Urban Flood Risk Assessment in Sidoarjo, Indonesia, Using Fuzzy Multi-Criteria Decision Making

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Abstract. Indonesia is very vulnerable to flooding due to urbanization of land use, industrialization and made worse by climate change. Sidoarjo is an urban area that frequently experiences regular flooding every year. The flooding break up local traffic, disrupting economic distribution and transportation routes. Minimum information about areas that are often flooded causes a lack of people and government attention to the effects of floods. In this paper, we develop a Fuzzy approach to determine the level of urban flood risk in Sidoarjo. The parameters consist of flood inundation, rainfall, population affected, and drainage. The Fuzzy sets produce fuzzy membership values, and evaluation rules determine the level of flood disaster in each village in Sidoarjo, classified into three levels of vulnerability, they are high, medium and low level of flood vulnerability. Analysis of the results of the calculation of flood risk assessment with Fuzzy multi-criteria decision making (FMCDM) shows a good result with accuracy of 66% compared to the analysis of the Sidoarjo Regional Disaster Management Agency inundation data. However, in reality flood risk is not only caused by inundation factor, the FMCDM method is represented a better assessment in real world. The spatial decision support system using geographical information systems (GIS) provides effective, efficient and useful in flood risk management for local and national governmental agencies.

1. Introduction

The National Disaster Management Agency of Indonesia noted that the flood disaster was ranked highest in the event of a disaster in the territory of Indonesia over the past 10 years[1]. Indonesia is very vulnerable to flooding due to urbanization of land use, industrialization and made worse by climate change. Since 1990, deaths due to flooding have been recorded, and heavy rains have doubled compared to other hydro-climate disasters in the same period. Intensification of the development of flood-plains as a residential and commercial destination also increases the risk of flooding in densely populated areas. Floods in urban areas are generally caused by high rainfall and poor recharge areas or improper drainage arrangements.

Sidoarjo is an urban area that often experiences regular flooding every year. Floods inundated a large part of the Sidoarjo region. Dozens of houses belonging to residents were flooded to as high as 40 to 50 centimeters. Flooding also breaks up local traffic, disrupting economic distribution and transportation routes. Floods are caused by high rainfall and tides, which have caused the Brantas river to overflow. In addition, flooding is also caused by changes in the function of the riverbanks resulting in narrowing, as well as many agricultural lands that have changed functions into housing and industry that override the drainage system [2].

Although there has been a flood prevention master plan in Sidoarjo since 2015, the reality shows that floods occur continuously and cause material damage, congestion and business disruptions. Lack of information or early warning causes the unpreparedness and inability of the community to deal with the dangers of flooding. Minimum information about areas that are often flooded causes a lack of people and government attention to the effects of floods. Therefore, information about flood risk areas is needed to give warnings to the people. This is also used by the government for planning prevention efforts with appropriate policies and measures. Flood risk assessment is not only determined by high rainfall, but also due to social and ecological factors, for example, the number of affected populations, availability of drainage and inundation history in specific areas. Therefore, a multi-criteria decision making method is needed to solve this problem.

In this paper, we develop a Fuzzy approach to determine the level of urban flood risk assessment in Sidoarjo. Fuzzy is an effective and practical multi-criteria decision making (MCDM) to select the most appropriate one among predetermined alternatives by evaluating them in terms of many criteria [3]. Another advantage of Fuzzy, it can classify directly the flood risk without additional process requiring. The parameters consist of flood inundation, rainfall, population affected, and drainage. Fuzzy sets produce fuzzy membership values and evaluation rules determine the level of flood undefined disaster in each village in Sidoarjo, classified into three levels of vulnerability, they are high, medium and low level of flood vulnerability. Spatial visualization in KML is generated as a decision support system. KML format is used to share spatial data attributes and Google Maps is used as the map engine. The spatial decision support system using GIS provides effective, efficient and useful in flood risk management for local and national governmental agencies.

2. Related Work

Urban flood risk assessment involves a set of specific urban-type such as economic, social and ecological criteria. Therefore, a multi-criteria decision making method is needed to solve this problem. The previous work of risk assessment was carried out by Kubal et al. [4] who developed multicriteria flood risk assessment of the more rural Mulde river basin to a city in Leipzig, Germany, using a "multicriteria decision rule" based on an additive weighting procedure, that focus on urban issues: population, vulnerable groups, and ecological indicators.

