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# Estimation of river based transportable volcanic material distribution using satellite DEM and precipitation data

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# Estimation of river based transportable volcanic material distribution using satellite DEM and precipitation data

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**Abstract.** The transportable volcanic materials of Mt. Marapi, which are deposited around the caldera, as a result from last eruption in November 2015, must be estimated as a first step to handle the lahar/ debris flow disaster. In this research, the method used to determine the amount of river-based transportable volcanic material distribution was offered. The LIDAR Satellite DEM and TRMM data from Global Precipitation Climatology Project (GPCP) have been used to estimate the deposited volcanic materials. Based on the GPCP data analysis, it was found that the rainfall pattern distribute into two area, which are 0.52 mm/ hr on west side and 0.61 mm/ hr on east side relative to the mountain summit. The deposited materials from Mt. Marapi 14 November 2015 eruption (volcanic boulders and lava) were located in the upstream of six prioritized watershed. The transportable volcanic material will predominantly flows to the South and North West direction. The potentially transported boulder and lava are around 80.33 % of the total erupted material that are deposited in the river upstream. Batang Kadurang Watershed has the highest transportable material of 1,905.18 $m^3$. The results of study can be used as a rapid disaster countermeasure for lahar disaster mitigation.

## 1. Introduction

Mt. Marapi, located close to Padang city in West Sumatera, Indonesia, has long history of eruptions that were ever recorded [1]. Instead of all these worrisome evidence, many people still choose to live in the mountain slope. It was noticed that there are about 57,453 inhabitants live within 10 km range from the mountain top in the recent period [2]. The eruption of Mt. Marapi volcano on November 14, 2015 had urge the river authority to prepare the lahar flow disaster mitigation strategy and planning in the region. In order to attain that objective, the river authority needs the estimation of transportable volcanic material distribution around the river on the volcano slope. The site visit to the volcanic material deposited area of Mt. Marapi on May 8, 2016 had shown that the material is very exposed to the rain triggered erosion [3]. The erupted materials that are mainly formed of sand, gravel, and boulders were depicted in Figure 1. The large amount of deposited materials on Mt. Marapi raises our research question on how the materials will be distributed into the watersheds within the mountain slope. There is no measurement at the top of Mt. Marapi. Therefore the method used in this paper aims to be an optimum solution when no erupted material deposit measurement data is available. This research proposes a new method on using the global free availability satellite data for river-based transportable volcanic material distribution analysis.

