Determination of Rain Intensity Based on Rain Characteristics Observed from Rain Observation Stations Around South Jakarta

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Abstract: South Jakarta has the highest rainfall concentration and the most flood location in Jakarta. Therefore, an urban drainage system is needed to control surface water so flood can be prevented. This research aims to support the urban drainage system planning by determining rainfall intensity based on three methods, those are Van Breen, Bell Tanimoto, and Hasper der Weduwen. The most suitable method will be selected by comparing the value of rainfall intensity with Talbot, Sherman, and Ishiguro approach. This research reveals that the most suitable method is the Van Breen Method with the Talbot equation. The result of the calculation is rainfall intensity for 2, 5, 10, 25, 50, and 100 years rain return period, with each range 27.2 – 182.8 mm/hour, 36.8-197.6 mm/hour, 43.1-206.3 mm/hour, 51.1-216.6 mm/hour, 57-223.9 mm/hour, and 63-230,8 mm/hour.

1. Introduction

Flood has been an endless problem for people all around the world from the past, present, and future [1-3]. In Indonesia, even though the timing and magnitude of floods vary, almost all regions face significant flooding hazards [4-7]. The flooding phenomenon and land subsidence are a natural phenomenon in Jakarta that continuously occurs, causing various damages and losses, and requires serious treatment [8]. South Jakarta is an area that has the most flood locations [9-11].

Lestanto and Paski analysis, shows that the overall rainfall data in South Jakarta has the highest underestimate chance [12]. According to Prabawadhani et al also showed that the highest rainfall concentrations tend to occur in the central to southern areas of DKI (Special Capital District) Jakarta Province, especially around the borders between DKI Jakarta (South Jakarta), West Java (Depok), and Banten (South Tangerang) [13]. Urban drainage is drainage in urban areas that functions to control surface water so that it does not harm the public. It can be done by planning a good drainage system by considering the hydrological conditions of the area.

In planning the drainage system, determining the value of rainfall intensity is needed to get the value of the flood discharge in the planning area. Rain intensity value will determine the quantity of rain per unit time. The length time of rain duration will be inversely proportional to the magnitude of the rainfall intensity. The shorter the duration is, the greater its intensity and return period. By knowing the intensity of occurred rain, is expected to be used as a basis for planning drainage channel capacity `in the return period. One approach that can be done to determine the

rainfall intensity is by calculating using Van Breen method, Bell Tanimoto method, and Hasper der Weduwen method.

This research aims to determine the rainfall intensity calculated based on three methods, those are the Van Breen, Bell Tanimoto, and Hasper der Weduwen. Derivation value is determined by comparing the value of rainfall intensity with Talbot, Sherman, and Ishiguro approach.

2. Methods

This research is conducted by adapting SNI 2415-2016 on the procedure for calculating flood discharge plans [14]. Starting by observing South Jakarta's geographic condition and obtaining annual maximum daily rainfall data for the last 25 years from observation stations located around South Jakarta. Then, the data from various stations are processed to get the mean values from each year. After that, the homogeneity test is applied to the mean values. Following the test is maximum daily rainfall analysis using 3 methods, such as the Gumbel method, Log Pearson Type II method and Normal distribution method. Among these three methods, only one will be used to determine rainfall intensity, which selected based on the Chi-Square compatibility test. Rainfall intensity analysis is conducted with the Van Breen method, Bell Tanimoto method, and Hasper der Weduwen method. One of the equations will be selected to create Intensity-Duration-Frequency Curve. The chosen equation is decided through comparing the gaps made by testing each equation with the Talbot, Sherman and Ishiguro equations.

3. Result and Discussion

3.1 Data of Annual Average Rainfall in Nearby Stations

Rainfall in South Jakarta is the amount of rainwater that falls in South Jakarta within a certain time. The rainfall data used is the maximum daily rainfall data for the last 25 years from three rain observation stations around South Jakarta. Rainfall data can be seen in Table 1. According to Prabhawadani et al., mentioned that the rain occurred in DKI Jakarta tends to accumulate a lot in the central to southern Jakarta [13].

