

PAPER • OPEN ACCESS

Application of elementary hydrology model for the assesment of watershed health at Progo Hulu watershed

To cite this article: D L S Nasution *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **260** 012035

View the [article online](#) for updates and enhancements.

Application of elementary hydrology model for the assesment of watershed health at Progo Hulu watershed

D L S Nasution¹, S Susanto² and A Sadeli³

¹Department of Agricultural Engineering, Universitas Sumatera Utara, Indonesia

²Department of Agricultural Engineering, Universitas Gadjah Mada, Daerah Istimewa Yogyakarta, Indonesia

³Department of Animal Science, Universitas Sumatera Utara, Indonesia

E-mail : nasutiondelima@gmail.com

Abstract. This study aimed to test the reliability of hidrology Model with MUSLE Method in predicting the hydrology indicators in assesment of watershed condition. The indicators were maximum discharge, minimum discharege, river regime coefficient, runoff coefficient, erosion and sedimentation. NRECA Hydrology Model compared to Mock Model to get a better Hydrology Model to apply in this area. The result showed that NRECA Model was better than Mock Model in predicting some hydrologic indicators and MUSLE Model was sensitive enough in predicting the other indicators which was shown by the result of good accuracy test. In this study, NRECA Model and MUSLE model performs well in predicting the hydrologic indicators in assessing Progo Hulu watershed condition.

1. Introduction

Progo Hulu watershed is a moonson tropic area with high rainfall and dramatically changing weather which in this condition erosion and landslide disasters were easily happened. The high rate of land erosion will cause high sediment in the river so that conservation of Progo Hulu watershed must be considered. In watershed management, there are three main aspects that are always concerned such as erosion, sedimentation, and hydrological indicators. In the water resources planning, watershed evaluation was a basic requirement for watershed conservation [1]. Watershed evaluation involved assessments of the specific processes, influence and problems to develop a plan of action for watershed preservation [2]. As a continuous process, 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 absence of a good control system as happened in most of developing countries such Indonesia. For a good practice in watershed evaluation, a good tool needs to be arranged by considering local circumstances [3].

The complexity of the watershed area still requires an hydrological approach to improve the situation, especially to conserve water resources [4]. In estimating and assessing the health of watershed an instrumentation is needed to determine the amount of water, water regime, and sedimentation that occurs in watershed that often known as hydrological model.

Both NRECA Hydrology Model and Mock Hydrology Model are blackbox elementary Model that have been commonly used in moonson tropic area. From several uses in other area, both models perform good accuracy. The testing experiment of both model was to choose the better model which



sensitive enough to dramatic changed of rainfall. The main objective of this research was to test the feasibility of the application of NRECA Hydrology Model and Mock Hydrology Model together with MUSLE Method in evaluating the health indicators of Progo Hulu Watershed.

2. Materials and Methods

In this research, NRECA Hydrology Model was compared to Mock Model. The most sensitive model will be applied to simulate the amount of maximum discharge, minimum discharge, river regime coefficient, water yield, and sedimentation while MUSLE Method was applied to calculate the amount of erosion. Reliability test of NRECA hidrology model and Mock Hydrology Model done by testing the calibration and validation of each model. The calibration process was done by trial and error to get the optimal parameters. There were 5 parametes calibrated for NRECA Hydrology Model and 6 parameters for Mock Model. After the optimal parameter was obtained in the calibration process, then the validation process will be done. Statistical test and graphical tests were carried out as references for the accuracy of model performance both in the calibration and validation processes to evaluate and choose the selected model that will be use to simulate the discharge value.

Statistical test was done by comparing model output with actual condition. As for the statistical parameters of the model reliability test were correlation coefficient (R) and error value (EV). The correlation coefficient (R) was the value that show the relationship between the output of the model and actual condition (observation data) where the error value showed the differences in the volume of output and observation result. The application results of the MUSLE Method in calculating erosion then compared to the actual erosion by performing statistical tests and graphical tests to determine the accuracy of the MUSLE Method application in calculating erosion in the Progo Hulu Watershed Area.

2.1. Analysis of Hydrological Indicators

After discharge value was obtained from simulation result of hydrological model application, then the value of hydrology indicators of watershed health will be calculated.

