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Rainfall-Runoff Transformation Analysis Using The HBV-96 Model in The Cidanau Watershed, Banten

Analisis Transformasi Hujan-Limpasan Menggunakan Model Hbv-96 pada DAS Cidanau, Banten

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ABSTRAK

Transformasi hujan-limpasan telah dilakukan pada DAS Cidanau, Benten menggunakan Model Hidrologi HBV-96 pada periode 2010-2011 sebagai periode kalibrasi dan 2012 sebagai periode validasi. Tujuan dari penelitian ini adalah untuk menganalisis kinerja model subtropis HBV-96 ke daerah tropis DAS Cidanau, Banten. Model HBV-96 dikalibrasi secara manual melalui uji coba penyesuaian parameter untuk mendapatkan kondisi fisik yang sesuai dengan DAS Cidanau. Hasil penelitian menunjukkan bahwa model dapat mentransformasi hujan menjadi debit limpasan dengan cukup baik dengan nilai korelasi (r) dan NSE pada kalibrasi sebesar 0,829 dan 0,672. Hasil perhitungan neraca air menunjukkan perbedaan total debit observasi dan total debit simulasi tidak terlalu jauh berbeda, yaitu sebesar 2253 mm dan 2139 mm. Hal ini menunjukkan model HBV-96 yang diaplikasikan di DAS Cidanau cukup baik dalam mentranformasikan data hujan menjadi limpasan dan perhitungan neraca air, walaupun belum baik dalam menggambarkan debit puncak.

Kata kunci: DAS Cidanau, HBV-96, Model Hidrologi, Rainfall-Runoff.

ABSTRACT

Rainfall-Runoff transformation has been carried out at Cidanau watersheed, Benten using the Hydrology Model named HBV-96 in the period 2010-20011 as calibration and 2012 as validation. The purpose of this study is to analyze the performance of the HBV-96 as a subtropical model to the tropical area of the Cidanau watershed, Banten. The HBV-96 model is calibrated manually through a parameter adjustment test to obtain physical conditions that are in accordance with the Cidanau watershed. The results show that the model can transform rain into runoff discharge quite well with correlation values (r) and NSE of 0.829 and 0.672. The results of the water balance calculation show that the difference between the total observation discharge and the total simulated discharge is not too different, which is 2253 mm and 2139 mm. This shows that the HBV-96 model applied in the Cidanau watershed is quite good in transforming rainfall data into runoff and water balance calculations, although it is not good in describing peak discharge.

Keywords: *Cidanau Watershed, HBV-96, Hydrology Model, Rainfall-Runoff.*

INTRODUCTION

The Cidanau watershed is part of the Cidanau River Area, Ciujung, Cidurian (WS C3) which is still vulnerable to flooding. Based on the results of the analysis of indications of temperature changes and rainfall with a length of 40 years of climate data (1981 – 2021) using RClimDex software in the WS C3 regional area, extreme rainfall changes with a slope of 0.835 mm/hr/year (RX1DAY) are indicated. This will have an impact on increasing the frequency of flood events (Balai Besar Wilayah Sungai Cidanau Ciujung Cidurian, 2023). Therefore, the estimated amount of discharge in response to rainfall in the watershed must be considered in the management of the Cidanau watershed. Data limitations have prompted the application of various hydrological models to estimate flow discharge in watersheds. Various hydrological models with various advantages have been implemented to overcome this problem.

To explain the process of changing rainfall input into output in the form of river discharge by considering the physical characteristics of the watershed, various hydrological models continue to be developed and adapted to the location of use. Hydrological simulation models are basically created to simplify the hydrological system, so that the behavior of some components in the system can be known. The parameters required as input data are also simpler, easy to measure and quick to obtain the output results. This kind of model is expected to be used to solve problems in a watershed that is incomplete or has no data as is the case with most watersheds in Indonesia (Sudiar, 2015). The HBV model (Hydrologiska Byråns Vattenbalansavedlning) is a hydrological model developed by *the Swedish Meteorological and Hydrological Institute* (SMHI) in Sweden since 1972. The HBV model is a fairly simple hydrological model, because it only requires rainfall and evapotranspiration data to produce *model output* in the form of a flow hydrograph from a watershed (Ningrum *et al.*, 2024). The selection of the HBV model is also because it does not require a lot of input and free parameters (Nonki *et al.*, 2021).

