The effect of sediment density parameter values on the debris flow velocity parameters

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Abstract. Debris flow is a phenomenon where the material from the eruption is carried away by the flow of water due to rain in the upstream area of the river and usually crashes into watersheds around the volcano. The potential for large debris flows can be caused by high rainfall and sediment deposits that occur during debris flows. Rainfall and sediment carried by water flow can affect the volume and velocity of debris flows. A debris flow simulation was carried out to anticipate casualties and damage using SIMLAR V2.1 by modifying rain intensity and the density of sediment carried by the debris flow. Based on the result, we can obtain the results of the velocity, volume, and area affected by the debris flow. The flow velocity values obtained for testing with rainfall intensity of 162 mm with a density of sediment 1370 kg/m3, 2340 kg/m^3, 2635 kg/m^3, and 2820 kg/m^3, respectively, were 2.72 m/s, 2.16 m/s, 2.50 m/s, and 2.57 m/s. The volume values with the same intensity and density of sediment are 186,381 m^3, 311,116 m^3, 274,030 m^3, and 294,987 m^3. Based on the test results, it can be concluded that sediment density significantly affects the velocity and volume of the debris flow. Where sediment density is inversely proportional to the flow velocity, the higher the sediment density, the slower the flow velocity, while the volume is directly proportional to the sediment density. The higher the density of the sediment, the higher the volume.

1 Introduction

Indonesia has active volcanoes scattered over almost the whole territory. Several mountains still show activity volcanic in the one last century [1]. The active volcano in Indonesia is 127, but only those monitored 24 hours by PVMBG, totaling 69 volcanoes. Volcanoes are shared into three types based on historical records, namely: the new type A, recorded after 1600 with the number 76 mountains, type B, recorded before 1600 with the number 30 mountains; and type C, which is not recorded in historical records however still showing activity volcanic until now totaling 21 mountains [2]. Based on data from PVMBG, Mount Merapi is included in type B because there are records of eruptions after the year 1600, although there were found tephra cello deposits which indicate the possibility that Mount Merapi erupted in 765-911 AD [3].

The volcanic activity of a volcano can cause primary and secondary disasters. The primary disaster from a volcanic eruption is an eruption and ashfall, which usually co-occur. At the same time, the secondary disaster of volcanic eruptions is cold debris flow [4]. Sleman Regency is one of the natural disaster-prone areas, one of which is caused by debris flows from the eruption of Mount Merapi. In 2010, the eruption of Mount Merapi caused damage to several buildings, residential areas, and existing infrastructure [5].

An example of a secondary disaster impact is the post-eruption of Mount Merapi in 2010 which access to Magelang-Yogyakarta St. cannot be passed because it is covered with volcanic material in the form of stones, gravel, and sand due to the brunt of cold debris flows from the Putih River, Magelang Regency, Central Java [6]. Debris flow occurs when material from the eruption is carried away by water flow due to rain in the upstream area of the river. This material then passes through rivers and is carried downstream, becoming sediment [7].

Debris flows that occurred on Mount Merapi in 2010 had a high frequency. At that time, there was also heavy rain. The potential for large enough debris flows can be caused by high rainfall and sediment deposits that occur during debris flows [8]. Rainfall and sediment carried by the flow of water can affect the volume and velocity of debris flows [9]. The sediment transport rate that occurs is influenced by the grain size and weight of the carried sediment particles [10]. The existing sediment's specific gravity is needed to determine the particle weight. During the eruption of Mount Merapi in 2010, the specific gravity of the deposit was 2 – 2.5 gr/cc. This particular gravity is found in the lava production zone,

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which is where rain falls as a trigger for debris flows [11].

A sabo building was built to anticipate debris flow disasters. The sabo building, also known as sabo technology, was built as a control for lava deposits [12]. Volcanic deposits can be soil, sand, stone, and others [13]. Sabo comes from the Japanese, 砂防 / sabō, which means controlling earth, sand, or other natural activities. While Dam is a building that functions as a flood controller with the concept of catch, contain, and release, the flood surge is managed, consolidated, and stabilized in more detail. Dams can be multi-story buildings, series, and single [13]. This building is expected to reduce the risk of debris flows.

A debris flow simulation can be carried out using numerical modeling to anticipate the adverse effects of debris flows. The debris flow simulation was carried out using the SIMLAR V 2.1 application to simulate areas that will be affected by the debris flow [14]. SIMLAR V 2.1 can act as a mesh area (coverage area) in a work program with a size of X: 400 and Y: 2000, in the sense that in the direction of "X" (horizontal) with maximum coverage of 4,000m and in the order of "Y" (vertical) with coverage maximum 20,000m. The latest version is SIMLAR 2.1 and is still being developed [15]. SIMLAR combines input materials such as topography, river morphology, hydrology, and sedimentation [4]. We should make direct observations in the field to check factual flood discharge data and accuracy on topographic maps to minimize the error rate on SIMLAR [16].

2 Method

2.1 Research locations

This research was conducted in the Gendol Watershed (DAS), which is located in Sleman Regency, Special Region of Yogyakarta. The shape of the Gendol River watershed is shown in Fig. 1. This location was chosen because it is vulnerable to the danger of cold debris flowing due to the eruption of Mount Merapi.

