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Two-Phase Fuzzy System for Multiple Hydro-Meteorological Spatial Risk Mapping in Surabaya, Indonesia

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Abstract. Disaster in Indonesia is caused by hydro-meteorological factors dominate disasters in Indonesia every year. Surabaya is the capital of East Java, which has population growth problems and a high incidence of hydro-meteorological disasters. Surabaya has a high vulnerability to floods, drought, and strong winds. The mapping of the risk of hydrometeorological hazards in cities with rapidly growing populations is used as a guide for preventive measures. The map can provide information on disaster risk which consists of 3 aspects, they are a hazard, vulnerability, and capacity. A multi-disaster map is needed because it provides a complete picture of the potential and history of disasters in an area. The hydro-meteorological multi-disaster map can be used by policymakers to weigh benefits or risks and to resolve contingent disasters. In this study, we proposed a multiple hydro-meteorological spatial risk mapping in Surabaya city using a two-phase Fuzzy system. The first phase assesses the risk of each flood, drought, and wind disaster in each sub-district based on multi-criteria, such as hazard, vulnerability, and capacity. The second phase calculates the risk assessment of the three disasters and divides it into three levels of risk, consist of the low, medium, and high for each sub-district. In 2014 and 2015, there are 16.1% of low risk, 77.4% of medium risk, and 6.5% high risk sub-districts for multiple hydro-meteorological risk assessments. The results of the analysis show that there are three districts in the city of Surabaya that are at high risk of hydro-meteorological disasters, consisting of Tambaksari, Wonokromo, and Sawahan.

1. Introduction

The geographical position of Indonesia between two continents and two oceans has made Indonesia potentially vulnerable to disasters, especially disasters caused by climate and weather change [1]. Indonesia's disaster trends issued by the National Disaster Management Agency (called BNPB) states that disasters caused by hydro-meteorological factors dominate disasters in Indonesia every year. According to data compiled in the Indonesian Disaster Information Data (DIBI) - BNPB, it is known that from more than 1,800 disaster events in the period 2005 to 2015 more than 78% (11,648) of disasters were hydro-meteorological disasters [2]. Hydro-meteorological disaster events include floods, extreme waves, land and forest fires, drought, and extreme weather. The trend of hydrometeorological disasters tends to increase in intensity, frequency, magnitude, and distribution [3]. This is due to the damage to watersheds, urbanization, poverty, and socio-cultural factors which certainly increase the threat of hydro-meteorological disasters.

Historical data shows that 95% of disasters in East Java are related to hydrometeorological disasters such as floods, landslides, and strong winds (DIBI, BNPB, 2017) [4]. Surabaya is the capital of East Java, which has population growth problems and a high incidence of hydro-meteorological disasters. Surabaya has a high vulnerability to floods, drought, and strong winds [4]. The mapping of the risk of hydrometeorological hazards in cities with rapidly growing populations is used as a guide for preventive measures [5]. Responding to the importance of disaster and population problems in urban areas, it is necessary to have a tool that can measure disaster risk, one of which is through map-making. In this case, policy and decision-makers need accurate tools for risk estimation to make the right decisions [6]. The map can provide information on disaster risk which consists of 3 aspects, they are a hazard, vulnerability, and the capacity of the community, NGOs, and the government [1] [5].

However, disaster risk assessment is still based on one type of disaster rather than a multi-disaster. As a result, there are often important steps or efforts that have not been completed. A multi-disaster map is needed because it provides a complete picture of the potential and history of disasters in an area. The hydro-meteorological multi-disaster map can be used by policymakers to weigh benefits or risks and to resolve contingent disasters. Multiple risk assessments are used as a strong and accurate basis to formulate potential risk reduction measures and more effective disaster management by the government.

In this study, we proposed a multiple hydro-meteorological spatial risk mapping in Surabaya city using a two-phase Fuzzy system. The first phase assesses the risk of each flood, drought, and wind disaster in each sub-district based on multi-criteria, such as hazard, vulnerability, and capacity. The second phase calculates the risk assessment of the three disasters and divides it into three levels of risk, consist of the low, medium, and high for each sub-district.