The HBV model has been implemented in more than 40 countries around the world with different versions such as in Sweden, Zimbabwe, India and Colombia (Sudiar, 2015). Meanwhile, in Indonesia, the use of hydrological modeling using the HBV model is still limited compared to other hydrological models (Masitoh & Dasanto, 2018). This HBV model has been applied to several watersheds in Indonesia, such as the Musi watershed, a correlation coefficient value of 0.73 was obtained (Sipayung & Cholianawati, 2010), in the Peusangan Aceh watershed with a correlation coefficient of 0.623 (Ilhamsyah *et al.*, 2012), in the Batang Arau watershed, a correlation coefficient value of 0.48 was obtained (Sudiar, 2015), in the Citahurm Hulu watershed, an NSE value of 0.63 (Masitoh & Dasanto, 2018), in the Citanduy watershed, a correlation coefficient of 0.75 (Amalia *et al.*, 2020), and in the Bogowonto watershed, the determination coefficient is 0.73 (Andini *et al.*, 2023). This shows the good performance of the HBV model for use in Indonesia.

Meanwhile, in the Cidanau watershed, previous research conducted by Sutoyo & Purwanto, (1999) analyzed the performance of the Tank Model to transform rain-runoff in the Cidanau watershed with a determination coefficient of 0.6. Furthermore, discharge modeling research has also been carried out on the Cidanau watershed with the HBV-96 model by Brink, 2009. The HBV-96 Model research conducted by Van provides an accurate prediction for discharge in the Cidanau watershed with an NSE coefficient of around 0.7 with a calibration period of 5 years (1996-2001). Most prediction periods

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correspond to measured discharges, but improvements can still be made for periods of extreme flow. During periods of low flow, predictions are too high and unrealistic because the modeled bottom flow is very constant. To further improve results, it is more accurate to use a longer calibration period than the current one and it is recommended to use a period of more than 10 years.

Based on field conditions and previous research, this study aims to study and analyze the performance of the HBV-96 subtropical model to the tropics in estimating the flow discharge at the Cidanau-Peusar watershed outlet in other years with a shorter calibration period.

METHODS

Research Location

Cidanau Watershed (201.1 Km^2) is one of the priority watersheds in Indonesia located in 6^o 7' - 6^o 18' South and 105^o 51' - 106^o 3' East. This watershed is surrounded by densely populated areas in Banten Province, such as the Cilegon Industrial Estate, Anyer Beach, Serang, and Pandeglang District (Heryansyah *et al*., 2004). The outlet in this study is the Cidano-Peusar Dischage Station.

