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Evaluation of the Compatibility of TRMM Satellite Data with Precipitation Observation Data

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***Abstract*— The availability of hydrological data is one of the challenges associated with developing water infrastructure in different areas. This led to the TRMM (Tropical Precipitation Measurement Mission) design by NASA, which involves using satellite weather monitoring technology to monitor and analyze tropical precipitation in different parts of the world. This study applied calibration and validation methods to the precipitation data of the TRMM satellite and observation station. The calibration analysis was conducted using the regression equation y = f(x) with the satellite and observational precipitation designated as the x and y variables. Therefore, this validation study was conducted to compare TRMM precipitation data with observed precipitation to determine its application as an alternate source of hydrological data. The Kuranji watershed was selected as the study site due to the availability of suitable data. Moreover, the validation analyses applied include the Root Mean Squared Error (RMSE), Nash-Sutcliffe Efficiency (NSE), Coefficient Correlation (R), and Relative Error (RE). These used two calculation forms: one for the uncorrected data and another for the corrected data. The results showed that the best-adjusted data validation from the Gunung Nago station in 2016 was recorded to be RMSE = 62.29, NSE = 0.04, R = 0.90, and RE = 11.33. The closeness of the R-value to one implies that the corrected TRMM data outperforms the uncorrected ones. Therefore, it was generally concluded that the TRMM data matches the observed precipitation data and can be used for hydrological study in the Kuranji watershed.**

***Keywords*— precipitation; TRMM; calibration; validation**

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I. INTRODUCTION

Precipitation is an important component of the global water cycle [1], [2] and is associated with atmospheric circulation in weather and climate change [3], which is important for weather forecasting [4], hydrological process modelling [5], disaster monitoring [6], and so on. Because precipitation varies widely in place and time, precise and dependable precipitation products with the higher temporal and spatial resolution are required for stakeholders' decision-making at the local scale [7], [8].

Precipitation data can be presented as both temporal or time series and spatial. The temporal ones indicate the tendency of an increase in the precipitation in a certain area, and the spatial-temporal distribution directly affects the availability of water resources in rivers or catchment areas [9]. The availability of precipitation data is an important part of hydrological analysis. Still, its inclusion is often limited by several factors, such as the lack of both spatial and temporal precipitation observation data, insufficient and incomplete precipitation time series data, an uneven number of precipitation stations, a limited number of observers and system observations as well as manual data input [10]. It is also difficult to obtain real-time surface precipitation observation data, which requires an initial check before it can be used directly [11]. However, there is a need for accurate spatial-temporal and long-term precipitation data in climate change forecasting, simulation study, hydrological forecasting, floods, landslides, droughts, disaster management and survey of water resources [12].

A multitude of factors that contribute to uncertainty, such as observation mistakes, boundary or initial conditions errors, model or system errors, scale discrepancies, and unknown heterogeneity of parameters, have a substantial impact on the performance of both lumped and distributed hydrologic models. Precipitation is typically regarded as the most important meteorological input in hydrological and water quality studies. Accurately precipitation measurement is required for reliable and consistent hydrologic projections for water quantity and quality. Precipitation data accuracy, including intensity, duration, geographical patterns, and extent, has a significant impact on the output of land surface and hydrologic models [13], [14], [15].

Large-scale hydrologic models frequently rely on remotely sensed precipitation data from satellite sensors due to a lack of ground-based monitoring equipment and rain gauge networks [16]. Precipitation, whether measured by rain gauges or satellites, exhibits regional and temporal variability and measurement mistakes. Although ground-based sensor networks, such as rain gauges and radars, provide the most direct surface precipitation observations and frequently provide measurements with high temporal frequency, these systems have significant drawbacks. Gauges are limited to point-scale observations, but they are also susceptible to misleading readings due to wind effects and evaporation. Spatial interpolation of point-based observations, in addition to measurement flaws, adds uncertainty to the final gridded precipitation datasets [17], [18], [19], [20]. The spatial distribution and density of gauges are critical factors in measuring adequacy. Several studies have found that sparse and irregular rain gauge networks have a significant impact on hydrologic model uncertainty and that uncertainty can be reduced by increasing gauge density or optimizing the distribution pattern [21], [22], [23]. Ground-based radar networks, on the other hand, frequently provide continuous spatial coverage with high spatial and temporal resolution. Still, their accuracy is limited by signal attenuation and extinction, surface backscatter, brightness and effects, and uncertainty in the reflectivity-rain-rate relationship [24], [25].

