Research Article

International Journal of Advanced Technology and Engineering Exploration, Vol 10(108)
ISSN (Print): 2394-5443 ISSN (Online): 2394-7454
http://dx.doi.org/10.19101/IJATEE.2023.10101719

Disaster mitigation preparedness of Semeru volcano eruption

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Received: 22-June-2023; Revised: 10-November-2023; Accepted: 12-November-2023

Abstract
The eruption of Semeru Volcano on January 16, 2021, in East Java, Indonesia, posed a complex natural disaster. The response required adapting evacuation sites, routes, and emergency protocols while adhering to health guidelines. Most disaster preparedness studies use technical approaches under normal conditions, often neglecting health protocols. Our research focused on the Pronojiwo Sub-District in Lumajang, East Java, the area closest to Semeru Volcano and most at risk. We employed shelter plan analysis, spatial analysis, and numerical simulation. The study aimed to assess the affected area following Semeru's eruption, considering critical factors like the impacted region, shelter availability, and evacuation routes. Numerical simulations revealed lava flows at 20 m/s with heights up to 3m. Notably, lava distribution exceeded predefined disaster-prone zones due to interaction with rainwater, extending beyond established boundaries. Shelter plan analysis indicated some shelters were unsuitable for temporary accommodation due to their location in areas affected by cold lava flows. Spatial analysis findings showed that shelter coverage areas remained insufficient to serve the residential zones around Mount Semeru impacted by the eruption's material flow. This research will serve as a valuable reference for government authorities, helping them determine effective evacuation routes and suitable shelters for refugees during future Mount Semeru eruptions, ensuring the safety and well-being of affected communities.

Keywords
Eruption, Disaster management, Numerical simulation, Spatial analysis, Shelter plan analysis.

1.Introduction
Natural disasters have significant repercussions on human lives, causing loss of life, environmental devastation, substantial property damage, and psychological trauma. Among various natural disasters, volcanic eruptions have a profound impact, unleashing volcanic hazards that encompass solid, liquid, and gaseous materials endangering human environments [1]. Volcanic hazards can be categorized into primary and secondary hazards. Primary hazards occur directly during an eruption, while secondary hazards arise indirectly after a volcanic event has concluded or gone dormant [2]. In late 2020 and early 2021, Mount Semeru exhibited heightened volcanic activity, reaching alert level II [3]. Explosive eruptions and effusive lava flows were observed towards the south and southeast slopes, along with the ejection of incandescent rocks around the summit crater.

Seismographic records from February 7, 2021, documented 85 eruption quakes, 9 tremor events, 7 harmonic tremors, 1 local tectonic quake, 1 distant tectonic earthquake, and 1 debris flow earthquake [4, 5]. Under alert level II status, the public, visitors, and tourists were advised not to approach within a 1-kilometer radius of the Semeru Volcano's crater peak and to maintain a 4-kilometer distance from the crater opening in the south-southeast sector. They were cautioned about hot cloud avalanches, lava flows, and river valley inundation from the volcano's summit. People were urged to steer clear of areas affected by hot cloud material due to high temperatures and remain cautious of potential landslides along the Besuk Kobokan hot cloud path [6]. Be alert to the threat of lava in the river channel or valley originating from Semeru Volcano, considering the significant amount of accumulated volcanic material [1, 7].

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Semeru Volcano erupted against the backdrop of the COVID-19 pandemic, necessitating strict adherence to health protocols, including social distancing and crowd avoidance [8]. Research on Disaster Preparedness for the Eruption of Semeru Volcano during the Pandemic Era focused on assessing the areas directly impacted by the volcano's eruption. The study centered on Pronojiwo Sub-District in Lumajang District, aiming to identify the affected area, locate potential shelters, and establish the best evacuation routes to ensure prompt and safe evacuations during Semeru Volcano eruptions [9].

Considering heavy rainfall during the eruption, this research sought to determine the extent of volcanic mudflow resulting from Mount Semeru's eruption mixed with rainwater. Additionally, it aimed to evaluate the suitability of available evacuation sites. Pronojiwo District in Lumajang, the most extensively affected region, was chosen as the study location. Numerous potential shelters were designated for refugees. A weighting method determined that shelters within the lahar flow path were unsuitable for temporary refuge. Numerical analysis was conducted to ascertain lahar velocity and eruption material height, facilitating an estimation of lahar distribution within the study area. Numerical wave flume (CADMAS Surf 2D) software was used for lahar velocity and height calculations. Simultaneously, the suitability of shelters was evaluated through a weighted parameter assessment, with ArcGIS employed to determine the extent of shelter services for settlements surrounding the Mount Semeru eruption-affected area.

