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Analysis of The Placement Pattern and The Needs of The Rain Station With Kagan-Rodda Methode on Das Progo Yogyakarta

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Abstract

Climate change that occurs has an impact on various fields. In the Yogyakarta region, most of the people work in agriculture and fishing. Where the two fields are closely related to rainfall data and rainfall patterns. Based on these conditions, it is necessary to conduct a study on the need for maximum rainfall data. From the data obtained from the Serayu Opak River Basin Center for the Progo Watershed in Yogyakarta, there are 8 active rain stations that are still operating, but they are not maximized because they are often damaged. So that it is necessary to analyze the needs of the rain station and the placement pattern needed to obtain the maximum rainfall data. The method used in this research is the Kagan-Rodda method. This method can analyze the needs and distribution patterns of the rain stations required by calculating the rainfall data from existing stations. From the calculation with this method, it is obtained that the need for rain stations for the Progo River Basin Yogyakarta region is 11 stations. It is recommended to add 3 new stations with a distribution pattern as described with the distance between stations of 12,742 km.

Keywords
Kagan-Rodda, Needs, Placement Pattern, Rain Station, Yogyakarta Progo Watershed

1. Introduction

Climate change that occurs has an impact on various fields. So it is necessary to carry out further analysis in order to obtain the latest data so that it can be used according to the needs of the community. One of the impacts of climate change is the rain pattern which is now difficult to predict.

Indonesia is a tropical country with 2 seasons, namely the rainy season and the dry season. In Yogyakarta, some people work as fishermen and most of them work in agriculture. The community's activities in these two fields are greatly influenced by the weather. So they need information about accurate weather data so that they can be used as a basis for carrying out activities. Especially in unpredictable rain so that analysis can be done by getting data from the rain station.

In order for the amount of rain to represent the actual depth of rain that occurs throughout the watershed, it requires a rain station with a certain number and density so that it can represent the amount of rain in the watershed. The rain station network must be planned according to the needs of the rainfall data to be collected. Especially in areas that have developed with a high level of density, the number of rain gauges needed must also be more.

Rain measurement data are obtained from rain stations that are spread over several points in a watershed area (DAS). In determining the rain that falls in a watershed, a number of rain stations are needed to be installed in such a way that data that represents the amount of rain in the watershed (Pulau Madura, 2018).

Hydrology is the science that talk about the water that is in the earth, namely the incident, turnover and distribution, physical properties and chemical, as well as his reaction to the environment, including its relationship with life (Linsley, R. K., Kohler, M. A., Joseph, P. L., & Hermawan 1996).

Cycle hydrology is one of the important aspects required in the hydrological analysis process. The hydrological cycle is the movement of seawater into the air, which then falls to the ground again as rain or other forms of precipitation, and eventually flows back into the ocean. In this hydrological cycle there are several interrelated processes, namely between the process of rain (precipitation), evaporation (evaporation), transpiration, infiltration, percolation, runoff and underground flow (soemarto 1987).

Watershed (DAS) is a land area which is an integral part of rivers and tributaries, which functions to accommodate, store, and flow from rainfall to lakes or to the sea naturally, where the land boundary is a topographical separator. and boundaries at sea to water areas that are still affected by land activities. A subwatershed is a part of a watershed that receives rainwater and flows it through a tributary to the main river. Each DAS is divided into Sub-DAS-Sub DAS (law No 2004).

The watershed designation is indicated by the name of the river in question and is bounded by a control point, which is generally a hydrometric station. Paying attention to this means that a watershed can be part of another watershed (Harto s. 1993).

Rain or precipitation is a general term to describe water vapor that condenses and falls from the atmosphere to the earth in all its forms in a series of hydrological cycles (Dr. Ir . Suripin 2004). Others say that precipitation is the common name for steam condensing and falling to the ground in a series of hydrological cycle processes, usually the amount is always expressed by the depth of the prespitation (mm). If the water vapor that falls liquid called rain(rainfall) and if the solid form called snow (Sosrodarsono 1976).