2. Literature Review

Typically, statistical techniques are used to determine the risk assessment of hydro-meteorological disasters. Soemabrata et al. [5] identified the city's vulnerability and capacity in facing hydro-meteorological hazards, consist of floods and landslides in Depok City using GIS techniques and statistical analysis to determine risk mapping. Villalta et al [6] used a Bayesian framework for integrated treatment and statistical modeling of the main components of risk: hazard, vulnerability, and exposure. This framework combines different spatial and temporal support data. The proposed methodology is applied in the Venezuelan state of Vargas to map spatial-temporal risk during the period 1970-2006 highlighting high and low risk areas based on extreme rainfall events. Lyu et al. [7] presented a regional flood risk assessment approach using a statistical method approach, multi-criteria analysis, analysis using geographic information systems (GIS) and remote sensing, and scenario-based analysis.

A popular multi-criteria decision analysis (MCDA) problem uses the analytical hierarchy process (AHP) because it can solve complex decision-making problems without data [8][9][10][11]. Currently, research-based on Artificial Intelligence is also being developed to develop data-based nonlinear models. Elsafi [12] used an Artificial Neural Network (ANN) as a modeling tool and validated the model accuracy of the Nile flow at Dongola Station in Sudan with flow readings from stations along the Blue Nile, White Nile, Main Nile, and Atbara River between 1965 and 2003. In the MCDA process, there are cases where there is no certainty and cannot fully reflect human intuition. Therefore, the Fuzzy model is adopted for risk assessment [13]. Fuzzy-AHP (FAHP) process was also adapted to determine the relative importance of the criteria used in the risk assessment analysis [14] [15]. The Fuzzy risk assessment modeling study provides an alternative perspective of useful alternative methods for mapping landslide and flood vulnerabilities.

3. Study Area

The Surabaya city is the capital of East Java Province of Indonesia that located between 07° 9' to 07°21' South Latitude and 112° 36' to 112° 54' East Longitude. The total area of Surabaya City is approximately 326.36 km which is divided into 31 sub-districts and 154 urban villages. Sub-districts in Surabaya which is divided into 5 districts, consist of Central Surabaya, North Surabaya, West Surabaya, South Surabaya, and East Surabaya. Surabaya features a tropical wet and dry climate, with distinct wet and dry seasons with an average high temperature of around 31 degrees Celsius and average low temperatures of around 26 degrees Celsius. Figure 1 is the mapping of the Surabaya area.

4. Methodology

The system diagram of multiple hydro-meteorological risks assessment and spatial mapping can be seen in Figure 2.

A detailed explanation of the system diagram in Figure 2 is as follows:

a) Data Collection
Some of the data are collected from various sources, including the National Disaster Management Agency, the Central Bureau of Statistics, and the Surabaya Disaster Management Unit. Besides, several report documents from the government from 2012 to 2015 were obtained, consisting of:
1. Vector map of sub-districts in Surabaya.
2. Flood, wind, drought disaster history as the hazard data.
3. Population and number of buildings as the vulnerability data.
4. Medical facility as the capacity data.

b) Data Processing (Pre-processing)
Data processing (pre-processing) is carried out to eliminate noise, redundancy of unnecessary data, and calculate the correlation value of each factor to determine the criteria used for hazard, vulnerability, and capacity. Data processing is used as an attribute of the vector map of the Surabaya sub-districts.

Figure 1. Map of the sub-districts in Surabaya.

Figure 2. Multiple hydro-meteorological risk mapping system diagram

c) Database
The results of data processing are stored in a database. The database consists of hydro-meteorological risk criteria and the data is then processed to produce a risk assessment.

