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Numerical Simulation for Scenario Based Volcanic Hazard Assessment (VHA) at Seulawah Agam Volcano, Aceh, Sumatra

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Abstract. Seulawah Agam is an active volcano with high 1,810 m located at 5.448°N 95.658°E and close to the capital of Aceh province densely populated. Following Sumatra-Andaman earthquake 26 December 2004, Sumatra Island has increased not only seismicity but also volcanic activity. On the other hand, Sinabung volcano categorized as inactive volcano, but beyond expectations on the 3rd September 2010 experienced eruption and the closest volcanic eruption location to Seulawah Agam volcano. Meanwhile, in 1 September 2010, Seulawah Agam categorized as active volcano was alert to level 2. We cannot predict what happens in future to the Seulawah Agam volcano, but we can provide volcano hazard assessment as important step for mitigation procedure. This paper introduces numerical study for volcanic eruption and integrated with a GIS-based tool for volcanic hazard assessment VORIS (VOlcanic Risk Information System) which develop by Alicia Felpeto. This model investigate scenario based volcanic eruption for ash fallout, PDC (pyroclastic density currents), and lava. Digital elevation model (DEM) from SRTM (Shuttle Radar Topography Mission), meteorological data from NOAA, and geological study are used in this model. In the statovolcano mountain four geothermal manifestations appeared, such as: Fumarol Simpago, crater Heutz, ground steam Ie-Jue, and hot spring Ie-Suum. In this numerical simulation, we consider the location as potential eruption vent to produce erupted material. Wind velocity data at 3rd January 2012 and 1 July 2012 above the summit is selected to represent wet and dry season condition for scenario based ash fallout. Further, the simulation show the ash fallout is possible to reach Banda Aceh and potentially disrupt flight at Sultan Iskandar Muda Air port. Lava flow simulations are only depending on topography data (DEM) and applying some parameter for maximum flow length 5 km. The Simulation resolution depend on DEM data (90m) which produce more precise then volcanic hazard map produce by Center of Volcanology and Geological Hazard Mitigation, Bandung (CVGHM) and more reasonable with topography slope of mountain at southern part and northern part. Furthermore, PDC simulations are conducted scenario for height eruption column (starting point of the flow) 20m dan 200m. The simulations show PDC can be reach longer location until Banda-Aceh Medan Highway compare then CVGHM map. This preliminary research should be developed to apply high resolution DEM and using adequate method for estimation eruption parameters. This method will be potential to provide more precise volcano hazard assessment for others volcano in Indonesia.
Keywords: Volcanic Hazard Assessments, Seulawah Agam Vocano

Introduction

Data from (ADRC, 2002) 20th Century [1901-2000] Asian Natural Disasters Data Book shows the reached 60.7070 soul. Floods (flood) are frequent disasters in Indonesia, however many deaths due to the earthquake and tsunami that reached 22,047 casualties and volcano also caused 17,940 casualties, see Figure 1. Therefore, the volcanic disaster is the second largest cause victim and should be serious attention in disaster mitigation program.

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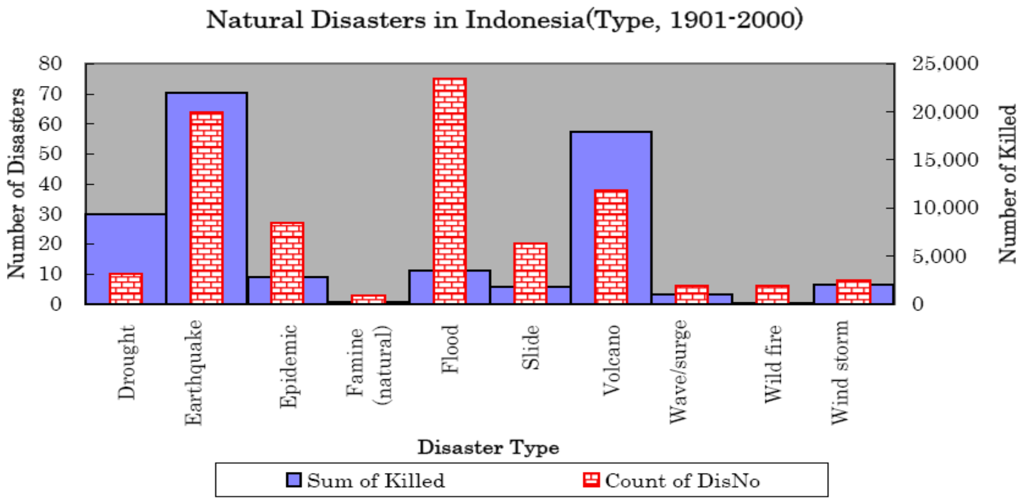

