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Rationalization of Rainfall Station Network in Welang Watershed Using Kagan-Rodda Method

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A B S T R A C T

Rationalizing rainfall station is important to get an effective and efficient number and distribution of rainfall stations. If rationalization isn't carried out, it affect to operating and maintenance costs of rainfall stations and accuracy of data. This study aimed to evaluate existing rainfall station and rationalize rainfall station, so rainfall station's location is evenly distributed. This study is located in Welang watershed with an area 477.78 km2. This research requires rainfall ground data from 9 rainfall stations and CHIRPS satellite rainfall data from Google Earth Engine. The data is tested with consistency, stationary, suitability, and rationalization based on World Meteorological Organization (WMO) standards and Kagan-Rodda method. Later, new rainfall station networks will be obtained with the influence area of rainfall stations suitable to WMO Standard. CHIRPS data is highly suitable with ground data, proven by high NSE, strong correlation, and low relative error, so CHIRPS data can be used for further analysis. According WMO, only 1 rainfall station in Welang watershed has been suitable for WMO standard. Those unsuitable with WMO standards need to be rationalized. Based rationalization results, with average error <10%, Welang watershed requires 4 rainfall stations by maintaining Lawang Station, moving Telebuk to Station B, Selowongko to Station C, and Tutur to Station D. The influence area of recommendation rainfall stations have been suitable to WMO Standards and obtained even distribution rainfall stations. This recommendation are expected to be considered by relevant institutes to move the location of the rainfall station to get more accurate rainfall data.

1. Introduction

Welang watershed is located in three areas: Pasuruan Regency, Pasuruan City, and Malang Regency. There are nine rainfall stations in this watershed. The ability of rainfall stations to monitor that area's hydrological conditions is needed to obtain accurate data [1]. Rainfall data generated from rainfall stations are important input data for water resources management [2] [3] [4].

Inaccurate rainfall data causes the results of resource management to be inaccurate because water resource management requires rainfall data that must represent conditions in the area. Rainfall ground data often produce inaccurate data caused by natural factors, human error, and the error of rainfall stations. Rainfall station conditions, including number and distribution, affect rainfall data accuracy. Rainfall data becomes more accurate as the number of rainfall stations increases. However, the operating and maintenance costs must also be considered [5] [6]. In addition, the limitation of rainfall measurement data in the field is one of the obstacles experienced in Indonesia. At the same time, good rainfall data in terms of quality and quantity is needed.

By rationalizing rainfall stations, it is expected to get a rainfall station that can represent rainfall data in the area. Rationalization of rainfall stations is rainfall station analysis to find out the amount of ideal and representative rain data station to the conditions of an area. Rationalization is used to design, evaluate, and redesign a rainfall station network [7] to make the number and distribution of rainfall stations in an area more practical. Besides rainfall stations, technological advances produce rainfall data from satellites with a high resolution, both spatial resolution (global and regional), as well as temporal resolution (hourly, daily, monthly) [8] [9] [10]. One of the satellites that can be used is the CHIRPS satellite, with a spatial resolution of 0.05° x 0.05° arc degrees or about 5 km and a temporal resolution (daily, monthly, yearly) [11] [12] [13] [14]. In this study, rainfall station network is regulated by World Meteorological Organization (WMO) standard and the rationalization of the rainfall station was carried out using the Kagan-Rodda method. Kagan-Rodda method is one of the relatively simple methods to rationalize rainfall station network and is calculated using statistical analysis by connecting the density of the rainfall station network compared to interpolation and averaging errors between other rainfall stations that area. Several other researchers who applied the Kagan-Rodda method got rationalization results in good rainfall station density [15] [16] [17]. But rationalization of rainfall stations using ground data and CHIRPS satellite data has never been carried out.

This study aimed to evaluate the existing rainfall station network based on the WMO standard and to obtain the number and distribution of effective and efficient rainfall stations so the location of rainfall stations are evenly distributed. In this study, collected data was carried out, after that the data was tested and continued to rationalize the rainfall station. This study will bring the result of shifting and merging of rainfall stations, so the number and influence area of each rainfall station is suitable with World Meteorological Organization (WMO) standard. The results of this recommendation are expected to be considered by the relevant institutes to move the location of the rainfall station to get more accurate rainfall data.

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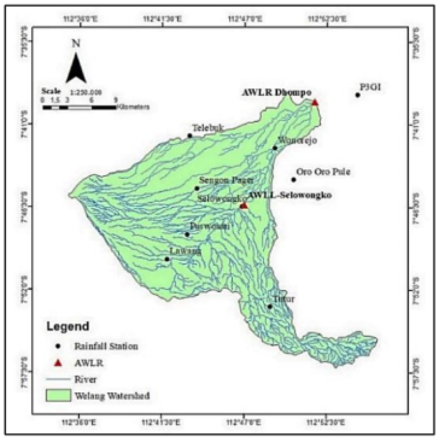
2. Research Method

This research is located in the Welang watershed, which has an area of 477.78 km^2. Welang watershed has nine rainfall stations, including Lawang Station, P3GI Station, Selowongko Station, Sengon Pager Station, Telebuk Station, Tutur Station, Wonorejo Station, Oro-Oro Pule Station, and Purwosari Station. In this study, rainfall data were obtained from ground data and CHIRPS satellite. Furthermore, both data were tested for consistency, stationary, suitability test of uncorrected data, regression analysis, and suitability test of corrected data to see the quality of data. Then, rationalization was carried out using the Kagan Rodda method based on the WMO standard.