2.Literature review

Several technical approaches were employed to assess the area affected by the eruption of Semeru Volcano. These approaches encompass spatial analysis utilizing ArcGIS to examine land use in the affected region, delineate residential areas, identify potential buildings suitable for shelter use, and analyze the road network. The assessment of available public buildings focused on places of worship, schools, and village offices. *Table 1* lists the villages located in Pronojiwo Sub-District, Lumajang District. Pronojiwo Sub-District comprises six villages: Sidomulyo Village, Pronojiwo, Taman Ayu, Sumber Urip, Oro-oro Ombo, and Supit Urang Village.

Table 1 Population of six villages in Pronojiwo [5]

S. No.	Village	Area (km^2)	Population
1	Sidomulyo	5.00	5,557
2	Pronojiwo	8.65	7,880
3	Tamanayu	3.75	5,269
4	Sumberurip	6.85	4,228
5	Oro-oro Ombo	8.29	8,816
6	Supiturang	6.20	6,048

To assess the area affected by the eruption of Semeru Volcano, one can refer to the disaster-prone area (DPA) delineated by the Centre for Volcanology and Geological Hazard Mitigation (Pusat Vulkanologi dan Mitigasi Bencana Geologi – PVMBG in Indonesian). In this context, PVMBG has categorized the DPA into three distinct zones. The Semeru Volcano DPA map is segmented into three DPAs: DPA I, DPA II, and DPA III. The DPA for Semeru Volcano encompasses DPA I and II, with radii of 8 and 5 kilometers from the eruption center of Semeru Volcano [10, 11].

1) DPA I is an area potentially impacted by lava, ash fall, and/or highly acidic water. If the eruption intensifies, this region could be affected by the expansion of hot clouds and the falling of heavy ash rain and incandescent stones. DPA I is further divided into two subareas: areas prone to lahars, located along valleys and riverbanks, particularly those originating in the summit area, including Kali Manjing, Kali Glidik, Besuk Sarat, Besuk Kembar, Besuk Kobokan, Kali Pancing, Besuk Semut, Besuk Tunggeng, Besuk Sat, Kali Mujur, and Kali Rejali. The other subarea is susceptible to ash rain, regardless of wind direction.
2) DPA II includes areas with potential hot clouds, lava flows, incandescent stone ejections, lava avalanches, heavy ash rain, hot mud rain, and toxic gases. DPA II is subdivided into two regions: areas prone to hot clouds, lava flows, and toxic gases, especially upstream of Kali Manjing, Kali Glidik, Kali Sumbersari, Besuk Sarat, Besuk Kembar, Besuk Kobokan, Kali Pancing, Besuk Semut, Besuk Tunggeng, Besuk Sat, Kali Mujur, Kali Liprak, Kali Regoyo, and Kali Rejali. The other region is susceptible to heavy ash rain, incandescent stone-throwing, and hot mud rain.

3) DPA III encompasses areas with the potential for hot clouds, lava flows, lava avalanches, incandescent stone-throwing, and/or toxic gases. DPA III covers the summit and its surrounding areas.

The optimal implementation of regulatory and policy frameworks in disaster management remains challenging. Disaster preparedness and mitigation efforts involve the utilization of technology and disaster-related information. In Indonesia, disaster management often faces obstacles in evacuation and transportation processes [12, 13]. Regulations should promote local wisdom and integrate scientific knowledge to enhance disaster resilience. The relationship between risk perception and cultural factors in natural and man-made disasters is intricate [14, 15]. Understanding the cultural factors that can bring about behavioral changes in the context of low prevalent disaster risk is crucial. This necessitates in-depth analysis and examination of the interplay between risk perception, culture, and behavior in disaster mitigation research.

Given the unpredictable nature of events, disaster management cannot follow a rigid and systematic approach [16, 17]. Establishing collective local wisdom and culture with shared objectives enables organizations and communities to prepare effectively for various emergencies, aligning with local behaviors [18]. For assessing seismic vulnerability in urbanized areas, a territorial-scale analysis requires a wealth of data concerning numerous building structural types and street classifications [19–21].

Geographic information systems (GIS) analysis demands complex calculations due to the diversity of building structural typologies and street classifications [22]. Community comprehension of disaster conditions is crucial during natural disasters [23, 24]. Accurate and comprehensive information is vital for communities when responding to disasters. This information affects the capacity of shelters, which may be significantly reduced, accommodating only 20-30% of their normal capacity during disasters [25].

Numerical simulations, such as the finite difference method, are employed to calculate magma dynamics and crustal deformation during volcanic eruptions. The model geometry includes a reservoir and cylindrical flow in a homogeneous volcanic mudflow [26, 27]. Another type of numerical simulation involves a simple semi-analytical model used to simulate deposition caused by volcanic eruption columns. This model is limited to areas distant from the crater, where the dynamics of eruption-related mudflows play a significant role [28, 29]. This implies that vertical wind and diffusion components have negligible impact on horizontal parameters. The results validate the model, which offers the advantage of simplicity and rapid computation [30, 31].

