DIFFERENT WAYS OF CALCULATING CATCHMENT RAINFALL: CASES IN INDONESIA

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ABSTRACT

Uncertainty in obtaining average catchment rainfall remains a basic question to which commonly (almost) nobody has any attention in the design of waterworks. Little attention is given to the influence of the applied method on the final design values. Applying Thiessen polygon for almost every effort of obtaining catchment average is still questionable since there are two other methods which are also often used. Up to now, there is no reliable information to which method is the best among the three most commonly applied methods. This study explores the behavior of the three methods of obtaining catchment rainfall, which are mean arithmetic, Thiessen polygon and isohyetal method. The accuracy is obtained by comparing the calculated design values computed by Unit Hydrograph and those obtained by frequency analysis of recorded discharge. The result says that no methods consistently superior.

Keywords: catchment rainfall, unit hydrograph, uncertainty.

INTRODUCTION

Bringing back the classic problems in hydrology, one may realize that working with hydrology is working with nature. It means that any solution in accommodating the natural behavior should be based on its specific behavior in the specific locality. Without any thought of ignoring the important role of other scientific considerations, experience says that hydrologic analysis is the starting point of almost any water resources works. It has a leading role in bringing the accuracy of further qualitative and quantitative analysis and design.

Within the domain of hydrologic analysis itself, one will realize that the very beginning of any hydrologic analysis for the purpose of planning or design of water works is estimating the value of rainfall fallen within the catchment. As has been stated elsewhere, the accuracy of this estimate may influence the expected accuracy of design value. Therefore, one has to be ascertained that the first step of the analysis contains the least error.

Following the previous studies, the accuracy of catchment rainfall estimate is not only caused by the estimating methods, but also by the functions of network density and the network pattern as well. The influence of networks density on the accuracy of catchment rainfall estimate can be found elsewhere in the literatures as well as the influence of the pattern of rain gauge location (Sri Harto, 1985; Igel, 2006). The combined effect of these factors can hardly be clearly identified. Therefore this study is merely trying to see the accuracy of the calculating methods with the existing rainfall networks. Nevertheless a minor discussion will be given related to the networks density.

The conventional methods of estimating catchment rainfall commonly applied in Indonesia are mean arithmetic, Thiessen polygon and isohyetal method. There are quite a few general comments about those methods which in most cases still recommend the application of Thiessen polygon. Sosrodarsono and Takeda (1987) recommended the following situation.

1. The arithmetic method is better applied if the number of rain gauges is adequate and spatially evenly distributed. But so far no quantitative clue is given for the adequacy of this rain gauge.
2. If the locations (pattern) of rain gauges are not evenly distributed over the catchment, then the influence of each rain gauge on the catchment rainfall should be considered.
3. The best rational method to estimate the catchment rainfall is isohyetal method. But this method involves relatively high personal judgment in interpolation especially if rainfall data shows high variability.

Based on the idea that a certain rain gauge has its individual circle of influence meaning the same rainfall fallen within this area, Thiessen polygon may be considered providing better accuracy. But one should realize the very low inter station correlation between rain gauges, as stated by Sri Harto (1985), that almost no relations between rainfalls at one rain gauge and the neighboring ones. Therefore, in fact efforts to apply theories of rainfall networks design to relate to the expected accuracy of rainfall estimate is still questionable, since the analysis is mostly based on daily or even hourly data, while the slightly reasonable networks analysis will be obtained on a monthly basis. Experience says that rainfall network design based on daily rainfall data will come to irrational number of rain gauges (Sri Harto, 1985). Therefore, Sri Harto (1985) suggested the evaluation of rainfall network in Indonesia should be based on monthly data.

Based on those arguments, this study is done only by considering the existing rainfall network density and the pattern of the rainfall station. The procedure followed in the study is set as follows.

