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# Spatial Disaster Risk Assesment of Kelud Eruption, Indonesia, using Fuzzy

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***Abstract*— Indonesia is one of the countries included in the area of the Ring of Fire or the Ring of the Pacific. This fact can be seen that in Indonesia there are 129 active volcanoes and 10 of them are the most active volcanoes. Mount Kelud is the most active volcano in the province of East Java, Indonesia. This mountain is recorded as actively erupting with a relatively short span of time (9-25 years), making it a volcano that is dangerous for humans. Readiness of citizens is very necessary as an effort to prevent and anticipate the eruption of Mount Kelud in the future. Disaster risk level assessments are needed to provide information for citizen and government preparedness in the face of volcanic eruptions. In this paper a new approach is proposed to assess the level of disaster risk of Kelud eruption using Fuzzy methods in each village in the disaster-prone area (KRB). Fuzzy methods classify disaster risk levels based on criteria of hazards, vulnerabilities and index of capacities. The level of disaster risk is divided into low, medium, and high which are spatially mapped. The result of calculations and spatial visualization show that the approach used produces a level of disaster risk that is fairer than only based on hazard.**

***Keywords*— disaster risk, fuzzy, spatial mapping, hazard, vulnerability, index of capacity.**

## I. INTRODUCTION

Indonesia is included in the "Ring of Fire" or Pacific Ring of Fire, this fact can be seen that in Indonesia there are 129 active volcanoes. 10 of them are stated as the most active volcanoes. Mount Kelud in East Java Province is one of the most active volcanoes in Indonesia.

East Java is one of the provinces prone to natural disasters. It was noted that East Java was ranked second after Central Java as the province most often hit by natural disasters. One of the most vigilant and quite frequent natural disasters is a volcano erupting. Because in East Java there are 48 mountains and 7 of them are declared still active so eruptions can occur at any time. One of the frequent eruptions is Mount Kelud. Mount Kelud is on the border of 3 regions, that is Kediri, Blitar, and Malang district, where Kediri District are the worst affected areas when Mount Kelud erupts. This fact is supported by data from the National Disaster Management Agency (BNPB) that Kediri Regency are included in the high risk level on the volcano disaster risk index. Until now the status of Mount Kelud is still declared vigilant by the Centre of Volcanology and Geological Hazard Mitigation (PVMBG).

Considering that the eruption of Mount Kelud is difficult to predict, the awareness of citizens about disaster prevention and mitigation efforts is more important to be done in anticipation of the eruption of Mount Kelud in the future. So that an application is needed so that the government and society have good preparedness for disaster mitigation and are able to give special attention to areas that have a high level of risk.

This paper proposes to make efforts to mitigate (reduce risk) disasters in each village in Mount Kelud disaster-prone areas (KRB) by determining the risk level assesment where the criteria used include: hazard, vulnerability and capacity using fuzzy method.

From the government side, the information can be used as a reference for the Regional Disaster Management Agency (BPBD) of Kediri District to pre-mitigating, at and after the eruption of Mount Kelud. In addition, this information can also be used as a recommendation in carrying out infrastructure development planning such as roads, bridges, tourist areas, etc. in Mount Kelud disaster-prone areas.

## II. STUDYAREA

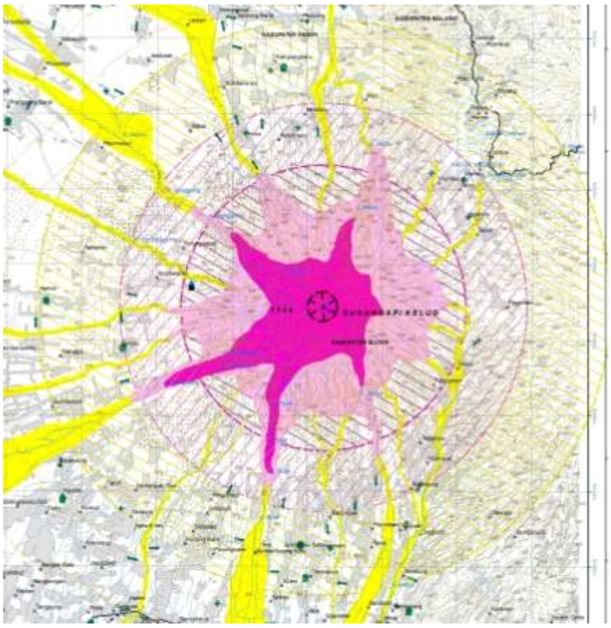

Fig. 1 Map of Kelud prone areas

The study area is located in Mount Kelud. Mount Kelud (Klut, Coloot) is one of the Strato volcanoes that is still active today. Mount Kelud is located at 7 ° 56 '00 South Latitude and 112 ° 18 ’30 ″ East Longitude. Administratively it is located on the border between three districts, that is Kediri, Blitar, and Malang district.

