Civil and Environmental Science Journal
Vol. 05, No. 02, pp. 129-143, 2022

Rationalization of rainfall station density in the Jatiroto sub-watershed using ground and satellite rainfall data

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Received 14-06-2022; accepted 27-09-2022

Abstract. This study uses ground and CHIRPS data to rationalize the density of rainfall stations in the Jatiroto Sub-watershed, Lumajang Regency. This study aimed to determine the suitability of the CHIRPS satellite rainfall data to the measurement data. In addition, it determines the density of rainfall stations based on WMO standards. Also, the Kagan-Rodda method uses measurement and satellite data to determine rainfall station recommendations' results. The method used for the suitability test uses the value of RMSE, NSE, Correlation Coefficient, and Relative Error. And the WMO standard for analyzing the number of rainfall station. Knowing the rationalization and recommendations for placing rainfall stations using the Kagan-Rodda method by considering WMO standards, root mean square error, and interpolation errors. The results obtained include the appropriateness of satellite data, the number of rainfall stations at the research location according to WMO standards, and recommendations for rainfall stations based on Kagan-Rodda.

Keywords: Appropriateness Test, WMO, Kagan-Rodda, Topography, Regression Analysis

1. Introduction

Hydraulic structure planning requires a good hydrological analysis [1]. Hydrological analysis requires rainfall data. The rainfall must be able to represent the conditions in the area and have good data quality. The data quality that will be taken for calculation of the analysis is influenced by the number of hydrological rainfall station that monitors a watershed.

The Jatiroto sub-watershed is one of the sub-watersheds located in Lumajang Regency, East Java. This sub-watershed is one of the areas prone to flooding. The flood occurred because the Jatiroto River could not accommodate the rainfall in the area. The Jatiroto sub-watershed has an area of 322 km^2 and has nine rainfall stations. The distribution of rainfall stations in the Jatiroto sub-watershed is uneven, with no existing rainfall stations upstream of the sub-watershed. The quality of rainfall data in the sub-watershed is not good enough because there are still missing rainfall data. This is due to the dysfunction of measuring instruments and human error, which causes an error in the measurement rainfall station. Suppose ground rainfall data cannot be fulfilled. In that case, it can also be considered rainfall data from satellites such as CHIRPS rainfall data [2]. So this study uses the CHIRPS rainfall data in the following analysis. Regarding operational costs, the more rainfall stations, the higher the maintenance costs. From these problems, optimal analysis is needed to determine the number of rainfall stations in the watershed.

This study aimed to determine the suitability of the CHIRPS satellite rainfall data to the measurement data. In addition, it determines the density of rainfall stations in the Jatiroto sub-watershed based on WMO standards. Also, the Kagan-Rodda method uses measurement and satellite data to determine rainfall station recommendations' results.

2. Material and Methods

2.1. Study Location

This research is located in the Jatiroto Sub-Watershed (Figure 1). The watershed is included in the Bondoyudo-Bedadung watershed area. The Jatiroto sub-watershed is located in Lumajang Regency, East Java. This sub-watershed is located at the coordinates of 112º50' 00” - 113º 22' 00” E dan 7º 52' 00” - 8º 23' 00” S.

The Jatiroto sub-watershed has nine rainfall stationsincluding Blimbing, Gedang Mas, Kali Penggung, Kaliboto, Maleman, Plandingan, Pondokwaluh, Rojopolo and Watuurip.

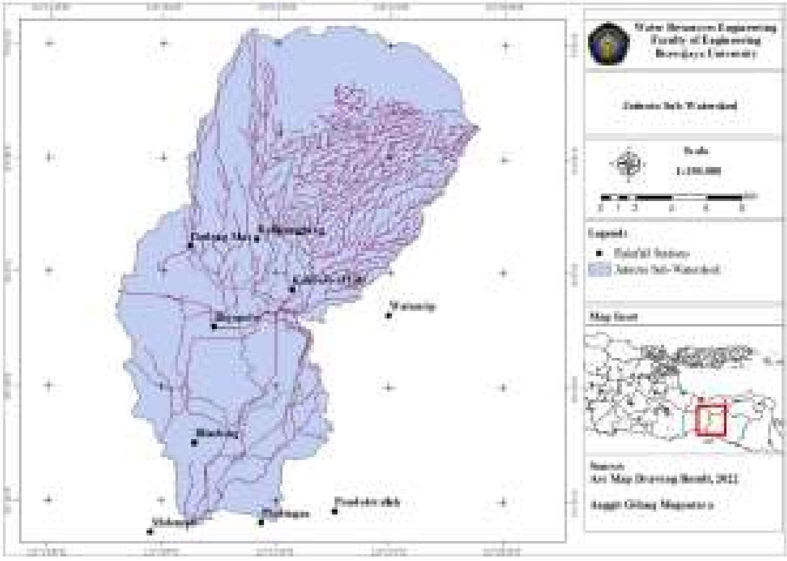


Figure 1. Study Location

2.2. Data Collection

The data used in this study is secondary data obtained from the Department of Public Works for Water Resources, East Java Province, and through the Google Earth Engine. The data needed to complete this research are as follows:

1. Ground rainfall data for 15 years in the Jatiroto Sub-Watershed (2006-2020)
2. CHIRPS satellite rainfall data for 15 years (2006-2020)
3. Location Data and The Coordinates of Rainfall stations in the Jatiroto Sub-Watershed
4. Map of Jatiroto Sub-watershed

2.3. Work Steps

In general and concise, the steps in this research are as follows:

a. Collect the rainfall data. Rainfall data used is ground rainfall data and CHIRPS satellite rainfall data. Ground rainfall data were obtained from nine existing rainfall stations. CHIRPS satellite rainfall data was obtained from downloading rainfall data from nine existing rainfall station points.
b. Fill in the missing rainfall data. If there is missing ground rainfall data, then fill in the missing rainfall data first.
c. Next, the consistency test and hydrological statistical test were carried out. This study uses the consistency test of multiple mass curves, the F and T Stationary Test, the Persistence Test with Spearman Test, and the Outliers Test.

d. The appropriateness Test of uncorrected data is analyzed by calculating the RMSE, NSE, Correlation Coefficient, and Relative Error. Then a regression analysis was carried out to obtain better quality data to get the corrected rainfall data. The appropriateness test of corrected satellite data was repeated by calculating the RMSE, NSE, Correlation Coefficient, and Relative Error.
e. Calculate the regional average rainfall using the Thiessen polygon method to determine the area of influence of each rainfall station and calculate the average rainfall value.
f. Evaluate the density of the existing rainfall station based on the WMO standard to determine whether the existing rainfall station has fulfilled the standard.
g. Analyze the density of rainfall stations based on the Kagan-Rodda method to determine the recommended point for the Kagan-Rodda rainfall station based on WMO standards.