Computational simulations are valuable tools applicable in various scenarios, especially when designing future mitigation plans. Two critical factors in modeling fluid behavior are data accuracy and the duration of numerical simulations [31]. In these simulations, complex parameter combinations, consisting of solid and fluid particles with varying physical properties, are frequently associated with geophysical flows and exhibit diverse and intricate dynamic characteristics in the results of numerical analyses [30]. The finite difference method in numerical simulations is particularly suitable for software applications, especially in modeling disaster mitigation, as it offers faster computing times than the Runge-Kutta 4th-order method [32].

$$\frac{\delta \gamma_x u}{\delta x} + \frac{\delta \gamma_z w}{\delta z} = S_p \tag{1}$$

$$\lambda_v \frac{\delta u}{\delta t} + \frac{\delta \lambda_x u u}{\delta x} + \frac{\delta \lambda_z w u}{\delta z} = -\frac{\gamma_v}{\rho}\frac{\delta p}{\delta x} + \frac{\delta}{\delta x}\left\{\gamma_x v_e \left(2\frac{\delta_u}{\delta_x}\right)\right\} + \frac{\delta}{\delta z}\left\{\gamma_z v_e \left(\frac{\delta_u}{\delta_z} + \frac{\delta_w}{\delta_x}\right)\right\} - D_x u + S_u - R_x \tag{2}$$

$$\lambda_v \frac{\delta w}{\delta t} + \frac{\delta \lambda_x u w}{\delta x} + \frac{\delta \lambda_z w w}{\delta z} = -\frac{\gamma_v}{\rho}\frac{\delta p}{\delta z} + \frac{\delta}{\delta z}\left\{\gamma_z v_e \left(2\frac{\delta_w}{\delta_z}\right)\right\} + \frac{\delta}{\delta x}\left\{\gamma_x v_e \left(\frac{\delta_w}{\delta_x} + \frac{\delta_u}{\delta_z}\right)\right\} - D_z w + S_w - R_z - \gamma_v g \tag{3}$$

$$\gamma_v \frac{\delta F}{\delta t} + \frac{\delta \gamma_x u F}{\delta x} + \frac{\delta \gamma_z w F}{\delta z} = S_F \tag{4}$$

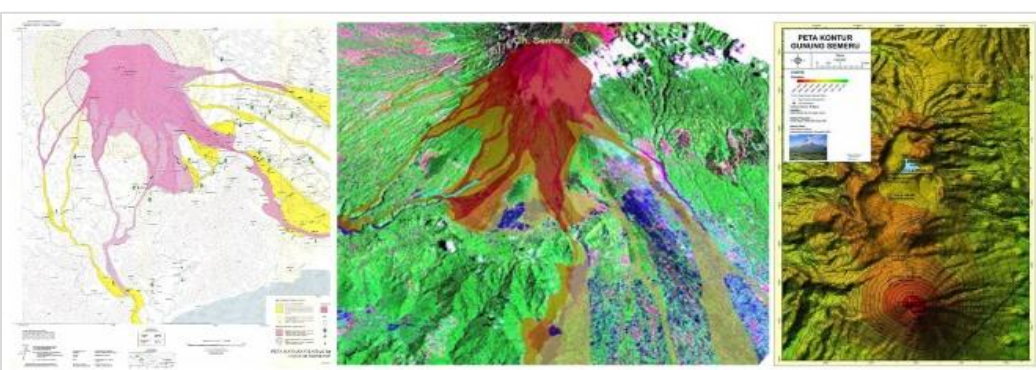
This study employed the CADMAS-Surf/2D program for numerical simulations. The equations (Equations 1-4) used include the continuity equation, the Navier-Stokes equations in both the x and z directions, and an advection equation to determine the mud water level (coefficient). The last equation incorporates the function F(x, z, t), which represents the volume ratio of water in each numerical cell [33, 34].In the earlier Navier-Stokes equations, 't' signifies time, while 'x' and 'z' denote the horizontal and vertical coordinates. In the equation below, 'p' represents pressure, and 'u' and 'w' are the horizontal and vertical velocity components. Additionally, 'ρ' is the fluid density, 'v' represents the sum of molecular kinematic viscosity and kinematic eddy viscosity, 'g' denotes the acceleration due to gravity, 'γ' is the porosity, 'γx' and 'γz' correspond to the components of air porosity, 'SF,' 'Su,' and 'Sw' signify sources of wave generation, 'Dx' and 'Dz' are the coefficients for the sponge layer, and 'Rx' and 'Rz' represent resistance components due to porosity along the x and z axes.

