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Hydrologic Modeling for Tropical Watershed Monitoring and Evaluation

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ABSTRACT: *Excessive farming without good conservation practices is causing watersheds degradation in Indonesia. Watershed assessment and control are needed to prevent more degradation. This study aims to evaluate performance of hydrologic model for watershed monitoring and evaluation. A rainfall-runoff hydrologic model of Mock was used as main tool for modeling and applied in the tropical watershed of Wadaslintang, Indonesia. The model consists of three tanks representing hydrologic cycle processes in the atmosphere, soil and ground water system. Some hydrological parameters such us specific maximum discharge, specific minimum discharge, river regime coefficient and runoff coefficient were used for watershed evaluation and analyzed using the model from 2002-2015. Model calibration and verification were performed by using one year water discharge data 1999/2000 and 2000/2001, respectively. The result showed that the model had a good accuracy for discharge measurement where the coefficient correlation (R) value of calibration and verification was more than 0.75, volume error (VE) was less than 0.05 and efficiency coefficient (E) was more than 0.80, means that there were strong relations between observed and calculated data. Hydrologic model of Mock provides a good alternative tool for rapid watershed assessment using hydrological parameters as part of monitoring and evaluation particularly in the regions with limited hydrological data.*
Keywords: *Tank model, rainfall-runoff, model calibration and verification, hydrological parameters, hydrology cycle*

I. INTRODUCTION

Floods during wet season are occurred in some area of Indonesia in consequence of watershed degradation as reported by Sumaryono et al. [1]; Sari and Susilo[2]; Fulazzaky[3]; Iskandar and Sugandi[4]; Hapsari and Zenurianto[5]. Land use changing due to uncontrolled farming was decreasing watershed function as a rainwater harvesting area. One of the watersheds with excessive farming activities in the upstream is Wadaslintang (192.53 km^2), located in Central Java province Indonesia (**Figure 1**).

Climatically, Wadaslintang watershed is located in the tropical region where there are two season in one year, wet season from October to March and dry season from April to September and the annual rainfall was more than 3000 mm. Wadaslintang watershed has an important role as catchment area of a reservoir in the downstream which is providing water for many uses such as fishery, water consumption, power plant, and irrigation. As one of water conservation facilities in central java with a capacity 443 million m^3, the reservoir also has a function for flood controlling.

