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B – data collection
C – statistical analysis
D – data interpretation
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F – literature search

Modelling of rainfall intensity in a watershed: A case study in Amprong watershed, Kedungkandang, Malang, East Java of Indonesia

Lily Montarcih LIMANTARA [ABCD] ✉, **Donny H. HARISUSENO** [CEF], **Vita A.K. DEWI** [BD]

University of Brawijaya, Faculty of Engineering, Department of Water Resources, Jl. Mt Haryono No 167, 65141 Malang, East Java Province, Indonesia; e-mail: lilymont2001@gmail.com; donnyhari@ub.ac.id

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Abstract

Analysis of rainfall intensity with specific probability is very important to control the negative impact of rainfall occurrence. Rainfall intensity (I), probability (p) and return period (T) are very important variables for the discharge analysis. There are several methods to estimate rainfall intensity, such as Talbot, Sherman, and Ishiguro. The aim of this research is to develop equation model which can predict rainfall intensity with specific duration and probability. The equation model is compared with the other methods. The result of rainfall intensity model with the value of correlation >0.94 and Nash–Sutcliffe coefficient >99 is quite good enough if compared with the observation result. For specific return period, the modelling result is less accurate which is most likely caused by election of duration. Advanced research in other location indicates that short duration gives the better result for rainfall intensity modelling, which is shown by the decreasing average value of mean absolute error (*MAE*) from 12.963 to 8.26.

Key words: *duration, forecasting, probability, flood probability, rainfall intensity*

INTRODUCTION

In hydrology, a simplified mathematical representation modelling of all or part of hydrological cycle process is important. Hydrological modelling is a tool that is generally used to estimate the hydrological response of the basin due to the rainfall [MOKHTARI *et al*. 2016]. However, rainfall is one of the God's graces which gives many benefits but it also has the potency of disaster if the quantity and the distribution are uncontrolled. In the other side, rainfall is as a natural phenomenon that is difficult to be modified or controlled. The maximal effort which is carried out by human is to know the pattern of its availability in the space, time, and the quantity. In the design of a hydraulic structure, there is needed the accurate dimension [LIMANTARA 2009] regarding to the life time of plan. For the design and analysis of structure, it is needed the right analysis [WARDOYO 2009]. If it is related to the water structure, the analysis due to the rainfall happened or the discharge or the volume with the certain probability will become very essential for the effort of negative impact controlling due to the rainfall. The three variables of rainfall which are generally used in the analysis, prediction, and the design are the rainfall thickness (R), the rainfall duration (t), and the distribution in the space and time. Based on the main variables, it can be differentiated the other rainfall variables such as the rainfall intensity (I) and the rainfall probability or the return period of the rain-

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fall event (*I*) [ROHMAT, SOEKARNO 2006]. These variables are very important in the technical design.

Rainfall intensity is caused by the rainfall duration and frequency of the happening so the amount of it, is vary [ILHAMSYAH 2012]. There are several methods for determining the rainfall intensity related to the rainfall duration such as the methods of TALBOT [1881], SHERMAN [1905], ISHIGURO [1953], and SOSRODARSONO and TAKEDA [2006]. According to the Malang Pos newspaper on 23[th] May 2013, it was said that one of the villages in the Kedungkandang district (Sawojajar region) is back flooding on the depth of 30 cm. It was caused by the rainfall during 2 hours and the drainage channel was not able to store the rainfall due to the capacity was too small.

One of the handling ways to control the flooding is to build the drainage channel which can store the discharge that is caused by the rainfall. In designing the water structure at first, there is determined the design flood. The amount of design flood is determined by the rainfall intensity. The data of rainfall intensity is different for each area and it is depended on the rainfall duration and the frequency of happening. Hence, the rainfall intensity is very important because it will influence the analysis process of water structure dimension, so it is needed the accuracy and right analysis. Based on the reason as above, this research intends to study the equation or formula of the rainfall intensity modelling. The analysis result will be very helpful in the design and management of water resource in the Amprong sub-watershed mainly in the Kedungkandang District.

MATERIALS AND METHODS

STUDY LOCATION

The upstream Brantas watershed is divided into some sub-watersheds such as the upper Brantas (Batu city), the Amprong sub-watershed (Malang city and Malang regency), and the Bango sub-watershed (Malang city and Malang regency). The study location is in the Amprong watershed which is focussed in the Kedungkandang district, Malang city. Based on the data of Brantas River Area Big Institution (Brantas BBWS), Kedungkandang district has the area of 39.715 km^2 which is divided into 12 villages. Map of the study location is as in the Figure 1.

