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EARLY WARNING SYSTEM OF FLOOD PREDICTION WITH FUZZY LOGIC

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Abstract. *Flooding is one of the natural phenomena that often occur in various areas. Flooding does not only occur in watersheds but can also occur in areas far from river flows, for example, in densely populated areas and roads that have no drainage or proper absorption. This research is conducted in three regions: Tangerang, Bekasi and Depok to reduce the impact of the flood disaster. The research aims to design and make the application which can detect the potential of flood in Tangerang, Bekasi, and Depok based on double exponential smoothing method and fuzzy logic method. This application can help the community in reporting flood disaster and inform the potential of flood that occurred in the one hour ahead to the people of that area using broadcast message via email and SMS gateway.*
Keywords: SMS gateway, Double exponential smoothing, Fuzzy logic, Potential flood

1. **Introduction.** Floods can also cause a high level of damage and casualties [1]. To reduce the impact of damage and casualties due to floods, a disaster warning application, and flood disaster reporting that occur in the area are needed so that the community can be alert to flood disasters. This application can help two sides, namely the government and society. This study aims to make an application for warning, reporting and detecting the potential flood in Tangerang, Bekasi and Depok area that can occur in the next hour, helping the community to report floods in these areas, helping the government to overcome flooding from reports of people using the application which can get the information about potential flooding to the community using the SMS gateway. There are many previous studies. In the first research, data visualization has been made for displaying and knowing river water level information in the Tangerang area, including the Cisadane River, Angke River, and Pesanggrahan River [2,3]. In the second study, the three methods were tested, namely the single exponential smoothing method, the double exponential smoothing method, and the holt method for predicting river. The method that has high accuracy in predicting river from the three methods is double exponential smoothing [4]. In the third study, it needs a flood detection system that can be connected to several hardware such as alarms, electric MCBs, and emergency lights so that the system can take several actions if there are floods such as sending short messages to residents, turning on alarms and emergency lights [5].

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For the difference between previous research, in this research the application is expected to be able to assist the government regarding the prevention of floods: (i) detecting potential flooding in the Tangerang, Bekasi, and Depok, (ii) reporting floods in the Tangerang, Bekasi, and Depok, (iii) can help government to deal with flooding from public reports and (iv) notify information about floods to the community in Tangerang using the SMS gateway. All the data are obtained from the Ciliwung Cisadane River Basin Center (BBWS) from 2009 to 2017 with complete data of 315,551 rows. In order to detect potential flooding, we use two variables to predict water level and rainfall to analyze possible water level rises patterns in three regions: Tangerang, Bekasi, and Depok. The reason for choosing the flood disaster in the Tangerang, Bekasi, and Depok area as the object of research is due to the fact that there was no application to help the community who could report floods in their area, and there was no warning application and detecting potential floods in those areas. The remainder of the paper is as follows. The problem statement and research methodology related to the problem considered are introduced in Section 2. Section 3 describes the definition of the problem and the solution procedure with a numerical example is performed with the solutions. Finally, the conclusions and further research areas appear in Section 4.

2. **Problem Statement and Research Methodology.** This study focuses on developing and planning models to tackle floods with the help of the application. The double exponential smoothing and fuzzy logic methods are applied to detecting potential flooding that can occur in the next hour in the area of Tangerang, Bekasi and Depok using the Accuweather API. The data will be detected using fuzzy logic with the Sugeno model inference system to determine the potential for flooding that will occur by designing warning applications, reporting and detecting potential flood disasters in the three regions: Tangerang, Bekasi, and Depok.

The exponential smoothing is a forecasting method for moving averages to carry out weighting decreasing exponentially towards lower observation values. This method is the development of the moving average method [8]. The fuzzy inference system is concluding a set of fuzzy rules. There are four processes in the Sugeno model fuzzy inference system, namely fuzzification, rule-based, inference engine and defuzzification [9]. This application can commemorate the occurrence of floods to the community through the SMS gateway. The SMS gateway is more directed to software that uses computer assistance and utilizes cellular technology that is integrated to distribute messages generated through information systems via SMS media regulated by cellular networks [10].

