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The Use of Tropical Rainfall Measuring Mission Rainfall Data as Input Data for Water Availability Analysis with Rainfall-Runoff Models in the Melawi Sub-Basin

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Abstract

Many rain-to-discharge transformation models have been made, such as the Mock Model and the NRECA Model, which are used to make monthly synthetic discharge data when there is not enough discharge data to analyze water availability in a Sub-Basin or Sub-Basin. Tropical Rainfall Measuring Mission (TRMM) data, created by NASA and JAXA, is one type of satellite-based rainfall data that can help overcome the lack of rainfall data. However, not all areas have rainfall recording stations, and if there are, not all existing rainfall recording stations operate correctly. Such conditions also occur in the Melawi Sub-Basin in West Kalimantan. This research aims to determine how much water is available in the Melawi Sub-Basin by putting satellite-based rainfall data into the NRECA model and the Mock model, which converts rainfall to discharge.

This study was done to determine how reliable TRMM satellite rainfall data are as input data for the rainfall-to-discharge transformation model used to determine how much water is available in the Melawi Sub-Basin. The goal of this study is to assess the suitability of TRMM data with observation station rainfall data in the Melawi Sub-Basin by validating TRMM satellite rainfall data with BMKG Susilo and BMKG Nanga Pinoh observation station rainfall data and to choose the appropriate rain-to-flow diversion model used in the Melawi Sub-Basin based on the results of model parameter calibration, with the models whose parameters are calibrated being the Mock Model and the NRECA.

The study results show that TRMM rainfall data in the Melawi Sub-Basin that has been validated and corrected with the equation Y = 0.748089283 X + 62.19135368 can be used as input data in the analysis of water availability, and the transformation model of rainfall into discharge that is more suitable is the Mock Model. In general, both the observation station rainfall pattern and the TRMM rainfall pattern tend to have the same pattern as the discharge pattern in the Melawi Sub-Basin. The fact that August has the lowest peak is clear evidence of this. Even though the highest point doesn't happen in the same month, the trend is the same, so TRMM rainfall data can be considered valid and used to replace observational rainfall data in the Melawi Sub-Basin. Similar research can be done on other Sub-Basins in Kalimantan Barat Province to help develop and manage water resources since many observation stations in Kalimantan Barat Province no longer work, and there are many large Sub-Basins in that province.

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1. Introduction

Hydrological data about river discharge is critical to understand because it is one of the primary data types used to plan and build Sub-Basins (Soeryamassoeka, 2020; Wuysang, 2021). However, in Indonesia, not all areas have the availability flow discharge data recorded at an estimated post-Automatic Water Level Recording (AWLR) for an extended period, as well as the Melawi Sub-Basin (Soeryamassoeka, 2018). A hydrological model can be used to get around the problems with the data we already have (Sudinda, 2000; Setyono, 2011; Ramadhani, 2017; Hendrasto et al., 2018; Soeryamasoeka, 2020). Hydrological models that can be used to estimate flow discharge include the NRECA (National Rural Electric Cooperative Association) model (Crawford & Thurin, 1981; Sudinda, 2000; Setyono, 2011; Ginting, 2016; Ramadhani, 2017; Hendrasto et al., 2018; Soeryamassoeka, 2020) and the Mock model (Mock, 1973; Indra et al., 2012; Ginting, 2016; Jihad, 2018; Juni et al., 2019), which is a model for transforming rain data into flow/discharge.

Rainfall is used in water resource planning and management because it is a climatic element with a high degree of variability in space and time scales (Ropelewski & Halpert, 1987; Adler et al., 2000; Njoroge, 2010; Guo & Liu, 2014; Sunilkumar et al., 2015; Soeryamassoeka, 2020). However, not all areas have rainfall recording stations, either using manual rain gauges or automatic rainfall recorders, and if they do, not all existing rainfall recording stations (rain observation stations) are operating correctly (Xie and Arkin; Su et al., 2007; Su & Lettenmaier, 2008; Kneis et al., 2014, 1996; Mamenun et al., 2014; Pratiwi et al., 2017; Soeryamassoeka, 2020). One frequently cited factor for the sparse distribution of rain gauge stations and their subpar performance (Mamenun et al., 2014; Pratiwi et al., 2017; Soeryamasoeka et al., 2020) is the high cost of building and maintaining rain gauge infrastructure in the region (Su et al., 2014). This includes the Melawi Sub-Basin. Predicting rainfall in some areas is, therefore, challenging.

From various studies that have been conducted to overcome the shortage of rainfall data, satellite rain data can be used, which has a high spatial and temporal resolution, comprehensive area coverage, near real-time data, fast access, and is economically viable (Mamenun et al., 2014; Pratiwi et al., 2017; Soeryamassoeka et al., 2020). With the latest technological developments in the form of remote sensing (satellite) technology that can make breakthroughs in terms of rainfall information, areas that were previously very difficult or almost impossible to measure rainfall, with this technology it is possible to have rainfall data (Xie & Arkin, 1996; Su & Lettenmaier, 2008; Kneis et al., 2014; Mamenun et al., 2014; Pratiwi et al., 2017; Soeryamassoeka, 2020; Soeryamassoeka et al., 2020),

Based on this description, it is necessary to conduct research on the use of satellite-based rainfall data as input data in rainfall-flow transformation models, namely the NRECA Model and the Mock Model, for the analysis of water availability in the Melawi Sub-Basin because the Melawi Sub-Basin lacks adequate rainfall data and measured discharge data (observation discharge).

This study was conducted to determine the reliability of TRMM satellite rainfall data as input data for water availability analysis using the rainfall-flow transformation model in the Melawi Sub-Basin.

The purpose of this research is to evaluate the suitability of TRMM data with rainfall data of observation stations in the Melawi Sub-Basin, by

a. validating TRMM satellite rainfall data with rainfall data from BMKG Susilo and BMKG Nanga Pinoh observation stations,
b. selecting the appropriate rainfall-flow transformation model used in the Melawi Sub-Basin based on the results of the calibration of model parameters, with the model whose parameters are calibrated are the Mock Model and the NRECA Model,
c. transform Tropical Rainfall Measuring Mission (TRMM) satellite rainfall data in the Melawi Sub-Basin into stream discharge using the selected model.

The outputs of this research are:

a. TRMM rainfall correction equation of the Melawi Sub-Basin, which can be used by anyone who conducts satellite rainfall analysis in the Melawi Sub-Basin.
b. Synthetic discharge of the Melawi Sub-Basin can be used by anyone who will conduct analyses for water resource management and development in the Melawi Sub-Basin.

Thus, the results of this study can be one of the references for hydrological analyses in Sub-Basins with limited rainfall and discharge data records, especially the Melawi Sub-Basin in West Kalimantan.

2. Materials and Methods

2.1 Theoretical Frame Work

For various types of hydrological data, one of the most critical data that often serve as input in the hydrological analysis is rainfall data (Rusli, 2017). Typically, rainfall data is obtained from rain recording stations (observational stations), both manually (rain gauges) and automatically (automatic rainfall recorders), which are spatially distributed in a region. Unfortunately, in most areas of West Kalimantan, especially in the Melawi Sub-Basin, the spatial density of stations and the even distribution of rain stations still need to be improved, as many existing stations are no longer operational. It is known that rainfall distribution in West Kalimantan, especially in the upstream Kapuas Sub-Basin, is highly uneven (Soeryamassoeka, 2020). This causes the quality of hydrological analysis in West Kalimantan, particularly in the Melawi Sub-Basin, to be suboptimal. Therefore, other rainfall data sources are needed to obtain precipitation data to improve hydrological analysis quality in the Melawi Sub-Basin. Another source of rainfall data that can be used to optimize the quality of hydrological analysis in the Melawi Sub-Basin is satellite-based rainfall data from the Tropical Rainfall Measuring Mission (TRMM).

Based on various studies conducted on satellite-based rainfall data (TRMM), in its use, TRMM rainfall data must be validated and corrected so that when used as input data or supporting data in hydrological analysis, the results can be satisfactory and optimal. In this study, TRMM rainfall data was obtained by creating a grid in the Melawi Sub-Basin, with the temporal resolution of the precipitation grid being the 1-dimensional and spatial resolution of 0.25°x 0.25°, covering a range from 50°N to 50°S (Huffman et al., 2007; Kneis et al., 2014; Wu et al., 2018). Next, the TRMM rainfall data will be validated statistically using the available observational stations, namely BMG Susilo Station and Nanga Pinoh Station. For validation, a rainfall correction equation will be obtained to correct the existing TRMM rainfall data, resulting in corrected TRMM rainfall data (TRMM'). Subsequently, the corrected TRMM rainfall data will be used as input data to generate synthetic streamflow data in the Melawi Sub-Basin using the NRECA Model and the Mock Model to assess the reliability of the corrected TRMM rainfall data.

2.2 Research Location

The location of this research is in the Melawi Sub-Basin, which is part of the Kapuas Sub-Basin.

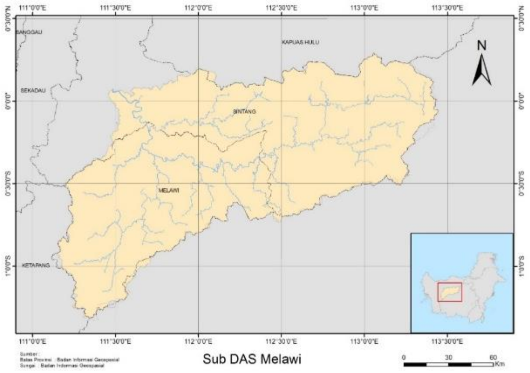
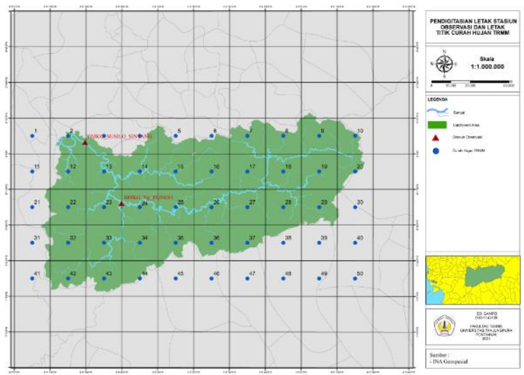


Fig. 1. The Melawi Sub-Basin

2.3 Data

The data used in this research are daily rainfall data that were converted into monthly rainfall and averaged over 22 years (1998-2019) for 2 (two) observation rainfall stations, namely BMKG Susilo and BMKG Nanga Pinoh, as well as 50 TRMM rainfall grid data, distributed in the Melawi Sub-Basin area. The TRMM rainfall data was obtained from the TRMM type 3B42RT satellite, which is near-real-time data with a data period from 1998 to 2019. The 3B42RT satellite data is in a grid format with a spatial resolution of 0.28° x 0.28°. The data format is binary and can be downloaded from ftp://disc2.nascom.nasa.gov/data/TRMM/Gridded. In addition to TRMM rainfall data and observation rainfall data, coordinates of the rainfall stations (BMKG) and the reviewed Sub-Basin (DAS) are also required. The determination of the observation rainfall stations as references for each sub-basin studied is based on their location within the grid created using QGIS 2.18.19.