2.1 Collecting Data

The data in this study are rainfall data from the nine rainfall stations shown in **Figure 1** and come from ground data and satellite rainfall data. Rainfall ground data is from the Water Resources Public Works of East Java Province. Satellite rainfall data comes from the CHIRPS satellite, which can be downloaded on the Google Earth Engine. The data used in this study is annual cumulative data with a data range of 15 years from 2006 to 2020. Both of data were tested with consistency and the stationary test. If the data is consistent and stationary, it is continued with the CHIRPS and ground data suitability test. The appropriate data were used to rationalize the rainfall station using the Kagan-Rodda method.



Source : Author's Analysis (ArcMap, 2022).

Figure 1. Distribution of Rainfall Stations and AWLR in Welang Watershed

2.2 Data Test

2.2.1 Consistency Test

The consistency test is used to know the consistency and similarity of rainfall data in one rainfall station to the other [18]. The consistency test determines the existence of data

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deviations caused by transmission or measurement errors. This test is carried out because the data used in the analysis must describe the actual hydrological conditions. The method used for this test is double mass curves. Double mass curves are performed by comparing the cumulative rainfall data at station X graphically with the cumulative value of the average annual rainfall from the rainfall stations around station X. If the pattern from the graph is a straight line and there are no faults, and then the data is consistent. The data tested in this study are rainfall ground data and CHIRPS rainfall data.

2.2.2 Stationary Test

The stationary test used the F-test and T-test methods to determine the variance value's stability and the mean value's stability. The steps of the F-test and T-test are started by grouping the data into two groups of data, and each data group is calculated the amount of data (Ni), standard deviation (Si), and the mean value of rainfall. Then calculate the value of F_{count} and t_{count} like the formulas below. Data is said to be stationary if the calculated value is greater than the critical value at a particular significance level [19]. The F-Test and T-Test formulas are as follows:

$$F_{count} = \frac{N_1 {S_1}^2.(N_2-1)}{N_2 {S_2}^2.(N_1-1)} \qquad t_{count} = \frac{\overline{X_1}-\overline{X_2}}{\sigma\sqrt{\frac{1}{N_1}+\frac{1}{N_2}}}$$

With:

S_1 = standard deviation of sample 1
S_2 = standard deviation of sample 2
N_1 = total data from sample 1
N_2 = total data from sample 2
$\overline{X_1}$ = average rainfall of sample 1
$\overline{X_2}$ = average rainfall of sample 2

2.2.3 Suitability Test of Uncorrected and Corrected Data

The suitability test of uncorrected and corrected data is used to determine the suitability of the rainfall ground data and uncorrected also corrected satellite rainfall data. In this study, the data suitability was tested by the Root Mean Square Error (RMSE) [20], Nash-Sutcliffe Efficiency (NSE) [21], Coefficient Correlation [2], dan Relative Error [22]. The formula used to calculate the methods are as follows.

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{N}(Pi-Qi)^2}{N}} \qquad R = \frac{N\sum_{i=1}^{N}PiQi-\sum_{i=1}^{N}Pi \text{ x } \sum_{i=1}^{N}Qi}{\sqrt{N\sum_{i=1}^{N}Pi^2-(\sum_{i=1}^{N}Pi)^2}\sqrt{N\sum_{i=1}^{N}Qi^2-(\sum_{i=1}^{N}Qi)^2}}$$

$$\text{NSE} = 1 - \frac{\sum_{i=1}^{N}(Pi-Qi)^2}{\sum_{i=1}^{N}(Pi-\overline{Pi})^2} \qquad \text{RE} = \frac{\sum_{i=1}^{N}(Pi-Qi)}{\sum_{i=1}^{N}Pi} \text{ x } 100\%$$

Where n is the total data, Pi is rainfall ground data, and Qi is the CHIRPS rainfall data.

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2.2.4 Regression Analysis

Regression analysis was used to correct CHIRPS satellite data. This study's analysis used linear regression, exponential, logarithmic, polynomial, and exponent [23]. The equations were obtained from the scatter plot graph from the fiveregression analysis. Then the equation is multiplied by the uncorrected CHIRPS satellite data. Furthermore, the correlation coefficient is calculated to determine the level of relationship between the two data, and the calibration R-value is obtained. Moreover, the equation with the highest correlation coefficient (R) is selected, which is used as a correction factor for CHIRPS satellite data.

2.3 Area Rainfall and WMO Standard

In this study, calculation of regional average rainfall using the Thiessen Polygon to determine the influence area of each rainfall station and calculate the average rainfall value. After that, evaluate the density of the existing rainfall stations using WMO standard, which provides guidelines for the minimum density of rainfall stations [24] for mountainous areas in the moderate, tropical, and Mediterranean zones, with an area of 100 km^2 - 250 km^2, it is sufficient to have one rainfall station [25].