This study encompasses the analysis of GIS-based volcanic hazards, including vulnerability and risk assessments of volcano eruptions. Volcanic hazard assessments are based on volcanic phenomena observed during eruptions. Computer models using field data, such as lava mudflows, volcanic analogues, evacuation routes, and other relevant probability values, are employed to construct hazard maps [35]. ArcGIS is a valuable tool for generating disaster hazard chain maps [36]. Spatial analysis methods, combined with data overlay techniques, are utilized to produce hazard, vulnerability, and capacity maps, ultimately culminating in the creation of disaster risk maps [21, 37]

3.Research methods

In assessing the area affected by the eruption of Semeru Volcano, several technical approaches were employed, including spatial analysis using ArcGIS and numerical simulations with CADMAS Surf. The spatial analysis was conducted using ArcGIS 10.3 software, which can display land cover conditions at the study location [38, 39]. The synergy between remote sensing techniques and GIS warrants further exploration, as it plays a crucial role in mapping the affected area. Identifying affected areas, a vital parameter in lava hazard assessment can yield excellent results when analyzing satellite remote sensing data. While GIS technology serves as a tool to visualize the spatial distribution of cold lava cover using existing attributes, the presented map of the affected area must be validated through field inspections [35, 40]. By understanding the conditions before and after the eruption, several analyses can be performed, including the calculation of the volume of volcanic material, the extent of lava coverage in residential areas, the number of directly affected houses, and the impact on assets and other properties, as well as natural features like rivers, forests, rice fields, and more [6, 41].

To estimate the slope and three dimensional (3D) shape of the study area, software such as Global Mapper 16 is employed. This enables the estimation of the volume of volcanic material based on land elevation data relative to sea level [42]. A comparison is made between image results from aerial photos and data from BingMap or GoogleMaps databases [43, 44]. Another dataset for comparison is based on the information available through the Google Maps feature. Semeru Volcano (8°06′05″S, 112°55′E), one of the most active volcanoes on Earth, is the highest mountain in Java, reaching an elevation of 3,676 meters. It is part of the Bromo-Tengger-Semeru volcanic massif [6, 10]. Semeru Volcano is classified as a type A stratovolcano with a lava dome and features a crater named Jonggring Seloko, situated at an altitude of 3,744 meters above sea level [11]. It is considered an active volcano with a history of powerful eruptions, documented in 1818, 1963, 1967-1968, 1985-1990, 1992, 1994, 1997, 2002, 2004-2005, 2007-2008, 2010, and 2012 [15]. The digital elevation model(DEM) of Semeru Volcano in the image above clearly shows the pyroclastic path passing through the Pronojiwo Sub-District, which aligns with the DPA map released by the government in 2014 (*Figures 1* and *2*).



(a) (b) (c)

Figure 1 (a) Semeru Volcano DPA Map, (b) flow of lava, and (c) SRTM Satellite Photos

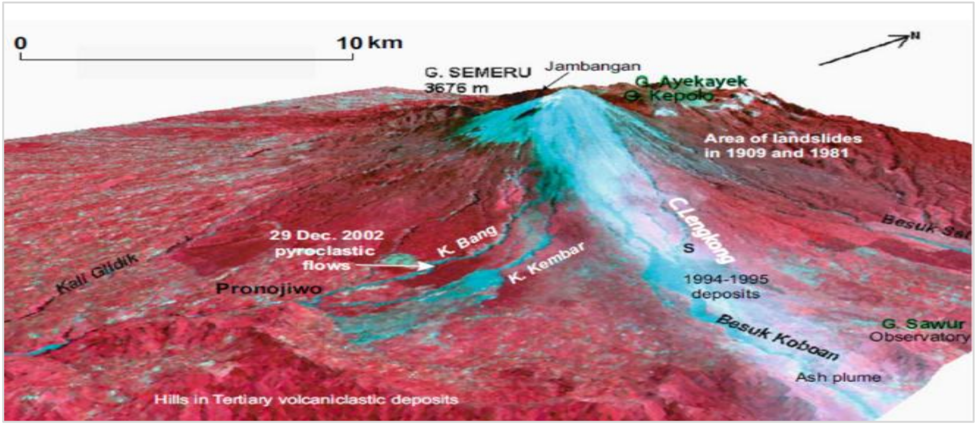


Figure 2 Satellite image (May 14, 1996) DEM

In this study, the chosen area for the case study is the Pronojiwo Sub-District, which covers an area of 40.55 km² situated between 112°54'09-113°01'09 East Longitude and 8°06'30- 8°15'43 South Latitude. Pronojiwo Sub-District is bounded to the north by Semeru Volcano, to the east by Candipuro Sub-District, to the south by Tempursari Sub-District, and the west by Malang District. This selection was made because it was the region most significantly impacted by Mount Semeru's eruption.

