

ANALYSIS ON EFFECTIVE BASIN DESIGN RAINFALL

Segel Ginting ¹⁾

Abstract

An analysis on design rainfall is very substantial in the design of a hydraulic structure, of which the main principle of analysis is to indicate the intensity of design rainfall possibly to occur. Due to inadequate data being the commonly reason put forward in design flood calculation, approach of calculation is carried out based on design rainfall. Design rainfall analysis can be done by several approaches, but most often applied is the statistical approach. Determination of design rainfall intensity of a specific river basin is usually based on annual maximum daily point rainfall data, and by applying the frequency analysis in the statistical analysis, maximum point daily rainfall for a certain probability or return period will be obtained. These results are called local design rainfall. Design rainfall obtained by application of abovementioned concept shall show results of very high quality. The data used to determine design rainfall are usually extensive if compared with maximum basin rainfall data. Based on such condition, the advanced design rainfall analysis will be based on the maximum basin rainfall data in order to obtain more effective results by calculating the event of extreme rainfall of each respective precipitation station. An equation is also obtained for the calculation of basin design rainfall based on local design rainfall for various return periods like: $ARF_{2\text{year}} = 1.96 A^{-0.17}$, $ARF_{3\text{year}} = 2.124 A^{-0.18}$, $ARF_{5\text{year}} = 2.319 A^{-0.20}$, for greater return periods calculation is done by the equation $ARF_{T\text{year}} = 1.96 A^{-0.17} \times 1.1 T^{-0.021}$.

Keywords: Basin Design Rainfall, Upper Citarum River Basin, Area Reduction Factor.

INTRODUCTION

Background

An analysis on design rainfall is very substantial in the design of a hydraulic structure, of which the main principle of analysis is to indicate the intensity of design rainfall possibly to occur. Due to inadequate data being the commonly reason put forward in design flood calculation, approach of calculation is carried out based on design rainfall. In order to obtain a design flood by using design rainfall data, a basin approach often introduced as rainfall-runoff model is to be needed.

Analysis of design rainfall can be implemented according a number of approaches, but most commonly used is the statistical approach related with frequency distribution analysis such as Normal, Log Normal, Pearson, Log Pearson, and Gumbel. Presently however, another frequency analysis known as Generalized Extreme Value (GEV) is being introduced.

¹⁾ Junior Researcher, Research Center for Water Resources
Jl. Ir. H. Junada 193, Bandung, West Java, Indonesia
E-mail : hendrycus2000@yahoo.com

Determination of design rainfall intensity of a specific river basin is usually based on annual maximum point daily rainfall data, and by applying the frequency analysis in the statistical analysis, maximum point daily rainfall for a certain probability or return period will be obtained. The result is often referred to as point design rainfall. In order to produce a basin design rainfall, an advanced analysis using the weight method or isohyet from point design rainfall data shall be needed.

Design rainfall obtained by application of above mentioned concept shall show results of very high quality. The data used to determine design rainfall are usually extensive if compared with maximum basin rainfall data. Based on such condition, advanced design rainfall analysis will be based on the maximum basin rainfall data in order to obtain more effective results by calculating the event of extreme rainfall of each respective rainfall station.

Objective and Aim

The objective and aim of this study is to calculate the intensity of basin design rainfall in a specific river basin by calculating the event of extreme rainfall of each representing rainfall station so that actual results are obtained.

Study Location

The location of study was decided on Upper Citarum River Basin in the West Java Province as shown in Figure 1.

