Jurnal Teknik Sipil: Vol 23, No. 1, February 2023, 46-53
Department of Civil Engineering, University of Tanjungpura.
ISSN: 1412-1576 (Print), 2621-8428 (Online), Indonesia

Constructions of UNTAN
Jurnal Teknik Sipil
Journal homepage: https://jurnal.untan.ac.id/index.php/jtsuntan

Generation of Synthetic Rainfall Data in Sekayam sub-watershed Based on TRMM Satellite Rainfall Data Correction Equation

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Abstract

The hydrological analysis is the first stage of the review in waterworks planning. Hydrological analysis necessitates the availability of sufficient data. Data availability tends to have several problems, including a lack of availability, incomplete/empty data, a smaller number of stations, observers, and observation systems, data entry that is still manual, and slow data collection. One possible solution is to use rain satellites. However, TRMM data must be evaluated for field suitability. TRMM (Tropical Rainfall Measurement Mission) rainfall data can help overcome this. TRMM is a NASA mission that uses weather monitoring satellite technology to monitor tropical rainfall. This is also the case for the Sekayam Subwatershed, part of the Kapuas River Basin.

In the Sekayam sub-watershed, there are 14 (fourteen) rainfall observation stations managed by the Balai Wilayah Sungai Kalimantan (BWSK) I, but currently only 5 observation stations are still active, namely the SGU-01 Sanggau, SGU-03 Balai Karangan, SGU-06 Entikong, SGU-19 Semuntai and SC-01 Kembayan observation stations with data recorded up to 2019, while the other 9 (nine) observation stations do not have long continuous data, because there are years where rainfall data is not recorded. This is because the recording of rainfall on average stopped until 2005, or even some have stopped operating since the 1990s or early 2000s. This study aims to generate representative synthetic TRMM daily rainfall amount data for the Sekayam sub-watershed based on the correction equations obtained in a series of TRMM rainfall data validation analyses, so that it can be used as alternative daily rainfall data in water resources planning and management in the Sekayam sub-watershed.

From the analysis, it can be seen that synthetic rainfall data in the Sekayam sub-watershed will be valid if it is generated with the linear model correction equation Y = 0.6708 X + 139.123 or can be interpreted as TRMM' = 0.6708 TRMM + 139.123.

Article history:
Submitted 05-01-2023
Revise on 05-01-2023
Published on 28-02-2023

Keyword:
TRMM, Sekayam, Satellite Rainfall Data, Synthetic Rainfall Data

DOI: http://dx.doi.org/10.26418/jtsft

1. Introduction

Regions in the tropics are highly dependent on rainfall for various needs (Wu et al., 2018), so to support the development and management of water resources, reliable and accurate information on rainfall data is needed in any water resources planning and management (Njoroge, 2010; Sunilkumar et al., 2015; Guo & Liu, 2016; Soeryamassoeka, 2020a). The high cost of building and maintaining rain gauge infrastructure (Su et al., 2014) limits the distribution of rain gauge stations, and their performance is not optimal (Mamenun et al., 2014; Jarwanti et al., 2021), so many areas still lack rainfall data (Jarwanti et al., 2021), including the Sekayam sub-watershed (6712.10 km^2) (Soeryamassoeka et al., 2020a). To address a lack of rainfall data in a given area, satellite-based rainfall data is now available, including TRMM rainfall data, whose rainfall measurements can cover large areas, are available in near real-time, and have quick access.

Given the Sekayam sub-watershed area of 6712.10 km^2, which is only served by four active rainfall stations, a study is required to validate Tropical Rainfall Measuring Mission (TRMM) satellite rainfall data to obtain alternative rainfall data in addition to rainfall data recorded at observation stations, which can be used to support the development and management of water resources in the Sekayam sub-watershed.

This study generates representative synthetic TRMM daily rainfall amount data for the Sekayam sub-watershed using correction equations from a series of TRMM rainfall data validation analyses to use in water resources planning and management.

2. Materials and Methods

2.1. Theoretical Frame Work

Rain data is the information needed to predict weather conditions, floods, and droughts (Pantarini et al., 2021). It is one of the essential input data components in water resource management and development (Zad et al., 2018). TRMM data can supplement and fulfill rain data due to the lack of automatic rain data (ARR) availability.

The Sekayam sub-watershed is part of the Kapuas River Basin, with an area of ± 6712.10 km2. With such a large area, there should be many rainfall recording stations in the Sekayam sub-watershed. However, there are only four operational stations in the Sekayam sub-watershed. Therefore, TRMM data confirmed against the active rainfall posts are needed to support water resources management and development research.

