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Rationalization of Rain Stations in the Ciliwung Cisadane River Basin

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Abstract

Hydrological calculations to support the development, research, management, conservation, and control of the destructive power of water resources need accurate, timely and sustainable rainfall. The accuracy of the hydrological base is dependent on the station's location for accurate monitoring of its flow characteristics. Therefore, further studies are required to determine the placement of hydrological stations in the Ciliwung Cisadane River Basin.

This rationalization is an approach to produce a reliable hydrological station network with accurate, effective and efficient data. It also describes and analyses the hydrological conditions of the study area. Data were obtained by using the WMO, Kriging, Kagan, Stepwise and Quality Control Methods.

Based on the results of the rationalization analysis, the maximum area of influence is 250.12 km^2 from the Bks 78-b Rain station located in the lowlands with a WMO standard density of 600-900 km^2 per post. From the analysis of the Kagan method, it is known that at an error rate of 10% a total number of 23 stations with an average distance of 16.23 km, and an error value of 5%, was obtained, while a distance of 8.21 km was acquired using 90 stations. Based on the Stepwise analysis there are 11 most influential rain stations, while the results of the quality control analysis showed that 14 rain stations are in good condition.

The recommendations based on Kagan resulted in a proposal of 9 new stations and the repair of 10 existing ones with an average error of 10%. In addition, using an error value of 5%, 47 new stations were proposed and 31 were repaired. Another recommendation is trying to provide a combination of Kagan with Kriging, which led to the proposal of 9 new stations and the repair of 9 existing ones, with an average error of 10%, while for 5% there are 13 new and 14 repair stations.

Keywords: Rain Station, WMO, Kagan, Kriging, Stepwise, Quality Control

I. INTRODUCTION

Hydrological calculations to support the development, research, management, conservation, and control of the destructive power of water resources need accurate, timely and sustainable rainfall. Its data needs to be adequately recorded because it is used in creating basic plans.

Hydrological station data are expected to be produced properly using appropriate methods and competent human resource quality. Its accuracy greatly depends on the capability of the station in monitoring the condition of the hydrological characteristics of a flow area accurately and correctly.

The approach to obtain a reliable data network is by rationalizing the hydrological station [10] [5]. Besides that, it is also able to produce accurate, effective and efficient rainfall data used to describe or represent the hydrological conditions in the study area. Presently, many methods have been developed for rationalization, based on the physiography area using the WMO standard [20], the Kriging [16] [6] [4] [18] [3] [2], Kagan [15] [9] [13] [7], Inverse Distance Weighted Interpolation [14], Stepwise [11] and Quality Control Methods [8] [21].

This research was conducted to obtain a hydrological network, for effective and efficient rain stations in the Ciliwung Cisadane river basin.

II. RELATED WORK

The Kagan method in the Keduang Wonogiri reservoir watershed was used to determine the average error of 5% using 68 rain stations and a distance between nodes at 2,591 Km. Furthermore, at an average error of 10% using 17 rain stations a distance of 5,319 Km is obtained [12]. Dhani et.al estimated the amount of rainfall in the district and sub-district of Semarang City using the Kriging method [6]. Awadallah utilized the GIS to analyze the optimal number and location of rainfall station based on WMO density [4]. Middle et al. stated that the suitable analysis was the Kriging Method because the results are more rational, compared to the Kagan Rodda in useful areas with not too large elevation/contour levels in the Parigi-Poso river basin in Central Sulawesi [19]. Adhikary stated that the analysis using the Kriging method showed the use of elevation as an additional variable besides the rainfall data in a geostatistical framework with the ability to significantly increase the estimated rainfall over the catchment [1].