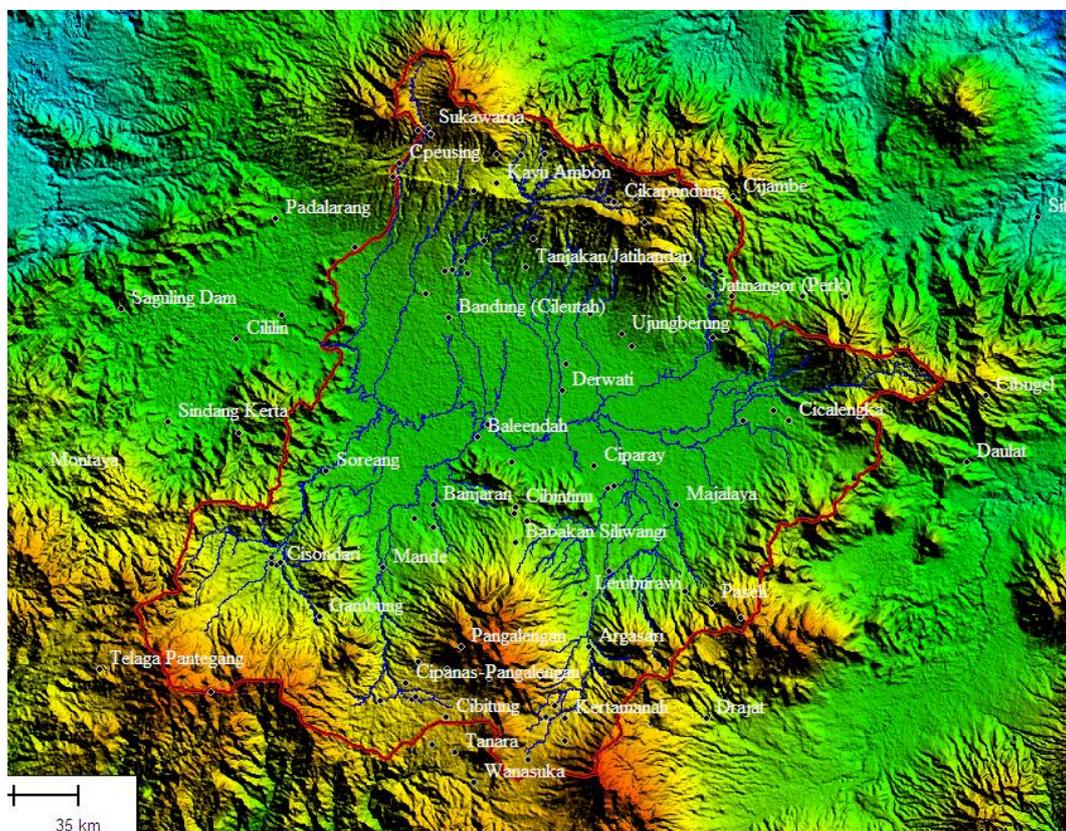


Figure 1. Location of study, Upper Citarum River Basin

THEORETICAL REVIEW

Design Rainfall

The Citarum River Basin is one of the large rivers on the island of Java. Upstream area of the river basin include the area of Bandung city and Bandung regency (Kota Bandung and Kabupaten Bandung). In the first months of 2010, Bandung and Kabupaten Bandung were often flooded due to heavy rainfall in the upstream area of the Citarum Basin.

Several studies were carried out in the upper area of the Citarum Basin and each study related with hydrology had calculated the intensity of design rainfall. According to the Hydrological report *REVIEW OF FLOOD CONTROL PLAN AND DETAIL DESIGN PREPARATION UNDER UPPER CITARUM BASIN URGENT FLOOD CONTROL PROJECT*, design rainfall calculations were made of the Upper Citarum Basin and several of its sub-river basins. Results of calculation are shown on Table 1.

Table 1. Design Rainfall of Upper Citarum Basin

Drainage Basin	Return Period (Year)						
	2	5	10	20	50	100	200
1. Citarik	47.5	60.8	69.2	77.0	86.7	94.0	101.1
2. Cisangkuy	50.1	63.7	72.1	80.0	89.8	97.1	104.2
3. Cidurian	53.1	68.2	77.8	86.7	98.0	106.3	114.5
4. Cikapundung	53.2	76.2	92.0	107.5	128.0	143.8	160.0
5. Ciwidey	57.8	81.3	97.2	112.6	132.8	148.4	164.1
6. Cibeureum	50.7	69.1	81.2	92.9	107.9	119.3	130.8
7. Cimahi	50.1	68.6	80.8	92.5	107.7	119.2	130.8
* Dayeuh Kolot	42.6	54.1	61.4	68.1	76.6	82.8	88.9
** Nanjung	41.2	52.8	60.0	66.8	75.3	81.6	87.8

Area Reduction Factor (ARF)

Area Reduction Factor (ARF) is one of the values needed in the analysis on extreme hydrological design as design rainfall. For an area, a , and duration of, d , ARF as the function of a , d , and T is the comparison between average rainfall intensity of a specific area, a , duration, d , and return period T , and the intensity of average rainfall at certain rainfall station for a similar duration (d) and return period (T). Empirically, ARF graphs are often shown in scale measures, for example the comparison (\sqrt{a}/d) at a given rate and return period T will show an ARF tendency of $(\sqrt{a}/d)^{-\alpha}$ for several α values. With the application of this equation, ARF scale characteristics for space and time based rainfall conditions will be obtained. Area reduction factors (ARF) are factors with fixed value for changing rainfall data from point rainfall into area rainfall. Many studies have been carried out to determine the ARF of a specific area. According to *Bell* (1976), ARF can be determined by two methods, namely

Storm Centered ARFs and Fixed Area ARFs. Generally, determination of ARFs in the United States uses the Technical Paper 29 (TP 29) expressed by the following (Allen and DeGaetano, 2005):

$$ARF = \frac{\frac{1}{n} \sum_{j=1}^n \bar{R}_j}{\frac{1}{k} \sum_{i=1}^k \left(\frac{1}{n} \sum_{j=1}^n R_{ij} \right)}$$

Where :

\bar{R}_j = annual maximum basin rainfall at year-j

R_{ij} = annual maximum point rainfall at station-I at year-j

k = the number of precipitation stations in certain area

n = the number of data years

Whereas, in 1972 *Leclerc* and *Schaake* made up an equation to calculate ARFs based on time and duration of rainfall in relation to the extent of area. The resulted equation (Allen and DeGaetano, 2005) is shown as follows:

$$ARF_{(A,t)} = 1 - \exp(at^b) + \exp(at^b - cA)$$

where :

t = duration of rainfall (hour)

A = extent of area (km²)

The study resulted coefficient values for the above equation such as 'a' value = -1,1; b = 0,25; and 'c' = 2,59 x 10⁻². Another equation also frequently used as expressed by Menabde, M., et.al., (2001) is $ARF_{(A,t)} = \frac{1}{1+(A/a_0(t))^a}$. Some applications of equation for calculation of ARFs are shown on Table 2.