Types of Rain include:

1. Convective Rain Orographic
2. Rain
3. Cyclonic Rain

Rainfall is the amount of water that falls in a certain period of time. Measurement of rainfall is carried out in units of height above the horizontal ground surface which is assumed to not occur evaporation or infiltration, run off, or evaporation.

Measurement of rainfall is carried out using a rainfall gauge. There are 2 (two) types of tools used in observing rainfall, namely:

1. Rain Gauge (OBS)
2. Automatic Rain Gauge
   a. Type Automatic Rain Gauge Hellman
   b. Rain Gauge Type Tipping Bucket

Kali Progo is a river that flows through Central Java and Yogyakarta Special Region. In DI Yogyakarta, this river is the natural boundary of Kulon Progo Regency with Sleman and Bantul Regencies. The following is the progo river data:

Long : 140 km
Source : Mount Sindoro
Muara : Indian Ocean
Basin size :
Total watershed area = 2,380 km^2 (920 sq mi)
Watershed area of Yogyakarta = 709.1 km^2

Figure 1 Progo Watershed Plan for Yogyakarta Region

From the data obtained from the Serayu-Opak River Basin, in the Progo River Basin for the Yogyakarta region there are 8 rain stations that are still active in recording rain data. However, the data is not always presented with galangal because sometimes there is damage to the equipment. So it is necessary to evaluate the need for rain stations in the Progo watershed area for Yogyakarta in order to obtain complete rainfall data. And also the placement pattern of rain stations also affects the rainfall data obtained, considering that one tool must have a maximum coverage. So that it can cause the rain data to be inaccurate.

2. Methodology

Rainfall data and location of rain stations are obtained from the Serayu-Opak River Basin, which covers the Progo Watershed. The researched Progo watershed is only in the Yogyakarta area. From these data, calculation analysis can be done to obtain the needs and the required placement pattern of rain stations, namely the Kagan-Rodda method.

From the BBWS data, data on the coordinates of the existing rain station points will be obtained. This becomes an evaluation material in determining the coverage area of an existing rain station.

Rainfall data obtained from BBWS is the daily rainfall data recorded by the rain station. So that the data is processed and then the average annual rainfall value is obtained in the calculation.

The choice of the approach method for the average rainfall in a river basin area (DAS) can be determined by considering the following factors (Dr. Ir . Suripin 2004).

1. Post rain gauge nets in the watershed, namely:
   a. If there is enough rain gauge, the average method, Isohyet or Polygon Thiessen can be used;
   b. If the rain gauge is limited, use Thiessen's mean and Polygon methods;
   c. If only a single rain gauge post, then use the rain point method.
2. Watershed Area
   a. Large watersheds (> 5000 km2), with the Isohyet Method;
   b. Medium watershed (500 - 5000 km2), with the Thiessen Polygon Method;
   c. Small watershed, (< 500 km2), with the algebraic mean method.
3. Watershed Topography
   a. Mountain areas, with the Algebra Average Method;
   b. Plains, with the Thiessen Polygon Method;
   c. Illy and irregular areas, with the Isohyet Method.

Then selected the method with a watershed area. Where the area of the Progo watershed for the Yogyakarta region is 709.1 km^2 , the method used in determining the average rainfall is the Thiessen Polygon method.

Then, Kagan Rodda's calculations will be carried out to get the needs and patterns of placing rain stations.

2.1. Kagan-Rodda Method

Determining the rain station network is not only limited to determining the number of rain stations required in a watershed, but also the location and distribution pattern. Information about rain conditions in a watershed (DAS) can be obtained by installing a rain gauge. The rain station network has a very important function, namely to reduce the variability of the magnitude of events or reduce uncertainty and increase understanding of measured and interpolated quantities (Harto s. 1993). WMO (World Meteorological Organization) states that in tropical areas such as Indonesia, a minimum network density of 100-250 km^2 of rain stations is required for normal conditions.

