Physical vulnerability assessment of settlements in lahar hazard prone areas along the river originated from Merapi Volcano

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Abstract: Merapi Vulcano is one of the most active volcanoes in the world. This volcano has a secondary hazard that is lahar flow. This research refers to the 2010 eruption of Merapi Vulcano in Indonesia. Eventhough there was a phreatic eruption in 2018, it did not increase the deposition of lahar material on its slopes. The communities living along the lahar prone rivers have various vulnerabilities including physical, social, economic and environmental vulnerability. This research aims to determine the physical vulnerability distribution of settlement in lahar hazard prone areas alongside Pabelan River. This study is a descriptive quantitative research using secondary data and spatial analysis. The results of this research show that the high vulnerability distribution covers the area of Mungkid Sub-district and Sawangan Sub-district as many as 5 clusters or equal to 7.49% of the research area. The medium level of physical vulnerability is Dukun Sub-district, Mungkid Sub-district and Muntilan Sub-district as many as 26 clusters or equal to 41.27% of the research area. The low physical vulnerability of settlements is scattered in Dukun Sub-district, Mungkid Sub-district, Muntilan Sub-district and Sawangan Sub-district as much as 32 clusters or equal to 50.79% of the research area. It can be concluded that the physical vulnerability of settlements in lahar hazard prone along the Pabelan river after the 2010 eruption of Merapi Vulcano is dominated by low vulnerability.

Keywords: physical vulnerability, lahar, Merapi Vulcano

1. Introduction
The events of post-volcano eruption in the form of lahar hazards caused various damages including properties, buildings and even fatalities. Therefore, lahar flow can be categorized as a disaster according to Law of the Republic of Indonesia Number 24 of 2007. This research refers to the 2010 eruption of Merapi Vulcano in Indonesia. Eventhough there was a phreatic eruption in 2018, it did not increase the deposition of lahar material on its slopes. Lahar flow once damaged 19 Sabo Dam which 3 of those were completely destroyed, more than 307 houses damaged and even the flow caused the need to closed down a national road access for 18 times in the span of 25 days [1]. Lahar flows consist mixture of water (can be rainwater or melted snow), sand, gravel and even massive rocks. They move in a rapid motion down the slopes while sweeping away all the things they pass through [2].

History once recorded that lahar coming from the eruption of Merapi Vulcano destroyed the hydrography system near Borobudur basin and created at least six paleolake in the last 119,000 year
There are 12 rivers originated from Merapi Vulcano which becomes streams vulnerable to lahar [4]. One of those rivers is Pabelan River in which this river cut across highly populated settlements in Magelang District. Pabelan River crosses 4 Sub-districts in Magelang District including Mungkid Sub-district, Muntilan Sub-district, Dukun Sub-district and Sawangan Sub-district. The level of population density in the areas along the lahar prone river is quite high. The data can be seen in Table 1.

Table 1. Population density in each Sub-district directly bordering with Pabelan River in Magelang District

| Sub-district Name | Total of Population (resident) | Sub-district Area (Km²) | Population Density (resident/ Km²) |
|-------------------|--------------------------------|-------------------------|-----------------------------------|
| Dukun             | 46,900                         | 53.41                   | 878                               |
| Mungkid           | 74,295                         | 37.95                   | 1,958                             |
| Muntilan          | 79.136                         | 28.61                   | 2,766                             |
| Sawangan          | 57.287                         | 72.37                   | 791                               |

Source: [19], [20], [21], [22]

Based on Table 1, it can be concluded that the densest population is Muntilan Sub-district with the level of density 2,766 residents per Km², and the lowest population density is Sawangan Sub-district. This numbers, if based on the classification of SNI 03-1733-2004 about area classification, is still categorized as low density (less than 15,000 residents per km²) but the varied characteristic of settlement distribution can increase the level of vulnerability especially physical vulnerability of buildings. According to Ikhsan [16], in the period between 2012 and 2015, in the headwater of Pabelan River there is an increased erosion of the riverbed which reached 30 – 45 meter in depth and lessen in the downstream to a depth of around 5 meter. This means that Pabelan River experiences normalization post mining of material deposit from lahar flow in 2010 – 2011.