▲ : Observation station
● : The grid of TRMM

Fig 2. Digitization of the location of observation rainfall stations and TRMM grids

2.4 Analysis Method

The research on the use of satellite-based rainfall data (Tropical Rainfall Measuring Mission/TRMM) as input for the Rainfall-Runoff Model of Melawi Sub-Basin consists of several analyses, namely (1) validation and correction of TRMM satellite rainfall data, (2) rainfall-runoff model analysis using the NRECA Model, and (3) rainfall-runoff model analysis using the Mock Model. The research process is as follows Fig.2:

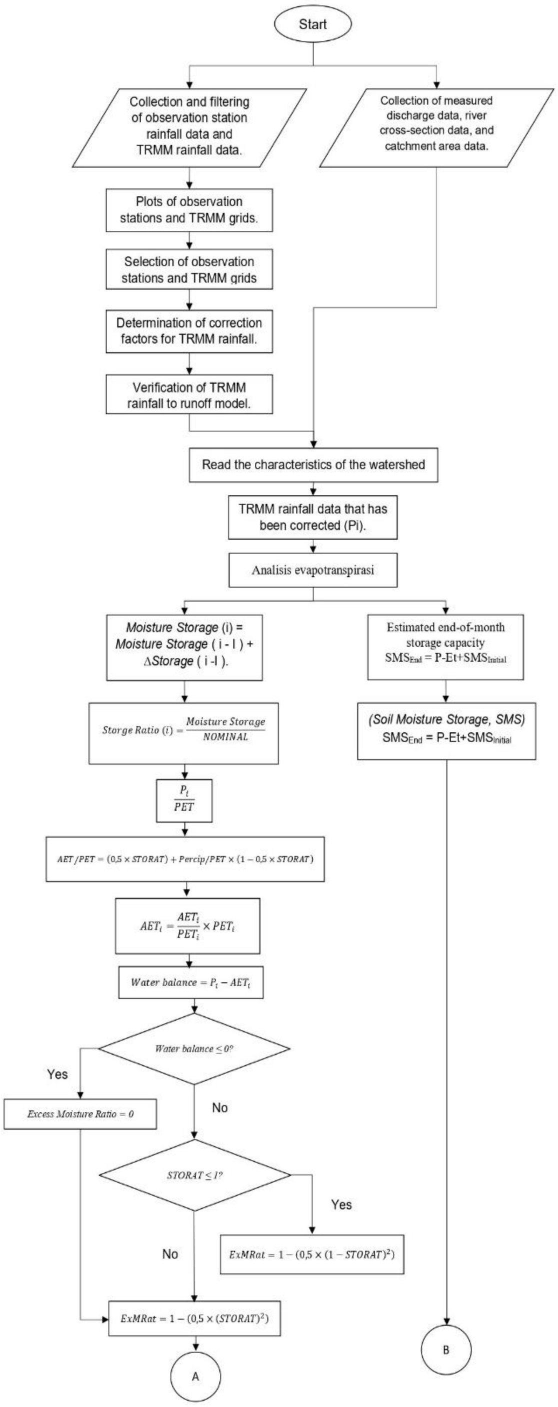


Fig. 2. Research Flowchart

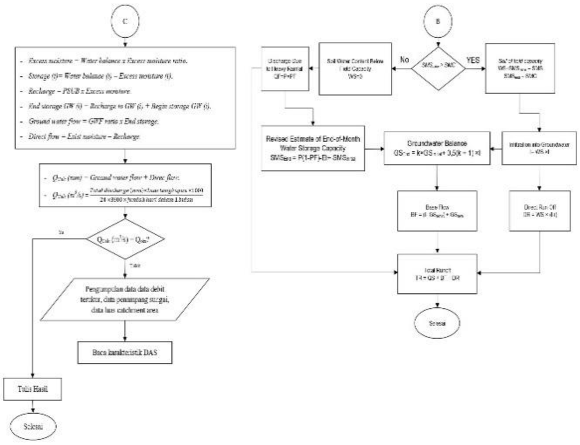


Fig. 2. (Continue) Research Flowchart

2.4.1. The Method of TRMM Rainfall Data Analysis

The Tropical Rainfall Measuring Mission (TRMM) is a remote sensing rainfall observation program jointly conducted by the National Space Development Agency of Japan (NASDA) and the National Aeronautics and Space Administration (NASA) (Kummerow et al., 2000; Nazrul et al., 2006; Wu et al., 2018; Soeryamassoeka, 2020).

The temporal resolution of the precipitation grid is one-dimensional, and the spatial resolution is 0.25° x 0.25°, covering a range from 50°N to 50°S (Wu et al., 2018; Kneis et al., 2014; Huffman et al., 2007). Since its publication in 1998, TRMM data has been widely used in various studies on weather and climate issues in Indonesia, such as the use of TRMM satellite data for the analysis of extreme weather conditions (Renggono et al., 2010; Marpaung et al., 2012; Noor et al., 2016).

There are various types and forms of rainfall data generated by TRMM, ranging from level 1 to level 3. Level 1 data is raw data that has been calibrated and geometrically corrected, level 2 data provides a geophysical parameter of rainfall at the exact spatial resolution but still in the original state when the satellite passed through the recorded area, while level 3 data provides rainfall values, mainly monthly rainfall conditions, which are a combination of rainfall conditions from level 2 (Syaifullah, 2014; Feidas, 2010).

2.4.2. Steps for TRMM Rainfall Analysis

The analysis of TRMM data is carried out as follows:

i. Data collection stage:

- Collect daily rainfall data from observation stations, namely BMKG Susilo and BMKG Nanga Pinoh, for 1998-2019.

- Download TRMM rainfall data for the years 1998-2019. Then, for analysis, extract TRMM rainfall data and data from rain gauge stations for the period 1998-2002 (5 years).

ii. Data processing stage:

Rainfall data from observation stations (BMKG Susilo and BMKG Nanga Pinoh) and TRMM satellite data are processed in this stage.
Data processing includes:

(i). *Selection of observation stations and TRMM grids to be used*.

The observation stations and TRMM grids are selected to assess the correlation between observation stations and the TRMM data to be used. The criteria for selection is the strength of the correlation between observation rainfall data and TRMM rainfall data. The regression model used is chosen based on the regression equation with the best correlation. The correlation equation is obtained based on the form of the regression equation. The general form of regression equation used is determined by examining the pattern of observed rainfall data and TRMM data at all study locations and the highest determination coefficient (R2) generated in each equation. The general form of regression equation used to determine the correlation is (Mamenun et al., 2014):

- Linear regression equation.
  $Y_i = a + bX_i + \varepsilon_i$ ……………..........…..(1)
- Exponential regression equation
  $Y_i = ae^{bX_i} + \varepsilon_i$ ....(2)
- Logarithmic regression equation
  $Y_i = a + b \text{ Ln } (X_i) + \varepsilon_i$..............................(3)

Y_i : Estimated rainfall data (mm).
X_i : Observed rainfall data (mm).
a : Intersection with the vertical axis.
b : Slope

The form of a correlation equation (r) used is:

$$r = \frac{n\,(\sum XY) - (\sum X)\,(\sum Y)}{\sqrt{\{n\,(\sum X^2) - (\sum X)^2\} - \{n\,(\sum Y^2) - (\sum Y)^2\}}} \quad ....(4)$$

r : The value of the correlation coefficient (r) (ranging from -1.0 to 1.0).
X : Variable X, rainfall value at the observation point (mm).
Y : Variable Y, estimated rainfall value (mm).
n : Amount of data.

In this research, only linear regression equation is used. The interpretation of correlation values is as follows (Asuero, 2006) according to the following table.

Table 1. Strength of Correlation

Size of r	Interpretation
0.90 to 1.00	Very high correlation
0.70 to 0.89	High correlation
0.50 to 0.69	Moderate correlation
0.30 to 0.49	Low correlation
0.00 to 0.29	Little if any correlation

After selecting observation stations and TRMM grids, data correction is performed using the selected observation stations.

2.4.3. Validation of TRMM Rainfall Data

Validation of TRMM rainfall data consists of calibration and correction stages (Soeryamassoeka, 2020).

(i) Model Calibration

Calibration is an effort to adjust the model output with data obtained from the field. Calibration aims to "adjust" the combination of parameters in the modeling so that the results can resemble the actual conditions. "adjust" refers to changing these parameters within a range appropriate for field conditions. This is commonly done because most parameters in the field cannot be measured precisely.

In this study, data calibration was performed using observation period data from 1998-2008 to evaluate and obtain correction equations for TRMM rainfall data by building monthly rainfall estimation models. The selected regression equations from the three models reviewed, namely linear regression, exponential regression, and logarithmic regression, were used as the basis for building the estimation models. The X variable represents rainfall data from observation stations, and the Y variable represents TRMM rainfall data.