2.2. Research Location

The research was conducted in the Sekayam sub-watershed, which is included in the administrative area of Kabupaten Sanggau. Compared to Sanggau Regency, which covers 12847.70 Km^2, the Sekayam sub-watershed covers 52.20% of the Kabupaten Sanggau.

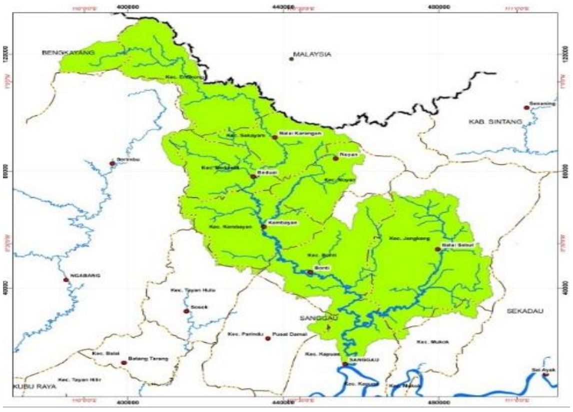

Fig. 1 Sekayam Sub-Watershed

2.3. Data

The data used in this study are as follows;

a) Rainfall observation stations coordinates and daily rainfall data of SGU-01 Sanggau, SGU-03 Balai Karangan, SGU-06 Entikong, SGU-19 Semuntai, and SC-01 Kembayan in the period 1998-2019 from Balai Wilayah Sungai Kalimantan (BWSK) I Kalimantan Barat.
b) DEM, river network map, and topographic map.
c) Make a map to place the TRMM grid to obtain the coordinates of each grid as a reference for downloading data.

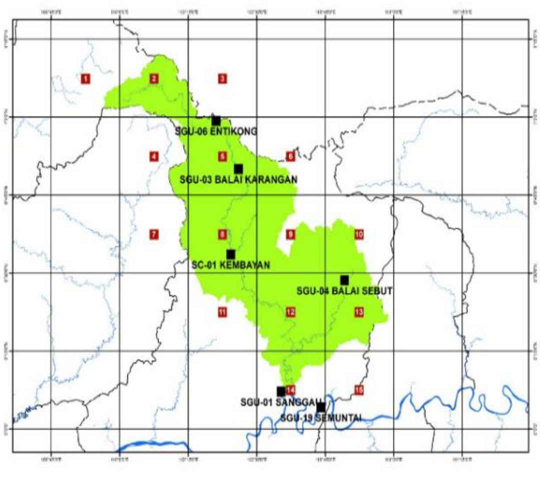

Fig. 2 Position of TRMM Grid and Observation Station of Sekayam Sub-watershed

d) Adjusting TRMM rainfall data with the number of TRMM_3B42RTv7 type station/observation data.

2.4. Analysis Method

This study analyzed data in these steps;

1) *Quality testing of observation station rainfall data with homogeneity test*.
   In this study, the data used is the amount of data per month in each year of observation.
2) *Quality testing of observation station rainfall data and TRMM Grid rainfall data with consistency test*.
   This study conducted the consistency test using the Cumulative Deviation (Adjusted Partial Some) method. The test equation can be done with W statistics, whose equation is as follows;

$$S^*k = \sum_{i=1}^{k} (Y_i - \bar{Y}) \quad \text{.........(1)}$$

k = 1, 2, 3,….,n.

Rescaled adjusted partial sums (RAPS) values, denoted by S**k, using the equation.

$$S^{**}k = \frac{S^*k}{D_y} \quad \text{.........(2)}$$

k =0, 1, 2, 3,…,n....(2)

$$Dy = \sum_{i=1}^{k} \frac{(Y_i - \bar{Y})^2}{n} \quad \text{.........(3)}$$

The test results are consistent if the

$$\frac{Q}{\sqrt{n}}_{\text{Calculation}} \leq \frac{Q}{\sqrt{n}}_{\text{Table}} \quad \text{.........(4)}$$

$$\frac{R}{\sqrt{n}}_{\text{Calculation}} \leq \frac{R}{\sqrt{n}}_{\text{Table}} \quad \text{.........(5)}$$