2.2 Research data

The first data needed is rain data. Rain greatly influences the occurrence of cold debris flows, and rainwater will flow volcanic material from the mountain slopes to valleys or lower plains, as shown in Fig. 2. The rain data used in the study was obtained from the Yogyakarta SABO Center. The rain station used is one station, namely the Ngandong station which is located at coordinates Latitude 07º35'46.10" (LS) and Longitude 110º24'11.10" (E).

The rainfall data used is from 2015 to 2019. In this study, the maximum duration of rain used was 3 hours. The rain date is automatically analyzed by SIMLAR V 2.1 and becomes the Nakayasu Synthetic Unit Hydrograph (HSS). Synthetic Unit Hydrograph is an analysis method of immeasurable flood discharge in planning water resources in a watershed (DAS), with the calculation components, namely the area of the watershed, the length of the river, and land use [18]. Fig. 3 is an example of Nakayasu's HSS on SIMLAR V 2.1.

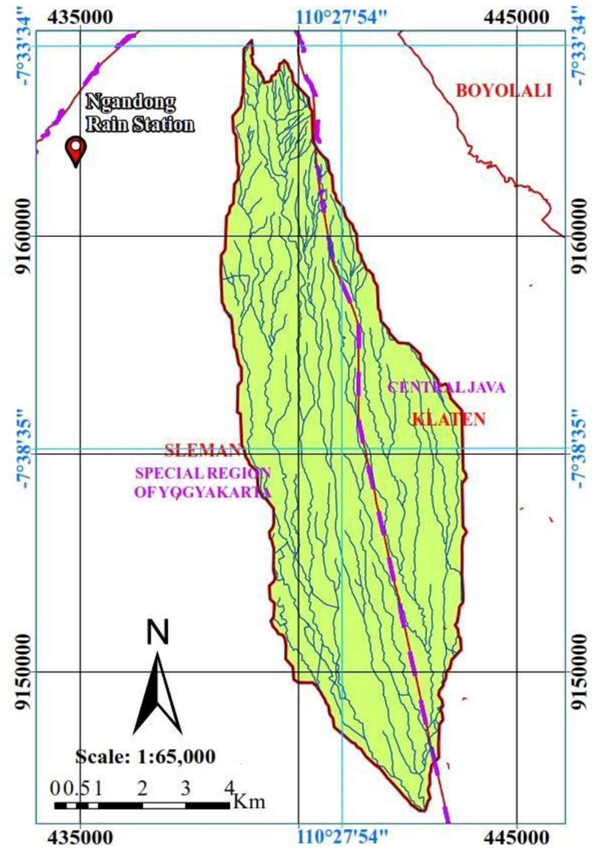

Fig. 1. The location of the Gendol River watershed.

Furthermore, the second data that must be inputted is the DEM map. DEM maps are used as topographical data. DEM itself stands for Digital Elevation Model. DEM data represents the surface and elevation from the earth's surface [19]. In addition, DEM also plays an essential role in disaster analysis, hydrology, agriculture, and other fields. For DEM data needs in Indonesia, the Geospatial Information Agency (BIG) has provided the National DEM (DEMNAS) [20]. The DEM map resolution is recommended to be less than ten m². If the resolution number is small, the simulation results' accuracy will also be high or good [15]. The Gendol River DAS DEM map is shown in Fig. 4.

The following data used is the sediment sample data. The sediments in this study were taken at 9 points in the Gendol River flow. At each point, three sides are taken: the right, left, and center. As input for the simulation, Sabo data is also needed. Location data and dimensions of the existing Sabo dam were obtained from the Sabo Center, Yogyakarta. The display of the Sabo dam data can be seen in Table 1.