Figure 1. Number of disasters and killed from 1900-2000 (ADRC, 2002).

After December 26, 2004 Aceh-Andaman earthquake has been followed by several large tectonic earthquakes until March 11, 2011 Tohoku earthquake with a magnitude of 8 on the Richter scale. In addition to tectonic earthquakes, Aceh-Andaman earthquake has been to enable as many as 8 volcanic eruptions in Indonesia in the period 2007-2009.
Meanwhile Seulawah Agam is located along the Sumatran Fault and it's volcano strongly influenced by post-seismic effects of 2004 earthquake. This effect has possibility to trigger volcanic eruptions and even volcanic effects are very harmful to the surrounding area. Following Sumatra-Andaman earthquake 26 December 2004, Sumatra Island has increased not only seismicity but also volcanic activity. On the other hand, Sinabung volcano categorized as inactive volcano, but beyond expectations on the 3rd September 2010 experienced eruption and the closest volcanic eruption location to Seulawah Agam volcano. Moreover, in 1 September 2010, CVGHM announced Seulawah Agam categorized as active volcano was alert to level 2. Therefore, we have investigated VHA for Seulawah Agam volcano with advection diffusion model to cover three mayor type of eruption hazard, namely: 1. Ash fallout, 2. PDC, and 3. Lava Flow.

Therefore, this natural phenomenon encourages us to pay more attention to the serious hazard mitigation process other volcanoes in Indonesia by volcanic hazard assessment (Feeley 2009). Early observations volcanic hazards is necessary for Aceh is encouraging the development process so that it can do better planning so that catastrophic events can be minimized disaster through spatial planning better. Thus this study is very useful to provide better planning for the construction of geothermal power plants is planned.

Materials and Methods

The model used for simulating ash fallout is an advection diffusion model that assumes that, far from the vent, the transport of the particles from a Plinian column is controlled by the advective effect of the wind, the diffusion due to atmospheric turbulence and the settling velocity of the particles. The main equation governing this process (Armienti *et al*., 1988), neglecting both the vertical wind and vertical diffusion is:

$$\frac{\partial C_j}{\partial t} + W_x \frac{\partial C_j}{\partial x} + W_y \frac{\partial C_j}{\partial y} + W_z \frac{\partial C_j}{\partial z} - \frac{\partial v_j C_j}{\partial z} = K_x \frac{\partial^2 C_j}{\partial x^2} + K_x \frac{\partial^2 C_j}{\partial y^2} + K_x \frac{\partial^2 C_j}{\partial z^2} + S_j$$

Where C_j is the concentration of particles of class, W wind velocity, K eddy eddy diffusion coefficients, and S source function.