Latest technologies, such as remote sensing technology, can overcome the lack or unavailability of precipitation data in the previous period through satellite. This means it is possible to obtain precipitation data through remote measurements, thereby making the collection process easy at any time and from any area. Satellites generally have several advantages over surface observation rain stations in measuring precipitation values [26]. These include high spatial and temporal resolution with a wide coverage area, near real-time data, continuous recording, fast access, climate impacts, less field variability, and easy collection of the data due to free download [27], [28]. Currently, multiple satellite-based precipitation products are available, each with differing degrees of accuracy. Climate Prediction Center (CPC) morphing algorithm (CMORPH) [29], Global Satellite Mapping of Precipitation (GSMaP) [30], [31], Tropical Precipitation Measuring Mission (TRMM), Multi-satellite Precipitation Analysis (TMPA) [32], and others are among them. Since their introduction, most of these gridded datasets have been reviewed for their suitability and usefulness for certain locations or intended uses [33].

TRMM (Tropical Precipitation Measurement Mission) is one of the most well-known products, with the express objective of measuring precipitation throughout the oceans and tropics [34]. TRMM was launched in 1997 with a mission duration of only a few years, and in May 2012, the TRMM Multi-satellite Precipitation Analysis (TMPA) was upgraded from version 6 (V6) to version 7 (V7) [35], [36]. An example of the remote sensing systems currently being used to measure and analyze precipitation is TRMM (Tropical Precipitation Measurement Mission) which is very important for tropical countries such as Indonesia [37], [38]. Over the past few years, the TRMM algorithm has advanced by combining a variety of current ground-based and satellite measurements to observe high spatial (0.25 x 0.25 degrees) and temporal resolution (three-hour instant capture) with increased precision [34],[39].

The TRMM precipitation data are very useful for planning, specifically in hydrometeorology. However, the data have not been significantly validated because they are temporary and spatial, indicating non-suitability for investigations or studies related to water resources, specifically in the design of water structures. Therefore, it is very important to ensure the data are validated using those retrieved from observation stations for onward application in the analysis and study of water resources [40], [41].

Furthermore, the upgraded near-real-time version 7 of TMPA 3B42RT and the research version 3B42 modified for monthly gauged precipitation have done well in capturing precipitation levels and patterns [42], [43], [44]. The near-real-time version 3B42RT outperformed the Precipitation Estimation from Remotely Sensed Information Using Neural Networks (PERSIANN) and Climate Prediction Center morphing method (CMORPH) precipitation estimates in capturing the five-year averaged gauged precipitation in Ethiopia [45].

Several studies have been conducted to assess the performance of regional TRMM products under different climatic conditions [46], [47], [48], [49]. The accuracy of the 3B42 TRMM in heavy rain has also been compared with ground-based data, and the results showed that the product detects heavy rains adequately in most countries but has limitations in predicting heavy rains in northern India and the southeastern peninsula of India [36].

TRMM products have also been discussed in several other countries, including China [50], [48], [51], Peru [52], [53], Malaysia [26], [38], Iran [54], [55], Brazil [56] dan Afrika [57], [58]. According to the results of the TRMM satellite data rectification, the accuracy of the monthly satellite precipitation data ($R = 0.8$) is greater than the daily scale ($R = 0.2$) [59]. TRMM and precipitation data have a precipitation correlation coefficient of roughly 0.90 [60]. Moreover, statistical studies at grid and basin scales showed that 3B42RT provided the highest overall quality, followed by IMERG-F and 3B42V7 [61]. Another study on data validation reported that the TRMM 3B42RT satellite pattern is quite close to the observed three precipitation data in Indonesia. This is in line with the high degree of correspondence with a correlation value of 0.99 recorded by comparing the TRMM 3B42 V7 satellite and observation data in analyzing the pattern and intensity of precipitation in the PSDA office [62]. It is important to note that a higher correlation value indicates a higher relationship between the data presented [63].

Although evaluating TRMM satellite precipitation products has been recently investigated in many areas, their hydrological applications in the watershed are still limited. The problems observed led this study to evaluate the correlation and similarity between the TRMM and the observation station precipitation data in the watershed. The findings are expected to provide a mechanism for selecting accurate satellite data to be used as an alternative source in hydrological analysis.