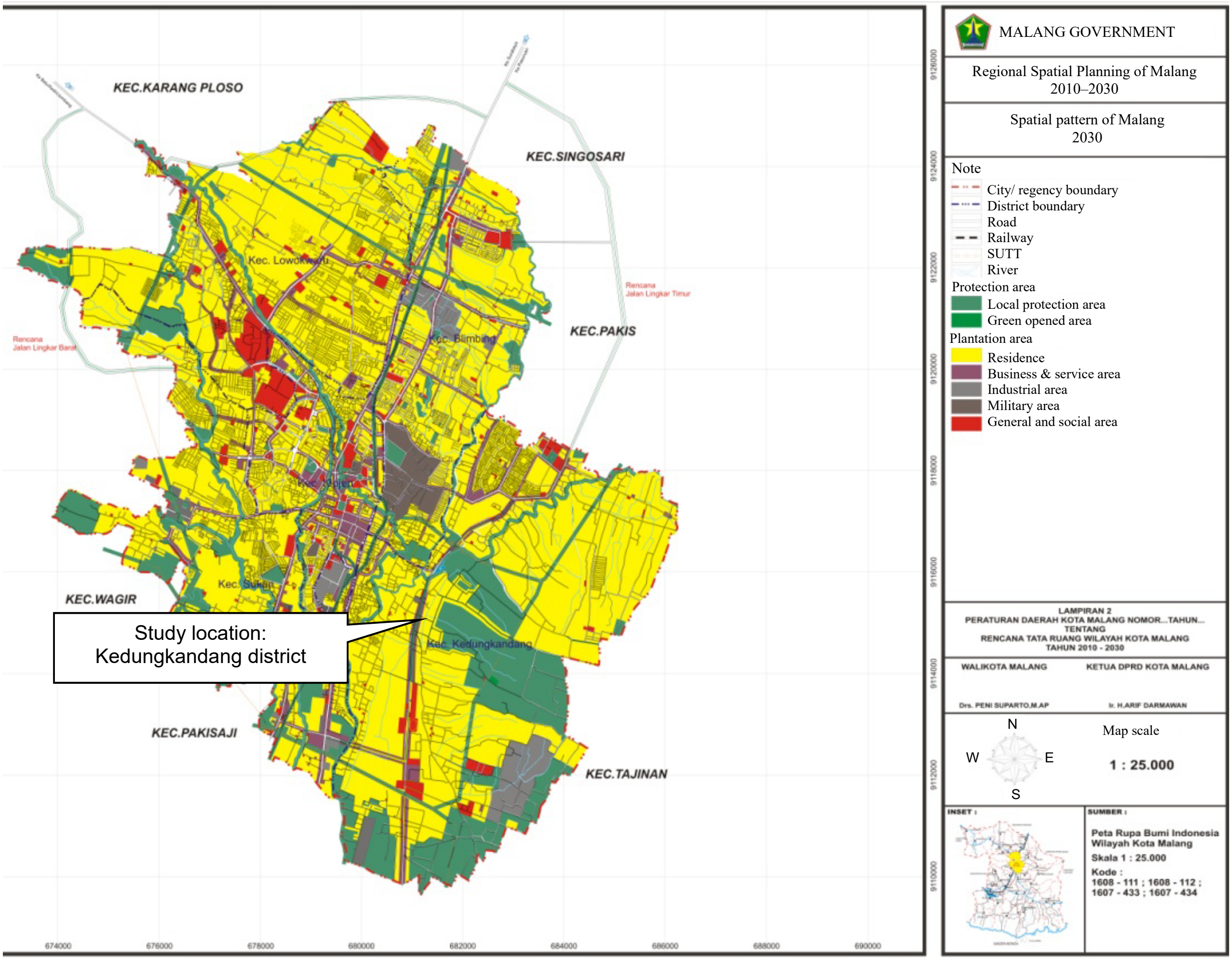

Fig. 1. Map of the study location; source: Malang city government

RAINFALL INTENSITY

Rainfall intensity is as an amount of rainfall per-unit of time that is expressed in mm·h^{-1} [HADISUSANTO 2010]. The rainfall intensity is notified with *I*. Data of the rainfall intensity can be directly obtained by using the automatic rainfall measuring tool. From the automatic rainfall recorder, it can automatically obtained the rainfall time in the smaller duration, *i.e.* 5 min, 10 min, 30 min, *etc.* From the analysis through the automatic rainfall curve will be produced the best rainfall intensity because it can directly illustrate the distribution pattern of the rainfall intensity surrounding it.

SOSRODARSONO and TAKEDA [2006] described that there are varies of the rainfall intensity. It is due to the rainfall duration and the frequency on the happening of rainfall. Several methods which are generally used to analyse the rainfall intensity are as follow [SOSRODARSONO, TAKEDA 2006]:

METHOD OF OBSERVATION

The average of the rainfall intensity in t hour is expressed in the formula as follow:

$$I_i = \frac{R_i}{t_i} \tag{1}$$

Where: I_i = rainfall intensity (mm·h^{-1}); t_i = rainfall duration (h); R_i = maximum hourly rainfall within 24 h or a day (mm).

METHOD OF SHERMAN

The formula was presented by SHERMAN [1905]. This formula is suitable for the rainfall time period that is more than 2 h and the equation is as follow:

$$I = \frac{a}{t^n} \tag{2}$$

$$a = \frac{(\sum \log I)(\sum \log t^2) - (\sum \log t \cdot \log I)(\sum \log t)}{n(\sum \log t^2) - (\sum \log t)(\sum \log t)} \tag{3}$$

$$b = \frac{(\sum \log I)(\sum \log t) - n(\sum \log t \cdot \log I)}{n(\sum \log t^2) - (\sum \log t)(\sum \log t)} \tag{4}$$

Where: I = rainfall intensity (mm·h^{-1}); t = rainfall duration (h); a, b = constant, it is depended on the rainfall duration that is happened in a watershed; n = number of data (pairs of I and t data).

