Managing lahar susceptibility area
(Case study in Kali Putih, Magelang, Indonesia)

Rosalina Kumalawati a,*, R. Rijanta b, Junun Sartohadi b, Rimawan Pradiptyo c, Seftiawan Samsu Rijal d

aFaculty of Teacherip Education, Universitas Lambung Mangkurat, Banjarmasin, Indonesia
bFaculty of Geography, Universitas Gadjah Mada, Yogyakarta, Indonesia
cFaculty of Economics and Business, Universitas Gadjah Mada, Yogyakarta, Indonesia
dMSc Student of Remote Sensing, Faculty of Geography, Universitas Gadjah Mada, Yogyakarta, Indonesia

Abstract

Merapi eruption in 2010 with VEI 4 cause three types of volcanic hazard; primary, secondary and tertiary. Primary hazard related with ashfall, pyroclastic surge, and lava flow. Secondary hazard occur after disaster phase, due to another triggering factor like rain and will cause lahar flow. Tertiary hazard is a long time impact of volcanic environment, loss of spring is an example for this one. From those volcanic hazard types, lahar become the most dangerous one because it impact take place along river channel. In Merapi post eruption 2010 case, the most destructive lahar was happen in Kali Putih, west flank of Merapi, as our research area.

This study has two aims, 1) to know the perception of community in lahar susceptibility area and 2) to do economics valuation related lahar, especially it materials. First aim could inform us the psychology condition of inhabitant who lived in hazard area and second aim head for build a new perspective that lahar is not only hazard but also resource due to its material could converted into profit. To reach those aims we build a comprehensive method with geographical method and economics method. Geographical method related with determining lahar susceptibility area using combination remote sensing, GIS and geomorphological approach. We use interpretation of high resolution satellite imagery to define any building in research area i.e. house, bridge, henhouse that affected with lahar and GIS for modeling lahar zonation while geomorphology assist us to know direction of lahar flow. Economics method was very useful to do the valuation of lahar. We conduct CVM (Contingent Valuation Method) because it can estimate economic value of any commodity that not usually trading by market and also this method could measure Willingness To Pay (WTP) and Willingness To Accept (WTA) in a community with emphasizing personal preference in their way to assess public goods with value currency standard.

The result shows that research area could divided into four criteria, safe zone, low susceptibility, moderate...
susceptibility and high susceptibility. Lahar overflow about 1.78 km² in five village; Gulon, Jumoyo, Seloboro and Sirahan in Salam Sub-district and Blongkeng in Ngluwar Sub-district. 4.124 building (house) stand in high susceptibility zone. Individual behavior and perceptions about lahar shows positive although its correlation is so weak. We calculate that if lahar material (sand) converted into Rupiah were equal with Rp. 462,434,733,686,- while the total amount to build a new permanent house with 90 m² is approximately Rp. 90,000,000. These means that lahar from Merapi post eruption 2010 could build 5,138 house. In this case, lahar not only become hazard but also resource, it depend on the management.

© 2013 The Authors. Published by Elsevier B.V. Selection and peer-review under responsibility of the SustaiN conference committee and supported by Kyoto University; (RISH), (OPIR), (GCOE-ARS) and (GSS) as co-hosts.

Keywords: lahar, Merapi, economic valuation, GIS

1. Introduction

Indonesia located in subduction zone of three major tectonic plates, Indo-Australia, Eurasia and Pacific. This condition make the country has a fertile soil and a lot of volcano, 129 are active and between 10-15 of them were in potential condition to erupt. One of the most active and most observed volcano in Indonesia is Merapi. It lies on 7° 32.5' south latitude and 110° 26.5' east longitude, in boundary between Yogyakarta Special District and Central Java. In 2010, Merapi erupted with VEI 4, the greatest VEI since 1822 with 150 million m³ pyroclastic materials or 5 times greater than last eruption in 2006.