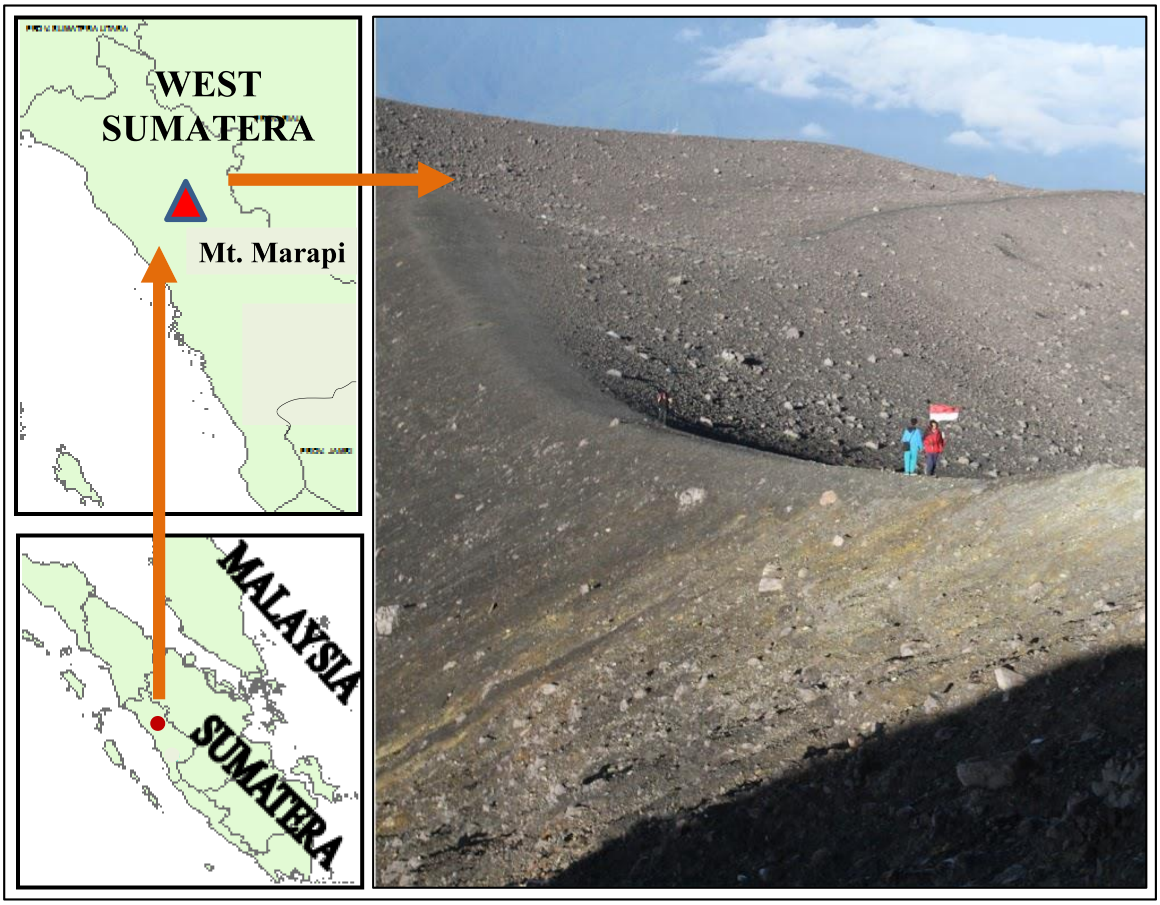


**Figure 1.** Sediment deposited in the top of Mt. Marapi volcano, West Sumatera, Indonesia.

## 2. Related works

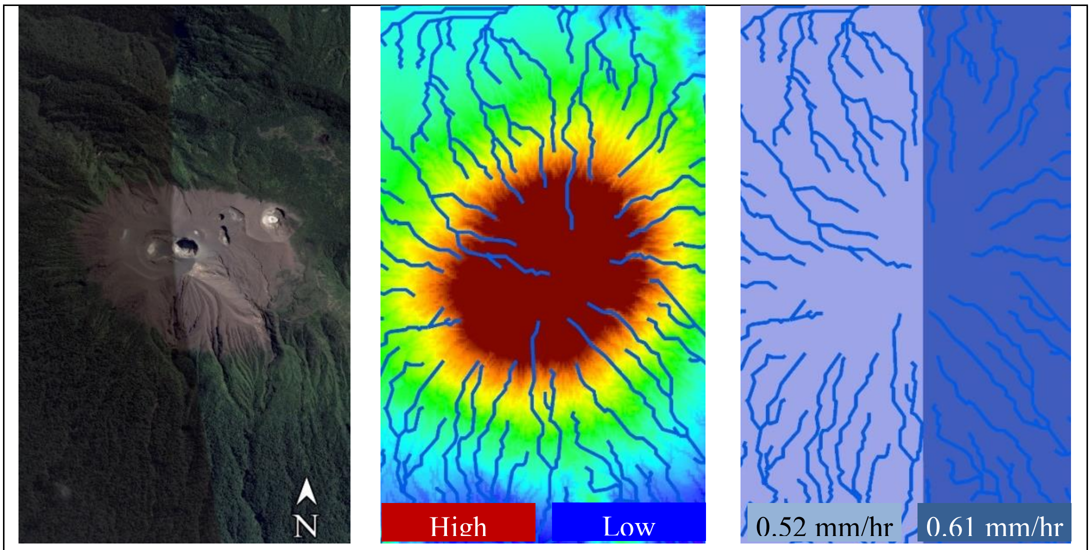
In the recent years, there are several data that are used for volcano erupted material deposition study. The common ground data collection is Thermal Infrared (TIR) sensor collected with airborne LiDAR (Light Detection and Ranging). The mentioned method will show the hot erupted material from the crater. The latest research demonstrates the use of cosmic-ray muon radiography (muography) that will produce a quantitative mass loss inside the crater during the eruption [4]. The two method utilize some sophisticated and exorbitant ground instrument risky operation within a volcanic eruption event. An approach in using the satellite imagery for estimating the volcanic erupted material volume had also been initiated. A recent paper mentions the use of ALOS Interferometric Synthetic Aperture Radar (INSAR) as an alternate for Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), Spinning Enhanced Visible and InfraRed Imager (SEVIRI), and Moderate Resolution Imaging Spectroradiometer (MODIS) [5]. However, these methods are highly dependent to the data availability within a certain spatial and temporal variability of the eruption event. In the case of 14 November 2015 Mt. Marapi eruption event, the mentioned instruments and data are hardly available for the river authority. The most reasonable method that is practical to be used by the local river authority is the Volcanic Explosivity Index (VEI) approach. The VEI analysis then usually combined with the lahar source zone digitation in order to map the material dispersion [6]. The calculation of deposit areas and volumes in June 2011 from satellite imagery and the average deposits thicknesses estimations from the field for each affected river can be used to estimate the material distribution within the adjacent volcanic river [7]. This research is trying to involve the rainfall pattern in the volcanic area as a governing parameter for the river based transportable volcanic material distribution analysis.