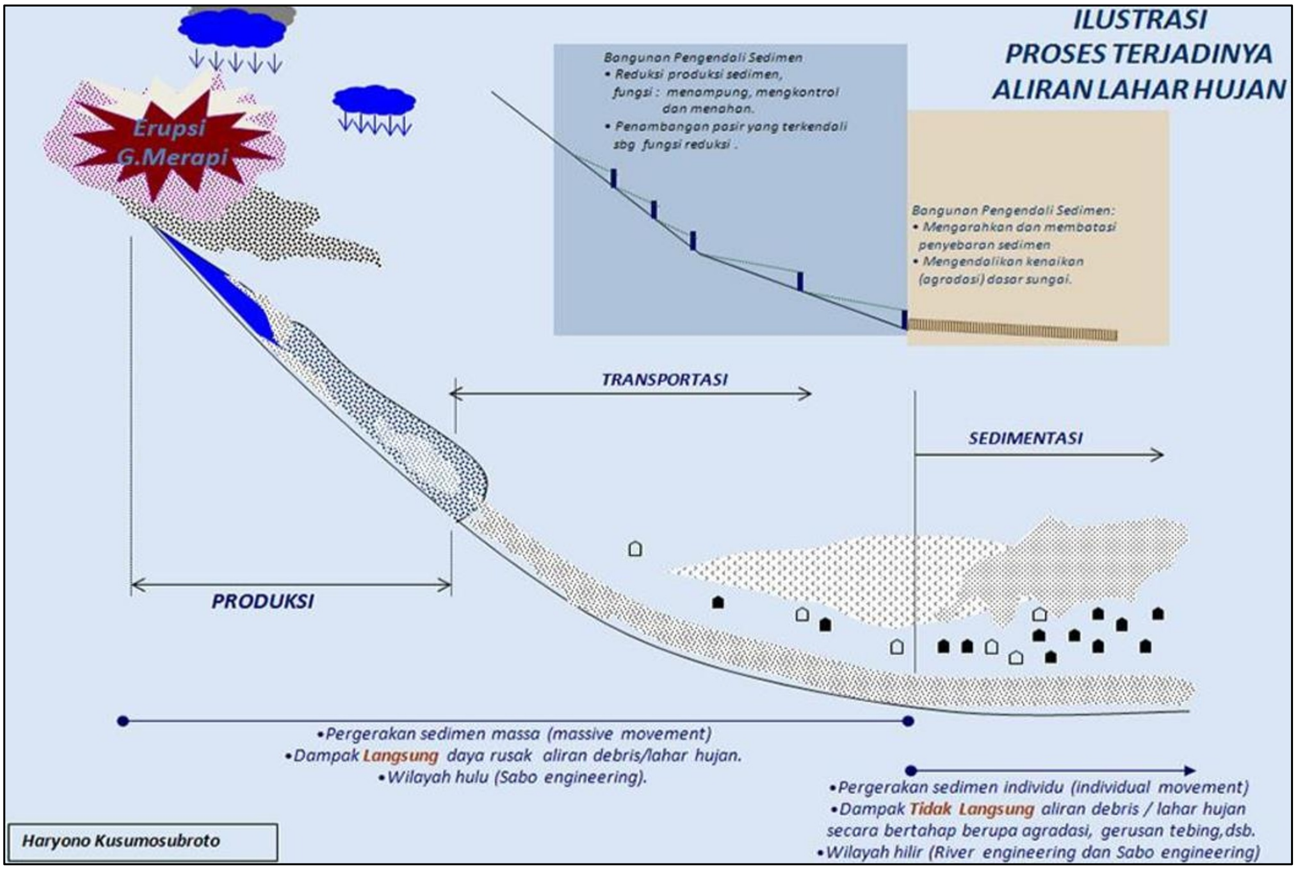

Fig. 2. The process occurs lava flood [17].

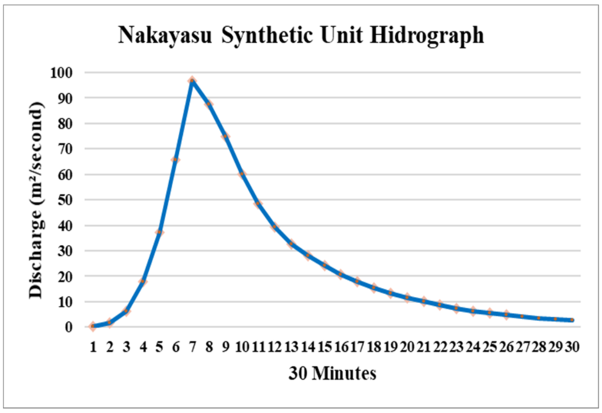

Fig. 3. HSS Nakayasu on SIMLAR V2.1.

2.3 Research Stages

2.3.1 Sampling

The sediments in this study were taken at 9 points in the Gendol River flow. Each issue is taken on three sides: the right, left, and center. Sediment sampling points are shown in Fig. 5, and the conditions at the sampling locations are shown in Fig. 6.

2.3.2 Sample testing

Testing samples taken from the field were carried out at the Universitas Muhammadiyah Yogyakarta Laboratory. Tests were carried out to obtain the value of the sediment density parameter. From the results of the tests that have been carried out, the lowest specific gravity value is 2340 kg/m^3, the highest is 2820 kg/m^3, and the average is 2635 kg/m^3. Table 2 shows the soil-specific gravity values.

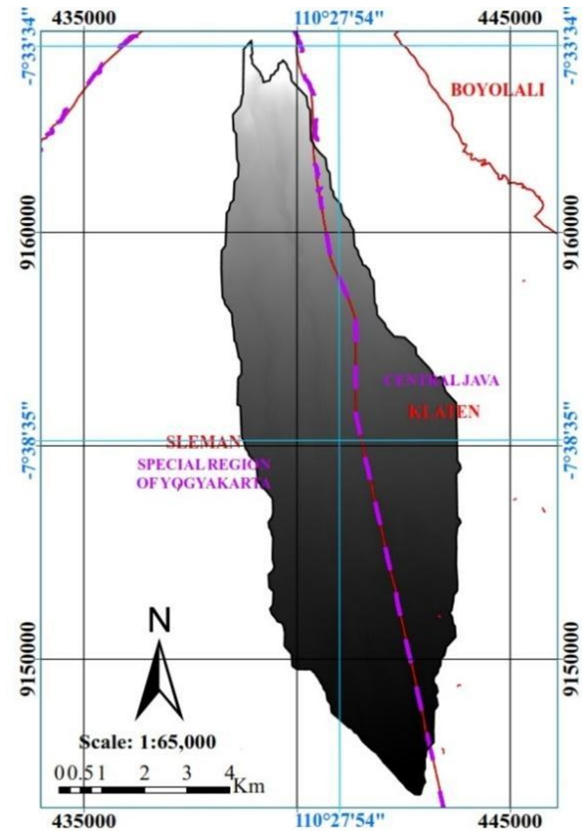

Fig. 4. The DEM of the Gendol River watershed.