According to the guidelines issued by the Centre of Volcanology and Geological Hazard Mitigation (PVMBG) in 2011, the Mount Kelud region was divided into 3 zones of Volcanic Disaster Areas (KRB). Where the area is KRB I, KRB II, and KRB III. Each KRB zone consists of flow zones and drop zones which have different weight values based on their vulnerability.

## III. METHODOLOGY

Figure 2 shows the diagram system of risk assessment map. Detailed explanation of block diagram system are as follows:

1.0 This is the process of calculating the Disaster Threat Index from the KRB Mount Kelud map with data from the affected villages obtained from the PVMBG.

2.0 It is the process of collecting related data from each approach used, namely: threats, vulnerabilities and capacities. For threats using the disaster threat index that has been obtained from the first process. For vulnerability use Population Density data which represents exposed population indexes and Productive Land Area which represents index of environmental loss and damage. The capacity index uses data on the number of medical personnel. Except for the Disaster Threat Index, each data is obtained from the Statistical Center Board (BPS) Kediri and Blitar district.

3.0 The process of entering data in a predetermined format so that it can be saved to the database.

4.0 The process of storing data into a prepared database.

5.0 The process of processing data using the fuzzy method. This process will provide an output in the form of risk level assesment for each village.

6.0 It is a process that produces a Disaster Risk Index from each village.

7.0 It is a process to display data into a website and visualize it on a map.

8.0 User whose access rights have been restricted, such as only being able to see previously processed data.

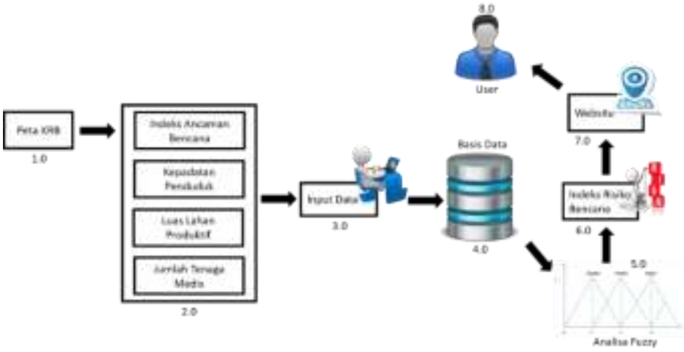


Fig. 2 System design

### A. *Statistical Analysis*

Correlation statistical analysis is used to find out influence of parameters on risk level assesment. Based on Table 1 show the correlation of each variable used, Each variable used and its relevance to the disaster risk index to determine the level of risk according to PERKA BNPB No. 2 of 2012.

TABLE I
COMPARISON CORRELATION VALUE BETWEEN VARIABLE

| Variable Name | Indicator | Value | Assumption |
|---|---|---|---|
| Hazard | Disaster Prone Areas (KRB) (source: PVMBG 2014) | Classification of disaster prone areas is adjusted by welding from PVMBG | Areas with a high level of disaster-prone areas, the higher the index of hazard |
| Vulnerability | Polpulation Density | Comparison of population per area | The greater the value of population density, the higher the index of vulnerability |
| | Productive Land Area | Produtive land area in each village | The wider the productive land, the higher the index of vulnerability |
| Capacity | Mumber of Medical Personnel | Number of medical personnel per village | The greater the number of medical personnel, the higher of index of capacity |

### B. *Fuzzy Method Analysis*

Fuzzy logic is an increase of Boolean logic which deals with the concept of partial truth. When classical logic states that all things can be expressed in binary terms (0 or 1, black or white, yes or no), fuzzy logic replaces the boolean truth with the level of truth. Fuzzy logic allows membership values between 0 and 1, gray level and also black and white, and in linguistic form, uncertain concepts such as "low", "medium", and "high". This logic is related to fuzzy sets and probability theories. Fuzzy logic was introduced by Dr. Lotfi Zadeh from the University of California, Berkeley in 1965.

In this chapter, we will explain in detail the fuzzy calculations starting from the data used and inserted until the output is in the form of a level of risk.

1. Fuzzy Input

At this stage determine and sort any data which will be used as fuzzy input. The following parameters of the data used:

- Index of hazard
- Population density
- Productive land area
- Member of medical personnel

2. Fuzzification

Looking for membership values for each parameter. Based on table 2 show the limit for each parameter based on PERKA BNPB.