In this research, shelter plan analysis was employed to evaluate the suitability of shelters [45, 46]. Potential shelters are assessed based on variables closely related to disaster preparedness, including shelter location, absence of lava flow risk, building dimensions, structural strength, and ease of accessibility to and from the shelter [47, 48]. Each variable is then assigned a weighted value, with 1 signifying the lowest value, 3 for moderate, and 5 for the highest value. In the context of numerical simulation, all parameters are calculated using CADMAS Surf 2D software [34, 49]. This process involves two critical components: determining the characteristics of the flume used in the simulation and calculating various parameters, such as wave height, material sliding speed, porosity, fluid density, and others. In this study, the flume was designed to be 600 meters long with a height of 50 meters, as depicted in *Figure 3*. The topographic slope ranges from 8% to 15%, and the initial height of the lava material is approximately 5 meters from the flume's mouth. The specific gravity of the lava material is assumed to be equivalent to a medium-density cement mixture, around 1500 kg/m³. On the other hand, in spatial analysis, the distribution of existing shelters serves as a crucial reference point for guiding refugees away from areas susceptible to the impact of Mount Semeru's eruption towards safer zones [6]. Multiple spatial analysis parameters are considered, including the distribution of shelters, residential areas, danger zones within the lava flow path, the accessibility of road networks, and areas beyond the reach of the advancing lava flow [11].

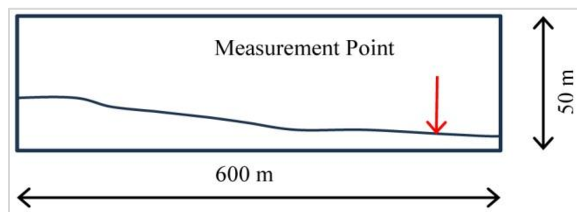


Figure 3 Dimension of the flume in simulation

4.Results and discussion

This research conducted three types of analyses: spatial analysis, numerical analysis, and shelter plan analysis. The numerical analysis results provide insights into the speed and height of the lava material. Spatial analysis helps determine the potential for lava flow and the extent of erupted material around Mount Semeru. Meanwhile, shelter plan analysis aids in identifying the distribution of potential shelters and assessing their vulnerability to eruptive materials from the eruption of Mount Semeru. Weighting criteria are applied to determine the suitability of shelters based on these factors [50].

The importance of processing remote sensing data and optimizing the use of GIS for natural disaster management is emphasized [13]. The sharing of spatial data is discussed in the context of establishing spatial data infrastructure to mitigate natural disasters [17]. Geospatial data collection enhances situational awareness and enables quick and accurate disaster management. In emergencies, it is essential to collect, maintain, and manage relevant information, present data rapidly, and ensure high accuracy in tracking and responding to disaster events for efficient and effective emergency management [16].

Figure 4 Evacuation Road between potential shelters

Using the parameters related to building suitability as shelters [51]. *Figure 4* illustrates the distribution of potential shelters in Pronojiwo Sub-District, Lumajang District. These potential shelters are grouped into mosques, schools, and government offices, including village halls, village offices, and local sub-district offices. The key criterion for selecting these shelters was that they were not located in the path of potential lava flows [52, 53]. To generate this map, the government issued the DPA Map with the administrative boundaries of the Pronojiwo Sub-District and the locations of potential shelters.

In Pronojiwo Village, three types of buildings and facilities can serve as shelters. These include two Public Elementary Schools, Pronojiwo State Elementary School 3 and Pronojiwo State Senior High School, three worship facilities (An-Nur Mosque and two prayer rooms), government facilities (multi-purpose hall), and the use of land for plantations and dry fields as shelter spaces. Taman Ayu Village has educational and worship facilities that can function as shelters, such as sekolah menengah pertama (SMP) Negeri 1 Pronojowo and a prayer room. Sumber Urip Village features a mosque that can serve as a shelter. Oro-Oro Ombo Village has an open field that can be used as a shelter. Supit Urang Village has one educational facility, Supiturang 2 Elementary School and Supiturang State Elementary School, three worship facilities (mosques and prayer rooms), and uses land for plantations and fields as shelter spaces [46, 54].

During the COVID-19 pandemic, it is essential to reevaluate the designated shelter capacities to ensure compliance with health protocols, including social distancing. When necessary, shelters should be refurbished and regularly disinfected before any disaster occurs. In general, the calculation for shelters occupied by refugees is based on the standard of 1.64 m^2 per person [20]. With a physical distancing requirement of 2 meters, the total area needed per refugee is 6 m^2.

This study did not involve in-depth numerical simulations. Numerical analysis was primarily used to compare the sliding speed of volcanic materials, particularly cold lava, which can directly impact the potential for flash floods during the rainy season. Several critical variables were considered during spatial analysis including land cover, housing distribution, topography, slopes, and other relevant factors [55]. *Figure 5* represents a three-dimensional depiction of volcanic material prior to the occurrence of the disaster. This contour interpretation is derived from elevation data at each measurement point, which is then converted into tabular data with reference to sea level height. It is important to note that the volume of volcanic material was not explicitly calculated in this analysis, and all computations are based on assumptions regarding the volume of volcanic material in the affected area.