Table 1. Sabo dam coordinate data.

Sabo's name	Coordinate (UTM)	
	X	Y
GE-D5 (Kaliadem)	440104	9158813
GE-D3 (Kopeng)	440410	9157653
GE-D2 (Kopeng)	440469	9157122
GE-D (Kepuharjo)	440484	9156806
GE-C13 (Ngancar)	440612	9155288
GE-C12 (Ngancar)	440805	9154517
GE-C10 (Bakalan)	440842	9153666
GE-C (Cangkringan I)	440926	9152969
GE-C (Bronggang)	440963	9152808
GE-C (Jetis I)	441169	9152099
GE-C (Plumbon I)	441507	9151194
GE-C7 (Morangan)	441654	9150487
GE-C9 (Kalimanggis)	441672	9150214
GE-C (Jambon)	441980	9149380
GE-C (Jerukan)	442057	9149108
GE-C (Rogobangsan)	442453	9147930
GE-C0 (Tulung)	442988	9145067

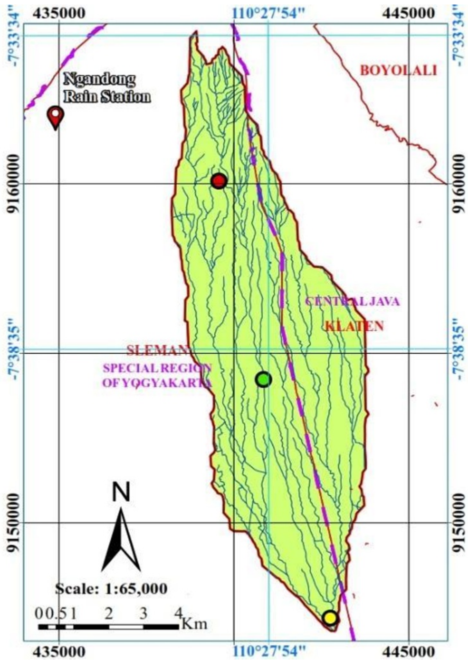

Fig. 5. Sediment sampling point.

Fig. 6. Sediment sampling location.

Table 2. Specific gravity and modified soil density.

Type Land	Specific Gravity (Gs)	Density (kg /m^3)
Gravel	2.65 – 2.68	2650 – 2680
Sand	2.65 – 2.68	2650 – 2680
Silt inorganic	2.62 – 2.68	2620 – 2680
Clay organic	2.58 – 2.65	2580 – 2650
Clay inorganic	2.68 – 2.75	2680 – 2750
Humus	1.37	1370
Peat	1.25 – 1.80	1250 – 1800

2.3.3 *Modelling simulation*

The SIMLAR calculated analysis of flood discharge to obtain flood hydrograph data in this research. The data needed to calculate SIMLAR is the watershed area, river length, and rainfall time. The simulation is carried out along 18.75 km according to the river's size on the watershed map.

The simulation begins by creating a new project in SIMLAR and then entering the hyetograph and hydrograph data. After that, input the DEM map, the boundaries of the simulation area, and other parameters that will be used. Sabo modeling is done by modifying the DEM map where the location of the sabo point needs to be raised in elevation to match the height of the sabo

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dam. Then, the movable bed thickness of the canal was changed to 0. This setting is helpful so that the sabo dam area cannot be degraded. In this study, several simulation scenarios were carried out, namely:

- Scenario 1: Density 1370 kg/m^3 based on the reference density.
- Scenario 2: Density 2340 kg/m^3 based on the lowest field density.
- Scenario 3: Density 2635 kg/m^3 based field average density.
- Scenario 4: Density 2820 kg/m^3 based on the highest density field.

2.3.4 Results Analysis Output

After the program simulation process is complete, the resulting output must be processed to get the required results. In this test, the necessary consequences are the flood's area, height, velocity, and volume. Data processing was carried out using the ArcGIS 10.4.1 application.

3 Results

Based on the research that has been done, the values for velocity, volume, area, and height are obtained.

3.1 Velocity

The maximum velocity values obtained from the simulation of each pattern are shown in Table 3, and a comparison of the velocity values obtained from the simulations carried out is shown in Fig. 7.

Table 3. Maximum velocity.

