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Rationalization of Hydrology Station Network Using Rainfall Ground and Satellite Data

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***Abstract*—** *The rainfall data used in the hydrology analysis is obtained from the precision of rainfall data measurement and the condition of the rain station. The higher density of rain station network, the data obtained will be more accurate, but it should be noted other aspects such as economic aspects. The best network is obtained by conducting a rationalization analysis to get the most effective number and location of rain station This research obtains rainfall data from satellite for analysis as a solution to the problem of data limitations while others only use ground data. The method of this research is the first, the existing rain station network is evaluated whether it comply with WMO (World Meteorological Organization) standards or not. Then regression analysis is carried out on ground and satellite rainfall and water discharge data to find out the correlation between them. Next, the rain station network is rationalized using Kagan Rodda interpolation method, which mean there are some changes in the number and location of the station. The location of the new rain station doesn't have rainfall ground data, so it uses satellite rainfall data. The correlation analysis is then carried out on the new rain station network using satellite rainfall data. This network is then compared to the existing network. This research is located in Kemuning River Catchment Area, Madura Island, which has six rain stations with a correlation coefficient of rainfall to discharge is 0.50. The number of rain stations on the recommendation network has not changed because the existing conditions has fulfilled WMO Standard. Whereas the location of the Palengan Laok Rain Station was relocated according to the Kagan-Rodda net so that the correlation coeffiicient of rainfall to the discharge increased to 0.53. The use of satellite data can be used for the analysis of rationalization of the rain station network with suggestions for correction of satellite data.*

***Keywords*—** *Rainfall satellite data, rainfall station network, rationalization analysis.*

I. INTRODUCTION

Rainfall data used in hydrological analysis is obtained from measurements at raindrops in the river basin. As a result, the accuracy of data is influenced by the conditions of the rain station, both location, number, and pattern of distribution or network. The higher the density of the rain station network, the better the data obtained will be more accurate, but it should be noted that other aspects that are non-technical in aspect such as the economic aspect. Because of the importance of adequate, accurate, timely and sustainable hydrological data and information, there is a need to find out whether the existing rain station can represent the condition of the area. The rationalization of the hydrological station network means the analysis process to obtain an optimal and efficient new hydrological network so that it can be said that the hydrological data obtained from these stations can represent the condition of the study area. An efficient network of rain stations can be useful as a policy maker for relevant agencies for efficiency in terms of costs, energy, equipment and time. So, the rationalization of the network of rain stations is needed to know which stations are dominant and/or can be relocated.

The method of hydrological analysis commonly used is a probability analysis of the data recorded in the rain station and directly in the river. Some regions in Indonesia often have a limited number of rainfall stations so that rainfall data isn't able to represent a region. Current technological advances make it easier for researchers to obtain map data and rain data from satellite imagery, which can be a solution to the problem of data limitations in Indonesia. The advantage of this method is that the satellite rain data used is continuous data (real time) with a high time resolution level that is recording every 30 minutes, and data is easily obtained by downloading from the satellite data provider website. This research was conducted with the aim of knowing the rainfall stations adequacy of the number and location in the Kemuning River Basin, rationalize the rain stations network by using ground and satellite rainfall data and to compare the correlation coefficient of area rainfall to discharge between the existing rain station network and the results of the analysis rain station.

The network of hydrological station studied was located in the Kemuning river basin on Madura Island. Kemuning River which passes through Sampang and Pamekasan Regencies is the largest river on Madura Island, so it has a major influence on the development of water resources management in the Madura River Basin. Therefore, the Kemuning river basin was chosen as the research location. The Kemuning river basin has 6 rain stations as in Fig. 1.

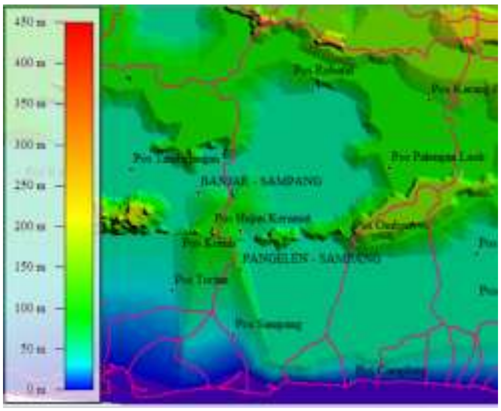

Fig. 1. Existing rain station location.