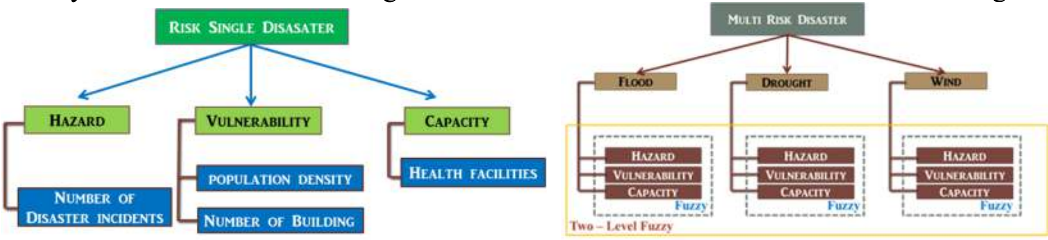
d) Two-phase Fuzzy risk assessment
The risk assessment calculation of multiple hydro-meteorological uses a two-phase Fuzzy system. The first phase of Fuzzy calculates a risk assessment of each disaster consisting of floods, winds, and drought based on 4 predetermined criteria or factors (hazard, vulnerability, and capacity) using Fuzzy Mamdani. The final result of this method is the defuzzification value and linguistic value in each sub-district. The second phase of Fuzzy processes the risk level for multiple hydro-meteorological combinations for each sub-district using the implication rules process based on crisp output and Fuzzy output in the first phase.

d) Spatial risk mapping

There are two types of spatial risk mapping visualization. The output from this first phase produces a risk level consisting of low, medium, and high which is visualized in spatial mapping. The output of the second phase is visualized in a spatial mapping consisting of low, medium, and high risk levels.

4.1. Risk Level Hierarchy

The risk level for each hydro-meteorological, such as flood, drought, and wind consist of four criteria, they are the number of disaster incident, population density, number of buildings, and health facilities. The hierarchy of criteria for determining the level of risk for each disaster can be seen in Figure 3(a).



(a) (b)

Figure 3. Hierarchy of hydro-meteorological disaster (a) each flood, drought, and wind; (b) multiple.

In Figure 3(a) can be seen that there are three criteria or factor of each hydro-meteorological that consist of hazard, vulnerability, and capacity. Below that criteria, there are several sub-criteria for the calculation process that determine the level of risk of hydro-meteorological, such as that is the number of disaster incidents, population density, number of buildings, and health facilities.

Meanwhile, the hierarchy of multiple hydro-meteorological risk levels is determined based on the crisp output and Fuzzy output of each flood, drought, and wind risk level. The hierarchy of the multiple hydro-meteorological risk levels can be seen in Figure 3(b).

4.2. Two-phase Fuzzy for Multiple Hydro-Meteorological Risk Level

There is a two-phase Fuzzy process to determine the multiple hydro-meteorological risk level. The first phase consists of Fuzzy input, fuzzification, implication rule, defuzzification, and Fuzzy output. The second phase consists of implication rule, defuzzification, and Fuzzy output.

4.2.1. Fuzzy Input. At this stage, the criteria are determined and selected as Fuzzy input. This stage is used in the first phase of the Fuzzy process and selects four criteria as a result of the correlation, the number of occurrences of each disaster D (flood, drought, and wind), population density PD, number of buildings NB, and health facilities HF.

4.2.2. Fuzzification. Fuzzification is the process of converting crisp into a Fuzzy membership function. After this process, each variable or criterion has a membership value according to the predetermined degree. Each criterion is determined the range of each Fuzzy set as in Table 1. The membership value of the Fuzzy set in each criterion is expressed as Fuzzy variable A which is divided into three levels, namely low, medium, and high. Diagram of Fuzzy set A can be seen in Figure 4.

Table 1. Range of Fuzzy set

No	Fuzzy Variable	Fuzzy Set Range		
		Low	Medium	High
1	Disaster (*D*)	0-4	1-8	>4
2	Population density (*PD*)	0-23269	2760-43778	>23269
3	Number of buildings (*NB*)	0-29240	2456-51024	>29240
4	Health facilities (*HF*)	0-72	28-115	>72