2.4. The Formulas Used

The formulas used in this study include the following:

a. Reciprocal Method

$$Px = \frac{\sum_{i=1}^{n} \frac{Pi}{Li^2}}{\sum_{i=1}^{n} \frac{1}{Li^2}}$$

b. Double Mass Curve Consistency Test

$$S = \frac{\Delta Y}{\Delta X}$$

$$\alpha = \arctan S$$

c. The Absence of Trend Test

$$KP = 1 - \left[\frac{6 \sum_{i=1}^{n} (dt)^2}{n^3 - n}\right]$$

d. Stationary Test

$$F_{count} = \frac{n_1 {S_1}^2 (n_2 - 1)}{n_2 {S_2}^2 (n_1 - 1)}$$

$$t_{count} = \frac{\overline{X_1} - \overline{X_2}}{\sigma \left|\frac{1}{N_1} + \frac{1}{N_2}\right|}$$

e. Persistence Test

$$t_{count} = KS \left[\frac{m-2}{1 - KS^2}\right]^{\frac{1}{2}}$$

f. The Appropriateness Test

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} (Pi - Qi)^2}{n}}$$

$$NSE = 1 - \frac{\sum_{i=1}^{n} (Pi - Qi)^2}{\sum (Pi - Prerata)^2}$$

$$R = \frac{N \sum_{i.1}^{V} PiQi - \sum_{i.1}^{V} \rho ixi \sum_{-1}^{n} Qi}{\sqrt{15 \times \sum_{i=1}^{N} {P_1}^2 - (\sum_{i=1}^{N} {P_1}^2)^2} \sqrt{N \sum_{i=1}^{N} {Q_1}^2 - (\sum_{i=1}^{N} {Q_1}^2)^2}}$$

$$KR = \frac{\sum_{i=1}^{N} (pi - Qi)}{\sum_{i=1}^{N} Pi} x \ 100\%$$

g. Coefficient of Variation (Cv)

$$Cv = \frac{Sd}{\bar{X}}$$

h. Relative Root Mean Square Error (Z1)

$$Z1 = Cv \, . \sqrt{\frac{\left[1 - r_{(0)} + \left(\frac{0.23\sqrt{A}}{d_{(0)}\sqrt{n}}\right)\right]}{n}}$$

i. Interpolation Error (Z3)

$$Z3 = Cv \, . \sqrt{\left[\frac{1}{3}\left(1 - r_{(0)}\right) + \frac{0.52 r_{(0)} \sqrt{\frac{A}{n}}}{d(0)}\right]}$$

j. The Length of Kagan-Rodda

$$L = 1{,}07 \, . \sqrt{\frac{A}{n}}$$

Where:

Px = missing rainfall data in rainfall station x
Pi = rainfall data on surrounding stations in the same period
Li = distance between rainfall station i and rainfall station x
S = gradient
KP = Spearman rank correlation coefficient
$\overline{X_1}$ = The average rainfall sample 1
$\overline{X_2}$ = The average rainfall sample 2
KS = serial correlation coefficient
m = N – 1
Qi = Estimated data
r(d) = correlation coefficient for station distance d

n = the amount of data
dt = the difference between Rt and Tt
Tt = The rank of time
Rt = ranking of hydrological variables in a time series
t = t-test count value
S_1 = standard deviation of sample 1
S_2 = standard deviation of sample 2
N_1 = the size of sample 1
N_2 = the size of sample 2

r(o) = correlation coefficient for short station distances
d = distance between rainfall stations(km)
d(o) = correlation radius
Cv = coefficient of variation
A = area of watershed (km^2)
Z1, Z3 = Relative Root Mean Square Error (%) and Interpolation Error (%)
L = The Length of Kagan-Rodda (km)

3. Result and Discussion

3.1. Filling in Missing Rainfall Data

The method used to fill in the missing rainfall data is the Reciprocal Method. The Reciprocal method is better because it considers the distance between rainfall stations in that location [3]. The following is an analysis of the calculation of estimated missing rainfall data at Blimbing rainfall station in October 2012:

Table 1. Calculation of Missing Rainfall Data at Blimbing Rainfall Station in October 2012 with the Reciprocal Method

Rainfall Station	Rainfall Data (Pi)	Distance (Li)	Li^2	1/Li^2	P/Li^2
Maleman	0	5.61	31.50	0.03	0.00
Plandingan	30	5.89	34.73	0.03	0.86
Rojopolo	0	6.64	44.11	0.02	0.00
Amount				0.08	0.86
Px					10.38

3.2. Consistency Test

A consistency test is carried out to analyze whether the data has deviations or not due to the influence of errors during data recording. The consistency test in this study used the Multiple Mass Curve method. The data is said to be consistent if it fulfills the resulting angle of 45°[4]. The following are the results of the calculation of the Rainfall Station Data Consistency Test in the Jatiroto Sub-watershed:

Table 2. Consistency Test of The Rainfall Data

Rainfall Station	Uncorrected α		Correction Factor (Fc)		Corrected α	Remarks
	Ground Data	CHIRPS	Ground Data	CHIRPS		
Blimbing	41.45	43.81	1.13	1.04	45.00	Consistent
Gedang Mas	47.74	47.62	0.91	0.91	45.00	Consistent
Kali Penggung	44.51	47.62	1.02	0.91	45.00	Consistent
Kaliboto	50.10	45.91	0.84	0.97	45.00	Consistent
Maleman	43.83	40.70	1.04	1.16	45.00	Consistent
Plandingan	38.25	42.10	1.27	1.11	45.00	Consistent
Pondokwaluh	43.29	43.25	1.06	1.06	45.00	Consistent
Rojopolo	44.09	45.23	1.03	0.99	45.00	Consistent
Watuurip	49.50	47.40	0.85	0.92	45.00	Consistent

3.3. *Stationary Test*

The stationary test was carried out to know the stability of the variance value and the stability of the average value of the data. To determine the stability of the variance value using the F-test method and the stability of the average value using the T-test. Suppose the calculation results in the rejected null hypothesis. The data has an unstable and inhomogeneous variance [5]. The data is stationary and homogeneous if the calculated value is smaller than the critical value [6]. The expected result of the stationary test is homogeneous data, namely data that is stable in the value of the variance and the average value. In this stationary test, rainfall measurements and rainfall data from the CHIRPS satellite are used. Stationary test results can be seen in Table3.