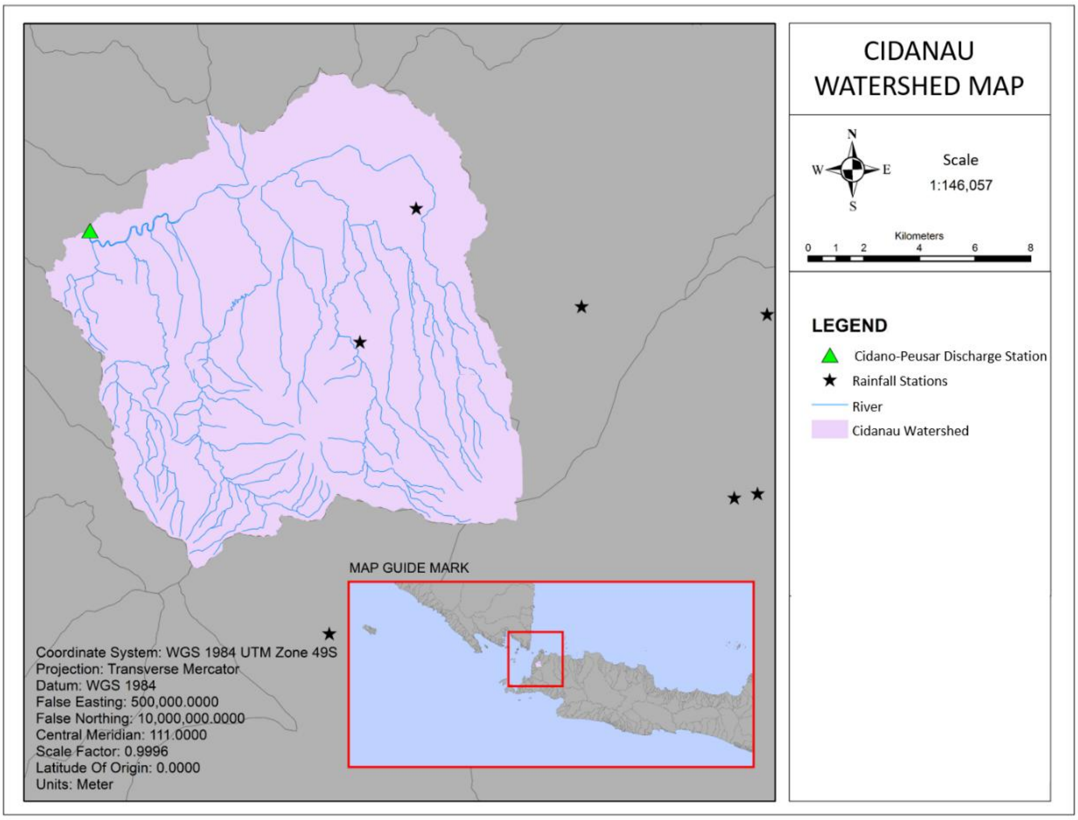

Figure 1. Map of Cidanau Watershed.

Data Collection Techniques

The data collection in this study was carried out by collecting secondary data obtained from the Center for Hydrology and Aquatic Environment, Directorate General of Water Resources, Ministry of PUPR, in the form of:

1. Rainfall Data – Krenceng Rainfall Post (2010-2012)
2. Rainfall Data – Padarincang Rainfall Post (2010-2012)
3. River Discharge Data – Cidano-Peusar Discharge Station (2010-2012)
4. Climatology Data – Darmaga Climatology Station (2008-2009)

HBV-96 Model

The HBV model (Hydrologiska Byråns Vattenbalansavedlning) is a conceptual hydrological model first developed by *the Swedish Meteorological and Hydrological Institute* (SMHI) with the concept of water balance (Lindstrom *et al.*, 1997). Until now, the HBV Model continues to be developed while maintaining the main concept of its modeling. Some of the types of HBV Models that have been developed are HBV3-ETH, HBV-96, and HBV Light (Masitoh & Dasanto, 2018). In this study, the HBV-96 model type was used. This model uses the concept of lumped which is a model that describes a system or physical circuit simply by assuming all components are concentrated at one point, so that the parameter values do not change spatially. The simplification of the model has the goal of the educational process so that the user understands the influence of variables on the overall hydrological process. This model can be simulated daily by using evapotranspiration and daily rain data as model *inputs* .

There are three components used in the HBV-96 model: (1) snowmelt and its accumulation, (2) soil moisture and evapotranspiration, and (3) groundwater and surface flow response represented by two tanks (Nonki *et al.*, 2021). Since the research area is tropical, snowmelt and accumulation are negligible (Lestari & Dasanto, 2019). Figure 2 provides an overview of the structure, parameters, and how the HBV-96 model works.

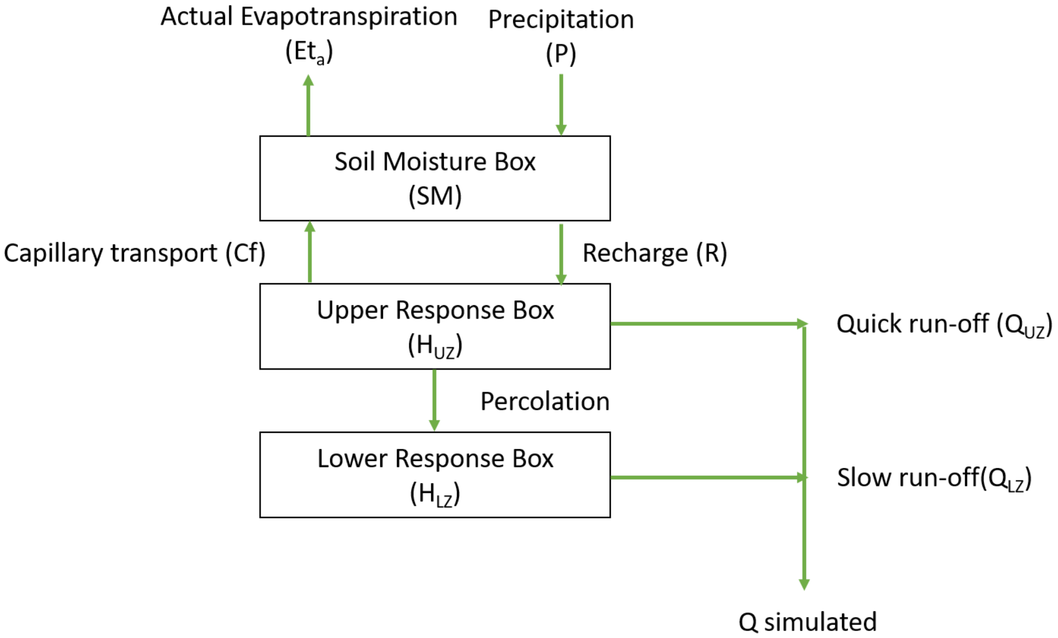

Figure 2. General Structure of Model HBV-96 (Brink, 2009)

Table 1 displays eight important parameters in the HBV model that describe soil moisture and response routines in response boxes, including the maximum limit of soil moisture charge (FC), the limit of evapotranspiration potential (LP), the beta coefficient (BETA), the capillary flux rate (CFLUX), the percolation rate (PERC), the coefficient for subsurface discharge (Kf), the coefficient for groundwater discharge (K4), and the recession parameter (ALFA) (Rusli *et al*., 2015).