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The model used for simulating lava flow is a probabilistic model that assumes that topography plays the major role on determining the path that a lava flow will follow (see Felpeto, 2002; Felpeto *et al*., 2001). The model computes several possible paths for the flow, assuming two simple rules: the flow can only propagate from one cell to one of its eight neighbors if the difference of corrected topographic height between them is positive, and the probability for the flow to move from one cell to one its neighbors is proportional to that difference. The determination of the probability of each point being invaded by lava is performed by computing several random paths by means of a Monte Carlo algorithm.
The model used for simulating the maximum potential extent affected by pyroclastic density currents (PDC) is a very simple model proposed by Malin and Sheridan (1982). The principle is that the height of the starting point of the flow (H_c) ratios to the length of the runout (L) as a type of friction parameter termed the Heim coefficient. The inclination of the energy cone is an angle ($\square_c$) defined by arctan (H_c/L). The intersection of the energy cone, originating at the eruptive source, with the ground surface defines the distal limits of the flow. So, the model is applied calculating the energy cone defined by H_c , $\square_c$ and the vent coordinates and intersecting it with the topography of the area. So, the cell ij can be affected by the flow if $h_{ij}>0$, where h_{ij} is:

$$h_{ij} = H_0 + H_C - \tan(\alpha_C) d_{ij} - h_{0ij}$$

The physical model integrated with GIS as a tool namely Voris (Volcanic Risk Information System) based GIS to determine the level of volcanic hazard. This application provides facility to generate scenario based volcanic hazard for different scenario. The latest version 2.0 has been able to Voris simulate effects of volcanic ash fallout, larva flow, pyroclastic density currents, and additional facilities for volcanic hazard calculations. This software was developed by the Institute of Earth Sciences (Felpeto *et al*, 2007). The software is an open source application that can be obtained in www.gvb-csic.es. This research is multidisciplinary in need of information on topography, meteorology and geology. SRTM data with resolution 90m is public domain and uses in this simulation for DEM (Farr 2007). The research will be conducted in the study area Seulawah Agam volcano located in the district of Aceh Besar, Aceh province (See Figure 2).

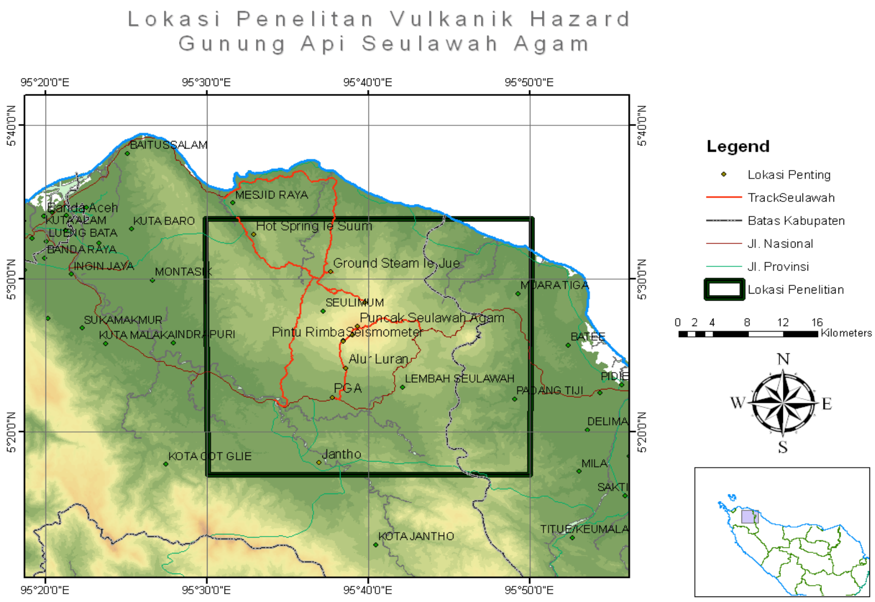

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Figure 2. Research of interest Seulawah Agam Volcano

This research is collaboration with a comprehensive approach that involves multiple disciplines and institutions to produce a study of the geology and geomorphology. This study will outline done in several stages as shown in the flow chart at Figure 3. This scenario volcano hazard map will be compared and verified with available Volcano Hazard Map of Seulawah Agam Volcano, Special Tertiary of Aceh Province (called CVGHM map), see Figure 4.