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III. METHOD

Research on the rationalization of rain stations in the Ciliwung Cisadane River Basin was carried out in several stages as follows:

1 **Data collection**

2 **WMO Method Analysis**

This is the easiest method offered by the World Metrological Organization (WMO) which combines topographic elements and the area of influence of each Hydrological observation post for rainfall stations. General guidance on determining the number of stations in a watershed (network density) is stated in the Guide on Hydrometeorological Practices (WMO, 2008) as follows:

Table 1: Minimun Rainfall station Network Density (area in Km^2)

Type of Area (Description)	Not Recorded	Recorded
Coast	900	9000
Mountain	250	2500
Land	575	5750
Hills	575	5750
Small island	25	250
Urban area	–	10-20
Pole	10000	100000

3 **Kagan Method Analysis**

Rodda (1972) stated that the method used to determine rainfall measurement stations analysed quantity, density, accuracy and distribution patterns. The Kagan method is based on an analysis of regional statistical quantities such as the distance between stations therefore, it provides an overview of the density and distribution patterns of rainfall stations. This method is not based on the height of a location or its layout on the surface of the earth with uneven topography, therefore the area to be set up by the rainfall station is considered flat.

$$r(d) = r_{(o)} + e^{\left[\frac{d}{d(o)}\right]}$$

$$Z_1 = C_v \sqrt{\frac{\left[1 - r_{(o)} + \left(0.23 \frac{\sqrt{A}}{d_{(o)}\sqrt{n}}\right)\right]}{n}}$$

$$Z_3 = C_v \sqrt{\frac{1}{3}\left[1 - r_{(o)}\right] + 0{,}52 \frac{r_{(o)}}{d_{(o)}} \sqrt{\frac{A}{n}}}$$

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

Description :

r (d): the correlation coefficient of rainfall between stations with distance (d),

r (o): the correlation coefficient of rainfall between extrapolated stations,

D : distance between stations (km),

Z1 : average error (%),

Z3 : interpolation error (%),

Cv : coefficient of monthly rainfall variation,

A : watershed area in km2,

n : number of available rain stations,

l : distance between stations (km)

4 **Isohyet Method Analysis**

Isohyet is a line on the map that connects places with the same rainfall level at a certain time. It is a method used to determine regional rainfall using a contour line to connect similar rainfall level and the average rainfall between two Isohyet lines with the area between the two lines divided by the stations. In rationalization, this method emphasizes the relationship between rainfall stations based on the Isohyet produced.

In making an Isohyet map, the rainfall data interpolation process was carried out using the Kriging method. According to Silva & Simões (2014), Kriging is a strong statistical interpolation method that is very useful in areas with great complexity in climatology and geomorphology.

5 ***Stepwise* Method**

The basic concept of the Stepwise method is multiple correlations, therefore it is widely referred to as the Multi Correlation Method. This method correlates the dependent and independent variables, using monthly rainfall data from the river basin/Watershed to rationalize networks.

The advantage of this model was used to choose the stations with the most dominant and largest correlation with the water discharge monitoring station. In addition, it determines how many influential rainfall stations are usually seen from an increase in the multiple correlation coefficients. The relationship between the numbers of rainfall stations with the best-estimated number of correlation level is described as follows:

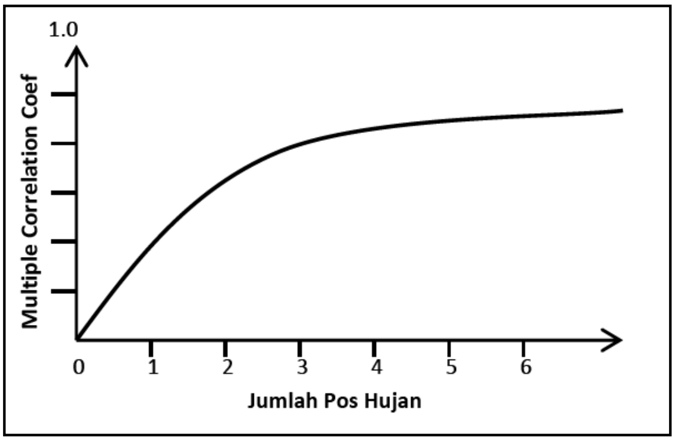

Figure 1: Graphic Relationship between Average Monthly Rainfall of Some stations with its Correlation Coefficient on River Discharge in Specified stations

6 Quality Control Method

This method utilized the Quality Control Method in the Water Resources Research and Development Center which has been adjusted by the Hydrological and Environmental Sub-Directorate of Natural Resources. It is based on an assessment of the Quality Control Guidelines for water discharge, rainfall and climatology, compiled by the Water Resources Research and Development Centre by providing scores according to the criteria and sub-criteria of the assessment.

