 Probabilistic Analysis of the Laharic Hazard Assessment on Experimental Power Reactor, Puspiptek Area, Serpong.

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Abstract. Nuclear energy has a large potency to become the backbone of renewable energy in Indonesia, and it is expected to become a significant lifting factor in fulfilling the national electrical energy, furthermore nuclear technology could be grouped into the clean and safe technology. One of Nuclear program in Indonesia is development of Experimental Power Reactor (RDE) in Puspiptek, Serpong. Safety aspect in nuclear reactor technology covering site, construction and technology. One of the important site safety aspect is volcanology aspect, because of a volcanic event is could occur before, during, and after volcanic eruption which has the potency in producing hazard threats. The volcanic aspect assessment is to understanding the characteristics of volcanism and capabilities of volcanic hazards. In the 150 km radius from RDE site, there are six capable volcanoes, which are covering Anak Krakatau, Gede, Salak, Tangkubanparahu, Guntur volcanoes possessing different probability based on the eruption index. This paper focusing on the lahar hazard analysis from Gede and Salak Volcanoes. Analysis method conducted in this research is probabilistic of lahar. This method is combining of DEM with 9 m/pixel resolution and analysis using LAHARZ software. Even so, the volcano hazard evaluation towards the site is conducted with a hazard potency source from the phenomenon of the Salak and Gede volcanoes which are at a distance respectivley of 41 km and 60 km from the RDE site. The Salak and Gede volcanoes are ones type of active volcanoes which show volcanic activity since 1600 until now. The maximum lahar potency using in this analysis are 60 million m³ from Salak Volcano produces a distribution spread of 35.35 km. Meanwhile, the reach of the lahar from Gede Volcano is 37.7 km. Therefore the lahar does not give any impacts to the RDE site

1. Introduction
Nuclear energy has a large potency to become the backbone of new-renewable energy in the future, and it is expected to become a significant lifting factor in fulfilling the national electrical energy, furthermore nuclear technology could be grouped into the clean technology, which has the important role in driving the national economy and reducing the greenhouse gas emissions [1].
program in Indonesia is development of Experimental Power Reactor (RDE) or Non-Commercial Power Reactor located in Puspiptek, Serpong.

Safety aspect in nuclear reactor technology covering site, construction and technology[2]. One of the important site safety aspect is volcanology aspect, because of a volcanic event is could occur before, during, and after volcanic eruption which has the potency in producing hazard threats[3][4]. A volcanic event is a volcanic phenomenon which could occur before, during, and after volcanic eruption which has the potency in producing hazard threats. The volcano phenomenon which produces a threat potency towards the safety of the site or nuclear installation, in general could be categorized into 14 types of hazard potencies, including flow of debris materials/lahars, lahar and floods[4].

Identification of the hazard potency of a volcano or volcano area is conducted through volcanology evaluation. Evaluation of volcano is a deterministic volcanism characteristic, understanding of evolution, and evaluation of the capability of a volcano[4]. The volcanism characteristic and evolution of volcano is a series of geological processes which figures out the system of magmatism, diatreme, magma chemical characteristics, and strength of eruption which could influence towards the growth of the volcano body. Therefore, the characteristics of volcanism and evolution of volcano could become the basis in determination of the capability of volcano as a definition of a volcanic system and evaluation of the volcanism reactivation potency in the future. If a volcano possesses the capability to erupt in the future, then a series of more detail investigation must be conducted as an estimate assessment or evaluation of the volcano hazard.

The presence of volcanoes in the 150 km radius area with the RDE site as the center point very much needs to be included into a disaster evaluation. Volcanoes which are in the radius which needs to be identified at least which have an age of <10 million years or in the geological time of the above Miocene until the Holocene age.

In a radius of 150 km from the Serpong RDE Site location at least there are 90 volcanoes with the Above Miocene until Holocene or having an age of at least 10 million years (see volcano catalogue). Several volcanoes among them are still active and including volcano type A, B, and C (Figure 1.). Based on the history of activity volcanoes in Indonesia are divided into three types[5][6], which are :

Volcano Type A : Since the year 1800 the volcano had erupted or shown increase in magmatic activity.
Volcano Type B : volcanoes which are still showing fumarola and solfatara activity, but since the year 1600 has never erupted (magmatic).
Volcano Type C : Volcanoes which have a solfatara or fumarola field.