Material eruption clustered in western flank of Merapi and due to the rain-triggered factor it become a lahar flow in Kali Putih and destructed several villages in Kali Putih channel as depict in figure 1. Lahar is a rapidly mudflow mixture of rock debris and water (other than normal streamflow) from a volcano. This term is Javanese origin that introduced by Scrivenor (1929) when he doing a monitoring of dynamic flow at Kelut Volcano, Indonesia and then in the 1949, Van Bemmelen try to added some definition to make it more clearly.

Lahar has a huge power to destruct anything along its stream. More than 1000 houses along Kali Putih was destructed and immobile main traffic-lane between Jogja-Semarang for a few days. Although there is no victims, lahar has sweep out their farming land and automatically the inhabitants lose their occupation and opportunity to earn the life. This condition made them try to convert their activity from farmer to the miner. They try to mining...
lahar debris such as sand, gravel and rock. In the circumstances, lahar become controversial between hazard and resource. When it come first it has a massive power to destruct but when it has passed, it leave an inheritance that could gain profit when its to be sold.

Lahar has two side of economics value, tangible and intangible. Tangible is means that the valuable of lahar whether it to be consumed or not, for instances lahar utilization to build a residence. Intangible significance with the non-valuable of lahar, its only by definition with long time environmentally maintenance. In fact, community in western Merapi volcano always think that lahar is only disaster and have no valuable thing to be used. We tried to explore the valuable thing of lahar. Our focus is to enrich community knowledge about lahar from another point of view.

2. Research Method

We do this research with two aims, first, to know the community perception in lahar susceptibility area and to do economic valuation of lahar. This chapter divided into three parts, i.e. method to define lahar susceptibility area, how to know the community perceptions and the economic valuation equations. Explanation of research method stated below.

2.1. Define lahar susceptibility area

There are four factor that influenced susceptibility level of an area i.e. geographic situation, pattern and distribution of element at risk, sensitivity and geomorphology. We build lahar hazard map by GPS tracking, cross section using laser ace and contour interpolation. GPS tracking and cross section measurement was done in the research area and contour interpolation perform with GIS Software. Element at risk condition, especially house we interpret from IKONOS imagery. Figure 2 below describe our workflow to build lahar susceptibility area.

Fig 2. Workflow to define area of lahar susceptibility

2.2. Measure the community perception

Measuring community perception in research area was conducted using Likert scale, with four multiple choice i.e. very agree scored by 4, agree equal with 3, no agree 2 and refuse 1. We try to get this primary data with in-depth interview using questionnaire with several stakeholders (village government, community and refugees). To validate the answer from every correspondence, we held a Focus Group Discussion (FGD) in three sub-district nearly Kali Putih channel, Srumbung, Salam and Ngluwar.

Questionnaire has three main parts, such as general data of respondents, building data and community perceptions. General data of respondents will be used to explore the condition of inhabitants in research area. Some question related to this points were distribution of respondents in every susceptibility level, age of respondent, respondent level of education, sex, marital status, religion and occupation. We assume among of those could influence the perception of community.

Some question about building reflect building condition after disaster phase. We want to know about it size, age, after disaster phase condition and status. Size and age of building describe the vulnerability of element at risk with
the lahar. The more wide building the more amount of losses, the more old building the more easy to damage. Community perceptions related with time of living, pretension to moving from the village after disaster, lahar experience in their life and how dangerous lahar for them. Every questions has asked in each susceptibility level, so we could compare the community knowledge and spatial distribution of it. See appendix 1 to make it more detail.

2.3. The economic valuation

Economic valuation to assess lahar impact using etic and emic. Etic is an expert approach while emic is local knowledge approach. We used Continent Valuation Method (CVM) to do this one. CVM is a method to estimate economic value of any commodity that not usually trading by market. It also could measure Willingness To Pay (WTP) and Willingness To Accept (WTA) in a community with emphasizing personal preference in their way to assess public goods with value currency standard. We set measures into two susceptibility area, high and medium with per individual household as the respondent. Valuation is only for sand and physically destruction of element at risk.

