Model Calibration Parameter Using Optimization Trial in HEC-HMS for Unda Watershed

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Abstract. In water resource planning, information on water availability is needed. Nowadays, data on water availability is still difficult to obtain. With technology in the form of a rainfall-runoff simulation model that can predict water availability in the Unda watershed. It can add information about the potential for water in the Unda watershed. It can be used to prepare water resources management in the Unda watershed so that the existing potential can be used sustainably. Based on the rainfall simulation model results in the Unda watershed, it can be concluded that after running the initial model and calibration. The results are obtained R² value was 0.68 and increased by 9.81% to 0.754. Both the initial model and the calibration model show an efficient R² value, NASH value increases by 49.93% to 0.713, which includes satisfactory criteria, RMSE value of 1.135 and decreased by 49.47% to 0.758, and the PBIAS value was 44.70% which was classified as unsatisfactory and decreased from 80.24% to 24.80% at the time of calibration which was classified as satisfactory. In general, the overall simulation results are quite good for representing the watershed's efficient hydrological process.

Keywords: Calibration, HEC-HMS, Unda watershed

1. Introduction
The issue of sustainable management of water resources is a major challenge and very important for society worldwide. Failure to manage water resources effectively will harm society and the country's economy. In planning the allocation of water resources in a river area, it requires an understanding of the dynamics of the water potential of the watershed and an assessment of the availability of the river area to determine the appropriate and sustainable use of water [1]. The Unda Watershed is one of the second largest watersheds in Bali Province. The Unda River is a river that has water potential every year or what is commonly called the Perennial river flow type with a total area of 222.85 km². There is still around 91.361 liters/second in one year the potential of surface water that has not been used in the Unda watershed is wasted [2].

Although it has many water sources, it turns out that the land is critical in the Unda watershed. Volcanic formations dominate the Unda watershed. 79.59% of the land use in the study area is dry land. The type k of Regosol soil that is very vulnerable in the study area is 68.41%. Meanwhile, 45.64% are undulating areas (hilly to mountainous) and illegal C excavation sites. Currently, the watershed function is starting to decline because there are some problems in watershed management [3].
The Unda watershed is one of the critical watersheds that is considered an urgent target for an integrated watershed management plan. The difference between the minimum and maximum discharges, which is quite significant, recorded during the 2016-2013 period, the maximum discharge of 53.4 m$^3$/s and the lowest discharge of 0.17 m$^3$/s, can indicate poor watershed performance. The Unda watershed has a large enough critical land [4].

Integrated water resources management in the Unda watershed needs to be done. Therefore, it can be used optimally for all types of needs. However, nowadays, water availability data is still difficult to obtain [5] [6] [7].

Hydrological modelling can estimate the hydrological response of a watershed due to precipitation. Various types of hydrological models, from black-box models that require fewer watershed data to physically-based models that require large amounts of watershed data have been developed. The selection of the model depends on the needs of the analysis and the results to be obtained. HEC-HMS is one of the hydrological models developed by the Hydrologic Engineering Center of the US Army Corps of engineers. This model can support rainfall-runoff simulation with several hydrological parameters to approach the simulation results to the actual event [8].

Rainfall-runoff hydrological studies have been carried out in many areas around the world to meet various desired needs. It is necessary to carry out the use effectively and appropriately, both now and in the future. So with technological advances in the form of a rain-runoff simulation model that can predict the availability of water in the Unda watershed, it can add information about the water potential in the Unda watershed. So that it can be used as a basis for preparing water resource management in the Unda watershed so that the existing potential can be used sustainably.

In making a model, a calibration process is needed to minimize the difference between the simulation discharge results and the observed discharge [9].

Previously, in determining the optimal parameters that produce good model reliability in the HEC HMS model, the calibration process requires a sensitivity analysis process to obtain optimal parameter values [10][11]. In the latest version of HEC HMS, an Optimization Trial Simulation tool has been provided, making it easier to determine the optimum value for each calibrated parameter[12]. For this reason, this study will simulate the HEC HMS model for the Unda watershed with the Optimization Trial Simulation tool to obtain optimum model reliability.

