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RAINWATER HARVESTING FOR FLOOD PEAK REDUCTION IN WAY AWI CATCHMENT, INDONESIA

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ABSTRACT: This study is motivated by floodings which occur frequently in Jagabaya village, Way Awi catchment, Bandar Lampung city, Indonesia. In addition to the intensity of rainfall, this area is considered as an urban area with intense housing and insufficient drainage capacity during heavy rain. This study aims to analyze flood peak reduction by simulating the application of rain barrels for each house. The volume of rain barrels used in the simulation is 0.5 to 5 m^3. An Intensity-Duration-Frequency (IDF) curve is generated using short-duration rainfall data (i.e. 5, 10, 15, 30, 60, 120, 180, 360 and 720 minutes) recorded from Panjang Meteorological Bureau, Lampung. The rational method, a simple rainfall-runoff model, is used to calculate runoff generated both from catchment and rooftop. The result shows that the application of rain barrels may reduce flood peak up to 28% for 2 year return period of flood, while for 100 year return period of flood, the reduction may reach 13.64%. From this study, it can be concluded that rainwater harvesting utilizing rain barrel is significant in reducing flood peak. Furthermore, this result can be used to persuade both the society as well as the local government to do such flood mitigation in this densely populated urban area.

Keywords: Rainwater harvesting, Rain barrel, Flood reduction, Flood mitigation

1. INTRODUCTION

Studies about floods have been widely conducted as floods have increasingly threatened many places in the world. Discussion about floods usually relates to rainfall, runoff and the effort to mitigate flooding [1]. For the rainfall-runoff transformation, a selected rainfall-runoff analysis should be suitable with the expected result. Unit hydrographs, either synthetic or instantaneous, have been intensively used to predict runoff in some studies. Such unit hydrograph is capable to improve runoff prediction [2], even in ungauged catchment [3-5] or gauged catchment [6], dealing with the parameters of the unit hydrograph to achieve a better runoff prediction [7], evaluating runoff prediction using unit hydrograph and physically-based model [8]. A conceptual model such as a bucket model is not only capable to predict runoff in a catchment [9-11] but also in a catchment with lakes ([12,13]). Physically-based models have also been used to predict runoff by incorporating river routing ([14,15]).

For urban drainage, in addition to some methods above, the Rational method is widely used as the transformation method from rainfall to runoff. This method is accurate in runoff prediction, especially for the small catchment areas. Furthermore, Intensity Duration Frequency (IDF) curve can be considered as a valuable tool for determining the depth of design rainfall required for calculation in the rational method. The rainfall Intensity-Duration-Frequency (IDF) relationship is one of the most commonly used tools in water resources engineering, either for planning, designing and operating of water resource projects, or for various engineering projects about floods. In spite of the early establishment of the IDF relationship, yet many studies about IDF have been done to date ([16-18]).

Flood control is closely related to flood mitigation. In a conventional approach, the principle of flood control is releasing water as fast as possible to drainage the network and finally delivering it to the sea. Recently this flood management concept has changed into a conservative drainage paradigm that applies Storing, Absorbing, Flowing and Maintaining concept. Runoff is not immediately released to the sea, but some are retained in storages such as a dam, long or short storages which can be utilized during the dry season as well as infiltration well [1] to contribute to the groundwater. Besides, rainwater can be harvested in the form of rain barrels which can be used for domestic purposes. Rainwater harvesting such as infiltration well and rain barrel can be applied by individuals in urban areas.

This study is located in Jagabaya village, Way Awi catchment, a small catchment part of Way Garuntang catchment located in Bandar Lampung, Lampung Province, Indonesia. The area is considered an urban area, which has intense housing and drainage network which usually insufficient to carry water during heavy rain (Fig. 1). As a result, this area experiences flooding frequently. Earlier studies on this catchment have investigated observed unit hydrograph [6] and rainfall characteristics of the catchment [16]. The previous study on this catchment [6] found that the average time to peak of observed unit hydrograph for Way Awi is 30 to 60 minutes while base time is 3 hours It is implied that when a flood comes, discharge rises rapidly and attenuates quickly. This is due to land use of the watershed which is covered mostly by impermeable areas.