3. Results and Discussion

3.1. Lahar susceptibility area

Lahar materials consist of sand, clay, gravel and rock, the flow stream down from highest to the lowest contour value. The most widely lahar overflow was happen in Jumoyo with 0.58 km², total amount of lahar overflow was 1.78 km². As the lahar stream, many river that located in the west flank of Merapi become high level of lahar susceptibility (Kali Blongkeng, Kali Batang, Kali Bebeng and Kali Putih). We decided that high susceptibility lahar area located more less 0-50 m from the river, the riverbank was low and the slope was flat or nearly flat. Those condition could make overflow of lahar because of it velocity and volume that can not be contained by the body of river. Moderate level of lahar has a distance in 50-100 m, low level in between 101-250. Safe zone was outrange of it. But it must put an attention with the riverbank and slope condition. The more low/flat it condition the more danger due to lahar.

Lahar susceptibility area put in 41,791 houses become vulnerable. Sirahan has 1,546 houses that located in the high susceptibility area as the highest one in the research area. Number of destructed house can be found also in Sirahan with 553 houses has a highest level of destructed. We divided level of destructed house as the most affected element of risk due to lahar into five classes i.e. collapse, high damage, medium damage, low damage and no damage. Our criteria to assess it are building material, number of floor, distance from the river and lahar sediment. Based on our observation, there are only three types of building materials that is brick/concrete brick, wood and combination of both. Almost of building on the research area has only one floor and they located in between 0-250 m from the river. Every house that located in the 0-100 m with 3 m lahar sediment certainly collapse. All of that, building with wood as it materials experience the worst damage although it only 1 m of lahar sediment. Minimum level that can be reached in the 3 m lahar sediment is heavy damage in every building material and distance.

The mapping of susceptibility area could make our settlement planning post lahar event more accurate, see figure 3. Settlement planning related with another physically development such as school, medical, road, bridge etc. If we can create it almost accurate we can adapt the nature phenomenon, because we could not avoid natural hazard but we could reduce the impact of it. Natural activities such as volcano and earthquake could not be stopped and nearly unpredictable, so human must have an attention with sign of nature and try to living harmony with it.

3.2. The community perception

We propose several questions to analyze the community perception related lahar, i.e. general information about respondent, their perception and distribution related lahar characteristic, and relationship between behavior and perception. The result shows community assumes that lahar hazard in their resident was medium, they are not affected seriously with lahar although in fact lahar could make their house collapse. There are no different invention
in every susceptibility lahar hazard level, the community still with their mind stated that lahar was a medium not high or low risk (see figure 4).

Fig 3. Lahar susceptibility in five most destructed village. Color gradation indicate susceptibility level, more dark more susceptible

3.3. Lahar as medium dangerous disaster

Commonly there are no different between any person who lived in different lahar susceptibility area. They are agreed with lahar is medium dangerous disaster (figure 4). This statement appropriate with basic theory “a person who ever experience with disaster could have more knowledge about it”\textsuperscript{9,10} and then they know how to react if
disaster are coming. As our primary data shows that the community who being our respondent is a natural inhabitant, they had lived there since 29 up to 58 years ago and 88,14% among them have experience the lahar before the 2010 event. It could bring their mind that lahar was not dangerous disaster. But, now the situation of Merapi eruption and its following hazard is totally different with its last eruption in a decade. Lahar as its secondary hazard flow through Kali Putih with more than 50 times lahar occurrences has changed their though to select the options into lahar is a very dangerous disaster with 42,2%, just slightly different about 13% with medium dangerous options which had 55,3%.

As lahar is a medium dangerous disaster, they would not to move from their village, all of our respondents has same choice of it. The community though that lahar only occur when Merapi has an eruption, then it just happen within 4 until 5 years once and if lahar come it only happen in a few days, they can move to the refugee shelter for a while then coming back to their village although the situation of their house were coming apart, they can build it together with ‘Gotong Royong” an Indonesian term for working together to build or do something. There is also another reason that could make the community wont to be moved. The y are afraid if in the new place, they had no suitable job or living guarantee that equal with as they have before.

