Evaluation of infrastructures and riparian area toward the potency of debris flow effect in Putih river watershed, Indonesia

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Abstract. Putih River is one of the rivers which was affected by debris flow after the eruption of Mount Merapi in 2010. The impact of the damage included riparian areas and infrastructures that built along the river. This research aims to evaluate the condition of riparian area in Putih river watershed with the established rules of Indonesian government and conditions of infrastructures that constructed along the river. The research was carried out by field survey that supported by Survey123 for ArcGIS and data processing using ArcGIS software. Based on the results, it shows that Jumoyo village had the largest of riparian area with 2.1 Ha for riparian area by 5 m width and 10 Ha for riparian area by 50 m width. The result also showed that Jumoyo village had the highest approximate population number within the riparian areas with 656 people for riparian area with 5 m width and 1465 people for riparian area with 50 m width. From the field survey result, it shows that there are 35 buildings/infrastructures in Putih River, consisting of 2 dams, 11 bridges, 1 ground sill, 20 sabo dams, and 1 sand pocket.

Keywords: Putih river, debris flow, riparian area, infrastructures

1. Introduction

Mount Merapi is one of the active volcanoes in Indonesia, also in the world, that it has very intense activities. Its activities resulted in lahar deposited (Figure 1) and also can give a massive damage to around Merapi areas. One of the areas that impacted by debris flow which followed by eruption of Mount Merapi especially eruption in 2010 is riparian area of Putih River. The damages in Putih River were about the infrastructures that built along the river and some habitations in riparian area of Putih River. Furthermore, the people that live in riparian area became a victim when the flood had coming that day. The areas that impact by debris flow after the eruption shown in figure 1 caused approximately 339 people die and 3424 houses had damaged [1]. This research aims to evaluate the conditions of infrastructures that built along the river and to analyze the conditions of riparian area that compared by government regulation. Thus, this research had two parts to discuss which are studying conditions of infrastructures after almost ten years since the eruption and analyzing the landuse of riparian area in Putih River.
Lahar is a secondary disaster after the eruption of the mount. The disaster triggered by high rainfall intensity cause flood that able to flow the materials of mount through the river [3]. There are three factors could make this happened. They are a millions of cubic meters of pyroclastic deposits in the river, rainfall intensity is high, and drainage pattern is very dense [4]. The disaster caused by lahar divided by 2 time periods. The first period is debris flow after the eruption directly occured in just a few months and the second period came more than a year after the eruption [5]. Lahar after eruption of Mount Merapi in 2010 spread more than 15 km from the crater. The geomorphic impacts of lahars on the distal slope of the volcano are then explained as they directly threaten houses and infrastructures: creation of large corridors, avulsions, riverbank erosion and riverbed downcutting are detailed through local scale examples [2]. The damages that followed by lahar in Putih River area were shown in Table
1 in category of houses, Table 2 in category of sabo dams and the other damages will discuss in rest of the paper.

Table 1. The amount of houses damaged impact by lahar in Putih River area [6]

| Village | Houses damaged | Total |
|---------|----------------|-------|
|         | Small | Medium | Heavy/Gone |
| Sirahan | 87    | 47     | 155      | 289 |
| Jumoyo  | 13    | 15     | 165      | 193 |
| Gulon   | 0     | 0      | 12       | 12  |
| Seloboro| 0     | 4      | 4        | 8   |
| Blongkeng| 0   | 0      | 28       | 28  |
| Srumbung| 0     | 0      | 2        | 2   |
| Total   | 100   | 66     | 366      | 532 |

Table 2. The amount of sabo dams damaged by lahar after Merapi eruption 2010 [7]

| River Name | District | Slightly Damaged | Medium Damaged | Severely Damaged | Total |
|------------|----------|------------------|----------------|------------------|-------|
| Pabelan    | Magelang | -                | 6              | 8                | 14    |
| Senowo     | Magelang | 2                | 3              | 2                | 7     |
| Trising    | Magelang | -                | 3              | 3                | 6     |
| Apu        | Magelang | -                | 1              | 3                | 4     |
| Lamat      | Magelang | -                | 3              | 1                | 4     |
| Putih      | Magelang | 2                | 11             | 6                | 19    |
| Batang     | Magelang | 1                | -              | -                | 1     |
| Bebeng     | Magelang | 3                | 3              | 1                | 7     |
| Krasak     | Sleman   | -                | 3              | -                | 3     |
| Boyong     | Sleman   | -                | 2              | 1                | 3     |
| Kuning     | Sleman   | -                | 5              | -                | 5     |
| Woro       | Klaten   | 1                | 2              | 1                | 4     |
| Total      |          | 9                | 42             | 26               | 77    |

Riparian area is a shadow line in right or left of the river which determined for river protection boundary [8]. As a protection of the river, the riparian area has to be used in a good way which mean it has to be clear from the habitations and houses. This is important for preventing some of disasters that happened around the river. Thera are many ways to determine the riparian area in some river. Such as government regulation that would be used in this research shown in Table 3. On the other hand, there ar a person used a morphlogy and flood hydraulics of the river to determine a riparian area besides the government regulations [9].