1. selecting five catchments,
2. evaluating rainfall networks,
3. applying consistency test,
4. computing catchment rainfall of each catchment with three above stated methods,
5. estimating rainfall with a certain return period,
6. transforming the above rainfall into hourly distribution,
7. applying the transformed value to compute discharge with certain return period using observed Unit Hydrograph,
8. comparing those values with the reference value obtained from frequency analysis of observed discharge data.

AREA OF STUDY

The study is done in five catchments in Central Jawa and Yogyakarta special territory. The description of each catchment is given in Table 1.

Table 1. The description of catchments under study

Catchment	Area (km^2)	Number of rain gauges
Keduang at Sidorejo	396.7	10
Bogowonto at Punggangan	275.9	4
Upper Progo at Kalibawang	1,676.5	12
Opak at Pulo	87.9	5
Winongo at Padokan	47.1	5

ANALYSIS AND DISCUSSION

Rainfall network is evaluated based on monthly data using Kagan's method (1972). This method has been studied by Sri Harto (1985) and further evaluated in some later studies, among others by Igel (2006) This method shows reasonable results for at least having ideas of how the condition of the existing networks is. Based on this evaluation, the averaging error in each study area is presented in Table 2.

Table 2. Averaging error of the existing network based on Kagan's method

No	Catchment	Area (km^2)	Number of rain gauge	averaging error		
				Arithmatics	Thiessen	Iso-hyet
1	Keduang	396.7	10	11.4	11.2	11.5
2	Bogowonto	275.9	4	6.1	6.4	7.8
3	Progo Hulu	1,676.5	12	10.3	10.5	9.8
4	Opak	87.9	5	8.6	8.9	9.2
5	Winongo	47.1	5	11.7	12.1	11.9

Looking at the above table, the existing networks are in relatively good condition with maximum averaging error around 12 %. From this point of view, it seems to be justifiable to exclude the influence of network density in further analysis.

Consistency of rainfall data, which is believed has to be tested for every rainfall data, is done based on Rescaled Adjusted Partial Sums (RAPS) as mentioned by Buishand (1982). The result of this test shows that the rainfall data for all 36 rain gauges is concluded consistent.

Rainfall with a certain return period (design rainfall) is calculated for each catchment with frequency analysis based on partial series. The result of this computation with different methods of calculating catchment rainfall is presented in Table 3.

To make those values more informative, the above Table is also presented in Figures 1 to 5. Those figures tell different values of catchment rainfall computed with different methods. Except for Bogowonto, Thiessen polygon shows moderate results compared to the other two.

Table 3. Design rainfall of each catchment calculated with three different methods

No	Catchment	Return Period (years)	Design rainfall (mm)		
			Arithmatic	Thiessen Polygon	Isohyet
1		10	58.2	57.9	63.3
2		15	60.8	60.3	66.0
3	Keduang	25	64.0	63.4	68.9
4		50	67.9	67.3	72.3
5		100	71.8	71.3	75.3
1		10	124.1	115.7	134.9
2		15	133.6	122.9	146.9
3	Bogowonto	25	146.7	132.8	162.5
4		50	166.4	147.5	184.2
5		100	188.7	164.0	207.0
1		10	95.9	94.2	105.3
2		15	106.1	111.0	123.8
3	Progo hulu	25	119.1	137.2	151.1
4		50	137.0	182.4	195.3
5		100	155.4	242.9	250.3
1		10	109.7	114.6	111.4
2		15	116.8	120.2	119.1
3	Opak	25	126.3	126.9	128.6
4		50	139.3	135.6	141.0
5		100	153.1	143.8	153.3
1		10	87.0	99.7	98.5
2		15	90.8	103.8	103.9
3	Winongo	25	95.4	108.6	110.1
4		50	101.1	114.4	117.6
5		100	106.2	119.7	124.4