The input variable is used to detect potential flooding in the next hour in Tangerang, which is the river water level and rainfall data. River water level prediction in Tangerang for the next hour uses the double exponential smoothing method and rainfall prediction in Tangerang uses the Accuweather API because Accuweather provides rainfall forecasting for the next hour. After the steps of river water level prediction and rainfall prediction have been completed, the data is converted into a fuzzy set and represented as a curve. Potential flooding can also be classified into four fuzzy sets, namely no flood, standby flood 3, standby flood 2 and standby flood 1 with these conditions: No Flooding, from 0 to 0.25; Flood Alert 3, from 0.26 to 0.5; Flood Alert 2, from 0.51 to 0.75, and Flood Alert 1, from 0.76 to 1. After the rule-based set stage has been obtained, the implication process is carried out in reasoning the rainfall and water level variables to determine the potential for flooding. The relationship between rainfall and water level uses the operator and ($\cap$) because the two variables are interconnected and influence each other. In this study using the Sugeno fuzzy logic model, the reasoning process uses MIN. After getting the results of the inference engine on each rule, look for the value of Z_1-Z_{20} in the flood potential fuzzification. After getting Z_1-Z_{20} the defuzzification process is carried out. In this study the defuzzification process uses weighted of average.

This system was developed using the SMS gateway feature to inform flood information to the community in the Tangerang, Bekasi, and Depok areas. The process for detecting potential flooding in Tangerang consists of six stages.

Step 1: Input variables such as water level, rainfall and name river. The input variables used to detect potential floods in one hour ahead in Tangerang, Bekasi and Depok are data of river water level, river name, and rainfall that is happening now in those areas. River water level data in Tangerang, Bekasi, and Depok, is obtained from two sources: Ciliwung Cisadane River Basin Center (BBWS), and the website for the Jakarta Water Resources Office in http://poskobanjirdsda.jakarta.go.id/. Rainfall data in Tangerang use Accuweather API.

Step 2: Prediction of water level and rainfall for the next hour. Predict river water level in three regions using a double exponential smoothing method. Predict rainfall using Accuweather API. The double exponential smoothing method consists of five processes:

Determining the value of a single exponential smoothing series (S'_t). Formula (1) shows the count value of a single exponential smoothing series:

$$S'_t = \alpha X_t + (1 - \alpha)\left(S'_{t-1}\right) \tag{1}$$

Determining the value of double exponential smoothing series (S''_t). Formula (2) shows the count value of the double exponential smoothing series:

$$S''_t = \alpha S'_t + (1 - \alpha)\left(S''_{t-1}\right) \tag{2}$$

Determining the value of transmitting constant (α_t). Formula (3) shows the count value of transmitting constantly:

$$\alpha_t = 2S'_t - S''_t \tag{3}$$

Determining the slope value (b_t). Formula (4) shows the count value of the slope:

$$b_t = (\alpha/1 - \alpha) * \left(S'_t - S''_t\right) \tag{4}$$

Determining the value of river water level forecasts the next hour (f_{t+1}). Formula (5) shows the water level forecast the next hour:

$$f_{t+1} = \alpha_t + b_t * 1 \tag{5}$$

Step 3: Fuzzification is the process of determining numerical values into fuzzy sets and determining the degree of membership in fuzzy. The degree of membership is stored in the function.

Step 4: Set rule-based to detect the potential flood that occurred in the next hour. This research gets rule-based to detect flood potency by doing data collecting technique using questionnaire and interview. This research conducted a direct interview with the hydrologist at Ciliwung Cisadane River Basin Center (BBWS) and answered some questionnaire questions. Table 1 shows 20 rule-based to detect the potential floods.