Table 3. F Stationary Test of Rainfall Data

No	Rainfall Station	α	Ground Rainfall		CHIRPS Rainfall		Remarks
			F_{count}	$F_{critical}$	F_{count}	$F_{critical}$	
1	Blimbing	5%	0.49	4.21	0.62	4.21	Stable Variance
2	Gedang Mas	5%	0.47	4.21	0.88	4.21	Stable Variance
3	Kali Penggung	5%	0.99	4.21	0.88	4.21	Stable Variance
4	Kaliboto	5%	0.99	4.21	0.84	4.21	Stable Variance
5	Maleman	5%	0.07	4.21	0.83	4.21	Stable Variance
6	Plandingan	5%	0.37	4.21	0.85	4.21	Stable Variance
7	Pondokwaluh	5%	0.45	4.21	0.82	4.21	Stable Variance
8	Rojopolo	5%	0.75	4.21	0.58	4.21	Stable Variance
9	Watuurip	5%	0.57	4.21	0.84	4.21	Stable Variance

Table 4. T Stationary Test of Rainfall Data

No	Rainfall Station	α	Ground Rainfall		CHIRPS Rainfall		Remarks
			t_{count}	$t_{critical}$	t_{count}	$t_{critical}$	
1	Blimbing	5%	-0.26	±2.16	0.20	±2.16	Stable Average
2	Gedang Mas	5%	0.75	±2.16	0.27	±2.16	Stable Average
3	Kali Penggung	5%	0.80	±2.16	0.27	±2.16	Stable Average
4	Kaliboto	5%	0.30	±2.16	0.21	±2.16	Stable Average
5	Maleman	5%	-1.23	±2.16	0.30	±2.16	Stable Average
6	Plandingan	5%	-0.28	±2.16	0.24	±2.16	Stable Average
7	Pondokwaluh	5%	0.17	±2.16	0.30	±2.16	Stable Average
8	Rojopolo	5%	-0.04	±2.16	0.12	±2.16	Stable Average
9	Watuurip	5%	-0.17	±2.16	0.16	±2.16	Stable Average

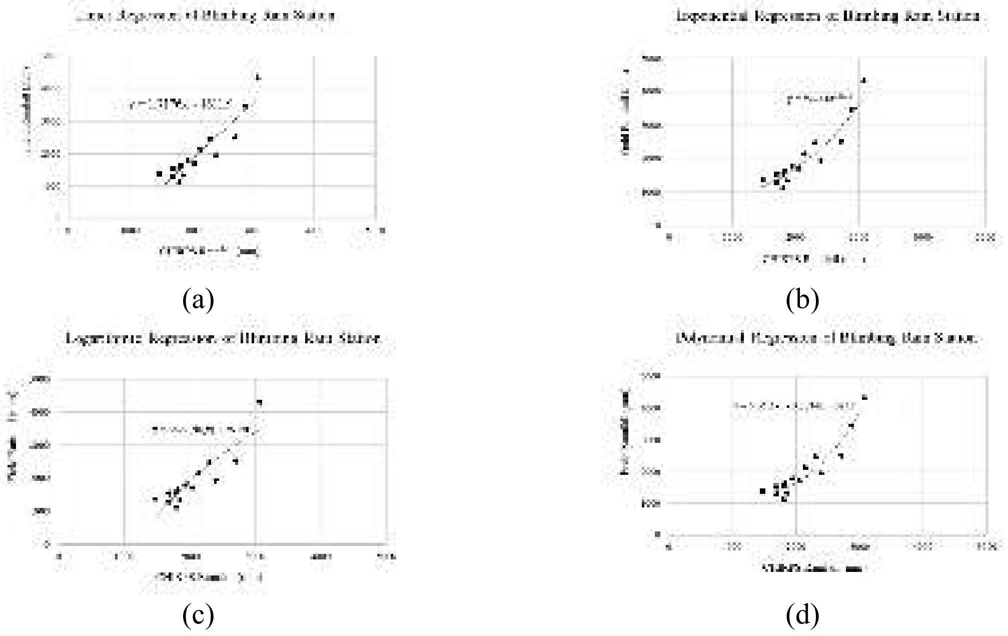
3.4. *Appropriateness Test*

An appropriateness test is a procedure for evaluating a data model to illustrate the level of uncertainty in the model and predict a hydrological analysis. The appropriateness test was carried out to determine the comparison between satellite rainfall data and ground rainfall data. The appropriateness test was carried out in two stages. There are the uncorrected data appropriateness test and the corrected data appropriateness test. The appropriateness test for uncorrected data was carried out by calculating the RMSE [7], NSE [8], Correlation Coefficient [9], and Relative Error [10]. Furthermore, regression analysis was carried out to improve the data quality. Several regression equations will be used in the regression analysis, including linear, exponential, logarithmic, polynomial, and power regression. This regression will produce a regression equation, and one equation will be selected with the largest correlation coefficient value. This appropriateness test uses rainfall data with a value in that the data used is not equal to zero. The regression equation cannot be performed if there is a zero value. Table 5 shows the results of the analysis of the uncorrected data appropriateness test.