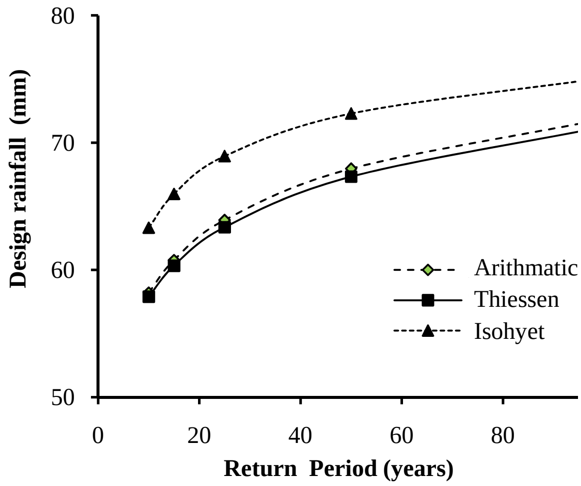

Figure 1. Values of design rainfall computed with three different methods for Keduang.

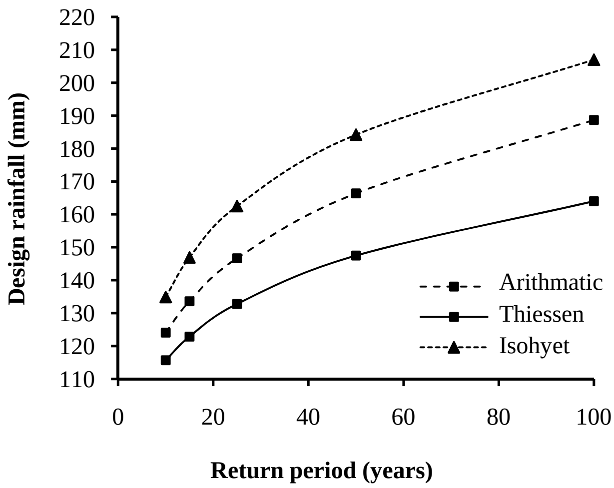

Figure 2. Values of design rainfall with three different methods for Bogowonto.

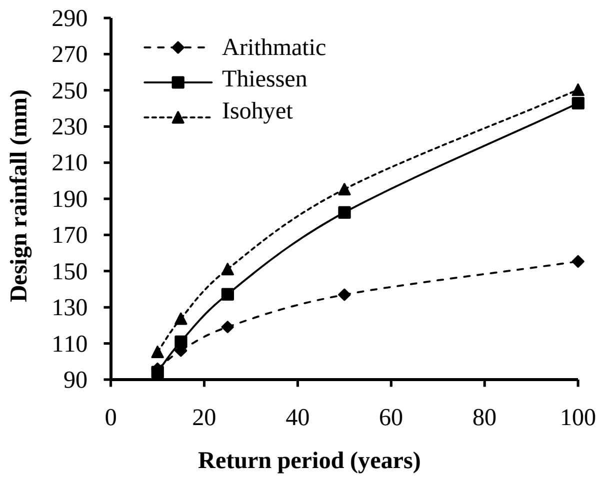

Figure 3. Values of design rainfall computed with three different methods for Upstream Progo

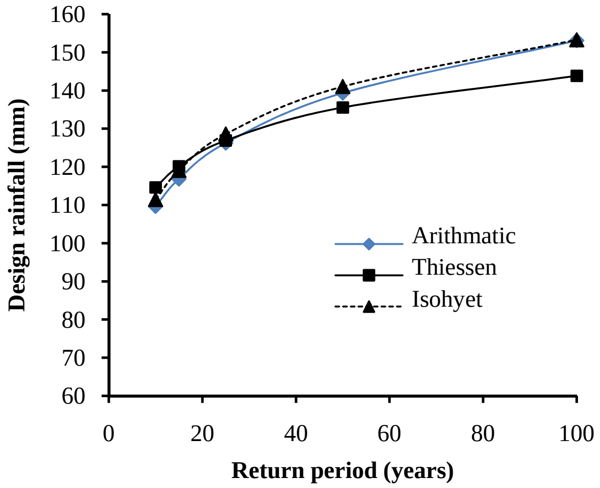

Figure 4. Values of design rainfall computed with three different methods for Opak