An alternative to solve the problem of frequent flooding in this type of area can be conducted by installing rain barrels on each house. Therefore, this study aims to analyze flood reduction if rain barrels applied in this study area. The result can be used by local governments to do such flood mitigation.

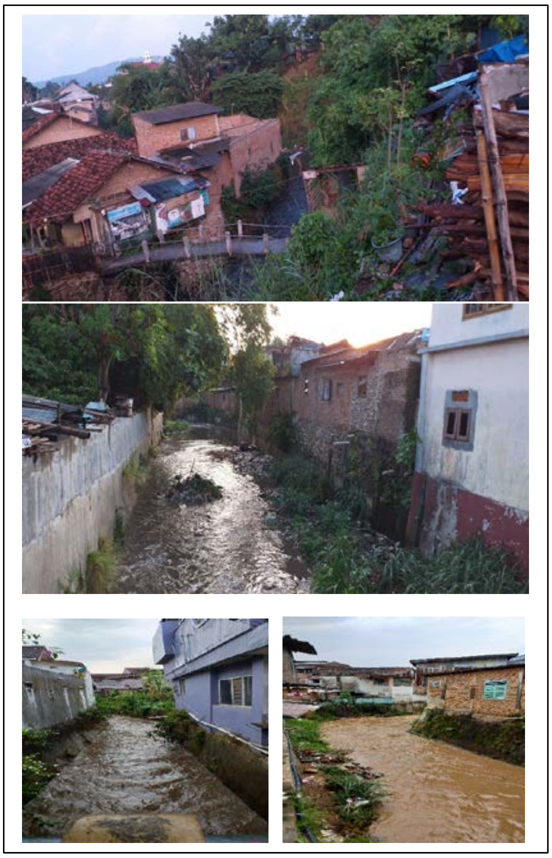

Fig. 1. The situation of the study area with intense housing and insufficient drainage capacity

2. METHODS

The study area is located in Jagabaya village which is included in Way Awi catchment and has an area of 25 hectares. Way Awi is part of Kuala Garuntang catchment (Fig. 2), the largest catchment in Bandar Lampung city, Lampung Province, Indonesia. The methodology of the research includes analysis of intensity duration frequency, flood estimation, flood reduction by rain barrel.

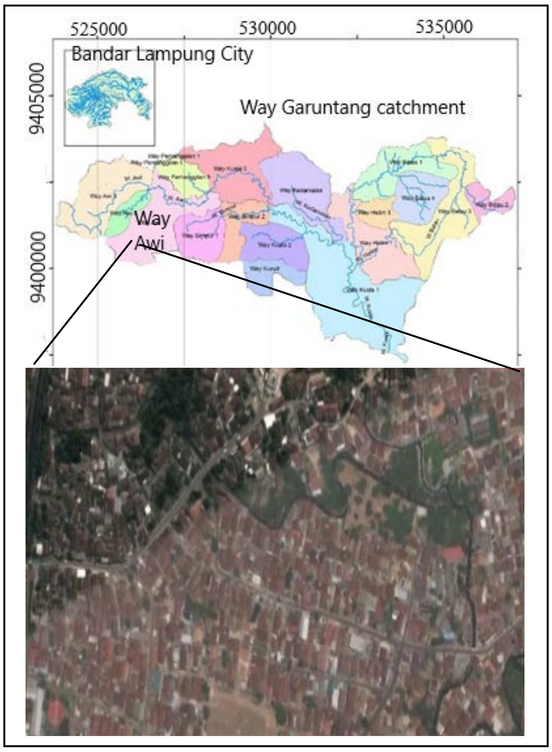

Fig. 2. Study area map

2.1. Analysis of Intensity Duration Frequency

The rainfall data used in this study was taken from an automatic rain gauge on rainfall recording station in Panjang Meteorological Bureau from 2000 to 2011 using an automatic Hellman rain gauge. Rainfall duration recorded are 5, 10, 15, 30, 45, 60, 120 minutes, 3 hours, 6 hours and 12 hours. The use of various rain durations is needed for the development of IDF curves.

