

ANALYSIS OF THE NETWORK DENSITY OF RAINFALL STATIONS AND HYDRO - METEOROLOGY OF CITANDUY WATERSHED, WEST JAVA PROVINCE

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ABSTRACT

This study aims to analyze the density and effectiveness of hydrological stations in the Citanduy Watershed, West Java, using both the Kagan and World Meteorological Organization (WMO) methods. The availability and strategic distribution of Rainfall Stations (PCH), Water Level Stations (PDA), and Climatology Stations are crucial for the accuracy of hydrological data used in flood management, infrastructure development, and water resource planning. The research utilizes a quantitative approach with spatial analysis methods, including Thiessen Polygon and correlation models. The findings indicate that the 24 existing rainfall posts generally meet WMO standards in terms of coverage, but based on the Kagan method, 4 PCHs require closure or relocation to optimize data quality. Furthermore, although 33 water level stations exceed WMO's minimum requirement of 4–12, the spatial density is uneven, and only 2 climatology stations are active, meeting the lower threshold but signaling the need for expansion. This study is novel in integrating WMO and Kagan density methods to assess and refine post placement across a single watershed, leading to more accurate hydrological monitoring. In total, the results recommend the refinement of four PCHs and the relocation or optimization of 16% of existing rainfall stations. This research contributes to optimizing station placement, improving hydrological data reliability, and enhancing the efficiency of monitoring networks for future watershed management.

KEYWORDS

Hydrological Network, Rainfall Station, Kagan Method, WMO Standard, Watershed Management



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INTRODUCTION

Hydrological research has further uses in environmental engineering, environmental policy, and planning (Adityo, 2023; Sheppard, 2017; Thevanes & Mangaleswaran, 2018). Hydrology also studies the behavior of rainfall, especially including the *rainfall repetition period*, because it is related to flood calculations and plans for each civil engineering structure, including dams, embankments, and bridges. Accurate data quality in determining the potential of surface water in a *River Area* (WS) is essential to optimize the needs and development of water resources in the river area (Mahadewi, 2023; Nuswanto, 2023; Sudiatmaka, 2022). This is inseparable from the importance of the ideal number of hydrological posts and the placement of post locations that can represent the characteristics of a *watershed* (DAS). For this reason, an analysis is needed that requires hydrological data in the form of rainfall data, discharge data, and accurate climate data as ready-to-use hydrological inputs for development, research, and the calculation of water resource management information (Adityo, 2021; Hosnah, 2021; Rohman & Harkrisnowo, 2022; Windari, 2022). Errors in monitoring basic hydrological data in a watershed will result in inaccurate ready-to-use data, leading to inefficient and ineffective water resource planning, research, and management results. However, the question is how many hydrological posts need to be placed in a watershed to accurately and correctly monitor hydrological characteristics. Likewise, it needs to be determined whether the number of available posts currently in a watershed is adequate and feasible, and whether the number and

location can monitor the hydrological characteristics of the area (Adityo, 2021; Mahadewi, 2021; Nuswanto, 2021).

The condition of the hydrological station network today is generally concentrated in lowland areas, and there is no post that can represent the hydrological conditions in the highlands/hills/mountains (Nuswanto, 2020; Sudiatmaka, 2020; Windari, 2020). To support this expectation, the network of hydrological stations must be planned and placed in the right location, monitored or operated properly, and supported by appropriate hydrological management methods and the quality of capable and skilled human resources (Hosnah, 2020; Rohman & Harkrisnowo, 2020). Thus, it can be concluded that the problems that often arise are: whether the number of hydrological stations that currently exist is adequate both in number and location and whether they can describe the conditions of the hydrological characteristics of the area (Azhari et al., 2022; Majesty, 2014).

To overcome this, it is necessary to analyze the density of the network of *Rainfall* and *Hydro-Meteorological* stations located in the Citanduy Watershed (*DAS*) so that it can be known early which posts are dominant and can describe the characteristic conditions of the watershed (referred to as *primary posts*) and which posts are less dominant and need to be relocated or closed (Azhari et al., 2022).

Purpose to plan an effective and efficient hydrological network and to be able to describe the conditions of hydrological characteristics in the Citanduy watershed, both for upstream and downstream areas. To fulfill assignments in the *Hydrometeorology Instrumentation* course. The purpose of this analysis is to determine if the density of the existing hydrological stations is adequate, both in number and location, for *Rainfall Posts*, *Water Forecasting Posts*, and *Climatology Posts* and to identify which posts are dominant and can describe the characteristic conditions of the watershed (referred to as *primary posts*) and which posts are less dominant and need to be relocated or closed.

The benefit of this study is to create an efficient and effective network of hydrological posts so that it can minimize the costs needed for the operation and maintenance of hydrological posts in the Citanduy watershed. In addition, the results of the evaluation of the distribution of *PCH* with rationalization will ensure that the data obtained is more optimal and improve the quality of hydrological analysis.

RESEARCH METHOD

Several methods and models have been developed to accommodate the rationalization of the *Hydrology* post network, producing good outputs in the form of effective and efficient hydrological post networks to support the planning, management, and development of water resources. The methods used include: *Quality Control Method*; *Kagan's Method*; *The Isohyet Method*; *Stepwise Method*; and *WMO Density Method*.

In this study, only the *Kagan Method* was used to carry out rationalization in the rainfall post network, while the *WMO Method* was used to carry out the rationalization of the water forecast post network and the *climatology post*.

Kagan Method

Based on several methods of determining the existing rainfall post network, *Kagan's method* is relatively simple, both in its meaning and calculation procedure. In addition to generating the number of posts needed with a certain level of rigor, *Kagan's method* can also provide a clear pattern of rainfall post placement.

Basically, this method uses statistical analysis by associating the density of the rainfall postal network, interpolation errors, and leveling errors. Based on the results of this analysis, the relationship between the postal distance and the level of leveling and interpolation errors will be obtained so that the optimal distance for the acceptable error level can be determined. From this optimal distance, an equilateral triangle network is formed, with the node points representing the theoretical ideal location for the placement of rainfall posts. The correlation function can be presented as in the following equation:

$$r(\rho) = r(o) e^{\frac{-\rho}{\rho_o}}$$

Information:

$r(\rho)$ = Correlation coefficients for distance ρ .