2. Research Methods

2.1. Research Location
The Unda Watershed is one of the second largest watersheds in Bali Province. The Unda River is a river that has water potential every year or what is commonly called the Perennial river flow type with a total area of 222.85 km$^2$. The Unda watershed is currently used to meet the needs of raw water and irrigation water in the area around the watershed. The water potential is large enough to make the Unda watershed one of the potential rivers in the Bali Province. However, some of the problems still being experienced by the Unda watershed make the potential that exists cannot be utilized effectively. The Unda watershed has two main rivers, namely the Telagawaja River and the Unda River. Using the HEC-HMS software's GIS menu, the Unda watershed is delineated into several sub-watersheds to obtain discharge data in several locations.
2.2. Research Tools and Materials
The tools used in data processing in this research are Microsoft Excel, Microsoft Word, and HEC-HMS 4.6.1. As for the research materials needed in this study in the form of primary data and secondary data. Primary data in the form of a survey of the existing condition of the Unda watershed for making assumptions in modelling, while secondary data in the form of digital elevation model (DEM) data of the Unda watershed, rain data, discharge data, as well as maps of land use and Unda soil types obtained from relevant agencies and literature studies in determining the assumptions in the modelling.

2.3. Preparation of Rainfall-Runoff Model Using HEC-HMS
The structure of the model development using HEC-HMS consists of five components that have several methods. This study uses the method that can be seen in Table 1 below.

| Model                      | Method       |
|----------------------------|--------------|
| Precipitation              | Specified Hyetograph |
| Runoff-Volume Models       | SCS CN       |
| Direct runoff Models       | SCS UH       |
| Channel Routing Models     | Lag          |
| Base flow Models           | Constant monthly |

Source: Analysis Results

2.4. Basin Model Processing
The preparation of the basin model is one of the important stages in analyzing the hydrological system using the HEC-HMS model. At this stage, it consists of arranging elements that can represent the physical watershed in nature. The elements that make up the watershed include sub-basin, reach, reservoir, junction, diversion, source, and sink. The Unda watershed model basin is divided into seven sub-basins based on the watershed topography. The delineation process into several sub-basins is done automatically with the help of the GIS menu in the HEC-HMS software.
2.5. Parameters Used in the HEC-HMS Model

The sub-basin element in HEC-HMS has only inflow and only one outflow. Outflow from the sub-basin is obtained based on rain data that has been processed in the watershed by converting excess rain into a flow (transform). While the reach element is an element with one or more inflows originating from other elements in the model. Outflow is derived from total inflow and channel calculations based on simulation of open flow in a channel or river. The parameters used in this study are listed in Table 2.

![Figure 2. Basin Model Unda Watershed](image)

Table 2. Parameters Used in the HEC-HMS Model

| Element         | Component | Method        | Parameter                  |
|-----------------|-----------|---------------|----------------------------|
| Sub-basin       | Surface   | Simple Surface| Initial Storage, Max storage |
|                 | Loss      | SCS CN        | Initial Abstraction, Curve Number, Impervious |
|                 | Transform | SCS UH        | Time Lag SCS               |
|                 | Base flow models | Constant Monthly | Base Flow |
| Reach           | Reach routing method | Lag | Lag Time |

Source: Analysis Results

2.5.1. Surface Method

The surface method in the sub-basin represents the ability of the land surface in the watershed to store water. Rain that falls directly on the ground surface will experience infiltration if the surface is only soil like rice fields. Suppose waterfalls are on closed surfaces such as roads and parking lots, the ability to store groundwater is 0.

The surface runoff will occur if the rate of precipitation exceeds the infiltration rate. Initial Storage is the percentage of ground surface storage at the beginning of the simulation. Initial Storage in this study is assumed to be 0 because the start of the simulation coincides with the dry month. At the same time, Storage is the maximum amount of water that can be accommodated on the soil surface before surface runoff occurs. Maximum Storage in the initial simulation of this study is assumed to be 50.8 mm based on the slope of the Unda watershed, which ranges from 0-5%.
Table 3. Surface Depression Storage

| Description | Slope (%) | Surface Storage (mm) |
|-------------|-----------|----------------------|
| Flat        | 0-5       | 50.8                 |
| Medium      | 5-30      | 6.35-12.7            |
| Steep       | >30       | 1.02                 |

Source: Ouédraogo et al [13]

2.5.2. Loss Method
The loss method simulates water loss in the watershed from rain to surface runoff. The model will simulate the process of rainwater loss due to land use and soil type through infiltration and evapotranspiration processes before finally becoming direct runoff. This study uses the SCS CN method. The SCS CN method uses the initial Abstraction, CN, and impervious parameters. Calculation of initial Abstraction, CN, and impervious values. The composite CN calculation should not include a watertight area. Calculation of the composite CN uses the curve number value based on the land cover and soil type. The value of the curve number indicates the amount of runoff that will occur, if the value of the curve number of 100 indicates that the rainwater will become full runoff and the watershed condition is bad. Rainfall loss, which occurs through the runoff/infiltration process is determined using the SCS Curve Number method. This method calculates the effective precipitation of a hydrological event based on empirically derived relationships between location, soil type, land use, previous moisture conditions and runoff [14].