III. I Data

This research was conducted in the Ciliwung Cisadane River Basin consist of 3 provinces such as Banten, West Java and Jakarta, with a total area of 5,287.19 km^2. It was supervised by the authority of the Central Government through the Ciliwung Cisadane River Basin Agency (BBWS CILCIS), Directorate General of Water Resources, Ministry of Public Works. The status is currently designated as a Cross-Provincial River Basin because it crosses 3 provinces, 13 sub-districts / cities and 15 watersheds.

From the results of the inventory data during this research, its river basin had 212 rain stations under the authority of several offices/departments, such as:

- Ciliwung Cisadane River Basin Agency: 30 stations
- Natural Resources Office, West Java Province: 4 stations
- Tangerang City Public Works Office : 3 stations
- Cidurian Cisadane *UPTD* (Regional Technical Implementation Unit) of *PSDA* (Water Resources Management Office): 9 stations
- Pondok Bitung Meteorological, Climatological, and Geophysical Agency: 32 stations
- Central Meteorological, Climatological, and Geophysical Agency: 5 stations
- Jakarta Natural Resource Office: 4 stations
- Bogor Meteorological, Climatological, and Geophysical Agency: 39 stations
- Jasa Tirta II Company: 26 stations
- Bogor City Public Works Office: 60 stations

IV. RESULT

IV. I Analysis of the Rationalization of Rain station *Networks Using the WMO Density Method*

Based on the division of rainwater density criteria according to WMO, the Ciliwung Cisadane River Basin downstream is categorized as a coastal zone, with a standard rainwater density of 900 km^2 per posts. In the upstream area, it is categorized as a mountain area with a medium, Mediterranean or tropical zone and a standard rainwater density of 250 km^2 per post. From the Thiessen polygon in Figure 2, it is known that the maximum area of influence is 250.12 km^2 from the Bks 78-b.

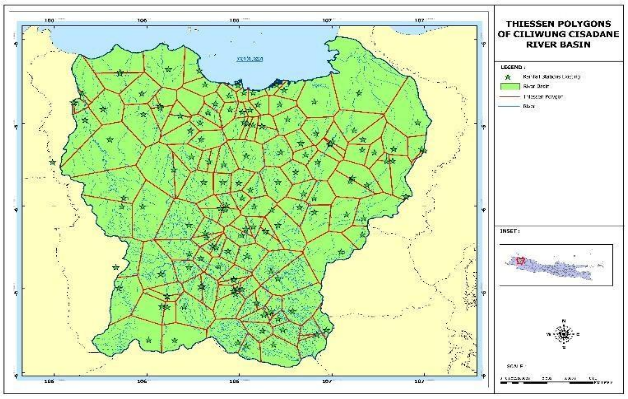

Figure 2: Polygon Thiessen Existing in the Ciliwung Cisadane River Basin

IV. II Analysis of the Rationalization of Rain Station Networks Using the Kagan Method

From the analysis results the number of rain stations, error rates, and distances are seen. For a 10% error rate a total of 23 rain stations are needed with an average distance of 16.23 km with for 5% error, and 90 stations with a distance of 8.21 km. The distribution of the rain station installation using the Kagan Method analysis is placed at the node point of an equilateral triangle as shown in Figure 4.

