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Research Article

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Linking maximum and minimum river discharge ratio with overland flow regimes

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Abstract Flood and drought events occurred in the tropics has a strong correlation with the hydrological function of a river basin as a rainwater catchment area. The ratio of maximum and minimum river discharge which is known as the coefficient of river regime (CRR) reflects thehydrologicalfunction of a river basin. This study aims to investigate the correlation between CRR with the overland flow (direct runoff) in a yearly basis.Three regimes of overland flow i.e. average, maximum and total of flow were considered for the correlation analysis. A simple hydrologic tank model was used to estimate overland flow and river discharge in the study site. The result shows CRR has a high correlation with the average overland flow. Whereas, maximum and total overland flow indicatesa very low and moderate correlation respectively. The present result provides a basic reference for CRR studies which is still limited.

Keywords Coefficient of river regime, direct runoff, hydrological function, riverflow, tank model

Introduction

Flood and drought have been recognized as one of critical water resources problems. In tropical countries, flood events are more commonly found during the wet (rainy) season. Even though has a high rainfall, drought can be found in the tropics, particularly in the river basin with a poor hydrologic function which cannot optimally storage the water during the wet season[1-2]. CRR reflects the ability of a river basin to keep rain water. Low CRR indicates low differences of river discharge along of the wet and dry seasons. Contrariwise, the difference is high for high CRR value which indicates low ability of river basin for storingrain water. This low ability is indicated from low infiltration capacity, whereas, the direct runoff tend to high. It indicates CRR could be linked with runoff dynamics. This study focuses on overland flow and CRR correlation. Overland flow is the main component of flood and plays important role in infiltration process and soil particles transportation during erosion process [3-5]. Hence, linking CRR with the overland flow is important for soil and water conservation practices consideration. CRR could also be used as the indicator for river basin monitoring and evaluation.

Materials and Methods

The present study was conducted in the Sempor watershed which covers about 44.16km^2 area of Kebumen Regency, Central Java Province, Indonesia (Figure 1).The average annual rainfall is 3,500 mm with average daily temperature and evapo-transpiration is 26^{o}C and 3 mm respectively. Sempor watershed captures rainwater for a reservoir in the downstream which is used for many purposes such as fishery, irrigation and power generation.