Figure 1. Map of volcanoes distribution in 150 km radius from RDE Site, Serpong, Banten
Active volcanoes of type A which are present in the 150 km radius from the Serpong RDE site are: Mountains of Krakatau, Salak, Gede-Pangrango, and TangkubanParahu. Volcanoes of type B are: Pulosari, Karang, Patuha, Wayang – Windu and Rajabasa Volcanoes. Whereas the volcanoes of type C which are Kiara Beres-Gagak and Perbakti volcanoes.

The laharian hazards assessment is conducted to evaluate the possibilities to give an impact towards the RDE site therefore could be considered as a factor for acceptance or rejection of the RDE site candidate. Hazards evaluation conducting on active volcanoes/A type volcanoes which has capabilities on laharian hazards to the site. In the 150 km radius from the Serpong RDE site, there are six capable volcanoes. Even so, the volcano hazard evaluation towards the site is conducted with a hazard potency source from the phenomenon of the Salak and Gede volcanoes which are at a distance respectively of 41 km and 60 km from the RDE site. The Salak and Gede volcanoes are type A active volcanoes which show volcanic activity since 1600 until now. As a strato type volcano which is made up of lava and pyroclastic, the potency of hazard threat which may probably appear is lava flow, pyroclastic flow, pyroclastic fallout and lahar.

2. Method

Evaluation of the laharian hazard is initiated by identifying all volcanoes and volcanic fields which have the capability as a volcano hazard source. Evaluation of the volcanoes hazard, which covers:

a. Selection of the type of hazard potency which is produced by the hazard source;

b. Historical activity of the hazard source in geological space and time which is probable.

In this case, the evaluation of volcano hazard of volcanic regions which possess the capability could be based on the deterministic and probabilistic methods.

Laharichazard analyzed based on result of the quantification results of volcanic capabilities combining by the results of topographic analysis from ASTER and SRTM DEM analysis[7]. Deterministic and probabilistic of laharian hazard processing and modeling conducted using LAHARZ software [8].

Lahar is a secondary sediment which is formed from volcanic sediment debris, like pyroclastic flow and pyroclastic fallout (eruption ash)[9]. Heavy rain in the Puncak region or slope of volcano mixed with material from the results of volcano eruption in the Puncak region forms a mass movement which moves down the slope through valleys. The percentage of mixture between the solid mass and water in the lahar varies, about 80% - 70% solid mass and 20% - 30% liquid. If the liquid mass is more dominant instead of the solid mass then the flow type is often categorized as “hyperconcentrated flow”. The modelling of the lahar flow uses the LAHARZ program. The LAHARZ program is a free software which is developed by USGS and in the development, implementation, and testing of the lahar hazard alternative modelling. The basic principle of LAHARZ takes into consideration several aspects, among them are: The affected lahar area based on the history of lahar affected areas in the past; The lahar hazard is at the bottom of the slope of the volcano; The lahar volume in general determines the distance of the affected lahar area; The river morphology determines the distribution spread; The height of the mountain; The River Flow region (DAS) which takes in the lahar potency.

The basic principle in the operation of LAHARZ is determined through assumptions in division of the volcano body into 2 hazard zones, which are the top part hazard zone (proximal hazard zone) and the bottom part hazard zone (distal hazard zone). The bottom part hazardzone is a lahar affected area which originates from debris material in the top hazard zone part. The relation of the two hazard zones is defined by a crossing line of “every cone” and surface of the volcano body (Figure 4).

The “Energy cone” possesses an axis at the peak of the volcano body, whereas the “cone slope” is based on the characteristics of the height ratio (H) towards the horizontal distance of the volcano (L) primary material distribution spread, like hot steam/clouds which possibly could become lahar. The H/L value which figure out the hazard zone top part ranges between 0,1 until 0,9 depending on the size and type of primary hazard of the volcano eruption. Besides as a limit between the hazard zone on the top part and bottom, the H/L value which crosses the river valley is defined as the initial point of lahar.
movement in LAHARZ even though the distal lahar comes from areas which originates from a proximal zone.

![Idealized Lahar Path](image)

**Figure 2.** Ideal cross section of the basic principle in the operation of LAHARZ[10]

Thus also with the volume of the lahar in the proximal part and distal are a variation even though operationally the distal lahar volume comes from the area which originates from the proximal zone. In the case of Gede and Salak Mountain, the H/L ratio which is used is 0.3 as a representation of the top part hazard zone which is caused by hot cloud/steam flow as far as ~ 8.5 km from the eruption centre.