Assessment of flood risk was also developed with analytical hierarchy process (AHP). This method normalized weights of criteria based on nine-point scale to specify flood hazard zones. But, it must be integrated with other methods to classify the level of flood risk. Wang et al [5] assessed flood risk in the Dongting Lake region, Hunan Province, Central China, using a semi-quantitative model and fuzzy analytic hierarchy process (FAHP) weighting approach, and obtain the final flood risk index map, that was classified into five categories of flood risk: very low, low, medium, high, and very high. Rahmati et al. [6] integrated AHP with weighted linear combination method using ArcGIS software to generate flood hazard prediction map according to distance to river, landuse, elevation and land slope in some part of the Yasooj River, Iran. Rahadianto et al. [7] used AHP to assess Bengawan Solo's river flood prone areas, Indonesia, according to hazard, vulnerability and index of capacity criteria. It classified the three level of flood risk: high, medium, and low using natural breaks. Febrianto et al. [8] develops a spatial decision support system for urban flood risk assessment using the AHP and natural break classification into three levels of risk: low, medium and high in Surabaya city, Indonesia. It shows that AHP can be used to assess the flood hazard potential, specifically for criteria that contain preference data.

The fuzzy methodology was established in the area of flood risk assessment to improve probability estimation because it indicates that the methodology is effective and practical. Li et al. [9] used a fuzzy model to evaluate flood risk with incomplete data sets and a large sample size of data based on variable fuzzy sets and information diffusion. Gou et al. [10] combined weights of entropy and membership degree functions of variable fuzzy set to calculate hazard levels, exposure levels, vulnerability levels and restorability levels, and the flood risk level for each assessment unit in central Liaoning Province, China. Nugraha et al. [11] produced a hazard, vulnerability and capacity maps on the tidal flood in Semarang, Indonesia, using fuzzy logic and weighted method approaches. Zou et al [12] combined set pair analysis (SPA), variable fuzzy sets (VFS) and fuzzy-AHP theory for comprehensive flood risk assessment of Jingjiang flood diversion district in China according to hazard, vulnerability and flood risk that were all classified into five grades as very low, low, medium, high and very high. Gueo et al. [13] proposed the relative membership degree functions of variable fuzzy set (VFS) theory were calculated using improved set pair analysis, while level values were calculated using VFSs, including hazard levels, exposure levels, vulnerability levels and restorability levels of flood disasters in central Liaoning Province, China, which was supported by geographical information systems (GIS). Rukmana et al. [14] determined flood risk level of the Bengawan Solo river using fuzzy method in East Java which consists of 5 districts namely Bojonegoro, Lamongan, Tuban, Gresik, and Ngawi. The fuzzy method calculated the classification of three levels of risk: low, medium, and high according to hazard, vulnerability and index of capacity.

The spatial decision support system developed using GIS eased the storage and access of data [5-8][11][13]. The results obtained can provide effective, efficient and useful in flood risk management for local and national governmental agencies.

3. Study Area

Sidoarjo district is one of the regencies in East Java Province. Geographically, Sidoarjo district is located between 112°5' and 112°9' East Longitude and between 7°3' and 7°5' South Latitude and total area of 719.63 km2. figure 1 is a map of the Sidoarjo district consists of 18 sub districts and 353 villages.

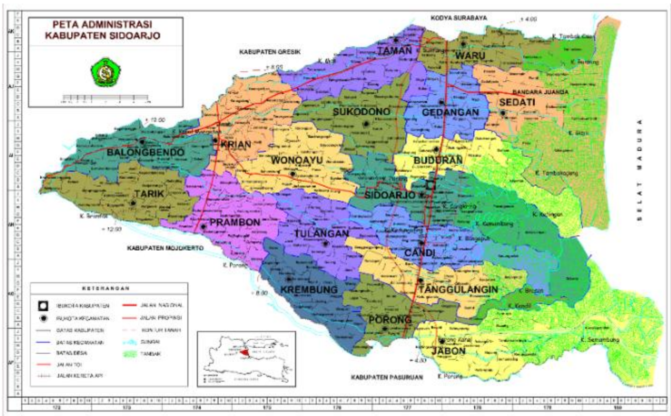

Figure 1. Map of Sidoarjo district

4. Urban Flood Risk Assessment using Fuzzy

System design of urban flood risk assessment in Sidoarjo, Indonesia, using Fuzzy multi-criteria decision making can be seen in figure 2. Detailed explanation of the urban flood risk assessment system design as follows