The models were built by determining the correction factors. Determining correction factors for TRMM satellite data was done by using the least squares method to find the values of parameters a and b as correction factors in the linear equation between observation data and TRMM satellite data (Mamenun, 2014). In this method, the minimum sum of squared errors (JKG) is sought, where the smaller the error or JKG value, the better the model equation. The condition for the minimum limit of $\bar{V} \rightarrow \varepsilon \approx 0$, or $\frac{\partial \varepsilon}{\partial a} = 0$, $\frac{\partial \varepsilon}{\partial b} = 0$ or Or in other words, JKG = min $\sum_{i=1}^{n} [Y_i - (a+bx_i)]^2$

In this study, the leading statistical indicators used to determine whether the rainfall data is suitable for use after validation are the deterministic value (R^2), correlation (r), and Root Mean Square Error (RMSE). If the values of these parameters are better after validation than before, then the TRMM rainfall data is considered suitable for use. However, if these criteria are not met, further analysis should be conducted, starting from testing homogeneity, calibration, verification, and validation, by discarding data that is considered deviant and causing errors (Soeryamassoeka, 2020).

(ii) Model Correction

The correction stage is used as the training for the correction equation obtained. This is done by using rainfall data from observation stations from 2009-2019 as variable X and the corrected TRMM rainfall data from 2009-2019 as variable Y (TRMM').

iii. Statistical measures for data correction

- *Root Mean Square (RMSE)*

RMSE is the average value of the sum of squared errors, which indicates the magnitude of the errors generated by a forecasting model. The more significant the difference between the actual and predicted values, the larger the RMSE value. The equation used is as follows (Mamenun et al., 2014).

$$RMSE = \sqrt{\left[\frac{1}{N}\sum_{i=1}^{N}(X - Y)^2\right]} \quad \text{............(5)}$$

X : Observed rainfall.

Y : TRMM rainfall.

n : Amount of data.

To assess the accuracy of the error analysis, the RMSE value is categorized into five classes for monthly precipitation events, as proposed by Hariarta in 2015. This parameter serves as a tool to evaluate the performance of TRMM in predicting rainfall compared to ground station measurements. The RMSE division values obtained for Sumbawa according to Hariarta's study in 2015 are presented in Table 2.

Table 2 RMSE Class Division (Harianta, 2015)

RMSE	Interpretation
0-100	Very Small
10-200	Small
200-300	Moderate
300-400	Large
400-500	Very Large

After the validation process, the precipitation data in the Melawi Sub-Basin is averaged and then graphed to observe the pattern of the validated rainfall. Subsequently, the averaged data is used to analyze the rainfall-runoff transformation. The correction of TRMM data and its performance improvement needs to be verified. In this study, runoff modeling will be used to evaluate the performance of the TRMM correction that has been conducted. This analysis was chosen because rainfall data is commonly used for water availability calculations.

The rainfall model used to verify the TRMM correction is the NRECA and Mock models, precisely the calibration of NRECA and Mock model parameters. Calibration is performed using data from 2006, as complete measured discharge data, which will serve as a reference for the calibration of the rainfall-runoff transformation model, is only available every month for the year 2006. Subsequently, data from other years is used for verification.

- *Observation standard deviation ratio (RSR)*

Calibration and verification of the model were conducted using precipitation data, incorrect TRMM data, and corrected TRMM data to assess the performance of the calibration results. To gauge the accuracy of the TRMM precipitation in the runoff model, researchers looked at the correlation coefficient and the ratio of the standard deviation of the observations. (observation standard deviation ratio or RSR) are used with the equation (Soeryamassoeka, 2020).

$$RSR = \frac{\sqrt{\sum_1^n |Q_{Obs} - Q_{Sim}|^2}}{\sqrt{\sum_1^n |Q_{Obs} - \overline{Q_{Obs}}|^2}} \quad \text{................................(6)}$$

RSR : standard deviation of observations.

Q_{Obs} : measured discharge.

Q_{sim} : calculated discharge.

$\overline{Q_{Obs}}$: average measured discharge.

2.4.4. Method for Runoff Model Analysis

Water availability is the most fundamental aspect of Sub-Basin hydrology (Bengtsson et al., 2012). Water availability in a Sub-Basin is influenced by several factors, such as climate, topography, geology, and vegetation covering the land surface. Water availability in a Sub-Basin is the minimum flow rate during both rainy and dry seasons, measured at the outlet of the Sub-Basin (Irsyad, 2011). Water availability is defined as the total volume of river flow from a catchment area (Post, 2012). Water availability in a Sub-Basin can be analyzed by converting rainfall into runoff using methods such as the NRECA and Mock models.

a. NRECA Model

Model NRECA (National Rural Electric Cooperative Association) was developed by Norman H. Crawford (USA) in 1981 by applying the following water balance equation (Sudinda, 2000; Ginting, 2016; Limantara & Putra, 2016; Reichl & Hack, 2017):

Runoff = Rainfall - Evapotranspiration + Change in Storage

This model simplifies the Stanford Sub-Basin Model IV (SWM) (Limantara & Putra, 2016). The structure of the NRECA model divides the monthly flow into two components: direct runoff (surface runoff) and base flow. Storage is divided into two types: moisture storage and groundwater storage. Changes in storage are calculated as the difference between ending and beginning storage. Rainfall and evaporation determine how much moisture is stored, with extra moisture turning into direct runoff and groundwater recharge. Groundwater recharge and outflow are the primary drivers of groundwater storage. (Badan Litbang Department PU, 1994).

The NRECA parameters are calibrated to find the most suitable parameters so that the calculated hydrograph approximates the observed values (Sudinda, 2000). Since the primary input of the model is rainfall, the calibration period depends on the availability of rainfall data; for rivers without streamflow data, rainfall and potential evapotranspiration data can be used to calculate continuous streamflow. This calculation method transforms monthly rainfall and potential evapotranspiration data into monthly streamflow. Since monthly intervals are used, the routing process can be neglected (Ginting, 2016).

The principle of the NRECA model is the water balance equation (Crawford & Thurin, 1981; Shrestha et al., 2004).

Q = P - AET + ÄS...(7)

Q : Flow depth (mm/month)

P : Rainfall (mm/month)

AET : Actual Evapotranspiration

AS : Change in storage (mm/month)

Water is retained in soil moisture, groundwater layers, aquifers, and lakes (Crawford & Thurin, 1981; Tunas & Lesmana, 2011). The water balance equation is used at regular intervals, where precipitation, actual evaporation, and runoff are the total volumes of water entering and leaving the Sub-Basin during that time interval. The change in storage is the change in saturated groundwater within the time interval calculated by subtracting the final storage from the initial storage.

The calculation of runoff using the NRECA model is divided into two parts, namely direct runoff (DRO) and groundwater flow to the river (GF).

Qi = (DROi + Gfi) A (m^3/s)............................(8)

Q_i : Runoff (m^3/s).

DRO_i : Direct runoff (m/s).

Gf_i : Groundwater flow to the river (m/s).

A : Catchment Area (km^2).

b. NRECA model parameters.

The parameters of the NRECA model are quantities that describe the characteristics of the Sub-Basin area and are one of the determining factors for estimating the magnitude of discharge. In order to obtain discharge values that are similar to or approximate those that occur in the field, the parameters of the NRECA model must be calibrated through trial and error so that they can be used to estimate the actual discharge. The calibrated parameter values can then be applied to other systems (hydrological cycles) with similar hydrological characteristics. The parameters of the NRECA model are:

(i) Nominal

NOMINAL is the elevation of the Soil Moisture Storage (SMS) that determines half of the monthly positive water balance to become excess moisture, which will become Direct Runoff (DRO) and Groundwater Flow.

If SMS < NOMINAL, most of the positive water balance will be stored as soil moisture.

If SMS > NOMINAL, most of the positive water balance will become DRO and Groundwater Flow.

Increasing this parameter will control the volume of runoff. The value of NOMINAL can be obtained using the equation:

NOMINAL = 100 + C x Average Annual Rainfall.

Value of C = 0.2, for Sub-Basins with year-round rainfall. C < 0.2, for Sub-Basins with seasonal rainfall patterns. NOMINAL can be reduced by up to 25% for Sub-Basins with limited vegetation and thin soil cover.

(ii) PSUB

PSUB represents the percentage of surface runoff that enters groundwater storage. PSUB is a part of the excess moisture that will infiltrate the ground. Soils with low permeability and infiltration will have a small value of PSUB.

PSUB = 0.5 for Sub-Basins with normal rainfall.
0.5 < PSUB < 0.9 for Sub-Basins with large permeable aquifers.
0.3 ≤ PSUB < 0.5 for Sub-Basins with limited aquifers and thin soil layers

(iii) GWF

GWF is a parameter that controls the amount of groundwater outflow from an aquifer as groundwater flow. A more considerable GWF value indicates an enormous groundwater reserve that flows into rivers, depleting the aquifer more quickly.

GWF = 0.5 for areas with normal/average rainfall in the river catchment.

0.2 ≤ GWF < 0.5 for areas with reliable continuous river flow.

0.5 < GWF ≤ 0.8 for areas with continuous small-scale river flow.

Direct runoff (DF) is determined based on the excess rainfall on the surface, considering potential evapotranspiration and infiltration. The value of DF is calculated using the equation:

Dfi = Exi * (1-Psub)……………………..….........(9)

Dfi: Direct runoff in a month i (mm) Exi: Excess moisture in a month i

The excess moisture ratio is calculated based on the excess moisture value multiplied by the available water or the water balance value. The water balance value is calculated by subtracting the actual evapotranspiration from the rainfall amount for that month, i.e., Pi-AETi. Therefore, mathematically, the value of excess moisture (Exi) is calculated using the following equation:

Exi = Ei * (Pi-AETi) …………………....………(10)

Exi: Excess moisture in a month i Pi: Rainfall in a month i (mm) AETi: Actual evapotranspiration in a month i.

The value of excess moisture ratio is determined based on the soil moisture storage ratio as shown in the following graph (Ginting, 2016).

