Settlement Relocation Modeling: Reacting to Merapi’s Eruption Incident

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Settlement Relocation Modeling: Reacting to Merapi’s Eruption Incident

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Abstract. Merapi eruption has made severe damages in Central Java Province. Klaten was one of the most affected area, specifically in Balerante Village. This research is made to comprehend GIS model on finding alternative locations for impacted settlement in hazardous zones of eruption. The principal objective of the research study is to identify and analyze physical condition, community characteristics, and local government regulation related to settlements relocation plan for impacted area of eruption. The output is location map which classified into four categories, i.e. not available, available with low accessibility, available with medium accessibility, and available with high accessibility.

Keywords: Merapi Eruption, Settlement, Relocation, GIS Model

1. Introduction

Indonesian archipelago is one of the regions having the most active volcanoes in the world, commonly called as The Ring of Fire. That is why Indonesia has a high vulnerability in geological hazards. Located between oceans and plains which are characterized by plenty of hills and mountains, Central Java becomes prone to the volcanic eruption. Some of volcanic mountains located in Central Java are Merapi, Slamet, Sindoro, and Sumbing. Most of all, Merapi has the highest number of eruptions in the previous years and have caused a great deal of damages and losses in majority areas of Central Java. Merapi is surrounded by four districts, i.e. Magelang, Boyolali and Klaten in Central Java Province, also Sleman in D.I Yogyakarta.

Various studies have identified society’s increasing vulnerability to disasters as a consequence of population expansion in hazardous areas and increasing economic and environmental strain [1–4]. Volcanic eruptions can become threats to the people living in the surrounding areas. The consequence of vulnerability from volcano eruptions can be different in each area, depending on the situation of natural events and human activities. The losses due to disasters also depend on the ability to prevent or avoid them. The impacts of disasters can be limited, depending on the type of spatial and large eruptions. The activities of Mount Merapi, for instance, can be monitored minute by minute by the use of sufficient monitoring equipment so that the casualties that may occur due to its activities can be minimized. This understanding is associated with the statement that disasters occur when hazards meet helplessness. Thus, the activity of the malicious nature will not be a natural disaster in areas
without human powerlessness. As an example, volcano eruption in uninhabited areas will be less harmful than eruptions in density settlement areas.

The direct danger from volcano hazard may occur due to the throwing rocks / bombs, lava flows and hot clouds blow as an incandescent eruption, toxic gases, and thick ash fall. While the danger arising from the flow of mud mixed with rocks categorize as following hazard. This flow of flooding, either still hot or already cooled heat is often referred as “lahar”. The Indonesian word “lahar” is applied as a general term for rapidly flowing, highly concentrated and poorly-sorted sediment-laden mixtures of water and rock debris from a volcano, not including normal stream flow [5,6]. Lahar following the volcanic slopes can lead to sweeping villages, rice fields or bridges.

Merapi volcano has been studied extensively on continuous research by indonesian and international scientists, government scientists, even students. Numerous projects and collaborative researches were directed at understanding the eruption impacts, management, assessment [7–10] and eruption forecasting [7,11–14].

An important lesson from this special issue is the warning outlined by several authors that Merapi volcano is capable of greater eruptions than those in the 20th century – the eruptions that may have disastrous consequences. The eruption in 4th and 5th November, 2010, was a “100-year event” [16]. It was approximately 10 times larger and more explosive than the eruptions of the past several decades, and it validated the concern about Merapi — that greater and more hazardous eruptions, like the one that took place in 1872, are a continuing threat at the volcano [1,12,16–19].

The growth of the population can also lead to disaster. A bigger population will increase the need of settlement, so it can encourage more people to live in dangerous and vulnerable areas. For example, local farmers rely for their livelihoods from the natural resources on their surrounding areas, but they often pay less attention to safety aspects. It makes many houses were established in the hazardous zone, so in the last few years, we often hear disaster incident that took many lives. Regarding this vulnerable condition, settlements are not allowed to be built in the disaster hazard so that the existed settlements built in such zone need to be relocated to more secured areas.