- Specific maximum discharge was peak of discharge that occurs in a year (m^3/s)
- Specific minimum discharge was the lowest discharge value in a year (m^3/s)
- River regime coefficient was the ratio of maximum and minimum water discharge in watershed
- Water yield was total of water discharge flowing at the outlet point of watershed in certain period.

$$\text{Water yield} = \sum_{n=1}^{12} dn \times 86400 \times Q \text{ sim} \quad (1)$$

Where dn = total of days in a year and Q sim = discharge result of model simulation

- Sedimentation

The amount of sediment total deposited in the stream was amount of suspended load and bed load. Suspended load was calculated by regression equation and correlation between discharge and sediment. Amount of suspended load transport which streams to Progo River calculated by regresion equation from CV Geodeco research. The equation was:

$$Q_s = 0.711 (Q_w^{1.077}) \quad (2)$$

Where Q_s = sediment delivery (kg/s) and Q_w = discharge (m^3/s)

Bed load was calculated by Meyer Peter and Mullers Methods (1948) [5].

The equation was

$$\gamma_w \left(\frac{K_s}{K_r} \right)^{1.5} H.S = 0.047 (\gamma_s - \gamma_w) d + 0.25 \left(\frac{\gamma_w}{g} \right)^{1/3} q_b^{2/3} \quad (3)$$

γ_w	= water density (t/m ³)	g	= gravity (m/s ²)
γ_s	= sediment density (t/m ³)	$\left(\frac{K_s}{K_r}\right)$	= ripple factor = $\mu = 1$
H	= Deep of river (m)	d	= median diameter $\approx d_{50}$ - d_{60} (m)
q_b	= sediment weight on water (t/m)/s		
S	= slope of the river bed		

f. Erosion. The calculation of erosion was using MUSLE Method equation:

$$A = a (Q \times Q_p)^b \times K \times LS \times CP \quad (4)$$

A = erosion value	$a = 11.6$ and $b = 0.56$ (constant)
Q = runoff volume	K = erodibility factor
Q_p = peak discharge	CP = landuse factor

3. Results and Discussion

3.1. Application of NRECA Hydrology Model at Progo Hulu Watershed

3.1.1. Calibration Process

Calibration stage was carried out to adjust the model parameter value in order to represent the actual watershed condition so that the discharge simulation value can nearly similar to observation discharge. Calibration process both in NRECA Hydrology Model and Mock Model was done by trial and error to get optimal parameter values in each model by comparing observation discharge (Q observation) and calculated discharge (Q calculated) at certain time (year 2007-2008). The optimal parameter values of NRECA Model is presented in the Table 1. Similarity, evaluation of calculated discharge by NRECA model with observation discharge in calibration process done by statistical test and graphical test. Statistical test result showed that value of correlation coefficient (R) was 0.923 and Error value was 0.0094. Graphical test result (R^2) was 0.859.

Table 1. Optimum parameters of NRECA Model

Watershed parameters	Unit	Symbol	Optimum value
Watershed Area	Ha	A	41.768
Initial ground moisture	mm	IGWS	600
Initial groundwater reservoir	mm	IMS	2
Characteristic of surface soil	-	PSUB	0.8
Characteristic of deep soil	-	GWF	0.2
Crop coefficient			0.2

Table 2. Optimum parameters of Mock Model

Watershed parameters	Unit	Symbol	Optimum value
Watershed Area	Km ²	A	417.68
Infiltration coefficient for wet season	-	WIC	0.5
Infiltration coefficient for dry season	-	DIC	0.4
Initial Soil Moisture	(mm)	ISM	100
Soil Moisture Capacity	(mm)	SMC	300
Initial Groundwater Storage	(mm)	IGWS	1200

The obtained optimum parameters of Mock Model can be seen in Tabel 2 Whereas the results of statistical test and graphical tests of the Mock Model on the calibration stage showed the value of correlation coefficient was 0.916 and error value 0.009, while the graphical test result (R^2) was 0.74 which could be seen in Figure 1 where the observed discharge (Q observation) was the measurement of discharge directly in the river while the calculated discharge (Q calculated) was the estimation value that obtained by using hydrologic model. In calibration process, the performance of NRECA hydrology model was better than the Mock Model.