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II. RESEARCH METHODS

The first analysis carried out was an analysis of the existing rain station network using stepwise regression analysis and WMO standard methods. Rationalization analysis was carried out with the existing interpolation method, Kagan Rodda, so that new networks were obtained. This new network certainly has stations that are in a different location from the existing conditions, where at the point of location the station does not have rain ground data. Correlation analysis is carried out on the new rain station network using satellite rain data. Furthermore, the correlation coefficient of area rainfall to the discharge from the rain station network is compared with correlation coefficient of area rainfall to discharge of the existing rain station network. The river discharge data are from AWLR station measurements. The scenario of the recommendation station network is carried out until the area rainfall correlation coefficient to discharge approaches the field condition which is shown by the correlation coefficient value increases compared to the existing network correlation coefficient, with the variable being changed is the number and location of the rain stations.

III. ANALYSIS

A. Satelite Rainfall Data

Satellite data is obtained by downloading rain data through the official website of NASA (National Aeronautics and Space Agency), namely https://giovanni.gsfc.nasa.gov/giovanni. Satellite data is available in various types, while the one used in this research is TRMM (Tropical Rainfall Measuring Mission) 3B42RT data. TRMM satellite rain data is specifically designed to calculate rainfall in the tropics area. This rain data has a time resolution up to 3 hours, but the satellite rain data used is daily rainfall data.

B. Simple Correlation Analysis

Correlation analysis determine the relationship between two variables, which in this research are rain and discharge. The value of the correlation coefficient (r) can vary from - 1 to + 1. If it approaches 0, the relationship between variables is very weak. If r approaches 1 means a positive / comparable relationship. If r approaches -1 means a negative / inverse relationship. The simple correlation analysis results of the existing rain station network are on this figure 2.

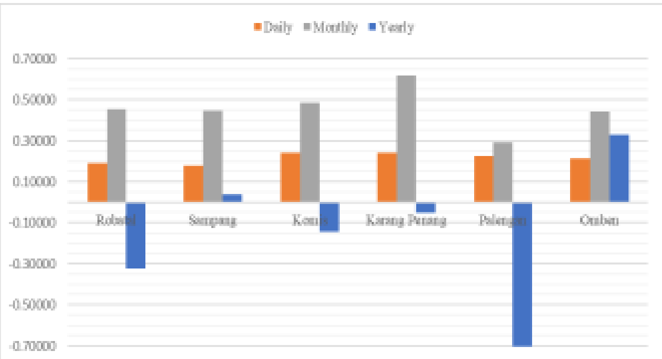

Fig. 2. Correlation coefficient of existing rain station.

C. Stepwise Regression Analysis of existing networks

The stepwise method is one method to get the best model from a regression analysis. The basic concept of the stepwise is multiple correlation method. The stepwise method is obtained from several stages of selecting independent variables to enter in the model, then choose one or several independent variables that are really significant to explain the dependent variable. The independent variable is rainfall data and the dependent variable is debit data. The advantage of this model is that it can choose which station is the most dominant and has the largest correlation with the discharge. Regression analysis was carried out with software SPSS 21, and the results shown in table I.

TABLE I. Stepwise regression analysis result.

	Highest to lowest correlation	Determ ination (R^2)	F Test	T Test	Norma lity	Auto correla tion	Hetero cedasti city
Daily Data	Komis, Kr.Penang Palengan, Omben, Robatal, Sampang	13.31 %	√	√	x	x	x
Monthly Data	Kr.penang Komis, Robatal, Sampang, Omben, Palengan	38.17 %	√	√	x	x	√

The stepwise regression test results on the existing network show the following results, where the relationship of rain to discharge tends to be weak and the data quality is not good. While monthly data has a better correlation than daily data for analysis.