Table 3. Regulations of Riparian Area [8]

| Type of River                | Outside Urban Area | Inside Urban Area | Article |
|------------------------------|--------------------|-------------------|---------|
|                              | Criteria           | Riparian area minimum | Criteria | Riparian area minimum |                 |
| River with embankment       | -                  | 5 m               | -       | 3 m                 | 7 & 8            |
| River without embankment    |                    |                   |         |                     |
| Large river (Watershed > 500 km²) | 100 m              | Depth ≤ 3 m       | 10 m    | 5 & 6               |
| Large river (Watershed < 500 km²) | 50 m              | Depth 3 - 20 m    | 15 m    | 5 & 6               |
2. Data and Method

The studied area is Putih River watershed that located in Magelang Regency, Central Java, Indonesia shown in Figure 2. The specific area was then selected based on the riparian area in main river of Putih River. There are 15 villages in 4 sub-districts in Putih River watershed.

| Water springs | - | 200 m | - | 200 m | 11 |
| River effected by tide | Same as river that didn’t effecteed by tide | 10 |

2.1. Data collection

The data were collected consist of secondary data and primary data. Secondary data were collected from institutional source about river infrastructures and morphology of Putih River. These data were collected for comparing between field survey and existing data. The other secondary data were collected from Indonesia Geospatial Portal about spatial data attributes for processing data.

Primary data were collected by field survey supported by Survey123 for ArcGIS. This application created by ESRI Indonesia for helping people do the field survey. For using this application, we have to make a form based on XLForm that connected with the application. The form then will publish in the application and ready to use. The application only used for helping the researcher to collect data in field.

2.2. Data Processing

The collected data were input into godatabase. The maps then could be constructed by GIS-based spatial multi-criteria analysis as provided by ArcMap 10.2 software. The data that obtained from the GIS-based were a riparian area and all quantitive data about that.

2.3. Data Analysis

The data were analyzed by descriptive quantitative method. For creating a riparian area, it used a base map from ArcMap 10.2 which connected with ArcGIS Online. The parameters for analyzing data were a landuse of the river watershed, data of habitations in riparian area and data of people that live in riparian area. Furthermore, the research produced a map of infrastructures that built along the river by adding the field survey data to the application.

Figure 2. Putih River watershed in Magelang Regency
3. Result and Discussion

3.1. Putih River Watershed

Putih River watershed has 26.12 km² of area with 25.4 km of length. It has 15 villages inside Putih River watershed which population forecast for each of village shown in Table 4. The area of each village in Table 4 were obtained from ArcMap 10.2 software after river watershed has created. This parameter is important for forecasting the population in some places. The other parameter is landuses of Putih River shown in Figure 3 that consist of habitations, farm, fields, plantations and vegetation non culvitation.

Table 4. Population forecast in Putih River watershed [10], [11]

| Village     | Area (km²) | Population density (People/ km²) | Population Forecast (jiwa) |
|-------------|------------|----------------------------------|----------------------------|
| Blongkeng   | 0.43       | 1466                             | 630                        |
| Plosogede   | 0.16       | 1440                             | 230                        |
| Gulon       | 3.55       | 1818                             | 6454                       |
| Jumoyo      | 2.09       | 2186                             | 4569                       |
| Sirahan     | 0.97       | 1264                             | 1226                       |
| Seloboro    | 0.73       | 1596                             | 1165                       |
| Mranggen    | 3.53       | 1068                             | 3770                       |
| Ngablak     | 3.73       | 675                              | 2518                       |
| Ngargosoko  | 3.3        | 559                              | 1845                       |
| Bringin     | 3.23       | 1340                             | 4328                       |
| Srumbung    | 0.75       | 1399                             | 1049                       |
| Tegalrandu  | 0.08       | 775                              | 62                         |
| Kemiren     | 0.39       | 194                              | 76                         |
| Polengan    | 0.89       | 1319                             | 1306                       |
| Ngargomulyo | 2.19       | 262                              | 574                        |
| **Total**   | **26.12**  |                                  | **29802**                  |