Table 5. The Appropriateness Test of Uncorrected Data

Rainfall Stations	**RMSE**	**NSE**		**KR**	**R**	
		Value	**Interpretation**	**%**	**Value**	**Interpretation**
Stasiun Blimbing	471	0.69	Satisfactory	4.86	0.92	Very Strong
Stasiun Gedang Mas	542	0.53	Satisfactory	5.28	0.76	Strong
Stasiun Kali Penggung	423	0.50	Satisfactory	1.13	0.71	Strong
Stasiun Kaliboto	353	0.67	Satisfactory	4.97	0.84	Very Strong
Stasiun Maleman	1007	0.36	Satisfactory	10.31	0.70	Strong
Stasiun Plandingan	334	0.73	Satisfactory	4.06	0.88	Very Strong
Stasiun Pondokwaluh	346	0.73	Satisfactory	6.99	0.90	Very Strong
Stasiun Rojopolo	339	0.71	Satisfactory	2.24	0.85	Very Strong
Stasiun Watuurip	336	0.53	Satisfactory	2.47	0.75	Strong

Based on the calculation table for the uncorrected data suitability test, all NSE interpretations have fulfilled all of them, and the interpretation of the correlation value is strong to very strong. However, the highest interpretation of the NSE is only in the compliant category, so the data is corrected using regression analysis to obtain data of better quality. Regression analysis uses five equations [11] to choose one equation with the largest R-value. Figure 2 is an example of correcting data using regression analysis for the Blimbing Rainfall Station.

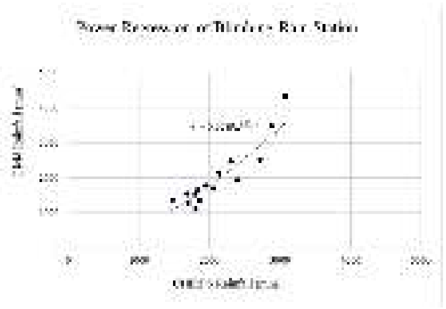


(a)

(b)

(c)

(d)



(e)

Figure 2. Regression Analysis with Scatter Plot in Blimbing Rainfall Station

3.5. Regression Analysis

The correction factor of the CHIRPS satellite data is used to determine the magnitude of the x and y parameters which act as correction factors in the equation of the measurement data line and the CHIRPS data. The line equation used is determined from the pattern of the rain measurement data series and CHIRPS, as well as the correlation coefficient. Next, the correction factor will correct the rainfall data using a predetermined equation by entering the CHIRPS data into the equation. It is because the value of the largest correlation coefficient has a strong relationship and is almost close to the ground rainfall data. The largest correlation coefficient (R) value will be used to select the equation to correct the CHIRPS satellite rainfall data.

Based on the regression analysis results for the Blimbing rainfall station, the largest correlation coefficient value is 0.96 with a polynomial regression equation. So, the polynomial equation is used as an equation to get the corrected data. After the corrected data is obtained, the data appropriateness test is repeated for the corrected rainfall data.

3.6. The Corrected Data Appropriateness Test

After obtaining the corrected data by correcting the regression equation with the largest correlation coefficient value, the corrected data appropriateness test was carried out by calculating the RMSE, NSE, Correlation Coefficient, and Relative Error. Table 6 shows the results of the corrected data suitability test analysis.

Table 6. The Corrected Data Appropriateness Test

Rainfall Station	**RMSE**	**NSE**		**RE**	**R**	
		Value	**Interpretation**	**%**	**Value**	**Interpretation**
Blimbing	254	0.91	Good	3.67	0.96	Very Strong
Gedang Mas	575	0.47	Satisfactory	12.93	0.76	Strong
Kali Penggung	463	0.40	Satisfactory	9.37	0.71	Strong
Kaliboto	360	0.67	Satisfactory	5.70	0.84	Very Strong
Maleman	880	0.51	Satisfactory	8.96	0.73	Strong
Plandingan	322	0.75	Satisfactory	6.67	0.90	Very Strong
Pondokwaluh	273	0.83	Good	1.67	0.91	Very Strong
Rojopolo	309	0.75	Good	1.81	0.87	Very Strong
Watuurip	302	0.62	Satisfactory	2.31	0.78	Strong

Based on the corrected data appropriateness test analysis, the highest interpretation has changed from "Satisfactory" to "Good". The interpretations of NSE values that change from "Satisfactory" to "Good" include Blimbing, Pondokwaluh, and Rojopolo. However, there is an NSE value after correction whose value decreases, proving that not all corrected data can result in better data quality. But, the corrected data is closer to the ground rainfall data; the correlation value evidences this for the corrected data, which increases for each rainfall station.

3.7. Regional Average Rainfall Analysis

The calculation of the regional average rainfall is used to obtain a rainfall value representing the rainfall value in the sub-watershed. There are several methods to calculate the regional average rainfall, such as the Average Method, Thiessen Polygon, and Isohyet Method. This study estimates the regional average rainfall using the Thiessen Polygon Method. The Thiessen Polygon is used because the Thiessen method is more accurate than the Average Method. The Thiessen Method is used in areas with uneven rainfall station distribution [12]. The Jatiroto sub-watershed has an uneven distribution of rainfall stations, so this method is used in this analysis. This Thiessen Method will consider a certain weight at each rainfall station, which means that each rainfall station is deemed to represent rainfall in a watershed with a particular area, it is a weighting factor for rainfall at the rainfall station concerned. Table 7 shows areas of influence using Thiessen Polygon method in the Jatiroto sub-watershed. Meanwhile, Tables 8 and 9 show the Regional Average Rainfall between ground and CHIRPS.

Table 7. Area of Influence Rainfall Station

Rainfall Station	Area km^2	Thiessen Coefficient	Percentage (%)	Rainfall Station	Area km^2	Thiessen Coefficient	Percentage (%)
Blimbing	40.33	0.13	12.53	Plandingan	11.89	0.04	3.69
Gedang Mas	30.16	0.09	9.37	Pondokwaluh	5.89	0.02	1.83
Kali Penggung	122.52	0.38	38.05	Rojopolo	42.25	0.13	13.12
Kaliboto	31.99	0.10	9.93	Watuurip	36.97	0.11	11.48
Maleman	0.00	0.00	0.00				

Table 8. Ground Regional Average Rainfall

Year	Rainfall
2006	1949
2007	2411
2008	2164
2009	2236
2010	3159
2011	1892
2012	1224
2013	2579
2014	1683
2015	1287
2016	3422
2017	2212
2018	1893
2019	1457
2020	2279

Table 9. CHIRPS Regional Average Rainfall

Year	Rainfall
2006	1579
2007	1702
2008	1869
2009	1762
2010	3017
2011	1980
2012	1650
2013	2582
2014	1685
2015	1605
2016	3096
2017	2237
2018	1678
2019	1456
2020	2106

3.8. WMO Analysis

Analyzing the density of rainfall stations can use the World Meteorological Organization (WMO) standard of reference. There is a minimum density value that WMO has mentioned, namely by considering the area of influence mentioned by WMO. Thiessen Polygon can calculate the area of influence of a watershed.