Graphical test that compare calculated discharge and actual discharge for both the NRECA Model and Mock Model in calibration stage are shown in the Figure 1

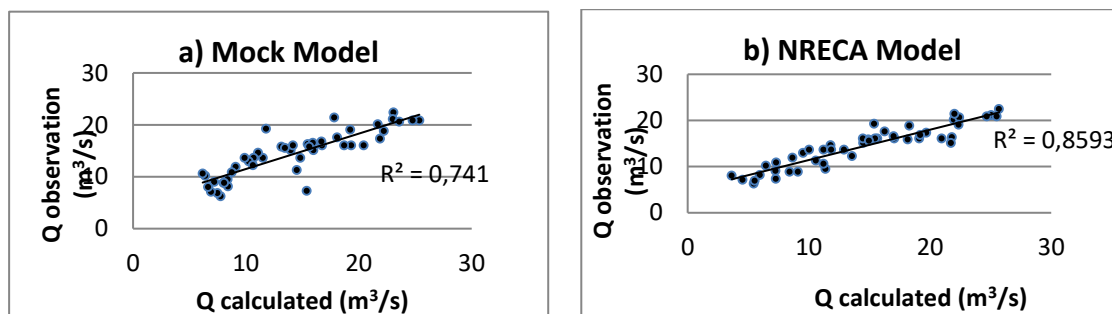


Figure 1. Scatter diagram (a) Mock Model (b) NRECA Model in Calibration process

3.1.2. Verification stage of NRECA Model and Mock Model

Optimum parameter value on calibration stage was obtained by statistical test which performing good value, then the next stage to verify the model performance by doing verification test. Verification test is similarity evaluation of calculated discharge (Q calculated) and observation discharge (Q observation) at a certain time (year 2009-2010) of NRECA Model and Mock Model. Statistical test of NRECA Model in verification stage showed correlation coefficient (R) value was 0.889 and error volume was 0.0172 where graphical test (R^2) was 0.808. The similarity of calculated discharge and observation discharge of Mock Model was noted by statistical test in verification stage shown coefficient correlation value (R) 0.909 and error volume was 0.108 when graphical test (R^2) was 0.826. Figure below is graphical test of comparison between the observation discharge and model simulation discharge (calculated discharge). Observation discharge is the observed actual discharge directly at river, where the calculated discharge is discharge value obtained by model simulation.

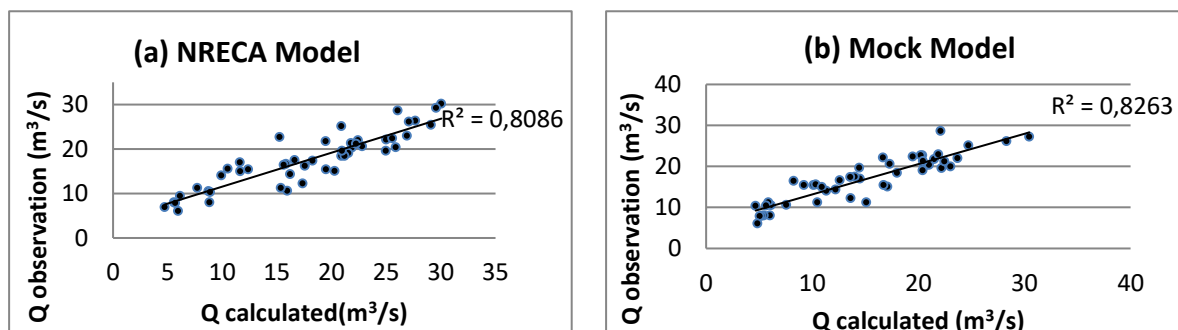


Figure 2. Scatter diagram (a) NRECA Model (b) Mock Model in Validation process

The performance of these two models were quite well applied in the Progo Hulu region which has a tropical monsoon climate where both models can respond well to very high rainfall at certain times which is then accompanied by dramatic changes to dry season at other times. Although there were still

irregularities, due to several hydrological model inability to imitate the actual hydrology behavior without deviation. This was caused by presuppositions, assumptions, and simplifications in modelling. The assumption that rain was evenly distributed within the radius of the influence of rain stations inside the watershed actually considerable potential error.