Figure 3. Land uses of Putih River Watershed
3.2. Evaluations of Riparian Area

Riparian area is a shadow line in right or left of the river which determined for river protection boundary [8]. As shown in Table 3, the basic of the evaluation is from Ministry of Public Work regulation number 28 of 2015 about Determination of Riparian Area and Lakeside Area. Putih River has 2 types of riparian area because it has embankments in some areas and no embankment in the other areas. Thus, it is determined that riparian area in Putih River are 5 km width from river bank and 50 km width from river bank. Because it can’t decide accurately where river part that has an embankment, it created both of riparian area in all along the river. After field survey and analysis in ArcMap 10.2 software, it found 3 types of riparian area in Putih River shown in Figure 4.

![Figure 4. Riparian area with (a) Habitation/houses (b) Empty land (c) Farm](image)

The results of analysis using ArcMap10.2 software are data of population forecast in riparian area and an area of habitations inside riparian area shown in Table 5. Also landuses of riparian area in Putih River shown in Table 6.

### Table 5. Population forecast and Habitation area in riparian area of Putih River

| Village     | Area Inside of Riparian Area (Ha) | Population Forecast (People) |
|-------------|-----------------------------------|------------------------------|
|             | 5 m  | 50 m | 5 m  | 50 m | 5 m  | 50 m |
| Blongkeng   | 3.97 | 14.39| 1.38 | 4.85| 59   | 205  |
| Plosogede   | 1.59 | 6.73 | 0.16 | 2.16| 29   | 101  |
| Gulon       | 1.4  | 4.36 | 0    | 0   | 18   | 73   |
| Jumoyo      | 30.39| 66.78| 2.1  | 10  | 656  | 1465 |
| Sirahan     | 7.41 | 26.83| 1.06 | 5.52| 88   | 341  |
| Seloboro    | 5.88 | 16.91| 0.61 | 3.06| 96   | 271  |
| Mranggen    | 15.18| 36.68| 0.13 | 2.72| 160  | 395  |
| Ngablak     | 23.81| 55.17| 0    | 0   | 162  | 371  |
| Ngargosoko  | 36.07| 63.35| 0    | 0   | 201  | 352  |
| Bringin     | 0    | 0    | 0    | 0   | 0    | 0    |
| Srumbung    | 15.68| 37.45| 0.05 | 1.7 | 224  | 518  |
| Tegalrandu  | 0.48 | 1.14 | 0    | 0   | 0    | 8    |
| Kemiren     | 0    | 0    | 0    | 0   | 0    | 0    |
| Polengan    | 0    | 0    | 0    | 0   | 0    | 0    |
| Ngargomulyo | 45.08| 85.84| 0    | 0   | 118  | 225  |
| **Total**   | 186.94| 415.63| 5.49 | 30.01| 1811| 4325 |

### Table 6. Landuses in riparian area of Putih River

| Landuse     | Area (Ha) | 5 m  | 50 m |
|-------------|-----------|------|------|
| Habitation  | 5.5       | 30   |      |
| Rice Fields | 25.69     | 79.52|      |
Rain-fed Rice Fields  4.61  22.95
Farm            4.01  11.92
Plantation      15.44  58.37
Vegetation non culvitation  20.46  29.83

|               | Rain-fed Rice Fields | Farm | Plantation | Vegetation non culvitation |
|---------------|----------------------|------|------------|-----------------------------|
|               | 4.61                 | 4.01 | 15.44      | 20.46                       |
|               | 22.95                | 11.92| 58.37      | 29.83                       |
| **Total**     | **75.71**            | **232.59** |

Population forecast in two riparian area are 1811 people in 5 km width of riparian area and 4325 people in 50 km width of riparian area. Jumoyo village has the highest population and the largest habitiaons as shown in Table 5. Because of it, Jumoyo village is the most susceptible village that has to be concern from disaster. Rice fields is the highest land used by people in riparian area as shown in Table 6.

3.3. Infrastructures Data in Putih River

This subject aim to update data of infrastructures in Putih River after almost 10 years since eruption of Mount Merapi 2010. As an explanation of collecting data method before, field survey is assisted by Survey123 for ArcGIS application that had a form before collecting. The results of field survey as Figure 5 shown that Putih River has 35 buildings consist of 2 dams, 11 bridges, 1 groundsill, 20 sabo dams, and 1 sand pocket. Every type of building will discuss on every part later.

