Modelling Multi Hazard Mapping in Semarang City Using GIS-Fuzzy Method

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Abstract. One important aspect of disaster mitigation planning is hazard mapping. Hazard mapping can provide spatial information on the distribution of locations that are threatened by disaster. Semarang City as the capital of Central Java Province is one of the cities with high natural disaster intensity. Frequent natural disasters Semarang city is tidal flood, floods, landslides, and droughts. Therefore, Semarang City needs spatial information by doing multi hazard mapping to support disaster mitigation planning in Semarang City. Multi Hazards map modelling can be derived from parameters such as slope maps, rainfall, land use, and soil types. This modelling is done by using GIS method with scoring and overlay technique. However, the accuracy of modelling would be better if the GIS method is combined with Fuzzy Logic techniques to provide a good classification in determining disaster threats. The Fuzzy-GIS method will build a multi hazards map of Semarang city can deliver results with good accuracy and with appropriate threat class spread so as to provide disaster information for disaster mitigation planning of Semarang city. From the multi-hazard modelling using GIS-Fuzzy can be known type of membership that has a good accuracy is the type of membership Gauss with RMSE of 0.404 the smallest of the other membership and VAF value of 72.909% of the largest of the other membership.

1. Introduction

Geographically Semarang City is bordered by Java seas in the north, as well as topographical condition of its territory consisting of hilly area, lowland and coastal area. It indicates the existence of various slope and bulge that causes Semarang City area has the potential to be vulnerable to the threat of natural disaster. Semarang city also is one of the major cities in Indonesia that is prone to natural disasters. Frequent natural disasters Semarang city is tidal flood, floods, landslides, and droughts [1]. The disaster has made a loss of economic aspects to fatalities. With this natural condition, the city has been long experiencing with potential multi hazards risks [2].

Geographical information about the disasters is urgently needed in the development of disaster mitigation plans. The presentation of spatial disaster threats is very beneficial because people can directly recognize the conditions of disaster-prone areas. Therefore it is necessary to make a potential map of disaster prone areas. One important aspect of disaster mitigation planning is to conduct hazard mapping. Multi hazard mapping is a map-making activity that represents negative impacts that may result in material and non-material losses in a region in the event of a disaster [3].
Geographical Information System (GIS) is an appropriate method in mapping disaster-prone areas for wide area coverage with a relatively short time. This method is carried out as an effort to analyze risk and hazard mapping through dissemination of hazard information so that the mapping will accelerate the process of delivering information to the community and related institutions and can increase preparedness in taking action to reduce the risk of flood threat in Semarang City. The development of GIS utilization has been quite popular. By integrating GIS technology and precise mathematical methods, it can produce spatial analysis with good precision and accuracy. Spatial analysis can be approached by method of weighting and classification of criteria needed. Various methods to get the weighting and classification, one of them is by doing the method of decision making using Fuzzy Logic method. The uncertainties caused by the insufficient knowledge about the interdependency of various parameters have been considered by means of fuzzy relations [4]. With the use of Fuzzy Logic method can strengthen the hypothesis to be achieved in the hazard mapping in a region.

The focus of this research is how to do a multi hazard mapping in Semarang city with GIS Fuzzy method. The purpose of this research was the formation of Multi Hazard Map in Semarang with the methods and accuracy in accordance with the conditions of Semarang city in order to assist policy makers in deciding policy in anticipation of hazardous occurrences as well as to disaster mitigation planning in city Semarang.