Frequency analysis is a procedure for estimating the frequency of past or future events. The procedure is used to determine the design rainfall in various durations based on the most suitable distribution of rainfall data.

Intensity Duration Frequency (IDF) is usually given in the form of a curve which gives the relationship between rainfall intensity as ordinate and the duration of rain as abscissa. In this study, IDF curves will be generated for return periods of 2, 5, 10, 25, 50, and 100 years.

2.2. Flood Estimation

Given rainfall intensity design obtained from intensity duration frequency analysis, flood design can be calculated using the rational method [19] which considers design discharge as the contribution of design rainfall intensity, catchment area and runoff coefficient [20]. In addition to estimating runoff from the catchment, the method is also used to predict runoff from the roof collected by the gutter and finally stored in the rain barrel.

2.3. Flood Reduction by Rain Barrel

A typical rooftop rainwater harvesting system comprises of three basic subsystems – a catchment system (roof), a delivery system (filters and gutters), and a storage system. The technique of rainwater harvesting is considered to be one of the most efficient efforts to overcome flooding. Rainwater that falls on the house's roof is considered as surface runoff too.

In this study, the focus is in the dense area where the number of house's roofs that can be utilized for rainwater harvesting is 503 house roofs consisting of 3 types of roof area, i.e roof area of 55 m^2 with a total of 167 houses, roof area of 99 m^2 with a total of 194 houses and roof area of 111 m^2 with a total of 142 houses. To get some insight into the significance of rain barrels in reducing runoff, this study simulates the number of rain barrels used. Considering 1 piece of rain barrel having a volume of 0.5 m^3, this study simulates the use of 1 to 10 rain barrels in each house and estimate runoff reduction resulted.

3. RESULTS AND DISCUSSION

3.1 Rainfall Intensity Analysis

In order to find rainfall intensity design, initially, frequency analysis needs to be done to compute required statistical variables and suitable probability distribution. The results of frequency analysis for variables Ř (average rainfall depth), S (standard deviation), C_v (coefficient of variance), C_s (coefficient of skewness) and C_k (coefficient of kurtosis) for all duration in this study is presented in Table 1. It is found that a suitable probability distribution of all durations is distribution Log Pearson Type III.

Using probability distribution suitable, frequency analysis is continued to calculate rainfall intensity design for each duration. The result of the rainfall frequency analysis is design rainfall for particular return periods, i.e. 2, 5, 10, 20, 25, 50, and 100 years in the duration of 5, 10, 15, 30, 45, 60, 120, 180, 360, 720 minutes. To get the intensity value for that duration, the maximum rainfall obtained from the frequency analysis can be converted into intensity using the relationship $I = 60\ R / t$, where R is the design rainfall and t is the duration. The result of rainfall intensity design for each duration and return periods are presented in Table 2.

Intensity Duration Frequency (IDF) is usually given in the form of a curve which gives the relationship between rainfall intensity as ordinate and the duration of rain as abscissa. From the distribution of rainfall intensity data, regression analysis is carried out to produce an IDF curve IDF curves for the study area, Way Awi can be seen in Fig. 3.