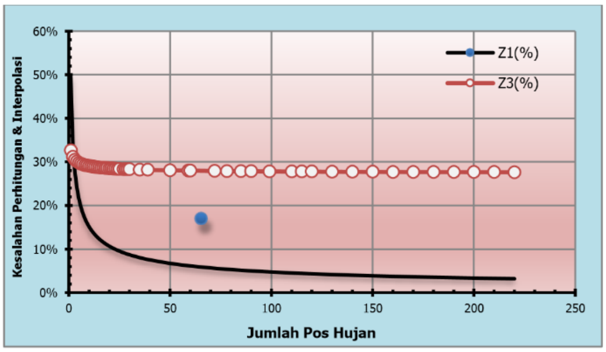

Figure 3: Number, Error Rate and Distance Between stations

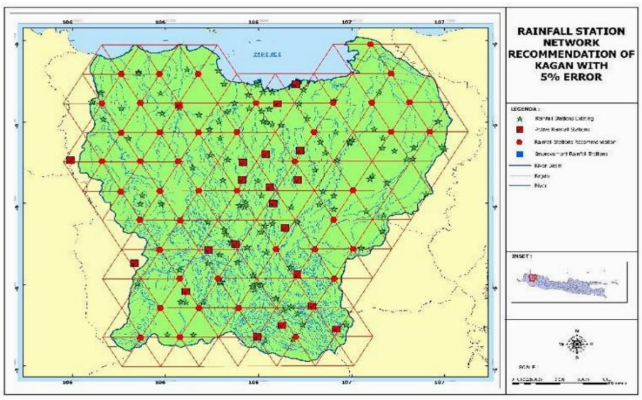

Figure 4: Distribution of Rain stations Using the Kagan Method in the Ciliwung Cisadane River Basin with 5% Error

IV.III Analysis of the Rationalization of Rain Station Networks Using Isohyet-Kriging Method

The density analysis using the Kriging method completes rain station data for the last 10 years (2009-2018). Based on the recapitulation results, there are 7 rain stations with complete data for the past 10 years. Kriging analysis was conducted after determining the semi-variogram, based on the smallest value of Root Mean Square Error (RMSE). Table 2, shows the RMSE value obtained by the Arc GIS program.

Table 2: Recapitulation of RMSE calculation results with Arc GIS

Method	Spherical	Exponential	Gaussian
RMSE	682.10	732.55	580.07

The isohyet map from the Kriging analysis results is shown in Figure 5.

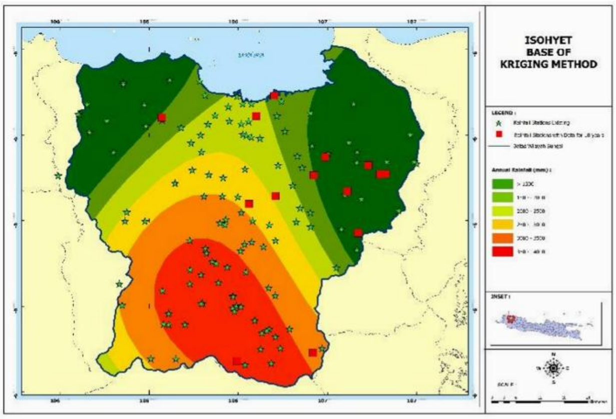

Figure 5: Isohyet Rain Kriging Analysis Results

IV. IV Analysis of the Rationalization of Rain Station Networks Using Stepwise Method

Stepwise analysis using 36 estimated water stations in the Ciliwung Cisadane River Basin showed that there are 11 influential rain stations as shown in Figure 6.

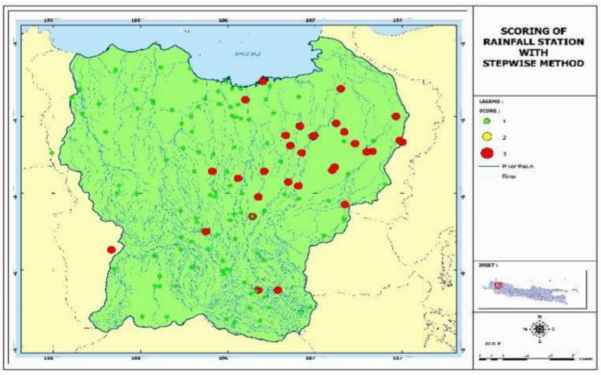

Figure 6: Influential Rain Stations from Stepwise Analysis Results

IV. VII Analysis of the Rationalization of Rain Station Networks Using Quality Control Methods

The Quality Control method led to a total value of each rainfall station from various criteria. This value used as a basis for determining the station conditions. The quality control analysis results are shown in Figure 6.