Table 1. Main parameters of the HBV-96 model.

Parameter	Information	Unit	Mean Value	Max Value
FC	Maximum soil moisture storage	mm	50	500
LP	Soil moisture threshold for evaporation reduction	mm	0.1	1
BETA	Power coefficient for recharging and percolation	-	0.04	6
MINUTE	Maximum flow from top to bottom reservoir	mm/day	0.001	2.5
ALPHA	Power coefficient for subsurface discharge	-	0.001	1
Kf	Coefficient for subsurface discharge	-	0.001	0.02
K4	Coefficients for groundwater discharge	1/day	0.001	0.15
CFLUX	Coeficin capillary	-		

In the first reservoir, namely the soil moisture box, the regional daily rainfall variables (P) and capillary transport (Cf) are inputs while the actual evapotranspiration (ET_a) and recharge (R) into output. The daily rainfall of the region is calculated using the Arithmetic Method because there are only two rainfall posts available. Based on the research by Brink, (2009). the use of different methods for measuring the daily rainfall of the region with the Arithmetic Method and the Thiessen Method did not show a significant difference in terms of the NSE coefficient. Although it is expected that the Thiessen method will be more representative of reality, as it takes into account the position of the measuring station. So in this study, the Arithmetic Method is used.

Parameters of FC, LP, BETA and initial soil moisture (SM_0) as the starting value. The variables in the soil moisture box can be calculated by equation (1)-(4) as follows (Brink, 2009).

$$ET_a = \begin{cases} \left(\frac{SM}{LP \; x \; FC}\right) EP & if \;\; SM < LP \; x \; FC \\ EP & if \; SM > LP \; x \; FC \end{cases} \quad (1)$$

$$Cf = CFLUX \frac{(FC - SM)}{FC} \quad (2)$$

$$R = P \left(\frac{SM}{FC}\right)^{BETA} \quad (3)$$

$$SM = SM_0 + P + Cf - ET_a - R \quad (4)$$

where EP is the potential evapotranspiration (mm), is the actual evapotranspiration (mm), Cf is the capillary transport (mm), R is the recharge to the upper response box (mm), P is the precipitate (mm). SM is the storage of soil moisture (mm). The value of Evapotranspiration Potential was obtained by the Penman-Monteith Method.

In the second box which is the upper response box or topcoat, the recharge (R) is the input while the capillary transfer (Cf) is the output. With initial storage in the upper response box (H_{UZ0}), the output of this reservoir is percolation (PC) and Quick run-off (Q_{UZ}), with the following equation (5)-(7) (Brink, 2009).

$$PC = PERC \left(\frac{SM}{FC}\right)^{BETA} \quad (5)$$

$$Q_{UZ} = K_f \ x \ H_{UZ}{}^{(ALFA+1)} \quad (6)$$

$$H_{UZ} = H_{uz0} + R - Cf - \text{PC} - Q_{UZ} \quad (7)$$

where PC permeates (mm) and is the water level in the upper layer or fast runoff reservoir (mm).

While in the last reservoir which is the bottom flow or lower response box, percolation (PC) is the input where the initial storage is in the lower response box (H_{LZ0}), The output of this reservoir is the basic flow (Q_{LZ}), with the following equations (8) and (9) (Brink, 2009).

$$Q_{LZ} = K_4 \ x \ H_{LZ} \quad (8)$$

$$H_{LZ} = H_{Lz0} + PC - Q_{LZ} \quad (9)$$

where H_{LZ} is the water level in the bottom layer or lower response box (mm).

The number of Q_{UZ} and Q_{LZ} which then becomes a discharge simulation on the *watershed output* (Q_{sim}), are as follows (10) (Brink, 2009).

$$Q_{sim} = Q_{UZ} + Q_{LZ} \quad (10)$$

Model Input

With the limitation of observation discharge data, calibration is carried out to obtain the most optimal model parameters. Model calibration is required by comparing the simulation results with field observations to identify optimal model parameters (Tibangayuka *et al.*, 2022).