$r(o)$ = Correlation coefficient between posts with very small distances (± 0 km).

ρ = Distance between posts (km).

ρ_o = Correlation radius, i.e. the distance between posts where the correlation decreases with the e.

Furthermore, by assuming the network density in an area (area) s of each station, where the dispersion of the average value given by the station follows the following equation:

$$E_1 = \sigma_h^2 \left[1 - r(o) + 0.23 \frac{\sqrt{s}}{\rho_o} \right]$$

For a larger area, the error dispersion in determining the average value in an area A consisting of N stations ($A = Ns$) can be calculated by the following equation:

$$E_N = \frac{\sigma_h^2}{N} \left[1 - r(o) + 0.23 \frac{\sqrt{A}}{\rho_o \sqrt{N}} \right]$$

Information:

σ_h^2 = Distribution of measurement results.

A = The area of the watershed (watershed), in km².

N = Number of posts.

For the area of the watershed of A km² and the number of existing rainfall posts as much as N , the *relative root mean square error* $Z1$ can be calculated using the following equation:

$$Z_1 = \frac{\sqrt{E_N}}{h} = C_v \sqrt{\frac{(1-r(o) + 0.23 \frac{\sqrt{A}}{\rho_o \sqrt{N}})}{N}}$$

$$C_v = \frac{\sigma_h}{h}$$

With this equation, the average error value can be calculated if the number of posts is known and vice versa, the number of posts can be known by setting the error criteria. Kagan places the postal network in an equilateral triangle with the distance of each as in this equation:

$$l = \sqrt{\frac{2s}{N\sqrt{3}}} = 1.07 \sqrt{\frac{A}{N}}$$

It should be remembered that, for the density of the network s , the distance l between the posts for a network that is triangular is 1.07 times greater than the square network. If this is taken into account, the interpolation accuracy of the two networks is estimated to be the same. By substituting the above equation, a simpler equation is obtained as in the following equation:

$$Z_3 = C_v \sqrt{\frac{1}{3} [1 - r(o)] + 0.49 \frac{r(o)}{\rho_o} l}$$

Apart from the above equation, to calculate the interpolation error can also be used by using the equation below.

$$Z_3 = C_v \sqrt{\frac{1}{3} [1 - r(o)] + 0.52 \frac{r(o)}{\rho_o} \sqrt{\frac{A}{N}}}$$

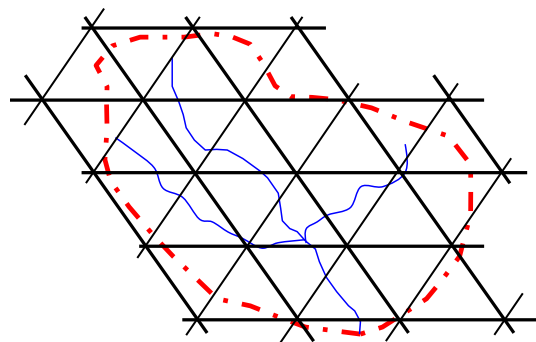


Figure 1. Equilateral Triangle Nets for Station Determination
Source: by Researcher

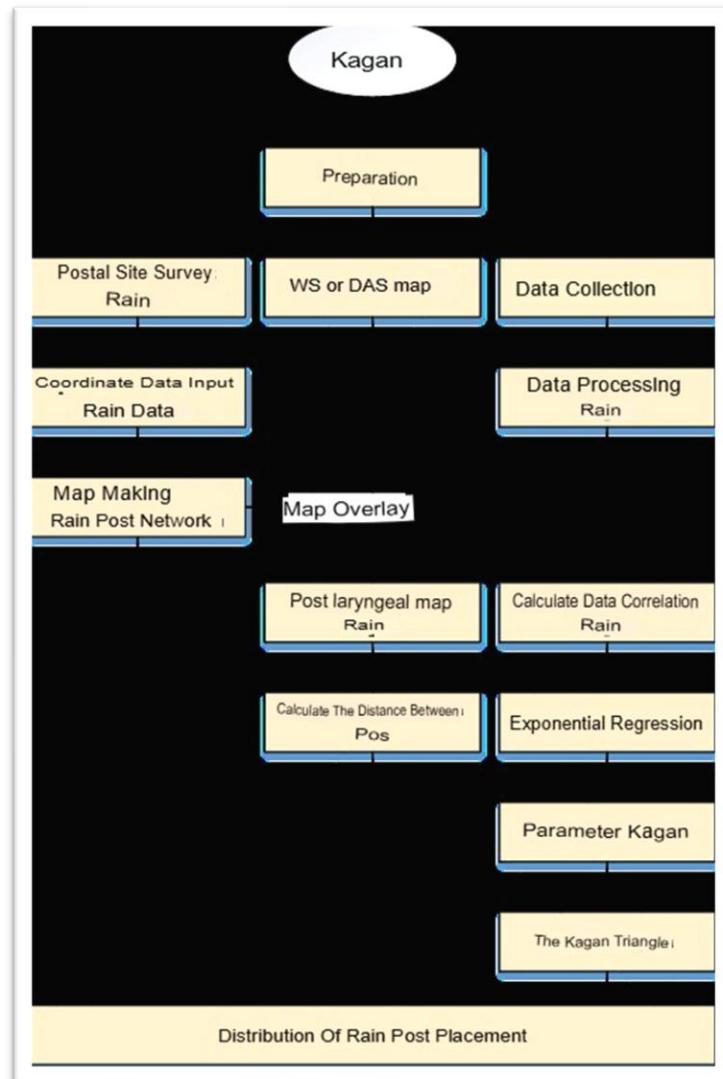


Figure 2. Stages of Rationalization of the Kagan Method
Source : by Researcher

WMO Density Method

The design of the *rainfall post* network is an important activity that must be carried out because the data to be obtained is an input to the *watershed system*. A network of *rainfall posts* is necessary because the rainfall input in the *watershed system* is irregular in space and time. Regional rainfall is needed to determine the amount of rainwater that exists throughout the watershed (evenly) and that will eventually flow to the watershed drainage system before entering the main river.

