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Volcanic hazard mapping in Indonesia

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Abstract: Indonesia is a wide archipelago where 129 active volcanoes are located. It means that about 13% of active volcanoes all over the world are located in the Indonesian archipelago. The volcanoes are located along the 7,000 km tectonic belt through Sumatera, Java, Nusa Tenggara, North Sulawesi, North Maluku, up to South Maluku. About 10% of the Indonesian population live in the dangerous volcanic areas. In the last 300 years, some 175 thousands people were killed by volcanic eruptions in Indonesia.

The volcanic hazard mitigation is carried out technically by the Volcanological Survey of Indonesia which is unified in the National Coordination Agency for Disaster Management. One of the programs carried out is Volcanic Hazard Mapping. The Volcanic Hazard Map is one identifying the degree of volcanic hazard in an area. It is used as a guidance for evacuation purposes when the volcano is in eruption or in increasing activity.

Determination of volcanic hazard zones can be divided into three levels of hazard zone where from the highest to the lowest are hazard zone III, hazard zone II, and hazard zone I, respectively. The Hazard Zone III is a zone which is very frequently affected by pyroclastic flow, lava flow, glowing rock fall, and poisonous gas, such as Mt. Semeru (East Java) and Mt. Merapi (Central Java). The Hazard Zone II is a zone which is potentially affected by pyroclastic flow, lava flow, ejected glowing rock, heavy ash fall, hot mud falls, lahar flow and poisonous gas. The Hazard Zone I is a zone which is potentially affected by lahar or flood and it still possible to be affected by an expanded pyroclastic flow and lava flow.

The three levels of the hazard zonation is applicable on the very active volcanoes, which erupts very frequently. This is supported by a lot of data about them and consequently, the character of the volcanoes can mostly be recognized. In fact, many other active volcanoes have very limited supporting data. In case of development of volcanic resources or that of developing an area especially on volcanoes area which have poor reference data, a detailed study of volcanic hazard assessment on the area is required to be done in the feasibility study.

The Volcanic Hazard Map can be utilized firstly as a guide for evacuating people when the volcano is erupting, secondly as one of the main references for Regional Planning, and thirdly, for early warning system.

INTRODUCTION

Indonesia is a country with 129 volcanoes or about 13% of all active volcanoes in the world. The volcanoes are located along a 7,000 km tectonic belt started from Sumatera through Java, Nusa Tenggara, North Sulawesi, North, Central and South Maluku islands (Fig. 1). 79 of them are classified as the most active ones, having erupted within the last 400 years.

10% of the Indonesian population or about 20 million people live in the volcanic areas. They enjoy several positive impacts to live there by utilizing volcanic resources. On the other hand they also are threatened by the danger of volcanic eruptions which can occur at any time.

Therefore, volcanic hazard mitigation in Indonesia especially in volcanic monitoring is important by monitoring on 31 of the 129 active volcanoes continuously from 65 volcano observatories done by the Volcanological Survey of Indonesia (VSI). In the mitigation purpose, Volcanic Hazard Map are also required, particularly in the evacuation process.

These maps can also be utilized as one of the main references for regional planning of volcanoes area. In some cases the volcanic hazard mapping is also similar as a volcanic hazard assessment.

In this opportunity, the study will clarify: general management in hazard mitigation particularly in volcanic hazard mitigation, how to make the volcanic hazard map, and the utilitization of the Volcanic Hazard Map in Indonesia (National Library of the Philippines Cip Data, 1991).