Based on the standards of the WMO, areas in the form of tropical Mediterranean mountain plains can be represented by at least one rainfall station in every 100-250 km^2 area [13]. Suppose it refers to the standard that has been set. In that case, it can be concluded that the ideal number of rainfall stations needed in the Jatiroto Sub-watershed, which has an area of 322 km^2 is 2-3 rainfall stations. Table 10 shows the area of the influence of the rainfall station and its description.

Table 10. Area of Influence of Rainfall Station

Rainfall Station	Area	Area of Rainfall Station in Ideal Condition	Rainfall Station	Area	Area of Rainfall Station in Ideal Condition
	km^2	100-250 km^2		km^2	100-250 km^2
Blimbing	40.33	Not Ideal	Plandingan	11.89	Not Ideal
Gedang Mas	30.16	Not Ideal	Pondokwaluh	5.89	Not Ideal
Kali Penggung	122.52	Ideal	Rojopolo	42.25	Not Ideal
Kaliboto	31.99	Not Ideal	Watuurip	36.97	Not Ideal
Maleman	0.00	Not Ideal			

From the analysis table of the area of influence of each rainfall station, it can be concluded that just one rainfall station that fulfills the ideal conditions set by WMO is the Kali Penggung rainfall station which has an area of influence of 123 km^2. The other rainfall stations have not fulfilled the ideal conditions set by WMO, so it is necessary to rationalize the density of rainfall stations in the Jatiroto Sub-Watershed.

3.9. Rainfall Station Density Rationalization Analysis Using the Kagan-Rodda Method

One method that can be used to rationalize the density of rainfall stations is the Kagan-Rodda method. The Kagan Rodda method uses statistical analysis calculations. It considers the density of the rainfall station network with a relative root mean square error (Z1), which should not exceed 10% [14], and also an interpolation error (Z3). Kagan stated that the network of eligible rainfall stations met the specified error criteria. According to Kagan [14], the criteria for placing rainfall stations depend on the distance between rainfall stations(L), which is obtained from the relationship between rainfall station distances and the rainfall correlation of each rainfall station.

The first step in performing the Kagan-Rodda analysis is calculating the variation coefficient. Table 11 shows the results of the calculation of the coefficient of variation of the measurement data and CHIRPS data data.

Table 11. The Calculation of Coefficient of Variation

Overview	Parameter	Value
Ground Data	Amount	31844.99
	$X_{average}$	2123.00
	Std Deviation	619.82
	Coef. of Variation	0.29
CHIRPS Satellite Data	Amount	29193.90
	$X_{average}$	1946.26
	Std Deviation	500.46
	Coef. of Variation	0.26

From the calculation of the coefficient of variation, it can be concluded that the coefficient of variation of the CHIRPS data is lower than the coefficient of variation of the ground rainfall data. It causes the CHIRPS rainfall data to be more homogeneous than the ground rainfall data.

Next, The correlation coefficient between rainfall stations was calculated for the ground and CHIRPS rainfall data. The correlation coefficient is determined by calculating the correlation value. The correlation coefficient will be used as a parameter of the relationship graph in the next analysis.

The following is an example of calculating the correlation coefficient for the Blimbing and Gedang Mas rainfall stations using measurement rainfall data.

$$r = \frac{n\sum_{i=1}^{n} X_iY_i - \sum_{i=1}^{n} X_i \sum_{i=1}^{n} Y_i}{\sqrt{\left[n\sum_{i=1}^{n} X^2 - \left(\sum_{i=1}^{n} X_i\right)^2 \left(n\sum_{i=1}^{n} {Y_i}^2 - \left(\sum_{i=1}^{n} Y_i\right)^2\right)\right]}}$$

$$r = \frac{(15\times66917146)-(30186\times29510)}{\sqrt{((15\times71538418)-30186^2)\times((15\times67428411)-29510^2)}}$$

$$r = 0.75$$

The correlation coefficient in all the rainfall stations is calculated for both ground rainfall dan CHIRPS rainfall. After calculating the correlation coefficient, then calculating the distance between rainfall stations. The ArcMap software is used for determining the distance between rainfall stations. The following table shows the results of calculating the distance between rainfall stations in the Jatiroto sub-watershed.

Table 12. The Distance between Rainfall Stations

Rainfall Stations	The Distance between Rainfall Stations (km)								
	Blimbing	Gedang Mas	Kali Penggung	Kaliboto	Maleman	Plandingan	Pondokwaluh	Rojopolo	Watuurip
Blimbing	-	11	12	10	6	6	9	7	13
Gedang Mas	11	-	4	6	16	16	17	5	12
Kali Penggung	12	4	-	3	18	16	16	6	9
Kaliboto	10	6	3	-	16	13	13	5	6
Maleman	6	16	18	16	-	6	10	12	18
Plandingan	6	16	16	13	6	-	4	11	14
Pondokwaluh	9	17	16	13	10	4	-	12	11
Rojopolo	7	5	6	5	12	11	12	-	10
Watuurip	13	12	9	6	18	14	11	10	-

After obtaining the correlation coefficient and the value of the distance between rainfall stations, these values are plotted in a relationship graph. The relationship graph will be used to determine the values of r(0) and d(0) in the following Kagan-Rodda analysis. In the relationship graph, the distance between stations is the X variable, and the correlation coefficient is the Y variable. The following is a graph of the relationship between distance and correlation coefficient for ground rainfall and CHIRPS data.