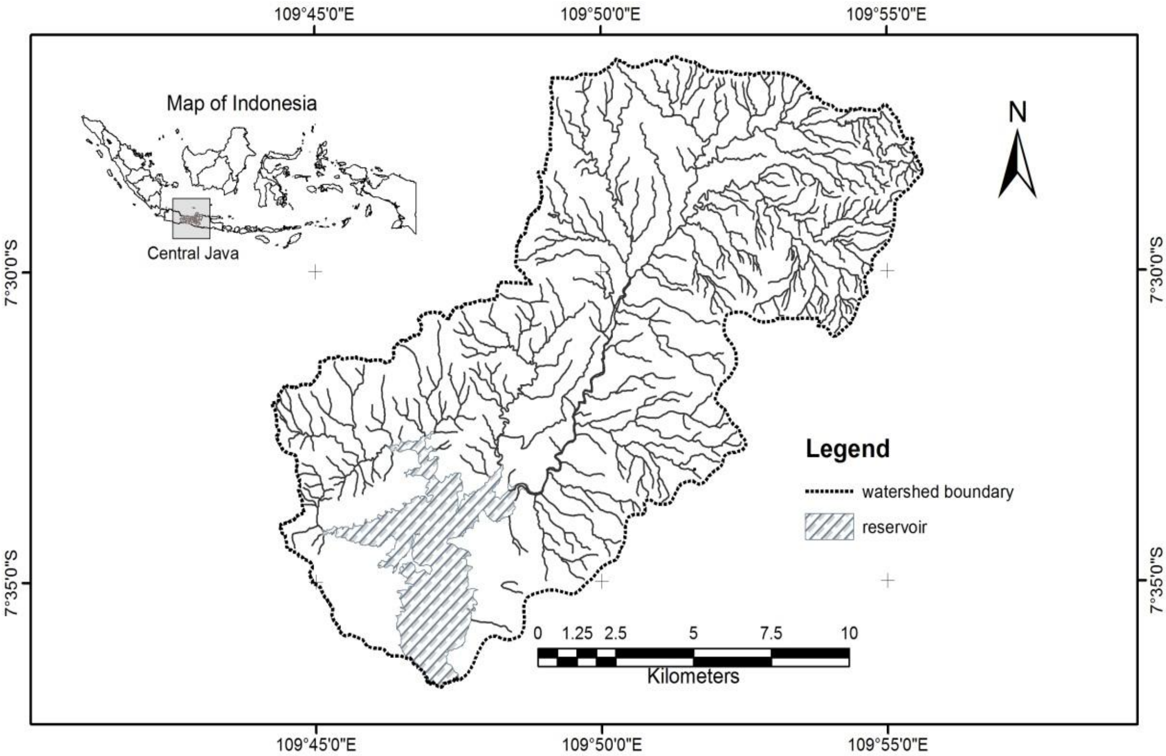


Figure 1. Map of Wadaslintang watershed

In 2010, Susanto et.al [6] reported a heavy class erosion and sedimentation occurred in Wadaslintang watershed where more than 70% areas are used for farming. Moreover, Allo[7] reported increasing of disaster event in form of land slide due to deforestation in unstable area of the watershed. Study by Marhendi[8] and Prawitasari[9] indicated a heavy level of sedimentation, erosion and maximum discharge occurred in the Wadaslintang watershed. Monitoring and evaluation of watershed is needed to prevent more environmental degradation and also to find the problems and solutions. Monitoring and evaluation are two of important things in the project planning and management. In the watershed management, monitoring is defined as the continuous process of information or data collection with certain intervals such as monthly, quarterly or annually. Evaluation is the process to analyze and interpret compiled data through monitoring [10]. Monitoring and evaluation has important function to assess and control watershed health and also to evaluate the effect of management activities in the watershed scale [11].

In the water resources planning, watershed evaluation was a basic requirement for watershed conservation [12]. Watershed evaluation involved assessments of the specific processes, influence and problems to develop a plan of action for watershed preservation [13]. The framework of watershed assessment is fixed but the structure in each component must be flexible and updated periodically. Concept of watershed assessment must be developed based on local issues [14]. The concepts of watershed monitoring and evaluation have been introduced mostly for a purpose by using a specific parameter (e.g. Zanbergen [15]; Bhuyan et al. [16]; Dai et al. [17]; Gutierrez et al. [18]; Ioja et al. [19]; Golden et al. [20]; Agostinho et al. [21]; Al-Faraj and Al-Dabbagh [22]; Abramic et al. [23]; Merkuryeva et al. [24]; Chapman et al. [25]; Getahun and Keefer [26]). For a rapid evaluation or areas with limited data, some simple parameters can be used, for example hydrological parameters where hydrologic modeling may be applied for the assessment as introduced by He et al. [27], Carluera and Marsily[28], Carleton et al. [29] and Wang et al. [30].

As a continuous process, monitoring and evaluation is very important especially for tropical countries which are having high annual rainfall. Lacking in the implementation of monitoring and evaluation is causing watershed degradation due to no a good control system as happened in most of developing countries such Indonesia. A good and modern monitoring system is costly and need to be supported by expert human resources. For a good practice in monitoring and evaluation, a good tool needs to be arranged by considering local circumstances. In this study, the hydrologic model will be evaluated for predicting the value of hydrologic parameters for watershed monitoring and evaluation purpose. Hydrologic modeling provides an alternative tool for watershed monitoring and evaluation particularly in the regions with limited hydrological data.

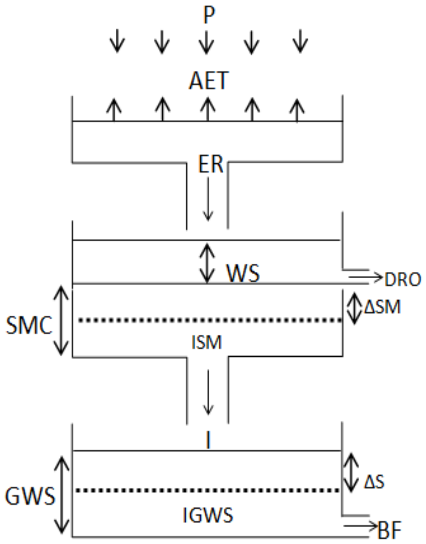
II. MATERIALS AND METHODS

Hydrologic modeling was conducted by using hydrologic model of Mock to calculate the value of four hydrologic parameters those were specific maximum discharge, specific minimum discharge (ratio of maximum and minimum water discharge toward total are of watershed), river regime coefficient (ratio of maximum and minimum water discharge in the watershed) and surface runoff coefficient.