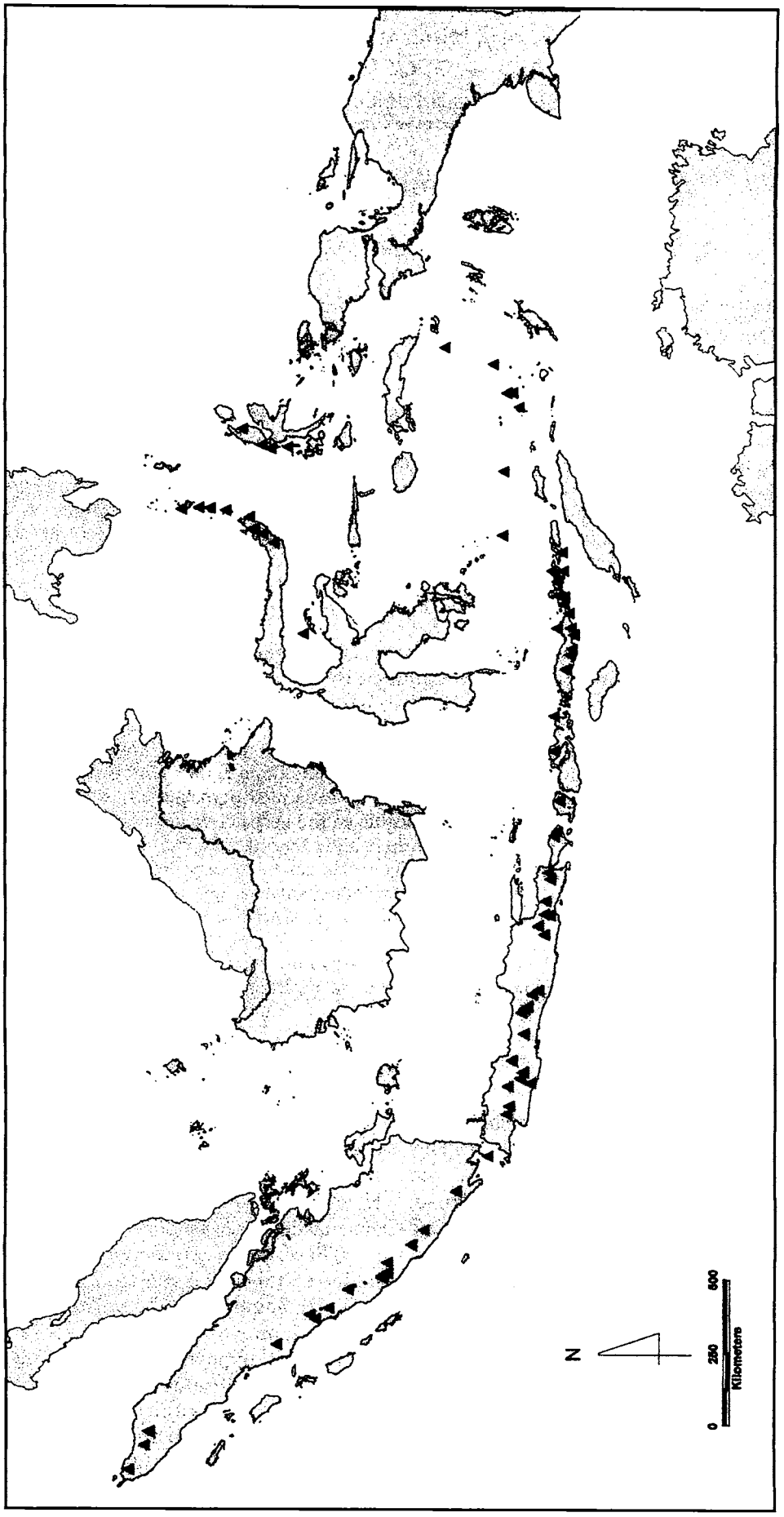

Figure 1. Distribution of active volcanoes in Indonesia.

VOLCANIC ERUPTION IN INDONESIA

By using the Volcanic Explosivity Index or VEI (Simkin and Siebert, 1994) the historical records of volcanic eruptions in Indonesia show that during the period of 1500–1900, the eruptions are generally small (VEI = 2, with 860 eruptions); moderate to large (VEI = 3, with 140 eruptions); or large to very large (VEI ≥ 4 with more or less 29 eruptions). These eruptions occurred from 74 volcanoes with a total of 1,029 eruptions, while in the period of 1980–1990, 101 volcanic eruptions occurred from 28 volcanoes in Indonesia.

In the last 300 years some 175 thousand people were killed by volcanic eruptions in Indonesia. The most hazardous volcanic eruption took place in 1815 when Tambora Volcano (Sumbawa Island) erupted and 12,000 people were killed directly and 80,000 people were killed indirectly.

