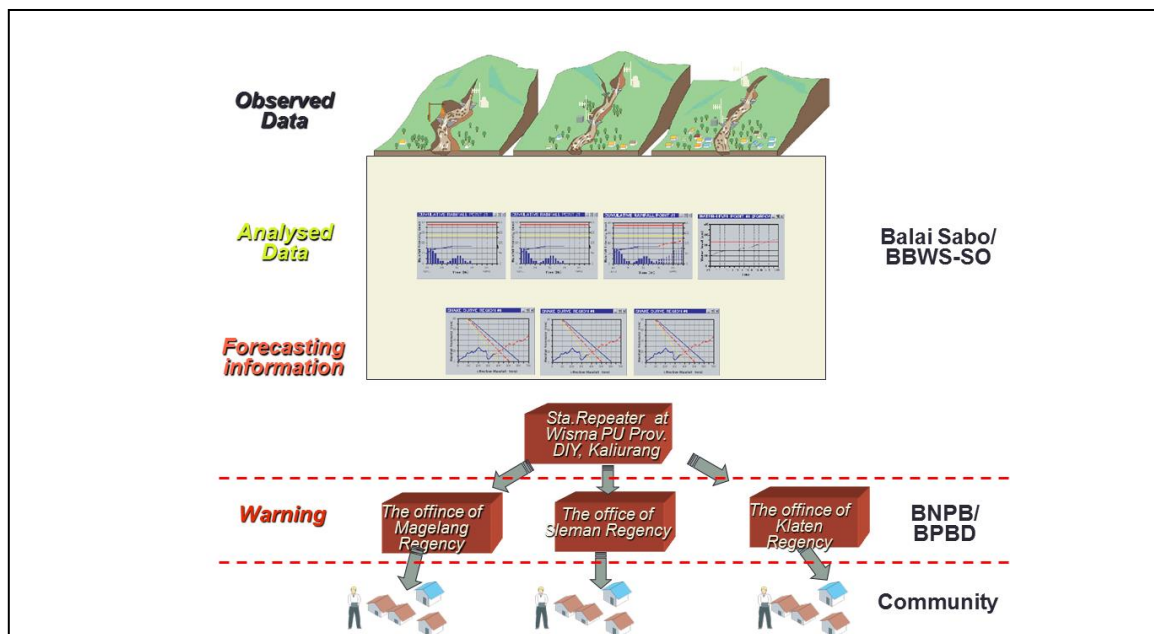

Figure 8 : The information flow of lahar monitoring and warning systems in Merapi

Disaster Information for Debris flow

Before raw data becomes the information of lahar flood, it has to follow a set of analysed and interpreted processes as shown on Figure 9. First, the indicators of lahar occurrenceare monitored by hydrological stations installed in the upstream of lahar river. The observed data from those stations are rainfall and water level data, the display of data is shown on Figure 10 Then, those data trend has to be analysed continously in a certain period of rainfall to obtain

the rainfall intensity data. Meanwhile, to forecast whether a certain rainfall will triggered lahar flood, those analysed data is plotted in judgment graph as shown on previous Figure 4 or 5. The lahar flood is predicted occured, if the analysed data is above the critical line. The forecasting of lahar flood occurrence will be communicated to the local government (BPBD) whose area will be effected by the flood.Finally, the local government will issue the warning information to the related community.
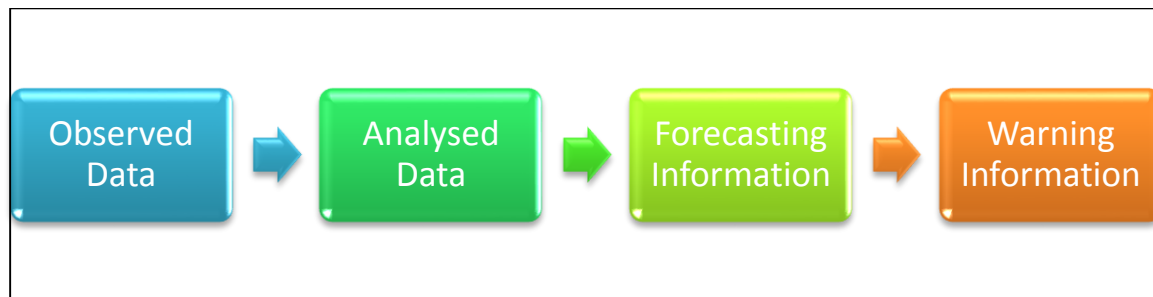