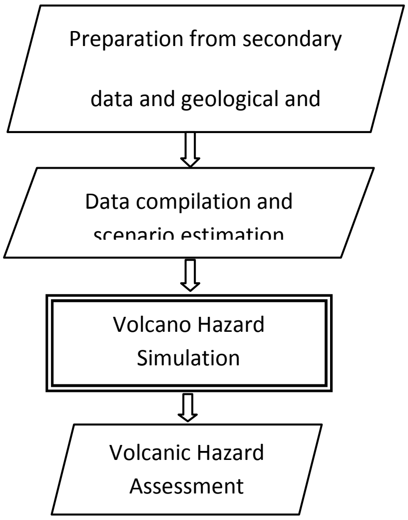

Figure 3. Flowchart of VHA research

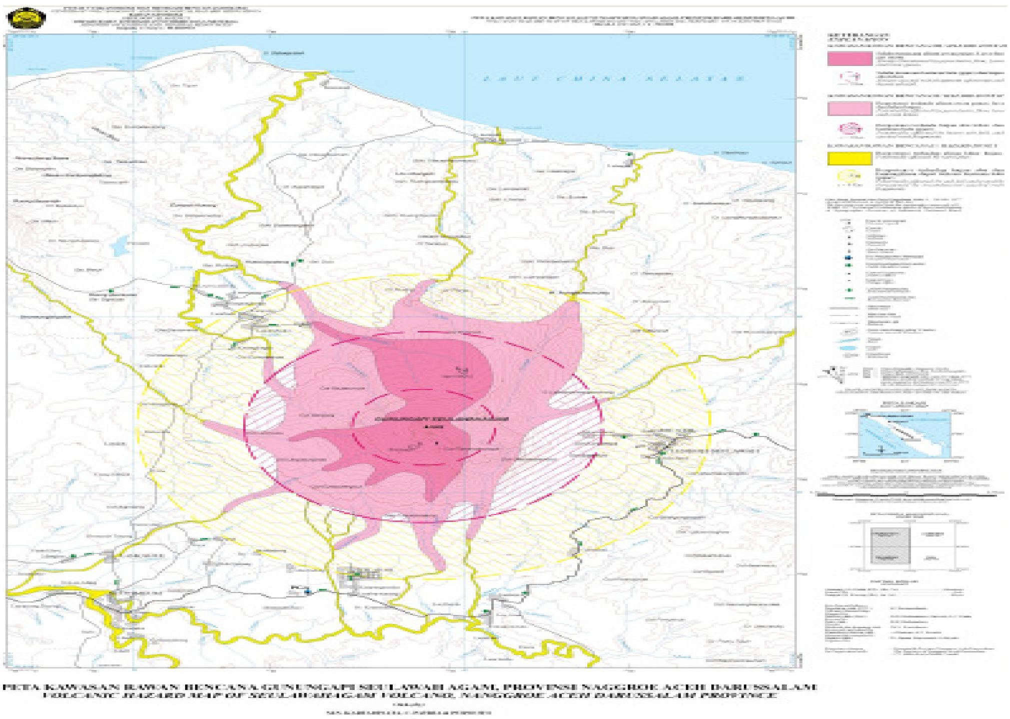

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Figure 4. Volcano Hazard Map of Seulawah Agam Volcano, Special Tertiary of Aceh Province (called CVGHM map) oleh Kartadinata 2007.

Results and Discussion

Geological study

Seulawah Agam volcano is a stratovolcano which characterized by a cone with steep sides (Figure 5). The volcano is formed by large eruption with composition of lava flows, tefra, and pyroclastic flows. In schematic of stratovolcano (Figure 6), the vent not only on the top but also at body and terrain position. In geological investigation, we find the vent from the existence of geothermal manifestations in the body of Seulawah Agam volcano: Heuzt crater and Simpago fumarol. However, no any visible geothermal manifestation in the top. In addition, the vents not only occur at body of the mountain, but also at the terrain part, such as Ie-Jue and Ie-Suum. The coordinate of geothermal manifestations at terrain area located at geological fault as shown in Figure 7.