Table 1. Annual Average Rainfall Data in Rain Observation Stations Wilayah Around South Jakarta

no	Year	Rain Observation Stations		
		Klimatologi Tangerang Selatan (mm)	Meteorologi Kemayoran (mm)	Halim Perdana Kusuma Jakarta (mm)
1	1995	113.30	48.30	295.10
2	1996	113.83	137.94	150.78
3	1997	82.62	80.13	161.55
4	1998	108.55	103.48	90.47
5	1999	97.57	93.91	90.47
6	2000	103.40	94.80	58.67
7	2001	104.00	82.20	100.27
8	2002	109.20	168.50	116.26
9	2003	119.20	119.19	162.74
10	2004	94.00	168.56	90.34
11	2005	104.50	161.78	102.36
12	2006	79.30	93.86	93.77
13	2007	272.05	305.96	230.57
14	2008	167.33	251.21	144.21
15	2009	91.27	159.69	148.77

16	2010	60.85	121.24	26.83
17	2011	93.57	155.39	84.53
18	2012	120.63	87.15	94.40
19	2013	145.12	160.22	161.00
20	2014	180.64	122.53	120.80
21	2015	176.86	229.89	124.60
22	2016	146.63	103.14	111.60
23	2017	121.23	148.87	136.30
24	2018	130.45	86.65	101.20
25	2019	117.00	74.97	72.65

Figure 1 shows the AMDR chart from 1995 to 2019. The AMDR mean in South Jakarta shows a value of 126.4 mm. According to Syafei and Hidayati, the five categories are rainfall with a range of < 100 mm (low), 100-200 mm (slightly low), 200-300 mm (moderate), 300-400 mm (slightly high), and > 400 mm (high) [15]. Overall rainfall in South Jakarta is considered as the medium category.
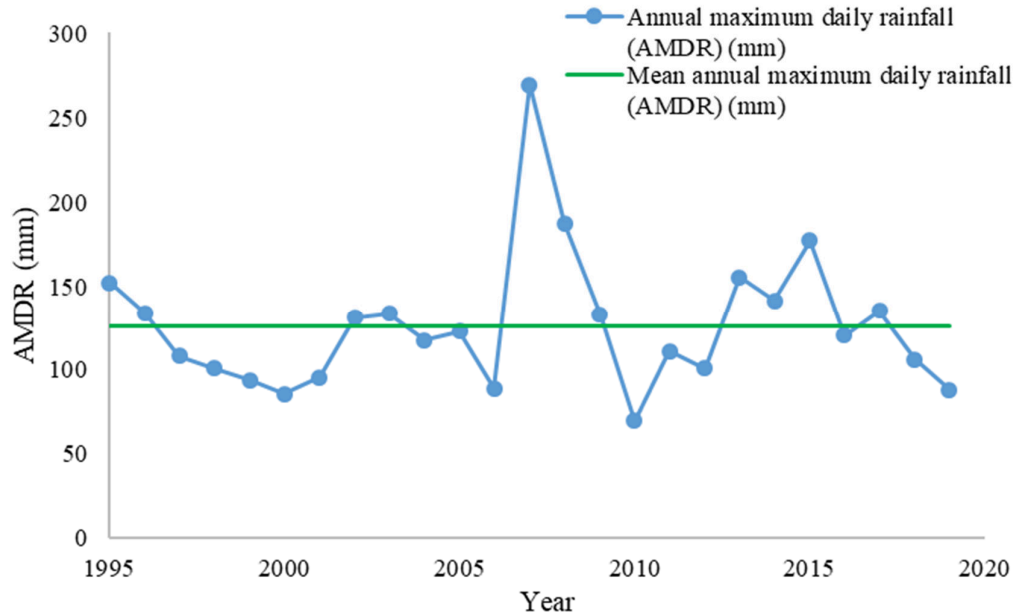

Fig. 1. Annual Maximum Daily Rainfall Data in South Jakarta

3.2 Homogeneity Test

The purpose is to test whether the maximum rainfall occurs homogeneously in the entire study area. If it is not homogeneous, the researchers need to find a homogeneous data set. To determine homogeneity, it is necessary to calculate the TR value from the x equation. Calculation results can be seen in Table 2.