2.4 Kagan-Rodda Method

One of the methods used to analyze the rainfall station network is Kagan-Rodda method. This method helps to obtain an optimal new rainfall station network. The steps for analyzing the rainfall station network using the Kagan – Rodda method are as follows:

- Calculate the coefficient of variation (Cv) then draw an exponential graph of the relationship between the correlation coefficient and rainfall station distance. The graph shows an exponential equation to get the value of $r_{(0)}$ and $d_{(0)}$.
- Determine the number of stations by considering averaging error (Z_1) and interpolation error (Z_3) values then determine the location of the rainfall station by drawing a net of Kagan Rodda with a length of L.

The formula for the Kagan-Rodda analysis is as follows:

$$Cv = \frac{Sd}{\bar{X}} \qquad r_{(d)} = r_{(0)}.e^{\left(\frac{-d}{d_0}\right)} \qquad L = 1.07.\sqrt{\frac{A}{n}}$$

$$Z_1 = Cv.\sqrt{\frac{\left[1 - r_{(0)} + \left(\frac{0.23\sqrt{A}}{d(0)\sqrt{n}}\right)\right]}{n}} \qquad Z_3 = Cv.\sqrt{\left[\frac{1}{3}\left(1 - r_{(0)}\right) + \frac{0.52\, r_{(0)}\sqrt{\frac{A}{n}}}{d_{(0)}}\right]}$$

with:

Cv = coefficient of variation

$d_{(o)}$ = radius correlation

Sd = standard of deviation

A = area (km^2)

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$\bar{X}$ = regional average rainfall
$r_{(d)}$ = correlation coefficient for rainfall stations with distance (d)
$r_{(o)}$ = correlation coefficient of rainfall between extrapolated stations
n = total station
Z_1, Z_3 = average error (%) and interpolation error (%)
L = Kagan-Rodda's distance (km)
d = distance between rainfall stations (km)

3. Results and Discussions

3.1 Data Test

The data tests carried out include data consistency tests and stationary tests to obtain consistent and homogeneous data results. Furthermore, the data suitability test is carried out to see the suitability results between the ground data and satellite data. Suppose the two data yields a low level of suitability. In that case, a regression analysis is performed to obtain the selected equation with the highest coefficient correlation (R) value to correct the satellite data. Furthermore, the suitability test is carried out again with the corrected data to see the level of suitability of the ground data and satellite data.

3.1.1 Rainfall Data Consistency Test and Stationary Test

From the initial analysis, results of the rainfall data consistency test using the ground and satellite data found that only 4 rainfall stations from satellite data, namely Selewongko, Sengon Pager, Telebuk, Tutur Station, were consistent with angles ranging from 42° to 48°. Meanwhile, other stations have not been consistent. So that the data is corrected by looking for a correction factor by calculating the ratio of the reference line's gradient to the broken line. In this study, the value of the correction factor ranges from 0.69 to 1.63. The value of the correction factor is then multiplied by the rainfall measurements and satellites. After correcting, the corrected angle is obtained between 42° to 48°. Therefore, it can be concluded that the rainfall ground data and CHIRPS rainfall data are consistent then a stationary test is carried out.

The results of the stationary test show that the F_{count} value at all stations, both from ground and satellite data, has a value between 0.588 to 3.526, while the $F_{critical}$ value is 4.21. In addition, t_{count} value at all stations from both ground and CHIRPS satellite has a value between -1.084 to 1.542, while $t_{critical}$ value is ±2.16. From this value, it is found that the value of $F_{count} < F_{critical}$ and $-t_{critical} < t_{count} < +t_{critical}$ for all stations. So, it can be concluded that the rainfall ground data and CHIRPS rainfall data are homogeneous.

3.1.2 Suitability Test of Uncorrected Data

Suitability Tests of uncorrected data results are shown in **Table 1**.

Table 1. Summary of Suitability Test of Uncorrected Data

Station	RMSE	NSE	Performance of NSE	R	Performance of R	RE
Lawang	337	0.6	Satisfactory	0.78	Strong	1.76%
P3GI	255	0.74	Satisfactory	0.87	Very Strong	2.75%
Selewongko	397	0.42	Satisfactory	0.70	Strong	6.27%
Sengon Pager	366	0.52	Satisfactory	0.78	Strong	7.92%
Telebuk	291	0.70	Satisfactory	0.84	Very Strong	1.84%
Tutur	480	0.29	Unsatisfactory	0.84	Very Strong	19.98%
Wonorejo	250	0.62	Satisfactory	0.84	Very Strong	3.10%
Oro-Oro Pule	513	0.43	Satisfactory	0.67	Strong	3.85%
Purwosari	339	0.68	Satisfactory	0.86	Very Strong	6.70%

Source : Author's Analysis (2022).

Based on **Table 1**, the suitability test of uncorrected data showed the highest RMSE results at the Oro – Oro Pule Rainfall Station. The correlation coefficient value showed a strong to very strong result, and the RE value ranged from 1% to 20%. The NSE value at Tutur Station was unsatisfactory because of NSE < 0.36. Therefore, the data must be corrected before being used for further analysis.