Table 2. Some equations for the calculation of ARF

No	ARF	Location	Ref.
1	$ARF = 1 - \exp(-0,84 t^{0,2}) + \exp(-0,84 t^{0,2} - 0,67A)$	New Jersey	Allen and DeGaetano, 2005
2	$ARF = 1 - \exp(-0,82 t^{0,21}) + \exp(-0,82 t^{0,21} - 0,2A)$	North Carolina	Allen and DeGaetano, 2005
3	$ARF = 1 - \exp(-1,1t^{0,25}) + \exp(-1,1t^{0,25} - 0,0038A)$		TP-29
4	$ARF = 1 - \exp(-1,1t^{0,25}) + \exp(-1,1t^{0,25} - 0,0259A)$	-	LeClerc and Schaake (1972)

Some countries have similarly developed ARFs for shorter duration, see Figure 2. Based on Figure 2 is shown that ARF value will be smaller the shorter duration time used in the analysis; similarly prevails for the basin area, the larger the basin area the smaller the ARF value.

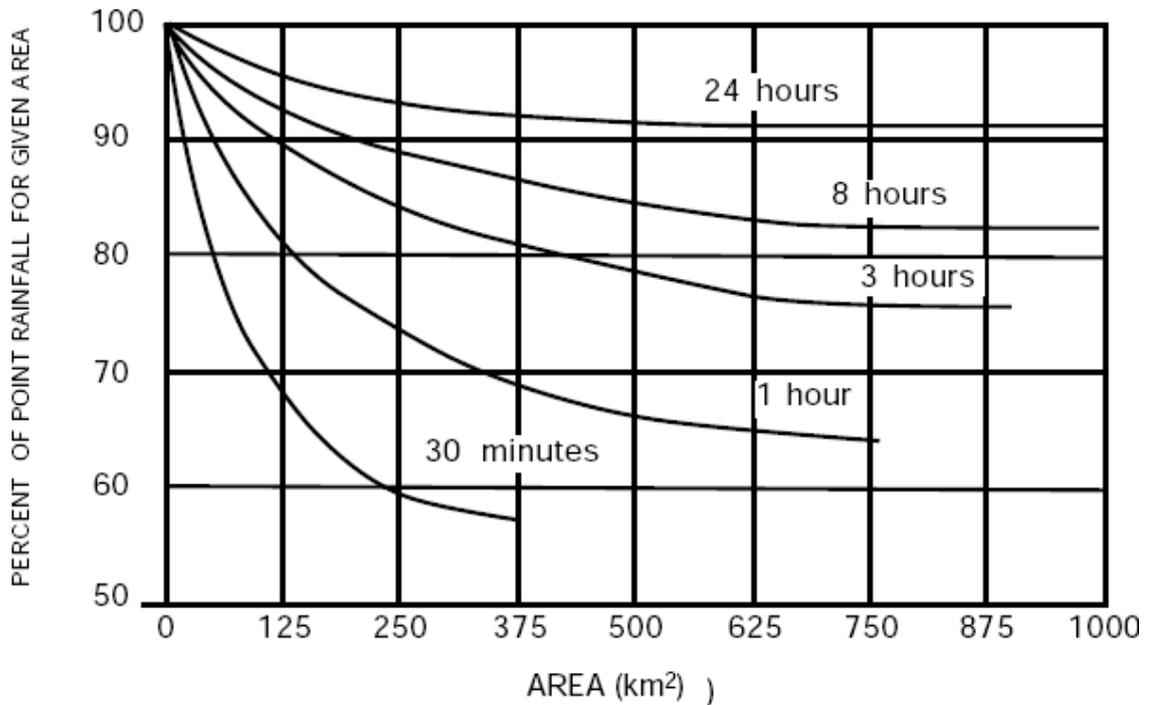


Figure 2. ARF Graph of several rainfall durations

METHODOLOGY

The methodology used in this study elaborated existing daily rainfall data of Upper Citarum and determined intensity of basin rainfall of each sub- river basin.

Basin Rainfall

The Thiessen method applied in the determination of basin rainfall was based on weighted average. The area of influence of respective precipitation station is shown by illustration of perpendicular axes to connection lines between two rainfall stations. The rainfall station used in the analysis is illustrated on the observed basin map which is then connected with the connection line forming a triangle. The perpendicular distribution lines of each connecting line shall then form polygons dividing the influence boundary of each station. Area of each polygon is presented in the percentage value of observed total area. Average rainfall for the complete area is calculated by adding the multiplication of rainfall of respective precipitation station with percentage of represented area.

$$C = \frac{A_i}{A_{\text{total}}}, \quad \bar{R} = \frac{A_1 R_1 + A_2 R_2 + A_3 R_3 \dots + A_i R_i}{A_1 + A_2 + A_3 \dots + A_i}$$