According to these condition, we suggest for those has any responsibility to them must giving a socialization first with anything related lahar or volcanic disaster. Try to make them more understand that they are living in the lahar path, inform them that lahar has three main triggering factor i.e. rain-fall, eruption with rain-fall and collapse of crater so that lahar could happen not only in eruption phase but also in the rainy season. And second, if the stakeholder want to relocate them, they must make sure that in the new site, inhabitant have a guarantee to get another activity that equal or more than that they have in the last village. Bring proof of it that living in the new place make them more happy/rich than before. Or, if they still wont to move from their old village, we must build
some spatial settlement allocation that was not lies on the lahar path, because the direction of lahar path could be prediction so we can bring the settlement more safety.

3.4. The economic valuation

Sabo DAM (lahar controlled structure) in figure 5, could not retain lahar in the 2010 case. All of Sabo DAM in Kali Putih stream designed to hold up approximately 1.172.160 m³ while in the last event, lahar volume were about 7.707.245 m³ or more than 600% bigger than estimation. It makes 17 Sabo DAM along Kali Putih become shattered. To normalize the river condition that fully dominated with lahar material, the activity of lahar material mining have been made. People carry away lahars sand, rock and gravel using several heavy equipment such as bulldozer, excavator and saver then sell it to the another city around Central Java Province. These activities does not done by natural inhabitant that lived there, it was people or company from another city that have a huge financial capital. Natural inhabitant rarely to be worked there, it implies they could not get a benefit from lahar material.

Fig 5. Latest condition of Sabo DAM in Jumoyo (a) and Srumbung (b) after lahar phase

Economic valuation of lahar plays a big role on this way. We must open the inhabitant and government eyes that lahar could converted into Rupiah if the management worked well. From our field observation, sand material price were about Rp. 60.000 per m³ and if it multiplied by total lahar volume in along Kali Putih as we stated above then the total amount is Rp. 462.434.733.

People building size in the research area dominated with less than 193 m² (appendix 1 questions number 8), we agreed with 90 m² as our standard building size. So we can converting the total amount of lahar’s sand into the amount of house that could be build. Three different standard price were propose, ministry of public works with Rp. 2.441.700/m², Indonesia statistical bureau (BPS) and BAPPEDA with Rp. 1.300.000/m², contractor with Rp. 1.250.000/m², and community standard price Rp. 1.000.000/m². We do calculating using community standard price because it can reflect natural condition of community and they have minimum standard price for every type of house, i.e. permanent house, semi-permanent and non-permanent. By using Rp. 462.434.733.686 it could build 5.138 houses unit. So, lahar in research area could become resource and make some profit for the community. Lowest disadvantages due to collapse of element of risk was experienced by non-permanent house with Rp. 9.430.000 and the most disadvantage is permanent house, their collapse equal with Rp. 104.000.000.

<table>
<thead>
<tr>
<th>Table 1. Standard price to build a 90 m² house</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price standard</td>
</tr>
<tr>
<td>Ministry of public works</td>
</tr>
<tr>
<td>Contractor</td>
</tr>
<tr>
<td>BPS/BAPPEDA</td>
</tr>
<tr>
<td>Community</td>
</tr>
</tbody>
</table>
4. Conclusion

Research area could divide into four criteria of susceptibility area, i.e. high susceptibility, medium susceptibility, low susceptibility and safe zone. The main parameters to decide it were riverbank condition and degree of slope. High susceptibility area covering four villages, three villages in Salam Sub-district (Gulon, Jumoyo and Sirahan) also one village in Ngluwar Sub-district (Blongkeng). Sirahan is the most destructed village due to lahar from Merapi 2010.

There is only one perception of lahar from the community who lived in the different susceptibility criteria, that is Medium (>50%). They do not think that lahar is the most deadly hazard due to Merapi eruption. Several factor that could influence their mind to think like that are period of disaster, magnitude and livelihood issue. Different condition of susceptibility are not has effect their thought. Collecting community perception is not easy to work. We need to build up enumerator capacity because they represent us to facing the respondent. Similarity thinking level between researcher and enumerator about the questionnaire need to be arrived, then expectable answer likely to be found. Enumerator must have a skill to explain what we want to reach within this research and they know how to delivered the question to the respondent, because maybe some question in the questionnaire are sensitive and it could be disturb their privacy. So, preparing the enumerator become mainly agenda on this research type.