3.1.3 Regression Analysis

Table 2 shows the selected regression equation for each rain station data.

Table 2. Summary of Selected Regression Equation

Station	R Calibration					R max	Selected Regression Equation
	Linear	Exponential	Logarithmic	Polynomial	Power		
Lawang	0.78	0.75	0.79	0.80	0.78	0.80	Polynomial
P3GI	0.87	0.87	0.85	0.88	0.87	0.88	Polynomial
Selowongko	0.70	0.70	0.70	0.70	0.70	0.70	Power
Sengon Pager	0.78	0.76	0.79	0.80	0.78	0.80	Polynomial
Telebuk	0.84	0.83	0.84	0.84	0.84	0.84	Logarithmic
Tutur	0.84	0.87	0.81	0.89	0.84	0.89	Polynomial
Wonorejo	0.84	0.85	0.81	0.87	0.83	0.87	Polynomial
Oro-Oro Pule	0.67	0.68	0.66	0.68	0.67	0.68	Polynomial
Purwosari	0.86	0.82	0.88	0.90	0.85	0.90	polynomial

Source : Author's Analysis (2022).

Based on the results in **Table 2**, from the regression analysis, the selected regression equation for each rainfall station is not always the same. In this study, the polynomial equation is the most selected regression equation for correcting the CHIRPS satellite rainfall data because it has the highest correlation coefficient value.

3.1.4 Suitability Testing of Corrected Data

After correcting the data using the selected regression equation, the corrected CHIRPS satellite data was tested for suitability using the RMSE, NSE, Correlation Coefficient, and Relative Error methods. The suitability tests of corrected data are shown in **Table 3**.

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Table 3. Summary of Suitability Test of Corrected Data

Station	RMSE	NSE	Performance of NSE	R	Performance of R	RE
Lawang	328	0.62	Satisfactory	0.79	Strong	0.02%
P3GI	277	0.69	Satisfactory	0.88	Very Strong	6.51%
Selewongko	372	0.49	Satisfactory	0.70	Strong	0.11%
Sengon Pager	354	0.55	Satisfactory	0.79	Strong	7.44%
Telebuk	284	0.71	Satisfactory	0.84	Very Strong	0.03%
Tutur	270	0.78	Good	0.89	Very Strong	3.97%
Wonorejo	211	0.73	Satisfactory	0.87	Very Strong	3.53%
Oro-Oro Pule	503	0.46	Good	0.68	Strong	1.61%
Purwosari	260	0.81	Good	0.90	Very Strong	1.57%

Source : Author's Analysis (2022).

Based on **Table 3**, the suitability test of corrected data showed better results, as evidenced by a smaller RMSE value. The NSE value of uncorrected data showed unsatisfactory. After correcting the data, the NSE value showed satisfactory category to good category for all rainfall station data. The correlation coefficient value indicates a strong to a very strong category, and the Relative Error value for each data station is minimal, approaching 0%. It meant that the suitability test of corrected data was successful, and the corrected CHIRPS satellite data could be used for further analysis.

3.2 Regional Average Rainfall and WMO Standard Analysis

The regional average rainfall is calculated using the Thiessen Polygon method to obtain the value of the Thiessen Coefficient from each rainfall station shown in **Table 4**.

Table 4. Influence Area of Rainfall Station and WMO Analysis

Station	Area (km^2)	Thiessen Coefficient	WMO Standard
Lawang	101.94	0.21	Ideal
P3GI	2.77	0.01	Not ideal
Selowongko	62.58	0.13	Not ideal
Sengon Pager	72.95	0.15	Not ideal
Telebuk	33.74	0.07	Not ideal
Tutur	87.90	0.18	Not ideal
Wonorejo	56.57	0.12	Not ideal
Oro-Oro Pule	2.21	0.05	Not ideal
Purwosari	57.12	0.12	Not ideal
Totals	**477.78**	**1**	

Source : Author's Analysis (2022).

WMO standard analysis determines the distribution conditions of the existing rainfall stations in the Welang watershed. Based on WMO standards, the Welang watershed, with an area of 477.78 km2, only requires four rainfall stations. Based on Table 6, from 9 rainfall stations, there is only one rainfall station, namely the Lawang Rainfall Station, which is suitable for the ideal

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conditions according to WMO standards. In contrast, the other rainfall stations have an area of < 100 km^2. Therefore, rationalization is needed to get the number and distribution of rainfall stations evenly and efficiently. Based on **Table 6**, the thiessen coefficient value is used to calculate the regional average rainfall for the rationalization analysis of the Kagan Rodda method.