In the numerical analysis, the material's density is the critical variable, enabling the determination of landslide velocity using a topographical model designed to resemble the location where the volcanic material from Mount Semeru is deposited [7]. The phenomenon of volcanic material propagation adds complexity to the research, as physical evidence from satellite imagery and land cover observations indicates that forests still dominate the affected areas. However, the volcanic material reaches not only forested regions but also settlements and other locations, extending beyond the valley areas that naturally follow the flow of volcanic material.

The analysis assumes that the affected area contains cold lava volcanic material with properties more concentrated than water, approximating the density of a cement mixture, approximately 1500 kg/m^3. *Figure 6* provides a screenshot showing the volcanic material that descended into the Pronojiwo area. The flume used in this simulation is 600 meters long and 50 meters high.

Within this numerical simulation, measurements were taken at a distance of 500 meters from the flume's lip (see *Figure 3*), focusing on landslide height and sliding speed parameters. The graph in *Figure 7* illustrates that the average sliding speed of volcanic material is approximately 20 m/second or 72 km/hour, while the height of the volcanic material ranges from 1.5 to 3.0 meters. With these recorded values for slide height and speed, it is evident that the volcanic material possesses an extraordinary destructive force capable of causing significant damage and burial to anything in its path.

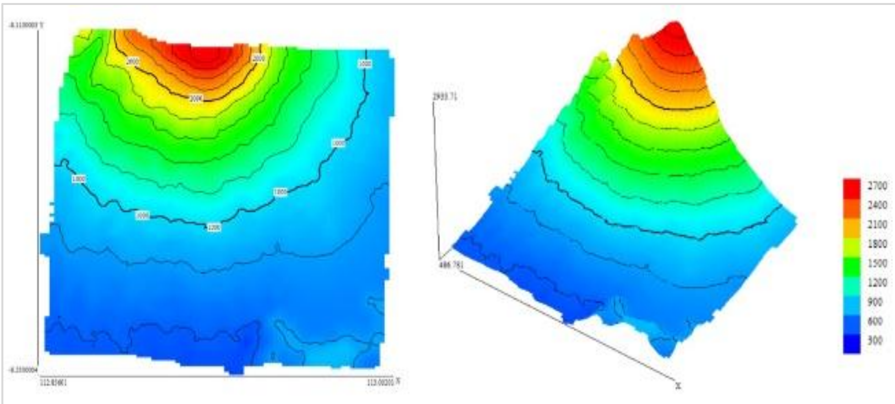


Figure 5 Shapes of the volcanic material slide

Figure 6 Screenshot of numerical simulation at 25th seconds to 50th second

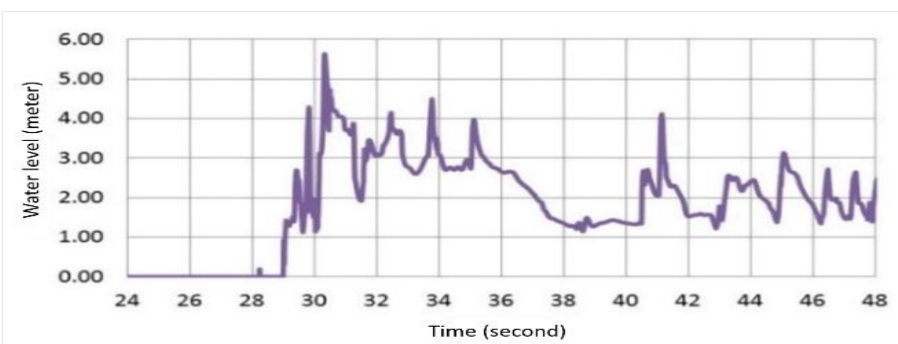


Figure 7 Graph of inundated material level

A preventive action that can be taken involves evacuating residential areas in cold lava flow zones, allowing the lava or volcanic material from the Semeru eruption to flow naturally. This entails clearing any obstacles, such as residual landslides and similar impediments. Blocking the flow of volcanic material can result in the creation of cold lava pockets, which may lead to the accumulation of material. This, in turn, can result in the mixing of cold lava remnants with rainwater, giving rise to mudslides with the potential to travel over greater distances and cause more extensive damage (*Figure 8*). Referring to *Figure 9* below, the lava flow adheres to a natural channel characterized by the shape of a valley and the topographic slope. The eruptive material will travel a considerable distance, following the course of the river in Pronojiwo. Additional shelters should be sited in locations that are safe from disaster threats and utilize facilities like schools, student dormitories, offices, government guesthouses, hotels, and similar establishments. The Regional Disaster Management Agency, in conjunction with the local government and the community, should prepare evacuation sites, ensuring the availability of sanitary facilities [8, 20]. This situation can lead to other issues concerning the procurement and distribution of essential supplies, including clean water, hand-washing equipment, soap, hand sanitizer, masks, thermometers, personal protective gear, and partitioned boxes for sheltering refugees. Hence, proactive measures such as self-sufficiency in procurement should be considered.