Table 4. Loss Parameter for Unda Watershed Model

| Subbasin | Initial Abstraction (mm) | Curve Number | Impervious (%) |
|----------|--------------------------|--------------|----------------|
| SB-1     | 52.55                    | 49.15        | 65             |
| SB-2     | 38.54                    | 56.86        | 65             |
| SB-4     | 44.95                    | 53.06        | 65             |
| SB-5     | 43.94                    | 53.62        | 65             |
| SB-6     | 45.16                    | 52.94        | 65             |
| SB-7     | 46.92                    | 51.98        | 65             |
| SB-11    | 28.36                    | 64.18        | 65             |
| SB-13    | 37.32                    | 57.65        | 65             |

2.5.3. Transform method
The transform method in the sub-basin simulates the process from rain to flow hydrograph. This study uses the SCS UH method using the lag time parameter. Lag time is the time interval between the center of mass of rain and the time of peak discharge. Lag time calculation of each sub-basin.

Table 5. Transform parameter for Unda Watershed Model

| Subbasin | Graph Type | Lag Time (min) |
|----------|------------|----------------|
| SB-1     | Standard   | 8357.25        |
| SB-2     | Standard   | 7243.42        |
| SB-4     | Standard   | 2846.8         |
| SB-5     | Standard   | 649.35         |
| SB-6     | Standard   | 2016           |
| SB-7     | Standard   | 2878.85        |
| SB-11    | Standard   | 463.61         |
| SB-13    | Standard   | 7516.62        |
2.5.4. Base flow Method
Conceptually, sub-basin elements represent infiltration, surface runoff, and subsurface processes that interact together. Subsurface processes are calculated through surface base flow or base flow. In this study, the base flow calculation uses the constant monthly method. The base flow value in each month is held constant at the beginning of the simulation using the lowest measured discharge value during the measurement from secondary data in the simulation period. The lowest discharge in the simulation period.

Table 6. Baseflow parameter for Unda Watershed Model

| Subbasin | Jan BF* (m³/s) | Feb BF* (m³/s) | March BF* (m³/s) | April BF* (m³/s) | May BF* (m³/s) | June BF* (m³/s) | July BF* (m³/s) | Aug BF* (m³/s) | Sept BF* (m³/s) | Oct BF* (m³/s) | Nov BF* (m³/s) | Dec BF* (m³/s) |
|----------|----------------|----------------|------------------|------------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|
| SB-1     | 0.12           | 0.05           | 0.02             | 0.22             | 0.02          | 0.02          | 0.05          | 1             | 0.6           | 0.11          | 0             | 0.02          |
| SB-2     | 0.12           | 0.05           | 0.02             | 0.22             | 0.02          | 0.02          | 0.05          | 1             | 0.6           | 0.11          | 0             | 0.02          |
| SB-4     | 0.12           | 0.05           | 0.02             | 0.22             | 0.02          | 0.02          | 0.05          | 1             | 0.6           | 0.11          | 0             | 0.02          |
| SB-5     | 0.12           | 0.05           | 0.02             | 0.22             | 0.02          | 0.02          | 0.05          | 1             | 0.6           | 0.11          | 0             | 0.02          |
| SB-6     | 0.12           | 0.05           | 0.02             | 0.22             | 0.02          | 0.02          | 0.05          | 1             | 0.6           | 0.11          | 0             | 0.02          |
| SB-7     | 0.12           | 0.05           | 0.02             | 0.22             | 0.02          | 0.02          | 0.05          | 1             | 0.6           | 0.11          | 0             | 0.02          |
| SB-11    | 0.12           | 0.05           | 0.02             | 0.22             | 0.02          | 0.02          | 0.05          | 1             | 0.6           | 0.11          | 0             | 0.02          |
| SB-13    | 0.12           | 0.05           | 0.02             | 0.22             | 0.02          | 0.02          | 0.05          | 1             | 0.6           | 0.11          | 0             | 0.02          |

*BF: Baseflow

2.5.5. Reach Routing Method
The reach routing method conceptually represents the condition of the river channel in the watershed. This study uses the Lag method. This method is the simplest of the included routing models. With that said, the outflow hydrograph is just the inflow hydrograph, but with all coordinates translated (lag in time) with a defined duration. The flow is not leveled, so the shape does not change [15].