The objective function used to calculate the deviation between the simulation and observation results is the Nash-Sutcliffe efficiency coefficient (NSE) and Correlation Coefficient (r) methods. Where Table 2 and Table 3 can be used to assess whether the model is accepted. The equations used in the Nash-Sutcliffe efficiency coefficient (NSE) method are as follows (11) (Eryani *et al.*, 2022).

$$NSE = 1 - \left(\frac{\sum_{i=1}^{n}(Q_{obs} - Q_{sim})^2}{\sum_{i=1}^{n}(Q_{obs} - \bar{Q})^2}\right) \quad (11)$$

Table 2. The Criteria of Nach-Sutcliffe (NSE) Value.

NSE Value	Interpretation
> 0.75	Well
0.36 – 0.75	Satisfying
< 0.36	Less satisfactory

As for the correlation coefficient (r) method, the equation used is as follows (12) (Krisnayanti *et al.*, 2022).

$$r = \frac{\sum_{i=1}^{n}(Q_{obs}-\overline{Q_{obs}})(Q_{sim}-\overline{Q_{sim}})}{\sqrt{\sum_{i=1}^{n}(Q_{obs}-\overline{Q_{obs}})^2}\sqrt{\sum_{i=1}^{n}(Q_{sim}-\overline{sim})^2}} \quad (12)$$

Table 3. The Criteria of Correlation Coefficient (r) Value.

r Value	Interpretation
> 0.7	High correlation
0.4 – 0.7	Subtantial relationship
0.2 – 0.4	Low correlation
< 0.2	Ignored

The calibration stage was carried out to simulate runoff discharge in 2010-2011 and the validation stage was carried out by simulating the runoff discharge in 2012 shown in Table 4.

Table 4. Model Input Period.

Simulation	Period
Calibration	2010-2011
Validation	2012

RESULTS AND DISCUSSION

Calibration of the HBV-96 Model

Calibration of model parameters is necessary to meet the optimization requirements of a hydrological model, in this case it meets the efficiency criteria of the model. The efficiency criteria in this study were calculated using the correlation coefficient (r) and NSE in equations (11) and (12). Model calibration is performed manually using trial adjustments of model parameters to model performance to obtain optimal values. Calibration was carried out by simulating the model in 2010-2011. The calibration of the parameters of the HBV model is shown in Table 5.

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Table 5. Calibration of HBV-96 model parameters.

Parameter	Unit	Minimum Values	Maximum Value	Calibration Value
FC	mm	50	500	500
LP	mm	0.1	1	0,705
BETA	-	0.04	6	0,880
PERC	mm/day	0.001	2,5	2,5
ALFA	-	0.001	1	0,878
Kf	-	0.001	0,02	0,001
K4	1/day	0.001	0,15	0,010
SM	mm	-	-	50
H_{UZ}	mm	-	-	120
H_{LZ}	mm	-	-	20

HBV-96 Model Simulation

The simulation results of the HBV-96 Model in the Cidanau watershed in 2010-2011 are shown in Figure 3. The results of the simulated discharge show a fluctuation pattern that is almost the same as the observation discharge. A correlation coefficient of 0.829 was obtained with an NSE value of 0.672. Referring to the standard value of the correlation coefficient where r > 0.7, the simulation discharge and the observation discharge can be said to be highly correlated. Meanwhile, based on the standard NSE value where the NSE > 0.36, the rain-runoff transformation using the HBV-96 Model in the Cidanau watershed can be said to be quite good. The results of the water balance calculation also show that the difference between the total observation discharge and the total simulated discharge is not too different, which is 2253 mm and 2139 mm.

However, the HBV-96 model in this study cannot simulate peak discharge as accurately as previous studies. The peak discharge of the simulation that occurred in December was only 23.3 mm/day while the peak discharge of observation reached 31.3 mm/day, as can also be seen from the Flow Duration Curve as shown in Figure 4. Not only that, the time of the simulated peak discharge event that occurred in December also experienced a delay of approximately 2 days. The rain-runoff model is quite well measured from the correlation coefficient, NSE and water balance, but the predicted discharge is often too low. This can be due to the spatial average rainfall which does not accurately represent the actual rainfall and also the calibration period is quite short than recommended (10 years).