Table 2. TR Calculation Results for Annual Maximum Daily Rainfall Homogeneity Test in South Jakarta

Stages of Homogeneity Calculation	Result
Total $(Ri-R)^2$	40967.97
Reduce Standard Deviation (Sn)	1.09
Reduced Mean (Yn)	0.53

Standard Deviation	41.32
$1/\alpha$	37.85
μ	106.34
Gumbell Regression Equation	$106.3429+37.853x$
Y0	106.34
Y5	295.60
Y1	144.20
Tr	1.12
R_{10}	345.00
TR	3.06

Test results show that the data from three rain stations in South Jakarta are homogeneous. From the calculation, value (N: TR) = (25: 3) obtained, it turns out that the point is within the region of homogeneity limit (Figure 2), so the data is 25 years homogeneous.
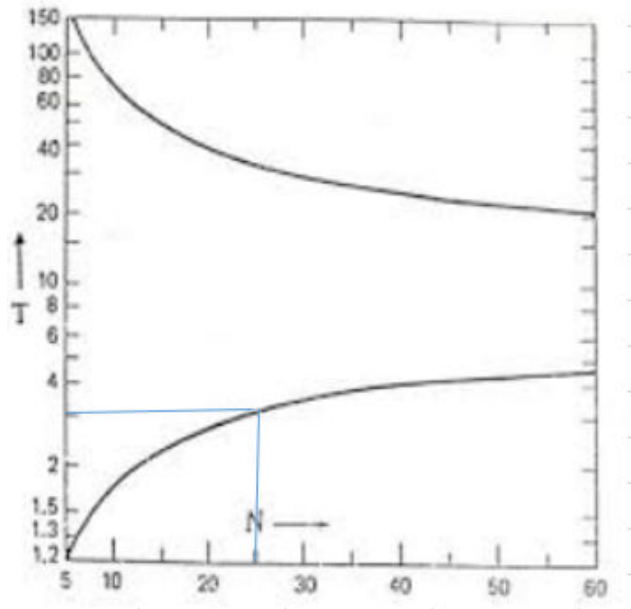

Fig. 2. Homogeneity of 25 Years of Rainfall Maximum Daily Rainfall in South Jakarta Region

3.3 Maximum Daily Rainfall Analysis

The maximum daily rainfall that will occur during a certain return period can be estimated by several methods such as the Gumbel method, Log Pearson Type II method and Normal distribution method. The purpose of this analysis is to obtain a regression line, which is a place of maximum rainfall value. The calculation results of this method can be seen in Table 3, Table 4, and Table 5.

Table 3. Results of Maximum Daily Rainfall Analysis with the Gumbell Method

Rain Return Periods (Tr)	Yt	K	Xt (mm/day)
2	0.37	-0.15	120.34
5	1.50	0.89	162.38
10	2.25	1.58	190.21
15	2.67	1.96	205.91

25	3.199	2.44	225.37
50	3.90	3.09	251.46
100	4.60	3.73	277.36

Table 4. Results of Calculation of Maximum Daily Rainfall Analysis with Pearson II Log Method

Rain Return Periods	K	log RT	Maximum rainfall
2	-0.11	2.07	117.25
5	0.79	2.18	152.35
10	1.33	2.25	178.13
25	1.96	2.33	213.74
50	2.40	2.38	242.50
100	2.81	2.44	273.29

Table 5. Results of Calculation of Maximum Daily Rainfall Analysis with the Normal Distribution Method

T	Kt	Xt (Rain Return Periods)
2	0.00	126.44
5	0.84	160.44
10	1.28	178.25
25	1.71	195.58
50	2.05	209.42
100	2.33	220.76

The selecting method of the maximum daily rainfall calculating is intended to choose the most appropriate method for estimating the amount of maximum daily rainfall that occurs in a particular Rain Return Periods. The results obtained from the three methods used. In selecting the analysis method of maximum daily rainfall, the Test of Goodness of fit frequency distribution from the data to the probability distribution function that expected to be able to represent the frequency, distribution is required. Parameter testing can be done with a compatibility test, Chi-Square. To conduct this compatibility test, the maximum daily rainfall will be compared based on the methods used. Chi-Square Test intended to determine whether the equation or method chosen could represent the statistical distribution of the sample of the analyzed data.

The results show that the Gumbel method provides this criterion. The Gumbel distribution has a coefficient of Skwennes or Cs≈1,14 and a coefficient of kurtosis (Coefficient Kurtosis) or Ck≈5,40, this method usually uses distributions and extreme values with exponential double distribution [16].