TALBOT'S METHOD

This formula was presented by TALBOT [1881]. It is many used because it is easily to be applied where a and b are determined by the value measured. The Talbot's method is also suitable for analysing the rainfall which is happened during 5 min until 2 h. This formula is expressed in the equation of least square as follow:

$$I = \frac{a}{t+b} \tag{5}$$

$$a = \frac{(\sum I \cdot t)(\sum I^2) - (\sum I^2 t)(\sum I)}{n(\sum I^2) - (\sum I)(\sum I)} \tag{6}$$

$$b = \frac{(\sum I)(\sum I \cdot t) - n(\sum I^2 t)}{n(\sum I^2) - (\sum I)(\sum I)} \tag{7}$$

Where: I, t, a, b as below Equation (4).

ISHIGURO'S METHOD

This formula was presented by ISHIGURO [1953] as follow:

$$I = \frac{a}{\sqrt{t}+b} \tag{8}$$

$$a = \frac{(\sum I \cdot t^{0.5})(\sum I^2) - (\sum I^2 \cdot t^{0.5})(\sum I)}{n(\sum I) - (\sum I)(\sum I)} \tag{9}$$

$$b = \frac{(\sum I)(\sum I \cdot t^{0.5}) - (\sum I^2 \cdot t^{0.5})}{n(\sum I) - (\sum I)(\sum I)} \tag{10}$$

Where: I, t, a, b as below Equation (4).

OUTLIERS TEST

Outliers are the data which deviates high enough from the group trend. The existence of outliers is generally assumed to disturb the type selection of a data sample distribution, so the outliers are needed to be removed [CHOW *et al.* 1988; HIDAYAT 2013]. The formula which is used to determine the upper and lower limit of outliers is as follow:

$$y_H = \overline{y} + K_n s_y \tag{12}$$

$$y_L = \overline{y} - K_n s_y \tag{13}$$

Where: y_H = upper threshold value; y_L = lower threshold value; $\overline{y}$ = mean value; s_y = deviation standard of log to sample; K_n = a value which is depended on the number of data sample (there is an outliers table); n = number of data.

STEPS OF MODELLING

The analysis is carried out based on the data that have been classified based on the duration. The steps of analysis for obtaining the model are as follow:

1. Data with the outliers behaviour is removed from the analysis.
2. *t*-test is carried out for knowing that the sample is come from the same population.
3. The data normality test is carried out for knowing the data is normal distributed or not. If the data is not normally distributed, it will be carried out the semi-log transformation. In this case, there is carried out the logarithmic transformation.
4. Data descending. On every group of rainfall duration, the rainfall intensity is to be descended from the highest intensity to the lowest one.
5. To analyse the probability of each data by using the formula of Weibull as follow [SOEMARTO 1987]:

$$p = \frac{m}{n+1} 100\% \tag{14}$$

Where: p = probability (%); m = number of discharge data; n = the amount of data.

6. To formulate the relation between the rainfall probability with the rainfall intensity for each group of the rainfall duration, so there is obtained the formula of $I_t = f(p)$.
7. To analyse the projection value of the rainfall intensity for the certain probability. In this case is to be analysed for p = 5 until 95% with the interval of 5% so it is obtained the projection value of the rainfall intensity based on the interval of rainfall probability on each group of t.
8. To formulate the linear equation between the rainfall intensity as the function of t for every interval of the rainfall probability. To obtain the good relation pattern, it is transformed into $I{\cdot}t^{-1}$, so it is obtained the linear equation of $I_p = a + b(I{\cdot}t^{-1})$ or $y = a + bx$ where $x = I{\cdot}t^{-1}$.
9. The coefficient value of a and b from the linear equation as above is classified based on the interval of the rainfall probability.
10. The relation between (A) p with the coefficient of a; and (B) p with the coefficient of b is as the exponential relation.
11. To regulate the final equation which is including to substitute the equation of (A) and (B) into the equation of $I_p = a + b(I{\cdot}t^{-1})$ and then to simplify it and it will be obtained I_{tp}.
12. To carry out the data verification test through two ways such as: 1) to compare the rainfall intensity as the model result with the empirical one, I_e is as the basic data; and 2) to compare the rainfall intensity as the model result with the analysis due to the other methods (Talbot, Sherman, and Ishiguro) and the observed model as the equation (1).

RESULTS AND DISCUSSION

Based on the recorded rainfall data during 5 years in the rainfall stations of Kedungkandang, there are obtained 3,567 rainfall events. The data consist of 2 variables such as the rainfall depth (R) and the rainfall duration (t). The rainfall intensity is classified based on the duration of 1 h, 2 h, 3 h, 4 h, and 5 h. Data of the rainfall intensity are classified as follow: 2,015 data of 1 hour duration; 772 data of 2 h duration; 411 data of 3 h duration; 260 data of 4 h duration, and 109 data of 5 h duration. For example the analysis of 5 h duration rainfall intensity is as follow:

$$I_i = \frac{R_i}{t_i}$$

$$I_i = \frac{101.70}{5}, \quad I_i = 20.34 \text{ mm}{\cdot}\text{h}^{-1}$$

Where: I_i = rainfall intensity; R_i = rainfall (mm), t_i = duration of a rainfall event (h).

Then, there is analysed the probability based on the Weibull formula:

$$p = \frac{m}{n+1} 100\%$$

$$p = (1{\cdot}(109 + 1)^{-1}) \cdot 100\%$$

$$p = 0.91\%$$

Where: p = probability of rainfall (%); m = rank number of rainfall intensity that has been descended; n = number of data.