Figure 5. Photo Seulawah Agam volcano taken from Lamteba village

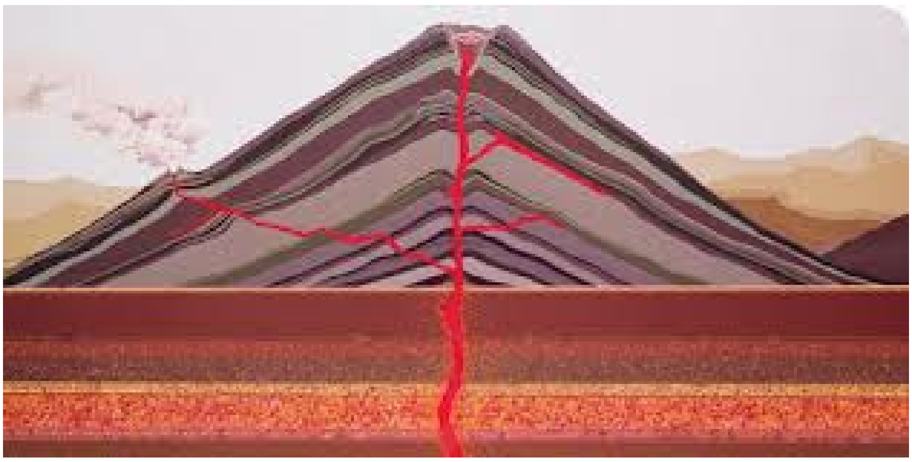

Figure 6. General schematic of stratovolcano

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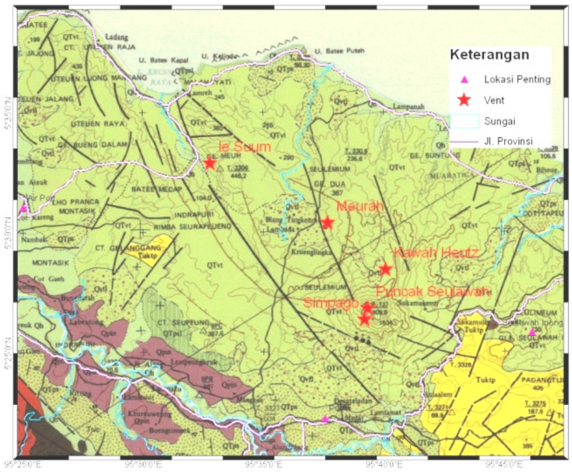

Figure 7. Geothermal manifestation and geological map scale 1:250.000 [Bennett 1981]

Ash fall Simulation

Wind velocity data is very important to simulate volcanic eruptions in particular to the effects of the spread of ash (small particles) entering to atmosphere. The wind velocity data is getting from NOAA (www.noaa.gov) located at top of the mountain (95.650E, 5.430N). Wind velocity data is used in early June 2012 that represents dry season and at the beginning of January 2012 represent the rainy season.

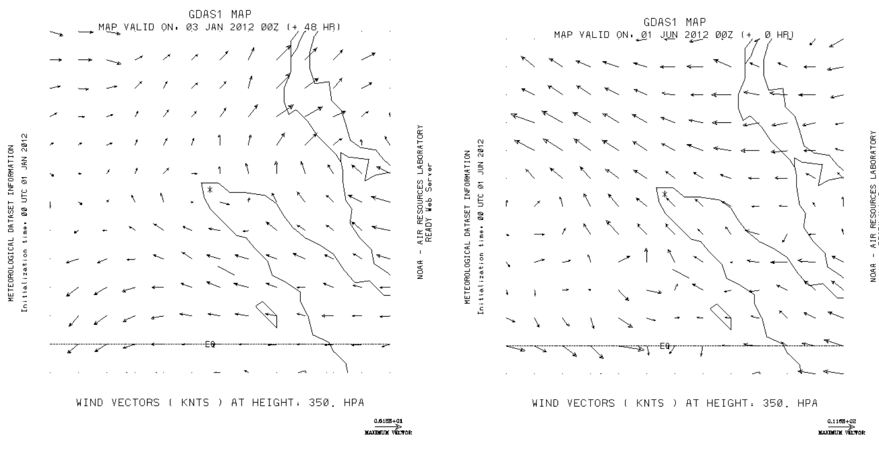

Figure 8. Wind velocity pattern at 350 m (msl) for 3-4 January 2012 (left), and 1-2 June 2012 (right).