In 1883 Krakatau erupted violently with the height of the eruption column of around 50 km and producing pyroclastic flows. The volcanic materials were ejected by the eruption and caused an empty space in the magma chamber. A collapse took place immediately after the eruption formed a caldera. Tsunami generated by the volcanic collapse and earthquake of Krakatau killed some 36,000 people in coastal area of West Java and South Sumatera.

The most recent volcanic eruption occurred at Colo Volcano, Central Sulawesi (1983), Kie Besi Volcano, North Maluku (1988), Ranakah Volcano, Flores (1989), Banda Api Volcano, Central Maluku (1988), Kelut Volcano, East Java (1990) and Merapi Volcano, Central Java (1992, 1994, 1996 and 1998). 35 of the hundreds of evacuees of Kelut eruption of 1990 was killed because the roof collapse. The 1994 Merapi eruption claimed 64 lives who were living in Hazard Zone III. *Nuee ardente* travelled down to the southern area which has not experienced such danger for more than 200 years. The last Merapi eruption took place in August 1998 and no one was killed by the eruption (Purbawinata *et al.*, 1997).

VOLCANIC HAZARD MITIGATION

An activity or an attempt to reduce casualties or property loss caused by volcanic eruptions is called volcanic hazard mitigation. The VSI, is the only principle agency which is responsible technically for volcanic hazard mitigation in Indonesia. The program for volcanic hazard mitigation purposes is listed in Table 1.

In this paper, the Volcanic Hazard Zonation will be the topic of study with Indonesia as the reference area.

Table 1. List of activities for volcanic hazard mitigation purposes done by the VSI.

- Geologic mapping
- Volcanic hazard zonation
- Volcanic monitoring
- Establishment of Volcano Observatory
- Telemetric and Satellite monitoring
- Early warning system monitoring
- Public education
- Training and Seminar.

Volcanic Hazard Mitigation

- Geological Mapping
- Volcanic Monitoring
  - * Geophysic
  - * Geodetic
  - * Geochemistry
  - * Visual
- Establishment of Volcano Observatory
- Development of Volcanic Monitoring
  - * Telemetric System
  - * Satellite System
- Volcanic Hazard Zonation
- Early Warning System
- People Education
- Training and Seminar
- Lahar Control Structure

Indonesia develops a management system in handling the natural disaster. The organization dealing with natural disaster (including volcanic hazard disaster) was strengthened by the establishment of The National Coordination Agency for Disaster Management (BAKORNAS PB) under Presidential Decree in 1979 which was completed by the decree of the Chairman of the BAKORNAS PB in 1995.

The BAKORNAS PB is chaired by Coordinator Minister of People's Welfare while members consist of several ministers such as ministers of Social Affairs, Home Affairs, Health, Public Work, Communication, The Commander in Chief of the Armed Forces of the Republic of Indonesia and the Governors/Head of Provincial Government where the volcano is located. Director General of Social Assistance Development, and Heads an Officials of Defence and Security Department, Mining and Energy Department, other related departments, and non government department institutions cooperated to BAKORNAS PB activities (BAKORNAS PB, 1985). All of these have chief of working group and secretary. The position of VSI is in the working group. Figure 2 shows a flow

chart of communication directions during Volcanic Hazard Mitigation especially when there is a volcanic activity.

VOLCANIC HAZARD MAP

Understanding

The Volcanic Hazard Map is a guidance map which identifies the degrees of hazards of volcanoes area when an eruption/activity occurs.

The map informed the types of volcanic hazard, hazard zones, directions of evacuation, evacuation site, and Disaster Relief Post. The map is compiled mainly based on morphology, topography, past eruption history, distribution of eruption products and field study.

All information are presented in figure with colors and symbols, while description are presented in a form of side note

The map is made in the scale of 1:100,000 or 1:50,000. An operational map with a greater scale than the above can be shown together with the Volcanic Hazard Map. The operation map shows a particular hazard zone which is a zone where have been potentially affected by volcanic eruption disaster both for primary or secondary dangers.