Simulation	Volume (m^3)	Increase (%)
Scenario 1	2.72	0
Scenario 2	2.16	- 20.5
Scenario 3	2.50	- 8
Scenario 4	2.56	- 5.9

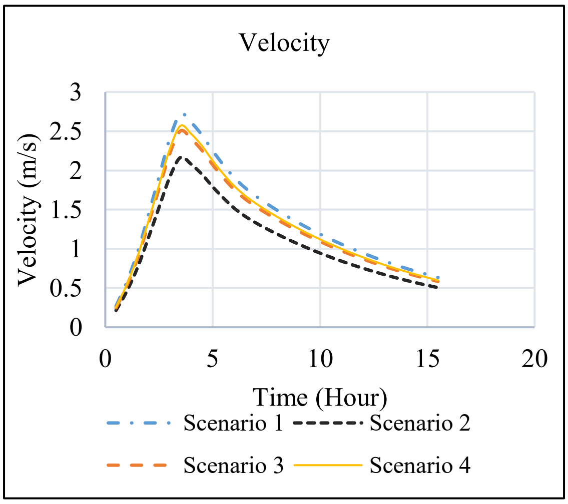

Fig. 7. Comparison of debris flow velocity.

Based on the results above, the specific gravity of the sediment and the hyetograph pattern influence the velocity value. The higher the density, the lower the velocity.

3.2 Volume

The maximum volume obtained from the simulation is shown in Table 4, and the maximum volume value obtained from the simulation that has been carried out is shown in Fig. 8.

Table 4. Maximum volume values.

Simulation	Volume (m3)	Increase (%)
Scenario 1	186.381	0
Scenario 2	311.116	66.9
Scenario 3	274.030	47
Scenario 4	294.987	58.3

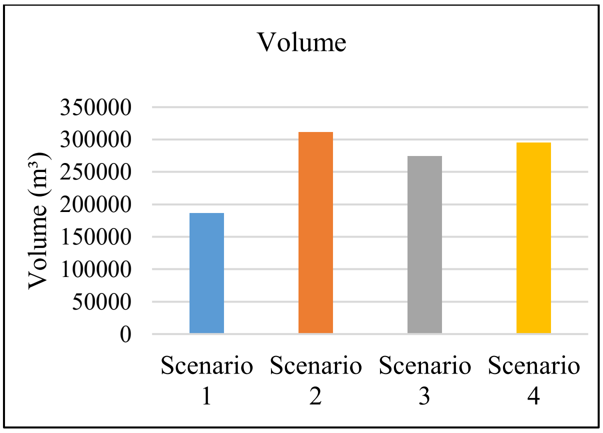

Fig. 8. Comparison of the volume of debris flows.

From the results of the volume analysis, it can be concluded that the volume is directly proportional to the value of the specific gravity of the sediment. The volume value will increase if the specific gravity of the deposit is enormous. This result is also in line with research [21].

3.3 Distribution area of debris flows

The results of the comparison of area values obtained at 15.5 hours or the last hour are shown in Fig. 9.

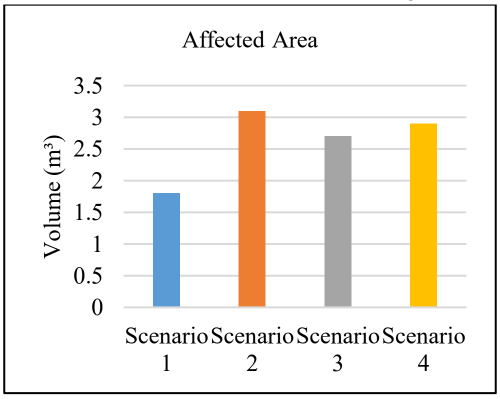

Fig. 9. Comparison of area values.

The value of the debris flow area for each pattern at the last hour is shown in Table 5.

Table 5. The area of the affected debris flow.

Simulation	Area (km^2)	Increase (%)
Scenario 1	2.27	0
Scenario 2	3.31	45.8
Scenario 3	3.00	32.2
Scenario 4	3.11	37

From the analysis of the affected area, it can be concluded that the affected area is directly proportional to the value of the specific gravity of the sediment, where the higher the specific gravity, the higher the volume and affected area. The distribution area results for all scenarios are shown in Fig. 10-13. The red color in Fig. 10-13 indicates the villages impacted by debris flows in scenario 1, 2, 3 and 4, respectively. The result shows that the list of villages is the same, but the affected area is different as shown in Table 5. The result in Table 5 shows that correlation between a specific gravity value and affected area is no clear pattern. However, if the value is bigger, the affected area tends to increase. The list of villages affected by the debris flow is shown in Table 7.