This is the easiest method offered by the *WMO* (World Meteorological Organization), which combines topographic elements and the extent of influence of each *Hydrological* observation post/station, especially for *rainfall posts*. General guidelines on determining the number of posts in a watershed (network density) are provided in the *Guide to Hydrometeorological Practices* (WMO, 1965) as follows:

Table 1. Minimum Density of Climatological Station Network

No.	Type (Description) Type Regional	Area of Hydrological Post (Km2) Normal Condition	Area Area by Hydrological Post (Km2) Difficult Conditions	Information
1.	Plains area: tropical and Mediterranean temperate.	1.000 – 2.500 (600 – 900)	3000 – 10.000 (900 – 3.000)	
2.	Mountainous areas: tropical Mediterranean and temperate. Small island areas are mountainous with varying rainfall.	300 – 2.500 (100 – 250) 140 – 300 (25)	1.000 – 5.000 (250 – 1.000)	The value in parentheses is the area area for the rainfall post network
3.	Arid and polar regions.	5.000 – 20.000 (1.500 – 10.000)		

Source: WMO Book No. 168, 1965

Table 2. Minimum Density of Automatic Rainfall Post Network (*Automatic Rainfall Recorder*)

No.	Type (Description) Type Regional	Normal Area (Km2) Per Post	Difficult Areas (Km2) Per Post
1.	Plains with temperate, Mediterranean or tropical zones.	600 – 900	900 – 3.000
2.	Mountainous areas with temperate, Mediterranean or tropical zones. Small mountainous islands with uneven rainfall distribution and very tight river flow patterns.	100 – 250 25	250 – 1.000
3.	Arid and polar regions Arid areas when rainfall < 300 mm/year.	1.500 – 10.000	

Source: WMO Books, 1974

Table 3. Minimum Density of Automatic *Water Level Recorder*

No.	Type (Description) Type Regional	Normal Area (Km2) Per Post	Difficult Areas (Km2) Per Post
1.	Plains with temperate, Mediterranean or tropical zones.	1.000 – 2.500	3.000 – 10.000
2.	Mountainous areas with temperate, Mediterranean or tropical zones. Small mountainous islands with uneven rainfall distribution and very tight river flow patterns.	300 – 1.000 140 – 300	1.000 – 5.000
3.	Arid and polar regions	5.000 – 20.000	

Source: WMO Books, 1974

Considerations that need to be considered in planning a Hydrology post network include:

1. Weather and climate characters in the region:
 - a. If there are special characters in the area, it must be considered in determining the density of the Hydrology post network.
 - b. The density of the Hydrology post network, especially rainfall posts in mountainous areas, is because the density of the rainfall post network in mountainous areas is relatively more than in the plains.
 - c. The need for the Hydrology post network is related to the need for early warning of floods.
2. The need for Hydrology data to support water resource management activities.
3. Consideration of the costs required in the construction and management of the Hydrology post with the benefits obtained from the construction of the rainfall post.

RESULTS AND DISCUSSION

To produce a valid analysis, long data and good quality are needed. In this job the post analyzed is one that has at least 10 years of data, has valid coordinates and tools that are still functioning. To find out the length of data that the post has, you can see the following table.

Table 4. Availability of Rainfall Post Data in the Citaduy Watershed.

No	Rain Station Name	Availability of Rainfall Data										Total Data (Years)
		Year										
		2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	
1	KADIPATEN	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	10
2	PAGERAGEUNG	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	10
3	CIHONJE	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	10
4	PANJALU	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	10
5	SUBANG	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	10
6	CIGALEUH	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	10
7	CISAYONG	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	10
8	CIKASASAH	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	10
9	CINEAM	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	10
10	PANAWANGAN	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	10
11	KAWALI	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	10
12	PANJALU	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	10
13	LANGENSARI	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	10
14	GUNUNGPUTRI	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	10
15	WANAREJA	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	10
16	SIDAMULIH	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	10
17	UJUNGBARANG	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	10
18	MAJENANG	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	10
19	CIMANGGU	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	10
20	PADAHERANG	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	10
21	MANGANTI	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	10
22	DAYEHLUHUR	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	10
23	JANGGALA	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	10
24	PADARINGAN	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	10
25	RANCAH	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	10
26	CIBARIWAL	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	Ada	10

Source : by Researcher

Table 5. Availability of Climatological Data in the Citanduy Watershed.

No	WS/DAS	Station Name	Register Number	Coordinate		Location			Built By	Year	Observer Name
				Latitude	Longitude	Village	district	City.			
(1)	(2)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
POS KLIMATOLOGI											
1	Citanduy/Citanduy	Banjar	02-3279-092-01-1	7°22'3.56"	108°33'47.69"	Pataruman	Pataruman	Banjar	BBWS Citanduy	2017	Hastuti
2	Citanduy/Citanduy	Majenang	02-3301-092-14-1	7°18'10.80"	108°44'51.39"	Cibeunying	Majenang	Cilacap	BBWS Citanduy	2017	Priyono

Resource: by Researcher

Analysis of Rationalization of the Rainfall Post Network (PCH) in the Citanduy Watershed

The method used in conducting the rationalization analysis of the rainfall post network is the WMO and Kagan density analysis. All of these methods support each other in identifying rainfall outposts that have the potential to remain, relocate, eliminate and also determine the location plan of the new outpost. The following are the results of the analysis of the rationalization of the rainfall post network in the Citanduy watershed.

Analysis of the Rainfall Post network using the WMO Density Method

The analysis of post density based on WMO is based on the topographic elements of an area and the extent of its influence for each rainfall post. The determination of the minimum density for rainfall posts based on the conditions of their topographic area can be seen in Table 2.2. For the Citanduy watershed which tends to be dominated by hills, if referring to the instructions from the WMO with a watershed area of 3,656.66 km², the minimum number of rainfall posts that must exist in the Citanduy watershed is 14-35 rain posts. With the criteria referred to by the WMO for areas with the dominance of hills under normal conditions, the minimum density of rainfall stations is at a value of 100-250 km² per rainfall. By looking at the distribution of existing rain posts as many as 24 Rainfall Posts (PCH), it can be stated that the network of rain posts in the Citanduy watershed has met the requirements.