Volcanic hazard classification

Level in volcanic hazard zoning are classified into three levels where from the highest to the lowest are Hazard Zone III, Hazard Zone II, and Hazard Zone I respectively (Crandell *et al.*, 1984).

The Volcanic Hazard Zone I areas potentially affected by lahar and possibly affected by the extension of pyroclastic flows and lavas. When the eruption activity increases, there are potentially affected by heavy ash rain and ejected rock fragments. These areas are distinguished into group i.e.:

a. Hazard Zone against mass flow such as lahar/ flood, and possibly the extension of pyroclastic flows. These zones are located along and near the river valleys originating from the summit areas.
b. Hazard Zone against airfall material such as dry volcanic ashfall regardless of the prevailing wind and possibly affected by rock fragments (glowing).

People living in the Hazard Zone I should increase their alertness when the eruption/activity or heavy rain occurs by paying attention to the development of the volcanic activity which is declared by the Volcanological Survey of Indonesia

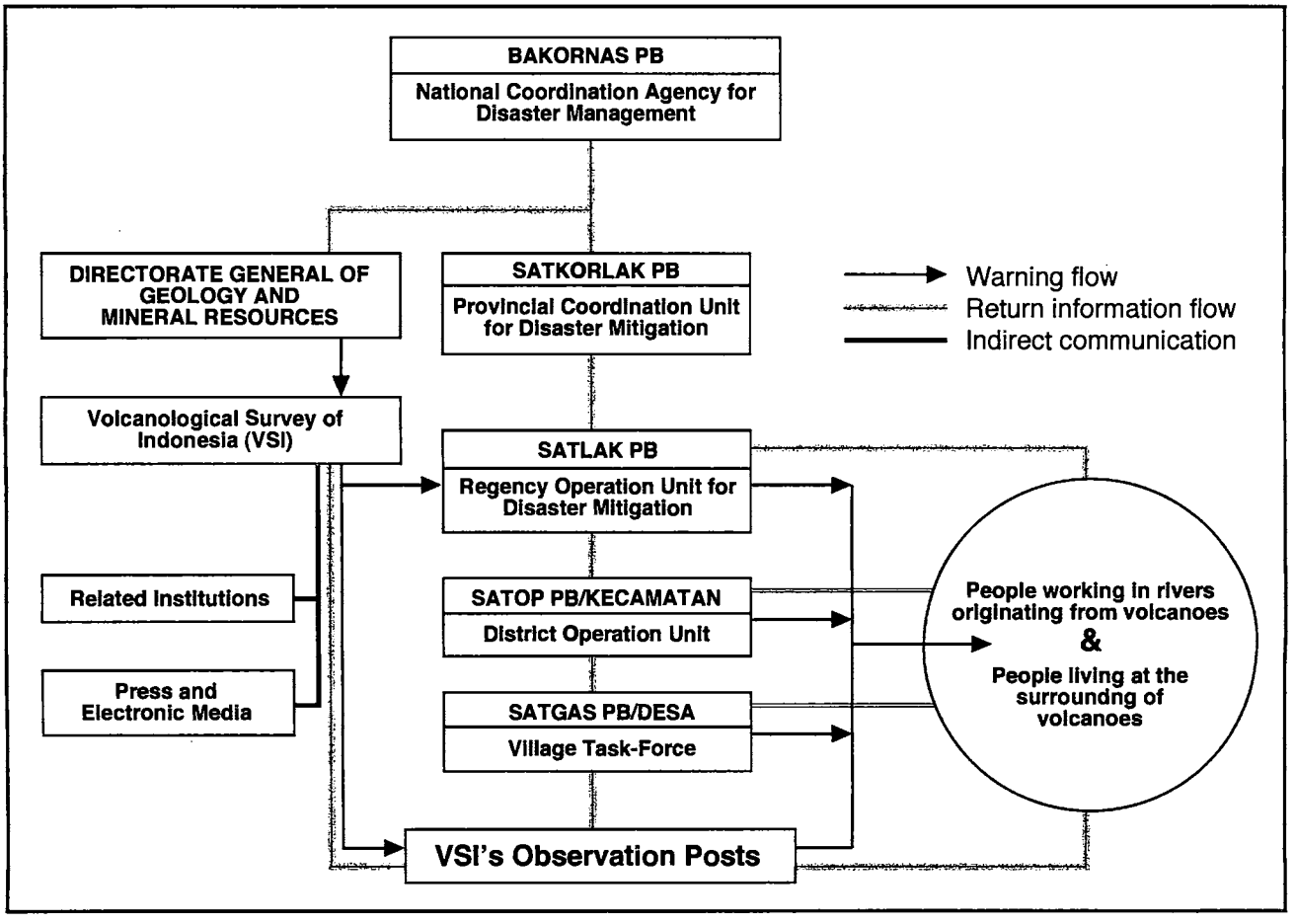

Figure 2. Organization of the disaster management.

while they are waiting for the instruction from the Local Government.

The Volcanic Hazard Zone II are areas potentially affected by pyroclastic flows, ejected rock fragment (glowing), lava flows, heavy ash rain, hot mud rain, lahar and toxic gases. This zone can be further subdivided into two groups i.e.:

a. Hazard Zone against mass flows such as pyroclastic flows, lava flows and lahar.
b. Hazard zone against ejected material and pyroclastic falls, such as ejected rock fragments (glowing), heavy ash rain and mud rain.

People living in the hazard zone II should prepare to evacuate when the activity of the volcano increases, until safe condition is declared. The statement of evacuation, stay in place and safe condition are decided by the Government based on the legal regulation after recommended by the VSI.

The Volcanic Hazard Zone III are areas very frequently affected by pyroclastic flows, lava flows, ejected or rock falls (glowing), and toxic gases. These zones are valid only for very active volcanoes with short repose period such as Marapi (West Sumatera), Merapi (Central Java), Semeru (East Java), Lokon (North Sulawesi), Karangetang (North Sulawesi), Dukono (North Maluku), Gamalama (North Maluku). This zone is usually the closest area to the source comparing to those for the zone I and II. No one is allowed to live permanently in this zone.

Step of volcanic hazard mapping