## 3. Methodology

The LIDAR Satellite Digital Elevation Model (DEM) and Tropical Rainfall Measuring Mission (TRMM) data from Global Precipitation Climatology Project (GPCP) are used to estimate the transportable volcanic material into the watershed within a single phase of volcano activity. All the dataset from Mt. Marapi case study are recommended to have EPSG: 32747 - WGS 84/ UTM Zone 47S coordinate system projection, as previewed in Figure 2. In order to achieve the goal, the erupted volcanic material needs to be estimated using Volcanic Explosivity Index (VEI) [8] and visual eruption plume height measurement (simple classical method that is used by The Mt. Marapi Monitoring Station Personnel). The technique is explained in equation 1, as follows:

$$EPh = (D_{CoE} \times \tan(\theta_{ToP})) - (Z_{lip} - Z_{sta}) \tag{1}$$

The eruption plume height ($EPh$) is calculated by subtracting the visual plume height with the crater lip reference. The visual plume height can be calculated by multiplying the horizontal distance from the centre of eruption point to the monitoring station ($D_{CoE}$) with tangent of top of plume viewpoint ($\theta_{ToP}$). The $D_{CoE}$ can be quantified from the google earth measurement by knowing the centre of eruption coordinate from the seismic analysis. On the other hand, the $\theta_{ToP}$ was measured by the volcano monitoring person by using inclinometer. The elevation of the crater lip ($Z_{lip}$) and the monitoring station ($Z_{sta}$) is usually had been recorded before the eruption event. All of these variables were in SI Unit. On 14 November 2015, the centre of eruption coordinate was projected at 0°23'28.44"S and 100°27'25.04"E with the crater lip elevation of + 2,716 m a.s.l. (metres above sea level). The $\theta_{ToP}$ is in the range from 7.55° to 7.9°, while the $D_{CoE}$ was measured ± 17,270 m. Meanwhile, the monitoring station is located at 0°27'20.3"S and 100°35'53.9"E with the elevation of + 472 m a.s.l. Therefore, the calculated $EPh$ value is in the range 50 m to 150 m. The symbol's indexes are available at https://goo.gl/PzOdSU.



**CNES ASTRIUM Image** **SRTM v.4.1** **TRMM 3B43**

**Figure 2.** The open access satellite data that are available around the Mt. Marapi.

### *3.1. Satellite DEM analysis*

The DEM that is used in this research is CIGAR-CSI SRTM v.4.1 data. This Shuttle Radar Topographic Mission DEM version 4.1 is an improved version, where the no data grid had been filled with a certain interpolation algorithm [9]. The data can be freely downloaded from the official CGIAR CSI website (http://srtm.csi.cgiar.org/SELECTION/inputCoord.asp). Another alternative DEM data that has potential to be used is ASTER GDEM v.2 data [10].