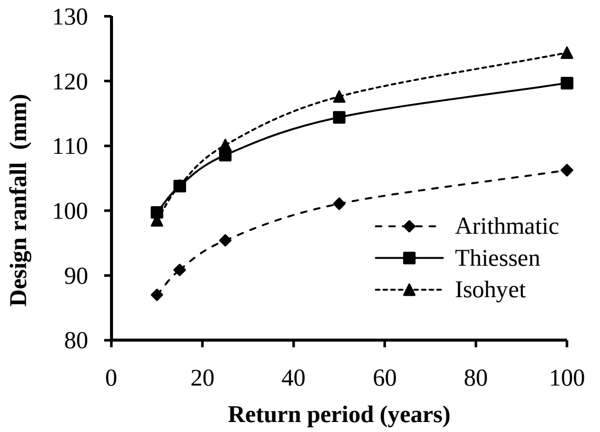

Figure 5. Values of design rainfall computed with three different methods for Winongo

Having a look at those results, it can be seen that neither arithmetic method, Thiessen polygon nor isohyets method consistently shows better estimate, but interchangeably one among the others. Apart from the possible influence of the network density, at least it is already understood that each method has its typical characteristics which are suitable for certain hydrologic conditions. This last statement is the one which is still being studied.

To further know the influence of those methods of catchment rainfall estimates, the deviation of the computation of discharge compared to the observed values will be studied. The simple transformation of rainfall into discharge is based on Unit Hydrograph (UH). Due to limited available hydrograph data, observed UHs are only derived from the maximum available existing recorded data, while Ika (2006) mentioned that error resulting from the application of UH becomes stable (around 10 %) if the representative UH derived from at least 10 observed cases.

Transforming rainfall with certain return period is presented in Table 3, and considering the hourly distribution derived from the rainfall recorder in the study area, the computed discharge of each catchment is presented in Table 4. In this table the observed flood with certain return period derived from frequency analysis is also included.

Table 4. Design discharge computed with three different methods of rainfall estimate compared to the observed one based on frequency analysis

Catchment	Return period (years)	Observed Design Discharge (m^3/sec)	Computed design discharge with different methods of rainfall estimates (m^3/sec)		
			Arith-matic	Thie-ssen	Isohyet
Keduang	10	263.7	163.3	162.5	215.5
	15	291.4	189.2	184.5	246.9
	25	326.1	222.0	215.0	285.9
	50	371.0	273.3	266.0	330.3
	100	414.6	324.9	316.8	367.4
Bogowonto	10	812.2	970.0	892.1	1,181.4
	15	915.3	1,058.1	958.9	1,181.4
	25	1,051.6	1,179.6	1,050.7	1,326.1
	50	1,242.5	1,357.7	1,183.2	1,522.1
	100	1,443.6	1,569.0	1,340.0	1,738.7
Up. Progo	10	1,146.6	267.7	235.9	254.8
	15	1,313.3	268.0	347.5	649.8
	25	1,535.7	525.3	1,031.5	1,424.2
	50	1,849.5	1,025.8	2,354.9	2,756.7
	100	2,182.3	1,546.2	4,238.2	4,468.8
Opak	10	44.9	95.9	108.9	100.6
	15	55.3	114.7	123.4	120.6
	25	71.7	139.4	141.1	145.5
	50	100.7	173.6	163.7	178.1
	100	140.4	209.5	185.4	210.1
Winongo	10	75.1	31.4	50.0	48.0
	15	79.2	35.8	56.5	56.6
	25	84.0	43.1	64.2	66.6
	50	89.8	52.1	73.5	78.6
	100	94.9	60.4	81.9	89.4

The deviation of those estimate values of design discharge to the observed values as function of return period are presented in Table 5. Values in Table 5 are also presented in Figures 6 to 10 respectively for easier interpretation.