TABLE 2
INPUT RANGE VARIABLE

| Parameter | Low | Medium | High |
|---|---|---|---|
| Index of hazard | 0.33 | 0.67 | 1 |
| Population density | 0-500 people/km$^2$ | 500-1000 people/km$^2$ | >1000 people/km$^2$ |
| Productive land area | <25 ha | 25-50 a | >50 ha |
| Number of medical personnel | 0-5 person | 5-10 person | >10 person |

Figure 3 show graph variable membership function in fuzzy method.

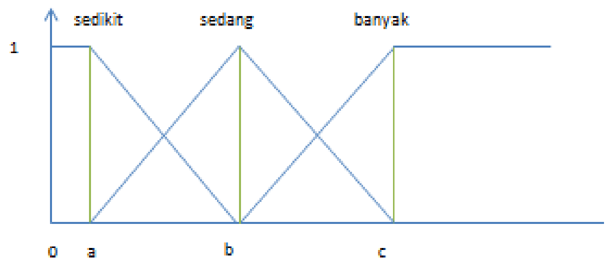

Fig. 3 fuzzy set of

Membership Function:

µVARIABELlow[x]:

1; x ≤ a *(1)*

(b-x)/(b-a) ; a ≤ x < b *(2)*

0; x ≥ b *(3)*

µVARIABELmedium[x]:

0; x ≤ a atau x ≥ c *(4)*

(x-a)/(b-a); a ≤ x < b *(5)*

(c-x)/(c-b); b ≤ x < c *(6)*

µVARIABELhigh[x]:

0; x ≤ b *(7)*

(x-b)/(c-b); b ≤ x < c *(8)*

1; x ≥ c *(9)*

In formula 1 until 9 show how to determine membership functions for each variable.

3. Implications of Rule

In the process of implicating the rule is the determination of each predicate value of each rule used in the defuzzification process. Every fuzzy process that is executed will form several rules according to the number of membership functions, if each fuzzy variable has two membership functions all then the number of rules fuzzyis two to the power of four. The value of the rank depends on the number of fuzzy variables that have two values on membership search.

TABLE 3
RULE EVALUATION

| No | Hazard | Pupulation density | Productive land area | Number of medical personel | Singleton |
|---|---|---|---|---|---|
| 1 | low | low | low | low | 2 |
| 2 | medium | medium | medium | medium | 1 |
| 3 | medium | high | medium | medium | 3 |
| 4 | high | medium | medium | high | 2 |
| 5 | high | high | high | high | 3 |

In Table 3 show 5 of a total 81 evalution rules. For example

IF HIGH hazard AND population density are HIGH AND productive land area is HIGH AND the number of medical personnel is LOW THEN HIGH

SINGLETON = 3

Predicate = (1; 0.828; 1; 1) = 0.0828

4. Defuzzification

Defuzzification is the process of determining the magnitude of the degree value fuzzy by searching for z values using a formula that can be seen in formula 10 below. By using fuzzy logic can be represented how the state of a place where numerical variables can be drawn intoconclusion *a* linguistic. Each variable has its own influence and contribution in determining fuzzy results because each variable will have its own membership function. Below is the formula used to find the value of *Crips* Fuzzyor commonly called the Defuzzification process. The result of the defuzzification value becomes the final value of the fuzzy process before it is processed into linguistic values.

$$Crisp\ Output = \frac{\Sigma_i\ (output\ fuzzy_i) \times \Sigma_i\ (singleton\ position\ on\ x\ axis_i)}{\Sigma_i\ (fuzzy\ output_i)} \qquad (10)$$

Fuzzy Output = Is a fuzzy output value of each rule (predicate).

Singleton = Is the weight of each predetermined rule.

5. Output Rule

Table 3 below shows the final value classification of *output* fuzzyused to determine the risk level of each village in KRB.

TABLE 4
FUZZY *OUTPUT* RANGE

| No. | Range | Output |
|---|---|---|
| 1 | 0 – 1.5 | low |
| 2 | 1.5 – 2.5 | medium |
| 3 | >2.5 | high |

After defuzzification process defuzzification value of the results will be adjusted with the above table 4 to determine the risk level of each village included in the *range* of low, medium or high.

## IV. Result and Discussion

In this section we discuss about the result and analysis of fuzzy method.

Figure 4 shows the risk level of each village included in the Mount Kelud Disaster Prone Areas (KRB).