3.2. Maximum Discharge, Minimum Discharge, River Regime Coefficient and Water Yield

Statistical test showed that NRECA Model performance better than Mock Model which was more commonly used in the tropical monsoon region. In this research, NRECA hydrology model applied to calculate the discharge value in Progo Hulu outlet and another watershed health indicators. Based on NRECA Model discharge simulation results which can be seen in the Figure 3, the specific maximum discharge value was $23.85 \text{ m}^3/\text{s}$ when compared to watershed area, which has value of $0.056 \text{ m}^3/\text{s}/\text{km}^2$. Meanwhile specific minimum discharge was $5.24 \text{ m}^3/\text{s}$ when compared to watershed area which has value of $0.125 \text{ m}^3/\text{s}/\text{km}^2$. River regime coefficient calculated by comparison of specific maximum discharge and specific minimum discharge, the value was 4.55. The value of specific maximum discharge, specific minimum discharge, and river regime coefficient showed that watershed in good condition. The other hidrology basic indicator was the runoff coefficient. Runoff coefficient is ratio of peak flow to rainfall intensity. Runoff coefficient value was 0.62 which means that there is, as much as 62% of rain falls into streams.

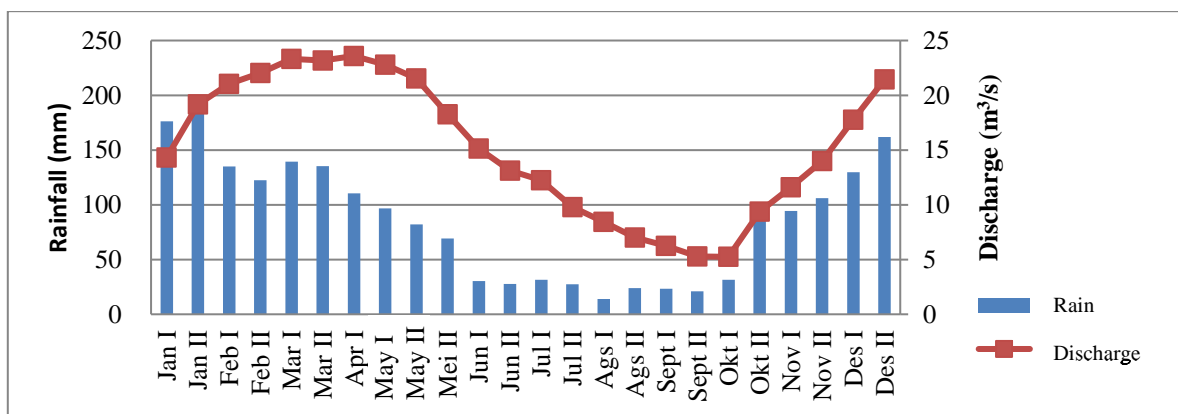


Figure 3. Discharge Simulation of NRECA Model

3.3. Water Yield

Based on NRECA hydrology simulation, water yield or the amount of water volume flowing in the Progo Hulu watershed area can be calculated as seen in Figure 4. From that figure, the condition of water availability in the Progo Hulu watershed in a balanced condition. This can be seen in dry months, there is still quite high rainfall (above 50 mm)

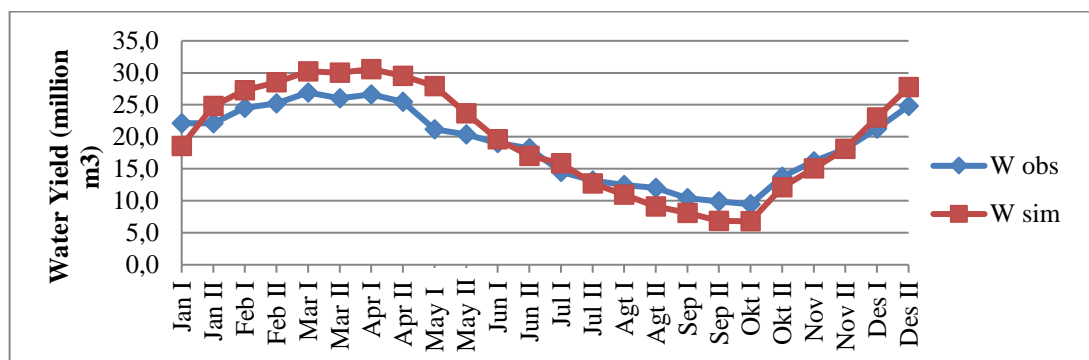


Figure 4. Monthly Water Yield of Progo Hulu Watershed

3.4. Erosion analysis

Actual erosion calculation based on SDR (sediment delivery ratio). It was calculated by deviding the observation sediment yield (S_y) and the SDR (sediment delivery ratio). Observation sediment value obtained from correlation of sediment discharge and stream discharge equation, while the SDR value was obtained based on the table of correlation watershed area and sediment delivery ratio.