Relocation is the moving process from one place to another. Thus, settlement relocation can be informed as a moving process of a certain area of settlement to another place. Relocation usually takes place when the old location is subject to a natural hazard; when the old location is completely destroyed and to move the debris and to make new plotting in the old settlement is inconvenient for rapid recovery and housing purposes; also when there is a chance to relocate the settlement to land which belongs to the Government since it is generally preferred not to have to pay for the land [20]. Furthermore relocation or resettlement processes are important for reducing future hazard risk in a disaster prone area [21], especially for the settlement which existence is taken place on a restricted area, such as on the riverbanks and hazardous area of disaster. Related to those context, people who are affected by Merapi eruption need a secured place for permanent settlement due to the damaged of their settlements. Relocation process is one alternative way to provide opportunities for people who live in the hazardous area of disaster. It will give them a bigger opportunity to carry on their lives in a better and secured condition.

The discussion about Merapi’s risk assessment, mitigation and other geothermal studies are commonly discussed, but the research that is intended to analyze about GIS relocation model based on physical condition, governmental and community aspects might be a new thing. This paper elaborates three aspects: physical, government and community aspects as an input in making GIS model for relocating the settlements existing in hazard zones area. The object of the study is communities in Kemalang Sub-district, who lives in Balerante Village, Klaten District. Balerante Village is considered as the most vulnerable because settlements damages caused by Merapi’s eruption in 2010 are mostly happened in this place.
2. Methods

This research uses quantitative approach, it is divided into several analyses; analysis based on physical aspect, government aspect and community aspect. Scoring and buffer analyses are applied in the process. The next step is analyzing the model simulation using model builder. While the last is making a descriptive analysis on the final output of the model. This research also uses descriptive quantitative method to explain and explore more about the phenomena. In descriptive ways, relocation model for impacted settlements can be formulated. Each indicator in natural condition of a scope area is converted in value and score. The conversion is needed to simplify numeric analysis process, so the land suitability degree of settlements on relocation model can be obtained. Variables in the physical aspect are obtained from the literature, while variables in the government and community aspect are obtained from direct interview of government officials and local village leader.

2.1. Physical Aspect

Physical condition of nature plays a big role; it helps define the most suitable land for a new settlement location. Land suitability for development of the city should consider several aspects, i.e. physical, socio-economic conditions, accessibility, environment and ecology, the potential of local resources as well as political factors [22].

Natural physical aspect is determined as one of the main analyses by setting four variables as a measurement. It consists of topographical land slopes, geology condition, hydrology condition, and soil type condition. The maps of physical variables are overlaid based on each weight. This step is also known as weighted overlay. Weighting is done to show the influence of each variable to its related aspect. Weighted overlay is expressed in percent (%) where the total amount is 100%. Influence level on each variable is varied, so it also gives different proportion on the weight. Land slopes variable has the biggest weight in comparison to other variables. It has 40% weight while other variable only has 20%. The reason is related to the natural condition of study area that tends to be sloping in most of the area. This sloping condition gives bigger influence on the risk of natural disasters such as eruption, earthquake, and landslide. Thus the weight of land slopes variables is twice bigger than others.

| Table 1. Score and Classification of Physical Aspect Variables |
|---------------------------------------------------------------|
| **Variable** | **Characteristic** | **Score** | **Weight** |
|---------------|-------------------|-----------|-----------|
| (1) Land slopes | Very steep (>45%) | 1         | 40%       |
|               | Steep (25 – 45%)  | 2         |           |
|               | Low steep (15 – 25%) | 3       |           |
|               | Sloping (2 – 15 %) | 4         |           |
|               | Flat (0 – 2 %)    | 5         |           |
| (2) Geology condition | Dacite | 1 | 20% |
|               | Merapi volcanic rocks | 3 |   |
|               | Old merapi volcanic rocks | 5 |   |
| (3) Hydrology condition | Scarce Groundwater | 1 | 20% |
|               | Local productive aquifer | 2 |   |
|               | Widespread productive aquifer | 3 |   |
|               | Widespread with medium productivity | 4 |   |
|               | Widespread aquifer with high productivity | 5 |   |
| (4) Soil type condition | Litosol - grey regosol | 1 | 20% |
|               | Grey brown regosol | 3 |   |
|               | Grey regosol | 5 |   |