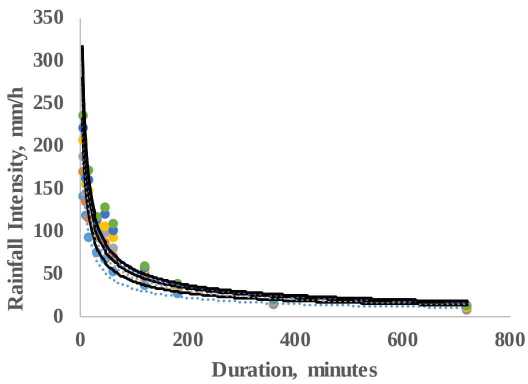

Fig. 3. IDF curve of the study area

Table 1. Statistical variables of rainfall data

PARAMETERS	DURATION									
	5'	10'	15'	30'	45'	60'	120'	180'	360'	720'
Ř	9.67	15.78	20.78	35.69	45.64	47.82	69.41	77.27	80.54	86.39
S	3	4.82	6.07	11.33	14.88	14.11	21.77	32.15	30.22	31.68
Cv	0.31	0.31	0.29	0.32	0.34	0.3	0.31	0.42	30.22	31.68
Cs	0.91	-0.57	0.04	-0.33	-0.36	0.15	-0.02	0.83	1.42	0.9
Ck	5.9	2.52	3.07	2.92	3.36	2.86	4.95	5.115	5.92	3.97
Suitable Probability Distribution	Log Pearson III									

Table 2. Rain intensity (mm/hour) with T year return period for a particular duration

Duration (minutes)	Rainfall intensity (mm/hour)					
	2 yrs	5 yrs	10 yrs	25 yrs	50 yrs	100 yrs
5	141.09	169.62	186.84	207.16	221.56	235.34
10	118.16	134.11	143.53	154.49	162.09	169.26
15	92.13	115.53	129.93	147.16	159.47	171.32
30	75.29	93.17	101.09	108.68	112.71	115.84
45	66.04	85.97	97.51	106.02	119.40	127.50
60	52.75	69.89	80.19	91.83	100.59	108.46
120	36.18	46.44	50.90	54.77	56.76	58.23
180	26.61	33.12	35.40	37.00	37.67	38.05
360	13.14	16.21	17.85	19.59	20.71	21.69
720	6.87	8.76	9.86	11.07	11.97	12.77

3.2. Rainwater Harvesting

Rainwater that falls on the roof of the house will overflow. The overflowing rainwater will be collected through a collection channel (gutter). Rainwater collected will be directed into a rain barrel which may be equipped with water tap as an outlet if it is used for daily water consumption. Construction for rainwater harvesting can be made quickly because it is quite simple and easy to make.

For calculation of flood peak reduction using rain barrels, a simulation has been done that each house utilized 0.5 m^3, 1 m^3, 1.5 m^3, 2 m^3, 2.5 m^3, 3 m^3, 4 m^3 and 5 m^3 volume of rain barrels. Rainfall duration used for the calculation is 1 hour (60 minutes) so that based on rainfall intensity design for that duration, flood design can be calculated as presented in Table 3. Flood design is calculated using the rational method with a runoff coefficient assumed to be 0.9. The result of the simulation of the volume of rain barrels to store rainwater by considering the number of houses and rain barrel volumes is presented in Table 4.

The percentage of flood peak reduction is calculated based on total volumes of rain barrels in the catchment and volume of runoff caused by rainfall of an hour duration. The result of simulation using various volumes of rain barrels for each house and for return periods of 2, 5, 10, 25, 50 and 100 years is presented in Table 5.

Table 3. Rainfall intensity designs and flood designs

	Return Period					
	2	5	10	25	50	100
I (mm/hr)	52.745	69.887	80.193	91.833	100.594	108.462
Q (m3/s)	2.491	3.300	3.787	4.337	4.750	5.122

Table 4. Result of simulation of various rain barrel volumes and corresponding rainwater volumes to store

Roof Area (m2)/ Number of houses	Rainbarrel Volume (m3)							
	0.5	1	1.5	2	2.5	3	4	5
55 / 167	83.5	167	250.5	334	417.5	501	668	835
99 / 194	97	194	291	388	485	582	776	970
111 / 142	71	142	213	284	355	426	568	710
Total Volume (m3)	251.5	503	754.5	1006	1257.5	1509	2012	2515

Table 5. Result of simulation of various rain barrel volumes and the corresponding percentage of flood peak reduction