Hydrologic model of Mock

Hydrologic model of Mock is a rainfall-runoff model which is containing three artificial tanks representing rainwater transformation processes in the atmosphere, soil and ground water system (**Figure 2**). This model was selected to calculate the value of hydrologic parameter for watershed monitoring and evaluation because the model is the most advanced model which is developed in the tropical region of Java Island Indonesia by Mock [31] as reported by Nurrochmad[32], Limantara[33], Setyawan et al. [34], Mulya et al. [35] and Sukirno and Susanto[36]. Basically the model is adopting the principle of water balance.

First tank describes excess rainfall calculation where precipitation data as input of the model and the value of actual evapotranspiration are needed. The second tank describes direct runoff and infiltration process in the soil surface and soil layer by considering soil moisture value. The last tank is describing the water flow in the ground water system and is used to measure base flow. Total water discharge (runoff) is obtained from the total value of direct runoff and base flow.



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 coeficient
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. Hydrologic tank model of Mock

Parameters of model

The model is consisted of thirteen main parameters such as precipitation (P), actual evapotranspiration (AET), excess rainfall (ER), water surplus (WS), initial soil moisture (ISM), soil moisture capacity (SMC), change of soil moisture (ΔSM), direct runoff (DRO), infiltration (I), initial ground water storage (IGWS), ground water storage (GWS), change of ground water volume (ΔS), and base flow (BF) and two additional parameter for calculating the value of main parameters those were infiltration coefficient (Ci) and recession constant (K). The values of four parameters (ISM, SMC, IGWS, Ci and K) were obtained during calibration process using Excel Solver.

Model validation

Validation was performed through model calibration and verification. Two years observed water discharge data were required for calibration and verification. Calibration was conducted by determining the value of four parameters those were initial soil moisture (ISM), soil moisture capacity (SMC), infiltration coefficient (Ci) and recession constant (K). Three statistical parameters namely correlation coefficient (R), volume error (VE) and efficiency coefficient (E) were applied to achieve the best accuracy of the model.

By using optimization function of Excel Solver, the statistical parameters were determined should be more than 0.70 for R, less than 0.05 for VE and should more than 0.5 for E to ensure the model is acceptable as described by Moriasi et al. [37] and Alvarenga et al. [38]. Infiltration coefficient (Ci) value was classified into two types, dry infiltration coefficient (Ci_d) for simulation during dry season and wet infiltration coefficient (Ci_w) for simulation during wet season. Meanwhile, the value of four parameter were assigned based on range value for Indonesia region, where the value of ISM was between 10 and 100, SMC was between 300 and 500, IGWS was between 1000 and 3000, Ci_w and Ci_d were between 0.5 and 1, Ci_d should bigger than Ci_w, and K was between 0.50 and 0.99 refer to Nurrochmad[32], Julia [39] and Sukirno and Susanto[36]. The values of those parameters were different for each watershed affected by physical condition of watershed.

III. RESULTS AND DISCUSSION

Model calibration and verification

Model validation through calibration and verification were conducted using semimonthly observed water discharge data 1999/2000 and 2000/2001. The validation and simulation were started from the beginning of rainy season (October) in each year, for example the calibration was conducted using data from October 1999 to March 2000. That procedure was selected to minimize error due to impreciseness of parameter value determination such as initial soil moisture (ISM) and initial ground water storage (IGWS) in the model calibration. The optimization values of some parameters were obtained during calibration process using Solver as shown in the **Table 1**.

Table 1. Optimization result of model calibration

Parameter	Symbol	Unit	Value
1. Area of watershed	A	km^2	192.53
2. Infiltration coefficient in rainy season	Ci_w	-	0.50
3. Infiltration coefficient in dry season	Ci_d	-	0.65
4. Initial soil moisture	ISM	mm	100
5. Soil moisture capacity	SMC	mm	386
6. Initial ground water storage	IGWS	mm	1053
7. Groundwater recession constant	K	-	0.85

Statistically, the model proves a good accuracy where the values of correlation coefficient (R) were 0.91 and 0.78, volume errors (VE) were 0.04 and 0.01 and efficiency coefficient (E) were 0.93 and 0.83 in the calibration and verification process. Those values prove that there were strong correlation between observed data and calculated data which were calculated using hydrology model of Mock (**Figure 3**).