However, by considering the development plan for water resources infrastructure (SDA), more rain posts can be built to support the operations of existing natural resources infrastructure.

No	Stasiun Hujan	Koordinat		Luas Pengaruh Thiessen (km ²)	Kriteria WMO
		X (LS)	Y (BT)		
1	Kadipaten	7°6'57,79"	108°5'35,08"	65.435822	Memenuhi
2	Pagerageung	7°6'56,96"	108°9'37,38"	114.017348	Memenuhi
3	Cihonje	7°11'32,17"	108°11'8,46"	137.804749	Memenuhi
4	Cigaleuh	7°15'5,60"	108°7'53,76"	79.29052	Memenuhi
5	Cikasasah	7°18'16,02"	108°7'16,07"	32.816259	Memenuhi
6	Cineam	7°24'31,74"	108°21'34,19"	200.795635	Memenuhi
7	Panjalu	7° 8'10,36"	108°16'9,54"	157.913959	Memenuhi
8	Panawangan	7° 7'37,78"	108°21'58,76"	159.454057	Memenuhi
9	Kawali	7°11'13,21"	108°22'11,31"	152.204703	Memenuhi
10	Subang	7° 8'51,27"	108°32'35,72"	141.430003	Memenuhi
11	Janggala	7°23'35,97"	108°25'31,26"	135.994094	Memenuhi
12	Rancah	7°11'47,34"	108°30'27,00"	193.464141	Memenuhi
13	Sidamulih	7°28'20,74"	108°28'57,27"	165.814694	Memenuhi
14	Gunungputri	7°25'45,58"	108°30'56,90"	131.175631	Memenuhi
15	Langensari	7°22'1,44"	108°37'34,53"	151.260232	Memenuhi
16	Padaringan	7°25'20,94"	108°36'32,31"	138.787497	Memenuhi
17	Ujungbarang	7°13'18,50"	108°47'7,96"	114.872087	Memenuhi
18	Cimanggu	7°21'18,36"	108°50'22,97"	251.337725	Memenuhi
19	Majenang	7°17'51,12"	108°45'52,13"	158.05888	Memenuhi
20	Cibariwal	7°18'16,45"	108°22'23,57"	243.149092	Memenuhi
21	Cisayong	7°15'34,57"	108°8'44,55"	98.133393	Memenuhi
22	Padaherang	7°32'26,62"	108°42'1,81"	244.039996	Memenuhi
23	Dayeuhluhur	7°15'32,36"	108°37'14,1"	243.001087	Memenuhi
24	Manganti	7°26'54,36"	108°43'7,69"	146.413671	Memenuhi
		TOTAL LUAS DAS		3,656.665	

Figure 1. Analysis of Rainfall Post Network with WMO Method on the Extent of Influence of PCH (Thiessen's Polygon)
Source: by Researcher



Figure 2. Polygon Thiessen Rainfall Post (PCH) in the Citanduy watershed

Analysis of the Rainfall Post network using the Kagan Method

A total of 24 PCH in a period of 10 years, namely 2012 – 2021 used in this study, there was no blank data. Data consistency tests have been carried out using *the Rescaled Adjusted Partial Sums* (RAPS) method, it was obtained that the data of 24 PCH is consistent.

The purpose of the consistency test in the rationalization of rainfall posts is:

- Ensure that the rainfall data used for analysis is consistent and reliable.
- Helps in evaluating the reliability of the model to provide accurate estimates, which can help in the planning and management of water resources.
- Ensure that the rainfall post chosen for further rationalization or analysis is one that provides consistent and representative data. It helps in the selection of the optimal location for infrastructure planning.
- Through rainfall data consistency testing, rainfall post rationalization research can gain a better understanding of the quality of the data used, improving the accuracy of predictions.

The kagan method is a method that uses elements of correlation of monthly rainfall data and the distance between rainfall posts. The correlation coefficient in Kagan's analysis was carried out using monthly rainfall data at each rainfall post. The purpose of this calculation is to find out the correlation relationship between rainfall posts. Meanwhile, the distance between rainfall posts is measured from one post to another and vice versa. The purpose of this calculation is to find out the distance between rainfall posts in the Citanduy watershed. The results of the correlation calculation between posts for monthly rainfall and their distances are shown in the following figure:

	KADIPATEN	PAGERAGEUNG	CHONJE	PANJALU	SUBANG	CIGALEUH	CISAYONG	CIKASASAH	CINEAM	PANAWANGAN	KAWALI	LANGENSARI	GUNUNGPUTRI	SIDAMULIH	UJUNGBARANG	MAJENANG	CIMANGGU	PADAHARANG	MANGANTI	DAYEULUHUR	JANGGALA	PADARINGAN	RANCAH	CIBARIWAL
Kadipaten	0.0																							
Pagerageung	7.5	0.0																						
Chonje	13.3	8.9	0.0																					
Panjalu	19.7	12.3	11.2	0.0																				
Subang	50.2	42.7	40.0	30.5	0.0																			
Cigaleuh	15.7	15.4	8.9	20.0	47.2	0.0																		
Cisayong	17.0	16.1	8.7	19.4	45.9	1.8	0.0																	
Cikasasah	21.2	21.4	14.4	24.9	50.0	6.0	5.7	0.0																
Cineam	44.0	39.4	30.9	31.9	35.5	30.8	29.0	28.9	0.0															
Panawangan	30.4	22.9	21.3	10.8	19.8	29.5	28.6	33.6	31.3	0.0														
Kawali	31.7	24.6	20.5	12.5	19.8	27.4	26.2	30.6	24.7	6.7	0.0													
Langensari	65.5	58.8	52.7	47.2	26.1	56.5	54.7	56.6	30.0	39.3	34.8	0.0												
Gunungputri	58.5	52.7	45.2	42.6	31.5	47.0	45.2	46.0	17.5	37.5	31.4	14.1	0.0											
Sidamulih	58.7	53.4	45.4	44.2	36.7	46.1	44.3	44.3	15.4	40.5	34.1	19.8	6.0	0.0										
Ujungbarang	77.8	70.5	66.7	58.2	28.2	72.7	71.2	74.4	51.7	47.8	46.4	24.0	37.8	43.7	0.0									
Majenang	105.5	94.9	91.0	77.8	34.8	99.5	97.2	101.1	63.6	62.6	62.0	21.7	39.1	44.3	3.3	0.0								
Cimanggu	87.1	80.0	74.9	67.9	40.2	79.5	77.9	80.1	53.7	58.4	55.5	23.8	36.9	41.8	16.0	10.5	0.0							
Padaherang	82.4	76.4	69.1	65.7	47.1	70.9	69.1	69.5	40.6	59.1	53.8	21.0	24.0	25.4	36.7	27.9	25.8	0.0						
Manganti	78.7	72.2	65.7	60.8	38.7	68.8	67.1	68.3	40.2	53.0	48.5	13.7	22.7	26.4	26.3	17.5	17.0	10.5	0.0					
Dayeuluhur	60.7	53.6	48.9	41.4	15.1	54.3	52.8	55.7	33.5	31.8	29.0	12.0	22.2	28.2	18.8	16.6	26.6	32.5	23.7	0.0				
Janggala	48.1	42.6	34.8	33.4	30.3	36.2	34.4	35.2	7.5	30.3	23.7	22.5	10.8	10.9	44.3	39.2	46.2	34.7	33.2	26.3	0.0			
Padaringan	66.7	60.4	53.5	49.4	31.4	56.4	54.6	55.8	27.8	42.5	37.3	6.5	10.4	15.1	29.7	22.2	26.7	16.6	12.5	18.2	20.7	0.0		
Rancah	46.9	39.6	35.8	27.3	6.7	42.2	40.8	44.6	28.8	17.5	15.3	23.1	25.9	30.8	31.0	30.7	40.9	43.9	36.5	14.4	23.7	27.5	0.0	
Cibariwal	37.5	31.6	24.3	22.0	25.7	27.5	25.8	28.0	11.7	19.7	13.1	29.0	21.1	22.3	46.7	43.5	52.1	44.9	41.6	28.0	11.4	29.3	19.2	0.0

Figure 3. Distance Between Rainfall Posts.

Source: Calculation Results

Pos Curah Hujan		KADIPATEN	PAGERAGEUNG	CHONJE	PANJALU	SUBANG	CIGALEUH	CISAYONG	CIKASASAH	CINEAM	PANAWANGAN	KAWALI	LANGENSARI	GUNUNGPUTRI	SIDAMULIH	UJUNGBARANG	MAJENANG	CIMANGGU	PADAHERANG	MANGANTI	DAYEHLUHUR	JANGGALA	PADARINGAN	RANCAH	CIBARWAL
1	Kadipaten	1.0000																							
2	Pagerageung	0.8578	1.0000																						
3	Chonje	0.7728	0.7641	1.0000																					
4	Panjalu	0.6812	0.6638	0.7866	1.0000																				
5	Subang	0.7422	0.7292	0.5943	0.6300	1.0000																			
6	Cigaleuh	0.5006	0.4518	0.5990	0.5933	0.5036	1.0000																		
7	Cisayong	0.6698	0.7302	0.6125	0.6577	0.7903	0.5384	1.0000																	
8	Cikasasah	0.5312	0.6068	0.6529	0.7346	0.6545	0.5229	0.7060	1.0000																
9	Cineam	0.6107	0.6349	0.5853	0.5991	0.6213	0.3864	0.6394	0.5348	1.0000															
10	Panawangan	0.7871	0.8031	0.7329	0.7325	0.7437	0.6076	0.7363	0.6824	0.6477	1.0000														
11	Kawali	0.6696	0.6760	0.6737	0.7085	0.6814	0.4734	0.7118	0.6056	0.6074	0.6902	1.0000													
12	Langensari	0.5374	0.5762	0.3968	0.3379	0.5271	0.2143	0.5304	0.2718	0.6214	0.4767	0.4466	1.0000												
13	Gunungputri	0.6059	0.6660	0.6240	0.5929	0.6492	0.4266	0.7336	0.5781	0.7939	0.6800	0.6206	0.6153	1.0000											
14	Sidamulih	0.5566	0.6548	0.5759	0.6524	0.5889	0.4493	0.7092	0.5770	0.7729	0.7367	0.6102	0.4928	0.8134	1.0000										
15	Ujungbarang	0.5518	0.6007	0.4835	0.5127	0.6657	0.4238	0.6939	0.4880	0.5928	0.6308	0.5460	0.4830	0.6785	0.5925	1.0000									
16	Majenang	0.4932	0.5977	0.4942	0.5380	0.6394	0.4709	0.7354	0.4437	0.6605	0.6621	0.5962	0.4939	0.6486	0.6930	0.6709	1.0000								
17	Cimanggu	0.5857	0.6233	0.5165	0.4987	0.5131	0.3374	0.5703	0.3299	0.4851	0.5460	0.4627	0.4872	0.5783	0.4837	0.4741	0.5779	1.0000							
18	Padaherang	0.3913	0.5662	0.4978	0.4652	0.4637	0.3523	0.5882	0.5080	0.6025	0.5751	0.4905	0.4631	0.6974	0.6928	0.4168	0.5455	0.4322	1.0000						
19	Manganti	0.5932	0.6991	0.5914	0.5505	0.5893	0.4106	0.7297	0.5446	0.6862	0.6506	0.6105	0.6523	0.7386	0.7097	0.5538	0.6771	0.6258	0.7451	1.0000					
20	Dayeuhluhur	0.7087	0.6762	0.6273	0.6569	0.7583	0.4791	0.7727	0.6397	0.6155	0.7171	0.6196	0.5911	0.6628	0.5705	0.6150	0.6613	0.6183	0.5617	0.7303	1.0000				
21	Janggala	0.6567	0.6888	0.6433	0.6386	0.6145	0.3853	0.6705	0.5452	0.8027	0.6531	0.6549	0.5288	0.8494	0.8307	0.6251	0.7019	0.5196	0.6479	0.6949	0.6281	1.0000			
22	Padaringan	0.5681	0.6329	0.5746	0.5964	0.6345	0.4386	0.7244	0.5256	0.7763	0.6743	0.6593	0.6464	0.8035	0.7726	0.6327	0.7235	0.5529	0.7747	0.8089	0.6420	0.7567	1.0000		
23	Rancah	0.6490	0.6680	0.5836	0.6394	0.7959	0.4496	0.7612	0.6043	0.6341	0.7143	0.6988	0.5407	0.6235	0.5575	0.6509	0.7008	0.5799	0.5278	0.6912	0.7982	0.6081	0.6876	1.0000	
24	Cibariwal	0.8023	0.8105	0.7589	0.7318	0.7162	0.6103	0.7293	0.6850	0.6616	0.9633	0.7164	0.4713	0.6967	0.6950	0.6914	0.6576	0.5468	0.5612	0.6490	0.7231	0.6803	0.6616	0.7274	1.0000