The aim of this research is to determine the distribution of physical vulnerability of settlements in the lahar prone area alongside the Pabelan River. Many researches study the analysis of disaster risk of volcano eruption but there are not many research specifically discuss the vulnerability from disasters caused by lahar flow. The level and distribution of physical vulnerability of settlements along the Pabelan river is not yet known, so this research can increase the level of capacity of both the local community and also for the local government. It is expected that through a map of settlement vulnerability in this research there will be an awareness enhancement of the people who live alongside the rivers vulnerable to lahar. It can also be used by the local government regarding the policy of relocating settlements with high risk in the lahar prone areas alongside the Pabelan River. Taking into consideration that Merapi Vulcano is highly active, the results of this study can be used as one of considerations for the government to plan disaster management in increasing resilience and as a strategy in lowering disaster risk in order to achieve the goal of sustainable development.

2. Literature Review

The hazard from post-eruption activities of Merapi Vulcano is the lahar flow. One of the rivers that is most at risk to lahar flow are Pabelan River, Gendol River, Krasak River, Boyong River and Kali Putih River [4]. According to UN-ISDR (www.unisdr.org), hazard is a dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage. Rivers in the slope of Merapi Vulcano which become the streams vulnerable to lahar cut across farm fields, settlements and even schools which make those areas to be highly vulnerable to lahar flow. The enhancement of settlement vulnerability in the area near Merapi slope is caused by the shift of demography and land use in Merapi Vulcano especially in the mount ring plain [5]. The changes in terms of social-economy, lahar frequency, and the size of lahar-affected area are the impact caused by lahar flow; furthermore, the spatial expansion from natural hazards has a direct influence to vulnerability pattern [6].

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There is a need to shift the paradigm from quantification and hazard analysis to identification, assessment and level of vulnerability in disaster risk management where the challenge of the complexity in measuring vulnerability quantification will always exist [7]. Physical vulnerability against a certain hazard can be induced by other hazard and in this case a lahar hazard triggered by volcano eruption and the lack of available data can increase the number of uncertainty involved in vulnerability assessment [6]. Observations on rainfall are needed in order to create an early warning for lahar flow from Merapi Volcano [8], [9]. Tiltmeter and extensometer can also be used to predict the weight of the stored debris alongside the river segments by real time and the concept of debris flow potential can help someone to evaluate the possibilities of debris flow during the volcano eruption [9] [18].

Disaster vulnerability is dynamic including physical, social, economic or environment vulnerability because vulnerability depends on the process, total number, disaster location and also the damage and consequences emerged [6]. Vulnerability against disasters can be defined as a condition of a community which leads or causes the inability to overcome existing disaster hazards (Regulation of Head of Indonesian National Board for Disaster Management Number 02 of 2012). The indicators used in determining physical vulnerability are measured by settlement density (permanent, semi-permanent and non-permanent), availability of public buildings/facilities and availability of critical facilities. Settlement density is derived from dividing them over built area or village area and divided by area (in ha) times the price of each unit from each parameter. Physical vulnerability index is obtained from the average of the weight of settlement density (permanent, semi-permanent and non-permanent), the availability of public buildings/facilities and the availability of critical facilities. The large and large number of public facilities can increase the level of physical vulnerability, especially public facilities located in settlement areas [17].