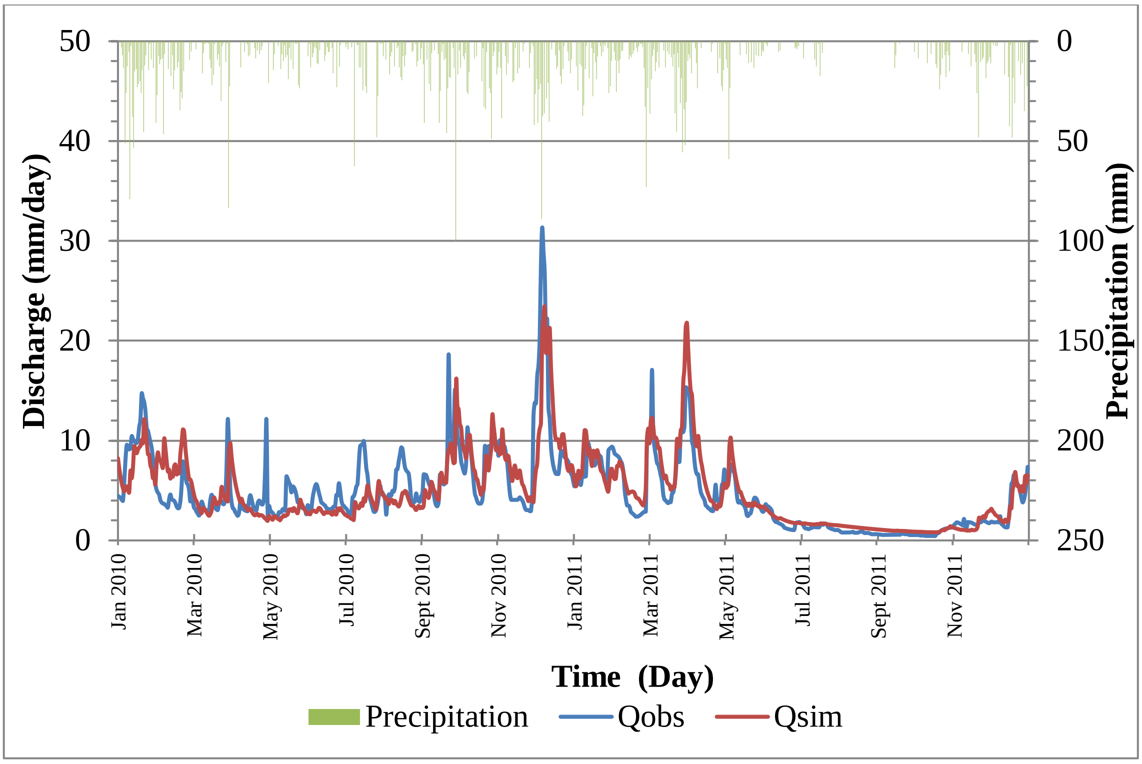

Figure 3. Comparison of simulated and observation discharge – Calibration (2010-2011).