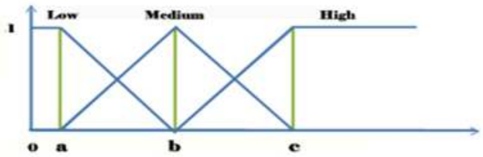


Figure 4. Diagram of Fuzzy Set *A*

The Fuzzy membership function equation set A of input x for low, medium, and high with the boundary of a, b and c are

$$\mu A_{\text{Low}}[x] : \begin{cases} 1; & \text{if } x \le a \\ (b - x) / (b - a); & \text{if } a \le x < b \\ 0; & \text{if } x \ge b \end{cases} \tag{1}$$

$$\mu A_{Medium}[x] : \begin{cases} 0; & \text{if } x \le a \text{ or } x \ge c \\ (x - a) / (b - a); & \text{if } a \le x < b \\ (c - x) / (c - b); & \text{if } b \le x < c \end{cases} \tag{2}$$

$$\mu A_{High}[x] : \begin{cases} 0; & \text{if } x \le b \\ (x - b) / (c - b); & \text{if } b \le x < c \\ 1; & \text{if } x \ge c \end{cases} \tag{3}$$

The following shows an example of a Fuzzy calculation for data from the Pakal sub-district. The number of flood events in Pakal sub-district is 8 times, according to equation above, the membership value for flood disaster D: $\mu D_{Low}[x] = 0$, $\mu D_{Medium}[x] = 0$, $\mu D_{High}[x] = 1$.

The degree of population density (PD) membership function of Pakal sub-district is 3265.03, then the membership value PD: $\mu PD_{Low}[x]$ = 23269- 3265.03 / 23269-2760 = 0.98, $\mu PD_{Medium}[x]$ = 3265.03 - 2760 / 23269-2760 = 0.02, $\mu PD_{High}[x]$= 0

The degree of number of buildings (NB) membership function of Pakal sub-district is 9230 then the membership NB: $\mu NB_{Low}[x]$ = 29240 - 9230 / 29240-7456 = 0.92, $\mu NB_{Medium}[x]$ = 9230 - 7456 / 29240-7456 = 0.08, $\mu NB_{High}[x] = 0$.

The Degree of health facilities (HF) membership function of Pakal sub-district is 58 then the membership value HF: $\mu HF_{Low}[x]$ = 72 - 58 / 72-28 = 0.32, $\mu HF_{Medium}[x]$ = 58 - 28 / 72-28 = 0.68, $\mu HF_{High}[x] = 0$.

4.2.3. Implications Rule. Fuzzy Inference is the process of formulating an input to output mapping using Fuzzy logic. The Fuzzy inference process involves the membership function of Fuzzy logic operators and IF-THEN rules. There are two best-known inference methods, namely the Mamdani inference method. This method uses a Fuzzy membership function at its output so that after the rule process is applied, there is a Fuzzy set that must be defuzzification process. If each Fuzzy variable has four membership functions, the number of Fuzzy rules is two to the power of four. In the Mamdani method, the implication function used for each rule is the minimum function. Each rule value has a weight value which is commonly called the z value of z1, z2, z3, and so on according to the number of rules. An example of an evaluation rule can be seen in Table 2.

An example of the use of the rule implication of Fuzzy membership value in Pakal sub-district as follows

- IF Disaster Incident is HIGH AND Number of Buildings is LOW AND Population Density is LOW AND Health Facilities is LOW THEN Single Risk is HIGH.
  Weight = 3 and Predicate = (1 ; 0.92 ; 0.98 ; 0.32) = 0.32 (Min).
- IF Disaster Incident is HIGH AND Number of Buildings is LOW AND Population Density is LOW AND Health Facilities is MEDIUM THEN Single Risk is MEDIUM.
  Weight = 2 and Predicate = (1 ; 0.92 ; 0.98 ; 0.68) = 0.68 (Min).

- IF Disaster Incident is HIGH AND Number of Buildings is LOW AND Population Density is MEDIUM AND Health Facilities is MEDIUM THEN Single Risk is MEDIUM.
  Weight = 2 and Predicate = (1 ; 0.92 ; 0.02 ; 0.68) = 0.02 (Min).
- IF Disaster Incident is HIGH AND Number of Buildings is MEDIUM AND Population Density is MEDIUM AND Health Facilities is MEDIUM THEN Single Risk is MEDIUM.
  Weight = 2 and Predicate = (1 ; 0.92 ; 0.08 ; 0.68) = 0.08 (Min).