a. Data consists of two types, spatial and attributes data. Spatial data is Sidoarjo district basemap, and multi-criteria attribute data consists of previous flood inundation (height and duration), rainfall, population affected and amount of drainage available. Definition of criteria based on the regulation of the national disaster management agency no 2 / 2012 concerning the general guidelines for disaster risk assessment and the results of interviews with experts. Data is collected from several authorized sources as follows
   - flood inundation height, duration of flood inundation and affected population data come from the Sidoarjo regional disaster management agency (BPBD Sidoarjo)
   - Rainfall data comes from the Meteorology, climatology and geophysics agency (BMKG Juanda)
   - Amount of drainage data comes from public work service Sidoarjo (Dinas PU Sidoarjo)

b. Data acquisition results are stored in a database to facilitate access and processing data.
c. Fuzzy multi-criteria decision making consists of three steps: fuzzification, evaluation rule and defuzzification. Fuzzification calculates a set of membership value for flood inundation height, duration of flood inundation, rainfall, affected population and amount of drainage available parameters or criteria. Evaluation rule checks the decision-making rule that is applied by fuzzy set values. Defuzzification determines degree of fuzzy value to obtain the flood risk.
d. The level of flood risk consists of high, medium and low flood vulnerability level.
e. Once the results are obtained, the spatial map is visualized in thematic with different color of vulnerability that indicates the level of flood risk. Red, yellow and green colors indicate the high, medium and low level of flood vulnerability.
f. Users can access some information in the spatial flood risk in Sidoarjo through the web browser.

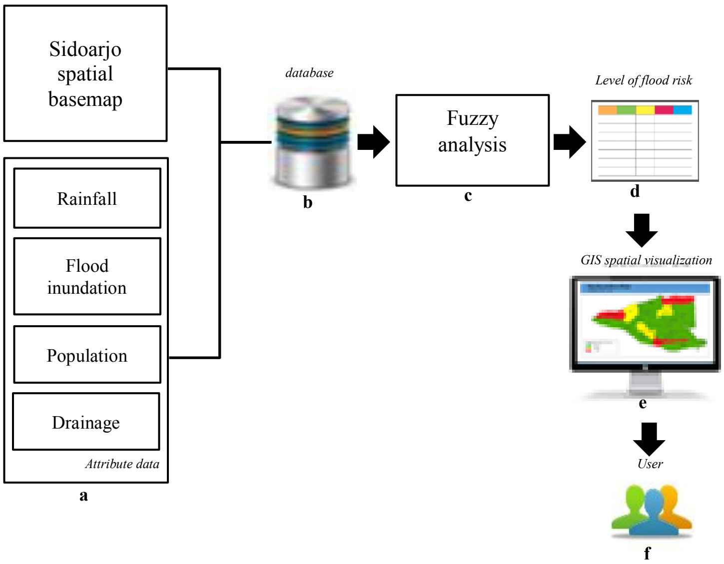

Figure 2. System design

4.1. Fuzzification

Table 1. The interval value of each parameters

Parameter	Linguistic definition		
	Low	Medium	High
Flood inundation height	<10 cm	10-80 cm	>80 cm
Duration of flood inundation	<1 day	1-9 days	>9 days
Rainfall	<5 mm	5-170 mm	>170 mm
Population affected	<0 people	0-3500 people	>3500 people
Amount of drainage	<1	1-4	>4

Fuzzification process calculates the membership value according to membership function for flood inundation height, duration of flood inundation, rainfall, affected population and amount of drainage parameters. The membership function changes the numerical value into a linguistic variable that is grouped into fuzzy set and membership function. Each parameter divides into three linguistic variables: low, medium and high. The interval value for each parameter can be seen in table 1.