Hydrologic modeling

The modeling was aim to achieve the value of hydrology parameters which were used for watershed evaluation. By using precipitation and climate data of the watershed, the modeling was running from 2000 to 2015. The result of annual water yield is given in the **Figure 4**.

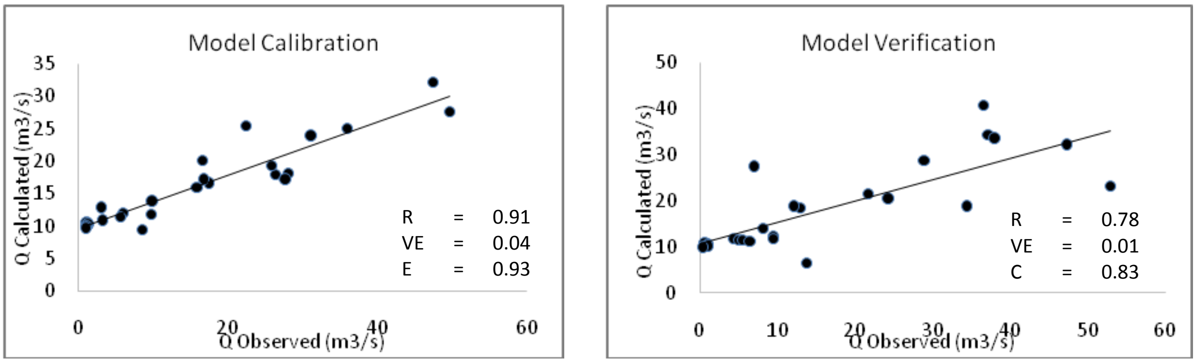


Figure 3. Data result of model calibration and verification

Generally, the annual water yield value is linearly with the value annual rainfall where the highest value of the water yield is during period October 2010 to March 2011 (696 million m^3) and the lowest is in the period of October 2007 to March 2008 (417 million m^3).

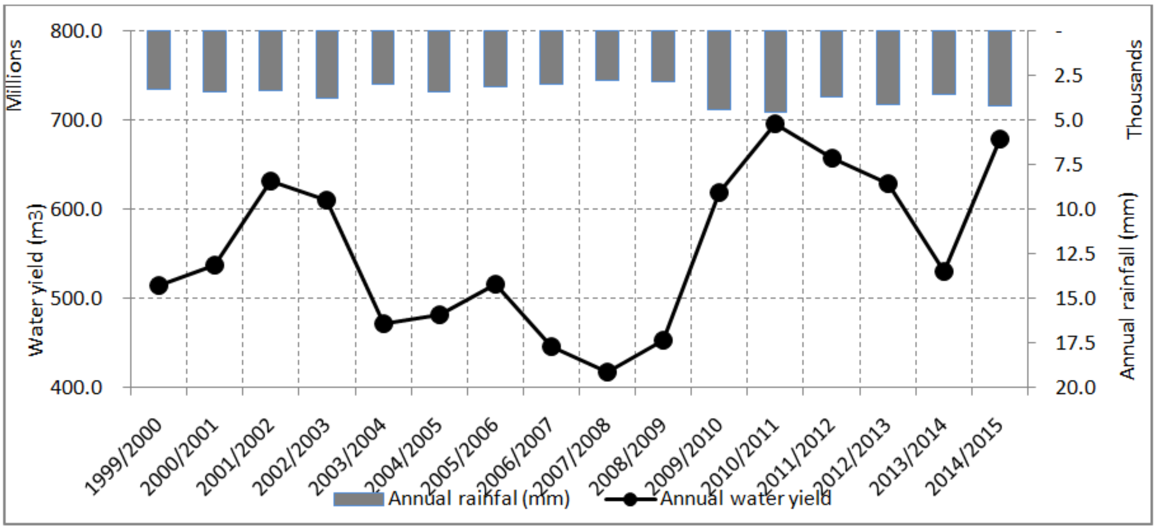


Figure 4. Annual water yield of Wadaslintang watershed

Watershed Evaluation

The evaluation was determined based on the value of four hydrological indicators. For watershed evaluation purpose, the values of those parameters were classified into three categories: good, moderate and bad. Average semimonthly runoff components during 2000-2015 are shown in the **Figure 5**. Specific maximum and minimum discharge are reflecting vulnerability to flooding and drought as reported by Paimin et al. [40]. For specific maximum discharge, the category was good for value < 0.58, moderate for 0.58-1.5 and bad for >1.5. The value less than 0.58 cms/km^2 had a low potency to cause flood and high potency for value more than 1.5. Category of minimum discharge was good for value >0.03, moderate for 0.01- 0.03 and bad for <0.01 of the discharge [40], [41].