For physically difficult conditions, a density of 250-1000 km2 is recommended. Narayanan in 1962 (Harto s. 1993) determined the method of placing a rain station by connecting the network density and statistical rainfall data. Themethod joint mapping technique is to apply the hydrological network relationship with the standard error of estimate which is then used to determine the density of the hydrological network with a certain level of accuracy (Solomon 1972). Meanwhile, the method of determining the rain network has the final result in the form of the number of rain stations, the distance between stations, and the distribution pattern in the form of an equilateral triangle (Rodda 1967).

The World Meteorological Organization or WMO (World Meteorological Organization) recommends the minimum density of rain station networks as follows:

Table 1 Minimum Density of Rain Station Network WMO Recommendation

No	Type	Area (km^2) per One Post	
		Normal	Difficult Conditions
1	Regional tropical plains and moderate Mediterranean	600-900	3000-9000
2	Mediterranean and tropical mountainous terrain was	100-250	1000-5000
3	Mountainous region mediterranean tropical and being	140-300	
4	Arid Region and the poles	1500-10000	

Source: (Linsley, Kohler, & Paulhus, 1986)

Qualitative guidance is given by (Rodda 1967), namely by utilizing the rainfall correlation coefficient (Harto s. 1993). Determination of a rain station network is not only limited to determining the number of stations required in a watershed, but also the location and distribution pattern of rain stations within the relevant watershed. In the research conducted by (Pulau Madura, 2018), for tropical areas where local rainfall with a very limited spread area has a variety of spaces for rain with certain periods, it is very uncertain even though it actually shows a relationship to some degree (Harto s. 1993).

Steps :

1. Data collection
2. Calculation of the maximum annual daily bulk at each station
3. Determination of the area covered by each station using the Thiessen polygon method, then the thiessen average rainfall value is obtained with the formula:

$$R = \frac{A_1R_1 + A_2R_2 + .\ldots + A_nR_n}{A_1 + A_2 + A_3 + .\ldots + A_n}$$

4. Measuring the distance between stations and determining the correlation value. The correlation value is obtained by making a graph of the rainfall relationship between stations.
5. Creating an exponential graph of the relationship between distance and correlation, which will then obtain the parameter for the Kagan-Rodda calculation, namely the correlation coefficient ($r_{(0)}$) and correlation radius ($d_{(0)}$)
6. Determine the mean value of the average CH value of each station (X), Standard Deviation (Sd), and Coefficient of Variation (Cv) where $Cv = \frac{Sd}{X}$
7. From the parameters that have been obtained, then proceed to analyze the interpolation error (Z2), the average error (Z1) and the distance between stations as well as the ideal number of stations available based on the error rate.

$$Z1 = Cv\sqrt{\frac{\left[1 - r(0) + \left(0.23\frac{\sqrt{A}}{(d(0)\sqrt{n})}\right)\right]}{n}}$$

$$Z2 = Cv\sqrt{\frac{1}{3}[1 - r(0)] + 0.52\frac{r(0)}{d(0)}\sqrt{\frac{A}{n}}}$$

8. The value of Z1 is used to determine the value of L, where L is the value of the distance to create a Kagan-Rodda net. Furthermore, these nets serve as the basis for determining the placement pattern and requirements of the rain station based on the Kagan-Rodda recommendation.

3. Result and Discussion

3.1. Analysis of The Maximum Daily

The rainfall data used is the data obtained from the Serayu Opak River Basin, Yogyakarta. There are 8 stations rainfall in Progo watershed for the region of Yogyakarta in Yogyakarta watershed area of 709.1 km^2. The data obtained is daily rainfall data which is then taken the maximum annual rainfall data which is presented in the following table:

Table 2 Annual Maximum Daily Rainfall Data (mm)

No.	Year	Maximum Annual Daily Rainfall (mm)
1	2009	72
2	2010	97,1
3	2011	93,8
4	2012	130,6
5	2013	129,3
6	2014	100,6
7	2015	121,0
8	2016	139,8
9	2017	211,6
10	2018	98,7

Source: Data in Research, 2020

The Thiessen polygon method was chosen because the area of the Progo watershed in the Yogyakarta area is 709.1 Km^2 > 500 Km^2 in the hydrological analysis. To calculate the Thiessen Average Rainfall, the coverage area of each rain station must be found. The area is calculated using autoCAD.