Table 7. Reach Routing Parameter for Unda Watershed Model

| Reach | Initial Type | Lag Time (min) |
|-------|--------------|----------------|
| R-1   | Discharge = Inflow | 4283.84 |
| R-3   | Discharge = Inflow | 463.61 |
| R-5   | Discharge = Inflow | 5645.75 |
| R-6   | Discharge = Inflow | 2504.22 |

2.5.6. Time Series Data
The time-series data used in this study are daily rainfall data and daily discharge. Daily rainfall data is obtained from daily regional rain, which will be simulated into discharge using HEC-HMS. In contrast, daily discharge data is obtained from measurements of the Unda-Cegeng discharge station used for calibration on the sink element on the HEC-HMS Unda Watershed model.

2.6. Model Calibration
Calibration will be carried out from January 1, 2014, to October 31, 2014; this time was chosen from selecting matches between the rainfall pattern and the observed discharge. The HEC-HMS 4.6.1 has been equipped with automatic calibration with an optimization trial manager.
3. Result and Discussion
Based on the basin model, meteorological model, time-series data, and control specifications, then run to observe the simulated discharge hydrograph and observation discharge. After seeing the level of match between the simulation discharge and the observed discharge, the overall fit of the initial model is still quite good. But still not good enough to represent the watershed. Although the model with the initial parameters still has a poor model reliability value, the results are quite satisfactory after being calibrated.

| Simulation       | NASH  | RMSE   | PBIAS  | R²    |
|------------------|-------|--------|--------|-------|
| Initial Model    | 0.357 | 1.135  | 44.70% | 0.68  |
| Calibration      | 0.713 | 0.758  | 24.80% | 0.754 |
| Value change     | 49.93%| -49.74%| -80.24%| 9.81% |

Source: Analysis Results

The R² (correlation coefficient) value shows the strength of the relationship between the two variables that you want to know. The correlation coefficient values ranged between -1.0 and 1.0. A correlation of -1.0 indicates a perfect but negative correlation, which is an inversely proportional relationship. In contrast, a correlation with a value of 1.0 indicates a perfect positive correlation that is directly proportional [12]. The correlation with a value of 0 indicates that the two variables do not show a relationship. In the initial model obtained, the value of R² is 0.68, while after calibrating the parameters, the R² value is 0.754. From this value, it can be seen that after calibration, the relationship between variables increased by 9.81%, which means that the simulation value is closer to the results in the field.

Nash Sutcliffe model efficiency coefficient is a normalized statistic that determines the relative magnitude of the residual variance compared to the measured data variance (Nash and Sutcliffe, 1970). The Nash-Sutcliffe efficiency indicates how well the observed and simulated data plots fit the 1:1 line.
NSE = 1, corresponding to a perfect fit of the model to the observed data. NSE = 0, indicating that the predictive model is as accurate as the observed data mean, INF < NSE < 0, indicating that the observed mean is a better predictor than the model. In the initial model, the NASH value is 0.357, which is still unsatisfactory. In contrast, after calibration, the NASH value increases by 49.93% to 0.713, which includes satisfactory criteria [16].

Understanding Root Mean Square Error (RMSE) is a method of measuring the difference in the value of a model's prediction as an estimate of the observed value. The Root Mean Square Error is the result of the square root of the Mean Square Error. The accuracy of the measurement error estimation method is indicated by the presence of a small RMSE value. The estimation method that has a smaller Root Mean Square Error (RMSE) is said to be more accurate than the estimation method that has a larger Root Mean Square Error (RMSE). The method of calculating the Root Mean Square Error (RMSE) is by subtracting the actual value from the forecast value, then squared, and the total results are then divided by the number of data. The initial model obtained the RMSE value of 1.135 and decreased by 49.47% to 0.758.

Percent bias is expressed in relative terms so that it is possible to evaluate the size of the bias due to under coverage for the parameters that are not known to be estimated. In the initial model, the PBIAS value was 44.70%, classified as unsatisfactory and decreased from 80.24% to 24.80% at calibration, classified as satisfactory [17]. Several parameter values have changed; namely, the lag time value for SB-1 changed from 8357.25 minutes to 29715 minutes. The Max Storage parameter changed from 50.8 to 158.04 mm, and the Initial Abstraction value was originally 52.55 to 52.777.

4. Conclusion
Based on the rainfall simulation model results in the Unda watershed, it can be concluded that after running the initial model and calibration, the results are obtained $R^2$ value was 0.68 and increased by 9.81% to 0.754. Both the initial model and the calibration model show an efficient $R^2$ value, NASH value increases by 49.93% to 0.713, which includes satisfactory criteria, RMSE value of 1.135 and decreased by 49.47% to 0.758, and the PBIAS value was 44.70% which was classified as unsatisfactory and decreased from 80.24% to 24.80% at the time of calibration which was classified as satisfactory. And overall fit of the model is quite good, indicating that the model represents the hydrological process in the watershed is efficient.

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