In this study, it was used with the following conditions. $\frac{Q}{\sqrt{n}}_{\text{Calculation}} \leq \frac{Q}{\sqrt{n}}_{\text{Table}}$. Q is found using the equation

$$Q = \max_{0 < k < n} |S^{**}k| \quad \text{.........(6)}$$

Table 1. Q and R Critique Table

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

3) *Uncorrected TRMM rainfall data test (TRMM rainfall data filtering).*
   Filtering of TRMM rainfall data is intended to select TRMM rainfall data after testing the data's quality with a homogeneity test and data consistency test.
   After the homogeneity and data consistency tests, the following equation is used to figure out how the rainfall at observation stations compares to the rainfall on the TRMM grid.

$$R^2 = \frac{[(n \, x \, \Sigma XY) - (\Sigma X \, \Sigma Y)]^2}{[(n \, x \, \Sigma X^2) - (\Sigma X)^2] \, x \, [(n \, x \, \Sigma Y^2) - (\Sigma Y)^2]} \quad \text{....(7)}$$

$$r = \sqrt{R} \quad \text{.........(8)}$$

$$r = \frac{n(\sum XY) - (\sum X)(\sum Y)}{\sqrt{\{n(\sum X^2) - (\sum X)^2\} - \{n(\sum Y^2) - (\sum Y)^2\}}} \quad \text{.........(9)}$$

X = X Variable, rainfall value at the observation post (mm)

Y = Y variable, estimated rainfall value (mm)

n = Amount of data

r = Correlation coefficient value (lies between-1.0-1.0).
Interpretation of Correlation Value (r) as the following table.

Table 2. Strength of Correlation (Senjaya, 2020; Soeryamassoeka, 2020)

Size of r	Interpretation
0,9 - 1,0	Very High Correlation
0,7 - 0,9	High Correlation
0,5 - 0,7	Moderate Correlation
0,3 - 0,5	Low Correlation
0,0 - 0,3	Little if any correlation

The following factors are considered when filtering TRMM rainfall data:

- If the analysis results of the TRMM Grid rainfall data's correlation coefficient (r) with the rainfall data of each observation station are valid if r is more significant than 0.5 (≥0,5) and rejected if r is less than 0.5 (<0,5).
- If the analysis of the root mean square error (RMSE) of TRMM Grid rainfall data shows that the RMSE is less than 300 (≤300), the analysis is considered valid. If the RMSE is more than 300 (>300), the analysis is not valid. The value of the Root Mean Square Error (RMSE) obtained from the equation.

RMSE = $\sqrt{\left[\frac{1}{N}\sum_{i=1}^{N}(X - Y)^2\right]}$ ....(10)

X = X Variable, rainfall value at the observation post (mm)
Y = Y variable, TRMM value (mm)
n = Amount of data
RMSE = Root Mean Square Error.

Table 3. RMSE Class Divission (Senjaya, Soeryamassoeka, 2020)

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

TRMM Grid rainfall data homogeneity test with observation stations and TRMM Grid rainfall data consistency test. The method used is the same as the homogeneity and consistency tests at the observation station.

4) *Calibration*

The calibration stage is the step for determining the correction equation. This study used a linear equation model to obtain the correction equation.

Y= a+bX………………………………………...(11)

Y = TRMM rainfall

a = $\frac{(\sum Y\, x \sum X^2) - (\sum X\, x \sum XY)}{(n\, x \sum X^2) - (\sum X)^2}$ ………….(12)

b = $\frac{(n\, x \sum XY) - (\sum X\, x \sum Y)}{(n\, x \sum X^2) - (\sum X)^2}$ …………….(13)

X = Rainfall recorded by observation station

The correlation value (r) and the root mean square error (RMSE) are used to calibrate. As with the uncorrected data, only the entered data is part of the observation station rainfall data, and the TRMM grid rainfall data needs to be tested (minimum of five years of observations, maximum of half the number of years of observations).

5) *TRMM Rainfall Data Validation*

In this step, the calibration equation is used on each calibrated TRMM grid to test data accuracy that wasn't tested in the calibration step.

Each grid's correlation coefficient (r) and RMSE are validated under the same conditions as the data filtering and calibration stages to see if the validation results are good enough.

6) *The calculation to obtain the amount of Correction Rainfall.*

After the validation stage, corrections are made to all TRMM rain data for each grid (1998–2019). Corrections are made by using the calibration equation on each calibrated TRMM grid that has the highest correlation value (r) among the different calibration equations.