Source: Minister of Forestry Decree No.873/UM/H/1980 and No.683/KPTS/UM/1981; Verhoef 1994; modified by researcher 2014

On the other hand, scoring is done on each variable with a value of 1 to 5 where the higher the score, means the higher suitability level of the land. For an example, areas with a high degree of slope...
will earn a small score because the higher the slope, the smaller the score. Meanwhile, the scoring on the hydrological conditions depends on the availability of the sources of water. This method is also applied for geology and soil type condition. The score is given according to the type of rock and the soil.

2.2. Government Aspect

One of the most important aspects to be considered in relocation action is regulatory factors. The policy about spatial planning has been regulated by the central government. However, it needs to be in line with the relevant local authorities. The criteria chosen as variables in the government aspects have been adapted to land use regulation based on government spatial plan of Klaten. The government aspect variables are also inferred as elimination criteria. The reason is mainly based on the regulation that these areas are not allowed or permitted to be relocation referrals. Score is also given on each variable of governmental aspect. The score in the government aspect is ranging from 0 to 1. The scoring method is given to identify restricted zones so it could be eliminated. A zero (0) score is given to the restricted area while score of one (1) is given for unrestricted area.

Table 2. Score and Classification of Government Aspect Variables

| No. | Variables                  | Area Classification                      | Score |
|-----|----------------------------|------------------------------------------|-------|
| 1   | Conservation Area          | Merapi’s National Park & Riverbanks Area | 0     |
|     |                            | Other Area                               | 1     |
| 2   | Riverbanks Area            | 0-50 Meter Buffer Area                   | 0     |
|     |                            | >50 Meter Buffer Area                    | 1     |
| 3   | Existing Settlement Area   | Build Up Area                            | 0     |
|     |                            | Non Build Up Area                        | 1     |
| 4   | Volcano Hazard Area        | Hazard Zone 1,2,3                        | 0     |
|     |                            | Non Hazard Zone                          | 1     |

Source: Law No. 26 of 2007; Presidential Decree No. 32 of 1990; Presidential Decree no. 57 of 1989; Regulation of the Minister of Agriculture and 837/KPTS/UM/11/1980 No.683/KPTS/UM/8/1981; modified by researcher, 2014

2.3. Community Aspect

The analysis in community aspect is emphasizing on the range of accessibility to roads, evacuation routes, shelter, high voltage wires, and other public facilities such as the range of educational facilities, health facilities as well as worship facilities. The determination of an ideal access to reach facilities was done by creating a buffer on roads, high voltage wires and evacuation centers. The buffer distances on each aspect were different from one to another. It depends on the rules and assumptions adapted based on the public’s ability to access the facility. The more varied the facilities and infrastructures of the residential means the higher the possibility it is chosen as the residential location.

2.4. The Existing Road

The road used as a parameter in this study is a collector road. In this variable, there are some classifications which depend on the buffer distance. It measured from how far people can walk within a period of 10-15 minutes. The classifications criteria are <500m, 500-1000m, and > 1000m.