For the other data are presented as in the Table 1.

Table 1. The analysis of intensity (I) and probability (p) with the duration of 5 h (t = 5 h)

R (mm)	I (mm·h^{-1})	log I	p (%)
101.70	20.34	1.31	0.91
92.30	18.46	1.27	1.82
91.10	18.22	1.26	2.73
86.70	17.34	1.24	3.64
85.20	17.04	1.23	4.55
85.00	17.00	1.23	5.45
82.30	16.46	1.22	6.36
74.00	14.80	1.17	7.27
73.20	14.64	1.17	8.18
68.90	13.78	1.14	9.09
68.60	13.72	1.14	10.00
67.70	13.54	1.13	10.91
67.60	13.52	1.13	11.82
65.00	13.00	1.11	12.73
61.30	12.26	1.09	13.64
61.00	12.20	1.09	14.55
60.70	12.14	1.08	15.45
59.10	11.82	1.07	16.36
56.30	11.26	1.05	17.27
56.20	11.24	1.05	18.18
55.60	11.12	1.05	19.09
52.00	10.40	1.02	20.00
50.50	10.10	1.00	20.91
50.10	10.02	1.00	21.82
49.90	9.98	1.00	22.73
49.00	9.80	0.99	23.64
43.10	8.62	0.94	24.55
42.30	8.46	0.93	25.45
40.40	8.08	0.91	26.36
39.70	7.94	0.90	27.27
39.30	7.86	0.90	28.18
38.20	7.64	0.88	29.09
36.90	7.38	0.87	30.00
36.30	7.26	0.86	30.91
35.40	7.08	0.85	31.82
35.00	7.00	0.85	32.73
35.00	7.00	0.85	33.64
34.20	6.84	0.84	34.55
34.10	6.82	0.83	35.45
33.80	6.76	0.83	36.36
32.60	6.52	0.81	37.27
31.20	6.24	0.80	38.18
31.00	6.20	0.79	39.09
30.90	6.18	0.79	40.00
30.40	6.08	0.78	40.91
30.30	6.06	0.78	41.82
30.30	6.06	0.78	42.73
28.00	5.60	0.75	43.64
27.40	5.48	0.74	44.55
26.90	5.38	0.73	45.45
25.20	5.04	0.70	46.36
24.40	4.88	0.69	47.27
23.60	4.72	0.67	48.18

R (mm)	I (mm·h^{-1})	log I	p (%)
22.30	4.46	0.65	49.09
21.80	4.36	0.64	50.00
21.80	4.36	0.64	50.91
21.70	4.34	0.64	51.82
21.10	4.22	0.63	52.73
20.30	4.06	0.61	53.64
19.30	3.86	0.59	54.55
18.30	3.66	0.56	55.45
17.80	3.56	0.55	56.36
17.70	3.54	0.55	57.27
17.70	3.54	0.55	58.18
17.60	3.52	0.55	59.09
17.30	3.46	0.54	60.00
16.90	3.38	0.53	60.91
16.30	3.26	0.51	61.82
15.30	3.06	0.49	62.73
15.10	3.02	0.48	63.64
14.80	2.96	0.47	64.55
13.90	2.78	0.44	65.45
13.60	2.72	0.43	66.36
13.30	2.66	0.42	67.27
13.20	2.64	0.42	68.18
13.20	2.64	0.42	69.09
13.00	2.60	0.41	70.00
12.70	2.54	0.40	70.91
12.40	2.48	0.39	71.82
12.40	2.48	0.39	72.73
12.20	2.44	0.39	73.64
11.40	2.28	0.36	74.55
11.10	2.22	0.35	75.45
11.00	2.20	0.34	76.36
10.80	2.16	0.33	77.27
10.10	2.02	0.31	78.18
9.20	1.84	0.26	79.09
8.90	1.78	0.25	80.00
8.30	1.66	0.22	80.91
8.20	1.64	0.21	81.82
6.90	1.38	0.14	82.73
6.80	1.36	0.13	83.64
6.80	1.36	0.13	84.55
5.60	1.12	0.05	85.45
5.50	1.10	0.04	86.36
5.50	1.10	0.04	87.27
4.60	0.92	–0.04	88.18
4.40	0.88	–0.06	89.09
3.90	0.78	–0.11	90.00
3.60	0.72	–0.14	90.91
3.10	0.62	–0.21	91.82
3.00	0.60	–0.22	92.73
2.60	0.52	–0.28	93.64
2.30	0.46	–0.34	94.55
1.80	0.36	–0.44	95.45
1.30	0.26	–0.59	96.36
1.20	0.24	–0.62	97.27
1.00	0.20	–0.70	98.18
0.80	0.16	–0.80	99.09

Source: own study.

Table 2 presents the recapitulation of the outliers test result, Table 3 presents the recapitulation of t-test result, and Table 4 presents the result of Kolmogorov test.

Table 2. Recapitulation of outliers test result for each of duration

Duration (h)	y_H	y_L	Note
1	58.278	0	3 outliers data
2	70.099	0	2 outliers data
3	84.428	0	no outliers data
4	94.300	0	no outliers data
5	105.882	0	no outliers data

Explanations: y_H = upper threshold value, y_L = lower threshold value.
Source: own study.