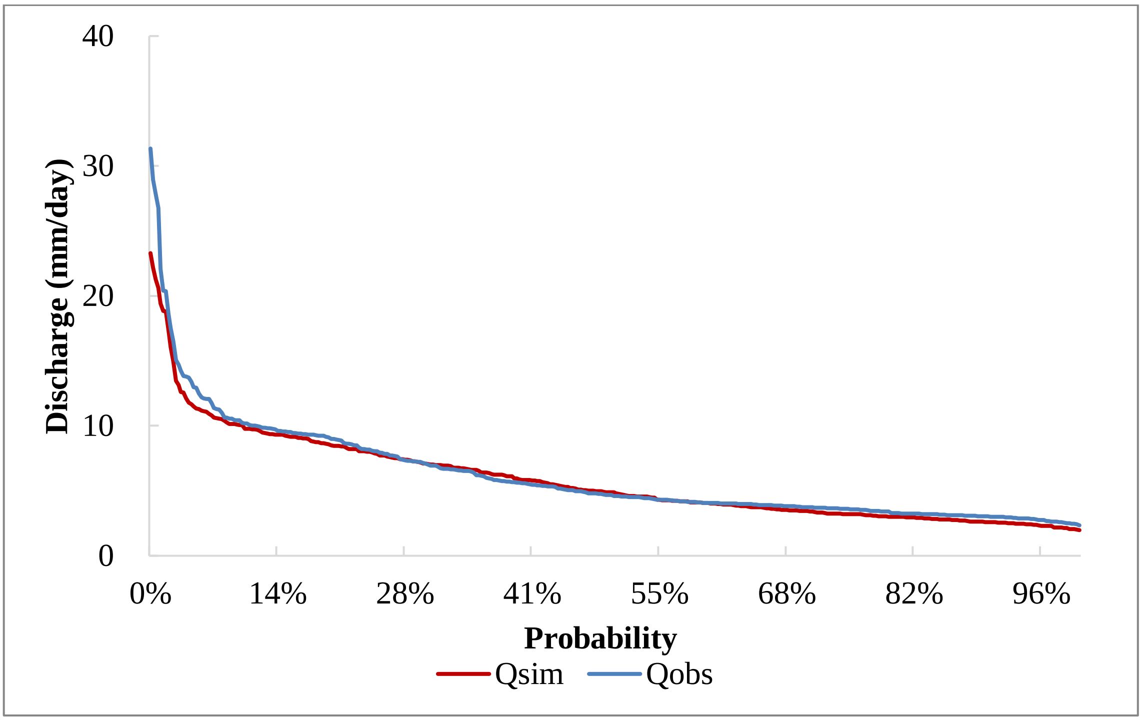

Figure 4. Flow Duration Curve – Calibration (2010-2011).

HBV-96 Model Validation

Model validation is needed to test the parameters obtained from the calibration process in other years. Whether the parameters obtained from the calibration process can confirm the rain data into a simulated discharge that is close to the observation discharge in other years. The efficiency criteria in validation were calculated using the correlation coefficient (r) and NSE in equations (11) and (12). Model validation was done manually by simulating the model in 2012.

The calibration results of the HBV-96 Model in the Cidanau watershed in 2012 are shown in Figure 5 which shows a fluctuation pattern that is almost the same as the observed discharge. A correlation coefficient of 0.806 was obtained with an NSE value of 0.527. Referring to the standard value of the correlation coefficient where $r > 0.7$, the simulation discharge and the observation discharge can be said to be highly correlated. Meanwhile, based on the standard NSE value where $NSE > 0.36$, the results of the parameter test in the validation process can be said to be quite good.

The peak discharge of the simulation in the validation year in January was lower than the discharge of observation, while in April it was higher. Therefore from the Flow Duration Curve, Figure 6, it can be seen that the difference between the peak discharge between the simulated and observed discharge is not so significant. The validation results also showed that there was a delay time or delay time compared to the observation discharge.

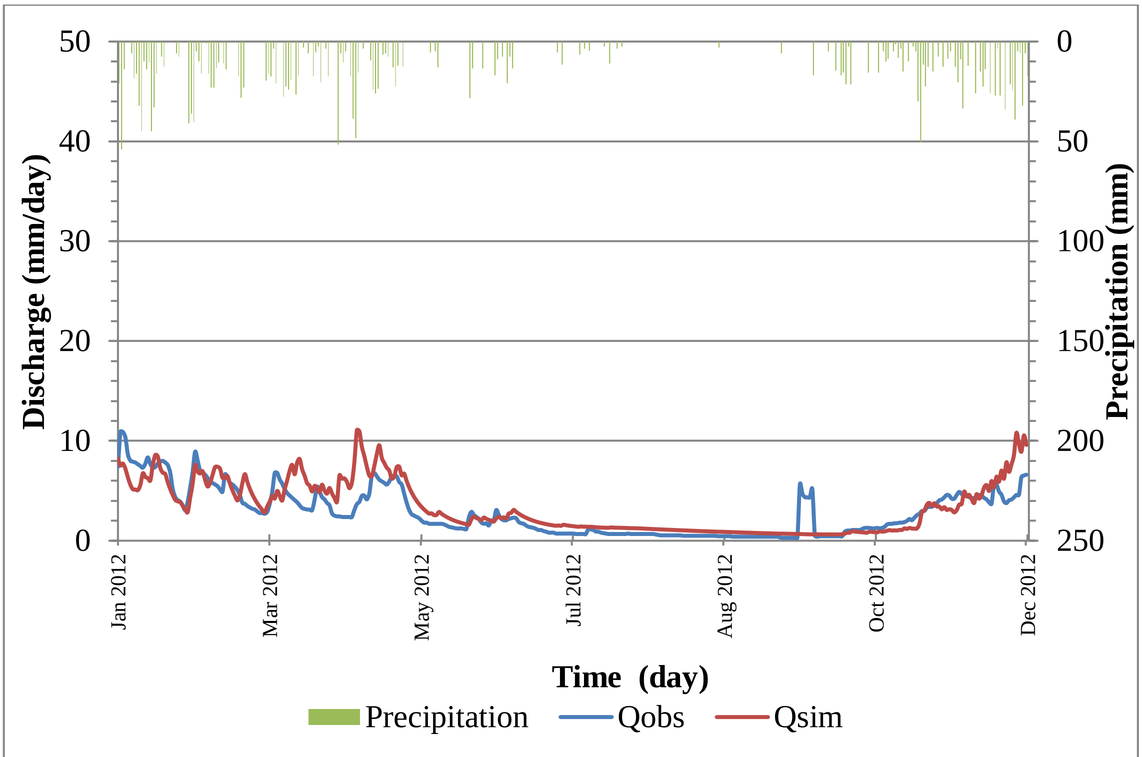

Figure 5. Comparison of simulated and observational discharges – Validation (2012).