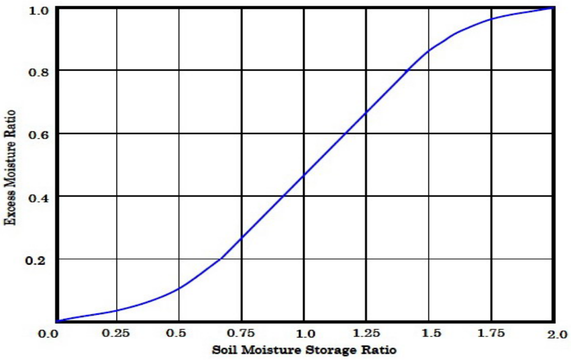


Fig. 3. The graph of soil moisture storage ratio

If the water balance value is greater than 0, then the excess moisture ratio is equal to the curved line graph in Figure (3). If the water balance value is less than 0, then the value of Exi is equal to 0.

The following mathematical equation can approximate the curved line graph in Figure (3):

$$E_i = 0{,}5 \times \left[\frac{\left(1+\left(exp\left(\frac{S_{ri}-1}{0{,}52}\right)-\exp\left(\frac{1-S_{ri}}{0{,}52}\right)\right)\right)}{\left(\exp\left(\frac{S_{ri}-1}{0{,}52}\right)+\exp\left(\frac{1-S_{ri}}{0{,}52}\right)\right)}\right] \text{...........(11)}$$

$$\text{or, } Ei = 0{,}5 \times\ 1 + \tanh \frac{S_{ri}-1}{0{,}52} \text{ ....(12)}$$

Ei : excess moisture ratio value in month i
Sri : storage ratio value in month i

Storage ratio is the ratio between the value of soil moisture storage and the NOMINAL parameter.

$$Sr = \frac{SMSTOR}{NOMINAL} \text{ ....(13)}$$

Actual evapotranspiration is the loss of water from actual soil moisture storage. The availability of soil moisture dramatically influences the magnitude of actual evapotranspiration. If the available soil moisture is sufficient to evaporate its potential water, then the actual value is equal to the potential value. If the soil moisture is insufficient, then the actual value is lower than the potential value. Because the calculation of actual evapotranspiration cannot be directly measured, it is estimated based on potential evapotranspiration (PET) or reference potential evapotranspiration (ETo) values.

PET can be calculated using the Penman equation. The Penman empirical formula considers climatological data such as temperature, solar radiation, humidity, and wind speed, making the results relatively more accurate. The calculation of Penman's potential evaporation is based on the fact that heat is required. There are several modifications to the Penman method, one of which is the FAO

Penman-Monteith method developed by Doorenbos and Pruitt (1975). Without considering night time wind speed, the estimated evapotranspiration rate can be calculated using the equation since wind speed data recorded during the day and night have not been separated at the study location.

$$ET_0 = \frac{\delta}{\delta + \tau} x R_n + \frac{\tau}{(\delta + \tau)} x[2{,}70(1{,}0 + 0{,}010\ U_2)(e_s - e_a)]$$

....(14)

The calculation of the magnitude of actual evapotranspiration (AET) determined based on PET is limited by the storage ratio criteria and also the rain/PET follows the principles as shown in the following figure:

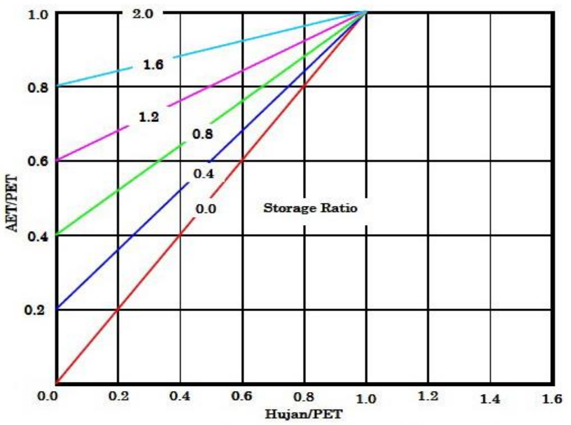


Fig 4. The graph of AET/PET comparison

Based on Figure 4, what is calculated is the magnitude of the AET/PET value based on the storage ratio and rain/PET values. To mathematically calculate the AET/PET value displayed as shown in Figure 4, the following steps should be taken:

$\frac{AET_i}{PET_i} = \left(1 - (0{,}5\ x\ Sr_i)\right) + (0{,}5\ x\ Sr_i)$...........(15)

For $Sr_i < 2$ dan $\frac{P_i}{PET_i} < 1$..............................(16)

$\frac{AET_i}{PET_i} = 1$ untuk $Sr_i > 2$ dan $\frac{P_i}{PET_i} > 1$............(17)

AET_i : Actual evapotranspiration of the i-th month.

Sr_i : The storage ratio value for the i-th month.

PET_i : The potential evapotranspiration value for the i-th month.

This baseflow comes from groundwater storage. This flow will move linearly towards the river according to its storage and groundwater parameter (GWF). This baseflow, along with surface runoff, becomes the flow in the river. The magnitude of this baseflow is calculated based on the equation:

GF_i = GWF x (PSUB x Exi + $GWSTOR_{i-1}$.....(18)

c. Mock Model

The Mock model was developed to calculate monthly average discharge. The data required for the calculation of discharge using the Mock method are rainfall, climatological data, and catchment area. Overall, the calculation of discharge using the Mock method refers to water balance, where the boundary conditions must be met (Soeryamassoeka, 2012).

The general form of the water balance equation is:

P = $E_a + \Delta GS + TRO$ ....(19)

P : Precipitation.

Ea : Actual Evapotranspiration

∆GS : Changes in groundwater storage..

TRO : Total Run off

The total volume of water on earth is constant, only its circulation and distribution varies. Water balance is a closed cycle that occurs during one year. Therefore, the water balance equation for a one-year period is:

P = $E_a + TRO$ ....(20)

Several things used as a reference in predicting discharge using the Mock method about water balance are:

- In one year, the change in groundwater storage (∆GS) must be equal to zero.
- The total amount of evapotranspiration and total runoff during one year must be equal to the total precipitation that occurred during that year. By still considering the boundary conditions of the water balance above, the discharge prediction using the mock method will be accurate.

d. Mock model parameters.

Generally, the parameters that will be explained here affect the amount of evapotranspiration, infiltration, groundwater storage, and storm runoff for each month, and most of these parameters are different. The parameters are:

(i). Infiltration coefficient (If), a coefficient based on soil porosity conditions and the slope of the drainage area. The infiltration coefficient is high if the soil is porous (absorbs water), the month is dry, and the land slope is not steep. Due to the different properties of each month, the If value can vary. In this calibration, the maximum value of the infiltration coefficient used is 1.00, and the minimum value is 0.01.

(ii). The streamflow recession constant (K) is the proportion of groundwater from the previous month that still exists in the current month. In this calibration, the maximum value of the streamflow recession coefficient is 1.00, and the minimum value is 0.01. In wet months, the value of K tends to be higher, meaning that the value of K varies each month.

(iii). Exposed surface (m) is the assumed proportion of the outer surface not covered by green vegetation in the dry season and is expressed as a percentage. The value of the exposed surface ranges from 0% to 50%. The value of m depends on the observed area. Mock classified the observed area into three parts: primary or secondary forest, eroded areas, and agricultural fields.

(iv). The reflection coefficient (α) is the ratio of the amount of solar radiation reflected by a surface to the amount of radiation that occurs. The reflection coefficient varies for each earth's surface. The value of α can be calculated based on the equation recommended by Wright in Cuenca 1986: $\alpha = 0.29+0.06 \sin [30(M + 0.0333N + 2.25]$.

(v). The percentage factor (PF) is the percentage of rainfall that becomes runoff. It is used to calculate storm runoff and is included in the total runoff only when P is less than the maximum value of soil moisture capacity (mm/month). The recommended value of PF by Mock is between 5% and 10%, but it is possible to increase it irregularly to a value of 37.3%.

e. Model Calibration

Calibration must be carried out for each parameter in the NRECA and mock models. Calibration is performed using the solver tool in Microsoft Excel. The reference is a measured discharge from 2005 with a correlation coefficient (r) and a root mean standard deviation ratio (RSR) as the benchmark. The value of r can be calculated using equation 4, and RSR with equation 6.

3. Result and Discussion

The following are the results of the analysis of the use of tropical rainfall measuring mission rainfall data as input data for water availability analysis with rainfall-runoff models in the Melawi sub-basin.

3.1 Analysis of TRMM Satellite Rainfall

As previously mentioned, the need for hydrological data, such as rainfall data, is one of the main problems in hydrological analysis, especially in the study location, the Melawi Sub-Basin. Rain gauge stations are not spatially distributed and tend to be concentrated in certain areas, so the data generated from these stations (observation/ground stations) cannot always be relied upon because not all of these observation stations record rainfall over long periods due to equipment damage or negligence by officers, which makes the data unusable in modeling. Therefore, satellite rainfall data from the Tropical Rainfall Measuring Mission (TRMM) can be used as an alternative.

However, TRMM data must be corrected before it can be used in the analysis by first comparing the rainfall data obtained from observation stations and TRMM measurements. This comparison checks whether the rainfall data from observation stations and TRMM are reliable for analysis. Correlation coefficients are used to evaluate this data. Because measurements are carried out in the same area for TRMM and observation stations, both data must have good correlation values. Rainfall data that pass the correlation assessment will be used in determining the correction of TRMM (Soeryamassoeka, 2020).

TRMM data is corrected monthly, assuming that the rainfall data from the observation stations is correct because it reflects the actual occurrence of events. In the correction process, the objective function is used to show the error of the TRMM in the observation station data. The correction will be done using a linear regression model with one unknown variable to be determined.

Examination and analysis of rainfall station and TRMM grid data throughout the study area is carried out in several stages:

(i). Stage 1: Spatially plotting all TRMM grids and observation stations to be used in the study area

(ii). Stage 2, selecting TRMM grids based on the correlation and RMSE analysis of TRMM grids to observation stations, with the criteria that the selected TRMM grid for validation must correlate (r) to the observation station ≥ 0.6 (Senjaya, 2020) and RMSE ≤ 130 mm (Soeryamassoeka, 2020).

(iii). Stage 3: Collect TRMM data for each selected grid in Stage 2 using observation stations (Susilo BMKG Station and Nanga Pinoh BMKG Station).