II. MATERIAL AND METHODS

A. Study Area

The Kuranji watershed in Padang City, West Sumatra, was selected as the study location. It is geographically located at 00^0 48'- 00^0 56' North Latitude and 100^0 20'-100^0 34' East Longitude. Moreover, its upstream is bordered by Padang City and Solok Regency on the west coast of Sumatra, which includes five sub-districts of Pauh, Kuranji, Nanggalo, North Padang, and Koto Tangah with an altitude of 1,858 m above sea level and an area of 215. 62 km^2 [64]. The map of the Kuranji watershed is shown in the following Figure 1.

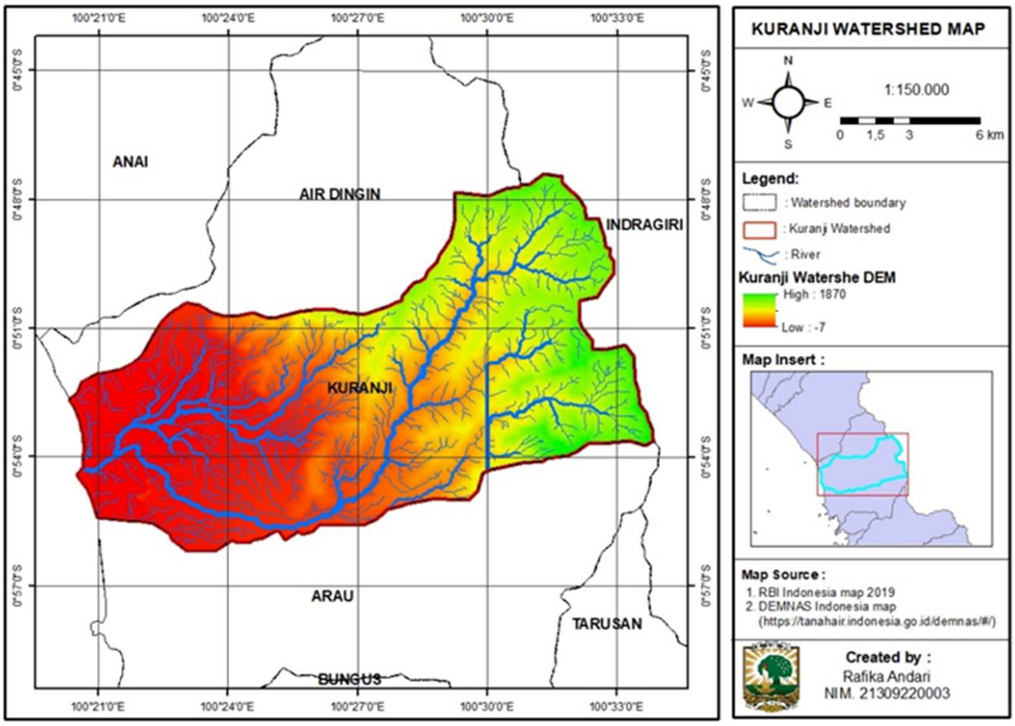

Fig. 1 Watershed map

B. Data

The daily precipitation data for five years from 2016 to 2020 in three observation stations of the Kuranji watershed, which include the Batu Busuk, Gunung Nago, and Limau Manis, were used in this study. The West Sumatra PSDA service obtained the data. Meanwhile, the level 3 data with a spatial resolution of 0.25^0 x 0.25^0, known as TRMM 3B42RT, are downloaded from the website https://giovanni.gsfc.nasa.gov/. The processes used in retrieving the data are stated in the following steps:

1. Go to the link https://giovanni.gsfc.nasa.gov/giovanni/.
2. Login through the account that was previously created.
3. TRMM data can be downloaded by completing the following data settings options:
   a. Select the plot to determine the desired data type
   b. Select the date range (UTC) to specify the desired time range
   c. Select Region (box or border shape) to select the desired precipitation area.
   d. Select Variable to select the desired data; in this case, type TRMM as the keyword, then select TRMM_3B42RT_daily data.
   e. Plot data was used to process the data to be downloaded.
   f. Successfully downloaded processing data can be retrieved on the data link displayed in the download option and available in Ms. Excel format.