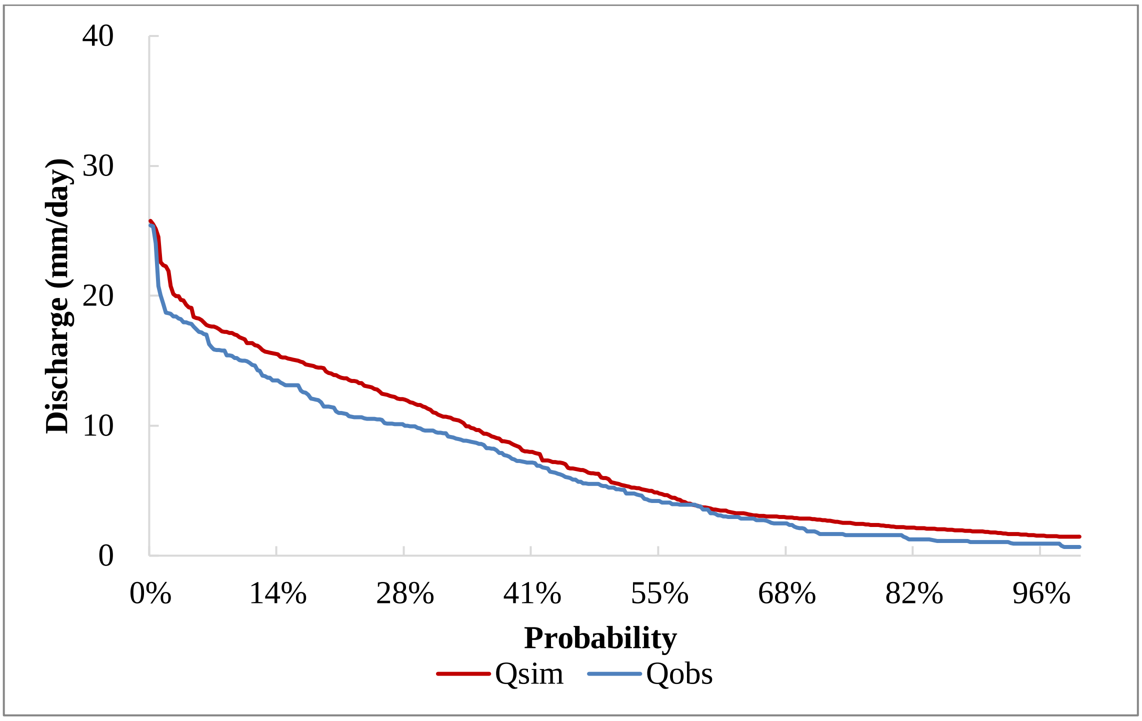

Figure 6. Flow Duration Curve – Validation (2012).

Additional Validation

In this study, model parameters were also adjusted to obtain peak discharge that was more in line with the observation value. This is done by enlarging the value of the ALFA parameter which affects the amount of flow in the second reservoir or fast runoff (Q_{UZ}). The peak discharge was obtained in the calibration period (2010-2011) which was closer to the observation value, but reduced the model performance in the validation process (2012).

In addition, validation was also carried out in 2010 and 2011 separately to determine the effectiveness of model parameters. The NSE value was obtained at 0.507 in 2010 and 0.728 in 2011. This shows that the parameters obtained from a relatively short calibration period or less than 10 years cannot accurately simulate runoff discharge for other perodes. In certain years, the model's performance is good, but in other periods it can be worse. The calibration recapitulation and model validation are shown in Table 6.

Table 6. Simulation Results of HBV-96 Model in Cidanau Watershed.

Simulation	Period	Correlation (r)	NSE
Calibration	2010-2011	0.829	0.672
Validation	2012	0.806	0.527
Additional Validation	2011	0.864	0.728
	2010	0.729	0.507

CONCLUSION

The HBV-96 model has good performance in the Cidanau watershed. The results of the hydrograph simulation using HBV-96 are close to the results of observations with correlation coefficients and NSE coefficients in the calibration periods of 0.829 and 0.672. But improvements can still be made for periods of extreme flow. This study also proves that a short calibration period is not very accurate to determine the value of the model's optical parameters that can be used in other periods, so for the next study it is recommended to use a calibration period of at least 10 years.

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