2. Hazard Mapping using GIS

To avoid the impact it causes, people need to first recognize and understand the threats or dangers that exist. One effort to recognize and understand the dangers is to conduct a hazard assessment. Hazard assessment involves analyzing the physical aspects of phenomena or natural events through the collection of historical data, interpretation of topographic, geological, and hydrological data to obtain forecasts of spatial and temporal probability of occurrence and magnitude of hazards. Furthermore, from hazard assessment can be done hazard mapping. Hazard mapping is assessing and presenting hazard information to display hazard characteristics (nature and type of hazards), intensity (time and duration of impacts) and extent of impact areas as hazard zones useful for disaster mitigation activities. Each type of disaster is assessed using a different model, even one type of disaster can be analyzed using different methods [3]. The method used mostly is using probabilistic (quantitative) or deterministic (usually qualitative) analysis. For each type of disaster can be analyzed by several methods. In general it can be said that in the hazard assessment the data relating to the return period and the intensity of the hazard plays an important role of quality assessment results. GIS technology helps a lot of hazard assessment because it is able to combine various data and accommodate the calculation of the occurrence of occurrence and modelling the probability of hazard into the data processing.

3. Assessment Method using Fuzzy Logic

A fuzzy set theory-based risk assessment process realizes the following process [5]. This process uses several rules simultaneously. The attribute of set of rules is that their solution by classical logic can be different or antinomic at the same time. Practically, this inconsistency can be (should be) resolved by the fuzzy logic. This process is a combination of four subprocesses: fuzzification, inference, composition, and defuzzification. The defuzzification subprocess is optional. In the Fuzzification sub process, the membership functions defined on the severities and probabilities of investigated hazards are applied to their actual values, to determine the degree of truth for each rule premise. In the Inference sub process, the truth-value for the premise of each rule is computed, and applied to the conclusion part of each rule. This results in one fuzzy subset to be assigned to each output variable for each rule. In the Composition sub process, all of the fuzzy subsets assigned to each output variable are combined together to form a single fuzzy subset for each output variable. Sometimes it is useful to just examine the fuzzy subsets that are the result of the composition process, but more often, this fuzzy value needs to be converted to a single number — a crisp value. This is
what the Defuzzification sub process does. There are more defuzzification methods than you can shake a stick at. Two of the more common techniques are the centroid and maximum methods. In the centroid method, the crisp value of the output variable is computed by finding the variable value of the center of gravity of the membership function for the fuzzy value. In the maximum method, one of the variable values at which the fuzzy subset has its maximum truth value is chosen as the crisp value for the output variable. There are several variations of the maximum method that differ only in what they do when there is more than one variable value at which this maximum truth value occurs. One of these, the average of maxima method, returns the average of the variable values at which the maximum truth value occurs [6].

4. Methods

In this case, the multi-hazard mapping of Semarang city consists of four natural hazards that often occur in the city of Semarang. The four natural hazards are floods, landslides, Tidal floods, and drought. Furthermore, each parameter of the hazard is done weighting and scoring that refers to the regulations in Indonesia, namely PERKA BNPB No. 2 of 2012 on General Guidelines for Disaster Risk Assessment [7]. The method used in mapping each of these hazard threats uses spatial analysis as GIS tools.

The formation of multi hazard map is done by overlaying from each hazard map with weight in accordance with BNPB PERKA no. 2 of 2012 [7] which was modified for four disasters in this study. In this research also conducted a multi-hazard mapping with the classification process using Fuzzy logic type Mamdani method with three types of membership that is Gauss, Trapezium, and Triangle. The next analysis was made a comparison of multi-hazard mapping between classification according to BNPB PERKA no. 2 in 2012 with classification using Fuzzy logic method, so that got conclusion in this research is knowing accuracy of classification of each method is in multi-hazard mapping in Semarang City (Figure 1).

![Flowchart of methodology](image-url)
4.1. Flood Hazard Mapping

This mapping involves the parameters and with the weight of each parameter as in Table 1. The four parameters have the same weight because these parameters have the same effect in the formation of the threat of flood hazard.

| No | Parameter            | Weight |
|----|----------------------|--------|
| 1  | General Flood Zone   | 0.25   |
| 2  | Rainfall             | 0.25   |
| 3  | Height               | 0.25   |
| 4  | Land Use             | 0.25   |

4.2. Tidal Flood Hazard Mapping

Making the tidal flood hazard map is done in several stages of work by different methods, which should prepare the data required for each stage. The data required for mapping the tidal flood is [8]:

a. Data tide that has been processed to obtain the value of MSL and HHWL.
b. Topographic maps which are then processed into DEM topography.
c. Data accelerating decline in soil surface which is then processed into DEM land subsidence.