For river regime coefficient the category was good for value <50, moderate for 50-120 and bad for >120. Those value was determined refer to Paimin et al. [40] where the value was determined for tropical region of Indonesia. River regime coefficient value is affected by climate and morphology condition of watershed. Wohl[42] reported the value of regime coefficient values in the rivers such as the Thames or the Rhine has coefficients less than100, meanwhile the coefficient for the Tone River of Japan exceeds 900.

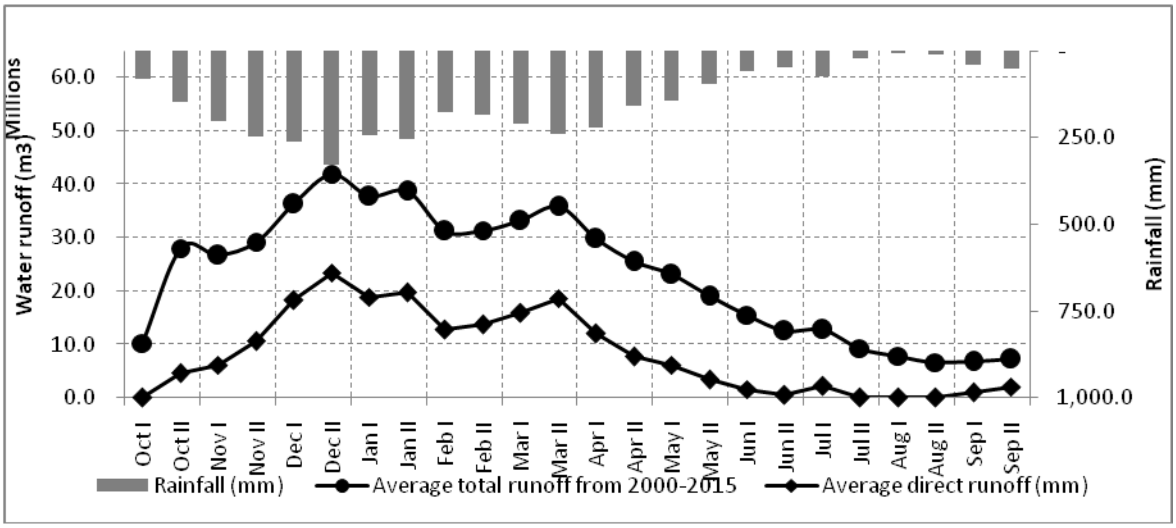


Figure 5. Average semimonthly runoff of Wadaslintang watershed from 2000-2015

For coefficient of surface runoff (C), the category was good for value < 0.1, moderate for between 0.1-0.3 and poor for >0.3 of C. The classification of C value refer to rational formula concept [43], reference C value by Natural Resources Conservation Service [44] and correlation of C with land covering [45], [46] where the value 0.1 of C was mostly used for area with low probability of surface runoff event (example: flat area with good permeability and permanent vegetation covering) and contrary to the value 0.3 of C. The result shows that the values of specific maximum discharge and specific minimum discharge were 0.28 (good category) and 0.01

(moderate category), respectively. Meanwhile, the values of river regime coefficient and runoff coefficient (average in wet season) were 25.83 (good category) and 0.28 (moderate category), respectively.

IV. CONCLUSION

The hydrologic tank model of Mock shows a good accuracy result for rainfall-runoff modeling in tropical the region where the values of correlation coefficient (R) were > 0.75 (0.91 and 0.78), volume errors (VE) were <0.05 (0.04 and 0.01) and efficiency coefficient (E) were >0.80 (0.93 and 0.83) in the validation model. Based on hydrologic parameters assessment the condition of watershed can be concluded in good condition. An advanced evaluation method needs to be applied by applying more parameters to achieve a better result of watershed evaluation especially for monitoring and evaluation purpose.

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