Table 3. Score and Buffer Distance of Existing Road Variables

| No. | Distance   | Walking Time Estimation | Score |
|-----|------------|-------------------------|-------|
| 1   | <500 m     | <10 minute              | 5     |
| 2   | 500-1000 m | 10-15 minute            | 3     |
| 3   | >1000 m    | >15 minute              | 1     |

Source: Modified by Researcher, 2014
2.5. Evacuation Route

Based on the field observation, evacuation route on Kemalang districts do not use special track but use the available collector roads. Therefore, the determination of buffer distance on evacuation routes uses the same classification as the existing road variables.

Table 4. Score and Buffer Distance of Evacuation Route Variables

| No. | Distance   | Walking Time Estimation | Score |
|-----|------------|-------------------------|-------|
| 1   | <500 m     | <10 minute              | 5     |
| 2   | 500-1000 m | 10-15 minute            | 3     |
| 3   | >1000 m    | >15 minute              | 1     |

Source: Modified by Researcher, 2014

2.6. Shelter Point

The buffer distance on shelter point is 500 meters. This distance is considered as the safest distance, so a score of 5 is given as the highest score. Meanwhile a score of 1, as the lowest score, is given to the settlement location with over 500 meters’ distance.

Table 5. Score and Buffer Distance of Shelter Point Variables

| No. | Distance | Walking Time Estimation | Score |
|-----|----------|-------------------------|-------|
| 1   | <500 m   | <10 minute              | 5     |
| 2   | >500 m   | >10 minute              | 1     |

Source: Modified by Researcher, 2014

2.7. High-Voltage Tower (SUTET)

The unavailability of electricity network map is the main reason why the researcher chose high voltage wires as a reference. The buffer distance of voltage wires is SNI 04-6918-2002 which refers to “free space and minimum free distance of high-voltage wires.” The rules are described as follows:

a) The minimum vertical clearance of conductors to the building is 9 meters.
b) The minimum clearance from the horizontal axis to the tower is 22 meter for a single circuit of 500 kilovolt high-voltage wires and 17 meter for double circuit of 500 kilovolt high-voltage wires.

The high-voltage tower found the study area is 1000 kilovolt high-voltage wires. However, there is no explanation about the double or single circuit description. Based on the information, a safe buffer distance is assumed as far as 50 meters.

Table 6. Score and Buffer Distance of High-Voltage Tower Variables

| No. | Distance | SNI Regulation          | Score |
|-----|----------|-------------------------|-------|
| 1   | <50 m    | Not Recommended         | 1     |
| 2   | >50 m    | Recommended             | 5     |

Source: SNI 04-6918-2002, Modified by Researcher, 2014

2.8. Public Facilities Availability

Access to the health, educational and worship facilities are determined using scalogram diagram method. Statistical data of facilities on each village are obtained from statistical bureau. The output of scalogram diagram is a facility access hierarchy from low, medium to high. The next step is making the public facility map through spatial process. The specific information about each facility could be seen in the following table.
Table 7. Scalogram Diagram, The Availability Of Education, Health & Worship Facilities