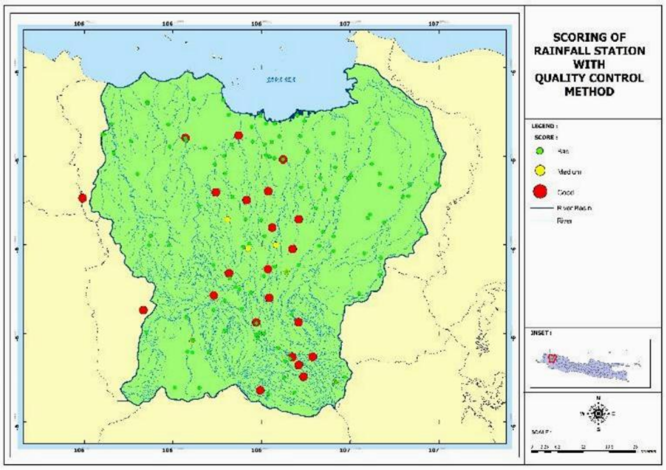

Figure 6. Condition of Rain Stations of the Quality Control Analysis Results

V. DISCUSSION

Based on the analysis results, many recommendations for effective and efficient rain station networks for the Ciliwung Cisadane River Basin were proposed.

V. I Rain Station Network Recommendations Based on WMO Density Method

From the analysis results based on WMO density, it was concluded that the current rain station network in the Ciliwung Cisadane River Basin fulfilled the density standards for the land and mountain categories. This means that additional rain stations are needed in the research location.

V.II Rain Station Network Recommendations Based on the Kagan Method

The network recommendation map based on the kagan analysis results showed that 23 rain station network was needed for an average error of 10%, while for an average error of 5%, 90 rain stations were required. Based on the kagan triangle, a rain station network recommendation was prepared for the Ciliwung Cisadane River Basin, with repairs carried out in the triangle node area. Based on the analysis results, the following recommendations were obtained:

The average error of 10%

- New stations: 9 posts
- Station Repair: 10 posts

Average error of 5%

- Stations: 47 posts
- Station Repair: 31 posts

The rain station network recommendation map is shown in **Figure 10** and **Figure 7**.

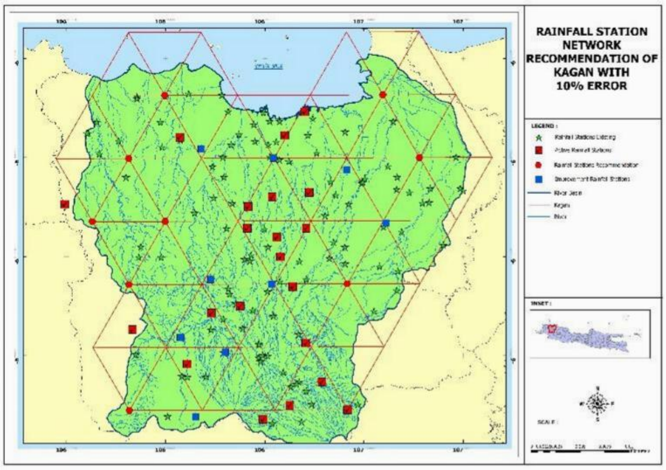

Figure 10: Map of Rain Station Network Recommendation of the Kagan Analysis Results with an Average Error of 10%

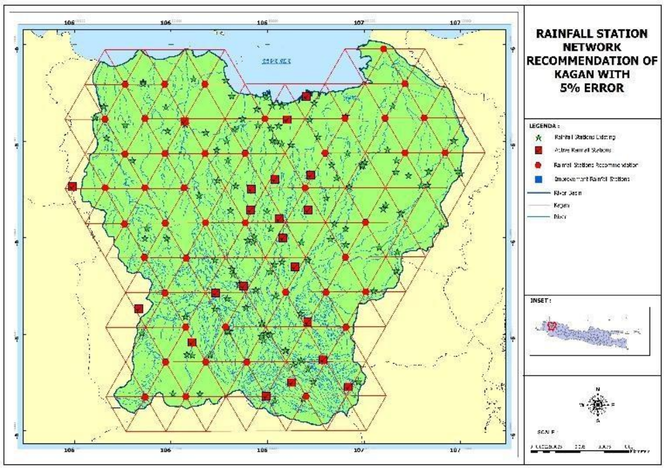

Figure 7: Map of Rain Station Network Recommendation of the Kagan Analysis Results with an Average Error of 5%