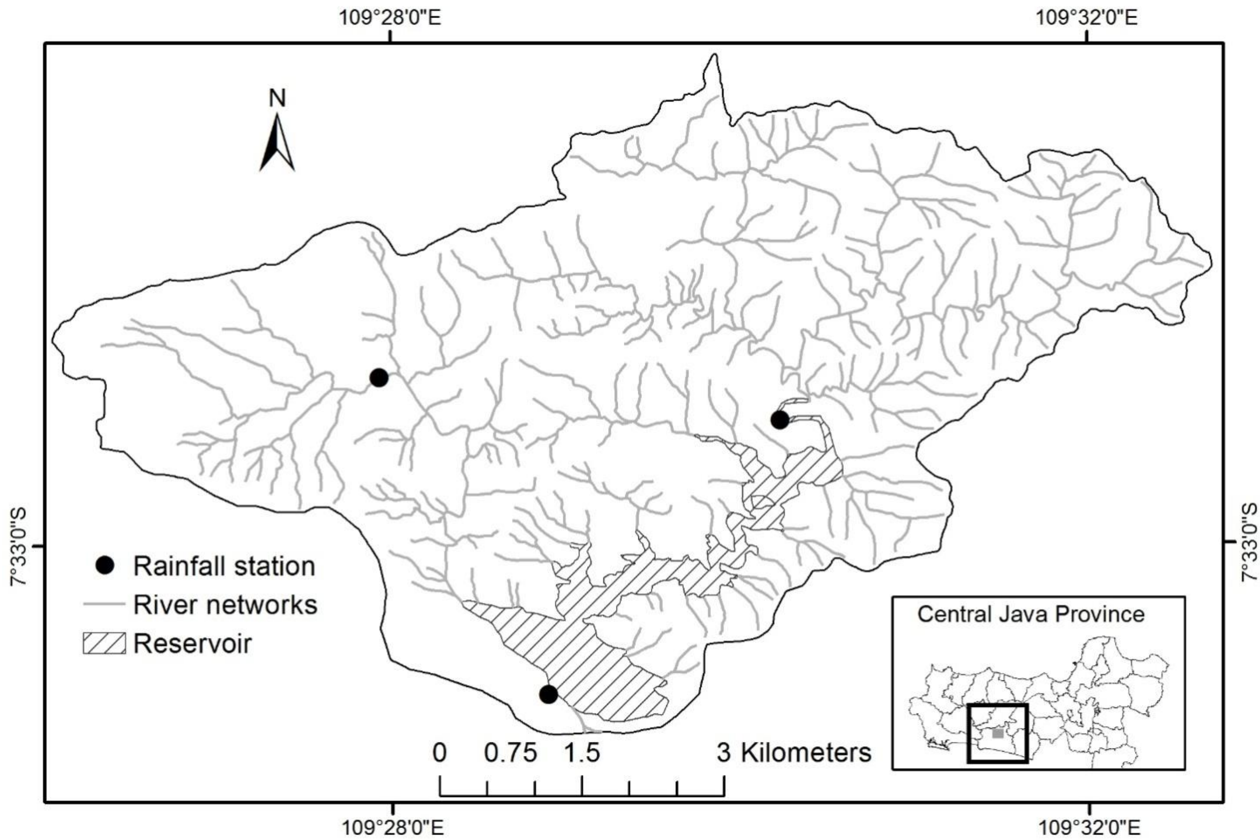
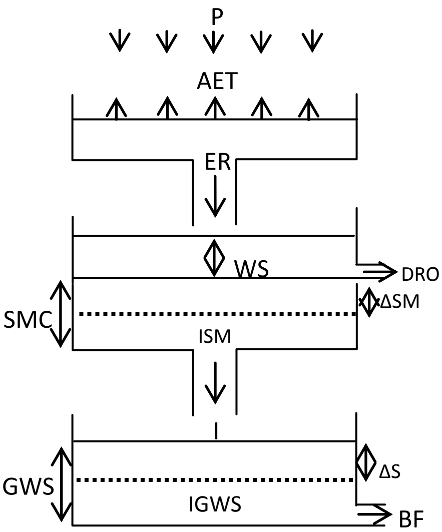


Figure 1: Location of Sempor watershed

Overland flow (direct runoff) and river discharge were calculated using hydrology tank model of Mock (Figure 2) for the period of 2008 to 2016 in half monthly basis. Mock model is a rainfall-runoff transformation model which is containing three artificial tanks, representing hydrology cycle processes in the atmosphere, soil and ground water system [6]. The Mock model was calibrated by using river discharge data and climate data in 2000. Rainfall and actual evapotranspiration were required as the main input of Mock model.



ER	=	P-AET	IGWS	=	GWS_{I-1}
WS	=	ER-ΔSM	DRO	=	WS-I
ΔSM	=	SMC-ISM	BF	=	I-ΔS
ISM	=	SM_{I-1}	ΔS	=	GWS – IGWS
I	=	Ci x WS	Q_{TOT}	=	DRO + BF
GWS	=	0.5 (1+K) I + K x IGWS			

P	=	precipitation	I	=	infiltration
AET	=	actual evapotranspiration	WS	=	water surplus
ER	=	excess rainfall	BF	=	base flow
DRO	=	direct runoff	Ci	=	infiltration coefficient
ΔSM	=	change of soil moisture	SMC	=	soil moisture capacity
ISM	=	initial soil moisture	K	=	recession constant
ΔS	=	change of ground water volume	Q_{TOT}	=	total water discharge
GWS	=	ground water storage			
IGWS	=	initial ground water storage			

Figure 2: Structure of the Mock model

River discharge-overland flow correlation was analyzed by regression analysis for nine years. According to Asuero et al. in 2006 [7], the strength of correlation was determined based on coefficient correlation (R) value as described in in Table 1. River discharge data (for Mock model calibration), rainfall data from three rainfall station in the study site and climate data were collected from the Office of Probolo River System, Central Java Province, Indonesia.