**Figure 1.** The Analysis of Physical Vulnerability according to Indonesian National Board for Disaster Management

The most fatal of secondary effect from volcanic activities is the debris flows and mudflows which collectively known as lahar [2]. Merapi Vulcano as one of the most active volcanoes in the world has the disaster potential in the form of pyroclastic and tephra. It was estimated that in the eruption of 2010, it produced more than 100 x 106 m³ volume of pyroclastic debris flowed to lahar prone rivers [10]. The term lahar derived from one of the local languages in Indonesia (Javanese) refers to its emergence extensively in escarpments in wet tropical area [11]. Lahar is produced when a massive amount of volcanic ashes and other tephra saturate with water and become unstable and suddenly flow down the slope [2], [11]. Settlements located near the banks of rivers flowed with lahar have a various
risk and hazard level to lahar but lahar flows tend to be more destructive on the areas alongside the streams [11], [12]. Unlike pyroclastic flows, lahar can happen without any eruption and generally a stream with low temperature [2]. The undecided rainfall intensity causes the difficulty to predict in which river the lahar will flow [4].

Lahar hazards are a result of the impact from the existence of a volcano in which this disaster can happen at the same time or after a short period of time and these events is not a rare thing [6]. The building vulnerability towards lahar flood is different from the building vulnerability towards regular flood. In the event of regular flood, a building of more than 20 years and built from natural materials tend to have higher damage level compared to the one that is built in the last 10 years and was built using materials that are more durable [13]. Debris flows are a combination of smooth sediments and huge rocks that have the consistency of a wet concrete; this flows can move for kilometers down the valleys from the part of the volcano where they were formed [2]. The size and level of the runoff from post-eruption volcano will gradually decrease after the eruption [14].

3. Method
The data collection technique used in this research is a secondary data collection. The data was taken from Citra Quickbird of Magelang District in 2017. The assessment of settlement physical vulnerability in the area alongside the lahar flow path from post-eruption of Merapi Volcano in Pabelan River used the spatial analysis technique which measures the parameter of the distance of houses to the river (buffer), the number of the houses in each cluster and the building materials of the houses. According to Kang [15] who combined the probability of physical damage caused by debris flows and the criteria proposed by HAZUS and then studied the theory to a building damage which was a result of debris flows happened in July and August 2011. The formula that used to analyzed the data is weighting, according to the number of parameter that used and also the impact of each parameter so that the weights has different. The weight, parameter classification and score that used in this research can be seen in Table 2.

| Parameter                  | Weight | Parameter Classification | Score |
|----------------------------|--------|--------------------------|-------|
| The distance to the river  | 40 %   | 100-150 m                | 1     |
|                            |        | 50-100 m                 | 2     |
|                            |        | 0-50 m                   | 3     |
| House                      | 30 %   | < 400 MIO                | 1     |
|                            |        | 400 – 800 MIO            | 2     |
|                            |        | > 800 MIO                | 3     |
| Building material          | 30 %   | Wood                     | 1     |
|                            |        | Brick                    | 2     |
|                            |        | Concrete frame           | 3     |

Based on the Table 2 above, the parameter of the distance to the river has the highest weight because it has the highest influence to a threat of lahar hazards. The parameter of the distance of houses to the river (buffer) are divided into 50 meter, 100 meter and 150 meter; the close a house to the river the higher the settlement physical vulnerability. The method used in determining the vulnerability of a house unit is a classification of the number of houses by the Indonesian National Board for Disaster Management which in an area with a low disaster potential the total of the houses. The parameter of houses used in this study was obtained from totaling the houses in each cluster and then in the area with low disaster risk the number was multiplied by IDR. 5.000,000, in the area with medium disaster risk it was multiplied by IDR. 10.000,000 and in the area with high disaster risk the total number was multiplied by IDR. 15.000,000. The results from the calculation then were used to classify the above parameter. Moreover, for the building materials, there was only 1 building from all 4 Sub-districts built using concrete frame which was crossed by the lahar flow.
According to Kang [15] who combined the probability of physical damage caused by debris flows and the criteria proposed by HAZUS and then studied the theory to a building damage which was a result of debris flows happened in July and August 2011. From this research, it was obtained a building damage scale classified by the materials used to build the building. Wood materials are the most vulnerable, bricks have a medium level of vulnerability when hit by debris flows and steel frames are at lowest vulnerability level. In each parameter was given a score then later to be weight. The results from the analysis were then classified into three which are low, medium and high vulnerability level. The population in this study is the whole settlements in the radius of 0 – 150 meter from Pabelan River including Mungkid Sub-district, Sawangan Sub-district, Dukun Sub-district and Muntilan Sub-district. The flow process of this research can be seen on the Figure 2.