D. Areal Rainfall and WMO Standard

One method of calculating regional average rainfall is known as the weighted mean method or Thiessen polygon method. This method gives the proportion of the area affected by the rain station to accommodate distance imbalances. This method is suitable for flat areas with an area of 500 - 5000 km^2 and the number of rain station is limited on the area. The results of the rain station area based on the polygon Thiessen method assessed on table II and the guidelines for minimum rain network density by the World Meteorological Organization for various regions supported in table III.

TABLE II. Polygon area of rainfall station

No	Rainfall station	Polygon Area (km^2)	Persentage
1	Robatal	88.66	25.71%
2	Komis	55.52	16.10%
3	Palengan Laok	54.52	15.81%
4	Karang penang	50.84	14.74%
5	Sampang	48.32	14.01%
6	Omben	46.97	13.62%

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TABLE III. Recommended minimum station density by WMO

Region Type	Range of norms (km^2/stn)	Range of norms tolerated
Mediterranean tropical flat	1000-2500 (600-900)	3000-9000
Mediterranean tropical mountains	300-1000 (100-250)	1000-5000
Mountains/island	140-300 (25)	
Arid and polar	5000-20000 (1500-10000)	

The Kemuning river basin area is 344.83 km^2, so it only requires 4 rainfall stations. These results were obtained from networks that had met the WMO standard, because one rainfall station was underwritten <100 km^2. However, the distribution location of rainfall station needs to be checked.

E. Rainfall Station Rationalization Analysis

Rainfall network station rationalization analyzed using Kagan Rodda interpolation method. First, calculate the areal rainfall using polygon Thiessen equation, which R is rainfall and A is the area of influence of polygon, as follows.

$$R = \frac{R_1A_1 + R_2A_2 + \cdots + R_nA_n}{A_1 + A_2 + \cdots A_n}$$

Then calculate the variation coefficient of average areal rainfall that has been calculated previously with the following equation

$$CV = \frac{S}{\bar{X}}$$

The value of S is the standard deviation and X is the average rainfall, which are calculated by the following equation

$$S = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(X_i - \bar{X})^2}$$

$$\bar{X} = \frac{1}{n}\sum_{i=1}^{n} X_i$$

The result of areal rainfall, average rainfall, sandard deviation and coefficient of variation for daily and monthly data as shown in table IV below.

TABLE IV. Polygon area of rainfall station

Year	R Daily	R Monthly
2006	52.279	347.547
2007	33.506	360.292
2008	46.498	314.907
2009	33.432	214.809
2010	34.563	245.754
2011	38.662	255.998
Average	39.823	289.884
Standard deviation	7.867	59.397
Variation coefficient	0.198	0.205

Graph of relation between rain stations distance with correlation coefficients made to obtain Kagan Rodda variables. The distance between stations can be calculated / measured from map data, while the correlation coefficient can be calculated with MS.Excel or SPSS software as analysis before. So that the graph can be seen on Figure 3 for daily and monthly data

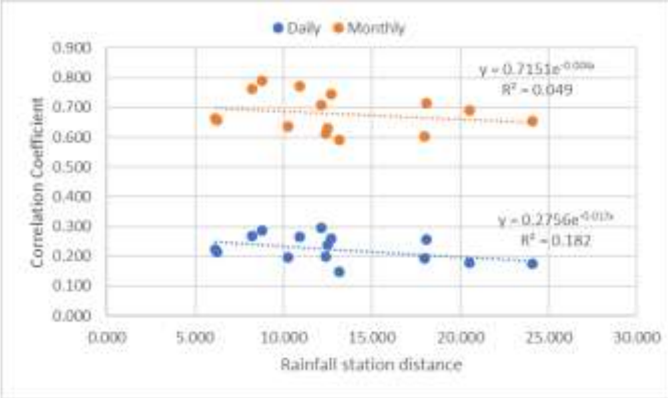

Fig. 3. Graph of distance and correlation cofficient between station.

So that both can be drawn in the graph, and the linear regression equation are like this equation

y = 〚0.2756.e〛 ^ (- 0.017x) for daily data, and

y = 〚0.7151.e〛 ^ (- 0.004x) for monthly data

The parameter value is the radius correlation for very close distances (r (0)) and the radius correlation (d (0)). As this formula above, these variables can be get.

$$r(d) = r_{(0)}e^{\left(\frac{-d}{d(0)}\right)}$$

The value of r (0) for daily data is 0.2756, and for monthly data is 0.7151 while the value of d (0) daily data is 0.017 and for monthly data is 0.004.