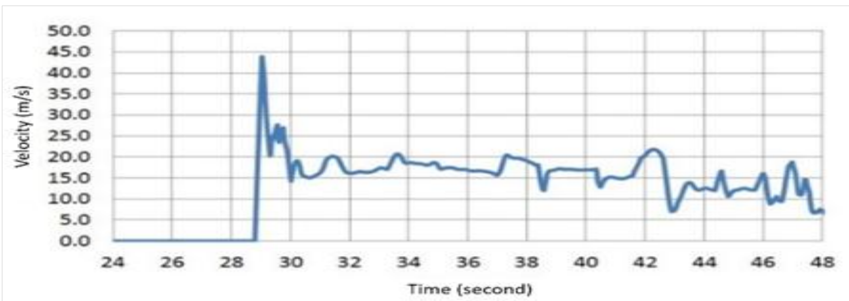


Figure 8 Graph of velocity

Figure 9 DPA and lava flow based on Semeru eruption (December 6, 2021)

The evacuation route to the shelter does not exceed a predefined distance of 792 m. The paths used consist of local and environmental roads, with varying road surfaces from asphalt to macadam pavements. The width of the road for this evacuation route is 4 m. The evacuation routes available in the four villages are the existing roads (*Figure 10*). However, it is necessary to repair damaged or perforated road conditions, widen the roads, and add new roads to facilitate evacuating disaster victims to the shelter. Regular road maintenance should also be conducted on the roads designated as evacuation routes to ensure they remain in good condition. *Figure 9* displays the results of mapping the Semeru Volcano disaster evacuation route. According to *Figures 3, 8, 9*, and *Table 2*, several factors influenced the selection of potential shelters in the study location. This included considering shelters not located in the path of the lava flow. Shelters numbered 10 to 17 are within the lava flow zone, although the weighting results indicate that sekolah menengah pertama Negeri (SMPN 2) Pronojiwo and Masjid Jami An-Nur fall into the suitable category for use. *Table 2* further reveals that four shelters are classified as the most appropriate due to building conditions, location, and spacious field area.

The research has limitations, including the choice of two dimensional (2D) numerical simulation software. A more comprehensive approach would involve using CADMAS Surf 3D to account for parameters across all three axes, x, y, and z, rather than only the x and z axes. Employing 3D numerical simulations would provide a more precise representation of fluid dispersion, assuming they are eruption materials. Another limitation is the post-eruption abandonment of most affected areas. Consequently, shelters in the research location are no longer usable, as the population has relocated from the lahar flow zones to safer areas in anticipation of another Mount Semeru eruption. Future studies should encompass broader locations, considering that the eruption of Mount Semeru coincided with heavy rainfall, leading to an expansion of affected areas. This expansion resulted from the eruption materials mixing with a substantial volume of rainwater, surpassing the delineations in the spatial analysis displayed on the computer screen.