3.1.1. Plot the observation stations and TRMM grids

Ideally, in the selection of rain gauges and TRMM grids, each TRMM grid should have at least one rain gauge because the area per grid is quite large, which is 0.25^{o} x $0.^{25o}$, or about 27.75 km x 27.5 km, while tropical storm rains tend to occur locally or less than 10 km away (Vernimmen et al., 2012; Mamenun et al., 2014; Soeryamassoeka, 2020). Thus, the more rain gauges in one grid, the more representative the rainfall can be for each grid. However, this criterion is difficult for the study area, namely the Melawi Sub-Basin, because the number of observation stations with consistent and long data is minimal. Therefore, for 50 TRMM grids, only two observation stations are used, as shown in Figure 5.

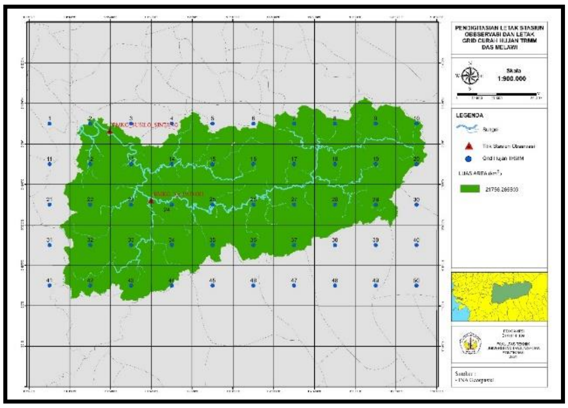


Fig.5. Digitizing the location of rainfall observation stations and TRMM rainfall in Melawi Sub-Basin

After the observation stations and TRMM grids are spatially plotted, all daily rainfall data from five observation stations are summarized into monthly rainfall and tested for homogeneity and consistency to be used as a reference for calibrating and validating TRMM rainfall data. Homogeneity testing is performed using a t-Test: assuming equal variances, with the equation as follows:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{(n_1-1)S_1^2 + (n_2-1)S_2^2}{n_1+n_2-2}\left(\frac{1}{n_1}+\frac{1}{n_2}\right)}} \quad \text{................(21)}$$

.

$\bar{X}_1$: The means value of sample 1 (rainfall of station 1).
$\bar{X}_2$: The means value of sample 2 (rainfall of station 2).
n_1 : The number of samples for sample 1
n_2 : The number of samples for sample 2
S_1 : The standard deviation of sample 1.
S_2 : The standard deviation of sample 2.
t : t-value
If the t-value is a t-table, then the two tested samples are homogenous, and if the t-value is > t-table, then the two tested samples are not homogenous.

The following is a summary of the results of homogeneity testing of rainfall data in the Melawi Sub-Sub-Basin.

Table 2. Results of Homogeneity Test of Rainfall Data from the Two Observation Stations

Station	BMKG Susilo	BMKG Nanga Pinoh
n	22	22,0
Average	3076,68	3704,14
S	480,32	544,45
dk		42
$t_{Calculation}$		-4,053601057
t_{Table}		2,324620144

Because the calculated t-value is < the table t-value, it can be concluded that the two observation stations used are homogenous.
After conducting a test of homogeneity of rainfall data from both observation stations, a consistent test of rainfall data from both stations was then performed.
After conducting a homogeneity test on the rainfall data from the two observation stations, the next step is to test the consistency of the rainfall data from both stations using the Cumulative Deviation (Rescaled Adjusted Partial Sum/RAPS) method.
Consistency testing of rainfall data using the RAPS method is done using a table, with explanations as follows:

- Column 1, data (Yi); find the average and standard deviation.
- Column 2; the difference between the I data and the average value (Y - $\bar{Y}$)
- Column 3; the value of the cumulative deviation from the average value (Sk) with the equation S*k = $\sum_{i=1}^{k}(Y_i - \bar{Y})$, with k = 1, 2, 3, ..., n.
- Column 4; the value of rescaled adjusted partial sums (RAPS) marked with S**k, using the equation S**k = $\frac{S^*k}{D_y}$, with k = 0, 1, 2, 3, ..., n and Dy = $\sum_{i=1}^{k}\frac{(Y_i - \bar{Y})^2}{n}$.
- Calculate the value of
  Q = $\max_{0<k<n}|S^{**}k|$ or
  R = $\max_{0<k<n}|S^{**}k|$ - $\min_{0<k<n}|S^{**}k|$.
- Calculate Q/√n or R/√n and compare its value with the critical value of Q or R from the following table;

Table 3. Critical Q and R values

n	$\frac{Q}{\sqrt{n}}$			$\frac{R}{\sqrt{n}}$		
	90%	95%	99%	90%	95%	99%
10	1.05	1.14	1.29	1.21	1.28	1.38
20	1.1	1.22	1.42	1.34	1.43	1.60
30	1.12	1.24	1.46	1.4	1.5	1.70
40	1.13	1.26	1.50	1.42	1.53	1.74
50	1.14	1.27	1.52	1.44	1.55	1.78
100	1.17	1.29	1.55	1.5	1.62	1.86
∞	1.22	1.36	1.63	1.62	1.75	2.00

If the value of Q is used as a testing reference, the result will be declared consistent if Q/√n is calculated < Q/√n table. If the value of R is used as a testing reference, the result will be declared consistent if R/√n is calculated > R/√n table.

To obtain the value of Q or R if n is not included in the table, interpolation is performed.

The test results are presented in the following tables;

Table 4. Consistency test results of BMKG Susilo Station rainfall Data based on Q value with RAPS method

Year	Yi 1	Y_i-Y_{rata} 2	S*K 3	S**K 4
1998	3483,70	407,02	407,02	0,85
1999	3073,80	-2,88	-2,88	-0,01
2000	3224,40	147,72	147,72	0,31
2001	2607,10	-469,58	-469,58	-0,98
2002	2984,50	-92,18	-92,18	-0,19
2003	3060,40	-16,28	-16,28	-0,03
2004	3147,90	71,22	71,22	0,15
2005	3232,50	155,82	155,82	0,32
2006	2661,80	-414,88	-414,88	-0,86
2007	3648,00	571,32	571,32	1,19
2008	3094,60	17,92	17,92	0,04
2009	3176,20	99,52	99,52	0,21
2010	4052,10	975,42	975,42	2,03
2011	2823,10	-253,58	-253,58	-0,53
2012	3181,60	104,92	104,92	0,22
2013	2476,20	-600,48	-600,48	-1,25
2014	1797,50	-1279,18	-1279,18	-2,66
2015	2706,10	-370,58	-370,58	-0,77
2016	3803,40	726,72	726,72	1,51
2017	2862,10	-214,58	-214,58	-0,45
2018	3467,60	390,92	390,92	0,81
2019	3122,30	45,62	45,62	0,09
n = 22 Y_{rata} = 3076,68 S = 480,32			Q =	2,03
$\frac{Q}{\sqrt{n}}$ =	0,433	$\frac{Q}{\sqrt{n}}$ Tabel	1,224	OK

Table 5. Consistency test results of BMKG Nanga Pinoh Station rainfall Data based on Q value with RAPS method

Tahun	Yi 1	Y_i-Y_{Rata} 2	S*K 3	S**K 4
1998	4435,20	731,06	731,06	1,34
1999	3856,40	152,26	152,26	0,28
2000	3934,20	230,06	230,06	0,42
2001	3371,40	-7075,54	-7075,54	-13,00
2002	3060,20	-643,94	-643,94	-1,18
2003	3279,40	-424,74	-424,74	-0,78
2004	3707,70	3,56	3,56	0,01
2005	3316,60	-387,54	-387,54	-0,71
2006	3031,50	-672,64	-672,64	-1,24
2007	4339,50	635,36	635,36	1,17
2008	4233,50	529,36	529,36	0,97
2009	3213,50	-490,64	-490,64	-0,90
2010	4870,40	1166,26	1166,26	2,14
2011	3201,50	-502,64	-502,64	-0,92
2012	3674,50	-29,64	-29,64	-0,05
2013	3798,80	94,66	94,66	0,17
2014	3037,20	-666,94	-666,94	-1,22
2015	3743,10	38,96	38,96	0,07
2016	4235,40	531,26	531,26	0,98
2017	4538,40	834,26	834,26	1,53
2018	3212,70	-491,44	-491,44	-0,90
2019	3400,00	-304,14	-304,14	-0,56
n = 22 Y_{rata} = 3704,14 S = 544,45			Q =	2,14
$\frac{Q}{\sqrt{n}}$ =	0,457	$\frac{Q}{\sqrt{n}}$ Tabel	1,224	OK

From the analysis of homogeneity and consistency, it can be known that the BMKG Susilo Station and the BMKG Nanga Pinoh Station can be used as comparison stations for calibrating and validating TRMM rainfall in the Melawi sub-Sub-Basin.

3.1.2. The selection of the TRMM grid is based on linear regression correlation

Due to the limitations of the availability of observation station data, data screening is carried out at the entire study site. Rainfall data from two observation stations, namely the BMKG Susilo Station and the BMKG Nanga Pinoh Station, will be calculated for their correlation with 50 TRMM data grids. The rainfall data from each station will be evaluated for its correlation coefficient with the TRMM data. The benchmark for determining whether the TRMM grid correctly represents rainfall events at the location is a correlation coefficient (r) of 0.6. If the correlation coefficient (r) is ≥ 0.6, the TRMM data is in line with the observation station data and can be used for further analysis. If the correlation coefficient (r) is less than 0.6, the TRMM data cannot be used and will be removed.

The following are the results of the selection of TRMM grids based on linear regression correlation.