Table 2. Evaluation Rule

No	Disaster	Population Density	Number of Building	Health Facility	Weight
1	Low	Low	Low	Low	1
2	Medium	Medium	Low	Medium	2
3	High	High	Medium	Low	3

4.2.4. Defuzzification. Defuzzification is the process of determining the degree of Fuzzy value by searching for the *z* value using a formula

$$Crisp\ Output(\gamma) = \frac{\sum_i (fuzzy\ output\ i) x (Singleton\ position\ on\ x\ axis\ i)}{\sum_i (fuzzy\ output\ i)} \tag{4}$$

An example of *z* value calculation of defuzzification process in Pakal sub-district is
z = (0.32*3)+(0.68*2)(0.02*2)+(0.08*2)/(0.32+0.68+0.02+ 0.08) = 2.52 /1.1 = 2.29

4.2.5. Fuzzy Output. The Fuzzy output process determines the value of the Fuzzy output itself. In this case, the Fuzzy output is determined with a certain range that can be seen in Table 3. Table 3 illustrates the final value of the Fuzzy output. After the defuzzification process, the value of defuzzification results is adjusted with Table 4 to determine the risk level each sub-district. Based on the z value of the sub-district Pakal is 2.29, so it is included in the MEDIUM risk level category for flood disaster. With the same process, the risk level is calculated for the drought and wind in the Pakal sub-district.

Table 3. Fuzzy Output Range

No	Range	Output
1	1 – 1.5	Low
2	1.5 – 2.5	Medium
3	2.5- 3	High

4.2.6. Second Phase Fuzzy. After calculating the risk level for each disaster (flood, drought, and wind) for each sub-district, the next step is to calculate the combined hydro-meteorological risk. In the second phase Fuzzy consists of a process of rule implication, defuzzification, and Fuzzy output. The result of the second phase Fuzzy process from the combination of the three disasters produces one risk level value. The examples of each hydro-meteorological risk calculations result from the first phase in some sub-districts can be seen in Table 4. Letter L means low risk levels, M means medium risk levels, and H means high risk levels.

Table 4. Example of first phase Fuzzy result

Sub-District	Flood		Wind		Drought	
	Crisp Output	Fuzzy Output	Crisp Output	Fuzzy Output	Crisp Output	Fuzzy Output
Bulak	2	M	1.03	L	1.69	M
Pakal	2	M	1.80	M	1.68	M
Wonokromo	3	H	2.5	H	2.43	M

The example of implication rule that is generated. Examples of the implications rule process from the example in Table 4 for Bulak and Wonokromo sub-districts can be seen below

- IF Flood is MEDIUM AND Wind is LOW AND Drought is LOW THEN Multiple Risk is LOW

Weight = 1 and Predicate = (2; 1.03; 1.69) = 1.03 (Min)

- IF Flood is HIGH AND Wind is HIGH AND Drought is MEDIUM THEN Multiple Risk is HIGH
  Weight = 1 and Predicate = (3, 2.5; 2.43) = 1.43 (Min Value)

The next step is calculating the *z* value of defuzzification to get the desired output result.

z = (1.43 * 3) /(1.43) = 4.28 / 1.43 = 3

The *z* value of 3 means that the Wonokromo sub-district is in the HIGH risk level of multiple hydro-meteorological.

5. Result and Discussion

The study was conducted in 31 sub-districts divided into five districts of East Surabaya, West Surabaya, North Surabaya, South Surabaya, and Central Surabaya.

5.1. Multiple Hydro-Meteorological Risk Level

The factors that influence the level of disaster risk consist of the number of disaster events, population density, number of buildings, and health facilities. The results of risk level calculations with Fuzzy multi-criteria for each disaster (flood, drought, and wind) and multiple hydro-meteorological of 31 sub-districts in 2015 can be seen in Table 5. In Table 5, the values and linguistics of the Fuzzy output are shown.