![Flow Chart](image)

**Figure 2. Flow Chart**

4. Results

The results from the spatial analysis and imagery interpretation, it is obtained that in total of 1,419 houses are in the vulnerable areas. The areas prone to lahar hazards are scattered in four Sub-districts. A total of 522 houses are classified in low vulnerability level, a total of 661 houses are in medium vulnerability level and 236 houses have high vulnerability level. The vulnerability assessment starts from the parameter of the distance from the river to the houses using the buffer analysis which is 50 meter, 100 meter and 150 meter on the right and left side along the Pabelan River from the upstream to the downstream which is located in the intersection with Progo River. Furthermore, an overlay was done to the settlement polygon in order to count the number of the houses which overlapped with the results of the river buffer. The results from the calculation then were used to classify the above parameter. Moreover, for the building materials, there was only 1 building from all 4 Sub-districts built using concrete which was crossed by the lahar flow. There were a total of 1,419 houses all around the 63 clusters. The following are the discussion of each parameter of physical vulnerability of settlement buildings along the Pabelan River.
4.1. The Parameter of the Distance to the River

The areas along the riverbank of Pabelan River have different variation of vulnerability from low to high scattered in 63 clusters. The distribution of cluster settlements with the physical vulnerability from low to high can be seen in Table 3.

| Distance to the River | Score | Vulnerability Level | Total of Clusters | Percentage (%) |
|-----------------------|-------|---------------------|-------------------|----------------|
| 100-150 m             | 1     | Low                 | 36                | 57.14          |
| 50-100 m              | 2     | Medium              | 18                | 28.57          |
| 0-50 m                | 3     | High                | 9                 | 14.29          |
| **Total**             | **63**| **100**             |                   |                |

Based on Table 3, it can be seen that most of the housings are less than 100 meter to 150 meter from the riverbank hence the vulnerability classification is dominant in the low level. The total of clusters with the low vulnerability level is 36 clusters or equal to 57.14% from the research area. This finding is in accordance with the settlement pattern of village community in Indonesia which is centered in farm lands where the river function as the source of agriculture irrigation so the settlement are not in the riverbank area. The housing pattern of villages in Jawa Island is different of that in Kalimantan Island. The people living in Kalimantan tend to build their house close to the river since they use the river is a main transportation. Meanwhile, the housing in the riverbank of Pabelan River is an exception since it happened as a consequence of demography dynamic and the rise of need for land. The settlements which are less than or equal 50 meter from the river with a high level of vulnerability are in a total of 9 which equals to 14.29% from research area.

4.2. The Parameter of Housings

The imagery interpretation of the objects interpreted as housings resulted in 1.179 building suspected as houses. The house distribution with physical vulnerability level from low to high can be observed in Table 4.

| House          | Score | Vulnerability Level | Total of Cluster | Percentage (%) |
|----------------|-------|---------------------|-------------------|----------------|
| < Rp 400 mil   | 1     | Low                 | 42                | 66.67          |
| Rp 400 – 800 mil| 2     | Medium              | 14                | 22.22          |
| > 800 mil      | 3     | High                | 7                 | 11.11          |
| **Total**      | **63**| **100**             |                   |                |

Based on the information in Table 4, it can be seen that most of the physical vulnerability of the house buildings are less than 400 million rupiahs in total of 42 clusters or equal 66% of the research area. The physical vulnerability of the house buildings is Rp. 400.000.000 to Rp. 800.000.000 in total of 14 clusters which equals to 22.22% of the research area. The clusters with high level of vulnerability are Rp. 800.000.000 in total of 7 clusters or equal to 11.11% of the research area.