Where:

- C = Thiessen weight
- A_i = Area of observation station i
- A = Total basin area
- \bar{R} = Average rainfall
- R_1, \dots, R_i = Rainfall at each point of measurement (station)



● Precipitation station

Figure 4. Thiessen Polygon Distribution

Frequency Analysis

Frequency distribution analysis is done by Generalized Extreme Value (GEV). General equation of the GEV distribution can explained as

$$F(x; \mu, \sigma, \xi) = \exp \left\{ - \left[1 + \xi \left(\frac{x - \mu}{\sigma} \right) \right]^{-1/\xi} \right\}$$

For, $1 + \xi(x - \mu) / \sigma > 0$, where $\mu \in R$ is showing the parameter of location, $\sigma > 0$ scale parameter, $\xi \in R$ shape parameter. Density function shows the following consequence

$$f = (x; \mu, \sigma, \xi) = \frac{1}{\sigma} \left[1 + \xi \left(\frac{x - \mu}{\sigma} \right) \right]^{(-1/\xi)-1} \exp \left\{ - \left[1 + \xi \left(\frac{x - \mu}{\sigma} \right) \right]^{-1/\xi} \right\}$$

Again for $1 + \xi(x - \mu) / \sigma > 0$. Mean second central moment, standard deviation, mode, skewness and kurtosis excess will be as follows:

$$E(X) = \mu - \frac{\sigma}{\xi} + \frac{\sigma}{\xi} g_1, \quad \text{Var}(X) = \frac{\sigma^2}{\xi^2} (g_2 - g_1^2), \quad \text{Mode}(X) = \mu - \frac{\sigma}{\xi} \left[(1 + \xi)^{-\xi} - 1 \right]$$

Skewness can be calculated by the equation below:

$$\text{Skew}(X) = \frac{g_3 - 3g_1g_2 + 2g_1^3}{(g_2 - g_1^2)^{3/2}}$$

Kurtosis will be:

$$\text{Kurtosis excess } (X) = \frac{g_4 - 4g_1g_3 + 6g_2g_1^2 + 3g_1^4}{(g_2 - g_1^2)^2}$$

where, $g_k = \Gamma(1 - k\xi)$, $k=1,2,3,4$, and $\Gamma(t)$ the gamma function.

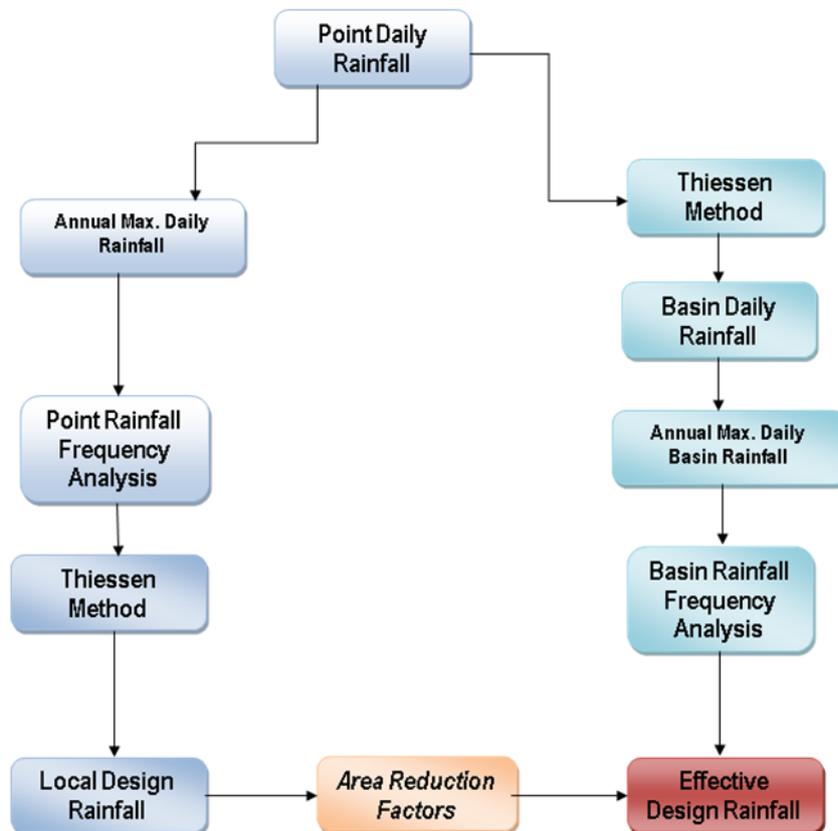


Figure 3. Flowchart applied in the study

RESULTS AND DISCUSSION

Data Processing and Selection

Rainfall data used in the study were obtained from various sources, namely Dinas PSDA, PUSAIR, PLN, Ministry of Agriculture, BMKG and the Dutch KNMI for long past years. Data used in the study range from between 1879 and 2008. Whereas, rainfall data include the daily rainfall data collected from several sources which were then screened for selection of most reliable data. Appropriate data were selected according to a number of analyses including raw data to digital data. A mass curve analysis is then made of all data to determine the data consistency. From the nearly 100 precipitation stations used after data selection, approximately 70 stations were then applied in the analysis.