3.3 Rationalization of Rainfall Stations with the Kagan-Rodda Method

The first step in this analysis is to calculate the coefficient of variation using average area rainfall from ground data and CHIRPS satellite rainfall data. From the data, the rainfall ground data values range from 1432 to 2802. While the rainfall values from the CHIRPS satellite data range from 1463 to 2911. From these values, the average rainfall for the ground data is 1924 and the standard deviation is 455.318. Meanwhile, the average rainfall for the CHIRPS satellite is 1961 and the standard deviation is 439.949. So the value of the coefficient of variation can be calculated as follow:

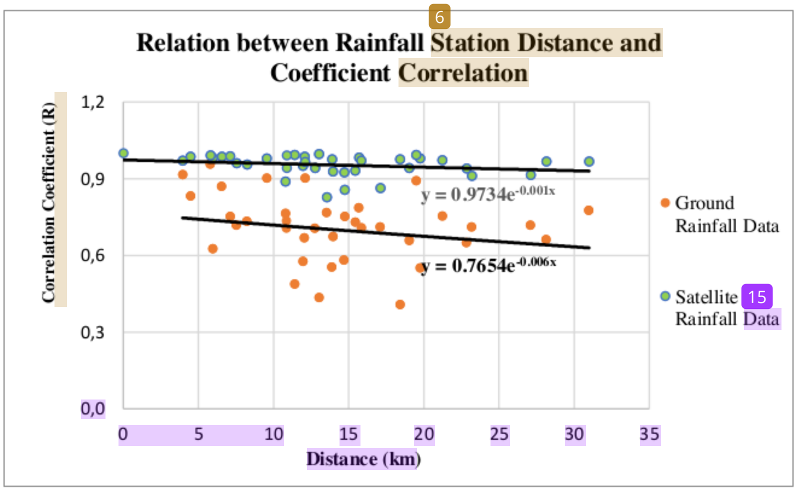
For Ground Data

$$\text{Cv} = \frac{Sd}{\bar{X}} = \frac{455.318}{1924} = 0.237$$

For CHIRPS Satellit Data

$$\text{Cv} = \frac{Sd}{\bar{X}} = \frac{439.949}{1961} = 0.224$$

Furthermore, the correlation coefficient between rainfall stations is calculated for ground and satellite rainfall data and then analyses the distance between rainfall stations. The relationship between rainfall station distance and coefficient correlation is depicted in the exponential graph shown in **Figure 2**.



Source : Author's Analysis (Ms Excel, 2022).

Figure 2. Graph Relation Between Distance and Coefficient Correlation

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Based on **Figure 2**, a regression equation is obtained for the rainfall ground data and satellite data as $y = 0.7654e^{-0.006x}$ for Ground Data and $y = 0.9734e^{-0.001x}$ for Satellite Data. From the formula, the parameter values obtained are $r_{(0)}$ and $d_{(0)}$. The value of $r_{(0)}$ for Ground Data is 0.7654 and the value of $r_{(0)}$ for Satellite Data is 0.9734, while $d_{(0)}$ is obtained from the following calculations.

For Ground Data

$$r_{(0)}.e^{\frac{-d}{d(0)}} = 0.7654e^{-0.006d}$$

$$\frac{-d}{d(0)} = -0.006d$$

$$d(0) = 1/0.006 = 166.67\text{km}$$

For Satellite Data

$$r_{(0)}.e^{\frac{-d}{d(0)}} = 0{,}9734e^{-0.006d}$$

$$\frac{-d}{d(0)} = -0.001d$$

$$d(0) = 1/0.001 = 100\text{ km}$$

Next, calculate the average error (Z_1) and interpolation error (Z_3) with a value of under 10%. **Table 5** shows the value of Z_1 and Z_3. Figure 3 shows the relationship between the number of rainfall stations and the average and interpolation error (Z_1 & Z_3).

Table 5. Summary of Z_1 and Z_3 Values for Ground and Satellite Data

N	Rainfall Ground Data		Rainfall Satellite Data	
	Z1	**Z3**	**Z1**	**Z3**
1	12.2%	8.5%	4.0%	3.2%
2	8.5%	8.0%	2.8%	2.9%
3	6.9%	7.8%	2.2%	2.8%
4	5.9%	7.6%	1.9%	2.7%
5	5.3%	7.5%	1.7%	2.6%
6	4.8%	7.5%	1.6%	2.6%
7	4.4%	7.4%	1.4%	2.6%
8	4.1%	7.4%	1.3%	2.5%
9	3.9%	7.3%	1.3%	2.5%

Source : Author's Analysis (2022).

Based on the results in **Table 5**, it is determined that the number of rainfall stations is four based on the value of Z_1 and Z_3 which is under 10% and based on WMO Standard. Z_1 and Z_3 values are 5.9% and 7.6% for ground data, and Z_1 and Z_3 values are 1.9% and 2.7% for satellite data. With four rainfall stations, the length of the rainfall station can be calculated as follows: $L = 1.07\sqrt{\frac{A}{n}} = 1.07\sqrt{\frac{477{,}780}{4}} = 11{,}694$ km.

The length of rainfall stations for ground data and satellite data produces the same value because the selection of the number of stations is four based on WMO standards, and the Z_1 and Z_3 values are below 10%.