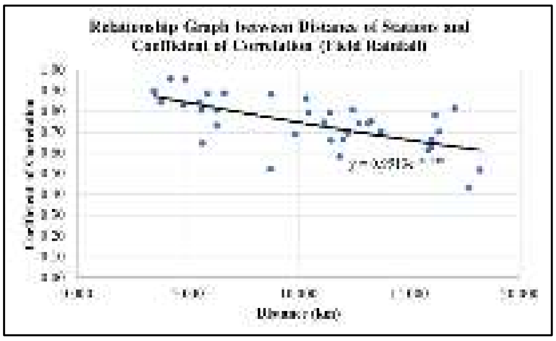


Figure 3. Relationship Graph of Ground Rainfall

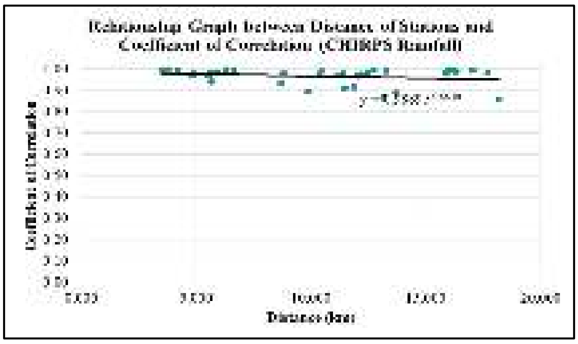


Figure 4. Relationship Graph of CHIRPS Rainfall

Based on the graph shown above, the measurement data produces the equation y = 0.9513-0.024x. so it can be determined that the value of r(0) = 0.9513 and the value of the correlation radius d(0) = 41.67. The following is a calculation of the value of d(0) for measurement data:

$$r_{(0)} \cdot e^{\frac{-d}{d_{(0)}}} = 0.9513^{-0.024x}$$
$$\frac{-d}{d_{(0)}} = -0.024d$$
$$d_{(0)} = \frac{1}{0.024}$$
$$d_{(0)} = 41.67 \text{ km}$$

In the same way, the d(0) value for CHIRPS data is also calculated, and the d(0) value is 500 km. Next, the value of d0 is used and becomes the input for calculating Z1, and Z3 also determines how many rainfall stations are needed. The Z1 dan Z3 used were by the previously analyzed WMO standards. Tables 13 and 14 show the calculation results for Z1 and Z3 for ground and CHIRPS rainfall.

Table 13. Z1 dan Z3 of Ground Rainfall

n	Cv	r(0)	A (km^2)	d(0)	A$^{1/2}$	n$^{1/2}$	(A/n)$^{1/2}$	Z1	Z3
1	0.29	0.951	322.01	41.67	17.94	1.00	17.94	11.22%	13.98%
2	0.29	0.951	322.01	41.67	17.94	1.41	12.69	7.11%	11.93%
3	**0.29**	**0.951**	**322.01**	**41.67**	**17.94**	**1.73**	**10.36**	**5.49%**	**10.89%**
4	0.29	0.951	322.01	41.67	17.94	2.00	8.97	4.58%	10.23%
5	0.29	0.951	322.01	41.67	17.94	2.24	8.03	3.98%	9.75%
6	0.29	0.951	322.01	41.67	17.94	2.45	7.33	3.56%	9.38%

Table 14. Z1 dan Z3 of CHIRPS rainfall

n	Cv	r(0)	A (km^2)	d(0)	A$^{1/2}$	n$^{1/2}$	(A/n)$^{1/2}$	Z1	Z3
1	0.26	0.989	322.01	500	17.94	1.000	17.9445	3.58%	3.83%
2	0.26	0.989	322.01	500	17.94	1.414	12.6887	2.37%	3.33%
3	**0.26**	**0.989**	**322.01**	**500**	**17.94**	**1.732**	**10.3603**	**1.87%**	**3.08%**
4	0.26	0.989	322.01	500	17.94	2.000	8.97225	1.59%	2.92%
5	0.26	0.989	322.01	500	17.94	2.236	8.02502	1.40%	2.81%
6	0.26	0.989	322.01	500	17.94	2.449	7.32581	1.26%	2.73%

Based on the table for calculating Z1 and interpolation error Z3, it is found that for the Jatiroto sub-watershed area of 322 km^2, according to the Kagan-Rodda method, three rainfall stations are needed.

The value of the Z1 of the ground rainfall data is 5.49%, and the Z3 is 10.89%. While the value of Z1 for the CHIRPS data is 1.87%, and the value of the Z3 is 3.08% for the CHIRPS rainfall. The determination of the three rainfall stations has been adjusted to the WMO standard. Figure 5 shows the relationship between the number of rainfall stations with Z1 and Z3 ground rainfall and the CHIRPS rainfall.

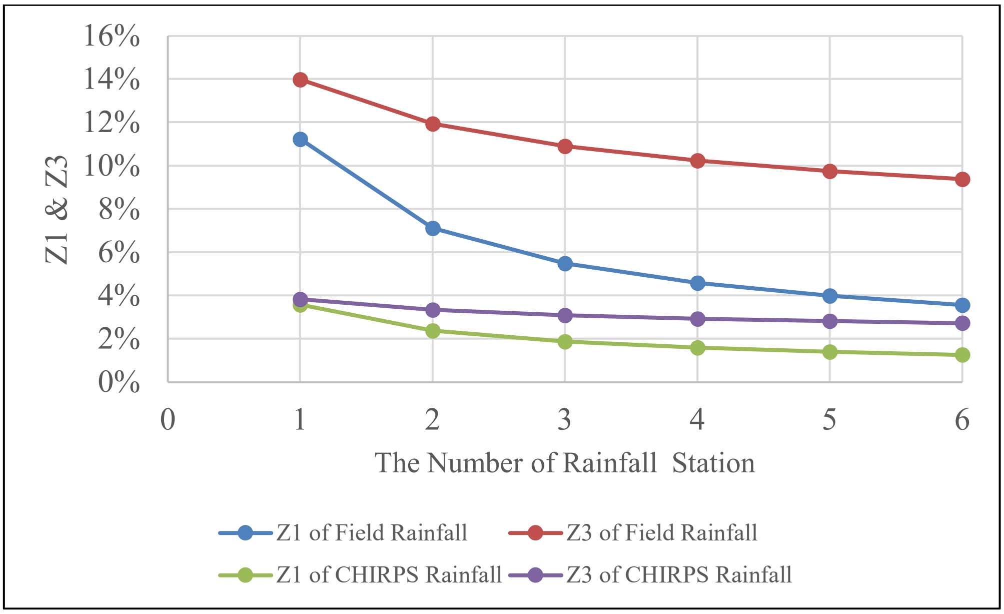


Figure 5. Z1 and Z3 Ground and CHIRPS Data

Figure 5 shows that the rainfall data from the CHIRPS satellite has an average error (Z1) and an interpolation error (Z3) which is smaller than the measured rainfall. It is because there is no significant difference between CHIRPS rainfall. Because the correlation is strong, the resulting smoothing error (Z1) and interpolation error (Z3) is smaller. In addition, the value of Z1 and Z3 in the CHIRPS satellite rainfall data is smaller than the ground rainfall data because the coefficient of variation (CV) value in the CHIRPS satellite rainfall data is smaller. It proves that the CHIRPS satellite rainfall data has a more evenly distributed (homogeneous) value than the ground rainfall data [15].