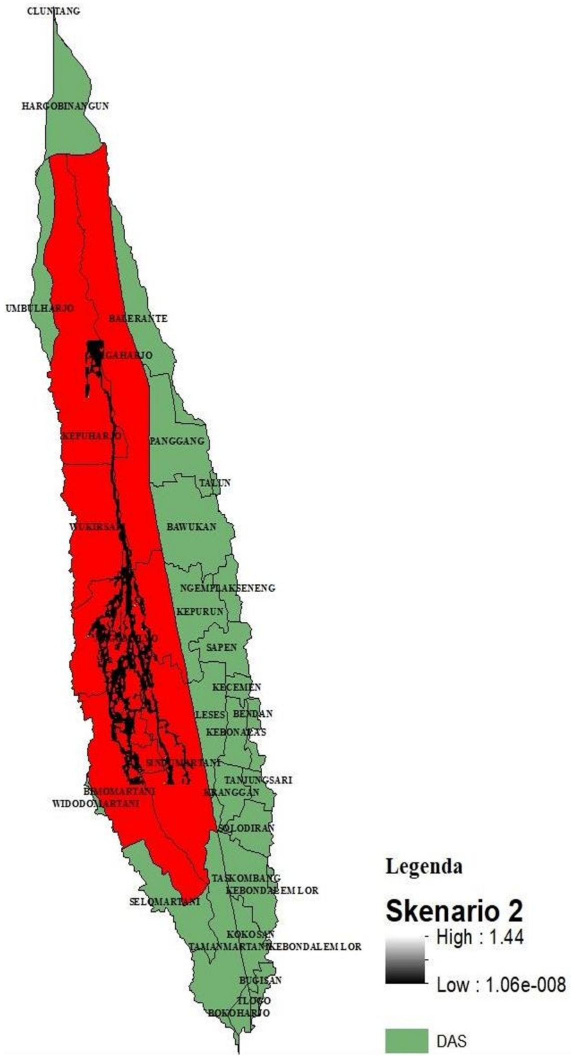

Fig. 10. Villages affected by scenario 1 debris flows.

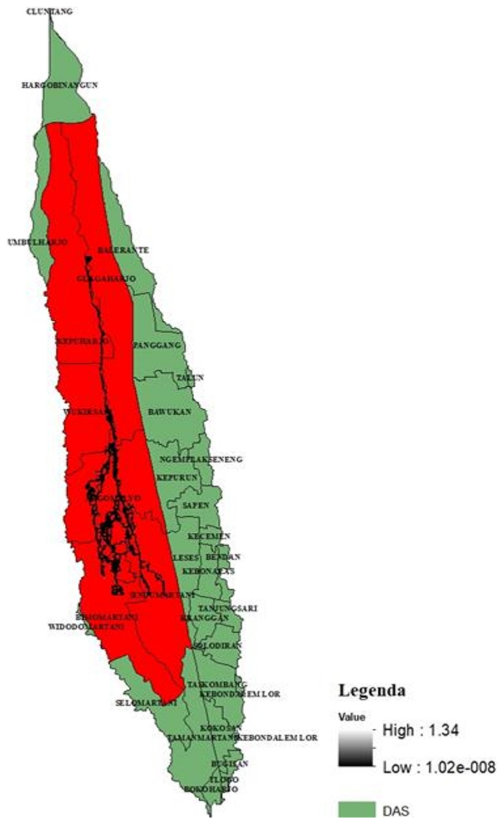

Fig. 11. Villages affected by scenario 2 debris flows.

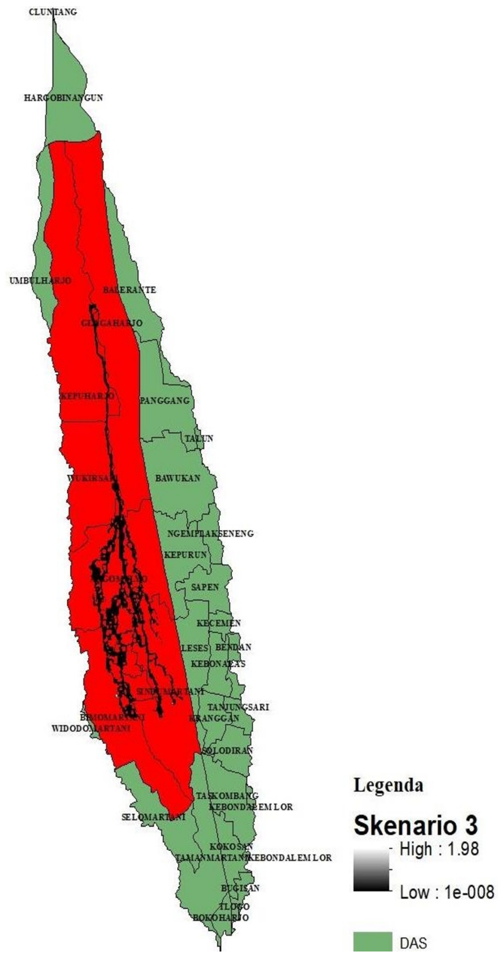

Fig. 12. Villages affected by scenario 3 debris flows.