Table 6. The result of the correlation analysis between TRMM grids and observation stations

Grid	BMKG Susilo Sintang	BMKG Nanga Pinoh	Grid	BMKG Susilo Sintang	BMKG Nanga Pinoh
1	0,8	0.69	26	0.65	0.78
2	0,79	0.70	27	0.65	0.76
3	0,78	0.71	28	0.66	0.73
4	0,75	0.71	29	0.61	0.65
5	0,7	0.71	30	0.57	0.63
6	0.68	0.72	31	0.71	0.78
7	0.69	0.71	32	0.69	0.80
8	0.67	0.67	33	0.67	0.81
9	0.62	0.60	34	0.66	0.80
10	0,59	0,59	35	0.65	0.78
11	0.74	0.75	36	0.63	0.76
12	0.73	0.76	37	0.63	0.75
13	0.69	0.77	38	0.62	0.72
14	0.69	0.75	39	0.58	0.65
15	0.68	0.75	40	0.54	0.63
16	0.68	0.74	41	0.69	0.76
17	0.67	0.74	42	0.67	0.78
18	0,65	0.71	43	0.66	0.79
19	0.62	0,62	44	0.63	0.77
20	0,58	0.60	45	0.63	0.74
21	0.71	0.78	46	0.61	0.73
22	0.69	0.80	47	0.59	0.72
23	0.67	0.81	48	0.57	0.70
24	0.66	0.79	49	0.54	0.63
25	0.65	0.78	50	0.51	0.62

From Table (6), it can be seen that there are nine TRMM grids (grids 10, 20, 30, 47, 48, 49, and 50) that correlate with BMKG Susilo station < 0.6, and one TRMM grid (grid 10) that correlates with BMKG Nanga Pinoh station < 0.6. Therefore, in the following calculation, those TRMM grids are not used.

3.1.3. Validation of TRMM rainfall data

After filtering the data, the next step is to validate the TRMM rainfall data. Validation is divided into two stages, namely, the calibration stage and the verification stage. Validation is done by dividing the data into two groups, with at least five data points in the first group. In this study, because the available rainfall data covers 22 years, the data is divided into a ratio of 11:11, where 11 years of data are used for calibration and the next 11 years for verification analysis. The calibration process uses a simple regression equation to determine the correction equation by selecting the most significant determination factor (R^2) as the determinant of the equation used.

Calibration is the process of optimizing parameter values to improve the coherence between hydrological responses, which in this study is done to obtain the appropriate equation for correcting TRMM data. Verification, conversely, tests the equation obtained in the calibration stage. During verification, the equation obtained during calibration is tested by inputting TRMM rainfall values into the equation obtained in the calibration stage. Subsequently, the correlation (r) and RMSE obtained during verification are compared with those obtained during calibration. If the correlation is ≥ 0.6 or the RMSE ≤ 130 mm, then the verification is acceptable, and the TRMM rainfall data will be valid.

The following is the calibration and verification of TRMM rainfall data for each grid. The calculation is done using a table to simplify the analysis. For example, the calibration and verification of grid 1 TRMM are presented. The steps taken for the calibration and verification analysis using an example calculation with grid 1 TRMM and the Susilo BMKG station are as follows:

- Divide the TRMM rainfall data and the observation station rainfall data into two groups with 11 years each for calibration (1998-2008) and verification (2009-2019).
- Create a scatterplot graph with TRMM rainfall data and observation station rainfall data. During calibration, the X-axis is the observation station rainfall data, and the Y-axis is the TRMM rainfall data. During verification, the X-axis is the observation station rainfall data, and the Y-axis is the TRMM rainfall data that has been input into the calibration equation.
- Display the regression equation formed by the relationship between TRMM rainfall data and observation station rainfall data.

The following is a summary of the calibration and verification results that have been conducted:

Table 7. Recapitulation of the calibration and verification results of TRMM Grid in the Melawi Sub-Basin using BMKG Susilo Station

Grid TRMM	R^2		r		RMSE	
	Calibration	Verification	Calibration	Verification	Calibration	Verification
1	0,640	0,574	0,800	0,758	63,441	93,549
2	0,625	0,573	0,791	0,757	68,247	97,489
3	0,602	0,550	0,776	0,742	70,135	104,180
4	0,570	0,516	0,755	0,718	73,221	111,369
5	0,490	0,440	0,700	0,664	86,611	127,042
6	0,463	0,414	0,681	0,644	87,230	123,024
7	0,469	0,404	0,685	0,635	84,510	121,006
8	0,448	0,396	0,669	0,629	84,211	110,821
9	0,382	0,349	0,618	0,591	88,225	101,523
10	0,347	0,319	0,589	0,564	94,531	108,939
11	0,552	0,520	0,743	0,721	79,066	103,552
12	0,536	0,506	0,732	0,712	86,217	108,030
13	0,489	0,467	0,699	0,683	96,472	117,904
14	0,476	0,449	0,690	0,670	92,374	120,154
15	0,463	0,435	0,680	0,659	90,815	116,610
16	0,457	0,447	0,676	0,669	90,898	109,744
17	0,443	0,419	0,665	0,647	89,624	110,570
18	0,428	0,366	0,654	0,605	83,784	108,923
19	0,379	0,325	0,615	0,570	90,593	106,871
20	0,341	0,282	0,584	0,531	94,061	114,442

Table 7. (Continue) Recapitulation of the calibration and verification results of TRMM Grid in the Melawi Sub-Basin using BMKG Susilo Station

Grid TRMM	R^2		r		RMSE	
	Calibration	Verification	Calibration	Verification	Calibration	Verification
21	0,509	0,470	0,714	0,685	86,397	111,216
22	0,479	0,442	0,692	0,665	94,979	120,300
23	0,446	0,405	0,668	0,636	100,097	124,273
24	0,436	0,410	0,660	0,640	98,956	116,705
25	0,426	0,393	0,653	0,627	93,468	110,230
26	0,424	0,394	0,652	0,628	92,486	106,546
27	0,420	0,374	0,648	0,612	91,105	111,416
28	0,422	0,372	0,650	0,610	91,166	112,007
29	0,371	0,317	0,609	0,563	92,027	108,750
31	0,499	0,485	0,707	0,696	89,660	104,680
32	0,474	0,459	0,689	0,677	96,441	112,307
33	0,446	0,412	0,668	0,642	95,334	113,552
34	0,431	0,395	0,657	0,628	96,875	112,151
35	0,417	0,375	0,646	0,612	95,222	112,684
36	0,402	0,367	0,634	0,606	97,880	112,675
37	0,396	0,345	0,630	0,587	96,973	121,500
38	0,391	0,351	0,625	0,592	96,920	117,866
39	0,342	0,319	0,584	0,565	103,810	121,256
40	0,294	0,239	0,543	0,489	108,466	138,518
41	0,474	0,450	0,689	0,671	89,950	100,170
42	0,448	0,413	0,670	0,643	89,887	102,868
43	0,429	0,394	0,655	0,628	95,138	108,262
44	0,401	0,368	0,633	0,607	100,390	116,595
45	0,398	0,356	0,631	0,597	99,748	122,683
46	0,373	0,323	0,611	0,568	104,878	131,044

Table 8. Recapitulation of the calibration and verification results of TRMM Grid in the Melawi Sub-Basin using BMKG Nanga Pinoh Station

Grid TRMM	R^2		r		RMSE	
	Calibration	Verification	Calibration	Verification	Calibration	Verification
1	0,734	0,461	0,857	0,679	63,441	121,877
2	0,706	0,508	0,840	0,713	68,247	115,907
3	0,694	0,542	0,833	0,736	70,135	110,932
4	0,672	0,519	0,820	0,720	73,221	111,581
5	0,584	0,503	0,764	0,709	86,611	111,747
6	0,673	0,509	0,820	0,714	87,230	112,700
7	0,665	0,485	0,815	0,696	84,510	115,924
8	0,610	0,427	0,781	0,653	84,211	123,208
9	0,470	0,327	0,686	0,572	88,225	137,468
11	0,701	0,570	0,837	0,755	79,066	103,552
12	0,700	0,601	0,837	0,775	86,217	104,837
13	0,688	0,622	0,830	0,788	96,472	98,715
14	0,708	0,596	0,842	0,772	92,374	100,043
15	0,684	0,581	0,827	0,762	90,815	105,487
16	0,684	0,568	0,827	0,754	90,898	109,937
17	0,676	0,533	0,822	0,730	89,624	113,496
18	0,646	0,482	0,804	0,695	83,784	120,866
19	0,479	0,348	0,692	0,590	90,593	134,061
20	0,468	0,310	0,684	0,557	94,061	133,220
21	0,725	0,618	0,851	0,786	86,397	104,451
22	0,738	0,681	0,859	0,825	94,979	93,110
23	0,753	0,679	0,868	0,824	100,097	90,035
24	0,733	0,651	0,856	0,807	98,956	95,562
25	0,718	0,651	0,847	0,807	93,468	102,286
26	0,720	0,616	0,849	0,785	92,486	107,569
27	0,721	0,554	0,849	0,745	91,105	110,843
28	0,658	0,504	0,811	0,710	91,166	115,943
29	0,512	0,391	0,715	0,625	92,027	129,803
30	0,477	0,355	0,691	0,596	97,330	130,026
31	0,700	0,612	0,837	0,783	89,660	106,530
32	0,723	0,644	0,850	0,802	96,441	98,528
33	0,746	0,665	0,864	0,816	95,334	96,443
34	0,730	0,648	0,854	0,805	96,875	100,493
35	0,707	0,619	0,841	0,787	95,222	104,928
36	0,685	0,585	0,827	0,765	97,880	106,890
37	0,648	0,576	0,805	0,759	96,973	107,906
38	0,600	0,528	0,774	0,727	96,920	114,048
39	0,451	0,443	0,672	0,666	103,810	122,394
40	0,452	0,370	0,672	0,608	108,466	124,918
41	0,677	0,567	0,823	0,753	89,950	113,691
42	0,710	0,596	0,842	0,772	89,887	110,154
43	0,729	0,628	0,854	0,792	95,138	104,503
44	0,691	0,584	0,831	0,764	100,390	105,143
45	0,654	0,554	0,809	0,744	99,748	108,297
46	0,607	0,535	0,779	0,731	104,878	109,970
47	0,562	0,522	0,750	0,723	110,710	111,795
48	0,514	0,510	0,717	0,714	114,233	114,413
49	0,393	0,425	0,627	0,652	121,138	123,255
50	0,389	0,375	0,624	0,612	121,165	126,668

From the results of the calibration and verification of TRMM grid data using both BMKG Susilo Station (Table 4.7) and BMKG Nanga Pinoh (Table 4.8), it is known that there are still TRMM grids whose correlation, when verified, is <0.6 (highlighted text), thus, those TRMM grid data are discarded and used in further analysis.