The next step is to determine the length of the Kagan-Rodda net triangle, which be used to draw the Kagan-Rodda net triangle. After the calculation, the length of L Kagan-Rodda in the Jatiroto sub-watershed was 11.09 km.

L Kagan Rodda for ground rainfall data and CHIRPS yielded the same value. It is because the variables that affect the Kagan-Rodda value are only the area of the watershed and the number of rainfall stations. The area and the number of rainfall stations of ground data and CHIRPS are the same, producing the same value. It resulted in the rationalization of rainfall stations for ground rainfall data and CHIRPS, yielding the same recommendations.

Next, create Kagan-Rodda nets by determining the reference stations. In this study, Model 1 used Blimbing Rainfall Station as a reference, and model 2 used Kali Penggung as a reference. Figures 6 and 7 show the Kagan-Rodda nets and Thiessen polygons for the Blimbing reference station.

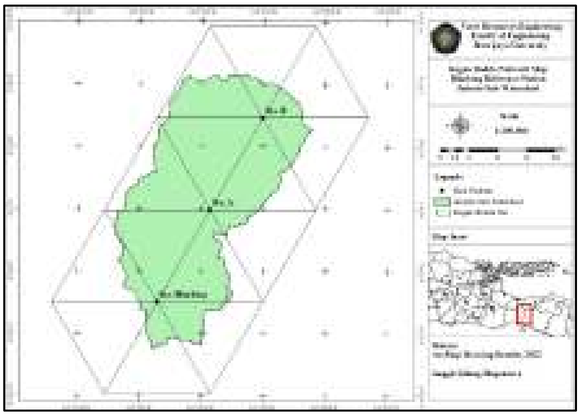


Figure 6. Kagan Rodda Net Model 1

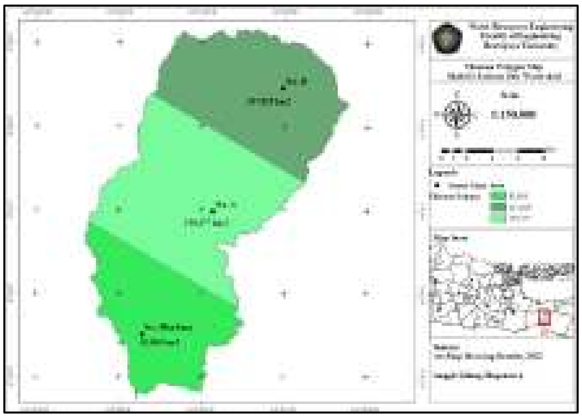


Figure 7. Thiessen Polygon Model 1

Model 1 produces three recommendations for rainfall stations, including Blimbing Station as a reference station, Station A and Station B. Each area of influence of the recommended rainfall station is shown in Table 14.

Table 14. Area of Influence Model 1

Station	Area of Influence (km^2)	Weight Area of Influence (%)
Blimbing	83.899	26.1
A	130.277	40.5
B	107.829	33.5

Based on the influence area, it can be concluded that there are still recommended rainfall stations that do not meet the ideal conditions of Blimbing Station, which has an influence area of less than 100 km^2. Then the second model was tried, and Kali Penggung acted as a reference station. Figures 8 and 9 show the Kagan-Rodda net and the Thiessen Polygon Map of the Kali Penggung as Reference Station.

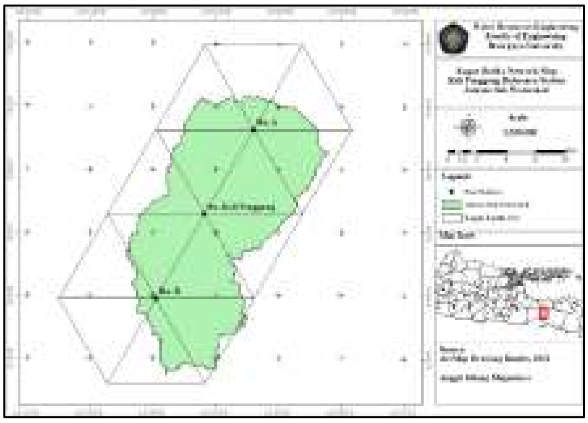


Figure 8. Kagan Rodda Net Model 2

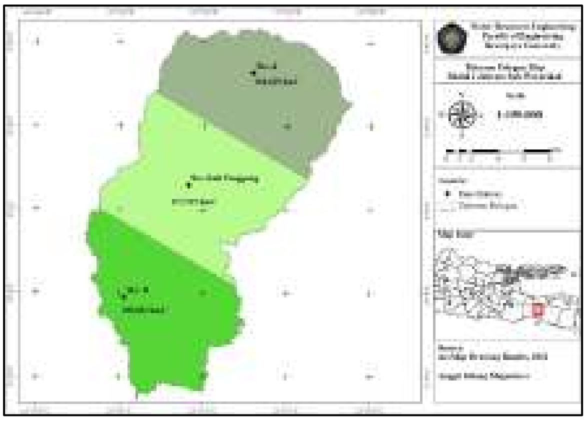


Figure 9. Thiessen Polygon Model 1

Model 2 produces three recommendations for rainfall stations, including Kali Penggung Station as a reference station, Station A and Station B. Each area of influence of the recommended rainfall station is shown in Table 15.

Table 15. Area of Influence Model 2

Station	Area of Influence (km^2)	Weight Area of Influence (%)
Kali Penggung	117.515	36.5
A	104.429	32.4
B	100.062	31.1

Based on the influence area of the second model, it can be concluded that all rainfall stations recommended by Kagan-Rodda have met the ideal WMO conditions. Each of which has an area of influence between 100-250 km^2. Thus, the second model can be considered in rationalizing rainfall stations in the Jatiroto Sub-Watershed. Table 16 shows the recapitulation of the rainfall station coordinates recommended by the second model of the Kagan Rodda method.