4.3. The Parameter of Building Material

In general, the types of building along the Pabelan River are dominated with the ones which used bricks as the main material. House buildings have the variation of the materials used in building them.
The physical vulnerability of settlement buildings is based on the variation of strength scale of the house building types against the damage caused by lahar flows. The house distribution of varied building construction types can be seen in Table 5.

**Table 5. Types of Building Construction and the Scale of Building Damage**

| Type of Construction | Score | Vulnerability Level | Total of Cluster | Percentage (%) |
|----------------------|-------|---------------------|------------------|----------------|
| Wood                 | 1     | Low                 | 0                | 0              |
| Brick                | 2     | Medium              | 62               | 98.41          |
| Steel Frame          | 3     | High                | 1                | 1.59           |
| **Total**            |       |                     | **63**           | **100**        |

Based on Table 5, it can be concluded that there is 1 cluster which has 1 building constructed using steel frame or equals with 1.58% form the research area. Referring to the above table, most of the buildings are constructed using bricks with the total of 62 clusters or equal to 98.41%. Based on the results and imagery interpretations, there is no house building that uses woods as construction material.

**4.4. The Distribution of Areas with Low Physical Vulnerability of Settlement Buildings in Lahar-Hazards Prone Area**

The areas which have a low level of vulnerability against lahar flows along Pabelan River is varied from the ones with a low level to the highest ones. The settlement area distribution of the low physical vulnerability against the lahar flows in Pabelan River can be seen in Table 6.

**Table 6. The Distribution of Settlement Buildings with Low Physical Vulnerability Level**

| Sub-district | Cluster | Total of House | Vulnerability | Level |
|--------------|---------|----------------|---------------|-------|
| Dukun        | 51      | 20             | 11            | Low   |
| Dukun        | 58      | 3              | 11            | Low   |
| Dukun        | 63      | 1              | 11            | Low   |
| Mungkid      | 2       | 12             | 11            | Low   |
| Mungkid      | 4       | 16             | 11            | Low   |
| Mungkid      | 6       | 30             | 14            | Low   |
| Mungkid      | 8       | 19             | 11            | Low   |
| Mungkid      | 10      | 2              | 11            | Low   |
| Mungkid      | 16      | 28             | 14            | Low   |
| Mungkid      | 19      | 3              | 11            | Low   |
| Mungkid      | 20      | 43             | 14            | Low   |
| Mungkid      | 31      | 5              | 11            | Low   |
| Mungkid      | 33      | 32             | 14            | Low   |
| Muntilan     | 1       | 6              | 11            | Low   |
| Muntilan     | 5       | 2              | 11            | Low   |
| Muntilan     | 11      | 15             | 11            | Low   |
| Muntilan     | 12      | 18             | 11            | Low   |
| Muntilan     | 14      | 7              | 11            | Low   |
| Muntilan     | 23      | 1              | 11            | Low   |
| Muntilan     | 29      | 6              | 11            | Low   |
Based on Table 6, it can be concluded that the areas with low physical vulnerability of settlement buildings have the interval of 11 to 14. The Sub-district with the biggest number of low level settlement physical vulnerability is Sawangan Sub-district with the total of 11 clusters. The Sub-district with the smallest number of low level settlement physical vulnerability is Dukun Sub-district with the total of 3 clusters. Cluster 20 has the greatest number of house in total in which there are 43 house units including the ones classified under low vulnerability level. Sawangan Sub-district has the biggest number of houses in low level vulnerability with the total of 210 houses among all the subdistrict. This phenomenon is caused by the settlement is in lengthways pattern and its distance is more than 100 meter to 150 meter from the riverbank and the material use for the buildings is bricks.