In general, the tidal flood mapping can be seen in Figure 2.

![Figure 2. Tidal Flood (Rob) Hazard Mapping Flowchart [8]](image)

4.3. Landslide Hazard Mapping

This mapping involves the parameters and with the weight of each parameter as in Table 2. The four parameters have the different weight because Slope and Geology parameters have more biggers effect than the others in the formation of the threat of Landslide hazard.
Table 2. Parameter Landslide Hazard [9]

| No | Parameter | Weight |
|----|-----------|--------|
| 1. | Slope     | 0.30   |
| 2. | Rainfall  | 0.20   |
| 3. | Geology   | 0.30   |
| 4. | Land Use  | 0.20   |

4.4. Drought Hazards Mapping

This mapping involves the parameters and with the weight of each parameter as in table-3. In this case, the four parameters have the different weight because NDVI and Rainfall parameters have bigger effect than the others in the formation of the threat of Drought hazard.

Table 3. Parameter Drought Hazard [9]

| No | Parameter       | Weight |
|----|-----------------|--------|
| 1. | NDVI            | 0.35   |
| 2. | Rainfall        | 0.35   |
| 3. | Type of soil    | 0.15   |
| 4. | Land Use        | 0.15   |

4.5. Multi Hazard Mapping

Once generated map of the threat of floods, tidal flooding, landslides, drought, then weighted and overlay. Referring to the Perka BNPB No. 2 In 2012, the weight of each disaster to disaster multi mapping can be seen in Table 4.

Table 4. Risk Weight Index [8]

| No | Hazard Type                      | Weight (%) |
|----|----------------------------------|------------|
| 1. | Flood                            | 0.1064     |
| 2. | Earthquake                       | 0.1064     |
| 3. | Tsunami                          | 0.0638     |
| 4. | Fire Building and Housing        | 0.0638     |
| 5. | Drought                          | 0.0638     |
| 6. | Extreme weather                  | 0.0638     |
| 7. | Landslide                        | 0.1064     |
| 8. | Volcano Eruption                 | 0.1064     |
| 9. | Extreme waves and Abrasion       | 0.0638     |
| 10.| Forest fires                     | 0.0638     |
| 11.| Failure Technology               | 0.0638     |
| 12.| Social conflict                  | 0.0638     |
| 13.| Epidemics and disease outbreaks  | 0.0638     |

From these provisions, a modification to the disaster that is used is flooding, tidal flood, landslides and droughts using a simple mathematical calculation with a parable a value of one to floods, tidal flood and landslides and the value of half of the drought, so that the weights and scoring for each disaster can be seen in table 5 and table 6.
Table 5. Multi Hazards Weight Index

| No | Hazard Type | Weight (%) |
|----|-------------|------------|
| 1. | Flood       | 0.286      |
| 2. | Tidal Flood | 0.286      |
| 3. | Landslide   | 0.286      |
| 4. | Drought     | 0.142      |

Table 6. Multi Hazards Weight Index

| No | Classify | Score |
|----|----------|-------|
| 1. | Low      | 1     |
| 2. | Medium   | 2     |
| 3. | High     | 3     |

In determining the multi-hazard classification values used for the process of obtaining multi-hazard values and classifications, comparisons of Fuzzy Inference System (FIS) results in three membership functions, namely triangular membership system, trapezium, and gauss, by implementing the FIS stages as mentioned above. Furthermore, validation of the three model performance tests of the three membership functions with reference to the multi-hazard classification assessment process from the scoring system approach and weighting based on the BNPB PERKA no. 2 Year 2012 [7]. In this validation is done by determining the value of RMSE (Root Mean Square Error) and VAF (Variance Accounted For) from the total value of total vulnerability score of the three functions of fuzzy logic membership compared with the value of hazard classification scores through the score and weighting respectively Components of hazard maps.