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4.1.1. Flood Inundation Height. Flood inundation occurs in urban areas due to high rainfall, which causes rivers and drainage cannot accommodate rainwater. Flood inundation height is low if it is less than 10 cm, medium if within 10-80 cm and high if more than 80 cm. Fuzzy set of flood inundation height can be shown in figure 3.

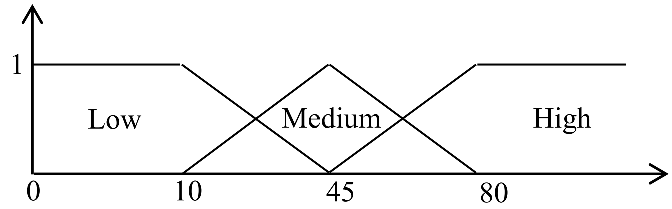


Figure 3. Fuzzy set of flood inundation height

4.1.2. Duration of Flood Inundation. The duration of flood inundation duration affects the flood disaster damage. Flood inundation duration becomes low if it is less than 1 day, medium if within 1-9 days and high if more than 9 days. The fuzzy set of flood inundation duration can be shown in figure 4.

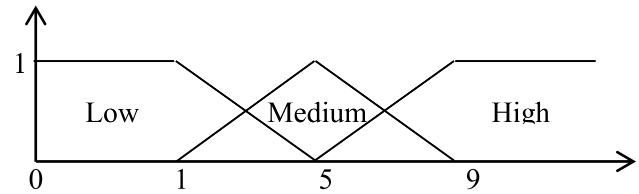


Figure 4. Fuzzy set of flood inundation duration

4.1.3. Rainfall. Rainfall is the most influential factor in urban flood damage. Rainfall below 5 mm is said low, between 5-170 mm is said medium and above 170 mm is said high. Fuzzy set curve of rainfall can be seen in figure 5.

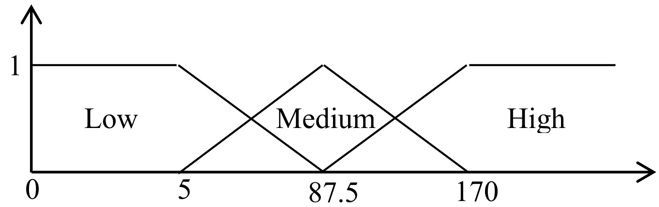


Figure 5. Fuzzy set of rainfall

4.1.4. Population Affected. Flooding in urban areas is the very influential impact on the population, because people's homes and public facilities are flooded. Floods have a low impact if no population is exposed, medium if less than 3500 and high if more than 3500. Fuzzy sets for population affected can be seen in figure 6.

4.1.5. Amount of Drainage. Availability of drainage and culvert affects the level of flood risk. The amount of drainage needed depends on the area of the district. In urban areas, drainage availability is said to be low if less than 1, medium if between 1-4 and high if more than 4. Fuzzy set curves of the amount of drainage availability can be seen in figure 7.

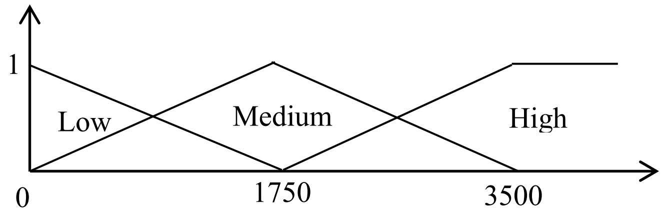


Figure 6. Fuzzy set of population affected

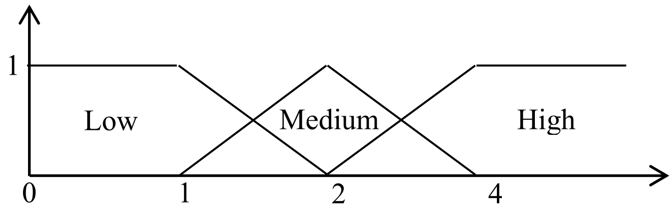


Figure 7. Fuzzy set of amout of drainage

In general, the fuzzy membership function of fuzzy sets is calculated from *x* numeric value based on triangular rules such as equations (1), (2), and (3). Equation (1) calculates the low fuzzy membership function $\mu_{\text{low}}(x)$ with a left boundary 0, peak *a* and right boundary *b*. Equation (2) calculates the medium fuzzy membership function $\mu_{\text{medium}}(x)$ with the left boundary *a*, peak *b* and right boundary *c*. Equation (3) calculates the high fuzzy membership function $\mu_{\text{high}}(x)$ from the left boundary *b*, peak *c* and infinite right boundary.