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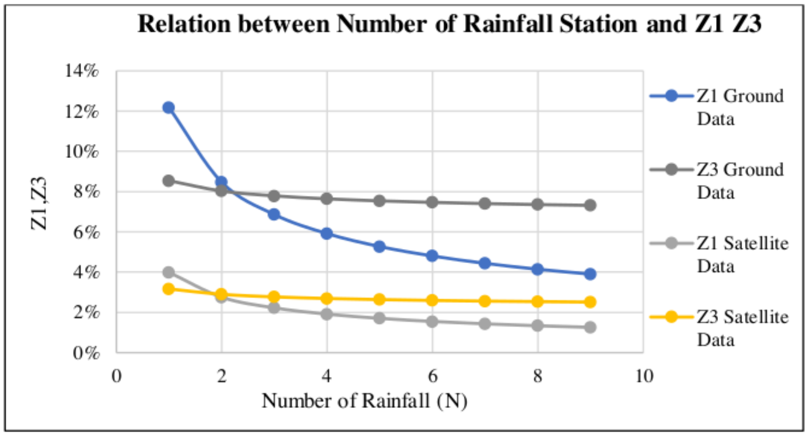


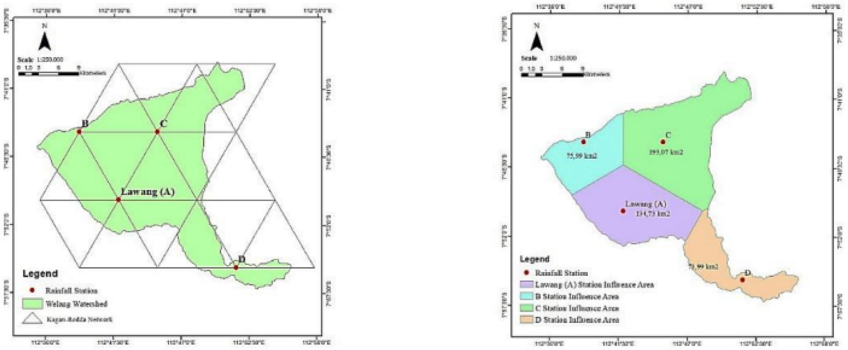
Source : Author's Analysis (Ms Excel, 2022).

Figure 3. Graph Relation between Number of Rainfall Stations and Z_1 Z_3

Based on Figure 3, the values of Z_1 and Z_3 in the CHIRPS satellite rainfall data are smaller than the rainfall ground data because the coefficient of variation (Cv) of CHIRPS satellite rainfall data is smaller. It proves that the CHIRPS satellite rainfall data has a homogeneous value compared to the rainfall ground data because if the value of Cv is getting smaller, then the data can be said to be more homogeneous.

3.4 Rationalization Scenario for Rainfall Station

Based on the result of the first rationalization scenario, the planned Kagan-Rodda nets and influence area of each rainfall station is shown in **Figure 4**.



(a) (b)

Source : Author's Analysis (Arc Map, 2022).

Figure 4. Kagan Rodda Nets (a) and Thiessen Polygon (b) for First Scenario

Figure 4(a) shows the first scenario of Kagan-Rodda by maintaining Lawang Station and moving several rainfall stations according to Kagan – Rodda nets, then **Figure 4(b)** shows the Thiessen Polygon to know the influence area of each rainfall station.

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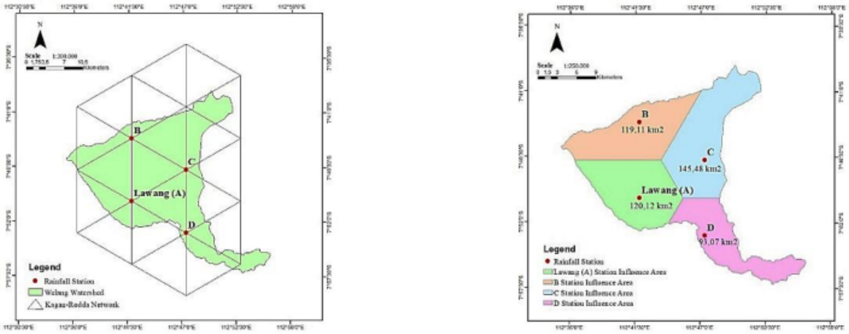
Table 6. Influence Area of First Scenario Rainfall Stations Networks

No	Station	Area (km^2)	WMO Standard
1	Lawang (A)	134.73	Ideal
2	B	75.99	Not Ideal
3	C	193.07	Ideal
4	D	73.99	Not Ideal

Source : Author's Analysis (2022).

The influence area of first scenario can be seen in **Table 6** that Lawang Station with an influence area of 134.73 km^2 and C Station with an influence area of 193.07 km^2 have been suitable WMO standards. In contrast, B and D stations are unsuitable for the WMO standard, with an area of 100-250 km^2/station. In addition, the distribution of rainfall stations in the first scenario was not evenly distributed indicated by the results of the location of rainfall stations and the influence area of each rainfall station in the first scenario. Then the second scenario was carried out and the results are shown in **Figure 5**.



(a) (b)

Source : Author's Analysis (Arc Map, 2022).

Figure 5. Kagan Rodda Nets (a) and Thiessen Polygon (b) for Second Scenario

Figure 5(a) shows that the second scenario was carried out while maintaining Lawang Station as a reference station. The Kagan-Rodda nets obtained recommended locations for B, C, and D rainfall stations. Then **Figure 5(b)** shows the Thiessen Polygon to know the influence area of each rainfall station from the second rationalization scenario.