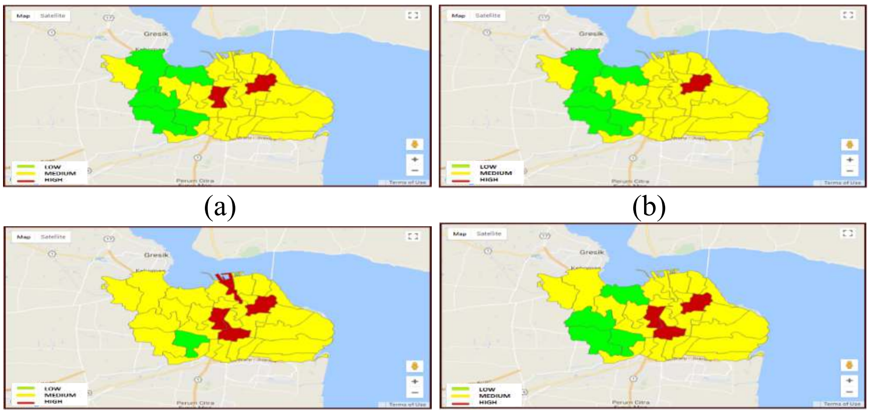
Table 5. The Fuzzy output results in multiple hydro-meteorological risk levels.

No	Sub-District	Fuzzy Output						Multiple Risk	
		Flood		Wind		Drought			
1	Bulak	2	Medium	1.69	Low	1.03	Medium	1	Low
2	Kenjeran	2	Medium	1.75	Medium	1.75	Medium	2	Medium
3	Krembangan	2.25	Medium	2	Medium	2	Medium	2	Medium
4	Pabean Cantikan	3	High	2.10	Medium	2.10	Medium	2	Medium
5	Semampir	2.21	Medium	2	Medium	2	Medium	2	Medium
6	Asemrowo	2	Medium	1.09	Low	1.44	Low	1	Low
7	Benowo	2	Medium	1.34	Low	1.20	Low	1	Low
8	Lakarsantri	2	Medium	1.18	Low	1.18	Low	1	Low
9	Pakal	2	Medium	1.68	Medium	1.81	Medium	2	Medium
10	Sambikerep	2	Medium	2	Low	1.12	Medium	1	Low
11	Sukomanunggal	2	Medium	1.74	Medium	1.74	Medium	2	Medium
12	Tandes	2	Medium	1.75	Medium	1.75	Medium	2	Medium
13	Gubeng	2	Medium	2	Medium	2	Medium	2	Medium
14	Gunung Anyar	2	Medium	1.59	Medium	1.59	Medium	2	Medium
15	Sukolilo	2.16	Medium	1.74	Medium	1.69	Medium	2	Medium
16	Tambaksari	2.72	High	2.68	High	2.68	High	3	High
17	Mulyorejo	1.63	Medium	1.61	Medium	1.61	Medium	2	Medium
18	Rungkut	1.76	Medium	1.77	Medium	1.77	Medium	2	Medium
19	Tenggilis Mejoyo	1.60	Medium	1.60	Medium	1.60	Medium	2	Medium
20	Tegalsari	2	Medium	2	Medium	2	Medium	2	Medium
21	Simokerto	2.70	High	2	Medium	2	Medium	2	Medium
22	Genteng	1.61	Medium	1.61	Medium	2	Medium	2	Medium
23	Bubutan	2.13	Medium	2	Medium	2	Medium	2	Medium
24	Wonokromo	3	High	2.43	High	2.5	Medium	3	High
25	Wonocolo	2	Medium	1.88	Medium	1.88	Medium	2	Medium
26	Wiyung	1.77	Medium	2	Medium	1.77	Medium	2	Medium
27	Karang Pilang	2	Medium	1.81	Medium	1.81	Medium	2	Medium
28	Jambangan	1.75	Medium	1.75	Medium	1.75	Medium	2	Medium
29	Gayungan	2	Medium	1.84	Medium	1.84	Medium	2	Medium
30	Dukuh Pakis	1.97	Medium	1.97	Medium	1.97	Medium	2	Medium
31	Sawahan	2.74	High	2.13	Medium	2.47	Medium	2	Medium