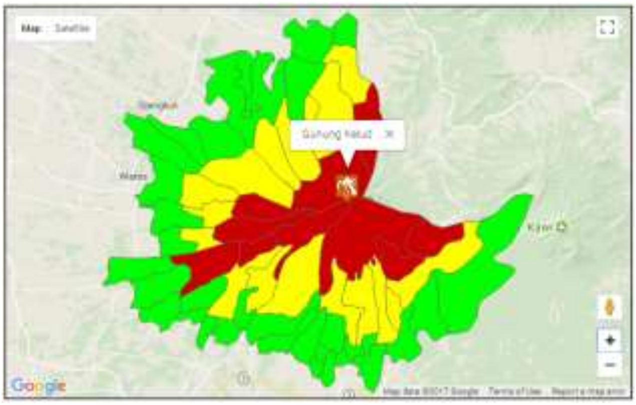

Fig. 4 *Hazard KRB Map*

There are a total of 56 villages included in thering KRB G. Kelud. More details, there are 32 villages included in KRB I (low) symbolized as green, 16 villages included in KRB II (medium) are symbolized as yellow, and 8 villages included in KRB III (high) are symbolized as red. This classification is based on areas that have the potential to be exposed to volcanic material in the form of flow and fall.

In figure 5 and 6 below, it shows the level of risk of each village in the Mount Kelud Disaster Prone Areas (KRB) in 2014 and 2015.

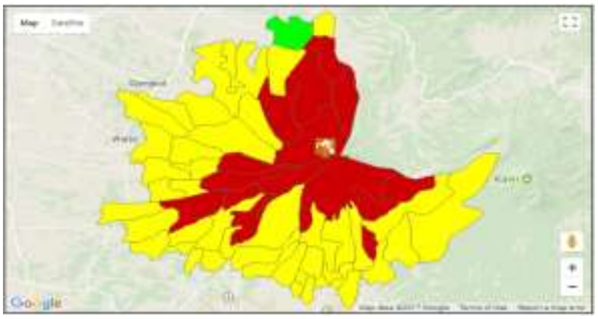

Fig. 5 *Risk level map for 2014*

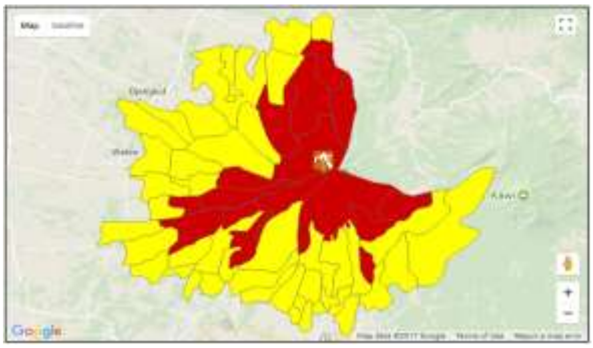

Fig. 6 *Risk level map for 2015*

In 2014 there were 1 village with a low risk level, 42 villages with moderate risk levels and 13 villages with high risk levels from a total of 56 villages. In 2015 there were 42 villages with moderate risk levels, 14 villages with high risk levels and no villages included in the low risk level of a total of 56 villages.

Table 5 below presents differences in the level of risk over a period of 2 years, 2014 and 2015.

TABLE 5
DIFFERENCES IN RISK LEVELS IN 2014 AND 2015

| No. | Village | 2014 | 2015 |
|---|---|---|---|
| 1 | Kepung | low | medium |
| 2 | Manggis | medium | high |

Judging from the results had the percentage rate difference with a value that is quite small at 4% or as much as two villages of a total of 56 villages due to changes in the data in each village for each of the criteria used during the period of 2 years not too significant. All villages that have different risk levels have increased risk levels from 2014 to 2015.

In Kepung village there is an increase in the level of risk because in 2015 there was a very rapid increase in population density, from 109 people/km² to 1088 people/km². While in the village of Manggis also experienced an increase in population density, but not too fast that is of 624 people/km² to 634 people/km² thus affecting the value of the original defuzzifikasinya under rule outpur range 2.5 to over rule outpur range 2.

### A. *Comparison of Risk Level Assesment by Fuzzy Method and Hazard PERKA*

1. In 2014

In table 5 below presents the difference in risk levels for 2014 with Hazard PERKA. A total of 36 villages have different risk levels and the remaining 20 villages out of a total of 56 villages have risk levels that are in accordance with hazard PERKA.