$$\mu_{\text{low}}(x) = \begin{cases} 1; & x < a \\ \frac{b-x}{b-a,}; & a \le x \le b \\ 0; & x > b \end{cases} \tag{1}$$

$$\mu_{\text{medium}}(x) = \begin{cases} 0; & for\ x < a\ and\ x > b \\ \frac{x-a}{b-a,}; & a \le x \le b \\ \frac{c-x}{c-b}; & b \le x \le c \end{cases} \tag{2}$$

$$\mu_{\text{high}}(x) = \begin{cases} 0; & x < b \\ \frac{x-b}{c-b,}; & b \le x \le c \\ 1; & x \ge c \end{cases} \tag{3}$$

4.2. Evaluation Rule

After the fuzzification process, at the implication stage, the rules are evaluated, checked, the decision making rules, the knowledge base, the rule bases are applied by adjusting the value conditions on the fuzzy set. There are 243 fuzzy rules derived from 3 (fields of each variable in the membership function) power to 5 (parameters of flood vulnerability variable). Because of the large number of rules, several lists of fuzzy rules for flood vulnerability are shown in table 2.

Table 2. Several list of fuzzy rules

Flood inundation height	Flood inundation duration	Rainfall	Population affected	Amount of drainage	Weight
high	high	high	medium	high	3
high	low	high	high	low	3
high	medium	high	high	low	3

Flood inundation height	Flood inundation duration	Rainfall	Population affected	Amount of drainage	Weight
high	high	high	high	low	3
high	low	high	high	medium	3
high	medium	high	high	medium	3
high	high	high	high	medium	3
high	low	high	high	high	3
high	medium	high	high	high	3
high	high	high	high	high	3

The rule weight represents the implication of the fuzzy rule as a singleton value of each rule that is used in the defuzzification process. The weight values are 1, 2, and 3 which represent the evaluation rule result of low, medium and high flood risk. For example in row 1 from table 2 which states "**IF HIGH flood inundation height AND HIGH duration of flood inundation AND HIGH rainfall AND HIGH population affected AND HIGH amount of drainage THEN HIGH flood risk**" then the weight of the evaluation rule is 3. This process also obtains the predicate value from the minimum value calculation of the fuzzy membership value.

4.3. Defuzzification

The input of the defuzzification process is a fuzzy set obtained from the composition of fuzzy rules, while the resulting output is a number in the fuzzy set domain, so if a fuzzy set is given in a certain range, then a crisp value can be taken as an output. In this paper, the defuzzification method used is the center of area (COA). In this method, a crisp solution is obtained by taking the center point of the fuzzy region, generally formulated in the equation (4).

$$z = \frac{\sum_{j=1}^{n} z_j \mu(z_j)}{\sum_{j=1}^{n} \mu(z_j)} \tag{4}$$

where z is crisp output, z_j is weight of singleton j axis and $\mu(z_j)$ is fuzzy membership value of z_j .

table 3 illustrates the classification results of the fuzzy output that is obtained from the crisp output z determines the level of flood risk in Sidoarjo district.

Table 3. Fuzzy output

Range of z value	Fuzzy Output
0.0 – 1.5	low
1.5 – 2.0	medium
2.0 – 3.0	high

For example, the Pekauman village in February 2016 consisted of the following data:

- Flood inundation height = 42 cm
- Duration of flood inundation = 5 day
- Rainfall = 61.8 mm
- Population affected = 828 people
- Amount of drainage = 3

The fuzzification stage calculates the fuzzy membership value of Pekauman village with equations (1) - (3) according to fuzzy set in figure 3 until figure 7 can be seen in table 4. At the implication stage, the rules are evaluated for each combination of fuzzy membership value and class. For example the rule "**IF MEDIUM flood inundation height AND MEDIUM duration of flood inundation AND**

MEDIUM rainfall AND LOW population affected AND HIGH amount of drainage THEN MEDIUM flood risk" calculate the predicate (0.914;1;0.688;0.527;0.5) resulting the weight of the evaluation rule is 2. The result of defuzzification stage using equation (4) is 2 or medium.