V.III Rain Station Network Recommendations Based on the Kagan and Kriging Methods

In this analysis, the results of the recommendations with Kagan were combined with the Kriging analysis. In addition the use of new stations with the same rain contours was limited. Based on the analysis results, the following recommendations were made:

Average error of 10% + kriging

- stations: 9 posts
- Station Repair: 9 posts

Average error of 5% + kriging

- Stations: 13 posts
- Station Repair: 14 posts

The rain station network recommendation map is shown in **Figure 8** and **Figure 9**

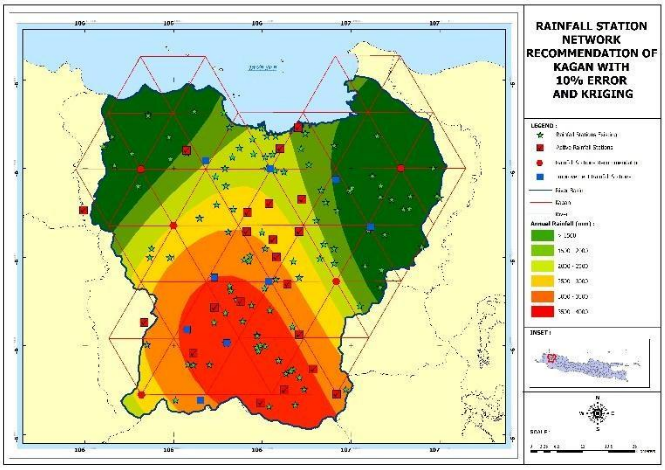

Figure 8: Map of Rain Station Network Recommendation of the Kagan Analysis Results with an Average Error of 10% and Kriging

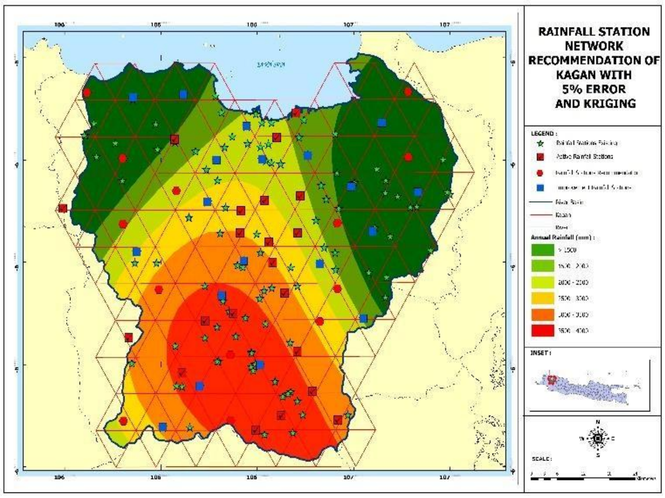

Figure 9: Map of Rain Station Network Recommendation of the Kagan Analysis Results with an Average Error of 5% and Kriging

VI. CONCLUSION

Based on the results of the analysis with several methods, it was concluded that:

1. Based on the WMO standards the density of rain stations in the Ciliwung Cisadane River Basin was still quite adequate.
2. Based on the kagan analysis, an error value of 10%, need 23 stations with a distance between of 16.23 km,

and an error value of 5%, need 90 stations with a distance of 8.21 km.

3. Based on the Stepwise analysis, there were 11 influential rain stations.

4. Based on the quality control analysis, there were 14 rain stations in good condition.

5. The recommendation based on Kagan led to a proposal of 9 new and 10 station repairs with an average error of 10%, while for an average error of 5%, there were 47 new and 31 station repairs.

6. The recommendation based on Kagan combined with Kriging resulted in a proposal of 9 new and 9 repair station with an average error of 10%, while for an average error of 5%, there were 13 new stations and 14 repairs.

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