Step 5: The inference engine is a process of implication in the reasoning variable of rainfall and water level to determine potential flood. The inference engine uses MIN to find α-predicate 1 to n according to rule-based. After the set rule-based stage has been obtained, then do the implication process in the reasoning variable rainfall and water level to determine the potential for floods that occur. The relationship of rainfall and water level uses the operator and ($\cap$) because the two variables are interrelated and mutually influential. In this study, using a fuzzy logic model Sugeno then the reasoning process uses MIN. Table 2 shows the inference engine to detect the potential floods.

Step 6: Defuzzification is to determine the membership function of the rule-based to get the value of Z_1-Z_{20}. After getting the total from defuzzification (Z) then obtain from the status of potential floods that occur in one hour ahead. In this study defuzzification

Table 1. Rule-based to detect the potential floods

No	Rainfall	Water Level	Potential Flood
1	Not Rain	Normal	Not Flood
2	Not Rain	Level 3	Flood Alert 3
3	Not Rain	Level 2	Flood Alert 2
4	Not Rain	Level 1	Flood Alert 1
5	Light Rain	Normal	Not Flood
6	Light Rain	Level 3	Flood Alert 3
7	Light Rain	Level 2	Flood Alert 2
8	Light Rain	Level 1	Flood Alert 1
9	Moderate Rain	Normal	Not Flood
10	Moderate Rain	Level 3	Flood Alert 3
11	Moderate Rain	Level 2	Flood Alert 2
12	Moderate Rain	Level 1	Flood Alert 1
13	Heavy Rain	Normal	Not Flood
14	Heavy Rain	Level 3	Flood Alert 3
15	Heavy Rain	Level 2	Flood Alert 2
16	Heavy Rain	Level 1	Flood Alert 1
17	Torrential Rain	Normal	Flood Alert 3
18	Torrential Rain	Level 3	Flood Alert 3
19	Torrential Rain	Level 2	Flood Alert 2
20	Torrential Rain	Level 1	Flood Alert 1