Figure 9 : The stages of lahar flood data process to become disaster information

Figure 10 : Display of rainfall data in several rainfall stations in Merapi volcano

Stakeholders

As mentioned before, that the lahar mitigation in Merapi involves many stakeholders across sectoral, this is related to the difference of tasks and authorities of each sectors. The stakeholders involved in the dissemination of lahar occurrence information are:

1. Balai Sabo (Research Center for Water Resouces of Ministry of Public Works), as the observer and forecaster of the lahar flood occurrence.

2. BPBD (the local government) or (if necessary) BNPB, as the sectoral coordinator of the disaster response that will communicate the disaster information to the effected local leader and relevant sectors which will be needed for the emergency response.
3. The local leader as the local coordinator who will guide the community in emergency situation.

However for years, Merapi has become an interesting object for observation of many institutions, for example monitoring for research purpose by Gajah Mada University (UGM), Balai Sabo (Ministry of Public Works) and BPPTKG (Ministry of Energy and Mineral Resources). Some of the information related to lahar flood monitoring can be accessed by public through internet connection. The type of information is varies, such as lahar visual camera, rainfall, water level, and hazard map. So in the emergency situation, the community themselves can monitor the situation progress in realtime. The addresses bellow are some website that provides the information of lahar flood:

- http://merapi.bgl.esdm.go.id/ (BPPTKG)
- http://data.hydraulic.lab.cee-ugm.ac.id (UGM)
- www.sabo.pusair-pu.go.id (Balai Sabo)

Today, many people has already used celular or radio frequency to communicate among community for sharing information when the lahar flood occured.This modality becomes part of lahar flood news broadcast (Legono, 2011).

Response Capacity of Merapi Community
Many people live in lahar rivers in Merapi. Most of them have already understood the consequencies of living in disaster area. Some groups of community have already established from community assisstance program due to strengthening the awareness and readiness of community in Merapi. Those community awareness groups are Komunitas Paguyuban Siaga (PASAG) Merapi, Wukirsari Sabo Community, Komunitas Saluran Komunikasi Sosial Bersama (SKSB) and Rekompak Merapi. Those awareness groups conducts community discussion and arrangement of action plan in dealing with disaster. Figure 11 shows some of the activities of communities in Merapi.

Figure 11 : Assisstance on the arrangement of community action plan: identification ideas (left); women empowerment through discussion (center); discussion on spatial planning (right)

According to Martief (2011), the community level in Merapi, regarding to their empowerment, is different between one community to others. Actually, there are three levels of empowerment: basic, middle and advance. The basic level is indicated by unability of technical skill, lack of disaster education and domination of metameirical understanding. At the middle level, usually the community has already had better logical perspective about disaster and ability of technical skillon prepareness. While, the advance level is showed by the ability of technical and managerial aspect in disaster prepareness.

In general the community groups in Merapi are in the middle level. In emergency situation, they have capacity on:

- Analysing the situation and condition,
- Identified and understanding the context,
- Analysing the risks partisipative,
- Arranging the action plan, and
- Monitoring the source of hazard.

On the other hand, only few that already have the managerial capacity such as:

- Self assessment and evaluation,
- Integration,
- External institutional and consultative, and
- Expanding linkage between other stakeholders.

Challenges in the Future

A long history of operating EWS in the area of Mt. Merapi has been experienced by our Institute since 1984. Critical rainfall triggering debris flow has been obtained for some particular rivers. Due to the dormant period of Mt. Merapi that varies from 1 to 18 years with an average of 4 years, the supply of sediment from eruption is interrupted. At the same time the sand mining activity has taken out a huge amount of material. Besides that, the longer the time elapsed from eruption the more consolidated the material. It makes the probability of debris flow occurrence decreases, so the critical rainfall needs updating. In order to update the critical line, the data of rainfall and debris flow occurrence should be collected continuously. For the purpose, a prime condition of monitoring system is absolutely needed. However, many times the telemetric gauging station in the field were broken due to vandalism. That is still a problem that needs solution.