Two great general steps are required in producing the Volcanic Hazard Map as follows:

a. Studio or desk work

This work consists of studying geomorphological units and geological units of the volcanic study area by using images interpretation. This work should be supplemented by studies of references concerning the volcano i.e. some volcanic activity history including some results from volcanic monitoring etc. This will gives information of the volcanic characteristics.

b. Field check work

This work is carried out at the volcanic study area to get information on geomorphological hazard in understanding what kind of volcanic hazards that potentially pass through some particular areas etc. Other required informations include potential volcanic hazard distribution, lahar control structures and social aspects.

The lahar control structures may include plotting of information about Sabo Dam construction to prevent volcanic hazard caused by lahar flow. The social aspects include data of population of people who live around the volcanic area.

All data from both works will be the main sources to produce the Volcanic Hazard Map.

Conditional of the map

The Volcanic Hazard Map is applicable for normal eruption/activity, when:

- The eruptions source is confirmed with in the central crater.
- The eruption column is more or less vertical, regardless of wind velocity and direction.
- No caldera formation.
- No substantial morphological change.

Consequently, the Volcanic Hazard Map will be revised when:

- There is a new eruption that exceeds the anticipated range of eruptive style and scale.
- There is a new development in volcanological science.

Recommendation

Some recommendation can be made in the map such as recommendation to plot evacuation directions, over flowing occurrences, and evacuation barracks. These can be used by the local government to manage people who live around the volcano when the volcano is in eruption or increasing in activity.

At this moment, some early warning system around the volcano especially at the dangerous areas are required to be installed in the field i.e. alarm system, posters of the road side etc. Posters can have content of recommendations to people living around the volcano to make their roofs steeper to avoid roof collapse, and to use break resistant and inflammable roof materials when hit by glowing rock fragments etc.

Some example of the map

Up to now, 19 of the 129 active volcanoes have been published for Volcanic Hazard Maps. Some of them have Volcanic Hazard Zone III, II and I, while the other only have Volcanic Hazard Zone II and I.