Table 5. Deviation of computed design discharge with three different methods of rainfall to the observed values as function of return period

Catchment	Return period (years)	Observed Design Discharge (m^3/sec)	Deviation of Computed design discharge with different methods of rainfall estimates (%)		
			Arithmatic	Thie-ssen	Iso-hyet
Keduang	10	263.7	- 37.7	-38.4	-18.3
	15	291.4	-35.1	-36.7	-15.3
	25	326.1	-31.9	-33.8	-12.3
	50	371.0	-26.3	-38.6	-11.0
	100	414.6	-21.6	-23.6	-11.4
Bogowonto	10	812.2	19.4	9.8	31.8
	15	915.3	15.6	4.8	29.1
	25	1,051.6	12.2	- 0.1	26.1
	50	1,242.5	9.3	- 4.8	22.5
	100	1,443.6	8.7	- 7.2	20.4
Up. Progo	10	1,146.6	- 76.7	- 79.4	- 77.8
	15	1,313.3	- 79.6	- 75.3	- 50.5
	25	1,535.7	- 65.8	- 32.8	- 7.3
	50	1,849.5	- 44.5	27.3	49.1
	100	2,182.3	- 29.2	84.2	104.8
Opak	10	44.9	113.7	142.6	124.1
	15	55.3	107.6	123.3	118.2
	25	71.7	94.4	96.4	103.0
	50	100.7	72.4	62.6	76.8
	100	140.4	49.2	32.0	49.0
Winongo	10	75.1	- 58.2	- 33.4	- 36.1
	15	79.2	- 54.9	- 28.7	- 28.5
	25	84.0	- 48.7	- 23.6	- 20.7
	50	89.8	- 41.9	- 18.2	- 12.4
	100	94.9	- 36.4	- 13.7	- 5.8

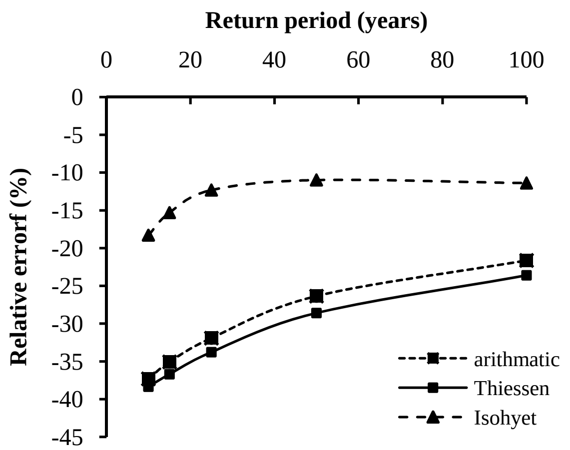

Figure 6. Relative error of design discharge with three different methods of rainfall estimate for Keduang

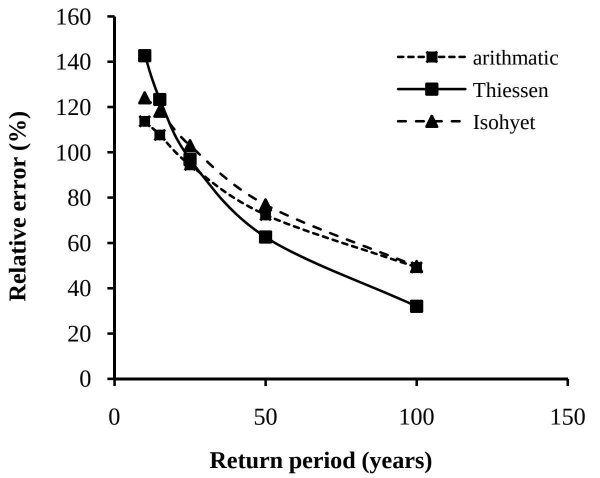

Figure 7. Relative error of design discharge with three different methods of rainfall estimate for Bogowonto