Draw an area map using the Thiessen Polygon method

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Figure 2 Area Map Using The Thiessen Polygon Method

Based on Figure 2 above which has been adjusted to the coordinates of the rain station, the results of the area analysis are as follows:

Table 3 Data on The Area of The Rain Station

Post CH Station	y	x	Area (Ha)	Area (Km^2)
Kalibawang	-7.091716	110.684722	14 680	146.8
Godean	-7.73425	110.30107	13 050	130.5
Kenteng	-7.76159	110.19672	11950	119.5
Kalijoho	-7.82217	110.23751	6120	61.2
Display	-7.8391	110.27467	6970	69.7
Gembongan	-7.85697	110.21126	6400	64
Brosot	-7.94022	110.23313	9500	95
Sanden	-7.95394	110.26765	2240	22.4
		Total Size	70 910	709.1

Source: Data in Research, 2020

It can The average rainfall data is obtained by calculating the Thiessen polygon as follows:

$$R = \frac{A_1R_1 + A_2R_2 + ... + A_nR_n}{A_1 + A_2 + A_3 + ... + A_n}$$

Table 4 Calculation of CH 3 Average Thiessen

No	Year	Pos/Rainfall station								Average of CH Thiessen
		Kalibawang	Godean	Kenteng	Kalijoho	Pajangan	Gembongan	Brosot	Sanden	
		146.80	130.50	119.50	61.20	69.70	64.00	95.00	22.40	
1	2009	100.0	0.0	68.0	68.3	120.5	121.0	98.0	0.0	44694.81
2	2010	95.0	0.0	67.0	132.0	55.0	132.0	143.0	153.0	47454.23
3	2011	82.0	109.0	54.0	109.0	62.3	104.0	93.0	137.0	52567.54
4	2012	150.0	106.0	95.0	115.0	111.9	85.0	124.0	258.0	73831.08
5	2013	93.0	79.0	170.0	140.0	87.5	150.0	165.0	150.0	74623.39
6	2014	85.0	103.5	88.0	76.0	55.0	97.0	160.0	140.0	60189.87
7	2015	93.0	80.8	81.0	127.0	95.0	180.0	122.0	189.0	59866.17
8	2016	100.0	118.5	147.0	120.0	94.5	207.0	158.0	173.0	76656.86
9	2017	93.0	125.0	163.0	343.0	339.0	148.0	214.0	268.0	114401.77
10	2018	90.0	154.5	77.0	97.0	97.0	38.0	118.0	118.0	66486.78

Source: Data in research, 2020

Distance Between Stations And Correlation Coefficient

From the available rain station data, it can be found the distance between rain stations and the correlation coefficient between these stations. Measurement of the distance between stations was carried out using AutoCAD and the correlation coefficient was searched using rainfall data. From the two data, a regression graph of the relationship between monthly rainfall data is made between the two stations. The following is an example of correlation calculation obtained from the graph

Table 5 Rainfall Data

Station	Rainfall											
Kalibawang	69	59.2	63.1	62.5	45.7	30.4	24.2	9.9	23.9	34.1	69.7	83.8
Godean	41.74	53.7	34.94	33.99	33.15	16.8	12.83	1.51	8.53	26.2	71.93	44.65