Figure 4. Monthly Data Correlations
Source: Calculation Results

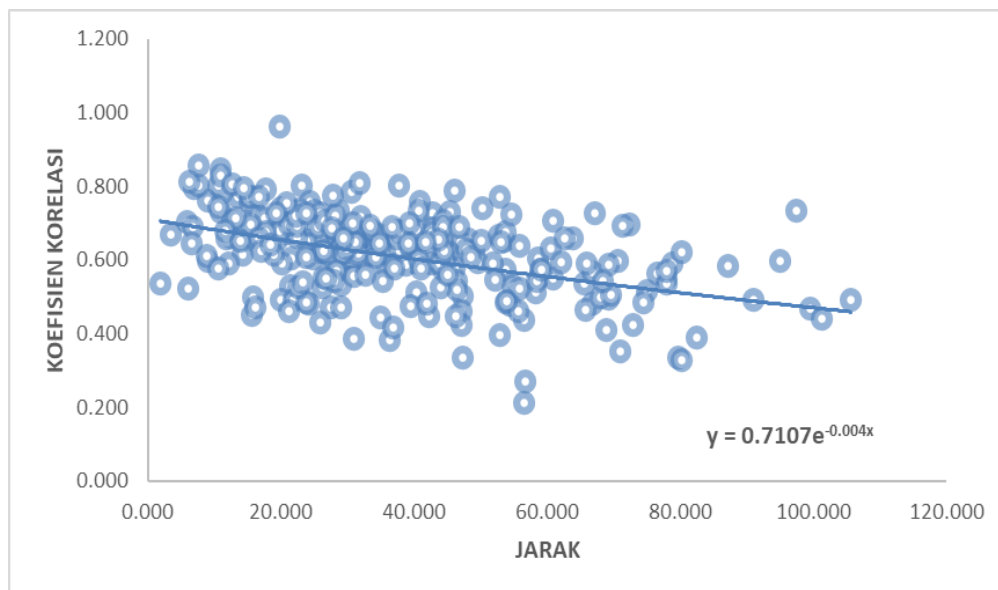


Figure 5. Graph of the Relationship between Correlation Coefficient and Distance Between Rainfall Posts of the Citanduy Watershed

The graph of the relationship between the correlation coefficient and the distance between rainfall posts means that the closer the distance to the rainfall post, the smaller the diversity of rainfall data at the post. Based on Figure 6.1, it can be seen that the relationship is quite widespread, this is due to the topographic characteristics in the study area that tend to be hilly so that it has quite diverse rainfall characteristics, the pattern of correlation coefficient and distance between rainfall posts can be known with $y = 0.7107e^{-0.004x}$

The next stage is to determine the number of rainfall posts that represent the study area by considering the value of the relative leveling error. Here is a resume table of relative alignment error values along with the possible distance and number of posts.

N	Z1	Z3	L	EN	N	Z1	Z3	L	EN
1	9.08	6.68	64.70	30521.44	31	1.52	5.19	11.62	188.60
2	6.27	6.19	45.75	10856.07	32	1.49	5.18	11.44	180.05
3	5.06	5.96	37.36	5936.50	33	1.47	5.18	11.26	172.13
4	4.35	5.81	32.35	3870.76	34	1.45	5.17	11.10	164.79
5	3.88	5.72	28.94	2779.08	35	1.43	5.17	10.94	157.96
6	3.53	5.64	26.41	2120.57	36	1.41	5.16	10.78	151.60
7	3.25	5.58	24.46	1687.51	37	1.39	5.16	10.64	145.65
8	3.04	5.54	22.88	1384.80	38	1.37	5.15	10.50	140.10
9	2.86	5.50	21.57	1163.36	39	1.35	5.15	10.36	134.89
10	2.71	5.46	20.46	995.58	40	1.33	5.14	10.23	130.00
11	2.58	5.43	19.51	864.83	41	1.32	5.14	10.10	125.41
12	2.47	5.41	18.68	760.59	42	1.30	5.13	9.98	121.09
13	2.37	5.39	17.95	675.88	43	1.29	5.13	9.87	117.01
14	2.28	5.37	17.29	605.93	44	1.27	5.13	9.75	113.16
15	2.20	5.35	16.71	547.36	45	1.26	5.12	9.65	109.52
16	2.13	5.33	16.18	497.74	46	1.24	5.12	9.54	106.07
17	2.06	5.32	15.69	455.25	47	1.23	5.12	9.44	102.80
18	2.00	5.30	15.25	418.54	48	1.22	5.11	9.34	99.71
19	1.95	5.29	14.84	386.56	49	1.20	5.11	9.24	96.76
20	1.90	5.28	14.47	358.50	50	1.19	5.11	9.15	93.96
21	1.85	5.27	14.12	333.71	51	1.18	5.10	9.06	91.30
22	1.81	5.26	13.79	311.68	52	1.17	5.10	8.97	88.76
23	1.77	5.25	13.49	292.00	53	1.16	5.10	8.89	86.34
24	1.73	5.24	13.21	274.33					
25	1.69	5.23	12.94	258.40					
26	1.66	5.22	12.69	243.97	99	0.84	5.02	6.50	35.02
27	1.63	5.21	12.45	230.85	100	0.84	5.02	6.47	34.52
28	1.60	5.21	12.23	218.88	101	0.84	5.02	6.44	34.03
29	1.57	5.20	12.02	207.92	102	0.83	5.02	6.41	33.56
30	1.54	5.19	11.81	197.86	103	0.83	5.02	6.38	33.09

