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STATEMENT

Hereby I, Candra Dewi, do declare that this thesis entitled “Spatial Multi Criteria Analysis for Detecting Mud Volcano Vulnerable Area in Sidoarjo Regency, East Java Province” is my own work and has not been submitted in any form for another degree or diploma programs (course) to any University or other institution. The content of the thesis has been examined by the advising committee and the external examiner.

Bogor, August 2008

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Managing an area for further planning requires information on risk level of area from natural hazard. Since May 29th 2006, a sea of hot mud has been gushing from the ground in Sidoarjo, East Java which caused economic, social, health and environmental impacts. Determining vulnerable area of hot mud volcano is important to provide information on the extent of the areas affected by the hazard. Vulnerability analysis requires set of factors determining dangerous level of particular area from a defined hazard source. Vulnerability analysis for natural hazard also deals with vagueness arising from expert judgment on related parameters.

The objectives of this research were to develop multi-criteria evaluation method using fuzzy analysis approach for mud volcano vulnerable area and to develop mud volcano vulnerable map using proposed method. This research handles imprecision and subjectiveness involved in expert knowledge by using Fuzzy Analytical Hierarchy Process (AHP). The alpha cut analysis and lambda function was performed in Fuzzy AHP process to assess the confidence level of experts about their preference.

The method was then applied to generate mud volcano vulnerability for settlement area in Sidoarjo. The criteria used in the evaluation consist of subsidence, bubble gases, mud flooded and water quality. The experts that give their judgment in form of Pairwise Comparison Matrix (PCM) represent all elements of the society such as The National Sidoarjo Mudflow Mitigation Team (BPLS), Settlement Agency of Sidoarjo, Centre of Environmental Geology, academic disaster researchers and the public as a victim of Lapindo mud. Having established Fuzzy AHP to obtain criterion performance, the spatial analysis was done by applying this performance to criterion layer to create vulnerability area. The sensitivity analysis of the method was analyzed by using alpha cut (values 0.4, 0.6 and 0.8) and lambda function (values 0, 0.5 and 1). Performing these alpha cut and lambda value showed the highest sensitivity could be observed at alpha 0.4 and lambda 0.

The comparison of vulnerability map resulted from applying Fuzzy AHP method at 100% confidence level with impacted area prepared by BPLS showed that these two maps have different class of vulnerability. The result of multi-criteria analysis showed that settlement areas located in impacted area were mostly categorized as high and moderate vulnerable class, while impacted area prepared by BPLS was categorized as high hazardous area. However, the surface area of the merged class Z1 and Z2 from vulnerability analysis covered area was almost same with impacted area prepared by BPLS.

Key words: Vulnerability analysis, Multi-criteria Evaluation Method, Fuzzy AHP, Alpha cut, Lambda function, Spatial analysis
SUMMARY


Managing an area for further planning require information about risk level of the area from natural hazard. Since May 29th 2006, a sea of hot mud has been gushing from the ground in Sidoarjo, East Java that caused several economic, social, health and environmental impacts. Determining vulnerable areas of mud volcano are important for the government of Sidoarjo to provide information about the extent of the areas affected by the hazard and the areas that still potential be further developed to reduce the impact of hazards.

Vulnerability analysis requires set of factors determining dangerous level of particular area from a defined hazard source. Vulnerability analysis for natural hazard also deals with vagueness arising from expert judgment on related parameters. The objectives of this research were to develop multi criteria evaluation method using fuzzy analysis approach for mud volcano vulnerable area and to develop mud volcano vulnerable map using proposed method. This research handles imprecision and subjectiveness involved in expert knowledge by using Fuzzy Analytical Hierarchy Process (AHP). The alpha cut analysis and lambda function is performed in Fuzzy AHP process to assess the confidence level of experts about their preference.

Determining criteria for mud volcano vulnerable analysis was done by examining a relevant literature, interview and discussion with some expert from several institutions. A number of physical criteria used in evaluation were identified based on the impact of hazard in a surface. These criteria consist of subsidence, bubbles gases, mud flooded area and water quality, while bubble gases consist of methane, hydrogen sulfide and carbon dioxide.

Defining class boundaries of the criteria require expert knowledge. The importance of one criterion to the other criterion in Pairwise Comparison Matrix is obtained from expert judgment. The experts who gave their judgment represent all elements of the society such as The National Sidoarjo Mudflow Mitigation Team (BPLS), Settlement Agency of Sidoarjo, Centre of Environmental Geology, academic disaster researchers and the public as a victim of Lapindo mud. This crisp PCM is used as an input of vulnerability assessment using Fuzzy AHP approach.

PCM from AHP was fuzzified to get the Fuzzy PCM by using triangular membership which has three values (Lower, Middle, and Upper). This fuzzification is performed over criteria weight matrix and criterion rating matrices within the values ranging from 1/9 to 9. Fuzzy extent analysis then was applied on fuzzy PCM to obtain the fuzzy performance rating of each alternative with respect all criteria and fuzzy weight. A fuzzy weighted performance then was obtained by multiplying the fuzzy weight with the fuzzy performance.

The alpha-cut analysis was used to avoid the complex process of comparing fuzzy utilities. Alpha-cut enables the decision makers or experts
confidence about the preference or judgment that has been made. Applying the $\alpha$-cut lower than 1 result the interval performances over the fuzzy weighted performance. The crisp performance from these intervals then was obtained by applying lambda function. Lambda function enables to include the decision maker or expert attitude about judgment has been made.