Sand material from lahar equal with Rp. 462.434.733.686 if it being sold and this is same with the total amount to build 5.138 houses unit with every single unit has 90 m² in size. Whereas, number of houses that destructed due to lahar were ‘only’ 1.290 houses. Quantity of houses that can be build using lahar material (sand) exceed the destructed house; so based on this invention we can say that lahar could be profitable for the community. We only calculate sand from lahar composition. There are still rock and gravel that have not been yet calculated. For those want to do same research there is still a chance to doing with rock and gravel.

Acknowledgements

This paper is part of Rosalina Kumalawati’s Dissertation. We are very thankful for any person who has ever in charge with it (family, assistant, colleague, etc.) and specially to our supervisor; Prof. Dr. R. Rijanta, Prof. Dr. Junun Sartohadi, and Dr. Rimawan Pradiptyo who were successfully encourage and guide us together to finish this research.
### Appendix A. Percentage of respondent answer (n = 1021)

<table>
<thead>
<tr>
<th>No.</th>
<th>Questions</th>
<th>Answer (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Number of respondent in each level of susceptibility</td>
<td>High: 40.4, Medium: 13.6, Low: 42.2, Safe: 3.8</td>
</tr>
<tr>
<td></td>
<td>Age of respondent</td>
<td>15-34 yo: 10.28, 35-54 yo: 65.13, 55-75 yo: 23.01, &gt;76 yo: 1.56</td>
</tr>
<tr>
<td>2</td>
<td>Respondent level of education</td>
<td>ES: 44.66, JHS: 20.37, SHS: 26.64, Bachelor: 8.32</td>
</tr>
<tr>
<td>3</td>
<td>Sex</td>
<td>Male: 82.27, Female: 17.72</td>
</tr>
<tr>
<td>4</td>
<td>Marital Status</td>
<td>Single: 1.66, Widower: 1.76, Widow: 8.52, Married: 88.05</td>
</tr>
<tr>
<td>5</td>
<td>Religion</td>
<td>Islam: 98.04, Catholic: 0.58, Christian: 1.07, Hindu: 0.29</td>
</tr>
<tr>
<td>6</td>
<td>Occupation</td>
<td>Farmer: 29.18, Laborer: 27.32, Enterpreneurship: 20.76, Others: 22.72</td>
</tr>
<tr>
<td>7</td>
<td>Building size</td>
<td>&lt;193 m²: 94.02, 193 - 386 m²: 4.6, &gt;386 m²: 1.37</td>
</tr>
<tr>
<td>8</td>
<td>Building age</td>
<td>&lt; 10 yrs: 25.17, 10 - 19 yrs: 40.74, 20 - 29 yrs: 34.08, &gt;30 yrs: 0</td>
</tr>
<tr>
<td>9</td>
<td>Building condition after lahar event</td>
<td>No Damage: 38.49, Low Damage: 43.09, Medium Damage: 9.69, Heavy Damage: 8.71</td>
</tr>
<tr>
<td>10</td>
<td>Ownership</td>
<td>Own: 92.85, By Family: 6.46, Rental: 0.68</td>
</tr>
<tr>
<td>11</td>
<td>Community perception</td>
<td>&lt; 29 yrs: 38.39, 29 - 58 yrs: 52.39, &gt; 58 yrs: 9.2</td>
</tr>
<tr>
<td>12</td>
<td>How long you living there?</td>
<td>Yes: 0, No: 100</td>
</tr>
<tr>
<td>13</td>
<td>Do you have a plan to move from your village after this condition?</td>
<td>Yes: 88.14, Never: 11.85</td>
</tr>
<tr>
<td>14</td>
<td>Have you experience the lahar event?</td>
<td>Very Dangerous: 42.2, Medium Dangerous: 55.3, Low Dangerous: 2.4</td>
</tr>
</tbody>
</table>
References