Table 7. Influence Area of Second Scenario Rainfall Stations Networks

No	Station	Area (km^2)	WMO Standard
1	Lawang (A)	120.12	Ideal
2	B	119.11	Ideal
3	C	145.48	Ideal
4	D	93.07	Not Ideal

Source : Author's Analysis (2022).

Table 7 shows that the distribution of rainfall stations in the second scenario was fairly even, as evidenced by the influence area of each rainfall station, which was evenly distributed. Therefore, the recommendation for rationalization of the Kagan-Rodda method used is a recommendation in the second scenario. Based on the second scenario, the distribution of rainfall stations and the influence area of each rainfall station are evenly distributed and suitable for WMO standards. Although the influence area of D Station is slightly below WMO standard, but the distribution of rainfall stations in this second scenario is already the most optimal.

Table 8. Recommended Rainfall Station Coordinates

Existing Station	Location		Recommendation Station	Location	
	Longitude	**Latitude**		**Longitude**	**Latitude**
Lawang	112° 41' 51.5"	7° 49' 58.1"	Lawang (A)	112° 41' 51.5"	7° 49' 58.1"
Telebuk	112° 43' 20"	7°41' 44.7"	B	112° 41' 51.11"	7° 43' 24.91"
Selowongko	112° 46' 51.8"	7° 46' 26.5"	C	112° 46'41.31"	7° 46' 42.81"
Tutur	112° 48' 44.9"	7° 53' 6.7"	D	112° 47' 28.05"	7° 53' 17.07"
P3GI	112° 54'33.5"	7° 38'58.6"			
Oro Oro Pule	112° 50' 18"	7° 44' 38.9"			
Sengon Pager	112° 43' 50.5"	7° 45' 14.6"			
Purwosari	112° 43' 11.9"	7° 48' 18.2"			
Wonorejo	112° 49' 2.4"	7° 42' 33.4"			

Source : Author's Analysis (2022).

Table 8 shows recommended rainfall station coordinates based on this study's rationalization result. The result of rationalization in this study is to maintain Lawang Station but move Telebuk to B Station, Selowongko to C Station, and Tutur Station to D Station.

4. Conclusion

Based on the evaluation of the existing rainfall station network in the Welang watershed, only the Lawang rainfall station that suitable for the WMO standard. Therefore, the rationalization of rainfall stations is carried out using the Kagan-Rodda method. The results of the Kagan-Rodda rationalization with rainfall ground data and the CHIRPS satellite data selected four stations with an average error (Z_1) and an interpolation error (Z_3) are below 10%. The recommendations for the selected rainfall stations are to keep Lawang Station, move Telebuk Station to B Station, Selowongko Station to C Station, and Tutur Station to D Station. The recommendations for the selected rainfall stations show that the influence area of each rainfall station follows WMO standards and gets an even distribution. The results of this recommendation are expected to be considered by the relevant institutes to move the location of the rainfall station to get more accurate rainfall data.

References

[1] F. Y. Pramono, Suripin, Suharyanto, and W. Sulistya, "Rationalization of rain stations in the ciliwung cisadane river basin," *Int. J. Eng. Res. Technol.*, vol. 12, no. 12, pp. 2957–2963, 2019.

[2] C. Y. Liu, P. Aryastana, G. R. Liu, and W. R. Huang, "Assessment of satellite precipitation product estimates over Bali Island," *Atmos. Res.*, vol. 244, no. January, p. 105032, 2020, doi: 10.1016/j.atmosres.2020.105032.

[3] H. Li, W. Wang, J. Fu, Z. Chen, Z. Ning, and Y. Liu, "Quantifying the relative contribution of climate variability and human activities impacts on baseflow dynamics in the Tarim River Basin, Northwest China," *J. Hydrol. Reg. Stud.*, vol. 36, no. May, p. 100853, 2021, doi: 10.1016/j.ejrh.2021.100853.

[4] M. Musie, S. Sen, and P. Srivastava, "Comparison and evaluation of gridded precipitation datasets for streamflow simulation in data scarce watersheds of Ethiopia," *J. Hydrol.*, vol. 579, no. August, p. 124168, 2019, doi: 10.1016/j.jhydrol.2019.124168.

[5] F. Ayu, R. Shiami, and U. Lasminto, "Rationalization of Hydrology Station Network Using Rainfall Ground and Satellite Data," *Int. Res. J. Adv. Eng. Sci.*, vol. 4, no. 3, pp. 225–229, 2019, doi: 10.5281/zenodo.3365590.

[6] M. Ghosh, J. Singh, S. Sekharan, S. Ghosh, P. E. Zope, and S. Karmakar, "Rationalization of automatic weather stations network over a coastal urban catchment: A multivariate approach," *Atmos. Res.*, vol. 254, no. February, p. 105511, 2021, doi: 10.1016/j.atmosres.2021.105511.

[7] V. Varekar, V. Yadav, and S. Karmakar, "Rationalization of water quality monitoring locations under spatiotemporal heterogeneity of diffuse pollution using seasonal export coefficient," *J. Environ. Manage.*, vol. 277, no. August 2020, p. 111342, 2021, doi: 10.1016/j.jenvman.2020.111342.