Kinematic lahar analysis has succeeded in making development in the empirical equation which could consider the area of the cross section of the river (valley cross-sectional area – A) and planimetric area (B) which are affected by the lahar with a variation of volume (V)[11]. Calibration of the empirical equation results in the relation of the three components to become:

\[
A = 0.05 \ V^{2/3} \\
B = 200 \ V^{2/3}
\]

The equations as a basic principle in the operation of LAHARZ is 2/3 calculated and plotted on a digital elevation model (DEM) through a geographic information system (GIS)[8].

3. Result and Discussion

There are two volcanoes that will evaluate in laharic hazards analysis, which are Salak and Gede-Pangrango Mountains. For each mountains has been recorded the historical data to be analysed.

3.1. Volcanoes Capabilities

3.1.1. Salak Volcano

The Salak Volcano is a type A Volcano which is most close to the RDE site, Serpong, which is only a distance of 45 km south of it. The salak mountain in its history could be grouped into two groups, which are the old Salak mountain and the young salak mountain based on the period of its formation, however the results of eruption of the old Salak Mountain period in general is covered again by sediment from the results of the Young Salak eruption. After the end of the Old Salakoeriod, then it was followed by volcanic activity of the Young Salak which erupted various volcanic rock sediment
to form a stratosalak cone now. The eruption history of salak Volcano which ever occurred for the first time noted is in 1668. The historical records of the salak Mountain eruption which are: 1668-1699, 1780, 1902-1903, 1935, 1938. Salak Mountain has three peak, which are Salak I (2.180 meters above sea level(masl)), Salak II (2.180 masl.), and Salak III or called by Sumbul Peak (1.926 masl.) also has some solfatarara/fumarole komplexs such as Cikuluwung Putri[12].

3.1.2. Gede-Pangrango Volcano
This volcano is a strato volcano with 2958 masl, for Gede Peak, together with the adjacent Pangrango Volcano(3019 masl) form a large area (base diameter 30 km, located 60 km south of RDE site. Pangrango has no historically recorded eruptions, Gede is one of the more active volcanoes with 26 eruptions were reported since 1747; the last of them occurred in 1947–1957. Modern activity of the volcano includes persistent solfataric activity in the summit crater (with temperatures 150–200 °C) and periodic seismic swarms possibly indicating shallow intrusions of magma in 1990, 1991, 1992, 1995, 1996, 1997, 2000, 2007, 2010, 2011, and 2012[13] [14]

The Young Gede Mountain consists of lava flow, pyroclastic flow and pyroclastic fallout as well as volcano avalanches. Because the eruption source is located on the top slope of the southwest part of Gemuruh Mountain, therefore the eruption product spread to the southwest-southeast slope along the depression zone between the body of Pangrango Mountain and gede Mountain. From its eruption product which is lava flow and pyroclastic sediment, this shows that the eruption of Young Gede Mountain is an effusive and explosive eruption, even though the eruption scale is relatively small compared to the eruption of Gemuruh Mountain (Old Gede Mountain)[12].

For the future activities the volumes of the eruption products of Gede has been estimated are approximate; however, during the Holocene the estimation suggest that the volcano produced about 1 km$^3$ of various primary deposits (dominantly pyroclasts). Taking into account high percentage of nonjuvenile material in the deposits, and the density differences between the magma and vesicular juvenile pyroclasts, we can roughly estimate that Gede erupted ~0.3 km$^3$ of magma during last 10,000 years, or on average ~30,000 m$^3$ of magma per year. Such small productivity suggests that the likelihood of future large-volume (VEI ≥ 5) eruption of the volcano is low. For example, the strongest eruptions of the volcano in the Holocene were of VEI3–4 with up to 0.15 km$^3$ of ejected pyroclastic material — this is realistic upper limit of parameters for the next significant eruption[15].

3.2. Evaluation of Laharic Hazard
Hazard evaluation will be conducted to from two mountains that are Gede and Salak Mountains. The initial step in estimation of volcano hazard is identifying the volcano hazard source, which covers:

Phenomenon which could be produced by the hazard source; The activity history during the geology time;

For every phenomenon, a conservative deterministic evaluation will be made for screening proposal. Following are several normal assumptions in this evaluation: Eruption occurs at the eruption point (centre or side eruption) at the closest location to the site; The amount and duration of the eruption is formulized maximally for several eruptions which is known from the comparison of the same type of volcano;

In a limited condition, the calculation of the worse impact towards the RDE site must be considered.