Return Period (years)	Rainbarrel Volume (m3)							
	0.5	1	1.5	2	2.5	3	4	5
2	2.805	5.610	8.415	11.219	14.024	16.829	22.439	28.048
5	2.117	4.234	6.351	8.467	10.584	12.701	16.935	21.169
10	1.845	3.690	5.534	7.379	9.224	11.069	14.759	18.448
25	1.611	3.222	4.833	6.444	8.055	9.666	12.888	16.110
50	1.471	2.941	4.412	5.883	7.353	8.824	11.765	14.707
100	1.364	2.728	4.092	5.456	6.820	8.184	10.912	13.640

The results are presented both in tables and figures for better understanding of the effect of rain barrels in reducing flood peak. The relationship of rainfall intensity designs for rainfall duration of 60 minutes (Table 2) and corresponding flood designs is presented in Fig. 4. It can be seen that both rainfall intensity designs and flood designs increase as return periods increase. The effect of the use of rain barrel for flood peak reduction is presented in Fig. 5, while there is a linear correlation between volumes of rain barrels used and the percentages of flood peak reductions. Using a simulation of total volumes of rain barrels utilized, the result shows that the use of rain barrel can reduce flood peak up to 28%.

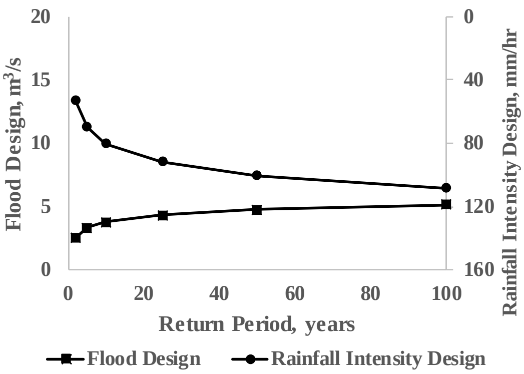

Fig. 4. Flood design and rainfall intensity design

A similar study on flood reduction in the district of AsanTanjung New Town (Korea) [21] has been done by using infiltration trench, vegetation swale, rain barrels and urban wetland showing the reduction of flood peak of 50 to 100 year return period to be about 7 to 15%. This result comparable with the result found in this study, that the reduction of flood peak using rain barrel volume up to 5 m^3 for the return period of 50 to 100 years can be up to 14.7%. This study shows that using only one type of rainwater harvesting, i.e. rain barrel, but applying it in each house will give considerable effect on flood reduction. The effect of rain barrels in flood peak reduction can be more significant if it is combined with other rainwater harvesting techniques such as ground tank, infiltration trench, and infiltration well.

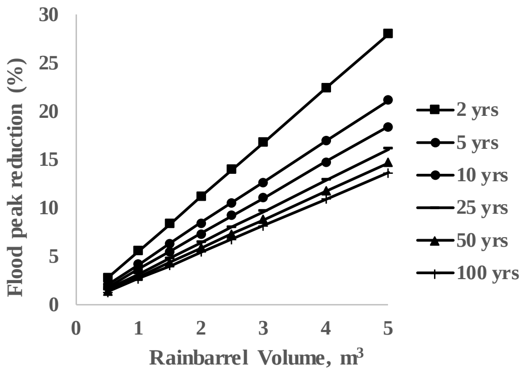

Fig. 5. Rain barrel volumes and corresponding flood peak reductions

4. CONCLUSION

Rainwater harvesting using rain barrels is significant in reducing flood peak in a densely populated urban area such as Way Awi catchment, Lampung, Indonesia. For return period of 2 years, the use of rain barrels with the volume of 0.5 to 5 m^3 will reduce flood peak up to 28%, 21.1%, 18.4%, 16.1%, 14.7% and 13.6% for return period of 2, 5, 10, 25, 50 and 100 years respectively. The application of rain barrels reduced flood peak up to 28% for 2 year return period of flood. However, the reduction was found 13.64% for 100 year return period of flood. It was observed that the rainwater harvesting utilizing rain barrel is a significant in reducing flood peak. The results obtained in this study are encouraging to persuade both the society as well as the local government to do such flood mitigation in the densely populated urban area.

5. ACKNOWLEDGMENT

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