C. Analysis Method

This study applied calibration and validation methods to the precipitation data of the TRMM satellite and observation station. The calibration analysis was conducted using the regression equation y = f(x) with the satellite and observational precipitation designated as the x and y variables, respectively [65]. The coherence of the calibration result was presented through a scatter plot, and the best coherence was indicated by the highest determination factor (R^2) [66]. This means the equation needed to correct the data is based on the highest R^2 value. It is important to note that different forms of equations are associated with the regression method, including linear regression, logarithmic functions, exponential functions, polynomial functions, and exponent functions [66].

The validation analysis was conducted by evaluating the model to determine the level of uncertainty possessed in predicting the hydrological process [66]. It is focused on assessing the accuracy of the TRMM data based on the level of its conformity with surface precipitation [67]. The statistical parameter analysis used for the validation was to calculate the correlation coefficient (R), Root Mean Square Error (RMSE), Nash-Sutcliffe Efficiency (NSE), and Relative Error (RE) between the observed and TRMM precipitation data [68]. These analyses are defined in the equations presented in the following Table I.

TABLE I
STATISTICAL PARAMETERS ANALYSIS USED IN THE VALIDATION METHOD

Statistical Parameter	Equation	Perfect Value
Correlation Coefficient (R)	$R = \frac{n\sum xy - \sum x \sum y}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}}$	1
Root Mean Square Error (RMSE)	$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(x-y)^2}{n}}$	0
Nash-Sutcliffe Efficiency (NSE)	$NSE = 1 - \frac{\sum_{i=1}^{n}(x-y)^2}{\sum_{i=1}^{n}(x-\overline{x})^2}$	1
Relative Error (RE)	$RE = \frac{\sum_{i=1}^{n}(x-y)}{\sum x}\ x\ 100\%$	0

Where n is the number of samples, x represents the observed precipitation data, and y is the satellite-based precipitation data. R-value indicates the degree of linear correlation between the TRMM precipitation forecast and the observed data among these statistical parameters. At the same time, NSE and RE were used to assess systematic bias to determine the deviation value of satellite precipitation from the observed data. RMSE was used to calculate the relative magnitude of the mean error.

III. RESULT AND DISCUSSION

A. Calibration Analysis Results

The results of the calibration analysis are presented in the following Figure 2. Figure 2 shows several significant differences, specifically in 2016 for Gunung Nago station. It showed a precipitation value of 1015.40 mm on October 17, 2016, and this is possibly caused by several factors such as errors due to sensors [69], algorithms data collection [70], cloud characteristics, climate, seasons, as well as geographical and topographical locations [71], [2].