| No. | Village | Kindergarten | Elementary School | Toddler High School | Health Center | Sub Health Center | Maternity Clinic | Clinic | Mosque | Museum | Cortical Church | Christian Church | Total Score | Criteria |
|-----|---------|--------------|-------------------|--------------------|--------------|------------------|-----------------|--------|--------|--------|----------------|-----------------|-------------|----------|
| 1   | Sumberi | 1            | 2                 | 0                  | 0            | 0                | 0               | 0      | 4      | 2      | 0              | 0               | 4           | Mali     |
| 2   | Brondan  | 1            | 2                 | 0                  | 1            | 0                | 0               | 0      | 4      | 1      | 1              | 1               | 5           | S`village |
| 3   | Kajang   | 1            | 1                 | 0                  | 1            | 0                | 0               | 0      | 2      | 21     | 0              | 0               | 23          | S`village |
| 4   | Dempel   | 1            | 2                 | 0                  | 0            | 0                | 3               | 0      | 0      | 0      | 4              | 0               | 4           | S@village |
| 5   | Kreimoga | 1            | 2                 | 0                  | 0            | 0                | 3               | 0      | 4      | 0      | 0              | 0               | 4           | S@village |
| 6   | Kandung  | 2            | 2                 | 0                  | 1            | 0                | 0               | 0      | 4      | 0      | 0              | 0               | 4           | S@village |
| 7   | Kapantas | 2            | 2                 | 0                  | 0            | 1                | 0               | 0      | 5      | 7      | 1              | 3               | 13          | High     |
| 8   | Patting  | 1            | 1                 | 0                  | 0            | 0                | 0               | 0      | 2      | 0      | 0              | 0               | 2           | Low      |
| 9   | Sabello  | 2            | 2                 | 0                  | 0            | 0                | 2               | 0      | 0      | 0      | 4              | 0               | 4           | S`village |
| 10  | Talun    | 2            | 2                 | 0                  | 0            | 0                | 0               | 1      | 0      | 0      | 4              | 0               | 4           | S`village |
| 11  | Cepuluk  | 2            | 2                 | 0                  | 0            | 0                | 0               | 0      | 4      | 10     | 1              | 1               | 11          | High     |
| 12  | Toengelu | 1            | 2                 | 0                  | 0            | 0                | 1               | 3      | 0      | 0      | 4              | 0               | 4           | S`village |

Source: Klaten in figures; Modified by Researcher, 2014

3. Results

3.1. GIS Model and Output Classification

The GIS functions help in managing the spatial data and visualizing the results [23]. Analysis of relocation model is split into three sub-models; physical aspect, government aspect, and community aspect. Splitting model method is intended to make a clear explanation in each step so it will be more understandable. The complete relocation model is shown in the figure below:

The output of GIS relocation model is a table and map which classified location based on its availability and accessibility status. Relocation map as the model output was divided into four classifications, i.e. not available, available with low accessibility, available with medium accessibility, and available with high accessibility. The criteria of relocation area are shown on the following table.
Table 8. Relocation Area Based on Criteria in Kemalang Sub District

| No. | Criteria                                      | Area (m²)  | Percentage (%) |
|-----|----------------------------------------------|------------|----------------|
| 1   | Not available                                | 35.43748056 | 68%            |
| 2   | Available – low accessibility                | 10.88708415 | 21%            |
| 3   | Available – medium accessibility             | 3.382845381 | 6%             |
| 4   | Available – high accessibility               | 2.722800762 | 5%             |
|     | Total                                        | 52.4302107  | 100.00         |

Source: Analysis of researcher, 2014

Figure 2. Settlement Relocation Area Map

On relocation model, governments have planned to provide 150m² land to the society for each household. The provision is 100m² for the building and 50m² for open space. The numbers of household that need to be relocated are 165. It means that government needs to provide 2.5 ha of land for relocation area. The total available areas with each level of accessibility that approved by government aspect in every village are elaborated as follows:

a. Available with low accessibility: Bawukan (67.59 ha), Bumiarjo (56.70 ha), Dompol (76.33 ha), Kemalang (33.45 ha), Kendalsari (118.71 ha), Panggang (60.90 ha), Sidorejo (110.30 ha), Talun (102.74 ha), Tangkil (103.04 ha), Tegalmulyo (103.04 ha), and Tlogowatu (233.93 ha);
b. Available with medium accessibility: Bawukan (47.32 ha), Bumiarjo (7.24 ha), Dompol (5.39 ha), Kemalang (40.37 ha), Kendalsari (9.05 ha), Kaputran (41.17 ha), Panggang (72.49 ha), Talun (11.71 ha), Tangkil (97.95 ha), and Tegalmulyo (3.64 ha);
c. Available with high accessibility: Bawukan (6.65 ha), Bumiarjo (21.76 ha), Dompol (21.94 ha), Kemalang (16.43 ha), Kendalsari (39.13 ha), Panggang (14.90 ha), Sidorejo (15.59 ha), Talun (32.82 ha), Tangkil (21.77 ha), Tegalmulyo (53.66 ha), and Tlogowatu (26.22 ha).