[8] T. A. J. G. Sirisena, S. Maskey, R. Ranasinghe, and M. S. Babel, "Effects of different precipitation inputs on streamflow simulation in the Irrawaddy River Basin, Myanmar," *J. Hydrol. Reg. Stud.*, vol. 19, no. October, pp. 265–278, 2018, doi: 10.1016/j.ejrh.2018.10.005.

[9] S. Prakash, A. K. Mitra, A. AghaKouchak, Z. Liu, H. Norouzi, and D. S. Pai, "A preliminary assessment of GPM-based multi-satellite precipitation estimates over a monsoon dominated region," *J. Hydrol.*, vol. 556, no. February 2014, pp. 865–876, 2018, doi: 10.1016/j.jhydrol.2016.01.029.

[10] F. Peng, S. Zhao, C. Chen, D. Cong, Y. Wang, and H. Ouyang, "Evaluation and comparison of the precipitation detection ability of multiple satellite products in a typical agriculture area of China," *Atmos. Res.*, vol. 236, no. August 2019, p. 104814, 2020, doi: 10.1016/j.atmosres.2019.104814.

[11] C. Ocampo-Marulanda, C. Fernández-Álvarez, W. L. Cerón, T. Canchala, Y. Carvajal-Escobar, and W. Alfonso-Morales, "A spatiotemporal assessment of the high-resolution CHIRPS rainfall dataset in southwestern Colombia using combined principal component analysis," *Ain Shams Eng. J.*, vol. 13, no. 5, p. 101739, 2022, doi: 10.1016/j.asej.2022.101739.

[12] Z. Shen *et al.*, "Recent global performance of the Climate Hazards group Infrared Precipitation (CHIRP) with Stations (CHIRPS)," *J. Hydrol.*, vol. 591, no. January, p. 125284, 2020, doi: 10.1016/j.jhydrol.2020.125284.

[13] A. Fadholi, R. Adzani, U. Gadjah Mada, and S. Meteorologi Depati Amir Pangkalpinang, "Analisis Frekuensi Curah Hujan Ekstrem Kepulauan Bangka Belitung Berbasis Data Climate Hazards Group Infrared Precipitation with Station (CHIRPS)," *J. Pendidik. Geogr.*, vol. 18, no. 1, pp. 22–32, 2018.

[14] A. Faisol, Indarto, E. Novita, and Budiyono, "Komparasi Antara Climate Hazards Group Infrared Precipitation With Stations (CHIRPS) dan Global Precipitation Measurement

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(GPM) dalam Membangkitkan Informasi Curah Hujan Harian di Provinsi Jawa Timur," *J. Teknol. Pertan. ANDALAS*, vol. 3, no. 2, pp. 148–156, 2020.

[15] 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.

[16] R. Renaldhy, I. Wayan Yasa, and E. Setiawan, "Evaluasi Rasionalisasi Stasiun Hujan Metode Kagan Rodda dengan Mempertimbangkan Kriteria Penentuan Lokasi Pembangunan Stasiun Hujan," *J. Tek. Pengair.*, vol. 12, no. 1, pp. 49–60, 2021, doi: 10.21776/ub.pengairan.2021.012.01.05.

[17] E. Prawati and V. Dermawan, "Rasionalisasi Jaringan Stasiun Hujan Menggunakan Metode Kagan Rodda Dengan Memperhitungkan Faktor Topografi Pada Das Sarokah Kabupaten Sumenep (Pulau Madura, Jawa Timur)," *Tapak*, vol. 8, no. 1, pp. 79–90, 2018.

[18] 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," *Civ. Environ. Sci. J.*, vol. 5, no. 1, pp. 64–77, 2022.

[19] N. Salsabila, L. M. Limantara, and J. Sidqi, "Analisis Curah Hujan Serial Terhadap Debit Maksimum di Sub DAS Kampili, DAS Jeneberang, Sulawesi Selatan," *J. Teknol. dan Rekayasa Sumber Air*, vol. 1, no. 2, pp. 736–749, 2021.

[20] 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.

[21] 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.

[22] 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.

[23] E. Dzisofi Amelia, S. Wahyuni, and D. Harisuseno, "Evaluasi Kesesuaian Data Satelit sebagai Alternatif Ketersediaan Data Evaporasi di Waduk Wonorejo Compatibility Evaluation Satellite Data as an Alternative of Evaporation Data Availability in Wonorejo Reservoir," *J. Tek. Pengair.*, vol. 2021, no. 2, pp. 127–138, 2021, [Online]. Available: https://doi.org/10.21776/ub.pengairan.2021.012.02.05.

[24] World Meteorological Organization, *Guide to Hydrological Practices*, vol. 56, no. 1. 2011.

[25] I. W. Astuti, E. Suhartanto, and J. S. Fidari, "Rasionalisasi Jaringan Pos Hujan dan Pos Duga Air Dengan Metode Stepwise dan Standar WMO (World Metrological Organization) di DAS Opak," J. Teknol. dan Rekayasa …, vol. 2, no. 1, pp. 377–385, 2021, [Online]. Available: https://jtresda.ub.ac.id/index.php/jtresda/article/view/205.

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