Then calculate equality errors (Z1) and error interpolation (Z2), if Cv is coefficient of variation, A is area of study location, n is number of rainfall stations, while r (0) and d (0) as obtained from the distance graph station and correlation coefficient. Equality and interpolations errors are calculated to determine the length of the net. The equation for equality and interpolation errors are as shown bellow

$$Z_1 = C_v\sqrt{\frac{\left[1 - r_{(0)} + \left(0{,}23\frac{\sqrt{A}}{d_{(0)}\sqrt{n}}\right)\right]}{n}}$$

$$Z_2 = C_v\sqrt{\frac{1}{3}\left[1 - r_{(0)}\right] + 0{,}52\frac{r_{(0)}}{d_{(0)}}\sqrt{\frac{A}{n}}}$$

The value of equality errors (Z1) and error interpolation (Z2) that recommended by several research are under 10%. The length of each number of rain station calculated with expression below

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

Four rainfall stations based on WMO standard is enough because has fulfilled maximal Z, so the length of station net is 9.93 km. Result for equality errors (Z1), interpolation error (Z2), and length of station net as shown in table V. This result also can be graphed as in figure 4, and Kagan Rodda network is shown on figure 5.

TABLE V. The value of errors and net length

n	Z1 (%)	Z2 (%)	L (km)
1	6.70	8.51	19.87
2	3.98	7.16	14.05
3	2.94	6.47	11.47
4	2.37	6.02	9.93
5	2.00	5.69	8.89
6	1.75	5.44	8.11
7	1.56	5.23	7.51
8	1.41	5.06	7.02
9	1.29	4.92	6.62
10	1.19	4.79	6.28

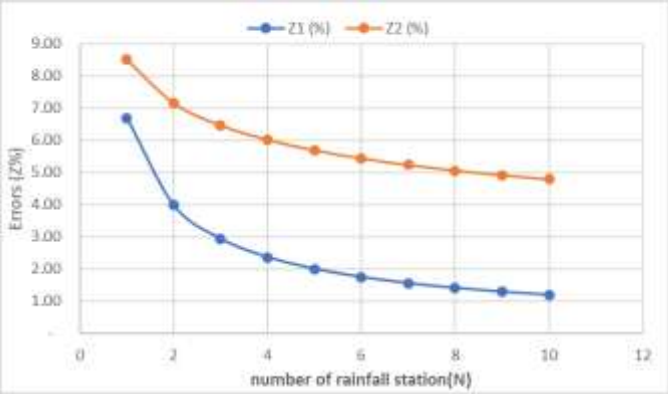

Fig. 4. Graph of equality errors (Z1), interpolation error (Z2)

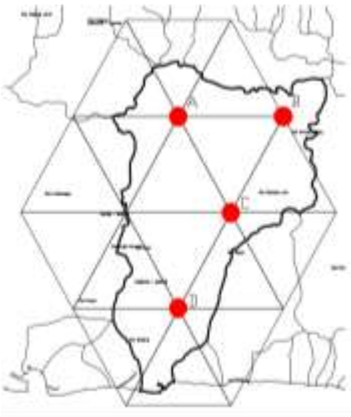
Fig. 5. Kagan Rodda station network

F. *Rationalization Scenario*

The first scenario is if the number of rainfall station is 4, by maintain the Robatal Station, because of the number adjusting the WMO requirements. While the location is adjust so that the number of stations in the river is according to plan and closest to the existing station so there is no need to relocate all stations or move too far away. The relocation are Karang Penang Station to point B, Pos Palengan to point C and Sampang Station to Point D as on figure 6 below. Then compare the correlation between areal rainfall data to discharge from this scenario. The correlation coefficient actually decreases, compared to the existing network correlation from 0.47 to 0.43 for monthly data as on figure 7. This is because the number of station decreases.