After validation with the calibration and verification steps, the most appropriate correction equation for TRMM grid rainfall data for the Melawi Sub-Sub-Basin was determined. The correction equation is taken from the grid with the best correlation value when calibrated using BMKG Susilo Station and BMKG Nanga Pinoh, resulting in only one correction equation. The analysis shows that Grid 23 TRMM has the best correlation value, so the equation generated during the calibration of Grid 23 TRMM is used as the correction equation for TRMM grid rainfall data in Melawi Sub-Sub-Basin. The equation is **Y = 0.748 X + 62.191**, where X is the TRMM rainfall data per grid.

The reliability of this equation must be assessed through similar calculations to those performed in the previous section to ensure a correlation of ≥ 0.6 and an RMSE reliance of ≤130 mm. The recapitulation of the calculation results is as follows:

Table 9. The recapitulation of the correlation and RMSE results of TRMM Grid correction in Melawi Sub-Basin using the equation Y = 0.748 X + 62.191 for BMKG Susilo Observation Station

Grid TRMM	R^2		r		RMSE	
	Before Correction	After Correction	Before Correction	After Correction	Before Correction	After Correction
1	0,640	0,640	0,800	0,800	63,441	73,409
2	0,625	0,625	0,791	0,791	68,247	74,850
3	0,602	0,602	0,776	0,776	70,135	77,959
4	0,570	0,570	0,755	0,755	73,221	82,191
5	0,490	0,490	0,700	0,700	86,611	92,346
6	0,463	0,463	0,681	0,681	87,230	139,645
7	0,469	0,469	0,685	0,685	84,510	91,953
8	0,448	0,448	0,669	0,669	84,211	91,321
11	0,552	0,552	0,743	0,743	79,066	82,439
12	0,536	0,536	0,732	0,732	86,217	84,146
13	0,489	0,489	0,699	0,699	96,472	90,107
14	0,476	0,476	0,690	0,690	92,374	91,917
15	0,463	0,463	0,680	0,680	90,815	92,085
16	0,457	0,457	0,676	0,676	90,898	91,213
17	0,443	0,443	0,665	0,665	89,624	92,104
18	0,428	0,428	0,654	0,654	83,784	91,902
21	0,509	0,509	0,714	0,714	86,397	86,833
22	0,479	0,479	0,692	0,692	94,979	91,089
23	0,446	0,446	0,668	0,668	100,097	94,673
24	0,436	0,436	0,660	0,660	98,956	94,249
25	0,426	0,426	0,653	0,653	93,468	93,089
26	0,424	0,424	0,652	0,652	92,486	92,251
27	0,420	0,420	0,648	0,648	91,105	93,389
28	0,422	0,625	0,650	0,791	91,166	74,850
29	0,371	0,371	0,609	0,609	92,027	95,442
31	0,499	0,499	0,707	0,707	89,660	86,538
32	0,474	0,474	0,689	0,689	96,441	90,126
33	0,446	0,446	0,668	0,668	95,334	92,405
34	0,431	0,431	0,657	0,657	96,875	92,912
35	0,417	0,417	0,646	0,646	95,222	93,892
36	0,402	0,402	0,634	0,634	97,880	95,887
37	0,396	0,396	0,630	0,630	96,973	97,336
38	0,391	0,391	0,625	0,625	96,920	97,065
39	0,342	0,342	0,584	0,584	103,810	101,869
41	0,474	0,474	0,689	0,689	89,950	87,184
42	0,448	0,448	0,670	0,670	89,887	89,605
43	0,429	0,429	0,655	0,655	95,138	92,158
44	0,401	0,401	0,633	0,633	100,390	96,379
45	0,398	0,398	0,631	0,631	99,748	97,741
46	0,373	0,373	0,611	0,611	104,878	101,465

Table 10. The recapitulation of the correlation and RMSE results of TRMM Grid correction in Melawi Sub-Basin using the equation Y = 0.748 X + 62.191 for BMKG Nanga Pinoh Observation Station

Grid TRMM	R^2		r		RMSE	
	Before Correction	After Correction	Before Correction	After Correction	Before Correction	After Correction
1	0,531	0,531	0,729	0,729	104,998	110,211
2	0,558	0,558	0,747	0,747	101,874	106,550
3	0,576	0,576	0,759	0,759	99,033	103,744
4	0,567	0,567	0,753	0,753	99,569	104,011
5	0,569	0,569	0,754	0,754	99,010	102,824
6	0,570	0,570	0,755	0,755	98,726	110,469
7	0,557	0,557	0,746	0,746	100,219	105,721
8	0,499	0,499	0,707	0,707	106,930	111,979
9	0,382	0,382	0,618	0,618	120,973	137,319
11	0,625	0,625	0,791	0,791	93,172	101,308
12	0,645	0,645	0,803	0,803	90,424	97,822
13	0,651	0,651	0,807	0,807	89,315	94,897
14	0,638	0,638	0,799	0,799	91,018	95,446
15	0,619	0,619	0,787	0,787	93,018	99,019
16	0,611	0,611	0,782	0,782	94,258	101,486
17	0,588	0,588	0,767	0,767	97,060	103,897
18	0,546	0,546	0,739	0,739	102,376	109,089
21	0,665	0,665	0,815	0,815	87,903	96,847
22	0,704	0,552	0,839	0,743	82,002	107,138
23	0,711	0,711	0,843	0,843	81,213	87,985
24	0,684	0,684	0,827	0,827	85,176	91,878
25	0,675	0,675	0,822	0,822	86,811	95,837
26	0,659	0,659	0,812	0,812	89,596	98,665
27	0,624	0,624	0,790	0,790	93,143	101,005
28	0,571	0,552	0,756	0,743	99,234	107,138
29	0,444	0,444	0,666	0,666	113,636	118,151
31	0,651	0,651	0,807	0,807	90,043	98,646
32	0,678	0,678	0,824	0,824	85,927	93,625
33	0,698	0,698	0,835	0,835	83,501	91,844
34	0,684	0,684	0,827	0,827	85,613	94,399
35	0,657	0,657	0,810	0,810	89,095	97,587
36	0,627	0,627	0,792	0,792	92,309	99,494
37	0,604	0,604	0,777	0,777	94,838	101,007
38	0,556	0,556	0,746	0,746	100,416	105,917
39	0,441	0,441	0,664	0,664	113,100	115,056
40	0,401	0,401	0,633	0,633	118,792	117,105
41	0,617	0,617	0,786	0,786	95,384	103,144
42	0,645	0,645	0,803	0,803	91,987	100,217
43	0,674	0,674	0,821	0,821	87,522	96,601
44	0,632	0,632	0,795	0,795	91,764	98,391
45	0,597	0,597	0,773	0,773	95,603	101,110
46	0,566	0,566	0,752	0,752	99,352	102,991
47	0,539	0,539	0,734	0,734	102,945	104,814
48	0,510	0,510	0,714	0,714	106,263	107,511
49	0,407	0,407	0,638	0,638	119,131	116,198
50	0,379	0,379	0,616	0,616	122,491	118,746

From the analysis that has been conducted, it can be concluded that the equation Y = 0.748 X + 62.191 can be used as a correction factor for TRMM rainfall data in the Melawi sub-basin because when this equation is used and compared with the two observation stations, BMKG Susilo and BMKG Nanga Pinoh, the correlation results are ≥ 0.6 and the RMSE ≤ 130 mm. Even though the RMSE is more prominent after the correction, as long as it is < 130 mm, the validation is considered valid.

3.2 Run-Off Model Analysis Result

The runoff model in this study was carried out using the NRECA and Mock models. In this study, a preliminary analysis was carried out to analyze the runoff model, namely (a) analysis of regional rainfall and (b) analysis of potential evapotranspiration.

3.2.1. Regional Rainfall Analysis Result

Rainfall in the area is used to obtain values that represent the amount of rainfall in a particular region. This study had two observation stations (BMKG Susilo Station and BMKG Nanga Pinoh Station) and 45 TRMM grids that could be used within and around the Melawi Sub-Basin, so the average rainfall value of the area is needed. The average rainfall of the area in this study was calculated using the Thiessen polygon method with ArcGIS 10.3 software as a tool. The Thiessen polygon is created by overlapping the Sub-Basin map with the locations of observation stations and TRMM grids so that the percentage of the influence of the area of a specific rain station on the entire Sub-Basin area can be obtained.

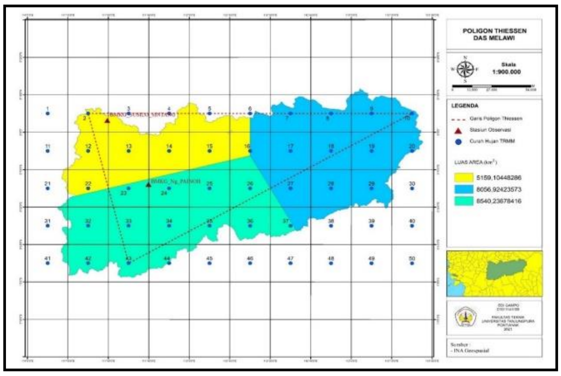


Fig 6. Thiessen Polygon Map of Melawi Sub-Basin

Based on the modelling results using ArcGIS 10.3 software, the Melawi Sub-Basin is divided into three (3) areas. The observation stations and TRMM grids included in each area are averaged for further calculations, while the TRMM grids not included can be ignored because they are not used. The percentage of each area to the total area size can be determined from the created Thiessen polygon map.