Table 2. The inference engine to detect the potential floods

α-predicate	**Relationship**	***Inference Engine***
α-predicate1	$\mu_{\text{Rainfall-Not Rain}} \cap \mu_{\text{Waterlevel-Normal}}$	$\min(\mu_{\text{Rainfall-Not Rain}}, \mu_{\text{Waterlevel-Normal}})$
α-predicate2	$\mu_{\text{Rainfall-Not Rain}} \cap \mu_{\text{Waterlevel-Level 3}}$	$\min(\mu_{\text{Rainfall-Not Rain}}, \mu_{\text{Waterlevel-Level 3}})$
α-predicate3	$\mu_{\text{Rainfall-Not Rain}} \cap \mu_{\text{Waterlevel-Level 2}}$	$\min(\mu_{\text{Rainfall-Not Rain}}, \mu_{\text{Waterlevel-Level 2}})$
α-predicate4	$\mu_{\text{Rainfall-Not Rain}} \cap \mu_{\text{Waterlevel-Level 1}}$	$\min(\mu_{\text{Rainfall-Not Rain}}, \mu_{\text{Waterlevel-Level 1}})$
α-predicate5	$\mu_{\text{Rainfall-Light Rain}} \cap \mu_{\text{Waterlevel-Normal}}$	$\min(\mu_{\text{Rainfall-Light Rain}}, \mu_{\text{Waterlevel-Normal}})$
α-predicate6	$\mu_{\text{Rainfall-Light Rain}} \cap \mu_{\text{Waterlevel-Level 3}}$	$\min(\mu_{\text{Rainfall-Light Rain}}, \mu_{\text{Waterlevel-Level 3}})$
α-predicate7	$\mu_{\text{Rainfall-Light Rain}} \cap \mu_{\text{Waterlevel-Level 2}}$	$\min(\mu_{\text{Rainfall-Light Rain}}, \mu_{\text{Waterlevel-Level 2}})$
α-predicate8	$\mu_{\text{Rainfall-Light Rain}} \cap \mu_{\text{Waterlevel-Level 1}}$	$\min(\mu_{\text{Rainfall-Light Rain}}, \mu_{\text{Waterlevel-Level 1}})$
α-predicate9	$\mu_{\text{Rainfall-Moderate Rain}} \cap \mu_{\text{Waterlevel-Normal}}$	$\min(\mu_{\text{Rainfall-Moderate Rain}}, \mu_{\text{Waterlevel-Normal}})$
α-predicate10	$\mu_{\text{Rainfall-Moderate Rain}} \cap \mu_{\text{Waterlevel-Level 3}}$	$\min(\mu_{\text{Rainfall-Moderate Rain}}, \mu_{\text{Waterlevel-Level 3}})$
α-predicate11	$\mu_{\text{Rainfall-Moderate Rain}} \cap \mu_{\text{Waterlevel-Level 2}}$	$\min(\mu_{\text{Rainfall-Moderate Rain}}, \mu_{\text{Waterlevel-Level 2}})$
α-predicate12	$\mu_{\text{Rainfall-Moderate Rain}} \cap \mu_{\text{Waterlevel-Level 1}}$	$\min(\mu_{\text{Rainfall-Moderate Rain}}, \mu_{\text{Waterlevel-Level 1}})$
α-predicate13	$\mu_{\text{Rainfall-Heavy Rain}} \cap \mu_{\text{Waterlevel-Normal}}$	$\min(\mu_{\text{Rainfall-Heavy Rain}}, \mu_{\text{Waterlevel-Normal}})$
α-predicate14	$\mu_{\text{Rainfall-Heavy Rain}} \cap \mu_{\text{Waterlevel-Level 3}}$	$\min(\mu_{\text{Rainfall-Heavy Rain}}, \mu_{\text{Waterlevel-Level 3}})$
α-predicate15	$\mu_{\text{Rainfall-Heavy Rain}} \cap \mu_{\text{Waterlevel-Level 2}}$	$\min(\mu_{\text{Rainfall-Heavy Rain}}, \mu_{\text{Waterlevel-Level 2}})$
α-predicate16	$\mu_{\text{Rainfall-Heavy Rain}} \cap \mu_{\text{Waterlevel-Level 1}}$	$\min(\mu_{\text{Rainfall-Heavy Rain}}, \mu_{\text{Waterlevel-Level 1}})$
α-predicate17	$\mu_{\text{Rainfall-Torrential Rain}} \cap \mu_{\text{Waterlevel-Normal}}$	$\min(\mu_{\text{Rainfall-Torrential Rain}}, \mu_{\text{Waterlevel-Level 1}})$
α-predicate18	$\mu_{\text{Rainfall-Torrential Rain}} \cap \mu_{\text{Waterlevel-Level 3}}$	$\min(\mu_{\text{Rainfall-Torrential Rain}}, \mu_{\text{Waterlevel-Level 3}})$
α-predicate19	$\mu_{\text{Rainfall-Torrential Rain}} \cap \mu_{\text{Waterlevel-Level 2}}$	$\min(\mu_{\text{Rainfall-Torrential Rain}}, \mu_{\text{Waterlevel-Level 2}})$
α-predicate20	$\mu_{\text{Rainfall-Torrential Rain}} \cap \mu_{\text{Waterlevel-Level 1}}$	$\min(\mu_{\text{Rainfall-Torrential Rain}}, \mu_{\text{Waterlevel-Level 1}})$

process uses weighted of average. Formula (6) shows the defuzzification weighted of average formula as follows:

$$Z = \frac{\alpha pred_1 * Z_1 + \alpha pred_2 * Z_2 + \cdots + \alpha pred_n * Z_n}{\alpha pred_1 + \alpha pred_2 + \cdots + \alpha pred_n} \tag{6}$$

The result of defuzzification (Z) has been obtained and then the result will be incorporated into IF ... THEN on every potential flood in Tangerang river to know the status of the potential flood that will occur in the next hour.