4.5. The Distribution of Areas with Medium Physical Vulnerability of Settlement Buildings in Lahar-Hazards Prone Area

The distribution of areas with settlement physical vulnerability towards medium level lahar flows is mostly from the houses in which the distance classified as medium level vulnerability. However, there are some that come from the distance classified as low and high level vulnerability. The distribution of those with medium level vulnerability can be observed in Table 7.

| Sub-district | Cluster | Total of House | Vulnerability | Level |
|--------------|---------|----------------|---------------|-------|
| Dukun        | 49      | 49             | 5             | Medium|
| Mungkid      | 7       | 3              | 17            | Medium|
| Mungkid      | 9       | 5              | 17            | Medium|
| Mungkid      | 34      | 2              | 17            | Medium|
| Mungkid      | 17      | 17             | 29            | Medium|
| Muntilan     | 3       | 54             | 17            | Medium|
| Muntilan     | 15      | 1              | 17            | Medium|
| Muntilan     | 24      | 1              | 17            | Medium|
| Muntilan     | 26      | 56             | 17            | Medium|
| Muntilan     | 30      | 2              | 17            | Medium|
| Muntilan     | 39      | 4              | 17            | Medium|
| Muntilan     | 44      | 1              | 17            | Medium|

Total 522
Based on Table 7, it can be concluded that the areas with medium physical vulnerability level have the interval from 17 to 20. There are 26 settlement clusters which are included in the medium level. The Sub-district which has the most medium physical vulnerability for settlements is Muntilan Sub-district with 12 clusters. The Sub-district with the least medium level of physical vulnerability is Dukun Sub-district with only 1 cluster. Cluster 2, 26, 35 and 61 are the settlement clusters with the low level of distance vulnerability but the house classification is more than Rp. 800.000.000 hence the scores of the settlement vulnerability become the medium level. Sawangan Sub-district has the biggest number of houses in low level vulnerability with the total of 363 houses among all the subdistrict.

4.6. The Distribution of Areas with High Physical Vulnerability of Settlement Buildings in Lahar-Hazards Prone Area

There are two clusters classified as high physical vulnerability of settlement buildings in lahar-hazards prone area that come from the medium level of distance vulnerability. From the 4 Sub-districts bordering with Pabelan River, the clusters in Dukun Sub-district and Muntilan Sub-district are not classified as high. The cluster distribution with high vulnerability can be seen in Table 8.

Table 8. The Distribution of Settlement Buildings with High Physical Vulnerability Level

| Sub-district | Cluster | Total of House | Vulnerability | Level |
|--------------|---------|----------------|---------------|-------|
| Mungkid      | 21      | 93             | 23            | High  |
| Mungkid      | 18      | 13             | 24            | High  |
| Mungkid      | 22      | 19             | 24            | High  |
| Sawangan     | 36      | 90             | 23            | High  |
| Sawangan     | 37      | 21             | 27            | High  |

Total 236
Based on Table 8, the information we can obtain is that the areas with high physical vulnerability of settlement buildings have the interval from 23 to 27. There are 5 settlement clusters classified as high. The Sub-district with the most number of high physical vulnerability of settlements is Mungkid Sub-district with 3 clusters. The Sub-district with the lowest number of high physical vulnerability of settlements is Sawangan Sub-district with 2 clusters. Cluster 21 and 36 are clusters from low level of distance vulnerability but the house is more than Rp. 800,000,000 so the vulnerability then classified as medium. Cluster 18, 22 and 37 are from the high level of distance vulnerability but classified as houses under Rp. 400,000,000 hence they are classified as high. Mungkid Sub-district has the biggest number of houses in low level vulnerability with the total of 125 houses among all the subdistrict.