Table 4. Fuzzy membership value of Pekauman village

Classification	Flood inundation height	Duration of flood inundation	Rainfall	Population affected	Amount of drainage
Low	0.0857	0	0.311	0.527	0
Medium	0.914	1	0.688	0.473	0.5
High	0	0	0	0	0.5

5. Result and Discussion

This section discusses the result of the system, that consist of spatial visualization of urban flood risk assessment using FMCDM, comparison flood risk assessment between FMCDM and BPBD inundation and flood disaster map feature.

5.1. Spatial Visualization of Urban Flood Risk Assessment using Fuzzy

The results of the risk assessment calculation using the fuzzy method are visualized in the form of a spatial map in KML format. There are three colors on the map including red, yellow and green. Red color indicates high flood risk areas, yellow color indicates medium flood risk areas, and green color indicates low flood risk areas. The flood inundation height, duration of flood inundation, rainfall, affected population and amount of drainage data from 106 villages of Sidoarjo district which affected by flooding in 2012, 2013, 2014 and 2016 is calculated using Fuzzy multi-criteria decision making steps. The spatial map is shown in figure 8(a-d).

(a) (b)

(c) (d)

Figure 8. Spatial visualization of flood risk assessment (a) 2012; (b) 2013; (c) 2014; (d) 2016.

Flood risk assessment results with FMCDM show an increasing the flood risk areas from year to year. In 2012, the level of flood vulnerability in the Sidoarjo district shows a medium flood risk level of 12 villages and the remaining show the low level. In 2013, the level of flood vulnerability increased to 16 villages of medium level. In 2014, the number of villages with medium levels of flood vulnerability increased to 41 and high flood risk became 1. In 2016 the level of flood vulnerability increased to 67 villages and high flood risk level of 24 villages.

The interesting thing is the results of the calculation of flood risk in 2014 and 2016 showed significant changes. The increasing level of the fuzzy results occurs because the value of the variable increases, hence the calculation leads to a higher level. Otherwise, the decreasing occurs because there is a smaller variable value that affects to the results of the fuzzy method which decreases. table 5 shows there are 106 village get the number of flood risk levels that have changed from 2014 to 2016. The level of flood vulnerability in Sidoarjo district in 2014-2016 sustained a significant increasing of 68% villages, 26% villages had decreased, and 6% villages still remained the same level. This shows that there must be an appropriate treatment for certain areas that previously did not sustain flooding. However, in the following years, there were a flood or villages that were previously of low level then changed to a higher level.

Table 5. Fuzzy output changing in 2014 and 2016

Type	Amount	Percentage
Increasing	33	26%
Decreasing	1	6%
Constant	72	68%
Total	106	100%

5.2. Comparison Flood Risk Assessment between FMCDM and BPBD Inundation.

The urban flood risk from fuzzy output is compared with Regional disaster management agency (BPBD) inundation data. table 6 shows the difference between FMCDM and BPBD inundation for 106 villages in 2016. The calculation of 106 villages that were affected by flooding in 2016 showed a similarity between FMCDM and BPBD results which was quite high at 66%. table 6 shows that the summary of flood risk results in the classification with FMCDM and BPBD inundations are dominated by medium vulnerability levels, reaching 82% and 66%.

Table 6. Flood risk comparison between fuzzy output and BPBD innudation for 106 village