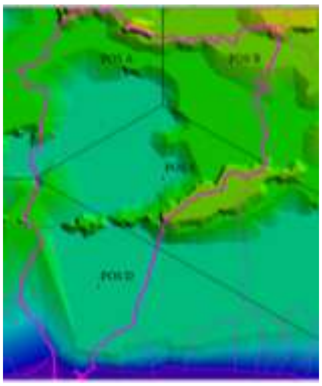
Fig. 6. Rain station location of first scenario

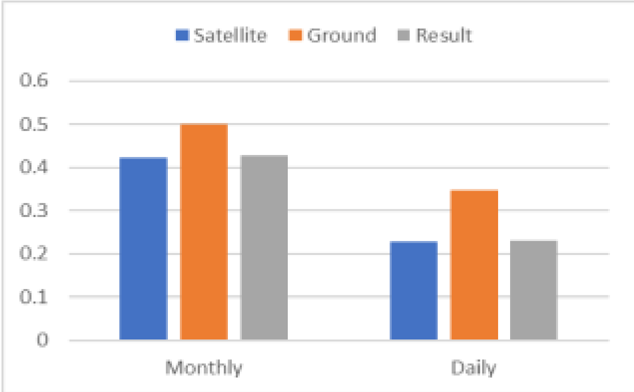

Fig. 7. Correlation coefficient of first scenario

The second scenario is if the number of rainfall stations is 6, by moving the Sampang rainfall station to the location of Station D (Fig. 8), because Sampang station has the lowest correlation coefficient from correlation analysis using the daily ground data. The result is that the correlation coefficient of new network decreases from the existing network from the existing condition of 0.47 to 0.46.

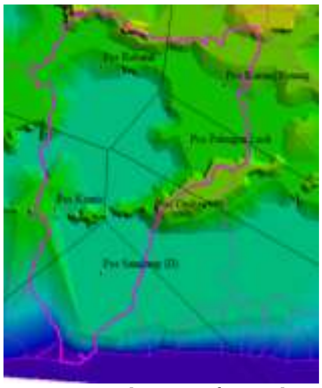
Fig. 8. Rain station location of second scenario

The third scenario is if the number of rainfall stations is 6, by moving the Palengan Laok rain station to the location of Station C (Fig. 9), because Palengan Laok station has the lowest correlation coefficient from correlation analysis using monthly data. The result is that the correlation coefficient increases compared to the existing network, from 0.47 to 0.50

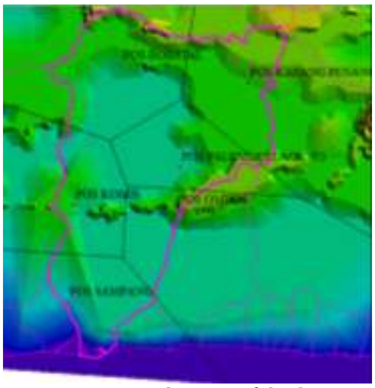

Fig. 9. Rain station location of third scenario

The fourth scenario is if the number of raindrops is 6, by moving the Omben rainfall station to location E (Fig. 10). The result is a correlation coefficient increases compared to the existing network but the change is very small from 0.50 to 0.51.

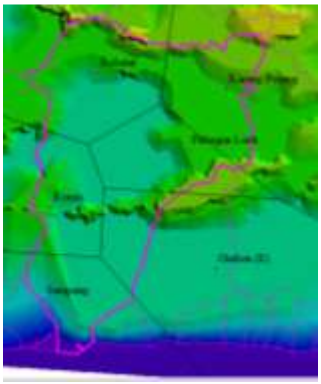

Fig. 10. Rain station location of fourth scenario

These four scenario then compared by chart on figure 11, and the best scenario that has a correlation coefficient enhancement value is the third scenario. Ex Sat is existing rainfall station network using satellite data, Ex Gr is existing rainfall station network using ground data. Result is new existing rainfall station network using satellite data for new location as methods described, and Result (gr) new existing rainfall station network using interpolated ground data for new location as usual method of rationalization.