In recent years a lot of equipment for Early Warning System have been installed by different institutes in the area of Merapi volcano. After 2010 eruption more equipment were also installed to monitor debris flow, a collaboration between Agency for Geology, Ministry of ESDM and National Agency for Disaster Countermeasure (www.bnpb.go.id, 28 Februari 2013) . So far, there are five institutes manage their own system as shown on Tabel 2. The area of Merapi Volcano especially on the West to Southeast sectors cover four regencies that directly threatened by debris flow disaster. The existing stands alone systems which are now operated

by different institutions may cause confusion to the residents to whom they should follow when a different warning message was announced.

Our challenge is how can we integrate into a one system in order to collect all the data and information to the main web server that can be accessed by BPBD and public. The first thing needed to realize the idea is the approval from the owner of the existing system to be integrated. Secondly, the support from BPNB/ BPBD is needed because the institution is the policy maker on the disaster mitigation as declared on UU RI No. 24/2007 about the Implementation of Disaster Countermeasure. When the two matters runs well, the next step will be technical matter. The location of central monitoring station can be the Local Representative of BNPB or another according to the agreement among the stake holders.

Table 2 : EWS in the area of Merapi Volcano

No	Name of institution	Type of equipment
1	Experimental station for Sabo	Radar system ,Broad band system.Radio system telemetry*)
2	Centre For Volcanology and Geological Hazard Mitigation (BPTPKG)	Cameras, geophone, Rain gauges, published by internet.
3	Provincial Agency for Disaster Measure of Yogyakarta Special Region.	Lahar sensor along Boyong river (realtime) donated by UN OCHA, radio system..
4	Regencial Agency for Disaster Measure of Sleman	CCTV, sirens published by radio system
5	Gadjah Mada University.	Raingauge, water level gauge and cameras, published via internet.

Source: result of consultation to each institution.

The proposed integration of the existing warning system in the area of Merapi volcano is presented on Figure 12.
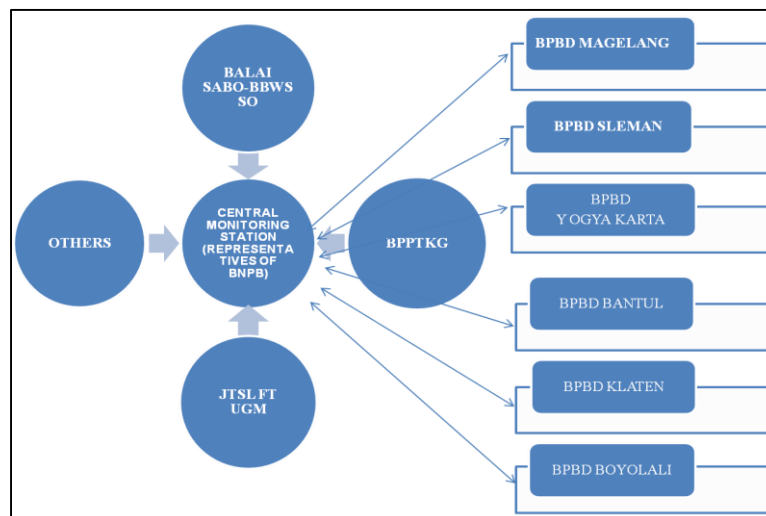

Figure 12 : Proposed integration of the existing warning system in
Merapi volcano

Concluding Remarks

- The Implementation of early warning system for lahar in Merapi is one of the efforts in reducing risks caused by lahar flood. The established system has been working for more than 30 years and effectively helping the community along the lahar rivers to get information on the occurrence of debris flow. The improvement on the early warning system is continuously conducted to adjust it with the recent technology development and future challenges.

- The flow information related to the occurrence of lahar flood and the responsibility has already determined, however the implementation is still unclear because many institutions also have the instrument in monitoring and publish the information freely. There is no coordination among those institutions.

- The information published is very useful, consist of hazard map, visual camera, rainfall, and water level monitoring. The media used to publish varies significantly, such as cellular phone, internet and radio frequency, thus the information is easily and immediately accessed by community at risk.

- Hazard mapping is quite necessary for the residents to be aware of debris flow disaster that may occur any time.

- The community around Merapi has already understood the consequencies of living in hazard area. They have prepared by initiating community groups for discussing problems and arranging action plan in emergency situation. However, the capacity of those groups need to improve continuously, especially its managerial capacity, which is related to capability on self-assessing and evaluating that is important factor for its sustainable development.

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