Figure 6. Resume of Relative Leveling Errors, along with the Number and Distance of Rainfall Posts in the Citanduy Watershed

Resource: by Researcher

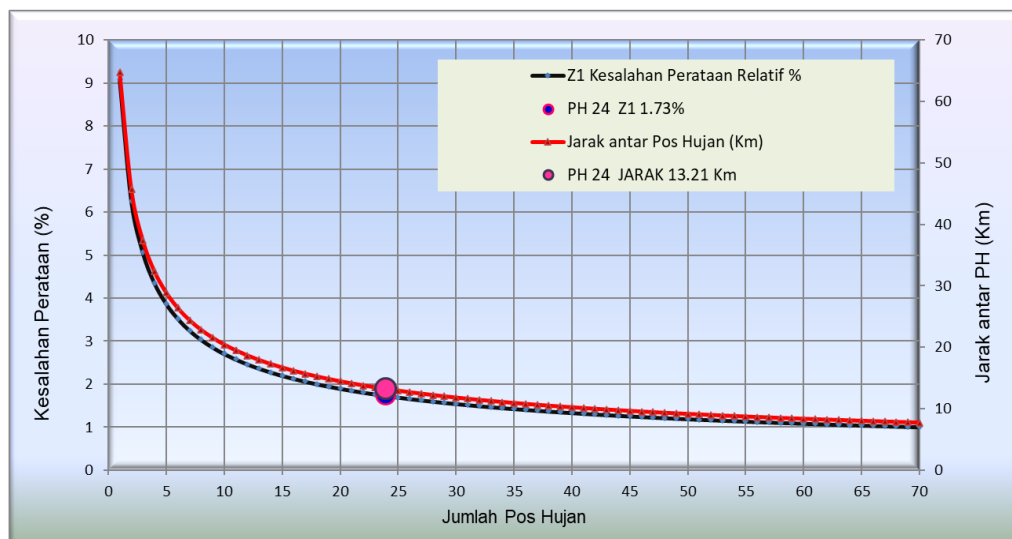


Figure 7. Graph of Relative Alignment Error Based on Distance Between Posts in the Citanduy Watershed.

Resource : by Researcher

Based on Figure 8, the relative alignment error value of 1.73% already indicates that the curve has begun to move downward, meaning that even without addition, it does not result

in a significant change in relative alignment error. The distribution map of the installation of rainfall posts from this kagan is depicted in the form of an equilateral triangle node. The kagan node point is the first step in determining the location of the optimal rainfall post. If there is an existing rainfall point at the kagan node point, then the kagan node point can be ignored. In addition, if the kagan node point is a location that does not meet the criteria for installing rainfall posts, for example, far from crowds, access to difficult and vulnerable locations, then the kagan node point can be shifted around the kagan triangle or even not used at all.

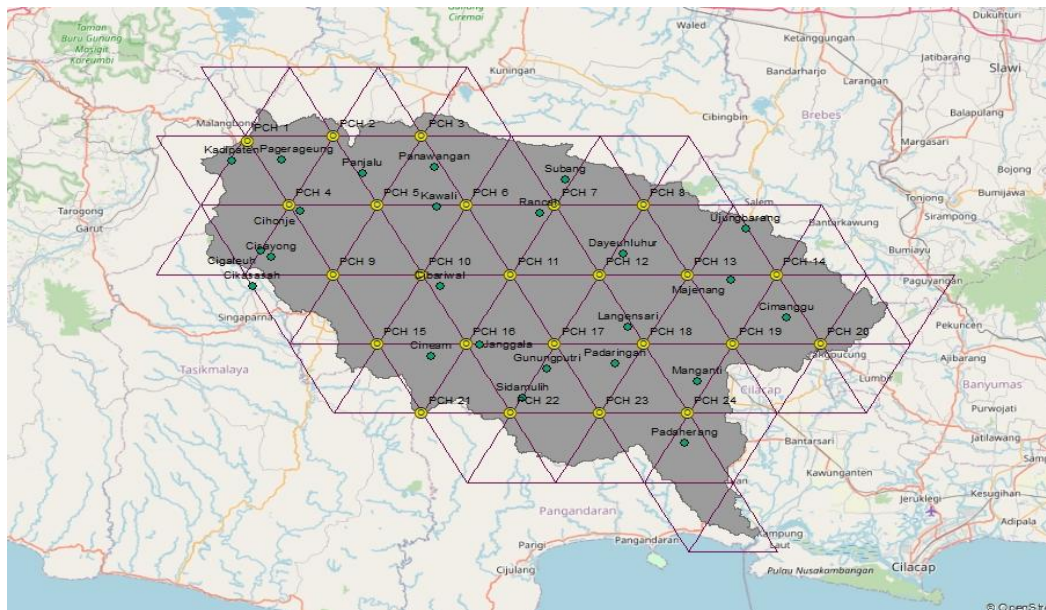


Figure 8. Map of Kagan's Net in the Citanduy Watershed

Rainfall Post Network Recommendations

Based on the results of the analysis that has been carried out and explained in Sub-Chapter 3.1.2, the results of the analysis can be recommended for 24 rainfall posts, as follows:

Table 6. Resume of the Results Of The Rationalization Analysis For Rainfall Posts In The Citanduy Watershed

No	PCH Eksisting	Information
1	Kadipaten Relokasi	ke PCH 1
2	Pagerageung Relokasi	ke PCH 2
3	Cihonje Relokasi	ke PCH 4
4	Cigaleuh	Removal
5	Cikassah	Removal
6	Cineam Relokasi	ke PCH 15
7	Panjaluh Relokasi	ke PCH 5
8	Panawangan Relokasi	ke PCH 3
9	Kawali Relokasi	ke PCH 6
10	Subang	Removal
11	Janggala Relokasi	ke PCH 16
12	Rancah Relokasi	ke PCH 7
13	Sidamulih Relokasi	ke PCH 22
14	Gunungputri Relokasi	ke PCH 17
15	Langensari Relokasi	ke PCH 18
16	Padaringan Relokasi	ke PCH 23