Source: Data in research, 2020

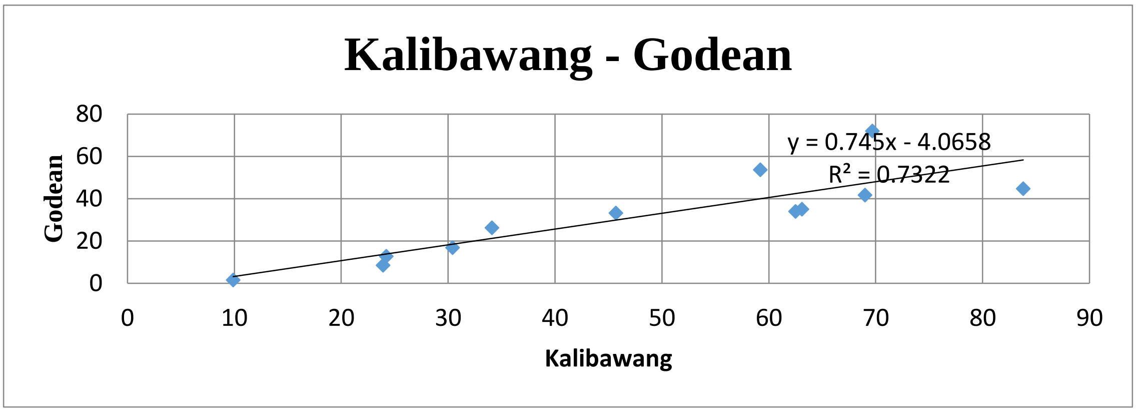

Figure 3 Graph Correlation between Kalibawang Station to Station Godean

From reading the chart above correlation values of $R^2 = 0.7322$. Correlation grafic phing was then continued for all stations, and the results can be presented in the following table:

Table 6 Calculation of Distance Between Stations and Correlation

Rainfall Station	Kalibawang	Godean	Kenteng	Kalijoho	Pajangan	Gembongan	Brosot	Sanden
Kalibawang	0.000	27.540	37.960	51.940	63.920	65.640	93.440	103.57
korelasi		0.732	0.860	0.883	0.875	0.918	0.947	0.910
Godean		0.000	38.400	33.510	40.840	46.990	71.950	80.13
korelasi			0.807	0.846	0.871	0.801	0.631	0.788
Kenteng			0.000	29.690	45.380	39.110	66.770	79.69
korelasi				0.809	0.872	0.907	0.790	0.7653
Kalijoho				0.000	15.680	13.900	41.570	52.61
korelasi					0.940	0.794	0.894	0.9113
Pajangan					0.000	14.010	31.440	39.77
korelasi						0.879	0.833	0.8721
Gembongan						0.000	28.330	40.65
korelasi							0.785	0.8648
Brosot							0.000	14.31
korelasi								0.8608
Sanden								0.000

Source: Data in Research, 2020

From making a graph of the distance relationship between stations, the correlation value is obtained. The next step is to make an exponential graph of the relationship between distance and correlation to obtain the correlation coefficient ($r_{(0)}$) and correlation radius ($d_{(0)}$).

The next step is to find the coefficient of variation (Cv).

Table 7 Calculation of Coefficient of Variation (Cv)

o	Year	Average of CH	X	Sd	Cv
	2009	44694.81	67077.2501	20083.96	0.299415
	2010	47454.23317			
	2011	52567.53774			
	2012	73831.08005			
	2013	74623.3884			
	2014	60189.87251			
	2015	59866.17038			
	2016	76656.86496			
	2017	114401.7659			
0	2018	66486.77754			

Source: Data in Research, 2020

Where:
X = Average of All CH Mean
Sd = Standard Deviation

$$Cv = \frac{Sd}{X} = \frac{20083{,}96}{67077{,}2501} = 0{,}299415$$

From the parameters that have been obtained from the above calculations, an analysis of the existing rain post network in the Progo River Basin is carried out in Yogyakarta. The analysis carried out includes the interpolation error, the average error and the distance between the posts as well as the ideal number of posts available based on the error rate. Here is the calculation:

$$Z1 = Cv\sqrt{\frac{\left[1 - r(0) + \left(0.23\frac{\sqrt{A}}{(d(0)\sqrt{n})}\right)\right]}{n}}$$

$$Z2 = Cv\sqrt{\frac{1}{3}[1 - r(0)] + 0.52\frac{r(0)}{d(0)}\sqrt{\frac{A}{n}}}$$