No	Village	FMCDM	BPBD	No	Village	FMCDM	BPBD
1	Pesawahan	Medium	Medium	54	Rangkahkidul	Medium	Medium
2	Lajuk	Medium	Medium	55	Gempolsari	Medium	High
3	Kebakalan	Medium	Medium	56	Banjarpanji	Medium	High
4	Kesambi	Medium	Medium	57	Kedungbanteng	Medium	High
5	Candipari	Medium	Medium	58	Tanjungsari	Medium	High
6	Gedang	Medium	Medium	59	Ngelom	Medium	High
7	Porong	Medium	Medium	60	Tropodo	Medium	High
8	Pamotan	Medium	Medium	61	Wedoro	Medium	Medium
9	Randegan	Medium	Low	62	Kepuhkiriman	Medium	Medium
10	Ketegan	High	High	63	Medaeng	Medium	High
11	Kedensari	Medium	Medium	64	Tambakrejo	Medium	Medium
12	Kalitengah	Medium	High	65	Kalipecabean	High	High
13	Kludan	Medium	Low	66	Wedoroklurak	High	Low
14	Kalidawir	High	Medium	67	Balongdowo	High	Medium
15	Sawotratap	Medium	Medium	68	Klurak	Medium	Medium
16	Bangah	Medium	Medium	69	Balonggabus	Medium	Medium
17	Semambung	Medium	High	70	Kendalpecabean	High	Medium

No	Village	FMCDM	BPBD	No	Village	FMCDM	BPBD
18	Pepe	Medium	Medium	71	Gelam	Medium	Low
19	Cemandi	Medium	Medium	72	Sumorame	Medium	Low
20	Buncitan	Medium	Medium	73	Kebonsari	Medium	Low
21	Sedatiagung	Medium	High	74	Ngampelsari	Medium	Low
22	Sedatigede	Medium	High	75	Watugolong	Medium	Medium
23	Semampir	Medium	Medium	76	Suko	Medium	Medium
24	Pabean	Medium	High	77	Taman	High	Medium
25	Segorotambak	Medium	Medium	78	Kletek	Medium	Medium
26	Kalanganyar	Medium	Medium	79	Prasung	Medium	Medium
27	Tambakcemandi	Medium	Medium	80	Wadungasih	Medium	Medium
28	Banjarkemuning	Medium	Medium	81	Sukorejo	Medium	Medium
29	Gisikcemandi	Medium	Medium	82	Sidokerto	Medium	Medium
30	Betro	Medium	Medium	83	Buduran	Medium	Medium
31	Kwangsan	Medium	Medium	84	Banjarkemantren	Medium	Medium
32	Pranti	Medium	Medium	85	Damarsi	Medium	Medium
33	Pepelegi	Medium	Medium	86	Sidokepung	Medium	Medium
34	Bungurasih	High	High	87	Siwalanpanji	Medium	Medium
35	Kedungrejo	Medium	High	88	Sawahan	Medium	Medium
36	Waru	Medium	High	89	Banjarsari	Medium	Medium
37	Kramatjegu	High	High	90	Dukuhtengah	Medium	Medium
38	Trosobo	High	High	91	Sidomulyo	Low	Medium
39	Sidodadi	High	High	92	Keboansikep	Medium	Medium
40	Bohar	Medium	High	93	Tebel	Medium	Medium
41	Bringinbendo	Medium	High	94	Barengkrajan	High	Medium
42	Sambibulu	High	High	95	Krian	Medium	Medium
43	Sidoklumpruk	Medium	Medium	96	Katerungan	Medium	Medium
44	Banjarbendo	Medium	Medium	97	Sidomulyo	Medium	Medium
45	LemahPutro	Medium	High	98	Keboharan	Medium	Medium
46	Magersari	Medium	Medium	99	Sidomojo	Medium	Medium
47	Sidokumpul	Medium	Medium	100	Ponokawan	Medium	Medium
48	Pekauman	Medium	High	101	Kureksari	Medium	High
49	Sidokare	High	High	102	Sekardangan	Medium	Medium
50	Gebang	High	High	103	Masangankulon	Low	Medium
51	Kemiri	High	Medium	104	Kebonagung	Medium	Low
52	Pucanganom	Medium	Medium	105	Kemangsen	Medium	Medium
53	Blurukidul	High	Medium	106	Jambangan	Medium	Medium

Table 7. Flood risk summary comparison between fmcdm and BPBD innudation

Result	Class			Total
	Low	Medium	High	
FMCDM	2	87	17	106
BPBD	8	70	28	106

BPBD only determines the vulnerability of the inundation height for each village, while FMCDM method, the level of flood hazard is determined based on five parameters that affect the inundation height, rainfall, the number of population affected, the amount of drainage and inundation duration of each village. However, in reality flood risk is not only caused by inundation factor, the FMCDM method is represented a better assessment in real world.