No	PCH Eksisting	Information
7	Ujungbarang Relokasi	ke PCH 14
18	Cimanggu Relokasi	ke PCH 20
19	Majenang Relokasi	ke PCH 13
20	Cibariwal Relokasi	ke PCH 10
21	Cisayong	Penghapusan
22	Padaherang Relokasi	ke PCH 24
23	Dayeuhluhur Relokasi	ke PCH 12
24	Manganti Relokasi	ke PCH 19

Table 7. Resume of the Results Of The Rationalization Analysis For Rainfall Posts In The Citanduy Watershed

No	Pos Curah Hujan Baru
1	PCH 8
2	PCH 9
3	PCH 11
4	PCH 21

Resource : by Researcher

Based on the results of the analysis, there are several existing PCHs that must be relocated or moved to other locations, and there are 4 existing PCHs that are recommended to be closed or no longer used, because, the PCHs are located close to other PCHs, and there are also those that are far away from the node point. In addition, of the 4 recommended closures, 4 new PCHs were obtained whose locations correspond to the node points on the Kagan Net Map in the Citanduy Watershed.

Analysis of the Rationalization of the Water Supply Post Network (PDA) in the Citanduy Watershed using the WMO Method

The determination of the minimum density for water forecasting posts based on the condition of their topographic area can be seen in Table 2.3. If you look at the area of the Citanduy watershed of 3,656.66 km², then the minimum water suspect posts that must be in the Citanduy WS are 4-12 water suspect posts. If you look at the distribution of existing water suspected posts in the watershed amounting to 33 water suspected posts, then the distribution of water suspected posts in the Citanduy watershed has been fulfilled.

Figure 8. Analysis of the Water Suspected Post Network (PDA) with the WMO Method on the area of influence of PDA (Thiessen's Polygon).

No	Pos Duga Air	Luas Pengaruh (km ²)	Kriteria WMO
1	Cirahong	293.17473	Tidak memenuhi
2	Bojongsalawe	59326298	Tidak memenuhi
3	Karangpucung	9.65618	Tidak memenuhi
4	Cipadung	18.373764	Tidak memenuhi
5	Pataruman	56.047791	Tidak memenuhi
6	Cikawung	60.19328	Tidak memenuhi
7	Gunungeupu	265.134792	Tidak memenuhi
8	Karangsani	5736864	Tidak memenuhi
9	Karangwangkal	58.006877	Tidak memenuhi
10	Tunggilis	44,030782	Tidak memenuhi
11	Kalipucang	26.737293	Tidak memenuhi

No	Pos Duga Air	Luas Pengaruh (km2)	Kriteria WMO
12	Majingklak	6.381805	Tidak memenuhi
13	Bananuka	126.973502	Tidak memenuhi
14	Cibeka	11.81526	Tidak memenuhi
15	Batununggul	6.42742	Tidak memenuhi
16	Tenjolaya	27.458211	Tidak memenuhi
17	Gimbal	21.482523	Tidak memenuhi
18	Situbatu	107.494622	Tidak memenuhi
19	Bendung	Ciputrahaji 194,391387	Tidak memenuhi
20	Bunter	106.225967	Tidak memenuhi
21	Bunar	48.703492	Tidak memenuhi
22	Cikadu	245.532765	Tidak memenuhi
23	Bebedahan	58.759927	Tidak memenuhi
24	Binangun	102.381289	Tidak memenuhi
25	Ciawitali	71009045	Tidak memenuhi
26	Kedungkuda	66.073797	Tidak memenuhi
27	Pitulasi/Panyarang	222.115027	Tidak memenuhi
28	Cukangleuleus	49,800774	Tidak memenuhi
29	Wanareja	156.717722	Tidak memenuhi
30	Cikondang	144,086608	Tidak memenuhi
	Surusunda	65.26303	Tidak memenuhi
TOTAL LUAS DAS			3,656.67



Figure 13. Polygon Thiessen Water Sump Post (PDA) in the Citanduy watershed.
Source : by Researcher

Analysis of Rationalization of the Climatology Post Network in the Citanduy Watershed with the WMO Density Method

The determination of the minimum density for climatology posts based on the conditions of their topographic area can be seen in Table 2.1. The density limit used is 300-2500 km² per climatology post, this value was chosen because the topography of the Citanduy watershed is dominated by hills. With an area of 3,656.66 km² of the Citanduy watershed, the minimum climatology posts that must exist are 1-12 climate posts. If viewed from the existing climatology posts against the minimum criteria that must be owned by the Citanduy watershed

as many as 2 posts, it can be stated that the number of climatology posts in the Citanduy watershed is in accordance with the criteria set by WMO. However, it allows the addition of posts when viewed from the distribution of existing post locations.

Table 9. Analysis of Climatological Post Network with WMO Method on the Area of Influence of Posts (Thiessen Polygon).

No	Climatology Post	Extent of influence Thiessen (km ²)	WMO Criteria
1	Pataruman	2,750.85	does not meet the
2	Majenang	905.82	fulfill

Source: by Researcher



Figure 14. Polygon Thiessen Climatology Post in the Citanduy watershed.

CONCLUSION

Based on the results of the analysis of the density rationalization of the network density of rainfall and hydro-meteorological stations, several conclusions were obtained as follows: Analysis of the density of the rainfall post network using the WMO method, all PCH as many as 24 PCH analyzed in this study meet the requirements for the area of influence of PCH with the Thiessen polygon. Analysis of the density of the rainfall post network using the Kagan method, as many as 4 existing PCHs are recommended to be closed or no longer used, because the PCH is located close to other PCHs, and there are also those that are far away from the node points, namely PCH Cigaleuh, PCH Cikasasah, PCH Subang and Pch Cisayong. While the remaining 20 PCHs need to be relocated or moved to another location according to the node point of the Kagan network map. Analysis of the density of the network of water suspected posts using the WMO method, as many as 33 PDAs in terms of number meet WMO requirements, because if based on WMO, there must be 4-12 PDAs in the Citanduy watershed. However, when viewed from the WMO area, it does not meet the requirements due to the density between PDAs. Analysis of the density of the climatology post network using the WMO method, as many as 2 climatology posts meet the requirements for the area of influence of PCH with the Thiessen polygon. However, it allows the addition of posts when viewed from the distribution of existing post locations.

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