Table 3. Recapitulation of t-test result

Duration (h)	t_{stat}	t_{critical}	Note
1	1.584	1.646	accepted
2	0.302	1.648	accepted
3	0.959	1.652	accepted
4	0.681	1.656	accepted
5	0.865	1.674	accepted

Source: own study.

Table 4. Result of Komogorov test

Number of data N		109
Normal parameters	mean	30.1798
	standard deviation	24.85461
Most extreme differences	absolute	0.138
	positive	0.138
	negative	–0.119
Kolmogorov–Smirnov Z		1.442
Asymptotic significance (2-tailed)		0.031
Test distribution is normal		

Source: own study.

Based on the results in Table 4 about the value of asymptotic significance (asymp. sig.) on the SPSS (Statistical Package for the Social Sciences) 16.0 is 0.031 (<16.00), it can be concluded that the data have not been normal. For solving the problem, it has to use the data transformation. Table 5 presents the normality test after data transformation.

Table 5. Recapitulation of the normality test after the data transformation

Duration h	D critical		D max		Note	
	1%	5%	1%	5%	1%	5%
1	0.036	0.030	0.029	0.029	accepted	accepted
2	0.059	0.049	0.042	0.042	accepted	accepted
3	0.080	0.067	0.065	0.065	accepted	accepted
4	0.101	0.084	0.083	0.083	accepted	accepted
5	0.156	0.130	0.086	0.086	accepted	accepted

Source: own study.

FORMULATION OF THE RAINFALL INTENSITY AS THE FUNCTION OF PROBABILITY

Based on the data analysis of basic rainfall intensity on each duration, it can be analysed the relation pattern between the log I and the rainfall probability on each group of the rainfall duration (t) and then it can be found the linear equation. The linear equation is in the form of $\log(I) = A + Bx$, where I is rainfall intensity, x is probability (p), and it is obtained the linear equation (for example for $I_{5\ h}$) as follow:

$t = 5$ h

$y = \log I$; $\log I = -0.0158x + 1.3767$

$I_{5\ h} = 10^y$;

$I_{5\ h} = 10^{-0.0158p+1.3767}$

The results for kinds of intensity can be seen as in the Table 6.

Table 6. Coefficient value A and B of linear equation for each of rainfall duration

Rainfall intensity	A	B
$I_{1\ h}$	–0.0204	1.4342
$I_{2\ h}$	–0.0172	1.4317
$I_{3\ h}$	–0.0159	1.4138
$I_{4\ h}$	–0.0166	1.4017
$I_{5\ h}$	**–0.0158**	**1.3767**

Source: own study.

FORMULATION OF RAINFALL INTENSITY AS THE FUNCTION OF RAINFALL DURATION AND PROBABILITY

From the analysis on each of intensity duration, the probability is distributed between 5% until 95%. For example, the analysis of the rainfall intensity for the rainfall probability function due to the duration of 5 h for the linear method is as follow:

$t = 5$ h

$y = \log I$; $\log I = -0.0158x + 1.3767$

$I_{5\ h} = 10^y$

$I_{5\ h} = 10^{-0.0158p+1.3767}$

$p = 5\%$

$I_{5\ h} = 10^{-0.0158 \cdot 5+1.3767} = 19.847\ \mathrm{mm \cdot h^{-1}}$

Table 7. Projection of the rainfall intensity based on the p = 5% until 95% with the interval of 5% on the rainfall duration group (t, h)

p	Rainfall duration (t, h)				
%	1	2	3	4	5
5	21.488	22.167	21.592	20.831	19.847
10	16.990	18.184	17.980	17.207	16.546
15	13.434	14.918	14.973	14.213	13.794
20	10.622	12.238	12.468	11.741	11.500
25	8.398	10.039	10.382	9.698	9.587
30	6.640	8.236	8.646	8.011	7.993
35	5.250	6.756	7.199	6.618	6.663
40	4.151	5.542	5.995	5.466	5.555
45	3.282	4.547	4.992	4.515	4.631
50	2.595	3.730	4.157	3.730	3.861
55	2.052	3.060	3.462	3.081	3.219
60	1.623	2.510	2.883	2.545	2.683
65	1.283	2.059	2.400	2.102	2.237
70	1.014	1.689	1.999	1.737	1.865
75	0.802	1.386	1.665	1.434	1.555
80	0.634	1.137	1.386	1.185	1.296
85	0.501	0.933	1.154	0.979	1.081
90	0.396	0.765	0.961	0.809	0.901
95	0.313	0.628	0.800	0.668	0.751

Explanations: $p = T_r^{-1} \cdot 100\%$ where T_r = return period (year). For example: for the return period T_r = 2 years, then the interpretation of probability (p) = $2^{-1} \cdot 100\% = 50\%$.
Source: own study.

Based on the analysis result as the example above, it is obtained the rainfall intensity as the function of rainfall probability for all kinds of duration and the results are presented as in the Table 7.

The values of I_p on the same probability are plotted on the y-coordinate and $I \cdot t^{-1}$ is plotted on the x-coordinate. Regarding to the number of p interval, there are 19 linear equations which is formed. The linear equations have the basic equation as $I = A + B \cdot t^{-1}$. Based on the linear equation of $I_p = f(t^{-1})$, due to the regression analysis, it is obtained the coefficient value of A and B with the probability from 5% until 95%. Figure 2 presents the example of the equation $I_p = f(t^{-1})$ for the probability of 50%. For the other equation is presented as in the Table 8.