3. **Solution Procedure.** In this study, there are two methods used to develop the application. First, the method to predict river or the river water level is a double exponential smoothing method because this method is widely used for predicting unstable data or fast-changing data such as water level data. The second is the fuzzy logic in fuzzy inference systems using the Sugeno method to detect potential flooding in designing Hybrid Mobile Applications based applications. This study built this hybrid mobile application using HTML 5 and bootstrap framework and lite material design for the mobile front-end while the back-end used the PHP, Ajax, and Javascript programming languages. The database used in this application is MySQL. The software used for developing this application is SMS-global, sublime text 3, XAMPP and Intel XDK.

This application is based on a hybrid mobile application because it makes it easier for users to use this application on various operating systems and various platforms used by users. The process to detect the potential flood in Tangerang, Bekasi and Depok has six stages: input variables, prediction water level, and rainfall, fuzzification, set rule-based, inference engine, and defuzzification. After that, the results of flood detection potential application design in Tangerang based on the double exponential smoothing method and fuzzy logic method are shown in the mobile apps (Android). This application can notify information about potential floods that occur in the next hour in the Tangerang area using broadcast messages via email and via SMS gateway. Messages are broadcast to the user when the potential floods occur in one hour ahead of the Flood Alert 2 and Flood Alert 1. In order to send information on potential floods and flood report information to the public use the SMS gateway opensource or use SMS-global to send paid messages for each SMS.

Figure 1 displays the flood reports from the user. This page has an input form to look for flood reports based on the date, region, and status of flood reports. This page has a table to display a list of flood reports.

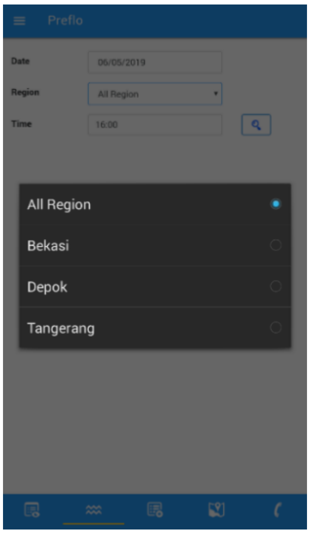


FIGURE 1. Flood prediction

Figure 2 shows the form works for officers to process flood reports from users or users who have reported flooding. This page has two forms: form to display detail of flood report from user and input form used by the officer to fill date data, flood report process time, officer name and supporting picture when processing flood report. This page can be accessed by officers only.

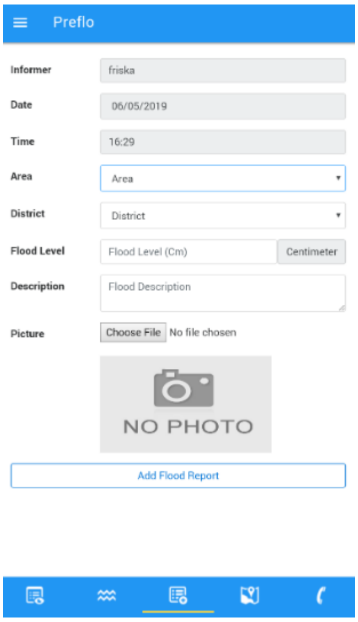
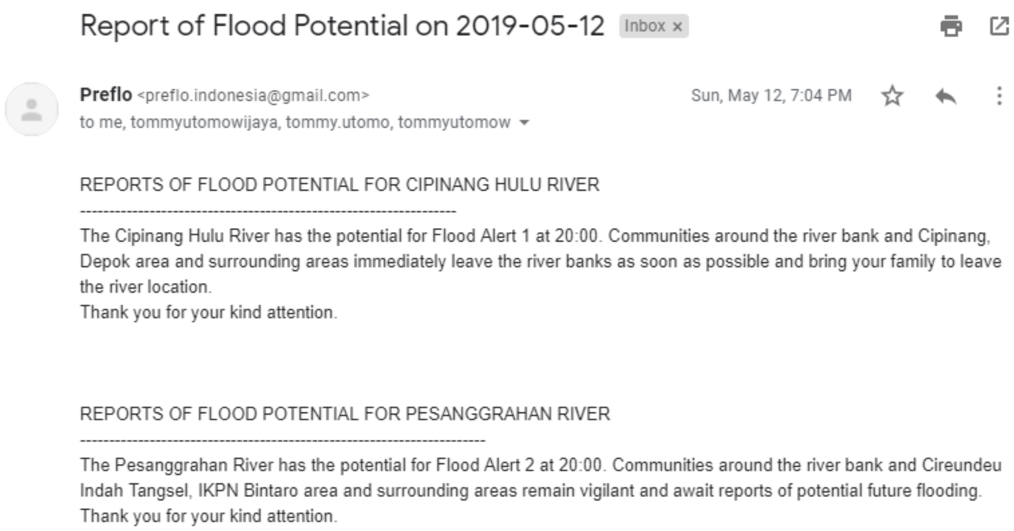