In contrary with government's point of view, society prefers to move communally and demands a settlement area as large as the previous neighborhood. On the interview, the chief of the residents said that every household owns about 1000m² of land in the current area. It means mathematically the overall land requirement is 16.5 ha. The total available area with each level of accessibility that approved by community aspect in every village are elaborates as follows:
a. Available with low accessibility: Bawukan (67.59 ha), Bumiarjo (56.70 ha), Dompol (76.33 ha), Kemalang (33.45 ha), Kendalsari (118.71 ha), Panggang (60.90 ha), Sidorejo (110.30 ha), Talun (102.74 ha), Tangkil (103.04 ha), Tegalmulyo (125.02 ha), and Tlogowatu (233.93 ha);
b. Available with medium accessibility: Bawukan (47.32 ha), Kemalang (40.37 ha), Kaputran (41.17 ha), Panggang (72.49 ha), and Tangkil (97.95 ha);
c. Available with high accessibility: Bumiarjo (21.76 ha), Dompol (21.94 ha), Kendalsari (39.13 ha), Talun (32.82 ha), Tangkil (21.77 ha), Tegalmulyo (53.66 ha), and Tlogowatu (26.22 ha).

In comparison to the land requirement on government aspect, the choice becomes more limited. However, this requirement can still be met even in relatively fewer options. The relocation area available according to the physical, government, and community aspect is shown on the following table and map:

![Priority Relocation Area Map](image)

Source: Analysis of researcher, 2014

Figure 3. Priority Relocation Area Map

| Village     | Area (ha) | Total Area (ha) | Relocation Area Priority |
|-------------|-----------|-----------------|--------------------------|
| Bawukan     | 4.16      | 4.16            |                          |
|             | 2.69      |                 |                          |
| Bumiarjo    | 2.91      | 9.61            |                          |
|             | 4.01      |                 |                          |
| Dompol      | 4.12      | 19.56           |                          |
|             | 12.6      |                 |                          |
| Kemalang    | 3.69      | 8.97            |                          |
|             | 5.28      |                 |                          |
| Kendalsari  | 4.8       | 13.4            |                          |
|             |           | 38.3            |                          |
|             |           | 20.1            | 2                        |
| Panggang    | 14.9      | 14.9            |                          |
| Sidorejo    | 13.6      | 13.6            |                          |
| Talun       | 5.59      | 32.39           |                          |
|             | 26.8      |                 | 3                        |
|             | 2.5       |                 |                          |
|             | 8.28      |                 |                          |
|             | 9.82      |                 |                          |
| Tangkil     | 5.67      | 23.09           |                          |
|             | 7.42      |                 |                          |
|             | 10        |                 |                          |
| Tlogowatu   | 3.8       | 50.3            |                          |
|             | 10.6      |                 |                          |
|             | 35.9      |                 | 1                        |

Source: Analysis of researcher, 2014
The final result founds that the priority relocation areas approved by the physical, government and community aspect are Tegalmulyo as the first priority with 35.9 ha area, Kendalsari as the second priority with 20.1 ha, and Talun as the third priority with 26.8 ha.

4. Conclusion

Good settlement relocation model should integrate at least three aspects: governmental, community and natural physical aspects. Those aspects have strong relations one and another, without it relocation model becomes less accurate because in reality the process will involve government as the regulator and community as the object. Moreover, natural condition is a basic factor because it is related to the conditions of an area. Government aspect becomes a priority in relocation model because it is related to the policies and regulations. Policies and regulations were made by the government through a complicated process of assessment with various considerations. Regulation about restriction is made because in fact, inadequate conditions have been found in the field. Analysis on community aspect is also very important. However, the object of relocation is communities, so the fulfillment of their needs, comforts and securities on the new settlements or environments should get more attention.

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