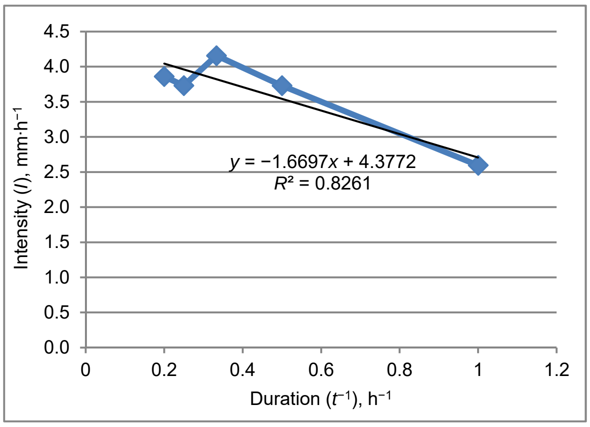

Fig. 2. The relation of the linear equation $I_p = f(t^{-1})$; source: own study

Table 8. Coefficient of A and B

Probability p	A	B
5	20.563	1.363
10	17.383	–0.003
15	14.678	–0.900
20	12.380	–1.459
25	10.432	–1.776
30	8.783	–1.922
35	7.387	–1.949
40	6.209	–1.899
45	5.215	–1.799
50	**4.377**	**–1.670**
55	3.672	–1.526
60	3.078	–1.377
65	2.578	–1.231
70	2.160	–1.093
75	1.808	–0.962
80	1.512	–0.843
85	1.265	–0.735
90	1.058	–0.638
95	0.884	–0.552

Source: own study.

The values of A and B are presented in the Table 8. Based on the Table 8, it is obtained the line equation that is formed between p with A and B is presented as in the Figure 3. From the Figure 3, it is obtained the value of A and B as follow:

$A = 25.555\exp(-0.035p)$ and $B = 0.0239p - 2.7938$.

Hence, there is obtained the equation of rainfall intensity model as follow:
$I_{t,p}$ = 25.555 exp(–0.035p) + (0.0239p – 2.7938) (t^{-1})

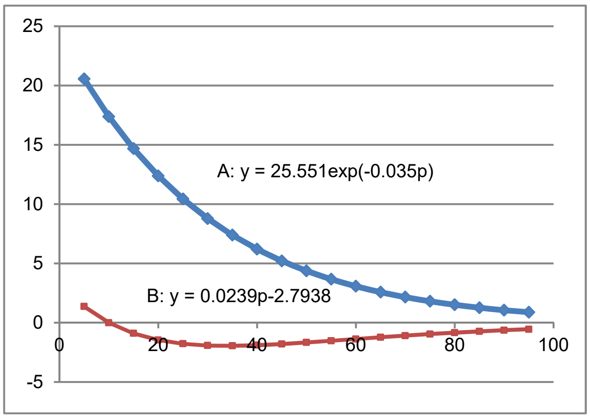

Fig. 3. The relation between probability and coefficient *A* and *B*; source: own study

THE COMPARISON BETWEEN MODELLING RESULT EQUATION AND THE OTHER METHODS

The data of intensity which are used for comparing the intensity modelling result equation, observed intensity, and the other methods: Talbot's, Sherman's, and Ishiguro's methods are presented as in the Table 9.

Table 9. Intensity (I) data (observed intensity) for comparing

Rainfall duration t h	Intensity I mm·h^{-1}
1	2.595
2	3.730
3	4.157
4	3.730
5	3.861

Explanations: I = observed intensity from Table 7 for the probability of 50%.
Source: own study.

The data in the Table 9 and 10 is used for calculating by using the methods of Talbot, Sherman and Ishiguro. The analysis for each method for the return period of 2 years is as follow.

- **Talbot's method**

Analysis of rainfall intensity by using Talbot's method with the return period (T_r) of 2 years and the probability (p) of 50% is based on the Table 10.

a = –18, b = –8.1

$$I = \frac{a}{t+b}$$

$$I = \frac{-18}{1+(-8.1)},\quad I = 2.5 \text{ mm·h}^{-1}$$

Analysis result of rainfall intensity by using the Talbot's method for the return period of 2 years is presented as in the Table 11.

- **Sherman's method**

Analysis of rainfall intensity by using Sherman's method with the return period (T_r) of 2 years and the probability (p) of 50% is based on the Table 10.

a = 2.85, n = –0.235

By substituting the value of a and b into the formula of Sherman, the intensity due to the Sherman's method is as follow:

$$I = \frac{a}{t^n}$$

$$I = \frac{2.85}{1^{-0.235}},\quad I = 2.85 \text{ mm·h}^{-1}$$

Analysis result of rainfall intensity by using Talbot method for the return period of 2 years is presented as in the Table 11.

- **Ishiguro's method**

Analysis of rainfall intensity by using Ishiguros' method with the return period (T_r) of 2 years and the probability (p) of 50% is based on the Table 10.

a = –6.106, b = –3.413

By substituting the value of a and b into the formula of Ishiguro, the intensity due to the Ishiguro's method is as follow:

$$I = \frac{a}{t^{0.5}+b}$$

$$I = \frac{-6.106}{1^{0.5}+(-3.413)},\quad I = 2.53 \text{ mm·h}^{-1}$$

Analysis result of rainfall intensity by using Talbot's method for the return period of 2 years is presented as in the Table 11.