Table 1: Level of correlation between CRR and overland flow regimes in the study site

Value of R	Level of correlation
0.90 to 1.00	Very high correlation
0.70 to 1.89	High correlation
0.50 to 0.69	Moderate correlation
0.30 to 0.49	Low correlation
0.00 to 0.29	Very low correlation

Results and Discussion

Mock model calibration

Calibration was conducted to determine the value of initial soil moisture (ISM), soil moisture capacity (SMC), infiltration coefficient (Ci), Initial ground water storage (IGWS) and recession constant (K). The optimization value those parameters were obtained by the function of Excel Solver (Table 2).

Table 2: Optimization value of Mock model parameters in the study site

Parameter	Symbol	Unit	Value
1. Area of watershed	A	km^2	44.16
2. Infiltration coefficient in rainy season	Ci_w	-	0.50
3. Infiltration coefficient in dry season	Ci_d	-	0.60
4. Initial soil moisture	ISM	mm	100
5. Soil moisture capacity	SMC	mm	200
6. Initial ground water storage	IGWS	mm	1500
7. Groundwater recession constant	K	-	0.99

We used the coefficient of correlation (R) to assess the correlation between calculated discharge and observed discharge in the calibration process. The calibration indicates a strong correlation between two those parameters (Figure 3), where the value of R was 0.9. It means the Mock model is accurate for river discharge calculation in this study.

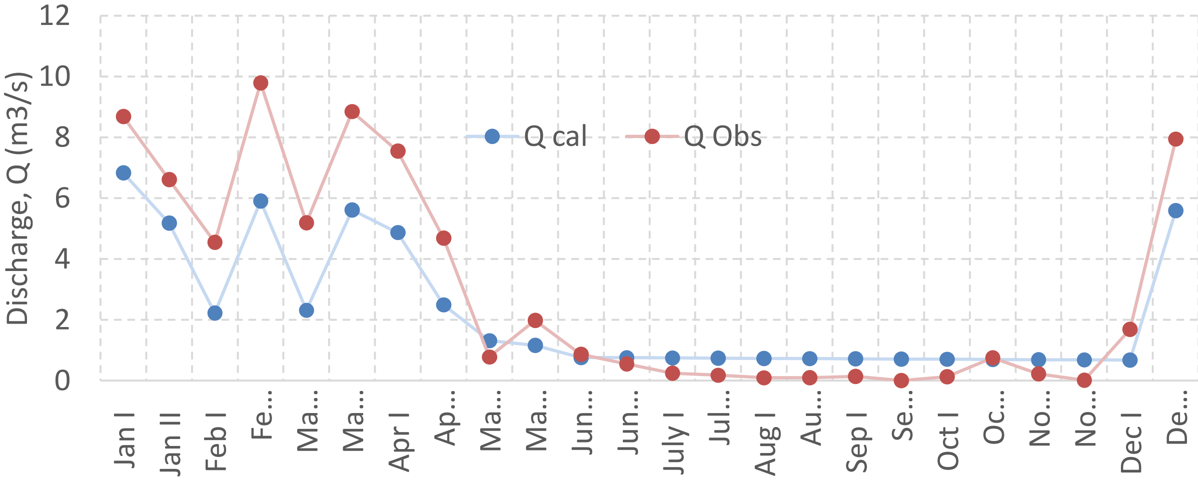


Figure 3: Observed and calculated discharge (Q) of the Mock model calibration in the study site

The Mock model was developed for tropical region Java Island Indonesia (Setyawan, 2016). It has been used for many hydrological studies. According to those studies, each of the five parameters has a range value (ISM: 10-100 mm, SMC: 300-700 mm, $Ci_{d,w}$: 0.5-1.0, IGWS: 1000-3000 mm, K: 0.5-1.0). For infiltration coefficient, Ci_d must higher than Ci_w due to during the dry season the infiltration capacity tends to be higher as an effect of soil moisture decreasing.