Ash fall simulation shows the 5 cm thickness near Banda Aceh. This simulation show distance of ash fall can be reach further then estimation range of CVGHM map. Indeed, the dust is not directly endanger human life, but when it reaches a certain thickness can damage the infrastructure. Especially, significant hazard of ash fall is effected aircraft at International airpot of Sultan Iskandar Muda.

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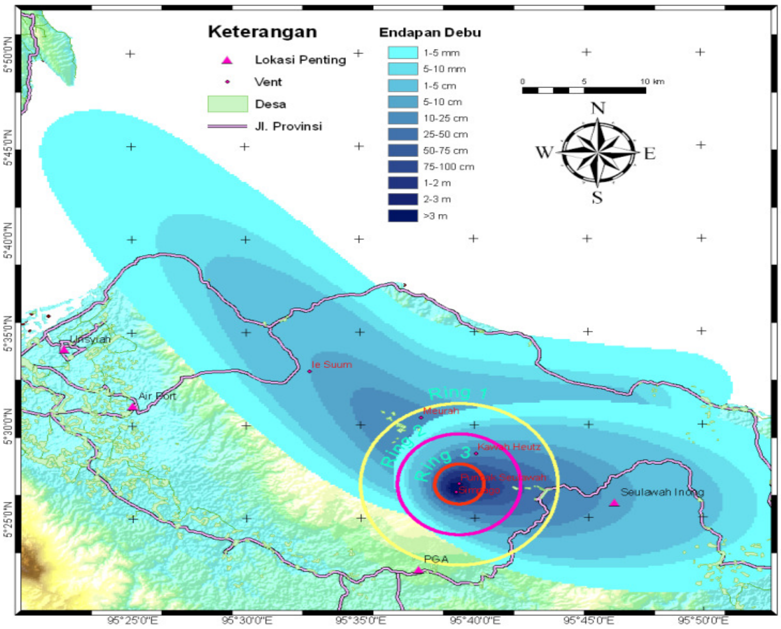

Figure 9. Ash fall simulation and compare with hazard ring of CVGHM map

Result of lava flow simulation shows more detail map for affected area compared with the maps created by CVGHM map. Lava flow simulation results only focus on certain areas along the topography track. At the Southwest region's, it reach longer than predicted by CVGHM map. Whereas, at the Northeast part, the estiomation of CVGHM map show lava flow can be reach longer than the prediction adn until Lamteuba. One possibility of this difference cause by model in this study is considering more intensive topography data than produce by CVGHM.

In this investigation we simulated PDC for high of eruption column for 20 m and 200 m and compare with CVGHM map. PDC flow is highly influenced by the topography. For example, eruption column high 20m for Simpago vent has spread for 8 km, on the contrary with Ie-Jue and Ie-Suum vents only spread les than 0.25 km. In addition, when the eruption column at 200m, the spread of PDC for Heuzt will be reach greater then 1 km and similar with Ie Jue and Ie Suum vent. Especially for Simpago vent with eruption column for 200 m will be reach residential areas and the national highway Banda Aceh-Medan. So the conditions for the region Simpago vent activity should always monitoring.