The crisp performance values of each criterion acquired from fuzzy AHP analysis were used to generate vulnerability map. Firstly, criteria layers are classified accordingly to the vulnerability class (Z1 – Z4). The next step is to apply crisp performance value that is acquired from fuzzy AHP process to each criterion map to obtain weighted criteria layers. After that, combines the weighted value of criterion map by summing up the crisp performance value of map layers. This will give the final result of vulnerability ratings at the final level. The final vulnerability ratings are then classified into final vulnerability map. The classification will be based on the value for Z1 – Z4 acquired from performances/weights calculation.

The method was applied to generate mud volcano vulnerability for settlement area in Sidoarjo by implementing spatial analysis. Based on vulnerability analysis at 100% confidence of expert, it was found that the high hazardous area (Z1) covers about 10.9% of the total settlement area, while 25% were considered as moderate hazardous area (Z2), 49.6% as low hazardous area (Z3) and 14.4 as not impacted area (Z4).

Sensitivity analysis is used to enlighten the effect of uncertainty in expert knowledge. The Fuzzy-AHP provides the sensitivity analysis that can be performed by changing in the values of the alpha ($\alpha$) and lambda ($\lambda$). This research used alpha values 0, 0.6 and 0.8 to address the confidence of expert preference and lambda values 0, 0.5 and 1 to fit the attitude of the expert about their preference or judgment.

Based on vulnerability analysis at alpha 0.4 and lambda 0, the low hazardous class (Z3) covers 51.4% of the available settlement area, 37% of the area is categorized as high hazardous class (Z1), 8.2% of the area as moderate hazardous (Z2) and 3.4% of the area recognized as not impacted class (Z4). At alpha 0.4 and lambda 0.5, class Z3 decreases to 37% of the area although it still covers the largest area, class Z2 covers 36.1% of the total area, class Z4 covers 26.9% of the total area, while class Z1 is restricted, it does not occupy any area. At alpha 0.4 and lambda 1, the classes perform the same order as under $\lambda = 0.5$. Area with low hazardous class consist of 38.6% of the total area, followed by moderate hazardous covering 36.5% and not impacted class with 24.9% of the total area. The high hazardous area is not available under this lambda value.

Based on vulnerability analysis at alpha 0.6 and lambda 0, all of vulnerable classes are identified and the most areas belong to low hazardous class covering 49.6% of the total area. The moderate hazardous class covers 25% of area. The not impacted class and high hazardous class cover 14.4% and 10.9%, respectively, of the total area. Using alpha 0.6 and lambda 0.5, class Z3 still has the largest area covering 50.2% of the total area and Z2 covers 35.8% of the area. Class Z4 occupies 13.6% and class Z1 is restricted to only 0.4% of the area. Using alpha 0.6 and lambda 1, the moderate hazardous class squeezes to 39.7% of the total area, followed by class Z2 covering 36.5% of the area, while Z4 extends to 23.8% of the area. The high hazardous class is uncovered for this lambda value.
Based on vulnerability analysis at alpha 0.8 and lambda 0, the low hazardous class covers 50% of the available area, 25% of the belongs to moderate hazardous class, 14.1% of area is categorized as not impacted class and 10.9% area is recognized as high hazardous class. At alpha 0.8 and lambda 0.5, class Z3 dominate with 50% of the total area and Z2 is restricted only to 32.7% of the area. Class Z4 cover 13.6% of the area and class Z1 only 3.6% of the area. At alpha 0.8 and lambda 1, 50.2% of the area belongs to moderate hazardous class, followed by class Z2 that covers 35.8% of the area and Z4 with 13.6%. The high hazardous area tightens to 0.4% of the area.

The sensitivity analysis at these alpha and lambda values mentioned above illustrate that the alpha cut shows the interval performance according to the vagueness of expert confidence, while the lambda can be used to measure the vagueness of expert knowledge at specific attitude value between these intervals. Performing the three scenarios shows that the highest sensitivity can be observed at alpha 0.4 and lambda 0. The class Z3 and Z4 are no more sensitive at optimum alpha value, while class Z2 is no more sensitive for $\lambda \geq 0.5$ at all alpha values. The choice of alpha 0.6 and 0.8 at $\lambda \leq 0.5$ illustrate the vulnerability area that is nearly the same, especially for lambda 0.

The comparison of vulnerability map resulted from applying Fuzzy AHP method at 100% confidence level with impacted area prepared by BPLS showed that these two maps have different class of vulnerability. The result of multi criteria analysis showed that settlement areas located in impacted area were mostly categorized as high and moderate vulnerable class, while impacted area prepared by BPLS was categorized as high hazardous area. However, the surface area of the merged class Z1 and Z2 from vulnerability analysis covered area was almost the same with impacted area prepared by BPLS.
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SPATIAL MULTI CRITERIA ANALYSIS FOR DETECTING MUD VOLCANO VULNERABLE AREA IN SIDOARJO REGENCY, EAST JAVA PROVINCE

CANDRA DEWI
A Thesis submitted for the degree of Master of Science of Bogor Agricultural University

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CURRICULUM VITAE

Candra Dewi was born in Tulungagung, East Java, Indonesia on November 14, 1977. She finished her Elementary, Junior, and High school in Government School, Tulungagung. She received her undergraduate diploma from Sepuluh Nopember Technology Institute, Faculty of Industrial Technology in field of Informatics in 2001. Since 2004 to present, she has been working as lecturer in Computer Science Study Program, Department of Mathematics, Faculty of Mathematics and Natural Science, Brawijaya University of Malang.

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