The elevation data that is encapsulated in the DEM and was analysed within the Geographical Information System Software (GIS). The input for the analysis is the watershed outlets within the radial range of 7 km from the Mt. Marapi crater. The DEM analysis outputs will be a sink filled raster, an AGREE surface reconditioned raster, a flow direction raster, a flow accumulation raster, a stream definition raster, a watershed definition raster, and a watershed boundary shapefile. In case of no watershed boundary was created, the selected watershed outlets must be shifted to exact overlaid the stream definition grid. The watershed boundary was used to calculate the watershed coverage area, to crop the GPCP data, and to determine the volcanic deposit watershed intersection area.

### 3.2. *GPCP data analysis*

The precipitation pattern analysis elaborate the monthly TRMM data, which is also freely downloadable from NASA MIRADOR Data Access Website (http://mirador.gsfc.nasa.gov). In concurrence with the aim of only identifying the rainfall pattern, the 3B43: Monthly 0.25 x 0.25 degree merged TRMM data is considered to be chosen. The 3B43 TRMM data was merged from 3B-42 TRMM data with some rain gauge estimates improvements [11].

The rainfall data were correlated and accumulated to each watershed. The rainfall data of November 2015 up to March 2016, which are 152 days in duration, in Mt. Marapi area were analysed based on the finding that hot pyroclastic material will not directly transported by rainfall occurrence until a certain period of time [12]. The first step before the rainfall accumulation step is to correlate the rainfall data with each watershed. This technique will result a rainfall intensity value that corresponds with each definite watershed. If there are more than one rainfall intensity value within a single watershed boundary, the final rainfall intensity value was weighted average rainfall data based on the rainfall value coverage area. The final step is to accumulate the rainfall within the selected period. It is necessary to remember that the rainfall unit in TRMM data is in mm/hr. Consequently, the accumulated rainfall within the month can be ensued by multiplying the rainfall intensity value with the number of days of the month and a constant of 24 (twenty four, which representing the number of hour in a day).

### 3.3. *Transportable material estimation*

The transportable volcanic material estimation into each watershed was calculated based on equation 2. The area of the watershed has 20 % weight and the watershed deposit intersection was attributed with 40 % weight. The reason is that the expected proportion of the material is about 59 % of boulders and 41 % of lapilli and ash, which is a typical for a Strombolian eruption [13,14]. The rest of 40% weight was appointed to the rainfall distribution variable due to the concern that rainfall is the main triggering factor for transporting the deposited material. The watershed rainfall data was considered based on its deviation divided by sum of deviation, as stated on equation 2 and 3.

$$V_i = \left(\left(A_i . {A_{tot}}^{-1}\right) \times 20\% + \left(D_i . {D_{tot}}^{-1}\right) \times 40\% + I_i \times 40\%\right) \times V_{tot} \tag{2}$$

$$I_i = (|x_n - m(X)|) \times \left(\textstyle\sum_1^n |x_n - m(X)|\right)^{-1} \tag{3}$$

The mentioned variables are watershed index ($i$), rainfall period index ($n$), transportable volcanic material in each watershed in m$^3$ ($V_i$), total volume of the erupted material in m$^3$ ($V_{tot}$), a certain watershed area in m$^2$ ($A_i$), sum of all watershed area in m$^2$ ($A_{tot}$), sum of all deposit area in ($D_{tot}$), rainfall deviation proportion for a certain watershed ($I_i$), rainfall in a certain period in mm ($x_n$), and rainfall central tendency or rainfall data mean in mm ($m(X)$). The watershed deposited intersection ($D_i$) is the intersection of watershed boundary and the deposited area boundary, measured in m$^2$. The deposited area boundary is digitized based on Landsat 7 ETM+ SLC-OFF that was acquired on 23 June 2015, Landsat 8 OLI that was acquired on 14 April 2016, and Google Earth CNES Astrium that was taken on 15 October 2015 from + 8,310 m a.s.l. The Landsat Satellite imagery is freely available from The USGS webpage (http://landsatlook.usgs.gov/viewer.html).