The Determination of Rain Intensity

The final stage of rainfall analysis is the analysis in the form of Intensity Duration Frequency (IDF), which shows the relationship between the drainage length time and the rain intensity, for each rain return period. If data for each rain duration is unknown, then an empirical approach needed to refer to the duration of 60 minutes (1 hour) and the maximum daily rainfall that occurs each year. Another common way is a pattern taking of rainfall intensity in other cities that have similar conditions. The methods used are Der Weduwen Hasper Method and Van Breen Method.

Based on the calculation of rainfall intensity, it appears that the highest / largest rainfall intensity value. The greatest value of rainfall intensity is used in determining the dimensions of drainage

channels, where the channel should be able to accommodate rainfall with maximum intensity. The amount of rainfall intensity varies due to the length of rainfall duration or the frequency of occurrence. For this reason, the selected rainfall intensity was tested with Talbot, Sherman and Ishiguro equations and then compared. This comparison will form the error gap, the results of error calculation for each method can be seen in Table 6. The chosen method in determining the rainfall intensity is Van Breen by comparison with the Talbot equation.

a. Van Breen method

The following equation is derived from rainfall intensity analysis in Java Island to be more suiteble for Jakarta.

$$I_T = \frac{54R_T + 0.07R_T{}^2}{t_c + 0.3R_T} \tag{1}$$

Where,
I_T : Rainfall intensity at rain return period year T (mm/hour)
R_T : Maximum daily rainfall at rain return period year T (mm/day)

b. Bell Tanimoto method

The rainfall intensity can be calculate using Bell Tanimoto equation as follows.

$$R_T^t = (0.21 \ln T + 0.52)(0.54t^{0.25} - 0.5)R_{10tahun}^{60tahun} \tag{2}$$

$$R_{10tahun}^{60menit} = \frac{X_{10}}{X_t}\left(\frac{R_1 + R_2}{2}\right) \tag{3}$$

$$I_T^t = \frac{60}{t}R_T^t \tag{4}$$

Where,
R : Maximum daily rainfall (mm)
T : Return period year T (year)
t : Rainfall duration (minute)
R_1 : Maximum daily rainfall on first hour (mm)
R_2 : Maximum daily rainfall on second hour (mm)

c. Hasper der Weduwen method

The rainfall intensity can be calculate using Hasper der Weduwen equation as follows.

$$R_i = X_t\left(\frac{1218}{X_t(1-t) + 1272t}\right) \tag{5}$$

If $1 \le t < 24$ hours, then,

$$R = \sqrt{\frac{11300t}{t + 3.12}}\left[\frac{R_i}{100}\right] \tag{6}$$

If $0 \le t < 1$ hour, then,

$$R = \sqrt{\frac{11300}{t + 3.12}}\left[\frac{R_i}{100}\right] \tag{7}$$

The rainfall intensity itself is calculated using equation as follows.

$$I = \frac{R}{t} \tag{8}$$

Where,
t : Rainfall duration (hour)
X_t : Maximum daily rainfall (mm)

Most suitable mathod to calculate rainfall intensity is selected with 3 equations, such as Talbot, Sherman and Ishiguro equations which are influenced by several factors. Those factors are rainfall intensity, rainfall duration in hours, and the amount of data, with each symbolized as I, t, and N.

a. Talbot equation

$$I = \frac{a}{t+b} \tag{9}$$

$$a = \frac{\sum It \sum I^2 - \sum(I^2 t) \sum I}{N \sum I^2 - (\sum I)^2} \tag{10}$$

$$b = \frac{\sum It \sum I - \sum(I^2 t)N}{N \sum I^2 - (\sum I)^2} \tag{11}$$

b. Sherman equation

$$I = \frac{a}{t^n} \tag{12}$$

$$\log a = \frac{\sum \log I \sum (\log t)^2 - \sum(\log t \log I) \sum \log t}{N \sum (\log t)^2 - (\sum \log t)^2} \tag{13}$$

$$n = \frac{\sum \log I \sum \log t - \sum(\log t \log I)N}{N \sum (\log t)^2 - (\sum \log t)^2} \tag{14}$$

c. Ishiguro equation

$$I = \frac{a}{\sqrt{t}+b} \tag{15}$$

$$a = \frac{\sum(I\sqrt{t}) \sum I^2 - \sum(I^2\sqrt{t}) \sum I}{N \sum I^2 - (\sum I)^2} \tag{16}$$

$$b = \frac{\sum I\sqrt{t} \sum I - \sum(I^2\sqrt{t})N}{N \sum I^2 - (\sum I)^2} \tag{17}$$