3. Result and Discussion

3.1. Rainfall Data Filtering Analysis Results

The initial stage of validating TRMM rainfall data is to filter the rainfall data to be used, both observation station data and TRMM grid data. Before using the TRMM satellite rainfall data validation analysis, especially corrective rain data for the evaluated area, it is essential to make sure that the rainfall data meets the standards. The quality of the observed rainfall data is filtered using tests for homogeneity and consistency. The analysis results show that the rainfall data recorded at several observation stations in the Sekayam sub-watershed is homogeneous. Given that there is a low likelihood that a recording error occurred and that the data at the observation stations in the Sekayam sub-watershed used in this study are accurate, rainfall data from all of the observation stations in the Sekayam sub-watershed can be used for this study. A consistency test was then carried out for each station using the Cumulative Deviation Method in order to confirm the accuracy of the observed rainfall data to be used in this study. The findings reveal that every rainfall data point is consistent, indicating good data accuracy and a low likelihood of recording errors in rainfall data recorded at various observation stations. The study can use rainfall data from all observation stations as a result.

TRMM satellite rainfall data goes through two stages of filtering: (a) correlation coefficient-based filtering and (b) homogeneity and consistency tests on the filtered TRMM rainfall data from the stage (a). The analysis shows that the TRMM Grid rainfall data that can be validated are Grid 5, Grid 6, Grid 8, and Grid 14. The four TRMM grids that meet this requirement are then tested for homogeneity and consistency to determine whether the data quality on the four grids is good.

3.2. Results of Analysis to Obtain Correction Rainfall

The steps taken to obtain the TRMM rainfall correction equation in the Sekayam sub-watershed are; (a) data calibration, (b) data validation, and (c) generation of synthetic rainfall data based on the grid calibration equation that has the best correlation value during calibration.

From the results of the calibration of Grid 14 TRMM rainfall amount data using SGU-01 Sanggau rainfall amount data, parameters are obtained to be used in correlation analysis (r) and in making correction equations, such as the following table;

Table 4. Parameter Calibration Results of TRMM Grid 14 Rainfall Data Using Rainfall Data of SGU-01 Sanggau Station

n	= 132
ΣXY	= 9875136,56
ΣX	= 30246,16
ΣY	= 38654,00
ΣX²	= 8448156,11
ΣY²	= 12816018,02
n x ΣXY	= 1303518026
ΣX x ΣY	= 1169135126
n x ΣX²	= 1115156607
(ΣX)²	= 914830329,1
n x ΣY²	= 1691714379
(ΣY)²	= 1494131643,29

$$R^2 = \frac{[(n\ x\ \sum XY) - (\sum X\ \sum Y)]^2}{[(n\ x\ \sum X^2) - (\sum X)^2]\ x\ [(n\ x\ \sum Y^2) - (\sum Y)^2]}$$

$$= 0{,}4562$$

$$r = \sqrt{R} = \sqrt{0{,}4562} = 0{,}6755$$

As for the RMSE value, the amount is

$$RMSE = \sqrt{\left[\frac{1}{N}\sum_{i=1}^{N}(X - Y)^2\right]} = 107{,}09 \text{ mm.}$$

$$Y = bX + a$$

$$a = \frac{(\sum Y\ x\ \sum X^2) - (\sum X\ x\ \sum XY)}{(n\ x\ \sum X^2) - (\sum X)^2} = 139{,}123$$

$$b = \frac{(n\ x\ \sum XY) - (\sum X\ x\ \sum Y)}{(n\ x\ \sum X^2) - (\sum X)^2} = 0{,}6708$$

So the linear equation before correction is Y = 0.6708 X + 139.123. In the same way, the correlation magnitude and correction equation for each TRMM Grid are obtained.

Following calibration, each grid is put through a validation process to check the accuracy of the calibration results.

TRMM rainfall amount data not used during calibration is used for validation. TRMM rainfall amount data from January 2009 to December 2019 is used in this study.

The correction equation developed at the calibration stage for each TRMM rainfall pair is then used to factor in the TRMM rainfall amount data. Variable Y is the observation station's rainfall amount data, and variable Y' is the generated TRMM rainfall amount data.