Table 16. Coordinate Point of Kagan-Rodda Recommendations

Kagan-Rodda Stations	Coordinate		Existing Stations	Coordinate	
	South Latitude	East Longitude		South Latitude	East Longitude
Kali Penggung	-8° 4' 59.2"	113° 20' 54.66"	Gedang Mas	-8° 5' 12.19"	113° 18' 51.52"
			Kali Penggung	-8° 4' 59.2"	113° 20' 54.67"
			Kaliboto	-8° 6' 32.18"	113° 21' 59.87"
			Watuurip	-8° 7' 19.02"	113° 24' 59.33"
A	-8° 0' 16.82"	113° 23' 36.05"	-		
B	-8° 9' 41.58"	113° 18' 13.22"	Blimbing	-8° 11' 14.65"	113° 19' 1.81"
			Maleman	-8° 13' 58.97"	113° 17' 40.96"
			Plandingan	-8° 13' 40.74"	113° 21' 6.3"
			Pondokwaluh	-8° 13' 18.72"	113° 23' 21.12"
			Rojopolo	-8° 7' 41.38"	113° 19' 37.56"

4. Conclusions

Based on the analysis that has been done, it can be concluded that it is necessary to rationalize the rainfall stations in the Jatiroto sub-watershed. It is because the density of the rainfall station does not meet WMO standards, and the rainfall stations are not evenly distributed. According to WMO standards, the Jatiroto Sub-Watershed, with an area of 322 km^2 requires 2-3 rainfall stations.

Rationalization was carried out using the Kagan-Rodda method, resulting in three recommendations for rainfall stations. The Kagan-Rodda recommendation maintains the Kali Penggung station, adds one rainfall station upstream of the sub-watershed, namely Station A, and moves Blimbing rainfall station to Station B. Kagan recommendation results in an area of influence that all meets WMO standards.

Acknowledgements

The author would like to thank to the Department of Public Works of Water Resources of East Java Province and the UPT of Water Resources Development of Lumajang Regency.

References

[1] Z. R. Alfirman. L. M. Limantara. and S. Wahyuni. “Rasionalisasi Kerapatan Pos Hujan Menggunakan Metode Kagan-Rodda Di Sub Das Lesti.” *J. Tek. Sipil*. vol. 8. no. 2. pp. 153–164. 2019.

[2] Misnawati. R. Boer. T. June. and A. Faqih. “Perbandingan Metodologi Koreksi Bias Data Curah Hujan CHIRPS.” *LIMNOTEK - Perair. Darat Trop. di Indones.*. vol. 25. no. 1. pp. 18–29. 2018. [Online]. Available: https://limnotek.limnologi.lipi.go.id/index.php/limnotek/article/view/224

[3] I. W. Yasa. M. B. Budianto. and N. M. K. Santi. “Analisis Beberapa Metode Pengisian data Hujan yang Hilang di Wilayah Sungai Pulau Lombok.” *Spektrum Sipil*. vol. 2. no. 1. pp. 49–60. 2015. [Online]. Available: https://spektrum.unram.ac.id/index.php/Spektrum/article/view/42

[4] R. W. Sayekti. S. Wahyuni. M. Bisri. M. J. Ismoyo. and N. A. Nathania. “Mathematical model distribution of some water quality parameters in the reservoir.” vol. 5. no. 1. pp. 64–77. 2022.

[5] 1995 Soewarno. “Rilid 2”.

[6] N. Salsabila. L. M. Limantara. and J. Sidqi. “Banjir Sulsel 3.” vol. 1. no. 2. pp. 736–749. 2021.

[7] M. H. Le. V. Lakshmi. J. Bolten. and D. Du Bui. “Adequacy of Satellite-derived Precipitation Estimate for Hydrological Modeling in Vietnam Basins.” *J. Hydrol.*. vol. 586. no. November 2019. p. 124820. 2020. doi: 10.1016/j.jhydrol.2020.124820.

[8] A. G. Mengistu. T. A. Woldesenbet. and Y. D. Taddele. “Evaluation of observed and satellite-based climate products for hydrological simulation in data-scarce Baro -Akob River Basin. Ethiopia.” *Ecohydrol. Hydrobiol.*. vol. 22. no. 2. pp. 234–245. 2022. doi: 10.1016/j.ecohyd.2021.11.006.

[9] Q. Wang. J. Xia. D. She. X. Zhang. J. Liu. and Y. Zhang. “Assessment of four latest long-term satellite-based precipitation products in capturing the extreme precipitation and streamflow across a humid region of southern China.” *Atmos. Res.*. vol. 257. no. 8. p. 105554. 2021. doi: 10.1016/j.atmosres.2021.105554.

[10] S. Wahyuni. D. Sisinggih. and I. A. G. Dewi. “Validation of Climate Hazard Group InfraRed Precipitation with Station (CHIRPS) Data in Wonorejo Reservoir. Indonesia.” *IOP Conf. Ser. Earth Environ. Sci.*. vol. 930. no. 1. 2021. doi: 10.1088/1755-1315/930/1/012042.

[11] H. Y. Chen and C. Chen. “Evaluation of Calibration Equations by Using Regression Analysis: An Example of Chemical Analysis.” *Sensors*. vol. 22. no. 2. 2022. doi: 10.3390/s22020447.

[12] T. Torres. “PENENTUAN JARAK ANTAR STASIUN HUJAN DENGAN METODE KAGAN RODDA DI DAS KEDUNGLARANGAN KABUPATEN PASURUAN PROVINSI JAWA TIMUR.” vol. 7. no. 1. p. 111. 2017.

[13] L. Sigar. C. Ranesa. L. M. Limantara. and D. Harisuseno. “ANALISIS RASIONALISASI JARINGAN POS HUJAN UNTUK KALIBRASI HIDROGRAF PADA DAS BABAK KABUPATEN LOMBOK TENGAH.” *J. Tek. Pengair.*. vol. 6. no. 1. pp. 46–54. 2015.

[14] S. H. Br.. *Analisis hidrologi*. Jakarta: Gramedia Pustaka Utama. 1993.

[15] Soewarno. *Aplikasi Metode Statistika untuk Analisis Data Hidrologi*. Yogyakarta: Graha Ilmu. 2014.