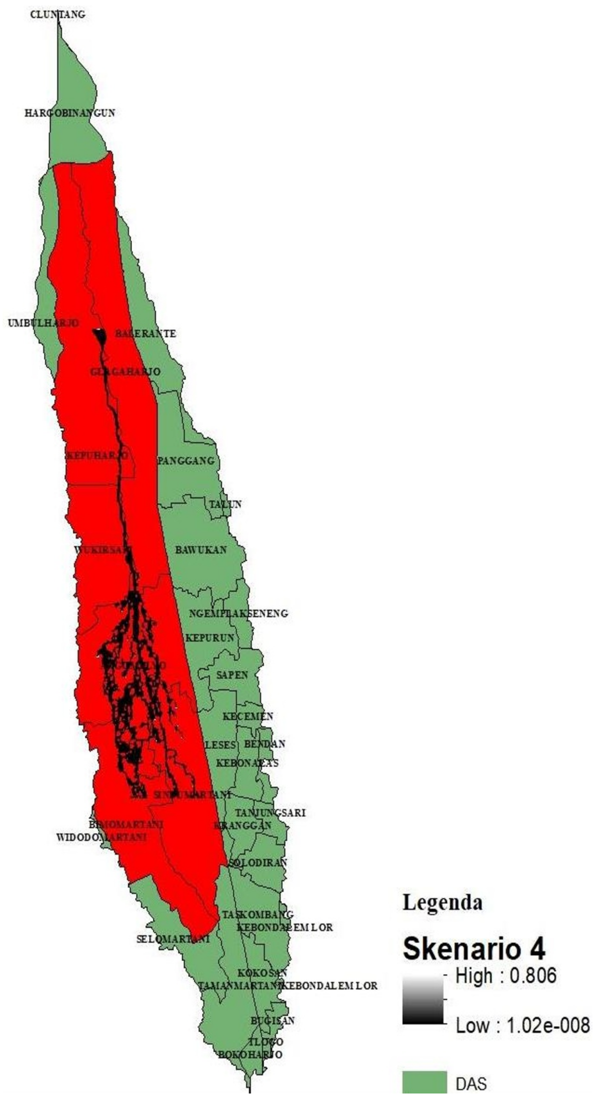

Fig. 13. Villages affected by scenario 4 debris flows.

3.4 Debris flow Height

The high value of the debris flow was obtained from the maximum or peak velocity-time, which was 3.5 hours from the start of the simulation. Based on the simulation results, the dominant height for debris flows is 0.0 m – 0.5 m. The maximum flood height values for scenario 1, scenario 2, scenario 3, and scenario 4, respectively, are 3.2 m in Sindumartani Village, 1.93 m in Argomulyo Village, 1.98 m in Argomulyo Village, and 3.18 m in Argomulyo Village and Sindumartani Village. A comparison of the high values of debris flows is shown in Fig. 14.

The maximum debris flow height values obtained from the simulation are shown in Table 6.

Based on the simulation results that have been carried out, the maximum height of the debris flow is obtained, as shown in the graph above. In each simulation, the dominant size of the debris flow is at a value of 0.0 m – 0.5 m.

Fig. 15-18 show the villages affected by the debris flow.

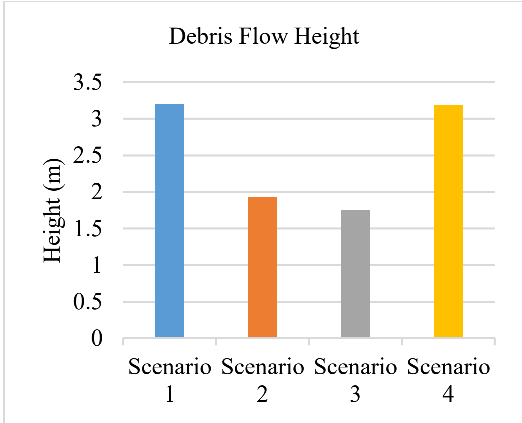

Fig. 14. Comparison of debris flow height.

Table 6. Maximum flood height.

Simulation	Flood height (m)
Scenario 1	3.2
Scenario 2	1.93
Scenario 3	1.98
Scenario 4	3.18

Table 7. List of villages affected by cold debris flows.

Village Affected by Debris flow
Argomulyo
Binomartani
Glagaharjo
Kepuharjo
Sindumartani
Wukirsari

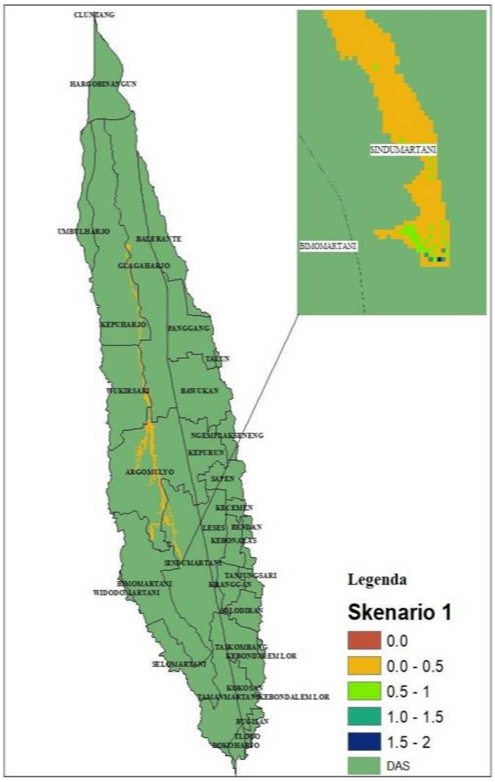

Fig. 15. Debris flow height scenario 1.