The result of statistic and graphic test, the similarity of actual erosion and calculated erosion showed that the correlation coefficient (R) = 0.829, the error value (VE) = 0.106 and the graphical test R^2 = 0.859. Figure 5 showed the comparison of the erosion calculation result using MUSLE Method with the actual erosion, where the amount of soil eroded for a year using MUSLE erosion calculation was 12.53mm/year.

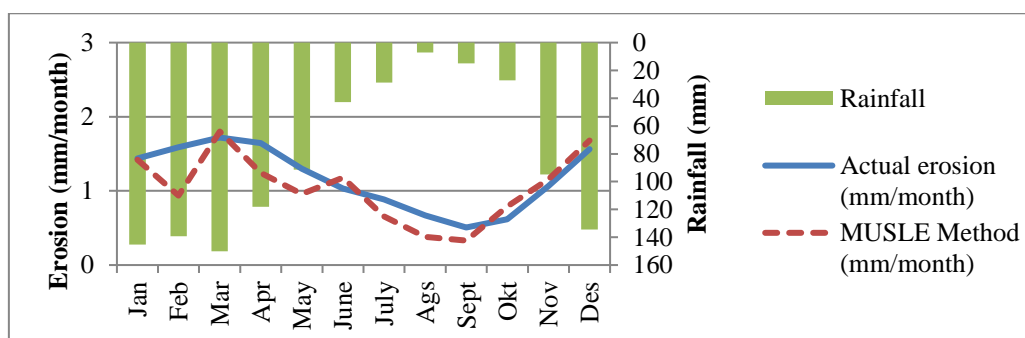


Figure 5. Comparison of actual erosion and erosion calculated by MUSLE Method

3.5. Sediment analysis

The average of total sediment in a year was 1,919,442.025 m³/year or was about 4,595.485 m³/year/km² or 4.60 mm/year. It means in a year, sedimentation in Progo Hulu watershed was quite high, which was in a bad category. Generally, the health condition of Progo Hulu watershed can be seen from the conditions of erosion and sedimentation, including in degraded conditions which were marked by the amount of erosion and sedimentation, both of which were above the permissible threshold.

4. Conclusions

NRECA hydrology model Mock Model were considered quite feasible to be applied in the tropical watershed area and large coverage area. Likewise, the MUSLE erosion model was considered quite feasible and could be applied to the study area. The application of NRECA water availability Model and MUSLE erosion prediction model in the Progo Hulu watershed area in this study indicated that this watershed was in a quite bad condition, so that erosion and sediment control simulation applications based on vegetation manipulation are needed to apply in this area.

References

- [1] Sterling S M, Garroway K, Guan Y, Ambrose S M, Horne P, and Kennedy G W 2014 A New Watershed Assessment Framework for Nova Scotia: A high-level, Integrated Approach for Regions Without a Dense Network of Monitoring Stations *Journal of Hydrology* **519** p 2596–612
- [2] Debarry P A 2004 *Watershed Processes, Assessment and Management* (New Jersey: John Wiley and Sons)
- [3] Chandra S, Chen Y L, Miky P 2016 Hydrologic Modeling for Tropical Watershed Monitoring and Evaluation *American Journal of Engineering Research (AJER)* **5** 11 p 36-42
- [4] Susanto S and Kaida 1991 Tropical Hydrology simulation Model 1-1 For Watershed Management. Using Trophysim 1 for Watershed Management Model Building *J. Japan Soc. Hydrol. & Water Resourch*
- [5] Murtiono U H 2008 Model Estimasi Volume Limpasan Permukaan, Debit Puncak Aliran, dan Erosi Tanah dengan Model Soil Conservation Service (SCS) Rasional dan Modified Universal Soil Loss Equation (MUSLE) Studi Kasus di DAS Keduang, Wonogiri [Estimation Model of Surface Runoff Volume, Peak Flow and Soil Erosion with Rational Conservation Service (SCS) and Modified Universal Soil Loss Equation (MUSLE) Models, Case Study in Keduang Watershed, Wonogiri] *Scientific Journal Geography Forum* **22** 2

Acknowledgement

This research was conducted by funding support from Ministry of Pekerjaan Umum Directorate General of Water Resources, work unit of The Serayu River Basin and the Opaq self management cooperation with Agricultural Engineering, Agricultural Technology Faculty Universitas Gadjah Mada.