A complete list of abbreviations is shown in *Appendix I.*

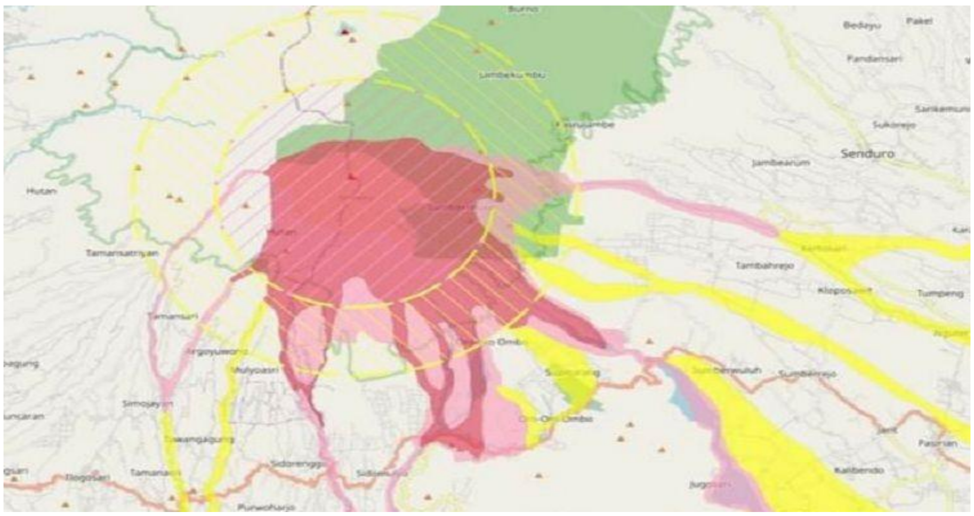


Figure 10 DPA based on computer analysis

Table 2 Weighting result of potential shelters

S. No.	Name of Potential Shelter	Distance	Level	Construction	Vulnerable	Build Area	Ground	Score
1	SDN Pronojiwo 1	5.00	2.00	5.00	5.00	4.00	5.00	26.00
2	TK PGRI Pronojiwo	5.00	2.00	4.00	5.00	2.00	2.00	20.00
3	SMP Islam Pronojiwo	5.00	2.00	4.00	5.00	3.00	2.00	21.00
4	MI Nurul Islam Pronojiwo	5.00	2.00	2.00	5.00	3.00	2.00	19.00
5	SMPN 1 Pronojiwo	5.00	2.00	5.00	5.00	4.00	4.00	25.00
6	Yayasan Hidayatullah Mubtaddin	4.00	2.00	5.00	5.00	4.00	5.00	25.00
7	SDN Pronojiwo 3	4.00	2.00	3.00	5.00	5.00	5.00	24.00
8	SMAN 1 Pronojiwo	3.00	2.00	5.00	5.00	4.00	5.00	24.00
9	PAUD KB Kenanga	2.00	2.00	2.00	5.00	4.00	2.00	17.00
10	SDN Pronojiwo 2	2.00	2.00	2.00	5.00	3.00	4.00	18.00
11	Madrasah Ibtidaiyah Nurul Islam	3.00	2.00	3.00	1.00	2.00	2.00	13.00
12	Madrasah Diniyah Nurul Islam	5.00	2.00	3.00	1.00	2.00	2.00	15.00
13	SMPN 2 Pronojiwo	5.00	2.00	4.00	1.00	2.00	4.00	18.00
14	SMP Nusantara	2.00	2.00	3.00	1.00	2.00	3.00	13.00
15	SDN Supiturang 01	2.00	2.00	2.00	1.00	2.00	2.00	11.00
16	MTs Miftahul Ulum	2.00	2.00	2.00	1.00	2.00	2.00	11.00
17	Masjid Jami An Nur	2.00	2.00	2.00	5.00	3.00	4.00	18.00
18	Masjid Besar Baiturrohman	5.00	5.00	4.00	5.00	3.00	4.00	26.00
19	Masjid Al-Hidayah	4.00	5.00	4.00	5.00	3.00	4.00	25.00
20	MTs Al Futuhiyah	2.00	2.00	2.00	3.00	3.00	1.00	13.00
			6-15		16-24		25-30	
			Not used		Good Place		Best Place	

5.Conclusion

The shelter plan for potential eruptions of Semeru Volcano in Pronojiwo Sub-District comprises educational facilities, worship facilities, and various land uses, including plantation moor, rice fields, and fields. Each village has a different number of shelters: Pronojiwo Village has six units, Taman Ayu Village has two units, Sumber Urip Village has 1 unit, Oro-oro Ombo Village has 1 unit, and Supit Urang Village has two units. The evacuation route to the shelters does not exceed a predetermined distance of 792 m.

The routes follow local and environmental roads, featuring asphalt to macadam pavements. The road's width for the evacuation route is 4 m. Numerical simulations indicate a sliding speed of volcanic material at 20 m/sec, equivalent to 76 km/hour, with inundation heights of up to 3 meters. Thus, immediate evacuation is necessary upon signs of a volcanic eruption.

Future research concerning Semeru-affected areas and disaster mitigation efforts should incorporate local wisdom variables, especially in determining evacuation routes and temporary shelters. This is crucial as the study of local wisdom and culture is significant, particularly for traditional communities around Mount Semeru.

Acknowledgment

The author expresses gratitude to the Department of Urban and Regional Planning, Brawijaya University, and the Research and Community Service of Brawijaya University, Indonesia, for providing funding for this research through the associate professors' program. Special acknowledgment is given to Professor Keisuke Murakami from Miyazaki University, who contributed to the field survey at the research site through the Japan Student Services Organization (JASSO) program.

Conflicts of interest

The authors have no conflicts of interest to declare.

Author's contribution statement

Fadly Usman: Investigation, paper collection, prepared original draft, data collection, conceptualization, result interpretation, analysis of collected papers and study conception. **Keisuke Murakami and Eddi Basuki Kurniawan:** Design, supervision, investigated limitations of study and manuscript preparation.

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Appendix I

S. No.	Abbveviation	Description
1	2D	Two Dimensional
2	3D	Three Dimensional
3	ρ	Fluid Dencity
4	v	Molecular Kinematic Viscosity and Kinematic Eddy Viscosity
5	γ	Porocity of Obstacle Material
6	x, z, t	Cell Numerically in Axis and Time
7	D	Coefficients for the Sponge Layer
8	R	Resistance Components Due to Porosity
9	g	Acceleration Due to Gravity
10	λ	Difference of Fluid Parameter
11	CADMAS Surf 2D	Numerical Wave Flume
12	DEM	Digital Elevation Model
13	DPA	Disaster-Prone Area
14	GIS	Geographic Information System
15	PVMBG	Pusat Vulkanologi dan Mitigasi Bencana Geologi in Indonesia (Centre for Volcanology and Mitigation of Geological Hazard – In English)
16	SMP	Sekolah Menengah Pertama
17	SMPN 2	Sekolah Menengah Pertama Negeri