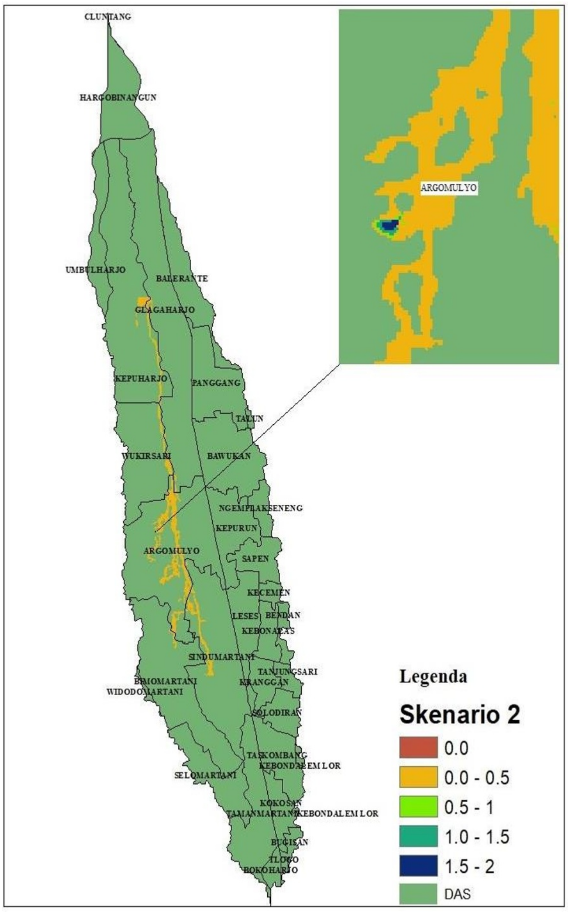

Fig. 16. Debris flow height scenario 2.

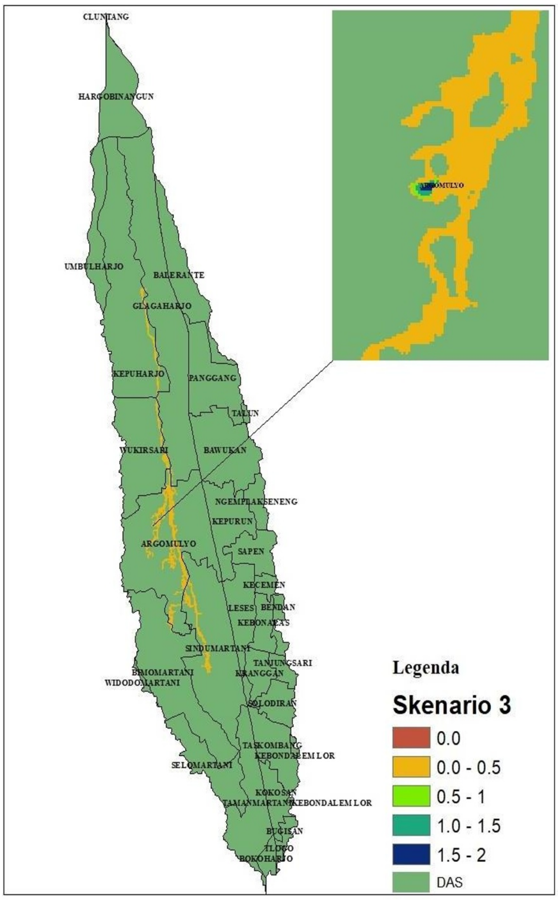

Fig. 17. Debris flow height scenario 3.

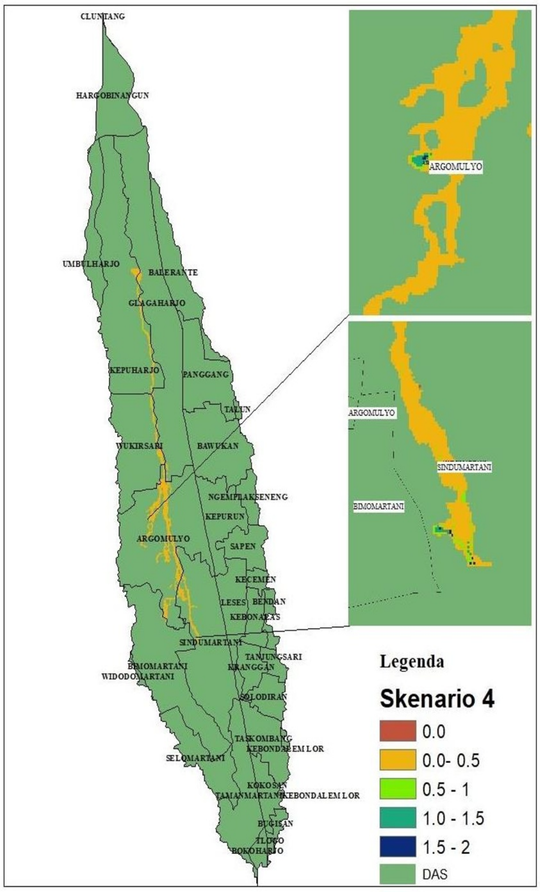

Fig. 18. Debris flow height scenario 4.

4 Conclusion

Based on the research results regarding the effect of the sediment density parameter values on the debris flow velocity parameters in the Gendol River using the SIMLAR application, several conclusions can be drawn as follows:

- Based on the results of the velocity analysis, it can be concluded that the velocity value follows the synthetic unit hydrograph pattern where the peak velocity occurs at 3.5 hours from the start of the simulation, and the velocity value is inversely proportional to the sediment density value. The higher the sediment density value, the lower the velocity value.
- Based on the results, volume and area analysis could conclude that volume and area values impacted compared straight with score mass type sediment. The higher the value of mass sediment, the more height is also the value of volume and area affected.

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