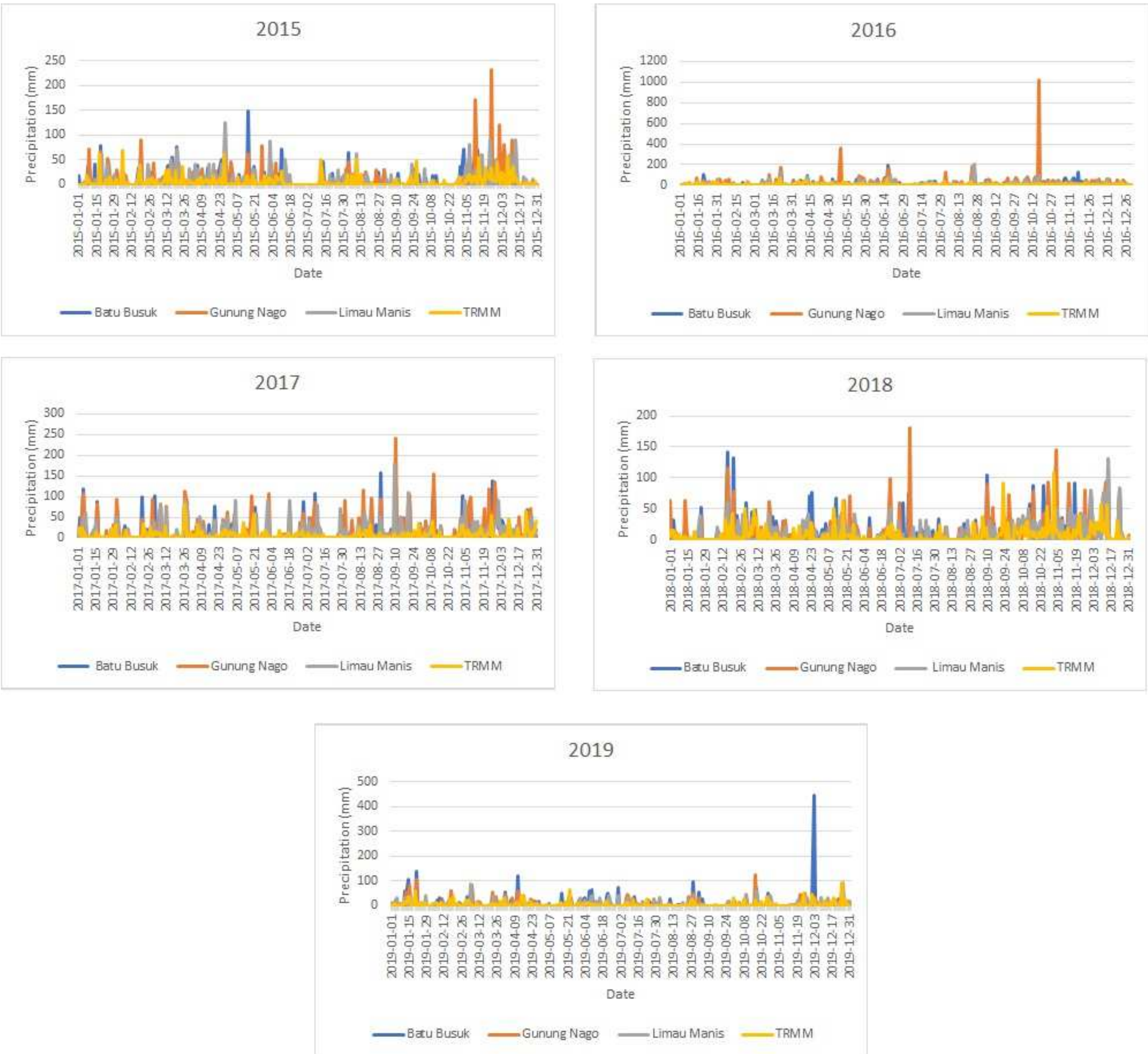

Fig. 2 Comparison of Observation Stations and TRMM Precipitation Data in 2015 – 2019

The corrected TRMM precipitation data was obtained through the calibration first conducted before checking the validity. The procedure involved used a simple regression equation to calculate the correction factor, and the most suitable equation has been selected based on the highest determination value (R^2).

The Scatter plot graph for the observation station and TRMM precipitation data with the largest R^2 value from 2015 to 2019 is shown in Figure 3. It was discovered that the daily scatter plot was spread by linear regression equation, which has a gradient value of less than 1 in the three stations. Moreover, the largest gradient value was recorded at Batu Busuk station in 2015, with an R^2 value of 0.0596.

Figure 3 shows that the polynomial equation of order three, which is represented as $y = 10^{-5}x^3 - 0.0034x^2 + 0.2731x + 4.1821$, was selected because it has the highest determination value (R^2) compared to the others.