![Figure 5. Map of Infrastructures in Putih River](image)

3.3.1. Dam

Dam a wall built across a river that stops the river's flow and collects the water, especially to make a reservoir (= an artificial lake) that provides water for an area such as for irrigation system, water resources, hydropower or flood control [12, 13]. There are 2 dams in Putih River shown in Figure 5 with DP as a code of infrastructures. This paper will explain one of them as a sample of the infrastructure. Krapyak Dam with DP01 as a code of infrastructure is one of dam in Putih River. Krapyak Dam is located in Seloboro village, Salam Sub-district, Magelang Regency. Krapyak dam shown in Figure 6 was destroyed after hit by lahar in 2010. There are several damages in main dam and wing dam and also found some aggregate among 1-2 meter of diameter in main dam [14]. In 2019, this dam looks very good without any damages in all part of dam as shown in Figure 6.
3.3.2. Bridge

There are 11 bridges in Putih River consist of 6 bridges that built with steel frame and 5 bridges that built with concrete beam. Location of bridges with steel frame shown in Figure 5 with BP01, BP03, BP04, BP05, BP06 and BP08 as a code of infrastructure. Then, the other code of infrastructures shown in Figure 5 are bridges with concrete beam. JP05 will be a sample for the bridge with steel frame shown in Figure 7 and JP07 will be a sample for the bridge with concrete beam also shown in Figure 7. All of bridges in Putih River commonly have a good condition without any damages in every segment of the bridge.

3.3.3. Groundsill

Groundsill is built for controlling a sedimentation process and preventing river expansion [15]. There is only one groundsill in Putih River that located in Gulon Village, Salam Sub-District, Magelang Regency shown in Figure 5 with GP01 as a code of infrastructure. Groundsill has a good condition and normally function without any damages as shown in Figure 8.
3.3.4. Sabo Dam

Sabo dam is one of the most important infrastructure for sabo system because it has an ability to store, sustain and control of debris flow [16]. As shown in Table 2, there are 19 sabo dams are broken after lahar came in 2010. In field survey and secondary data from some institution, they are found 20 sabo dams in Putih River which consist of 17 sabo dams were found in field survey with SD as a code of infrastructure and 3 sabo dams from secondary data with SD PPK as a code of infrastructure shown in Figure 5 [17]. The picture of sabo dams with SD13 as a code shown in Figure 9 as a sample of the infrastructure. Generally, all sabo dams are built in Putih River have a good condition but in a few of sabo dams still have a lot of sediments which can interfere a function of sabo dam when debris flow come.

![Figure 9. Sabo dam with SD13 as a code in Jumoyo Village](image)

3.3.5. Sand Pocket

Sand pocket is a sabo construction that generally built cross the river which all covered in right or left side but also has a simple spillway for flowing the water [18]. In Putih River, there is only one sand pocket that located in Ngargosoko Village, Sumbung Sub-district, Magelang Regency shown in Figure 5 with SP01 as a code of infrastructure. This sand pocket has a good condition as shown in Figure10 even tough it has a huge volume of sediment. In this area, there are many people do the sand mining.

![Figure 10. Sand pocket in Putih River](image)

4. Conclusion and Recommendation

According to data from ArcMap 10.2 software, landuse in Putih River watershed dominated by rice fields with 1088.81 Ha. It equals with landuse in riparian area which also dominated by rice fields with 25.69 Ha for riparian area with 5 km width and 79.52 Ha for riparian area with 50 km. There are still many people live in riparian area which are a susceptible area for living. It carried out that riparian area still has 5.5 Ha of habitations for riparian area with 5 km width and 30.01 Ha for riparian area with 50 km width. It also known that people that live in riparian area amount of 1811 people for riparian area with 5 km width and 4325 people for riparian area with 50 km width. Jumoyo Village is
one of village that has a highest number of population either houses in riparian area. Jumoyo Village has 656 people which means 36.2% from all populations that live in riparian area with 5 km width and has 1465 people which means 33.9% from all populations that live in riparian area with 50 km width. There are 35 infrastructures that built along Putih River consisting of 2 dams, 11 bridges, 1 groundsill, 20 sabo dams, and 1 sand pocket. Generally, the infrastructures still has a good conditions and it didn’t found any damages that can make it should be rehabilitated. It has to be concern for Government to be more strict for the function of riparian area in Putih River because it is very important for saving people life from disaster. It has to be careful for choosing an application for supporting to collect data because Survey123 for ArcGIS is using an internet and GPS for operating the application. It makes difficult for collecting data in remote area that doesn’t have internet access.

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