Average river discharge

The discharge has a linear correlation with rainfall (Figure 4). The discharge is low during the dry season from April to September. The highest average discharge is found in November, whereas the lowest is found in September. Figure 4 indicates the discharge including overland flow during the wet season tends to high with low infiltration. Hence, ground water storage during the dry season tends to be low. Soil and water conservation practices are required to maximize water infiltration during the wet season.

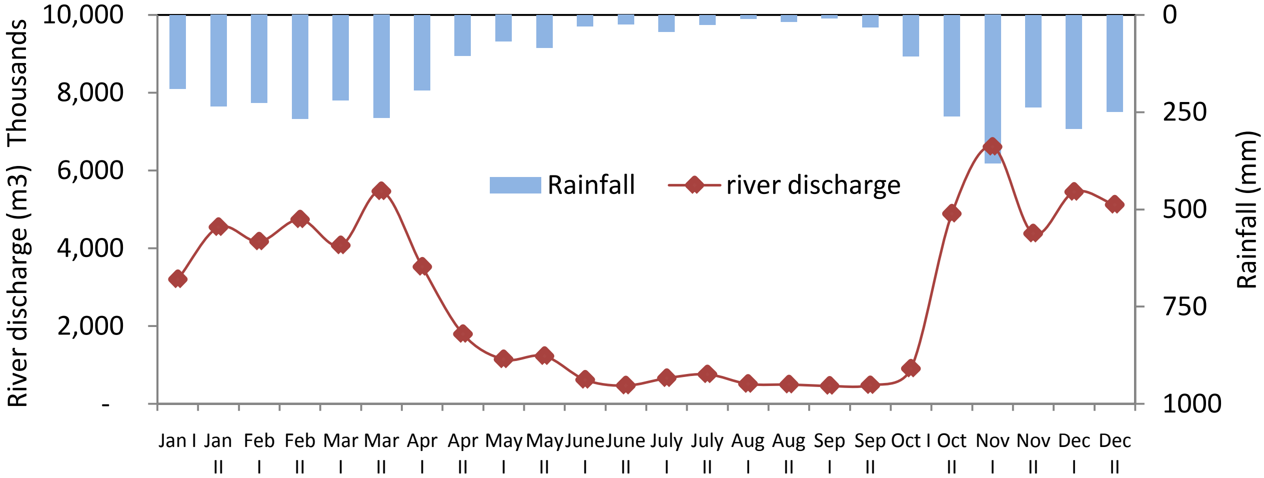
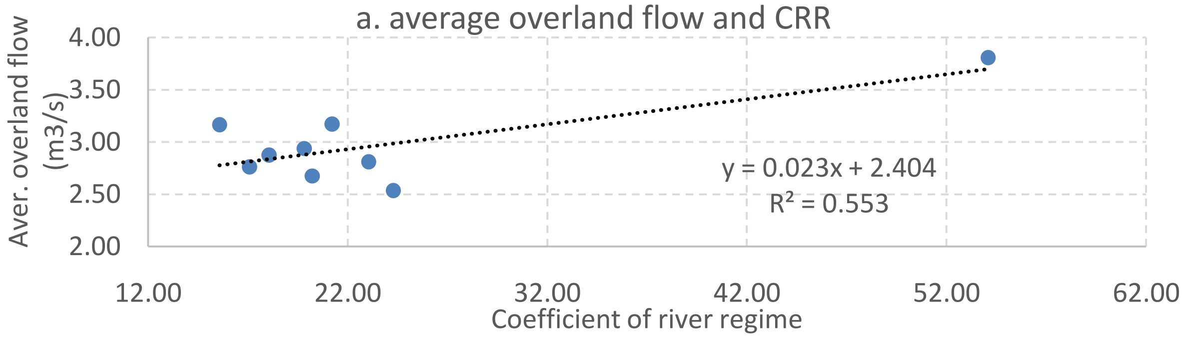