The areas with physical vulnerability of settlement buildings in lahar-hazards prone area are scattered all over the research area. Each of the area has various vulnerability scores. The distribution of areas with physical vulnerability is arranged by the level of vulnerability of lahar-hazards prone area around Pabelan River. The vulnerability level of lahar flows is classified into three categories: low, medium and high. The higher the level of physical vulnerability the higher the chance to experience loss caused by lahar flows. That chance can be light damage, medium damage and severe damage and even completely collapse. The level of settlement physical vulnerability alongside Pabelan River from the lowest to the highest can be observed in Table 9.

| Vulnerability Level | Total of Vulnerable House | Vulnerability Percentage (%) |
|---------------------|---------------------------|------------------------------|
| Low                 | 522                       | 36.79                        |
| Medium              | 661                       | 46.58                        |
| High                | 236                       | 16.63                        |
| Total               | 1.419                     | 100                          |

Based on Table 9, it was found that the settlement buildings alongside Pabelan River are dominated by those with medium vulnerability level which is 1 total of 46.58% of all the areas. The high vulnerability levels are distributed in most of the research area. Sawangan and Mungkid Subdistrict had all of the variation risk level. The distribution of physical vulnerability level of lahar-hazards prone along Pabelan River can be observed in the Figure 3. In the figure 3a we can observe the cluster 1 until 6 which dominated by low vulnerability cluster in Mungkid and Muntilan Subdistrict. Cluster 8-16 shown in Figure 3b that varied form low until high vulnerability. Cluster number 11 in Muntilan Subdistrict has a part or cluster that located near by the river, but in moderate vulnerability because of the low number of house and the material used for the building. From the Figure 3c we can informed that there was dominated by high vulnerability cluster. In map 3d we can only observed 5 cluster with various vulnerability. Cluster number 35 in Sawangan Subdistrict is the longest and the widest cluster with high vulnerability. It caused by the distance to the river and also affected by settlement density. In the Figure 3e we can conclude that it dominate with low vulnerability. In the figure 3f only 2 cluster shown, and it has low vulnerability. In Figure 3g we can observed that it has unique phenomenon. Cluster 61 has area which slightly far from the river but the higher vulnerability cluster reversed. In the Figure 3h only shown one cluster with low vulnerability density.
Figure 3. The distribution map of settlement physical vulnerability towards lahar flows along Pabelan River.
Figure 3a-3h. settlement distribution
5. Discussion
Based on the results of this research, it can be concluded that the distribution of settlement physical vulnerability in lahar-hazards prone area along Pabelan River is affected by the distance of the settlement buildings to the river, the number if the buildings in each cluster and the type of the construction material. The closer the settlement buildings and the more buildings in each cluster, the wider the distribution of the physical vulnerability of settlement towards disasters. The highest distribution of high physical vulnerability is Mungkid Sub-district and Sawangan Sub-district with 5 clusters or equal to 7.49% of the research area. The medium level of physical vulnerability is Dukun Sub-district, Mungkid Sub-district and Muntilan Sub-district. The medium level is distributed to 26 clusters or equal to 41.27% of the research area. The low physical vulnerability of settlements is scattered in Dukun Sub-district, Mungkid Sub-district, Muntilan Sub-district and Sawangan Sub-district. The low level of physical vulnerability is distributed to 32 clusters or equal to 50.79% of the research area. The more we go to the upstream, the fewer houses we can find. Its also affected towards the result of this research. For the upcoming research, we suggested the researcher to considering about the morphometry of the river. This research didn’t used morphometry because of lack imagery before Pabelan river was hit by lahar. The benefits from this research can be used for the local community to be aware of their environment, also for the local government to make the wisest policy. The advantages of this research can be considered as part of disaster risk analysis. This research can also be carried out in other rivers which originated in Merapi Volcano and becoming lahar prone rivers. We know that this research is far from perfection, but we also hope there will be more better research of this similar topic in the future.