Design Rainfall Analysis

Design rainfall analysis is carried out by application of annual maximum basin rainfall data of each sub-basin found within the Upper Citarum. Apart from aforesaid data, analysis had also used the annual maximum point rainfall data. Based on annual maximum basin rainfall, a frequency analysis is done to determine probable rainfall intensity for various return periods as can be seen on Table 3.

Table 3. Basin Design Rainfall of several sub-basins in Upper Citarum

Sub Basin	Area (km ²)	Return Periods							
		2	3	5	10	25	50	100	200
Sapan	765.62	48.4	54.8	61.8	70.8	82.4	91.1	99.8	108.6
Majalaya	234.70	58.0	63.9	70.4	78.4	88.2	95.4	102.3	109.1
Dayeuhkolot	1355.47	42.5	47.2	52.2	58.1	65.0	69.8	74.3	78.4
Cisangkuy	287.36	57.6	64.6	71.6	79.3	87.5	92.6	97.1	100.9
Ciwidey	214.63	59.0	67.9	78.6	93.2	113.8	130.8	149.2	169.2
Citarik	242.89	59.0	67.8	78.5	93.5	115.4	133.9	154.6	177.6
Cikeruh	184.26	60.6	69.3	79.2	92.0	108.8	121.6	134.8	148.3
Cipamakolan	52.52	54.7	63.1	72.8	85.7	103.2	117.1	131.8	147.2
Cikapundung	139.51	49.3	54.5	60.3	67.6	77.1	84.1	91.3	98.5
Nanjung	1700.74	41.1	45.4	49.9	55.0	60.8	64.6	68.1	71.2

By application of the annual maximum point rainfall data, possible rainfall intensity for certain return period at respective analyzed precipitation station can be obtained. Frequency analysis results of each precipitation station are shown on Table 4.