Analysis of intensity for each method with the other return periods is carried out with the same way. Then, the result of modelling equation is compared with the other methods result. The other methods are Sherman's, Talbot's, and Ishiguro's methods. Figure 4 present the comparison curves between modelling equation result, observed model, and the Sherman's, Talbot's, and Ishiguro's methods. The result of rainfall intensity for each method, observed and model is presented as in the Table 11.

Table 10. Analysis of intensity (I) with the return period of 2 years and the probability of 50%

No	T	I	$I·t$	I^2	$I^2·t$	log t	log I	log t·log I	log t^2	$t^{0.5}$	$I·t^{0.5}$	$I^2·t^{0.5}$
1	1.00	2.60	2.60	6.73	6.73	0.00	0.41	0.00	0.00	1.00	2.60	6.73
2	2.00	3.73	7.46	13.91	27.83	0.30	0.57	0.17	0.09	1.41	5.28	19.68
3	3.00	4.16	12.47	17.28	51.84	0.48	0.62	0.30	0.23	1.73	7.20	29.93
4	4.00	3.73	14.92	13.91	55.65	0.60	0.57	0.34	0.36	2.00	7.46	27.83
5	5.00	3.86	19.31	14.91	74.54	0.70	0.59	0.41	0.49	2.24	8.63	33.33
Total		18.07	56.75	66.75	216.59	2.08	2.76	1.22	1.17	8.38	31.16	117.50

Source: own study.

Table 11. The result of intensity (I) for each method with the return period of 2 years

Time duration	$I_{observed}$	I_{Talbot}	$I_{Ishiguro}$	$I_{Sherman}$	I_{model}
h	mm·h^{-1}				
1	2.60	2.50	2.53	2.85	2.84
2	3.73	2.90	3.05	3.35	3.64
3	4.16	3.50	3.63	3.69	3.91
4	3.73	4.40	4.32	3.95	4.04
5	3.86	5.80	5.18	4.16	4.12

Explanations: I_{model} regarding to the final equation of rainfall intensity as follow: $I_{t,p} = 25.555 \exp(-0.035p) + (0.0239p - 2.7938)\ t^{-1}$
Source: own study.

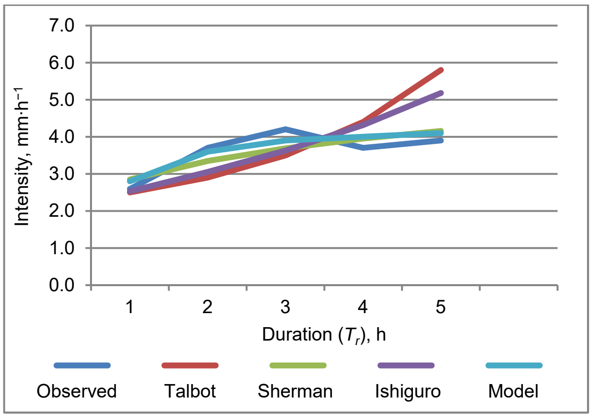

Fig. 4. The comparison of rainfall intensity result with the return period (T_r) of 2 years; source: own study

ANALYSIS OF CORRELATION

Analysis of correlation is as the association degree in regression analysis [SOEWARNO 1995]. The value of correlation coefficient is in the range of $-1.0 \le r \le 1.0$. For example: correlation coefficient of the modelling equation for the return period of 2 years by using Talbot method as in the Table 12. However, the correlation coefficient for each method with the return period of 2 years is presented as in the Table 13.

Table 12. The correlation coefficient of modelling equation for the return period of 2 years

x	y	x^2	y^2	xy
2.50	2.60	6.25	6.73	6.49
2.90	3.73	8.41	13.91	10.82
3.50	4.16	12.25	17.28	14.55
4.40	3.73	19.36	13.91	16.41
5.80	3.86	33.64	14.91	22.39
19.10	18.07	79.91	66.75	70.66

Explanation: x = intensity by using Talbot method; y = observed rainfall intensity.
Source: own study.

$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{n\sum x^2 - \sum(x)^2}\ \sqrt{n\sum y^2 - \sum(y)^2}}$$

$r = 0.52$

The correlation coefficient is completely presented as in the Table 13.

Table 13. The correlation coefficient to the observed intensity with the return period of 2 years

Method	Correlation coefficient to the observed intensity
Talbot	0.52
Sherman	0.78
Ishiguro	0.61
Model	0.91

Source: own study.

The results indicate that the rainfall intensity modelling is close to the observation result. The conclusion is based on the coefficient of Nash–Sutcliffe [NANDAKUMAR, MEIN 1997; RITTER, CARPENA 2013] as presented in the Table 14. However, when it is applied with the certain return period and compared with the method of Talbot, the result of intensity rainfall modelling is close to the observation result. It is shown by the value of mean absolute error (*MAE*) as presented in the Table 15. It is allegedly due to the selection of duration classification is less small or it is extrapolated.