5. Result and Analysis

5.1. Result of Flood Map

From the results of the weighting parameter overlay and altitude, average monthly rainfall, land use and flood zone generated 20.309% of the area of Semarang get into high threat grade, 43.722% and 35.969% threat was low threat. To map the threat of floods can be seen in Figure 3(a).

Having obtained the mapping of flood threat, validation was done to determine the compatibility between maps threat of flooding to the events on the field. From the results obtained validate the suitability of 52.841%. The discrepancy between the results of the flood threat maps with field validation point is caused by several factors which are already doing to address the problem of floods such as river dredging/times [1]. A further factor is the intensity of rainfall in 2015 that was lower than in previous years.

5.2. Result of Tidal Flood Map

From the data processing DEM topography, DEM soil degradation and tide data that has been dioverlay produced 12.821% of the area of Semarang indicated the threat of tidal flood high class, 3.275% moderate hazard, 2.512% low threat and 81.391% of the area of Semarang no indication hit flood threats rob. To rob flood hazard maps can be seen in Figure 3(b).
Having obtained the threat of tidal flood mapping, validation was done to determine the compatibility between the tidal flood hazard maps with the events on the field. From the results obtained validate the suitability of 85.227%. Some validation point for the tidal flood was not in accordance with the results of the tidal flood hazard map for the ground on some elevated location [8].

5.3. Result of Landslide Map

From the results of the weighting parameter overlay and topography, the average annual rainfall, land use and geology of the region produced 0.252% Semarang enter into the category of high threat, medium threat 19.014% and 80.734% low threat. Map threat of landslides can be seen in Figure 3(c)

Having obtained the mapping of the threat of landslides, validation was done to determine the suitability of landslide hazard map with the events on the field. From the results obtained validate the suitability of 86.932%. Some point the validation does not correspond to the map results threat of landslides due to rainfall intensity in 2015 is not so high [1].

5.4. Result of Drought Map

From the results of the overlay and the weighting parameter NDVI classification, the average monthly rainfall, land use and soil types produced 7.317% of the area of Semarang in the category as high threat, medium threat 43.403% and 49.280% low threat. Map of drought can be seen in Figure 3(d).

![Figure 3. Hazard Mapping in Semarang City](image)
Having obtained the mapping of flood threat, validation was done to determine the compatibility between maps threat of flooding to the events on the field. From the results obtained validate the suitability of 41.143%. The discrepancy between the map drought with a point validation has been done due to the drought response, which has included the rehabilitation of irrigation networks and also the program PAMSIMAS. So some locations are usually threatened by drought, little by little has been addressed [1].

5.5. Result and Analysis of Multi Hazard Map using GIS-Fuzzy

The results of multi hazard using by PERKA BNPB No. 2 Year of 2012 obtained from areas with a low threat to the disaster area multi 18521.62 ha, accounting for 48.13% of the area of Semarang city and spread over 11 districts in the city of Semarang. 44.73% of the city or area of 17212.58 ha is a region with a medium-class hazard threats that are scattered throughout the districts in the city of Semarang. For the rest, 7.15% of the territory of the city, with an area of 2750.59 hectares is an area that has a high-class hazard threat, spread across eight districts in the city of Semarang.

Then the results of multi hazard using by fuzzy logic obtained from areas with a low-class hazard threat to the disaster area multi 24895.78 ha, accounting for 64.69% of the area of Semarang city and spread over 12 districts in the city of Semarang. 35.31% of the city or area of 13589.01 ha is a region with a medium-class hazard threats that are scattered throughout the districts in the city of Semarang. But there are no area is an area that has a high-class hazard threat in the city of Semarang. In Figure 4 we can see the comparison graph of the two methods in the multi-hazard map result.

For the distribution of disaster points overlapped with each map can be generated distribution of occurrence corresponds to table-7. From the table it can be analyzed that the class presented between the two methods has the same dominant distribution in the medium class, except at the occurrence points on the threat of tidal flood. From the spatial distribution, it can be seen in Figure 5, assuming the smallest spatial unit is sub district, then no one sub district has a hazard event of more than three types of hazards. From these assumptions, it can be concluded that the multi-hazard class generated from the Fuzzy Logic method can provide a realistic picture according to the actual conditions in the field.