Semeru Volcano (East Java) is one of the examples of the Volcanic Hazard Map (Fig. 3) which has been published. It shows the Volcanic Hazard Zone III, II and I (Badan Standarisasi Nasional, 1998).

POTENTIAL OF VOLCANIC HAZARD RELATED WITH THE VOLCANIC HAZARD MAP

The volcanic eruption products related with volcanic hazard are classified in Table 2.

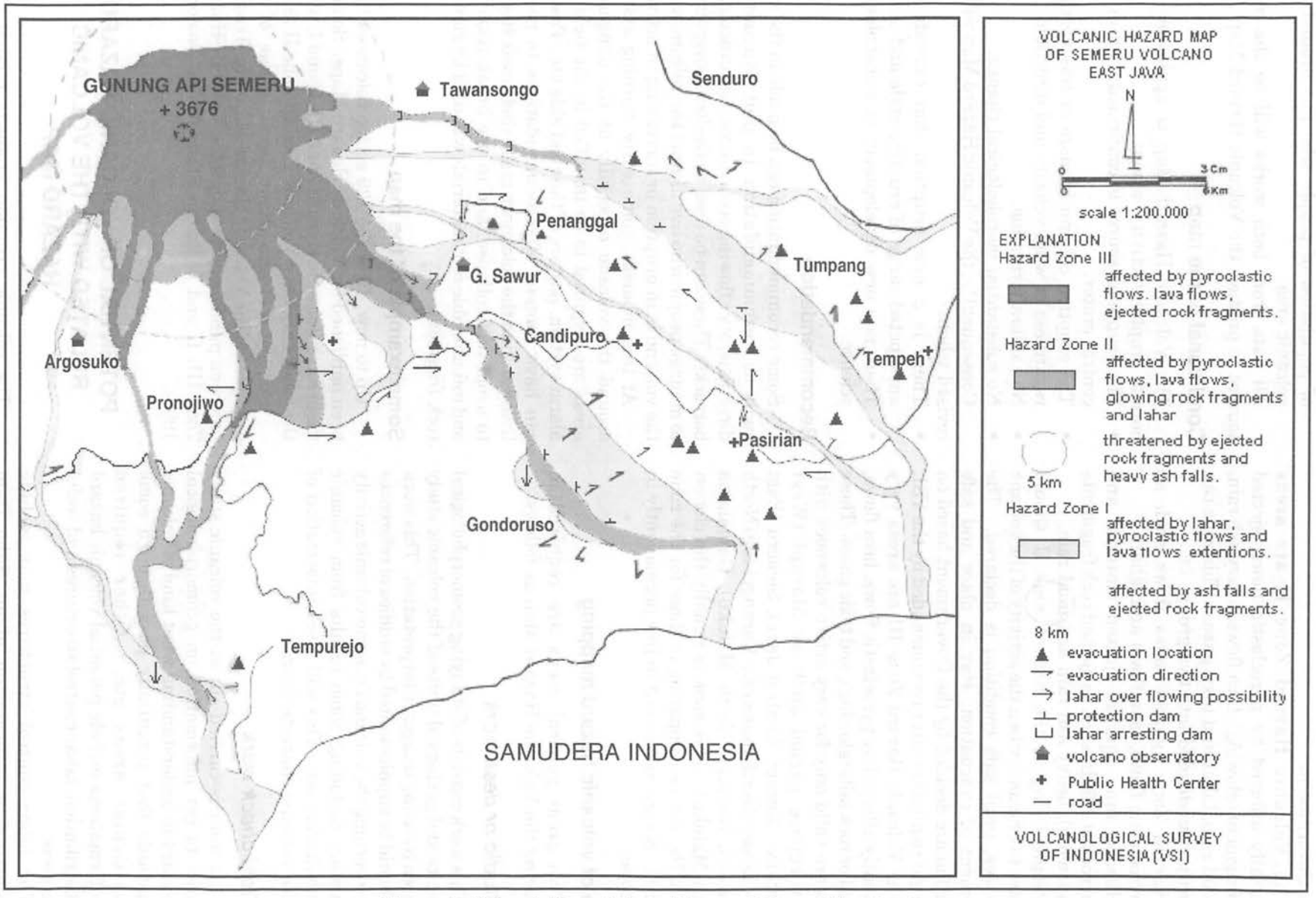

Figure 3. Volcanic Hazard Map of Semeru Volcano (East Java).