The results of estimation of the hazard will result in a zone or spread of hazard from every type of hazard threat. The distance from the source to the end border limit is called Screening Distance Value (SDV) for every hazard phenomenon. Evaluation of the volcano hazard which possesses capability could be conducted through probabilistic approach.

Probabilistic is a value which is used to measure the possibility of the occurrence of a random event. The probabilistic method estimates the possibility of a hazard occurring in a region based on location, eruption index, and event as well as the eruption history. The probability event could be calculated based on events of every eruption index from the eruption history.
Based on the historical eruption data from the database of Indonesian volcanoes, the data of volcanoes from the Global Volcanism Program database and other literature sources, could be made into a table based on yearly probability of volcano eruption based on the eruption index (VEI 0-7) for Gede, Salak mountain and volcanoes around the site area (Figure 2). This analysis assumes based on the eruption event in the past which is written in a base data of the history of man.

In the above figure shows the figure of probability of the eruption of Gede Mountain with a scenario VEI 4 and an eruption column height of about 10 km, a probability value is obtained of the annual eruption event of Gede Mountain is 4.8%, whereas Salak Mountain possess a probability of 1%. From the data this could be the basis of probabilistic spread of volcanic ash of Gede and Salak Mountains as volcanoes of type A in Indonesia.

3.2.1. Topographic Analysis
The DEM which is used in the modelling is a DEM 9 from the Geospatial Information Agency (BIG). Modelling of lahar flow Modelling of lahar is very much influenced by the morphology and material volume of the lahar potency volume. One way of determining the region which has the potency to take in lahar material which is analysing the River Flow region (DAS). The DAS is obtained from the division of river order which is compared with the pattern and type of river flow therefore the limit between DAS could be determined. From the data the material could be delineated which flows based on the DAS area.

![Figure 3. Probabilistic Value of Volcanoes around the site area](image)

The position of the RDE site in DAS is given the colour yellow with an area of 11,805.8 Ha. The position of the site also is in the same DAS area with the north slope of Salak Mountain and a part in the southwest of Gede Mountain (Figure 3.). This shows the potency of lahar which could occur in the site area if possessing a high lahar flow volume.

![Figure 4. Division of the River Flow Region. The Site Area is in the same DAS with the north slope of Salak Mountain and southwest slope of Gede Mountain](image)
3.2.2. Laharic Hazards Modelling
The laharmodelling scenario is conducted at the river channel in the slope of Salak and Gede Mountains which flow to the RDE Site area. The modelling scenario uses 6 (six)material volume scenario of lahar potency, which are 2 million m³, 5 million m³, 10 million m³, 20 million m³, 30 million m³, 60 million m³(Table 1.).

| Volume (m³) | G. Gede (km) | G. Salak (km) |
|------------|-------------|--------------|
| 2 Millions | 18,5        | 16,48        |
| 5 Millions | 22,1        | 19,86        |
| 10 Millions| 25,3        | 22,6         |
| 20 Millions| 27,3        | 26,24        |
| 30 Millions| 32,23       | 30,07        |
| 60 Millions| 37,7        | 35,35        |

Table 1. Following is the result of modeling of lahar of Gede Mountain showing lahar volume:

The results of modelling with different numbers of lahar which is produced from Gede and Salak Mountains show the site area with a distance of 41 km from Salak Mountain could be reached by the lahar flow if the volume of the lahar is about 60 million m³. For lahar produced by Gede Mountain show a site area with a distance of 60 km from Gede Mountain therefore the volume of 60 million m³ does not give any impacts and possibly could be reached by the lahar volume produced is far above the 60 million m³ (Figure 5).

Figure 5. Lahar Modelling map of Salak and Gede Mountain towards the RDE Site Location.

4. Conclusion
Active volcanoes of type A which are present in the 150 km radius from the Serpong RDE site are: Mountains of Krakatau, Salak, Gede-Pangrango, and TangkubanParahu. Volcanoes of type B are: Pulosari, Karang, Patuha, Wayang – Windu and Rajabasa Volcanoes. Whereas the volcanoes of type C which are Kiara Beres-Gagak and Perbakti volcanoes. Volcanic hazards research concluded the
volcanoes that have laharc hazards potential to reach RDE site coming from Gede and Salak Mountains.

Probabilistic analysis result with Lahar potency of 60 million m$^3$ from Salak Volcano produces a distribution spread of 35.35 km therefore does not give any impacts to the RDE site which is a distance of 41 km. Meanwhile, the reach of the lahar from Gede Volcano is 37.7 km therefore does not give any impacts to the site which is at a distance of 60 km.

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