5.3. Flood Disaster Map Feature

This application also has a feature to display points of flood inundation locations that occurred in 2012 to 2016. There is a red marker as a marker of flood events. Users can see information on villages affected by flooding as shown in figure 9.

In this feature, user can see the graph of the flood incident per year and graph of prone level flood of Sidoarjo district. If the user places the cursor on the graphic bar, it will show the number of events from a certain year and the number of low, medium and high level of flood risk as shown in figure 10.

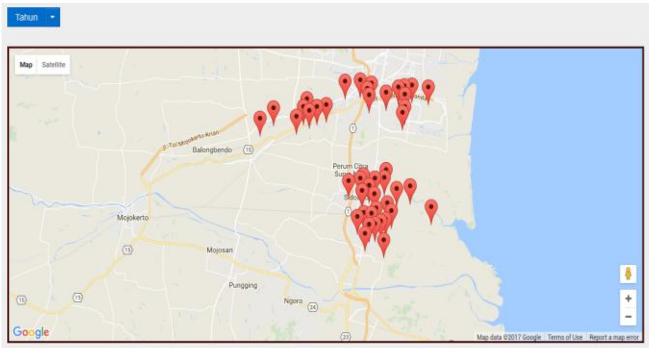
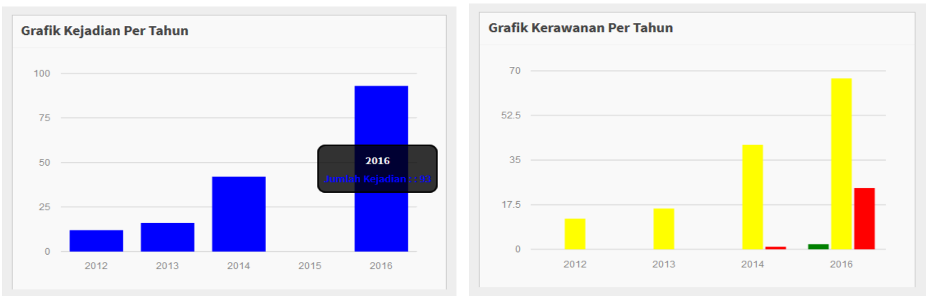


Figure 9. Flood disaster map of Sidoarjo district in 2016.



(a) (b)

Figure 10. (a) Graph of flood disaster event per year of Sidoarjo district; (b) Graph of flood risk per year of Sidoarjo district

The validation of the application to the regional disaster management agency (BPBD) of Sidoarjo district concluded a number of things:

1. The information provided in this application is very complete for flood disaster mitigation, although BPBD already has a disaster application that utilizes information technology.
2. BPBD has mapped flood risk area information, but only based on one variable, the inundation height. FMCDM provides a new approach to measure flood vulnerability based on five parameters namely flood inundation height, duration of flood inundation, rainfall, affected population and amount of drainage. The results of the level of flood vulnerability with FMCDM have 66% similarity in BPBD calculation results. However, in reality, flood risk is not only caused by an inundation factor. The FMCDM method is represented a better assessment in the real world.
3. This application is easy to use by users and useful for the community and related agencies.

6. Conclusion

This system determines the urban flood risk areas of Sidoarjo district covering the results of low, medium, and high level of flood risk from the calculation of FMCDM with five parameters including flood inundation height, duration of flood inundation, rainfall, affected population and amount of drainage 2012, 2013, 2014 and 2016. The level of flood vulnerability in Sidoarjo district in 2014-2016 sustained a significant increasing of 68% villages, 26% villages had decreased, and 6% villages still remained the same level.

BPBD has mapped flood risk area information, but only based on one variable, the inundation height. FMCDM provides a new approach to measure flood vulnerability based on 5 parameters namely flood inundation height, duration of flood inundation, rainfall, affected population and amount of drainage. The results of the level of flood vulnerability with FMCDM have 66% similarity in BPBD calculation results. However, in reality, flood risk is not only caused by an inundation factor. The FMCDM method is represented a better assessment in the real world.

This system provides a complete urban flood disaster mitigation in Sidoarjo that is easy to use by users and useful for the community and related agencies.

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