![Figure 4. Comparison graph of the two methods in the multi-hazard map result](image-url)
Table 7. Comparing of Distribution Disaster Point in Multi Hazard Map

| Class Hazard | Flood | Tidal Flood | Multi Hazard | Drought |
|--------------|-------|-------------|--------------|---------|
| Low          | 9     | 10          | 10           | 9       | 8| |
| Medium       | 19    | 21          | 18           | 22      | 11      | 15 |
| High         | 3     | 0           | 3            | 0       | 3       | 0 |
| Sum          | 31    | 31          | 20           | 20      | 23      | 23 |

* using Fuzzy Logic Method

Figure 5. Comparison of Result of Multi Hazard Mapping in Semarang City

Furthermore, to know the type of membership with more accuracy, it can be seen in table-8. From the table it can be seen the best type of membership in determining the classification of multi-hazard map of the city of Semarang is using the Gauss membership system with RMSE of 0.404 the smallest of the other membership and VAF value of 72.909% of the largest of the other membership.

Table 8. Validation Test of Membership Function Fuzzy Logic

| Test Variable | BNPB Classification | Fuzzy Logic typeMamdani |
|---------------|---------------------|-------------------------|
|               | Gauss | Trapesium | Triangle |
| Rata-rata     | 1.481 | 1.206     | 1.169     | 1.189 |
| Variansi      | 0.183 | 0.251     | 0.322     | 0.279 |
| RMSE          | 0.404 | 0.465     | 0.426     |
| VAF ( % )     | 72.909 | 56.813   | 65.576   |
| Validation Test | In   | In        | In        |
6. Conclusion

Based on these results, we can conclude that the multi hazards mapping in Semarang city was done by using GIS and Fuzzy Logic method. With the combination of both methods, it can produce multi hazards modelling in Semarang city that can be concluded in accordance with the conditions in the field. Modelling of multi hazard in Semarang city can be seen there is no significant difference from the result of multi hazard classification using PERKA BNPB and Fuzzy Logic. With the visual analysis of multi-hazard map using fuzzy logic, it can be known that the result gives enough representation of actual situation in the field and with existing disaster event that happened. Then from the multi-hazard modelling using GIS-Fuzzy can be known type of membership that has a good accuracy is the type of membership Gaus with RMSE of 0.404 the smallest of the other membership and VAF value of 72.909% of the largest of the other membership.

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8. References

[1] Nugraha A L, Hani’ah and Pratiwi R D 2017 Assessment of multi hazards in Semarang city AIP Conference Proceedings vol 1857p 100006
[2] Setyono J S, Yuniartanti R K and others 2016 The Challenges of Disaster Governance in an Indonesian Multi-hazards City: A Case of Semarang, Central Java Procedia-Social Behav. Sci. 227 347–353
[3] Aditya T 2010 Visualisasi Risiko Bencana di Atas Peta (Visualization of Hazard Risk in a Map), Department of Geodetic Engineering Gadjah Mada Univ. Yogyakarta. Indones.
[4] Karimi I and Hüllermeier E 2007 Risk assessment system of natural hazards: A new approach based on fuzzy probability Fuzzy Sets Syst. 158 987–999
[5] Pokoradi L 2002 Fuzzy logic-based risk assessment AARMS, Acad. Appl. Res. Mil. Sci. 1 63–73
[6] Pokorádi L 2008 Systems and Processes Modeling Campus Kiadó, Debrecen 242
[7] BNPB RI 2012 General Guidelines for Disaster Risk Assessment
[8] Nugraha A L, Santosa P B and Aditya T 2015 Dissemination of tidal flood risk map using online map in semarang Procedia Environ. Sci. 23 64–71
[9] Darmawan M and Theml S 2008 Katalog Methodologi Penyusunan Peta Geo Hazard Dengan GIS BRR NAD-Nias. Banda Aceh