1. Lava flows, pyroclastic flows, pyroclastic fall, pyroclastic surges. According to the volcanic hazards, these products are classified as primary danger. These products mostly kill the people, destroy property and environment. The most dangerous area is at the summit area.
2. Lahar flows, phreatic explosion deposits. According to the volcanic hazards, these products can be classified as secondary danger. This products mostly destroy property, environment and kill people.

Producing the Volcanic Hazard Map related with the above volcanic eruption products, some methods have to be done such as:

1. Volcanic Hazard Prediction
   This information can be obtained by studying the volcano characteristic (to understand i.e. Merapi type, Strombolian type, Vulcanian type, Plinian type etc.), the time of eruption data (to know statistical data).

Table 2. Relationship between volcanic products and volcanic danger.

VOLCANIC DANGER	VOLCANIC PRODUCTS		
	KIND OF PRODUCT	MECHANISM	ENVIRONMENTAL IMPACT
PRIMARY	Pyroclastic	Flows	Killed, burnt, destroyed
		Falls	Damaged, destroyed
		Ballistic Trajectory	Burnt, damaged
	Lava	Flows	Destroyed, damaged
		Dome Formation	Destroyed, damaged
	Lahar related to volcanic eruption	Flows	Destroyed, damaged
	Gass	Embayment	Killed, damaged
SECONDARY	Lahar	Flows	Sank, destroyed
	Floods	Flows	Damaged

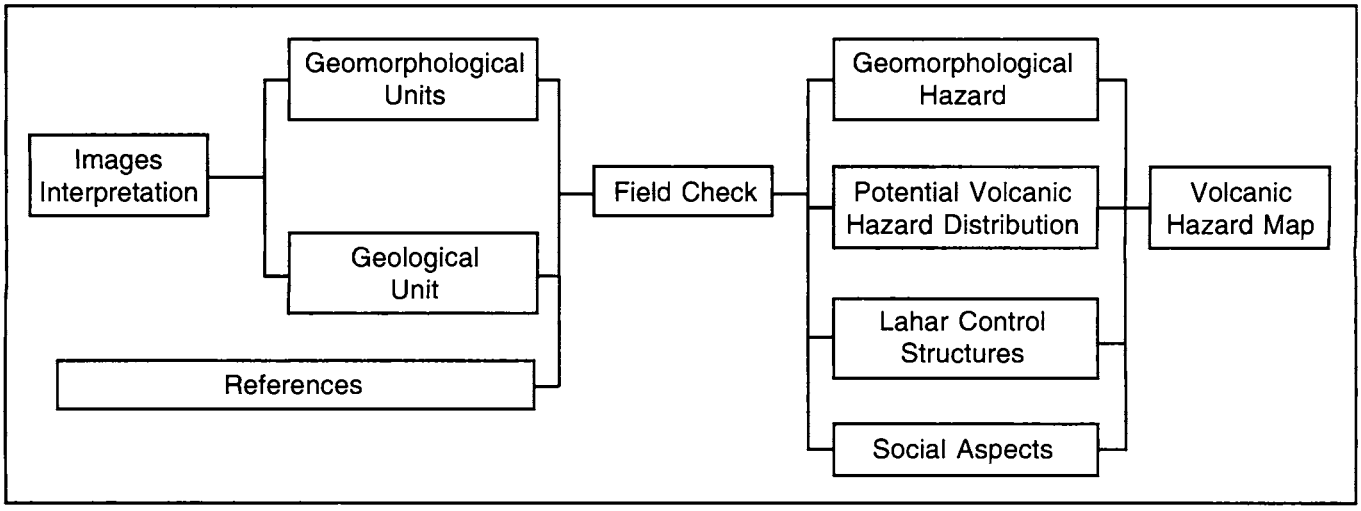

Figure 4. Steps of establishment the Volcanic Hazard Map.