Table 4: Analysis on annual maximum daily data frequency

No.	No. Sta.	Name of Station	Coordinate		Authority	Return Period									
			X	Y		2	3	5	10	25	50	100	200	500	1000
1	(132)	Telaga Pantegang	759997.35679	9207006.31558	BMG	92.1	102.2	114.1	130.1	151.9	169.5	188.1	207.9	236.2	259.3
2	(135)	Kawah Ciwidey	768736.70063	9205270.28968	BMG	83.2	91.2	99.8	109.9	121.9	130.3	138.1	145.5	154.7	161.1
3	(147)	Sukawana	784910.87284	9249445.45002	BMG	84.1	97.0	111.9	131.6	157.9	178.5	200.0	222.4	253.7	278.7
4	(150)	Padalarang	773783.68236	9242526.37794	BMG	72.1	82.9	93.6	105.3	117.8	125.6	132.4	138.3	144.8	149.0
5	151	Batuajar (kec)	774266.48078	9234932.03602	BMG	69.4	73.8	78.5	84.3	91.2	96.2	100.9	105.4	111.2	115.4
6	(151a)	Sindang Kerta	765347.21116	9226502.48570	BMG	82.7	92.4	103.1	116.7	134.0	146.9	159.8	172.6	189.7	202.7
7	(152)	Cimahi	779977.16659	9240250.24293	BMG	71.4	80.9	90.6	101.8	114.5	123.0	130.6	137.6	145.8	151.4
8	(153a)	Gambung	777210.98177	9211218.31275	BMG	81.5	88.9	98.8	114.2	139.6	163.9	194.1	231.5	295.1	356.9
9	(153b)	Ciwidey	773487.54334	9215357.10847	BMG	78.0	87.2	97.4	110.3	126.4	138.3	150.1	161.8	177.2	188.8
10	(154b)	Margahayu 2	791076.70208	9247567.92373	BMG	81.1	90.0	101.9	120.5	151.4	181.2	218.1	264.1	342.6	419.3
11	(156a)	Lembang (Meteo)	789309.39384	9244626.33552	BMG	73.4	80.8	90.2	104.1	125.6	144.9	167.6	194.2	236.8	275.6
12	157	Cikapundung	800274.27820	9243828.38354	BMG	91.1	102.5	114.6	129.0	145.9	157.6	168.5	178.8	191.4	200.3
13	163b	Soreang	778406.45000	9222185.05000	BMG	72.0	78.6	85.8	94.6	105.3	113.0	120.3	127.5	136.5	143.2
14	(160)	Pakar/PLTA Bengkok	790056.32387	9240749.27919	BMG	72.7	81.5	92.3	107.2	128.6	146.7	166.6	188.7	221.6	249.7
15	(162)	Bandung (Cileutah)	787319.72429	9234677.85837	BMG	75.8	85.0	95.2	108.0	124.3	136.4	148.4	160.4	176.2	188.2
16	(162a)	Cihampelas	787555.21246	9238426.74286	BMG	75.8	84.1	93.8	106.6	123.9	137.6	151.9	167.0	181.1	205.1
17	(163)	Bandung (Cipaganti)	787032.52063	9238343.52009	BMG	76.2	84.2	92.5	102.2	113.5	121.1	128.2	134.7	142.6	148.1
18	(163a)	Banjaran	786123.02763	9218177.57009	BMG	84.8	94.6	105.6	119.8	138.3	152.3	166.5	181.0	200.6	215.7
19	(163c)	Cisondari	773490.16775	9215848.87632	BMG	80.3	91.7	106.2	128.1	162.7	194.4	232.2	277.4	351.0	419.5
20	(163g)	Husein(Andir)	785486.71518	9236532.17209	BMG	75.1	83.7	92.6	103.1	115.2	123.5	131.1	138.1	146.6	152.6
21	(164)	Jatinangor (Perk)	807605.31155	9236407.63159	BMG	81.3	88.8	97.2	108.0	122.0	132.7	143.5	154.4	169.2	180.7
22	(164a)	Buahbatu	790345.18247	9226330.72924	BMG	78.1	87.5	97.3	108.8	122.1	131.0	139.3	146.9	156.0	162.4
23	(164b)	Pasirjati	798400.00000	9235000.00000	BMG	79.9	89.3	100.3	114.8	134.6	150.3	166.8	184.2	208.8	228.7
24	(166)	Ciparay	800268.36701	9221417.07496	BMG	81.2	90.1	99.8	111.9	127.0	137.9	148.7	159.2	173.0	183.2
25	(167)	Majalaya	805100.00000	9220000.00000	BMG	83.7	95.4	108.0	123.2	141.5	154.4	166.7	178.5	193.3	203.9
26	(168)	Arjasari (Perk)	784622.46681	9218923.62734	BMG	93.9	103.3	113.1	124.5	137.5	146.2	154.2	161.5	170.3	176.3
27	(170)	Paseh (Cipaku)	807861.16496	9212241.37939	BMG	83.7	92.6	102.8	116.1	133.5	147.1	161.0	175.4	195.1	210.7
28	158	Panglipurgalih	802113.77638	9243821.28640	BMG	75.2	83.3	93.3	107.4	128.2	146.1	166.3	189.0	223.7	253.9
29	159	Gunung Kasur	802103.26527	9241973.11489	BMG	83.3	92.8	103.6	117.6	135.7	149.6	163.7	178.2	197.8	213.1
30	153	Riunggunung	776310.17956	9243961.59695	BMG	90.1	102.1	115.3	131.8	152.6	167.9	183.0	197.9	217.5	232.3
31	(172)	Cinyiruan	787165.71881	9207013.36743	BMG	73.5	79.8	86.7	95.1	105.4	112.8	120.0	126.9	135.8	142.3
32	(173a)	Chinchona	784722.11051	9204869.28022	BMG	70.4	76.3	83.5	93.9	109.3	122.8	138.1	155.6	182.6	206.5
33	(173b)	Pangalengan	788281.42316	9208851.41502	BMG	79.7	87.6	96.0	106.1	117.9	126.1	133.8	141.0	150.0	156.3
34	(174)	Cibeureum	794880.98337	9203280.12720	BMG	77.0	85.4	94.2	104.5	116.7	125.0	132.7	139.9	148.7	154.9
35	(178)	Argasari	798229.22552	9208793.99783	BMG	81.0	89.9	100.5	115.0	135.3	151.9	169.9	189.4	217.8	241.4
36	(180)	Malabar (Perk)	786027.24519	9201148.61187	BMG	69.4	75.9	83.2	92.6	104.5	113.5	122.5	131.6	143.7	153.1
37	(187)	Drajat	807407.19145	9203205.35674	BMG	74.6	82.9	91.1	100.0	109.5	115.4	120.5	124.9	129.8	132.9
38	(195d)	Tanjungsari (Bojong Seugit)	808538.68878	9238400.52883	BMG	82.6	93.0	104.3	118.4	135.8	148.4	160.7	172.7	188.3	199.8
39	196a	Cicalengka	812561.78100	9225874.61700	BMG	80.1	90.6	103.4	121.4	147.6	169.8	194.6	222.3	264.2	300.3
40	(199)	Daulat	827802.82848	9223371.29730	BMG	77.0	85.1	95.0	109.0	129.3	146.7	166.0	187.7	220.4	248.7
41	1	Cicalengka	812713.06193	9227375.40644	PLN	65.6	74.2	83.8	95.9	111.1	122.4	133.6	144.8	159.5	170.7
42	2	Paseh	805716.99914	9213158.13104	PLN	79.7	90.4	100.5	111.0	121.4	127.5	132.4	136.4	140.6	143.1
43	3	Chinchona	784722.11051	9204869.28022	PLN	63.9	72.2	81.8	94.6	111.8	125.3	139.4	154.3	175.1	191.8
44	4	Ciparay	799757.90252	9221309.36904	PLN	77.7	86.8	97.9	113.6	136.3	155.6	177.1	201.2	237.5	268.8
45	5	Ujung Berung	801628.49433	9232457.99037	PLN	74.6	81.3	87.2	92.8	97.9	100.5	102.5	104.0	105.4	106.2
46	6	Bandung	788302.62138	9239154.26449	PLN	71.9	81.8	94.1	111.4	137.0	159.0	183.8	211.7	254.3	291.5

Results from Table 4 are then used in the analysis on Thiessen method for obtaining rainfall data of various return periods at each sub-basin in Upper citarum. The results are shown on Table 5.