## 4. Result and discussion

The deposited materials from Mt. Marapi 14 November 2015 (volcanic boulders and lava) were identified in the upstream of 6 (six) prioritized watershed. The boulders and lava covered ± 2.36 km$^2$ area on the mountain top. The pyroclastic materials (lapilli, sand, and ash) were spread onto a total of 28 lahar-risked watersheds around the volcano slope. The eruption has volcanic explosivity index of 1, with the plume height of ± 150 m [15,16]. These facts are used for estimating the deposited material in the mountaintop, which is resulting a maximum number ± 10,000 m$^3$ total volcanic materials. The deposited material site within the volcano vicinity is appropriate presented on Figure 3. The thickness of the sediment deposition cannot be presented here due to the lack of sediment boring log data in the location. The Figure 3 also previews the separation of pyroclastic and lahar zone within the radial boundary of 3 km, 5 km, and 7 km from the mountain top. This boundary were generated based on the latest measured existing data in Mt. Marapi area [17].

The 6 (six) prioritized rivers that have volcanic boulder and lava deposition in the upstream acquire larger portion of estimated transportable volcanic material compared to the rest 22 (twenty two) rivers that have no volcanic boulder and lava deposition in their watersheds. The boulder and lava deposited at the upstream area of the rivers potentially transport 80.33 % of the total erupted materials as summarized at Table 1. Interestingly, Batang Kadurang Watershed has the highest transportable materials compared to the other prioritized rivers, followed with Batang Katik in the second rank. It means that the transportable volcanic material will predominantly flows to the South and North West direction relative to the mountain summit. The materials which have high probability flowing into the rivers in each watershed will not completely all transported, some of them remain at the top due to self-consolidation burden [18].