TABLE 6
RISK LEVEL COMPARISON OF 2014 WITH HAZARD PERKA

| No. | Village | Hazard PERKA | 2014 | No. | Village | Hazard PERKA | 2014 |
|---|---|---|---|---|---|---|---|
| 1 | Kampung baru | medium | high | 19 | Sukosewu | low | medium |
| 2 | Siman | medium | high | 20 | Slumbung | medium | medium |
| 3 | Brumbung | low | medium | 21 | Slorok | low | medium |
| 4 | Margourip | low | medium | 22 | Sidodadi | low | medium |
| 5 | Pandantoyo | low | medium | 23 | Kemloko | low | medium |
| 6 | Jagul | low | medium | 24 | Ngoran | low | medium |
| 7 | Jarak | low | medium | 25 | Nglegok | low | medium |
| 8 | Plosokidul | low | medium | 26 | Modangan Dua | low | medium |
| 9 | Wonorejo Trisulo | low | medium | 27 | Modangan | medium | high |
| 10 | Puncu | medium | high | 28 | kedawung | low | medium |
| 11 | Asmorobangun | low | medium | 29 | Karangbendo | low | medium |
| 12 | Manggis | low | medium | 30 | Candirejo | low | medium |
| 13 | Sumberagung | low | medium | 31 | Sidorejo | low | medium |
| 14 | Gondang | low | medium | 32 | Jajar | low | medium |
| 15 | Kotes | low | medium | 33 | Tembalang | low | medium |
| 16 | Tambakan | low | medium | 34 | Ngadirenggo | low | medium |
| 17 | Butun | low | medium | 35 | Tegalasri | low | medium |
| 18 | Gandusari | low | medium | 36 | Balerejo | low | medium |

2. In 2015

In table 7 below presents the difference in risk levels for 2014 with Hazard PERKA. 38 villages have different risk levels and the remaining 18 villages out of a total of 56 villages have the same level of risk as hazard PERKA.

TABLE 7
RISK LEVEL COMPARISON OF 2015 WITH HAZARD PERKA

| No | Village | Hazard PERKA | 2014 | No | Village | Hazard PERKA | 2014 |
|---|---|---|---|---|---|---|---|
| 1 | Kampun gbaru | medium | high | 20 | Gandusari | low | medium |
| 2 | Siman | medium | high | 21 | Sukosewu | low | medium |
| 3 | Brumbu ng | low | medium | 22 | Slumbung | medium | high |
| 4 | Kepung | low | medium | 23 | Slorok | low | medium |
| 5 | Margour ip | low | medium | 24 | Sidodadi | low | medium |
| 6 | Mangost een | medium | high | 25 | Kemloko | low | medium |
| 7 | Pandant oyo | low | medium | 26 | Ngoran | low | medium |
| 8 | Jagul | low | medium | 27 | Nglegok | low | medium |
| 9 | Jarak | low | medium | 28 | Modangan Dua | low | medium |
| 10 | Plosokid ul | low | medium | 29 | Modangan | medium | high |
| 11 | Trisulo Wonorej o | low | medium | 30 | kedawung | low | medium |
| 12 | Puncu | medium | high | 31 | Karangben do | low | medium |
| 13 | Asmoro bangun | low | medium | 32 | Candirejo | low | medium |
| 14 | Manggis | low | medium | 33 | Sidorejo | low | medium |
| 15 | Sumber agung | low | medium | 34 | Jajar | low | medium |
| 16 | Gondan g | low | medium | 35 | Tembalang | low | medium |
| 17 | Kotes | low | medium | 36 | Ngadireng go | low | medium |
| 18 | Tambak an | low | medium | 37 | Tegalasri | low | medium |
| 19 | Butun | low | medium | 38 | Balerejo | low | medium |

In Modangan village, the village is a village unit with Modangan Dua but because the area is very large it is divided into 2 hamlets. The two hamlets have different threat indices. Modangan Dua has a low threat level while Modangan has a moderate threat level even though all data from each criterion are the same. So that it can be seen that the value of the threat has a big effect on the level of risk. In addition, the Modangan village has a high productive land area of 178 ha so that the risk level increases because the level of loss and damage to the environment will be high if an eruption occurs.

Judging from the results of the risk level mapping in 2015, all villages that had different risk levels experienced an increase in the level of risk because the data in each criterion was in the *range* and high weight.

## V. CONCLUSIONS

This application determines the risk level assesment for each village in Mount Kelud disaster-prone areas using fuzzy method, where the criteria used include: hazard, vulnerability and capacity. By using fuzzy method, the results are classified into three levels of risk that is high, medium and low.

Based on the results of the trials from the Regional Disaster Management Agency of Kediri District which has been validated with Hazard PERKA National Disaster Management Agency, spatial disaster risk assesment of Kelud Eruption declared accurate.


## ACKNOWLEDGMENT

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