Table 8 Calculation of Interpolation Error Analysis

n	Cv	r(0)	A (Km^2)	d(0)	$\sqrt{A}$	$\sqrt{n}$	$\sqrt{\frac{A}{n}}$	Z_1 (%)	Z_2 (%)
1	0.299	0.845	709.100	-11111.11111	26.6	1.000	26.629	11.77	6.74
2	0.299	0.845	709.100	-11111.11111	26.6	1.414	18.829	8.32	6.76
3	0.299	0.845	709.100	-11111.11111	26.6	1.732	15.374	6.80	6.77
4	0.299	0.845	709.100	-11111.11111	26.6	2.000	13.314	5.89	6.77
5	0.299	0.845	709.100	-11111.11111	26.6	2.236	11.909	5.27	6.77
6	0.299	0.845	709.100	-11111.11111	26.6	2.449	10.871	4.81	6.78
7	0.299	0.845	709.100	-11111.11111	26.6	2.646	10.065	4.45	6.78
8	0.299	0.845	709.100	-11111.11111	26.6	2.828	9.415	4.17	6.78

Source: Data in Research, 2020

Based on the above, the acquisition count of the amount of rainfall in the watershed tasiun Progo, Yogyakarta as many as eight stations with average error value - average (Z_1) exceeds 5% there are 5 stations. Next is to make a equilater tringle net with the distance between the rain stations is L. Where the value of L can be obtained from the following calculations:

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$$L = 1.07\sqrt{\frac{A}{n}} = \sqrt{\frac{709,1}{5}} = 12,742\ km$$

Which is then drawn on the map of the Progo watershed according to the distance L that has been obtained to determine the distribution of rain stations / posts on the Kagan Rodda network. The following is presented in the following image.

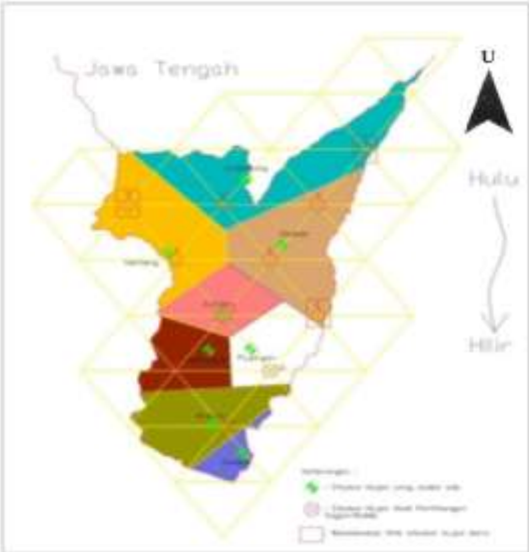

Figure 4 Rain Station Network Map Recommended by Kagan Rodda

From the calculation and manufacture of the Kagan-Rodda nets, 11 rain station points should have been installed with an L value of 12.742 Km. There are 8 existing and installed rain stations, so it is advisable to add 3 new rain stations according to the recommendations from the calculation results and the creation of the Kagan-Rodda nets, which are adjusted to the distance values that have been obtained and the existing ones from existing rain stations or installed.

4. Conclussion

Based on the results of the analysis and discussion in the previous chapter, the following conclusions can be drawn:

1. The results of the needs analysis and placement pattern using the Kagan Rodda method in the Progo Watershed in Yogyakarta, it is found that the Progo Yogyakarta watershed requires 11 rain stations.
2. The existing and installed network of rain stations are 8 stations, so it is necessary to add 3 new rain stations based on the map of the rain station network recommended by Kagan-Rodda with a side length of triangle (L) = 12,742 km.

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