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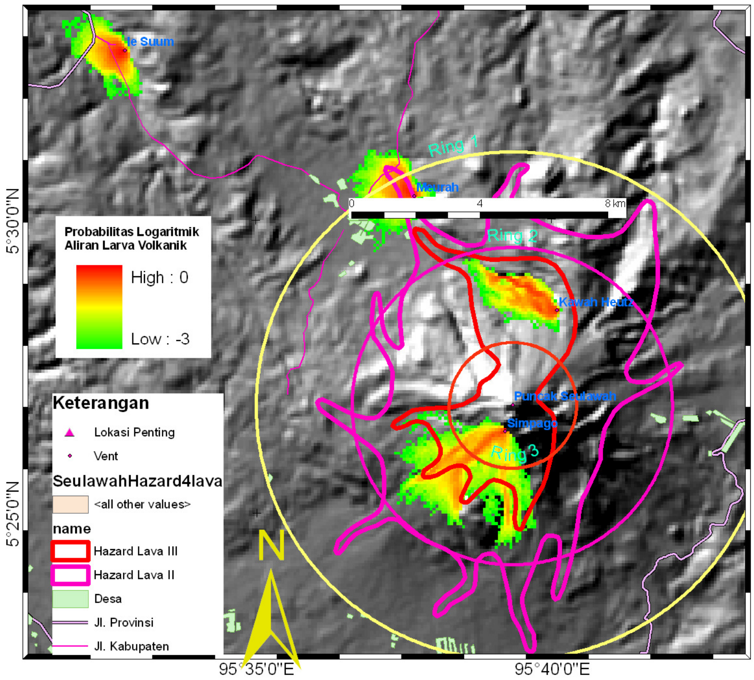

Figure 10. Map of lava flows compared to map the lava flow (Hazard III) and lava flows (Hazard II)

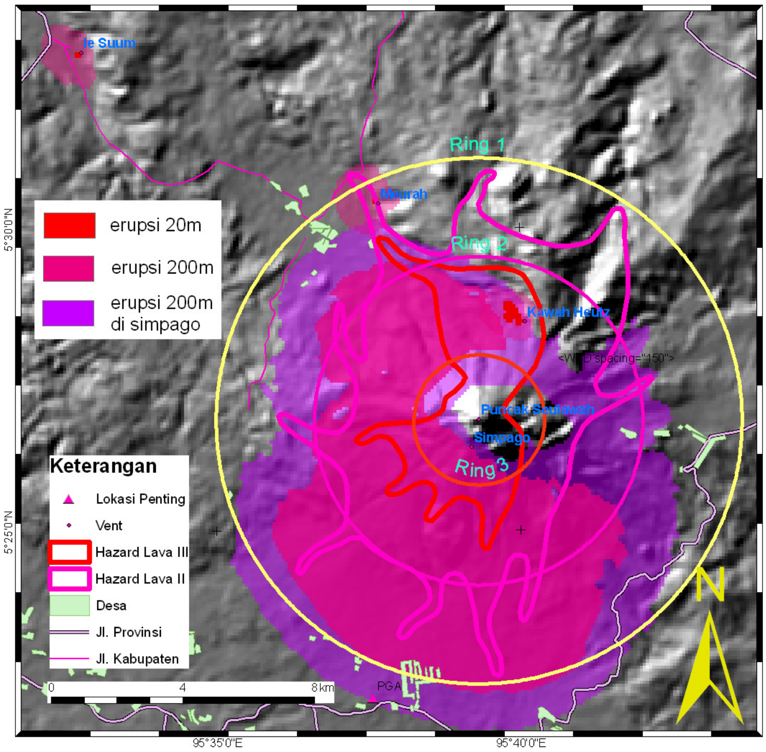

Figure 11. PDC simulation results are compared with a map of the EMR.

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Conclusions

In general, the results of this scenario-based simulations show reasonable results respect to geology, topography and meteorology data. Volcanic ash fallout can be reach the location of Banda Aceh but for PDC and lava flows around the mountain just Seulawah Agam area. Lava flow map obtained more accurate when compared to maps generated by CVGHM. PDC hazard erupted from crater Simpago has high risk because it can be reach residential area and main highway.

Acknowledgements

Honestly we thank to Alicia Felpeto for availability the model and manual. We also would like to thank for Program Penelitian Unggulan Perguruan Tinggi Tahun Anggaran 2012 for financial support.

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