Table 14. Coefficient of Nash–Sutcliffe (E_{NS}) between rainfall modelling and observed model

Rainfall intensity	E_{NS} linear method
$I_{1\ h}$	99.737
$I_{2\ h}$	99.904
$I_{3\ h}$	99.924
$I_{4\ h}$	99.877
$I_{5\ h}$	99.890

Source: own study.

Table 15. Mean absolute error (*MAE*) for the observed intensity with the return period of 2 years

Method	*MAE*
Talbot	0.839
Sherman	0.019
Ishiguro	0.125
Model	0.139

Source: own study.

Based on the result as above, it is shown that the correlation coefficients for the return periods (T_r) of 2 years are high enough for all analysed models. The highest correlation to the observed intensity is the model (intensity modelling) with the correlation coefficient is 0.91. However, the values of *MAE* as presented in the Table 15 shows that there are relatively low values of the error for all analysed models with the return period of 2 years. The lowest *MAE* is the Sherman with the value of 0.019.

In this research, there are selected the duration of 1 h, 2 h, 3 h, 4 h, and 5 h. It is due to the data availability in the Kedungkandang rainfall stations are as hourly data. To evaluate the truth of conjecture, it is carried out to compare it with the other region by selecting the duration with smaller interval, for example 15 min. Global modelling result in the other area

(Mojokerto) has almost the same value with observed intensity in the field. Research in the Kedungkandang is not too good when it is compared with the other methods. It is due to the selection of duration interval is too big and it can be answered by carrying out the research in the new location (Mojokerto) with the duration of 0.25 h; 0.5 h; 1 h; 2 h; and 4 h.

Result by classifying the duration of 1 h, 2 h, 3 h, 4 h, and 5 h is good in the Kedungkandang and Mojokerto. However, the result is not too good if it is compared with the other methods with the certain return period. This uncertainty parameter has to be attended and depth considered in the hydrological modelling [HOYBYE, ROSBJERG 1999]. However, if it is carried out by using the duration of 0.25 h, 0.5 h, 1 h, 2 h, and 4 h, it gives the better result which is shown by the decreasing of the mean absolute error (*MAE*). It indicates that the duration with small interval will produce the equation that is closer to the observation result.

Table 16 presents the recommendation of using the rainfall intensity modelling based on the result comparison between the observation and the rainfall intensity modelling.

Table 16. Recommendation of using the rainfall intensity modelling

Duration (h)	1	2	3	4	5
Probability (%)	>75	>45	>30	>40	>40

Source: own study.

CONCLUSIONS

1. The final equation of rainfall intensity as the result of modelling in Kedungkandang district is $I_{t,p}$ = 25.555 exp(–0.035p) + (0.0239p–2.7938) t^{-1}, where $I_{t,p}$ is the rainfall intensity (mm·h^{-1}); t is the rainfall duration (h); and p is the rainfall probability (%). The prediction of the rainfall intensity ($I_{t,p}$) on any duration (t, h) and any rainfall probability (p, %) can be carried out by using the equation.

2. The comparison result of the rainfall intensity between the modelling equation result and the observation result shows the good result. It is shown by the Nash–Sutcliffe coefficient is >75. The comparison result of the rainfall intensity with the return period of 2 years among the methods of Talbot, Sherman, and Ishiguro in the study location, is obtained not too good result. It is due to the selection of the duration classification. However, the Sherman and the modelling equation set apart the other ones. The correlation coefficients are higher and the error is lower (as seen in the Table 17 and 19). Particularly correlation for the Talbot method is very low.

For answering the conjecture, it has been carried out the research in the other region (Mojokerto) with the same method and procedure and the additional treatment by decreasing the duration interval such as 0.25 h, 0.5 h, 1 h, 2 h, and 4 h.

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Lily Montarcih LIMANTARA, Donny H. HARISUSENO, Vita A.K. DEWI

Modelowanie intensywności opadów w zlewni – przykład zlewni Amprong w Kedungkandang, Malang, Wschodnia Jawa, Indonezja

STRESZCZENIE

Analiza intensywności opadów o określonym prawdopodobieństwie jest bardzo ważna, aby móc kontrolować negatywny wpływ opadów. Intensywność opadu (*I*), jego prawdopodobieństwo (*p*) i okres powtarzalności (*t*) są istotnymi zmiennymi w analizie odpływu. Istnieje kilka metod (Talbota, Shermana i Ishiguro) wykorzystywanych do oceny intensywności opadu. Celem badań było zbudowanie modelu, który może przewidywać intensywność opadu o określonym czasie trwania i prawdopodobieństwie. Wyniki uzyskane za pomocą modelowania porównano z uzyskanymi innymi metodami. Wyniki modelu intensywności opadów z wartością korelacji >0,94 i współczynnikiem Nasha–Sutcliffe'a > 0,99 są wystarczająco dobre, jeśli porówna się je z danymi pochodzącymi z obserwacji. W odniesieniu do określonego okresu powtarzalności wyniki modelowania są mniej dokładne, prawdopodobnie ze względu na wybrany czas trwania. Zaawansowane badania w innych lokalizacjach wskazują, że w przypadku wyboru krótkich czasów trwania opadu uzyskuje się lepsze wyniki modelowania intensywności opadu, czego dowodem jest malejący z 12,963 do 8,26 średni błąd bezwzględny.

Słowa kluczowe: *czas trwania opadu, intensywność opadu, modelowanie, prawdopodobieństwo powodzi, prognozowanie*