Figure 4: Average river discharge of the study site

According to the average evapotranspiration (ET) in the study site (3 mm), it needs about 1,000 mm per year water for ET. Water yield during the dry season is significantly decreasing. The reservoir in the downstream has very important role to store water during the wet season. Hydrological processes are also affected by land cover/land use types. Hence, to increase infiltration capacity, land use management could be considered in the study site.

Overland flow and river discharge correlation

The Mock model was used to calculate river discharge and overland flow for nine last year. The correlation between CRR and average overland flow, maximum overland flow and total overland flow are described in Figure 5.



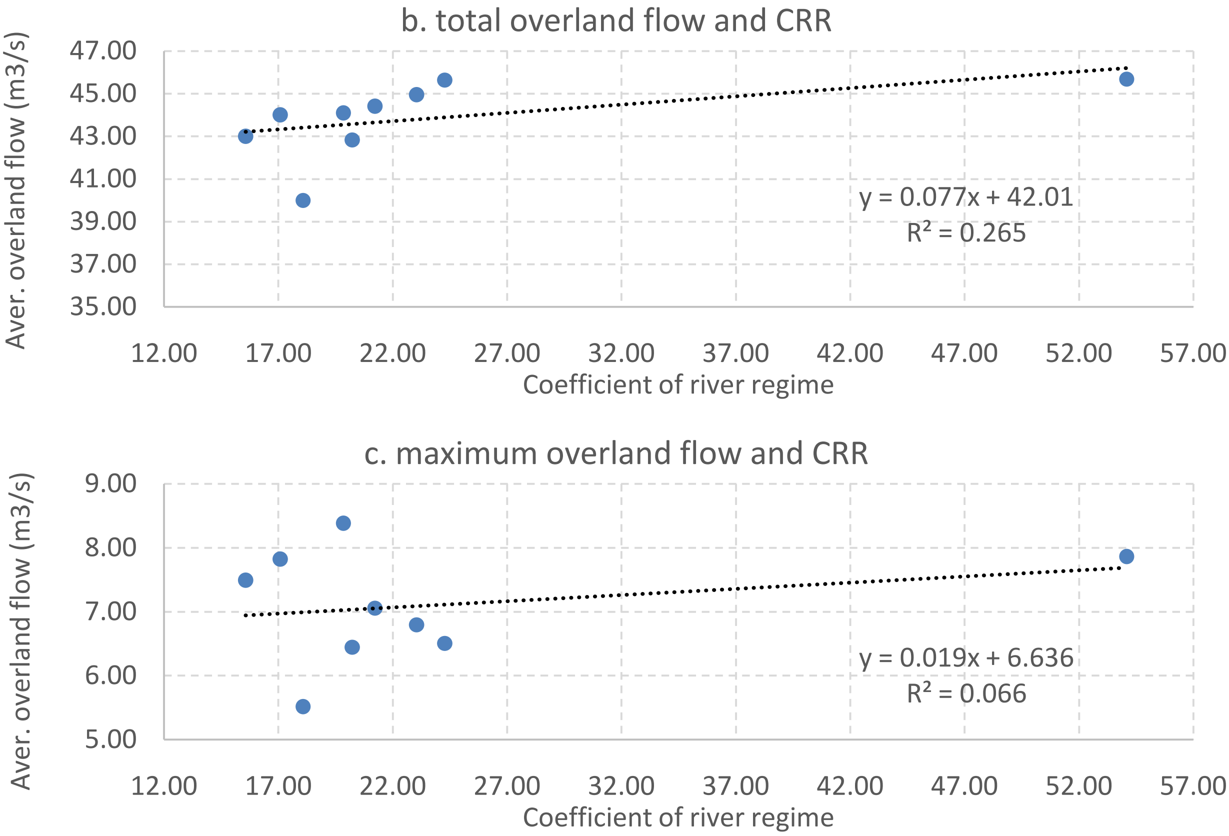


Figure 5: Correlation of CRR-average (a), total (b) and maximum (c) overland flow