With the most significant correlation value of rainfall amount on Grid 14 TRMM calibrated with SGU-01 Sanggau rainfall amount data, it is clear from the analysis results shown in Tables (7) and (8) that the magnitude of the correlation will be better after calibration and validation

Table 5. Correlation (r) Values of Calibration Results of Filtered TRMM Rainfall Data Using Rainfall Data of Each Observation Station in the Sekayam Sub-Watershed

Observation station	SGU-01 Sanggau			SGU-03 Balai Karangan		
Grid TRMM	*Before Correction*	*Calibration*	*Validation*	*Before Correction*	*Calibration*	*Validation*
5				0,626	0,617	0,696
6				0,522	0,527	0,531
8				0,519	0,523	0,588
14	0,673	0,675	0,700			

Observation station	SGU-06 Entikong			SGU-19 Semuntai		
Grid TRMM	*Before Correction*	*Calibration*	*Validation*	*Before Correction*	*Calibration*	*Validation*
5	0,545	0,614	0,617			
6	0,504	0,533	0,546			
8						
14				0,635	0,649	0,658

Observation station	SC-01 Kembayan		
Grid TRMM	*Before Correction*	*Calibration*	*Validation*
5			
6			
8	0,603	0,605	0,611
14			

Table 6. RMSE Values of Calibration Results of Filtered TRMM Rainfall Data Using Rainfall Data of Each Observation Station in the Sekayam Sub-Watershed

Observation station	SGU-01 Sanggau			SGU-03 Balai Karangan		
Grid TRMM	*Before Correction*	*Calibration*	*Validation*	*Before Correction*	*Calibration*	*Validation*
5				133,00	114,84	95,55
6				137,86	126,26	101,80
8				141,98	125,28	97,26
14	101,65	107,09	106,36			

Observation station	SGU-06 Entikong			SGU-19 Semuntai		
Grid TRMM	*Before Correction*	*Calibration*	*Validation*	*Before Correction*	*Calibration*	*Validation*
5	140,63	110,86	137,93			
6	146,39	122,41	132,95			
8						
14				155,77	79,83	181,37

Observation station	SC-01 Kembayan		
Grid TRMM	*Before Correction*	*Calibration*	*Validation*
5			
6			
8	127,86	108,01	93,55
14			

The calibration and validation results show that the correction equation for the TRMM Grid rainfall amount data in the Sekayam sub-watershed is **Y = 0.6708 X + 139.123**, which is the TRMM Grid 14 calibration equation calibrated with SGU-01 Sanggau Station.

The calibration and validation analysis results show that the TRMM Grid 14 calibration equation, calibrated with the SGU-01 Sanggau Station, is the correct equation for the TRMM Grid rainfall amount data in the Sekayam sub-watershed. Y = 0.6708 X + 139.123 is the equation. As a result, using this equation, it is possible to generate or correct TRMM rainfall data in the Sekayam sub-watershed.

From the analysis that has been carried out, it can be seen the magnitude of the RMSE on the corrected rainfall in each grid RMSE

Table 7. Recapitulation of RMSE and R_{Bias} Analysis Results of TRMM Grid of Sekayam Sub-Watershed After Correction

Grid TRMM	RMSE	R_{Bias}
5	56,65	14,11
6	55,80	13,83
8	58,52	15,85
14	60,43	16,39

Table 7 shows that the RMSE of corrected rainfall generated by the correction equation is less than the acceptable standard of 300 mm and dan R_{Bias} < 25%, which shows that the Sekayam sub-watershed rainfall validation analysis results are reliable and in line with the theory for validating satellite rainfall data.

Comparison of TRMM (uncorrected TRMM rainfall) and TRMM' (corrected TRMM rainfall) rainfall amount data can be seen from the following graphs;

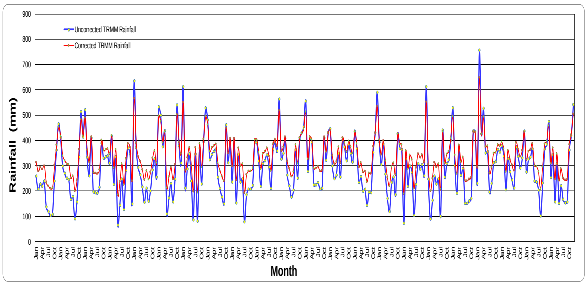

Fig. 3 Comparison Chart of Uncorrected and Corrected TRMM Grid 5 Rainfall Data for the Period 1998-2019

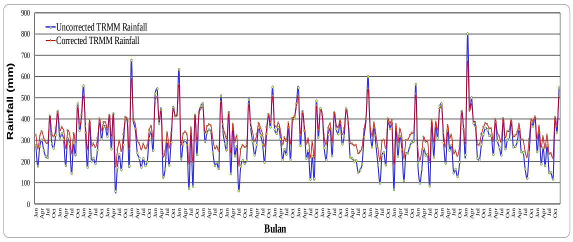

Fig. 4 Comparison Chart of Uncorrected and Corrected TRMM Grid 6 Rainfall Data for the Period 1998-2019