5.2. Spatial Risk Mapping

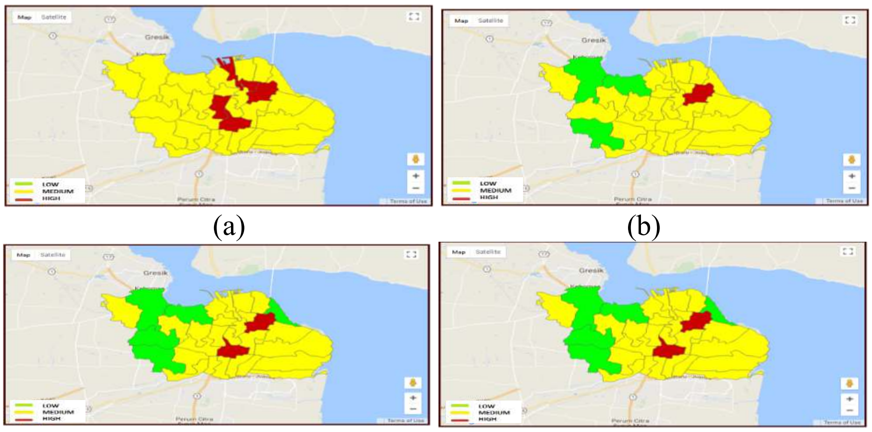
This section discusses the visualization of risk level spatial mapping in 2014 and 2015. The spatial mapping of each and multiple hydro-meteorological risk levels in 2014 can be seen in Figure 5. Figure 5(a) shows the flood spatial risk mapping, Figure 5(b) show the drought spatial risk mapping, and Figure 5(c) show the wind spatial risk mapping. Meanwhile, the 2014 multiple hydro-meteorological visualizations based on two-phase Fuzzy calculations can be seen in Figure 5(d). The green, yellow, and red colors respectively represent low, medium, and high risk levels.

In 2014 there are 4 sub-districts with a high risk of flooding, consisting of Wonokromo, Sawahan, Pabean Cantika, and Tambaksari sub-districts, 1 sub-district with low risk, and 26 sub-districts with medium risk. Simokerto sub-district has a high risk of drought, 5 sub-districts with low risk, and 25 sub-districts with medium risk. There are 3 sub-districts with a high risk of wind, consisting of Wonokromo, Sawahan, and Tambaksari sub-districts, 4 sub-districts with low risk, and 24 sub-districts with medium risk. The results of multiple hydro-meteorological calculations show that there are 2 sub-districts with high risk, consisting of Sawahan and Tambaksari sub-districts, 5 sub-districts with low risk, and 24 sub-districts with medium risk.



(a) (b) (c) (d)

Figure 5. Spatial risk mapping visualization of 31 sub-district in 2014 (a) flood; (b) drought; (c) wind; (d) multiple hydro-meteorological.



(a) (b) (c) (d)

Figure 6. Spatial risk mapping visualization of 31 sub-district in 2015 (a) flood; (b) drought; (c) wind; (d) multiple hydro-meteorological.