Table 5. Local Design Rainfall of several sub-basins in Upper Citarum

Sub Basin	Area (km ²)	Return Periods							
		2	3	5	10	25	50	100	200
Sapan	765.62	78.6	87.7	97.9	111.0	128.1	141.5	155.3	169.8
Sapan	765.62	48.4	54.8	61.8	70.8	82.4	91.1	99.8	108.6
Majalaya	234.70	80.9	90.0	100.1	113.1	129.9	142.7	155.8	169.3
Dayeuhkolot	1355.47	79.0	87.9	98.0	111.1	128.6	142.4	157.0	172.7
Cisangkuy	287.36	80.2	88.2	97.2	109.1	125.1	137.9	151.7	166.8
Ciwidey	214.63	79.5	88.2	98.3	112.2	132.0	148.7	167.6	189.1
Citarik	242.89	75.4	85.0	95.9	110.3	129.5	144.7	160.8	177.8
Cikeruh	184.26	79.1	87.4	96.3	107.3	120.9	131.1	141.4	151.8

Cipamakolan	52.52	81.6	91.4	102.5	116.7	135.3	149.6	164.4	179.7
Cikapundung	139.51	79.6	88.9	99.9	114.8	136.2	154.4	175.0	198.5
Nanjung	1700.74	78.8	87.6	97.6	110.6	128.0	141.9	156.6	172.4

Results as shown on Table 3 and 5 were obtained from the two approaches of design rainfall determining the design rainfall intensity. These results also showed that design rainfall resulted by annual maximum local rainfall data shall be greater if compared using the annual maximum basin rainfall. Quantitatively, a reduction of almost 50% was observed when using annual maximum basin rainfall data. Details are shown by the empirical relation in order to connect the design rainfall obtained by use of annual maximum local rainfall and the design rainfall using the annual basin rainfall.

Effective Basin Design Rainfall based on Local Design Rainfall

Basin design rainfall is very essential in a basin hydrological analysis, and will be more effective if compared with the design rainfall obtained using annual maximum point rainfall data (local design rainfall). However, since data availability is a prime factor in basin design rainfall analysis, the approach of point design rainfall analysis is the most frequently used. Therefore, in order to find a solution to the problem, a bridging analysis is required to facilitate the basin design rainfall analysis (effective) using annual maximum point rainfall data (local). Basin design rainfall intensity of a specific river basin can be calculated by using local design rainfall data as follows:

$$P_{basin} = ARF \times P_{local}$$

Where:

P_{basin} : Basin Design Rainfall (Effective)

P_{local} : Local Design Rainfall

ARF is the reduction factor obtained from the analysis in the following sub-chapter.

Calculation of Reduction Factor

The reduction factor is the coefficient used to reduce the resulted value into the expected value. The term of reduction factor has various meanings depending on the context studied. In this case, the reduction factor is presented as a coefficient used to determine the intensity of basin design rainfall from local design rainfall data, as explained previously. The value of reduction factor depends very much on the basin area and selected return period.

For Upper Citarum, calculation of reduction factor value is made into an empirical equation connecting basin area with the reduction factor and also its return period. Equation for calculation of reduction factor varies based on the return period, but for easy application is made only for 2, 3, and 5 year return period as is shown below.