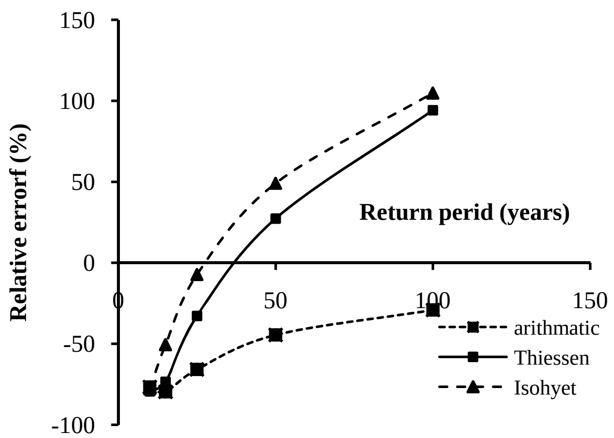

Figure 8. Relative error of design discharge with three different methods of rainfall estimate for Upper Progo

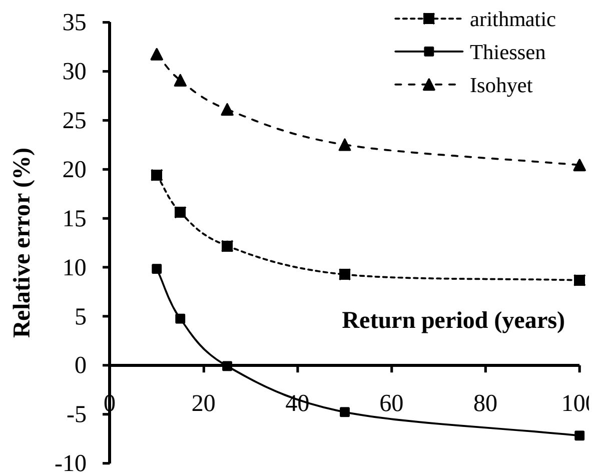

Figure 9. Relative error of design discharge with three different methods of rainfall estimate for Opak

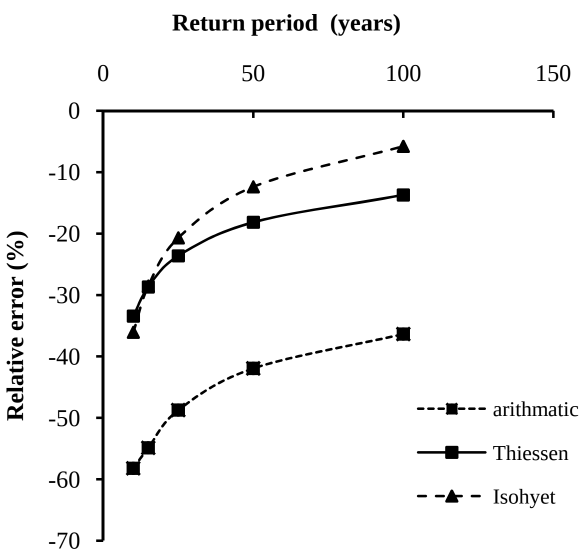

Figure 10. Relative error of design discharge with three different methods of rainfall estimate for Winongo

From the previous tables and figures one may be brought to the following facts.

1. For all methods of estimating rainfall, the higher the return period the higher accuracy will be. This result is in line with those obtained by Igel (2006) and Erni (2008).
2. It looks that rainfall estimates based on Thiessen polygon applied in computing design discharge shows relatively stable deviation from the observed values. It means that although it is not the most accurate method, compared to the other two methods, its 'error shift' is the least. Quite possibly this is caused by the fact that Thiessen polygon has already taken into consideration the contributing area of each rainfall station as the weighting factor. Although the assumption of equal rainfall in the polygon is in Indonesia (tropical region) not really applicable, at least this is better than the other two methods which ignore the role of surrounding areas to the value of point rainfall.
3. The obtained deviation is quite possibly caused by the combined error contributed by network density, network pattern.

CONCLUSION

From the preceding discussions, some conclusions can be drawn.

1. Practically, among the known three methods in estimating rainfall values, none of them is considered superior.
2. In more cases, rainfall estimates with Thyssen's polygon show better results compared to that based on the other two methods.
3. Looking further to the result in applying those three methods on the calculation of design flood based on Unit Hydrograph, Thyssen's method still shows better result compared to the other two methods.

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