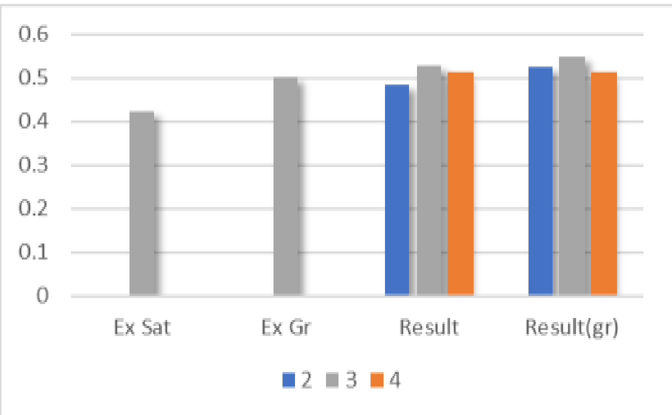

Fig. 11. Kagan Rodda station network

IV. Conclusion

1. On the existing rain station network
   a. Rain and discharge from the existing rain station resulted in low correlation, and quality data. Rainfall station with the highest to lowest correlation coefficient values are Karang Penang, Komis, Robatal, Sampang, Omben, and the lowest Palengan Laok.
   b. Evaluation analysis of the existing rainfall station network using WMO (World Meteorological Organization) standard and Thiessen Polygon show that its has met the standards, where each rainfall station has an area of influence <100 km2, so don't need to add rainfall station.
2. The number of recommended rain station based on WMO and Kagan-Rodda standards is 4 stations, with the distance between stations (length of net) is the same which is 9.93 km. Whereas in the existing conditions Kemuning river basin has 6 rain station with varying distances between rainfall station. The results of rationalization analysis using the Kagan Rodda method and satellite rain data obtained by the network of rainfall station that have better reliability, while maintaining the number of stations, 6 station, but relocating the Palengan Laok rain station (third scenario)
3. The recommended rain station network where rainfall data at the locations of relocated station taken from satellites results in a greater correlation of areal rainfall to discharge than existing networks using both ground data and satellite data. Furthermore, if the recommendation network uses ground interpolation data compared to the existing ground network, the correlation coefficient increases. Ground data tends to give a higher correlation coefficient value than satellite data, this is because satellite data has more errors.

References

[1] D.W.Pratiwi, Joko S, and Adam P.R, "Evaluasi Data Hujan Satelit untuk Prediksi Data Hujan Pengamatan Menggunakan Cross Correlation," Universitas Gajah Mada., Yogyakarta, Indonesia, 2017.

[2] Mamenum, Hidayat P, and Ardhasena S, "Validasi dan Koreksi Data Satelt TRMM pada Tiga Pola Hujan di Indonesia," Jurnal Meteorologi dan Geofisika., Jakarta, Indonesia, 2014.

[3] Y.R.Siswanti,Very D, and Ery S, "Rasionalisasi Jaringan Pos Hujan Menggunakan Metode Kagan Rodda dengan Memperhitungkan Faktor Topografi pada Daerah Aliran Sungai (DAS) Sarokah, Kabupaten Sumenep, Pulau Madura," Universitas Brawijaya, Malang, Indonesia, 2018

[4] Risdiyanto,Idung, "Karakteristik Daerah Aliran Sungai (DAS) di Pulau Madura," Bogor Agricultural University, Bogor, Indonesia, 2013.

[5] D S.Arifah, Ery Suhartanto,and Dian C, "Rasionalisasi Jaringan Pos Pos Hujan pada DAS Kemuning Kabupaten Sampang Menggunakan Metode Kagan -Rodda dan Krigging dengan Mempertimbangkan Aspek Topografi," Universitas Brawijaya, Malang, Indonesia, 2018

[6] Rodda, J. C., "*Precipitation Network,*" WMO Bulletin, No. 324, pp. II.21-1-6, 1967

[7] Triatmodjo, Bambang., "*Hidrologi Terapan,*" Beta Offset, Yogyakarta, 2008

Faradilla Ayu Rizki Shiami and Umboro Lasminto, "Rationalization of Hydrology Station Network Using Rainfall Ground and Satellite Data," *International Research Journal of Advanced Engineering and Science*, Volume 4, Issue 3, pp. 225-229, 2019.