Where,
I : Rainfall intensity (mm/hour)
t : Rainfall duration (minute)
N : amount of data

In Figure 3 can be seen the calculation results or intensity–duration–frequency (IDF) curve plot. This IDF curve will show the relationship between rainfall intensity and the length of rain duration [17]. According to Narulita, and Marganingrum, the IDF curve is a tool that can be used to calculate flood discharge plans that needed for the planning of flood control building [18]. In planning the drainage system in an effective flood risk mitigation effort in Jakarta, the duration of the design storm is more than 1 day [19]. The need for a combination of flood control infrastructure can reduce the risk of flood disasters [20]; this importance of plan discharge in the design.

Table 6. Result of Average Error for Each Calculation Method of Van Breen, Bell Tanimoto and Hasper der Weduwen

Rain Return Periods	Van Breen			Bell Tanimoto			Hasper der Weduwen		
	Talbot	Sherman	Ishiguro	Talbot	Sherman	Ishiguro	Talbot	Sherman	Ishiguro
2	0.000	9.983	10.864	2.536	1.510	38.682	11.634	6.573	118.745
5	0.000	11.611	11.221	4.411	2.627	84.470	15.346	6.230	291.400
10	0.000	12.457	11.344	6.044	3.599	62.614	17.684	5.861	138.992
25	0.000	13.344	11.428	8.534	5.083	79.333	20.517	5.587	147.283
50	0000	13.902	11.456	10.681	6.361	94.458	22.541	6.156	152.552
100	0.000	14.389	11.465	13.059	7.778	560.949	24.493	6.610	157.842

Based on gap comparison in Table 6, Van Breen method with Talbot equation is the most suitable to determine South Jakarta's rainfall intensity. Therefore, the result of these calculation, which can be seen in Table 7, will be used to generate IDF curve.

Table 7. Result of Method of Van Breen with Talbot Equation Calculation

| Rain Return Periods	2	5	10	25	50	100
Duration (minute)	I (mm/hour)					
5	182.768	197.606	206.305	216.572	223.839	230.845
10	162.946	180.778	190.924	202.620	210.739	218.462
20	133.901	154.469	166.149	179.493	188.658	197.294
40	98.712	119.645	131.913	146.134	155.973	165.268
60	78.169	97.634	109.376	123.231	132.941	142.187
80	64.703	82.463	93.416	106.534	115.835	124.763
100	55.195	71.373	81.521	93.822	102.630	111.143
120	48.124	62.912	72.313	83.821	92.128	100.204
140	42.658	56.244	64.974	75.746	83.575	91.226
160	38.308	50.855	58.987	69.090	76.476	83.724
180	34.762	46.408	54.011	63.510	70.488	77.362
200	31.818	42.676	49.808	58.763	65.370	71.899
220	29.333	39.500	46.213	54.677	60.944	67.156
240	27.208	36.763	43.102	51.122	57.080	63.000
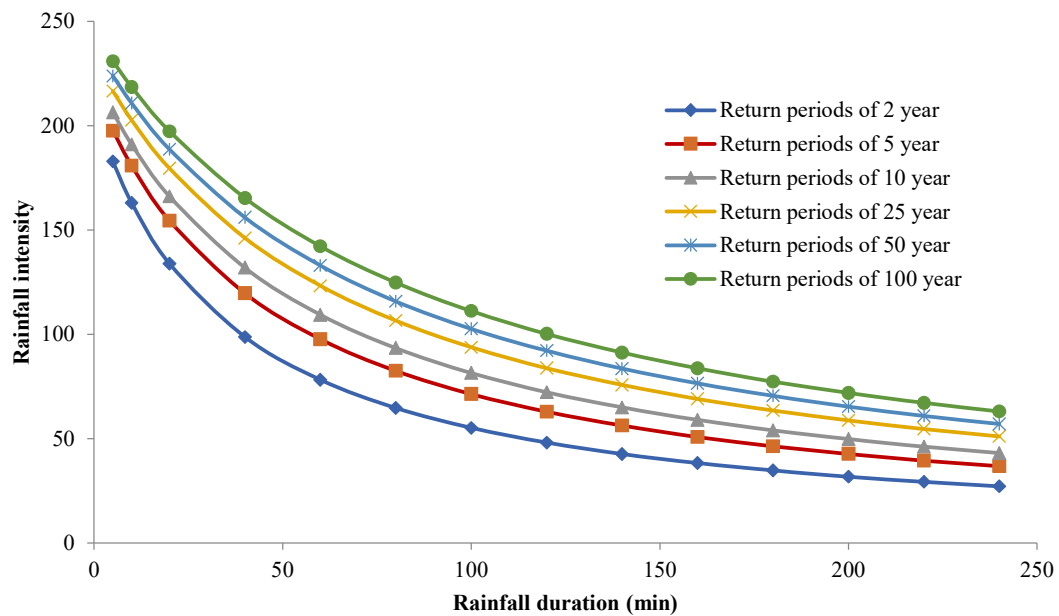
Fig. 3. IDF graph with Van Breen and Talbot equations