FIGURE 2. Flood report

This application serves to show potential floods that occur in the hour ahead. This application has an input form to look for potential flood based on date and time ago also contains a panel that will display potential flood information for an hour ahead. When the river shows the potential of alert 2 and alert 1 then all the users receive a notification via email and SMS. Figure 3 displays a broadcast message sent via email to report potential floods occurring in the next hour.


Report of Flood Potential on 2019-05-12 Inbox ×

Preflo <preflo.indonesia@gmail.com> Sun, May 12, 7:04 PM
to me, tommyutomowijaya, tommy.utomo, tommyutomow

REPORTS OF FLOOD POTENTIAL FOR CIPINANG HULU RIVER

The Cipinang Hulu River has the potential for Flood Alert 1 at 20:00. Communities around the river bank and Cipinang, Depok area and surrounding areas immediately leave the river banks as soon as possible and bring your family to leave the river location.
Thank you for your kind attention.

REPORTS OF FLOOD POTENTIAL FOR PESANGGRAHAN RIVER

The Pesanggrahan River has the potential for Flood Alert 2 at 20:00. Communities around the river bank and Cireundeu Indah Tangsel, IKPN Bintaro area and surrounding areas remain vigilant and await reports of potential future flooding.
Thank you for your kind attention.

FIGURE 3. Warning system by email

This study detects flood potential for one hour ahead with two variables: prediction of river water level for one hour using a double exponential smoothing method and rainfall prediction for one hour ahead of using Accuweather API. Then the two variables are processed using fuzzy logic Sugeno model to know the potential flood that occurred in one hour ahead. The output consists of four, i.e., Not Flood, Flood Alert 3, Flood Alert 2 and Flood Alert 1. Officers can process reports directly because users who report flooding can upload flood images. Also, user can know the progress of the flood report has been processed or not by officers. This application notifies potential flood information that occurs for an hour ahead using a broadcast message via email and SMS gateway so that the user can directly receive the information. Messages are distributed to the user when potential floods occur one hour ahead of the Flood Alert 2 and Flood Alert 1.

4. **Conclusions.** This research found the potential of the flood that occurs in the next hour in the three regions: Tangerang, Bekasi and Depok. This research used two variables which are water level and rainfall. This research predicted water level in the next hour using the double exponential smoothing method and the rainfall in the next hour using the Accuweather API. This application can notify a user about the potential floods that occur in the next hour in the area using broadcast messages via email and via SMS gateway. Messages are broadcast to the user when the potential floods occur in one hour ahead of the Flood Alert 2 and Flood Alert 1. Furthermore, other problems in disaster management can be solved and finding a better solution procedure will be studied in future research.

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