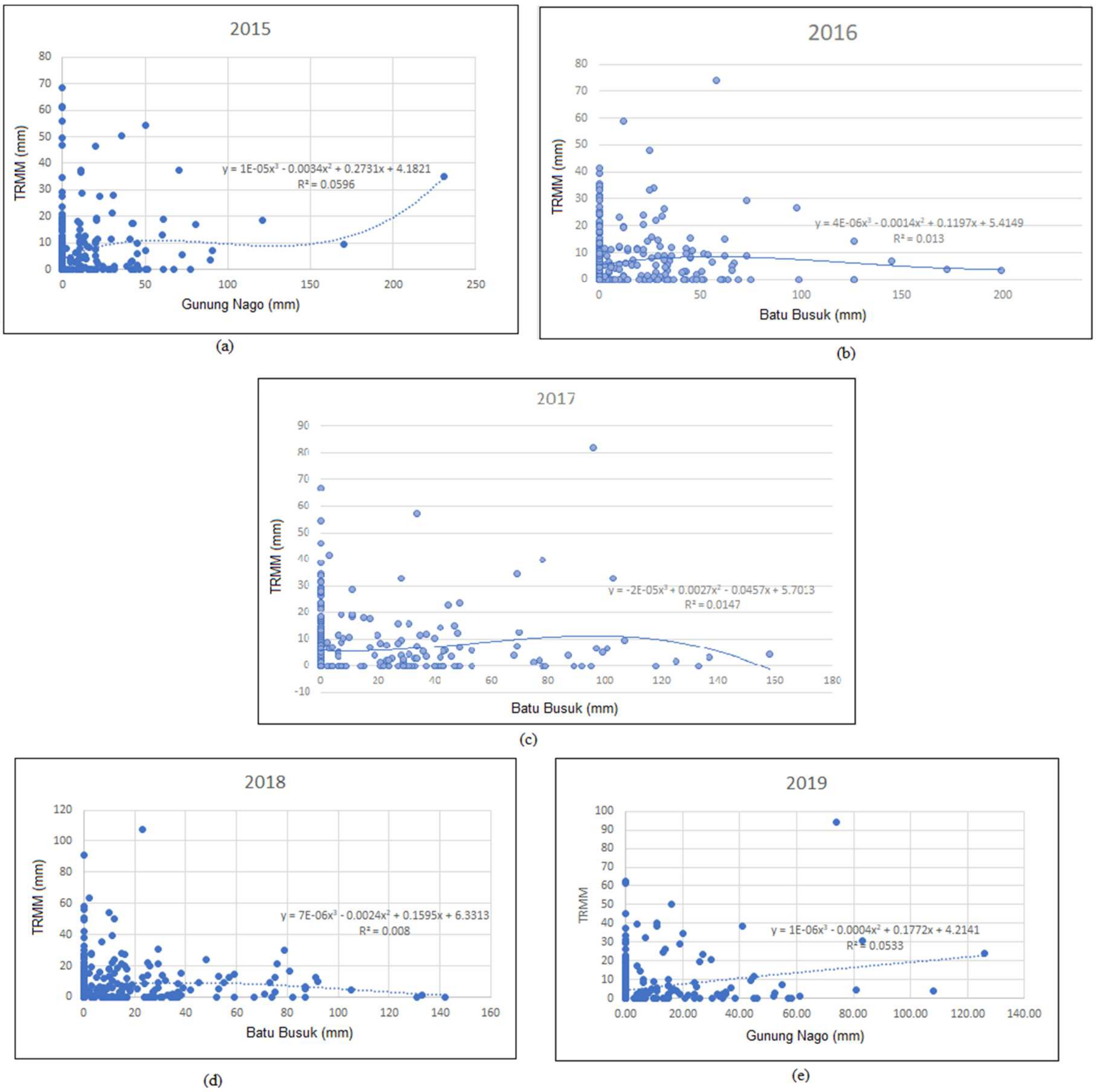

Fig. 3 Scatter Data Calibration Plot Using Linear Regression Equation

B. Validation Analysis Results

The validation analysis was conducted using the data with rain values, while those with 0 (zero) were ignored. This is important because the focus is usually on the rain that falls on the earth's surface. Still, TRMM provides data from atmospheric satellite observations, and some of its recorded values might not have reached the earth's surface as rain. Therefore, only the data containing rain values were used in the validation analysis.

1) Uncorrected Data Validation Analysis

The results of uncorrected data validation between the TRMM satellite and observed precipitation data from 2015 to 2019 are presented in Table II. Table II shows that Gunung Nago station has the largest RMSE value while Limau Manis has the lowest. The high value is associated with the station generating the largest precipitation data.

TABLE II

CALCULATION RESULTS OF UNCORRECTED DATA VALIDATION

Station	Time	RMSE	NSE		RE	R	
			Score	Ip		Score	Ip
Batu Busuk	2015	20,31	0.25	NE	1,74	-0.01	Weak
	2016	28.01	0.07	NE	6.91	0.07	Weak
	2017	29.45	0.01	NE	6.97	-0.02	Weak
	2018	26.14	0.33	NE	4.72	0.02	Weak
	2019	29.96	0.07	NE	3.76	0.11	Weak
Gn. Nago	2015	63.45	0.07	NE	11,91	-0.05	Weak
	2016	63.12	0.02	NE	11.18	0.01	Weak
	2017	3.01	0.39	E	6.06	0.01	Weak
	2018	27.01	0.35	NE	4.88	-0.01	Weak
	2019	0.81	0.15	NE	0.65	0.23	Weak
Limau Manis	2015	2.41	0.31	NE	5,83	0.05	Weak
	2016	2.29	0.26	NE	5.09	0.03	Weak
	2017	2.38	0.50	E	6.06	-0.02	Weak
	2018	20.01	0.59	E	1.31	0.03	Weak
	2019	0.16	0.89	E	0.02	0.10	Weak