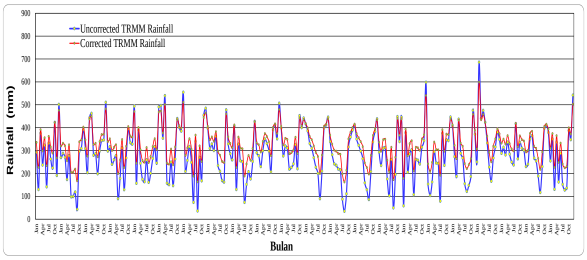

Fig. 5 Comparison Chart of Uncorrected and Corrected TRMM Grid 8 Rainfall Data for the Period 1998-2019

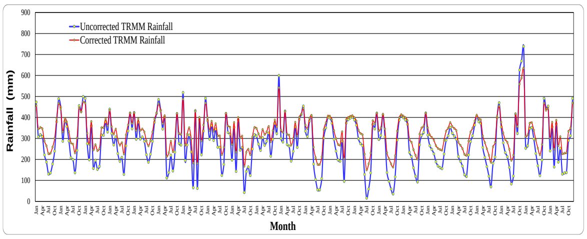

Fig. 6 Comparison Chart of Uncorrected and Corrected TRMM Grid 14 Rainfall Data for the Period 1998-2019

The steps taken are by the standard, based on the TRMM daily rain data correction procedure, because the corrected TRMM rainfall has a correlation coefficient with the observation station that has a minimum interpretation of moderate or good enough, whose value is at least 0.5. The TRMM Grid, on the other hand, with a correlation value of 0.5, is not corrected because the correlation with the observation station does not meet the standard criteria set. Thus, a correction cannot be made using the post.

What can be done for TRMM grids that cannot be corrected in this study is to use other observation stations. However, because the data at the Sekayam sub-watershed observation stations other than the ones used in this study needs to be completed, they are not used to correct existing TRMM rainfall data.

4. Conclusion

From the results of the analysis for filtering TRMM daily rainfall amount data in the Sekayam sub-watershed, it can be seen that the five observation stations whose daily rainfall amount data are used as the dependent variable to filter TRMM daily rainfall amount data only correlate according to the technical standards of validation against 4 (four) grids, SGU-01 Sanggau and SGU-19 Semuntai correlate with Grid 14 TRMM, SGU-03 BalaiKarangan and SGU-06 Entikong correlate with Grid 5 and Grid 6 TRMM, SGU-03 Balai Karangan, and SC-01 Kembayan correlate with Grid 8 TRMM.

Only SGU-03 Balai Karangan and Grid 8 are far apart, but they still have a correlation that is taken into account by the technical standard, namely r = 0,519>0,5. The majority of the observation stations that correlate with the TRMM Grid are those that are nearby.

Because observation stations far from the TRMM Grid do not always correlate with the TRMM Grid, each observation station must be used as a dependent variable to validate each existing TRMM Grid and obtain a correction equation to generate synthetic data based on TRMM rainfall data.

Validation of TRMM daily rainfall amount data for the Sekayam sub-watershed reveals that when TRMM rainfall is corrected, the RMSE shrinks while the relative bias remains acceptable. This implies that the correction equation discovered in this study can be used to generate rain data for the Sekayam watershed, but additional research is required

5. Acknowledgment

First of all, I want to thank my parents and sister for always being there for me and making sure I was able to finish this study successfully. I am incredibly grateful to Dr. S.B. Soeryamassoeka, S.T., M.T., IPM and Eko Yulianto, S.T., M.T., IPM., for providing some suggestions and knowledge in the guidance process so that this study produces a creation that can be useful as a reference in the assesment of water resources development and management in West Kalimantan Province, Indonesia. I would also like to thank the Jurnal Teknik Sipil UNTAN (JTS) Team, who have agreed to publish the results of this study so that it can become a valuable reference for everyone, especially in the assesment of national road structures in West Kalimantan Province, Indonesia

6. Author's Note

Everything written in this article is original because it sums up my studies with Dr. S.B. Soeryamassoeka, S.T., M.T., IPM and Eko Yulianto, S.T., M.T., IPM., The contents of this article have been reviewed in a thesis defense at the Department of Civil Engineering, The University of Tanjungpura, on 29 July 2022 by Danang Gunarto, S.T., M.T.and Dr. Nurhayati, S.T., M.T.

I as the author of this journal state that no conflict occurs in the publication of this journal and no other party publishes this journal, this journal is free from plagiarism.

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