In designing drainage infrastructure, the use of return periods is very important to get the urgency of the channel. In macro drainage, an infrastructure design of water resource is applied in the return period of 20-50 years, then for the application techniques of artificial impregnation will be using the same return period [21]. According to Masduki, 1988 for micro drainage channels such

as Housing, Parks, Non-built land, tertiary channels, and secondary channels can use the return period of 2 to 5 years [22].

The use of a 100-year return period is recommended for the design of macro floods and watersheds with an area of 1300-6500 ha (Masduki, 1988). An example that has happened is the Ciliwung watershed that reached 142.5 mm/day on 2 February 2007, which was repeated about once 100 years [23]. The rain occurrence of which caused flooding in DKI Jakarta in 2013 and 2014, the rain that caused flooding in 2014 is still in the stage of a 2 years return period, while the 2013 flood event is still in the category of annual planned rain [24].

4. Conclusion

Based on rainfall intensity analysis, the Van Breen Method with Talbot equation is the most suitable method to determine South Jakarta's Rainfall and it will be used to create IDF curve. The result of this calculation is rainfall intensity for 2, 5, 10, 25, 50, and 100 years rain return period, with each range 27.2 – 182.8 mm/hour, 36.8-197.6 mm/hour, 43.1-206.3 mm/hour, 51.1-216.6 mm/hour, 57-223.9 mm/hour, and 63-230.8 mm/hour.

References

[1] Cirella, G. T., & Iyalomhe, F. O. (2018). Flooding conceptual review: Sustainability-focalized best practices in Nigeria. Applied Sciences, 8(9), 1558.

[2] Gleick, P. H. (2003). Global freshwater resources: soft-path solutions for the 21st century. Science, 302(5650), 1524-1528.

[3] van Popering-Verkerk, J., & van Buuren, A. (2017). Developing collaborative capacity in pilot projects: Lessons from three Dutch flood risk management experiments. Journal of Cleaner Production, 169, 225-233.

[4] Barkey, R., Nursaputra, M., Mappiase, M. F., Achmad, M., Solle, M., & Dassir, M. (2019, February). Climate change impacts related flood hazard to communities around Bantimurung Bulusaraung National Park, Indonesia. In IOP Conference Series: Earth and Environmental Science (Vol. 235, No. 1, p. 012022). IOP Publishing.

[5] Hadihardaja, I. K., & Vadiya, R. (2016). Identification of flash flood hazard zones in mountainous small watershed of Aceh Besar Regency, Aceh Province, Indonesia. The Egyptian Journal of Remote Sensing and Space Science, 19(1), 143-160.

[6] Kusmiyarti, T. B., Wiguna, P. P. K., & Dewi, N. R. (2018, February). Flood Risk Analysis in Denpasar City, Bali, Indonesia. In IOP Conference Series: Earth and Environmental Science (Vol. 123, No. 1, p. 012012). IOP Publishing.

[7] Hartanto, I. S., & Rachmawati, R. (2017). Assessing the Spatial-Temporal Land use Change and Encroachment Activities Due to Flood Hazard in North Coast of Central Java, Indonesia. The Indonesian Journal of Geography, 49(2), 55-66.