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References
[1] Hadmoko D S et al. Post-eruptive Lahars at Kali Putih following the 2010 eruption of Merapi volcano, Indonesia: occurrences and impacts J Natural Hazards, (German: Springer Nature)
[2] Keller E A and Blodgett R H 2008 Natural hazards : earth's processes as hazards, disasters, and catastrophes. (New Jersey: Pearson/Prentice Hall), pp. 85.
[3] Gomez C et al. Borobudur, a basin under volcanic influence: 361,000 years BP to present Journal of Volcanology and Geothermal Research 196 pp. 245–264.
[4] Hapsari R I et al. 2019 X-MP Radar for Developing a Lahar Rainfall Threshold for the Merapi Volcano Using a Bayesian Approach Journal of Disaster Research Vol.14 No.5.
[5] Belizal E de et al. 2013 Rain-triggered lahars following the 2010 eruption of Merapi volcano, Indonesia: a major risk”, Journal of Volcanology and Geothermal Research 261 pp. 330–347.
[6] Papathoma-Köhle M, Gems B, Sturm M, Fuchs S 2016 Matrices, curves and indicators: A review of approaches to assess physical vulnerability to debris flows J Earth-Science Reviews
[7] Joseph J 2013 Measuring vulnerability to natural hazards: a macro framework Journal Disaster (UK: Blackwell Publishing) pp. 185-200.
[8] Hambali R, Legono D, Jayadi R, and Oishi S 2019 Improving Spatial Rainfall Estimates at Mt. Merapi Area Using Radar-Rain Gauge Conditional Merging J of Disaster Research Vol.14 No.1 pp. 69-79.
[9] Putra SS, Ridwan B W, Yamanoki K, Shimomura M, Sulistiyani, and Hadiyuwono D, “Point-Based Rainfall Intensity Information System in Mt. Merapi Area by X-Band Radar”, J of Disaster Research Vol.14 No.1, pp. 80-89.
[10] Lavigne F et al. 2011 Lahar hazards and risks following the 2010 eruption of Merapi volcano, Indonesia”. Geophysical Research Abstracts Vol. 13, EGU 2011-4400
[11] Smith K and Petley D N 2009 Environmental Hazard: Assessing risk and reducing disaster (Routledge)
[12] Franck Lavigne 1999 Lahar hazard micro-zonation and risk assessment in Yogyakarta city, Indonesia” in GeoJournal 49 (Kluwer), pp. 173–183.
[13] Fatemi M N, Shimoda M, Okyere S A, Diko S K, Kita M, and Matsubara S 2020 Physical Vulnerability and Local Responses to Flood Damage in Peri-Urban Areas of Dhaka, Bangladesh J Sustainability (MDPI) pp 12.
[14] Gonda Y, Miyata S, Fujita M, Legono D, and Tsutsumi D 2019 Temporal Changes in Runoff Characteristics of Lahars After the 1984 Eruption of Mt. Merapi, Indonesia”. JDR Vol.14 No.1, (Japan : Fujipress) pp. 61-68.
[15] Kang H S and Kim Y T 2015 The physical vulnerability of different types of building structure to debris flow events J Nat Hazards 80 (Springer) pp. 1475–1493
[16] Ikhsan J et al. 2020 Dynamics of lahar-affected river tributaries of the Progo river after the 2010 Mt. Merapi eruption Proc. Int. Conf. Of Water Resources Engineering Department IOP Conf. Ser.: Earth Environ. Sci. 437 012009
[17] Fitria L M, Ni’mah N M, and Danu L K 2019 “Kerentanan Fisik Terhadap Bencana Banjir di Kawasan Perkotaan Yogyakarta”. J Reka Ruang Vol.2, No.1, pp.1-9.
[18] Iguchi M 2019 Proposal of Estimation Method for Debris Flow Potential Considering Eruptive Activity. J of Disaster Research Vol.14 No.1 pp. 126-134.
[19] Badan Pusat Statistik 2018 “Kecamatan Dukun Dalam Angka 2018”, ISSN: 2406-9949.
[20] Badan Pusat Statistik 2018 “Kecamatan Mungkid Dalam Angka 2018”, ISSN: 2442-5753.
[21] Badan Pusat Statistik 2018 “Kecamatan Muntilan Dalam Angka 2018”, ISSN: 2356-2331.
[22] Badan Pusat Statistik 2018 “Kecamatan Sawangan Dalam Angka 2018”, ISSN: 2442-529X.