$$ARF_{2\text{year}} = 1.96 A^{-0.17},$$

$$ARF_{3\text{year}} = 2.124 A^{-0.18},$$

$$ARF_{5\text{year}} = 2.319 A^{-0.20}$$

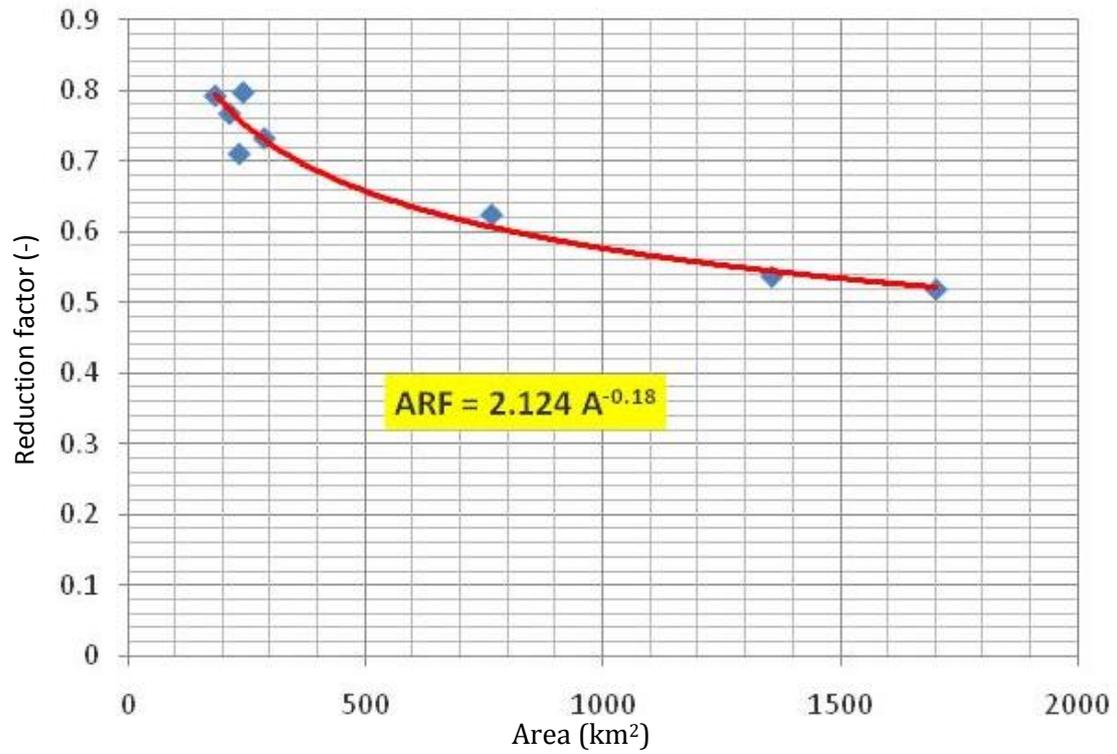


Figure 4. Area reduction factor curve

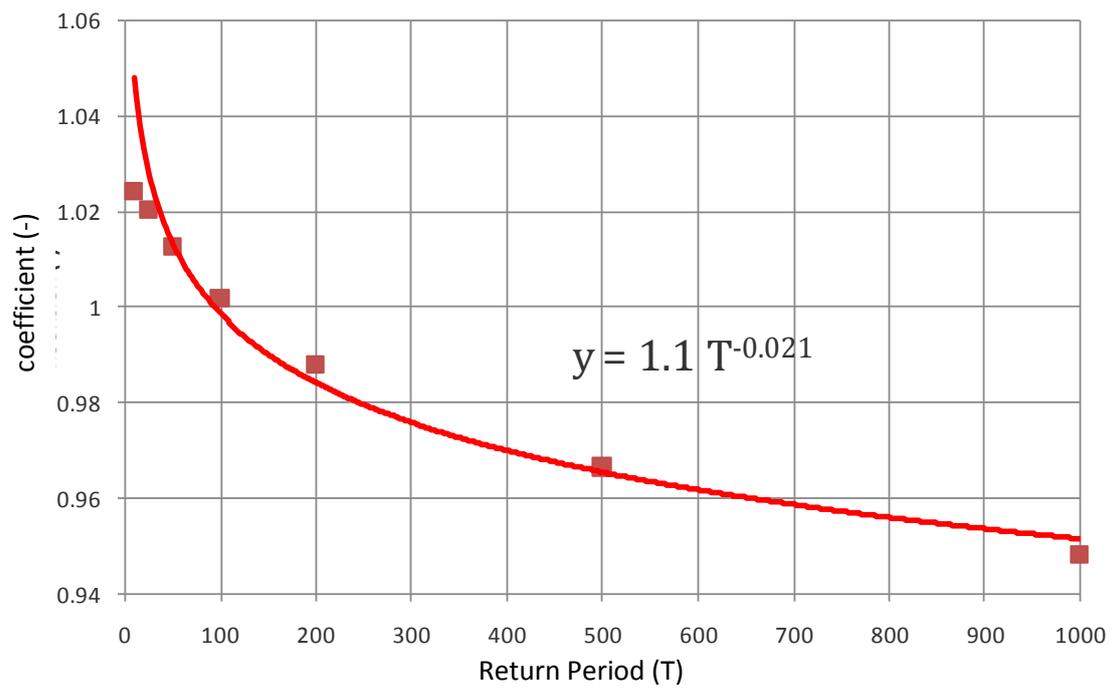


Figure 5. Graph connecting coefficient with return period

For a longer return periods, equation for 2 year return period is being applied as standard to be multiplied by the coefficient calculated using a return period variable. Equation to calculate the coefficient value is as follows,

$$ARF_{T\ year} = 1.96 A^{-0.17} \times 1.1 T^{-0.021}$$

Where :

A : Basin area (km²)

T : Return period (year)

CONCLUSION

Study results conclude the following:

- Basin design rainfall based on maximum basin rainfall data shows lower results if compared with application of annual maximum point rainfall data.
- The calculation of basin design rainfall based on annual maximum point rainfall can be done by multiplication of the reduction factor (ARF).
- Reduction factor results depends on basin area and also the return period. Equations to calculate the reduction factor include the following:
 - $ARF_{2\ year} = 1.96 A^{-0.17}$, for 2 year period
 - $ARF_{3\ year} = 2.124 A^{-0.18}$, for 3 year period
 - $ARF_{5\ year} = 2.319 A^{-0.20}$, for 5 year period,

Whereas for longer return periods, calculation can be made by the following equation:

$$ARF_{T\ year} = 1.96 A^{-0.17} \times 1.1 T^{-0.021}.$$

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