[8] Yuhanafia, N., & Andreas, H. (2017). Increase of the Estimation between the Economic Loss due to Flood and the Effect of Land Subsidence in Jakarta. Journal of Geografi Gea, 17(2), 182-190. (in Indonesian)

[9] Margatama, L., Al-Hikmah, S. S., Riyanto, I., Pebrianti, D., Bayuaji, L., Sudiana, D., & Sumantyo, J. T. S. (2018, April). Increasing disaster awareness of the community by flood potential mapping of densely populated urban river watershed in south and west jakarta with LIDAR data segmentation. In 2018 IEEE International Conference on Applied System Invention (ICASI) (pp. 370-373). IEEE.

[10] Marko, K., Kusratmoko, E., Tambunan, M. P., & Pahlevi, R. (2019, November). A Spatial Approach in Assessing Flood Losses in Floodplain Area of Pesanggrahan River (Case Study on Ulujami and Cipulir Urban Villages, South Jakarta). In IOP Conference Series: Earth and Environmental Science (Vol. 338, No. 1, p. 012030). IOP Publishing.

[11] Utami, I., & Marzuki, M. (2020). Analysis of Twitter-Based Flood Information System. Journal of Fisika, Unand, 9(1), 67-72. (in Indonesian)

[12] Lestanto, A. W., & Paski, J. A. I. (2018). WRF Performance Test using Radar, Satellite and Synoptic Assimilation Data for Rain Prediction in Jakarta. Journal of Sains & Teknologi Modifikasi Cuaca, 19(1), 1-10. (in Indonesian)

[13] Prabawadhani, D. R., Harsoyo, B., Seto, T. H., & Prayoga, B. R. (2016). Temporal and Spatial Characteristics of Rainfall causing Flooding in Jakarta and its Surrounding Areas. Journal of Sains & Teknologi Modifikasi Cuaca, 17(1), 21-25. (in Indonesian)

[14] SNI 2415:2016. Indonesian National Standard. Procedure for Calculating the Planned Flood Discharge. (in Indonesian)

[15] Syafei, M., & Hidayati, R. (2018). Effect of the Altitude and Rainfall on Diarrhea (A Case Study: Bogor Regency). Journal of Agromet Indonesia, 28(1). (in Indonesian)

[16] Fahliananta, R. (2019). Study of Drainage Channel System Calculation on Jl. Haji Isa III, Tanjung Redeb District, Berau Regency. Student Journal of Kurva S, 1(1), 1709-1716. (in Indonesian)

[17] Permatasari, M., Nugraha, M. C., & Hartati, E. (2019). Determination of the Rain Intensity Method based on the Rain Characteristics from the Rain Observation Stations around the District of East Karawang. Journal of Serambi Engineering, 5(1). (in Indonesian)

[18] Narulita, I., & Marganingrum, D. (2017). Analysis of Rainfall, Land Cover Change and IDF Curve Arrangement for Flood Potential Analysis: A Case Study of Cerucuk Watershed, Belitung Island. Journal of Lingkungan dan Bencana Geologi, 8(2). (in Indonesian)

[19] Liu, J., Doan, C. D., Liong, S. Y., Sanders, R., Dao, A. T., & Fewtrell, T. (2015). Regional frequency analysis of extreme rainfall events in Jakarta. Natural Hazards, 75(2), 1075-1104.

[20] Januriyadi, N. F., Yulizar, Y., Pamungkas, R. C., Amru, F., & Fadhilah, N. (2019). Effectiveness of the Infiltration Wells in reducing the Risk of Flood Disaster in the City of Jakarta. (in Indonesian)

[21] Pradiko, H., Sabar, A., Soewondo, P., Suryadi, Y., & Jatikusuma, I. (2017). Individual-Scale Environmental Drainage Model in Settlement Areas in the North Bandung. Journal of Civil Engineering, 24(1), 83-90. (in Indonesian)

[22] Masduki H.S. 1998. Drainage System Planning. Bandung: Institut Teknologi Bandung. (in Indonesian)

[23] Nugroho, S. P. (2018). Analysis of Rainfall causing Large Floods in Jakarta in the Early February 2007. Journal of Air Indonesia, 4(1). (in Indonesian)

[24] Ginting, S., Farid, M., & Kusuma, S. B. (2015). Development of a Flood Hazard Map based on a Quasi-Mathematical Model of 2 Dimensions. Journal of Civil Engineering, 22(3), 219-234. (in Indonesian)