The spatial mapping of each and multiple hydro-meteorological risk levels in 2016 can be seen in Figure 6. Figure 6(a), 6(b), and 6(c) shows the flood, drought, and wind spatial risk mapping, respectively. While the 2015 multiple hydro-meteorological visualizations based on two-phase Fuzzy calculations can be seen in Figure 6(d). In 2015 there were 5 sub-districts with a high risk of flooding, consisting of Wonokromo, Simokerto, Sawahan, Pabean Cantika, and Tambaksari sub-districts, none are in low risk, and 26 sub-districts with medium risk. Tambaksari sub-district is a high risk of drought, 3 sub-districts with low risk, and 27 sub-districts with medium-risk. There are 2 sub-districts with a high risk of wind, consisting of Wonokromo and Tambaksari sub-districts, 5 sub-districts with low risk, and 24 sub-districts with medium risk. The results of multiple hydro-meteorological calculations show that there are 2 sub-districts in high risk, consisting of Wonokromo and Tambaksari sub-districts, 5 sub-districts with low risk, and 24 sub-districts with medium risk. Based on the results of Fuzzy calculations in Table 6 and visualization of spatial mapping in Figures 5 and 6, it can be summarized the number and percentage of 31 sub-districts with low, medium, and high risk levels for each type of disaster, they are flood, drought, and wind. and multiple hydro-meteorological in Table 6. In Table 6, it can be seen that in 2014 and 2015, there were 16.1% of sub-districts at the low risk level, 77.4% at the medium risk level, and 6.5% at the high risk level for multiple hydro-meteorological risk assessments using two-phase Fuzzy. The number of sub-districts in the medium-risk area is very high, both for each type of disaster (flood, drought, and wind) or multiple hydro-meteorological. This is affected by the two main factors, the high population density and the number of disasters. In 2014 and 2015, 2 sub-districts had a high level of risk, but different sub-districts. In 2014, the sub-districts that have a high risk level are Sawahan and Tambaksari sub-districts, while in 2015, the sub-districts that have a high risk level are Tambaksari and Wonokromo sub-districts. This is due to the density of the population and the high number of buildings. However, there is an increase in the number of disasters in the Wonokromo sub-district to 9 incidents, while the Sawahan sub-district experienced a decrease in the number of incidents only 4. Therefore, the areas at high risk of hydro-meteorological disasters in Surabaya are Tambaksari, Wonokromo, and Sawahan sub-districts.

Table 6. Number and percentage of risk levels in 2014-2015 for flood, drought, and wind, and multiple hydro-meteorological of 31 sub-districts.

Hazard type	2014			2015		
	Low	Medium	High	Low	Medium	High
Flood	1 (3.2%)	26 (83.9%)	4 (12.9%)	0 (0.0%)	26 (83.9%)	5 (16.1%)
Drought	1 (3.2%)	25 (80.7%)	5 (16.1%)	3 (9.7%)	27 (87.1%)	1 (3.2%)
Wind	4 (12.9%)	24 (77.4%)	3 (9.7%)	5 (16.1%)	24 (77.4%)	2 (6.5%)
Multiple hydro-meteorological	5 (16.1%)	24 (77.4%)	2 (6.5%)	5 (16.1%)	24 (77.4%)	2 (6.5%)

Disasters in Surabaya are common, especially in dense residential areas and industrial areas. The results of discussions with related parties, areas prone to hydro-meteorological disasters are caused by several things such as disaster events, population density, building conditions, building density levels, the proportion of built activities with land area, and the number of health facilities. The most influential factor in determining the risk level is the magnitude of the disaster event and the number of capacity factors. The number of catastrophic events is a major cause of the hydrometeorological disaster, the higher the risk level and capacity are the factors capable of compromising threats and vulnerabilities so that the risk level becomes low.

The impact of damage or loss felt by the risk area will vary according to the level of risk. The results of this study can help reduce the impact of disasters and minimize the number of losses. The government can make improvements to vulnerability factors and disaster factors because hydro-meteorological disasters are a damage factor due to human activities and the environment, climate change and weather only trigger. This application is very useful as a reference for grouping areas at risk of hydro-meteorological disasters in Surabaya city and periodically visualizing areas at risk of hydro-meteorological disasters. Thus, it can provide benefits to the community and government, for example selecting areas that are suitable or valuable for investment, areas that are not at risk of hydro-meteorological disasters.

6. Conclusion

The two-phase Fuzzy method developed to assess multiple hydro-meteorological risk levels produces a detailed level of risk (sub-districts) in Surabaya as an urban city based on multi-criteria, consisting of the number of disaster incidents, population density, number of buildings, and health facilities. In 2014 and 2015, there were 16.1% of sub-districts at the low risk level, 77.4% at the medium risk level, and 6.5% at the high risk level for multiple hydro-meteorological risk assessments using two-phase

Fuzzy. The number of sub-districts in the medium-risk area is very high, both for each type of disaster (flood, drought, and wind) or multiple hydro-meteorological. The results of the analysis show that there are three districts in the city of Surabaya that are at high risk of hydro-meteorological disasters, consisting of Tambaksari, Wonokromo, and Sawahan.

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