Table 3. Relationship among prevention effort, number of people killed and volcanic mitigation management.

PREVENTION EFFORT	VOLCANO	VICTIM	EVACUEES
No Preventions System	Merapi, 928	Mataram Kingdom destroyed	
	Merapi, 1672	3,000	
	Awu, 1711	3,000	
	1812	hundreds	
	1856	2,806	
No Volcano Observatory	1892	1,532	
	Papandayan, 1772	2,951	
	Tambora, 1815	92,000	
	Galunggung, 1882	4,011	
	Krakatau, 1883	36,541	
	Kelut, 1901	a lots	
	Kelut, 1919	5,160	
	Merapi, 1930	1,369	
	Agung, 1953	1,148	
There is Prevention System	Kelut, 1951	7	
	Merapi, 1954	4	
	Merapi, 1961	6	
	Kelut, 1966	210	
Volcano Observatory	Awu, 1966	39	
	Merapi, 1969	3	average 1,200
Bunker	Dieng/Sinila, 1979	149	600
	Gamalama, 1980	–	5,255
	Gamalama, 1990	–	1,092
	Gamkonora, 1981	–	2,000
	Galunggung, 1982/1983	–	72,000
	Colo, 1983	–	7,000
	Merapi, 1984	–	680
	Karangetang, 1984	–	3,000
	Sangeangapi, 1985	–	195
	Banda Api, 1985	4	1,600
	Kie Besi/P.Makian, 1988	–	12,932/25,000*)
	Kelut, 1990	35**)	19,855
	Lokon, 1990	1 @	–
	Lokon, 1992	–	10,000
	Karangetang, 1992	7	–
	Krakatau, 1993	1 @	–
	Marapi, 1993	1 @	–
	Semeru, 1994	9	275
	Merapi, 1994	64	5,426

Note : *) A number of people before the presence of residence at Halmahera Island.
**) Fell down roof of evacuation building.
@) Many tourist climbed the volcano without permission.

2. Volcanic Hazard Assessment
   This method can be understood by applying especially Volcanic Hazard Zonation.
3. Volcanic Hazard Prevention
   This method consists of lahar control structure (such as recommendation to build lahar, pocket, lahar dike etc.), evacuation of people, and regional planning of the volcanoes area.

General steps for Volcanic Hazard Mitigation Mapping is shows in Figure 4.

On the other hand, to build the Volcanic Hazard Map technically, some technical aspects of engineering geology are involved. In studying morphology, some important points will be involved.

1. Morphographic study such as:
   - Study of summit area
   - Study of drainage pattern
   - Study of anomalies of the drainage
   - Study of tributary
2. Morphometric study such as:
   - Slope characteristics:
     Slope angle, slope form, slope length, degree of dissection of the slope by gullies
   - Valley forms:
     Width, depth, shape, straightness, curvature
   - Valley distributions

USE OF THE VOLCANIC HAZARD MAP

Three main uses of the Volcanic Hazard Map can be considered as follows.

Firstly, it provides important information to the people who live around the volcano on how to evacuate from dangerous place to the save area when the volcano is in eruption or in increasing in activity. Some recommendation in the map such as evacuation direction (arrow marks) can be applied by installing arrow marks in the field by the Local Government to make evacuees easy in their evacuation.

Secondly, the map can be used as one of the main references in Regional Planning done by the government for both local and regional scale.

Thirdly, the map also can consist of recommendations such as informations for early warning system utility, which is useful for volcanic hazard mitigation.

Education or giving information about volcanoes including the volcanic hazard map is important to be done periodically to the people who live and to some staffs of the local government at around the volcano to make them easy in understanding the volcano.

The Volcanic Hazard Maps give very good guidance to the Volcanic Hazard Mitigation Management especially to reduce number of people killed by volcanic eruption. This indicates that the management system is successful. Table 3 shows a relationship among the volcanic eruption, prevention effort, number of victims and evacuees from time to time.

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