Ip = Interpretation; NE=Not Eligible; E=Eligible

Moreover, NSE showed that some data failed to meet the required standards, which means the technique validation is not in line with the requirements. The calculation of RE of the uncorrected data showed a fairly large value in 2015, with 11.91, while the lowest was 0.02 in 2019 at Limau Manis. This means the validation using the relative error method is still not good due to two data with values exceeding 50% at Gunung Nago. Meanwhile, the correlation coefficient values for the three stations are below 0.5, indicating a weak correlation. It was also discovered that some stations have a negative correlation value, which means the variables have an inverse relationship such that high observed precipitation data was matched with low TRMM and vice versa. It was observed from the four analysis methods applied to the uncorrected data that the validation results were not good. This means conducting further analysis by correcting TRMM before they are validated through the observed precipitation data is necessary.

2) Corrected Data Validation Analysis

The TRMM precipitation data was corrected through calibration analysis. The results presented in Figure 3 showed that the polynomial equation could be used for the correction. This was achieved using Batu Busuk station data for February 9, 2016, as an example: x = 5 was applied to $y = 10^{-5}x^3 - 0.0034x^2 + 0.2731x + 4.1821$ to produce a corrected precipitation value of 5.42 mm. The coefficient of determination was later obtained after the TRMM data for each studied year had been corrected, which is known as the verification step. It was, therefore, discovered from the R^2 value that there is a strong relationship between the corrected TRMM and observed precipitation data, as indicated in the following Table III. Table III shows that the highest RMSE value was recorded at Gunung Nago in 2016, while the lowest was at Limau Manis in 2019. Meanwhile, NSE indicated that no data meets the required standards, which means the technique's validation is not in line with the requirement.

RE calculation showed a fairly large value ranging from 0.96 to 11.33, with the smallest recorded at Gunung Nago in 2019 and the largest at the same station in 2016. This means the application of this method is also not good because some observation stations have values that exceed 50%. However, the correlation coefficient values were high for the stations in the range of 0.75 - 0.99. This indicates a strong relationship between the TRMM satellite and observation precipitation data for the stations during the 2015-2019 period.

TABLE III

CORRECTED DATA VALIDATION RESULTS

Station	Time	RMSE	NSE		RE	R	
			Score	Ip		Score	Ip
Batu Busuk	2015	17.26	0.01	NE	1,91	0.83	VS
	2016	26.89	0.15	NE	7.07	0.85	VS
	2017	27.63	0.13	NE	7.06	0.90	VS
	2018	23.09	0.18	NE	4.77	0.88	VS
	2019	29.07	0.08	NE	3.48	0.86	VS
Gn. Nago	2015	22.09	0.14	NE	3,24	0.83	VS
	2016	62.29	0.04	NE	11,33	0.90	VS
	2017	31.19	0.12	NE	9.08	0.85	VS
	2018	23.69	0.18	NE	4.95	0.85	VS
	2019	15.49	0.12	NE	0.96	0.85	VS
Limau Manis	2015	20.88	0.19	NE	5.24	0.78	VS
	2016	20.88	0.19	NE	5.24	0.78	VS
	2017	22.29	0.16	NE	5.69	0.82	VS
	2018	15.84	0.21	NE	1.37	0.78	VS
	2019	12.03	0.14	NE	1.59	0.78	VS

Ip = Interpretation; NE=Not Eligible; E=Eligible; VS=Very Strong

IV. CONCLUSION

This study focuses on assessing the suitability of using TRMM satellite precipitation data in the hydrological analysis of the Kuranji watershed. This was achieved by comparing the daily precipitation data from this source with those from the observation stations. It is important to note that the TRMM precipitation data were calibrated before the validation to obtain corrected data.

The validation analysis showed that the corrected TRMM data outperforms the uncorrected ones, as indicated by the increase in the correlation coefficient value of 0.11 recorded for the uncorrected data to 0.90 for corrected data. It was discovered that the validation results are almost quite good, with a very strong correlation. Therefore, further studies must be conducted by correcting bulk TRMM precipitation data before validation because the results obtained in this study are not optimal, as indicated by the numerous "Not Eligible" NSE and high RMSE values.

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