The following are the results of the recapitulation of rainfall analysis in the Melawi Sub-Basin area

Table 11. Recapitulation of the results of rainfall calculations for the Melawi Sub-Basin area (mm) for the period 1998-2019

Tahun	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1998	264,21	223,54	220,07	318,02	244,44	206,54	248,23	421,34	305,73	267,36	266,59	278,28
1999	349,59	187,04	294,81	290,35	305,19	165,29	174,81	304,86	271,07	441,72	305,80	376,69
2000	415,30	270,21	249,80	375,36	183,70	213,54	168,15	221,01	394,55	335,78	329,83	266,04
2001	364,21	242,12	193,71	298,90	159,06	168,73	224,30	149,78	252,82	226,94	411,97	237,92
2002	382,57	241,60	314,05	227,11	269,58	260,27	141,26	126,38	183,23	201,77	311,80	320,86
2003	354,66	394,08	289,74	283,01	146,97	230,29	200,10	161,74	217,20	306,85	305,82	284,22
2004	393,67	162,42	296,91	301,11	241,51	106,70	381,62	71,36	317,89	238,74	390,94	513,30
2005	263,96	291,17	332,39	236,91	348,82	264,89	264,32	140,96	259,74	397,26	272,17	327,22
2006	210,96	171,89	84,70	66,39	82,39	95,90	104,87	96,16	200,00	201,87	219,42	176,28
2007	316,32	273,98	246,85	336,86	328,85	260,09	291,67	214,42	272,89	359,42	321,79	531,31
2008	284,07	224,87	444,20	268,77	241,51	254,70	235,78	328,04	317,10	446,91	388,36	305,20
2009	297,74	254,90	289,09	367,39	224,74	227,86	185,38	177,22	139,86	337,54	327,72	464,71
2010	332,53	304,40	338,58	272,83	302,27	289,50	435,68	439,75	442,19	378,14	360,51	352,34
2011	293,34	206,17	251,12	274,24	277,98	232,65	180,66	153,34	196,80	421,90	329,84	367,91
2012	239,34	353,53	344,62	274,60	182,32	177,70	268,37	251,39	163,83	469,18	405,60	342,18
2013	210,89	322,96	250,30	282,08	301,87	152,46	298,53	233,81	341,66	224,45	319,74	518,65
2014	226,38	123,11	285,37	271,38	308,83	243,33	114,54	244,91	184,36	287,39	411,01	334,43
2015	374,31	315,01	276,97	363,21	267,11	274,52	182,44	138,91	152,58	206,35	456,42	332,66
2016	329,60	482,59	439,14	399,27	320,98	304,04	253,84	167,75	291,62	364,24	339,57	279,01
2017	280,75	349,70	242,57	279,50	341,26	200,64	263,61	405,97	379,03	348,56	347,81	280,04
2018	293,54	290,04	378,23	330,93	372,70	197,81	184,62	154,05	161,56	451,36	384,73	421,93
2019	313,35	406,08	288,58	319,02	194,66	259,63	132,28	166,83	150,23	254,85	344,48	464,17

Furthermore, the amount of rainfall in the area for each month in each of these years will be used in the subsequent analysis, namely the potential evapotranspiration analysis and the rainfall-runoff analysis.

3.2.2. Potential Evapotranspiration Analysis Result

Potential evapotranspiration is one of the other influential inputs in the rainfall-runoff model besides rainfall. In this research, the analysis used the Modified Penman Method of the FAO, 1997. The spreadsheet table is used to make evapotranspiration calculation easier to understand.

The following are the results of potential evapotranspiration analysis in the Melawi sub-basin

Table 12. Recapitulation of the results of rainfall calculations for the Melawi Sub-Basin area (mm) for the period 1998-2019

Year	Month (mm/day)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1998	3,76	4,40	3,81	3,31	3,21	2,82	2,79	3,00	3,38	3,55	3,52	3,87
1999	3,47	4,46	3,55	3,47	3,12	2,99	3,17	3,47	3,59	3,12	3,46	3,47
2000	3,22	4,09	3,89	3,34	3,38	2,71	3,22	3,62	3,32	3,57	3,41	3,89
2001	3,42	4,05	4,02	3,46	3,42	2,93	3,08	4,03	3,47	3,72	3,09	3,90
2002	3,44	4,26	3,42	3,66	3,21	2,71	3,50	4,19	3,93	3,89	3,36	3,82
2003	3,60	3,91	3,67	3,50	3,54	2,89	3,08	3,88	3,75	3,45	3,33	3,77
2004	3,37	4,58	3,60	3,46	3,23	3,27	2,66	4,49	3,46	3,75	3,26	3,16
2005	3,84	3,94	3,72	3,73	3,02	2,76	3,01	3,94	3,65	3,27	3,44	3,81
2006	3,72	4,00	4,01	3,22	3,23	2,70	3,42	4,23	3,75	4,10	3,47	3,69
2007	3,49	4,21	3,79	3,43	2,98	2,71	2,85	3,62	3,58	3,43	3,32	3,26
2008	3,80	4,22	3,18	3,89	3,45	2,79	2,99	3,40	3,47	3,22	3,26	3,73
2009	3,57	4,13	3,83	3,40	3,42	2,99	3,22	4,06	4,33	3,63	3,27	3,41
2010	3,46	4,10	3,47	3,59	3,13	2,69	2,61	3,14	3,12	3,53	3,30	3,66
2011	3,63	4,43	3,76	3,66	3,20	2,86	3,22	4,15	3,88	3,33	3,44	3,68
2012	3,93	3,91	3,49	3,62	3,49	3,15	3,12	3,87	4,18	3,35	3,20	3,68
2013	4,16	3,85	3,89	3,62	3,08	3,47	3,13	3,86	3,77	4,19	3,77	3,56
2014	4,10	4,56	4,21	3,38	3,05	3,45	4,32	3,60	3,98	4,03	3,68	3,96
2015	3,58	3,87	3,68	3,37	3,40	2,79	3,33	4,00	4,04	3,74	3,05	3,80
2016	3,60	3,66	3,38	3,41	3,05	2,73	3,06	4,01	3,58	3,48	3,44	3,86
2017	3,80	3,82	3,74	3,63	3,06	2,95	2,95	3,16	3,36	3,49	3,36	3,80
2018	3,70	4,13	3,46	3,49	3,08	3,06	3,47	4,33	4,11	3,41	3,41	3,61
2019	3,80	3,83	3,95	3,63	3,57	2,86	3,55	4,34	4,30	3,70	3,72	3,64
Ave	**3,66**	**4,11**	**3,71**	**3,51**	**3,24**	**2,92**	**3,17**	**3,84**	**3,73**	**3,59**	**3,39**	**3,68**

From the results of the monthly evapotranspiration calculation and analysis in the Melawi Sub-Basin, it can be seen that the evapotranspiration in August is more significant than in other months, indicating that in August, the amount of water lost from the water body is more significant than in other months.

3.2.3. Determination of the appropriate runoff model based on the calibration results of the model parameters

Before conducting monthly discharge analysis in the Melawi Sub-Basin, the appropriate analysis model selection is conducted first. The determination of the Model is based on the calibration results of the model parameters. If the NRECA model calibrates the PSUB parameter (part of excess moisture that will flow into the soil) and GWF (a parameter that controls the amount of flow out of the groundwater storage as groundwater flow), then in the Mock Model, the calibrated parameters are if (infiltration coefficient), k (recession constant), m (exposed factor, surface, and P-percent). Since the measured discharge data available in the Melawi Sub-Basin is only for the year 2006, which is the data measured at the mouth of the Melawi River (near the Melawi bridge, Sintang City), the model parameter calibration is only carried out for the year 2006.

From the calculation results of both simulations using solver and analytical methods, the NRECA parameters obtained were PSUB 0.47 and GWF 0.61. From the analysis, it can be seen that during the calibration of NRECA parameters, the value of r is 0.8258. The RSR is 1.242, so the obtained NRECA parameters are not good enough because they have an RSR > 0.7, so for analysis in Melawi Sub-Basin, the Mock Model is more suitable to be used. Meanwhile, for the Mock model, the calibration results show that during the calibration of Mock parameters, the value of r is 0.90349, and RSR is 0.5382, so the obtained Mock parameters can be used in the calculation.

Table 13. Comparison of the calibration results between the NRECA Model and the Mock Model

Defining Variables	Model	
	MOCK	NRECA
r	0,922	0,297
RSR	0,530	2,656

4. Conclusion

From the series of analyses that have been carried out, it can be seen that not all TRMM grid rainfall data can be used for analysis. Therefore, many grids are needed to use TRMM rainfall data to cover the entire Melawi Sub-Basin. Thus, if there are TRMM grids whose data does not meet the requirements for use in the screening stage, there are still other TRMM grids that can be used so that the analysis can continue.

Based on the homogeneity test results using the t-test on observation station rainfall data and TRMM satellite rainfall data, it can be concluded that the rainfall data in the Melawi Sub-Basin is homogeneous with TRMM satellite rainfall data.

From the TRMM grid analysis in the Melawi Sub-Basin, it can be said that satellite rainfall data can be used as an alternative analysis data in the Melawi Sub-Basin because, out of

50 TRMM grids, there are still 38, or around 76%, of TRMM grid data that can still be used.

The calibration results of the NRECA and Mock runoff models show that the Mock model is more suitable for use as an analysis model to obtain a monthly synthetic discharge in the Melawi Sub-Basin.

Several suggestions that can be given related to this research are:

- Similar research can be conducted for other Sub-Basins in West Kalimantan to support the development and management of water resources, considering that many observation stations in West Kalimantan are no longer functioning. At the same time, there are many large river basin an sub-basin in West Kalimantan.
- Similar research can be conducted on grids with the same observation stations so that deviations between satellite data and data at observation stations can be determined.
- This research can be continued by examining maximum rainfall data as input for the rainfall-runoff model to predict the magnitude of the flow hydrograph in the Melawi Sub-Basin.
- Relatively long flow data is needed to obtain more accurate rainfall-runoff model parameters.

5. Acknowledgment

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6. Author's Note

All of the content written in this article is original as it summarizes my studies with Mr. S.B. Soeryamassoeka and Mrs. Kartini. The contents of this article were reviewed during my thesis defense at the Department of Civil Engineering, University of Tanjungpura, on July 28, 2021, by Mrs. Henny Herawati and Mr. Eko Yuliato.

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