Figure 5 shows coefficient correlation (R) of the CRR-annual average overland flow, total overland flow and maximum overland flow was 0.74, 0.51 and 0.24 respectively for the period of 2008-2016. CRR in the study site has a high correlation with the average of overland flow. Meanwhile, total overland flow events and maximum overland flow have respectively moderate and very low correlation with CRR. The value of overland flow regimes in each year (average, total and maximum) is obtained from overland flow events during one year. Figure 6 shows the average half monthly overland flows in the study site for nine last years. From this figure, it can be recognized that overland flows are zero for some period (half monthly) during the dry season. Hence, the average overland flows used for correlation analysis in this study are mostly occurred during the wet season.

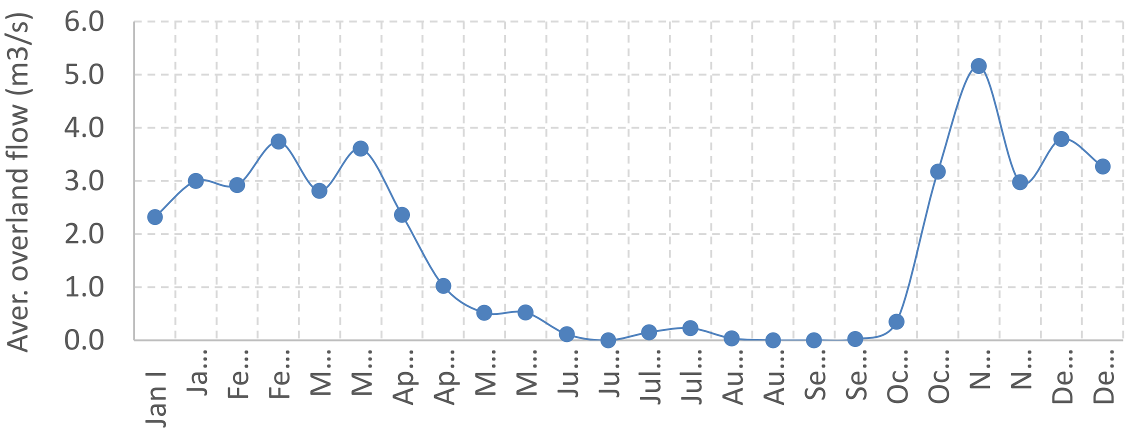


Figure 6: Average overland flow in the study site

The highest and lowest value of CRR was found in 2012 (54.08) and 2014 (15.57) respectively. Generally, maximum river discharges were found in November (wet season), while, the minimum river discharges were found in September (the end of dry season). Average overland flows increase with the increasing of CRR especially during the wet season. Jin et al. in 2015 [3], noted that infiltration is significantly decreasing when the overland flow is increasing. Increasing conservation practices to increase infiltration during the wet season must be considered to achieve a stability of water balance along of the seasons. Hence, flood and drought event could be significantly controlled.

Conclusion

The ratio of maximum and minimum river discharge (CRR) in a year can be used to estimate average overland flow for the same period due to two these parameters has a high correlation. The maximum river discharges are found when the rainfall is high, while, the minimum river discharges are found in the peak (end) of the dry season. The study reveals overland flow tends to high, whereas infiltration is low during the wet season. Hence, ground water storage and base flow is low during the dry season, indicated from the value of river discharges. Good conservation practices are required to optimizing groundwater recharge during the wet season.

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