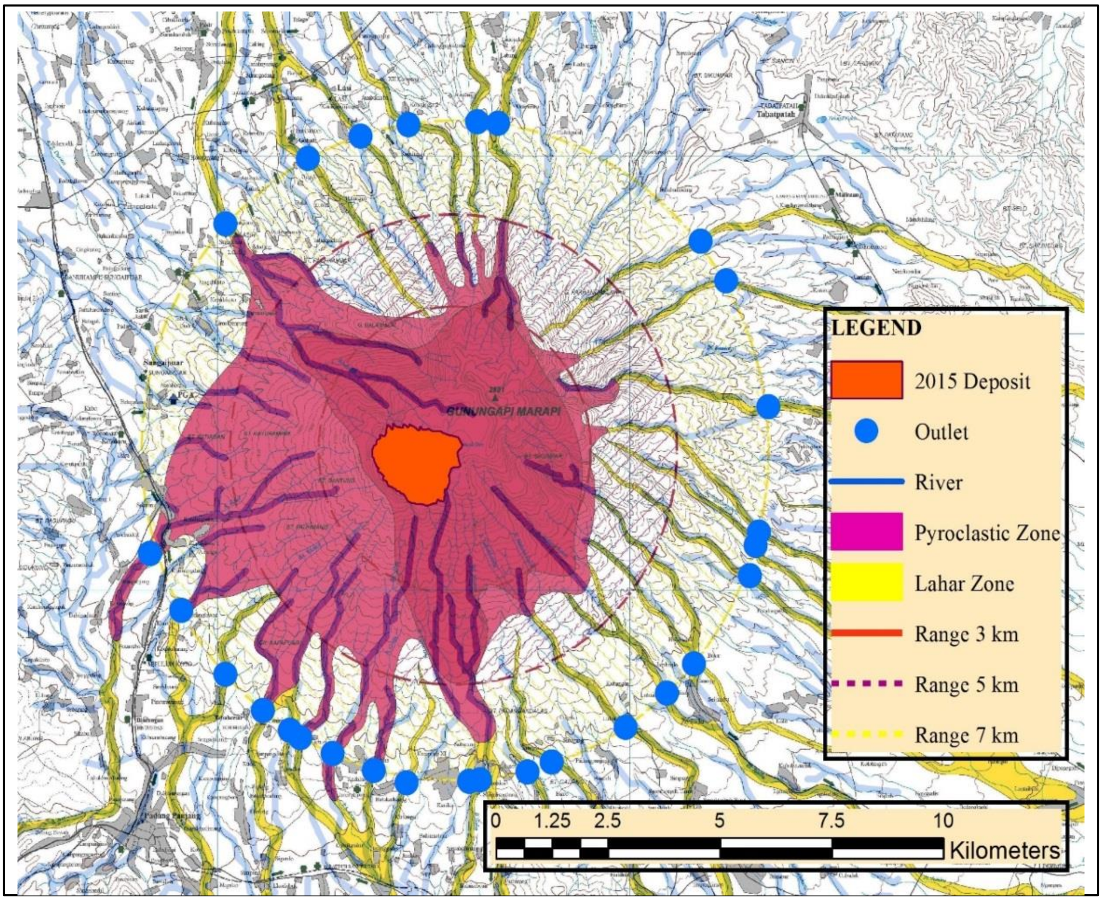


**Figure 3.** Volcano risk map overlaid with prioritized watershed outlet.

**Table 1.** Transportable materials estimation based on Mt. Marapi 14 November 2015 eruption.

| Prioritized Watershed | Outlet Coordinate | Area | Deposit intersection | Rainfall accumulation | Transportable material estimation |
|---|---|---|---|---|---|
| | | [km$^2$] | [km$^2$] | [mm in 152 days] | [m$^3$] |
| BA. Katik | 100.418568°E, 0.346353°S | 13.14 | 0.69 | 1,026.2 | 1,796.58 |
| B. Malana | 100.507400°E, 0.436777°S | 6.96 | 0.04 | 1,280.2 | 1,530.47 |
| B. Kadurang | 100.455062°E, 0.454103°S | 5.10 | 0.83 | 1,023.2 | 1,905.18 |
| B. Arau | 100.440153°E, 0.448458°S | 4.19 | 0.41 | 1,023.2 | 1,176.48 |
| BA. Siririt | 100.431505°E, 0.443938°S | 2.63 | 0.11 | 1,023.2 | 639.13 |
| B. Gantung | 100.403345°E, 0.409848°S | 5.72 | 0.28 | 1,023.2 | 984.45 |
| Others | - | 70.33 | 0 | 1,181.5 | 1,967.70 |
| Overall | - | 108.07 | 2.36 | 1,143.1 | 10,000.00 |
| Weight | - | 20 % | 40 % | 40 % | - |

The transportable volcanic materials estimation that is developed in this paper has high correlation with material deposit extent situation. Therefore, the watershed that has no deposit intersection is presumed to have smaller amount that is transportable into its outlet. Most of the materials transported in the watershed that has no deposit intersection, are predicted to be lapilli and volcanic ashes. The lava and volcanic boulders may be transported in the watershed that has intersection with the deposit area. The rainfall distribution around Mt. Marapi area also gives some significant effect to the final predicted volcanic material volume. The use of TRMM 0.25° x 0.25° gridded precipitation data is quite enough in representing the rainfall distribution in Mt. Marapi into the east side and the west side rainfall distribution pattern. Finally, the proposed transportable volcanic material method still have uncertainties, which mainly caused by the total erupted material prediction. In case of disaster preparedness task force, it is suggested to use maximum possible erupted material for each class of Volcanic Explosivity Index.

## 5. Conclusion

The river based transportable volcanic materials can be estimated by considering the area of deposited materials, watershed terrain profile, and rainfall pattern of the studied area. The web based free available satellite imagery, digital elevation model, and rainfall distribution data will be an alternative solution when there are no ground measurement data of the required input parameter, especially within the rapid disaster countermeasure program. This method can be used to identify the prioritized watershed that will transport the erupted materials in the watershed outlet, including the maximum estimated material. In the near future, it is recommended to calibrate the model by watershed outlet sediment transport measurement data or lahar flood occurrence record to enhance the model for wider application.

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