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Research Article

Rain Station Network Analysis in the Sampean Watershed: Comparison of Variations in Data Aggregation

Entin Hidayah[1,*], Gusfan Halik[1], Minarni Nur Trilita[2]
[1]Department of Civil Engineering, University of Jember, Jl. Kalimantan No. 37 Jember, 68121, Indonesia
[2] Department of Civil Engineering, Universitas Pembangunan Nasional Veteran Jawa Timur, Surabaya, 60293, Indonesia
*Coresponding author, E-mail address : entin.teknik@unej.ac.id

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ABSTRACT

The lack of rainfall-runoff accuracy is important for some applications. The choice of data aggregation that affects the estimation results is important at the level of accuracy. Some commonly used aggregations are daily, ten days, and monthly rainfall. This study aimed to compare the results of the estimation of the effect of data aggregation and to analyze the density of the rain gauge network in the Sampean watershed. The evaluation of the rain station network is carried out through the Kagan calculation. Rainfall data are from the rainfall data records for 20 years at 33 rain gauge stations. Measurement of the performance of aggregation variations using the relationship between the correlation value of rainfall with the distance between station locations. Station network positioning is assessed from alignment errors and interpolation errors. The results showed differences in the correlation and estimation values in the variation of data aggregation.The greater interval can increase the effectiveness of deployment with minimum error. Based on Kagan's analysis, there is an uneven distribution of gauge stations in the Sampean watershed eventhough the average and interpolation error in the monthly rainfall is less than 5%. It is this inequality that causes gauge stations to be inefficient.

Keywords : Rain gauge network; correlation; Kagan; data aggregation

1. Introduction

Accurate rainfall-runoff modeling is fundamental in the planning and managing water resources such as drinking water, agriculture, industry, hydropower, and other needs. The source of the inaccuracy of the hydrological model is caused by the inappropriateness of the model structure, data input errors, and difficulties in parameter estimation (Rafiei Emam et al., 2018). This causes the accuracy of rainfall estimates to be essential and challenging (Wu et al., 2020; Xu et al., 2015). The ability of rain gauge to monitor hydrological characteristics, condition of measuring instruments, and discrepancies in the amount of rain gaugeis caused by natural factors. The mean rainfall is a source of error from the modeling input. Therefore, regional average rainfall data representing the depth of precipitation in the watershed are needed to model rainfall flows (Razmkhah et al., 2016). In addition, the data input factor that affected the performance of the discharge estimate is the lack of density and distribution of the rain gauge network (Bárdossy & Das, 2008). Therefore, it is necessary to rationalize the density of the station network to find out how many gauge stations are ideal, effective, and representative according to regional conditions.

Regional mean rainfall is mostly obtained from sparsely located rainfall measurement points, and several studies have shown that this results in large area uncertainty of daily time intervals (Ndiritu & Mkhize, 2017). However, water resources management does not always use daily time intervals. As well as assessing water availability for various purposes using ten days, and even monthly data inputs and river flow simulations are an important component of this assessment. Rainfall data with minimum error in data input is one of the determining components in subsequent calculations, such as modeling and prediction.There are some methods to minimize rainfall estimation error in the spatial correlation network between measuring stations: the p-median model (Wang et al., 2020), the Kriging method (Adhikary et al., 2015; Fattoruso et al., 2020), Remote Sensing Data (Morsy et al., 2021), Multi-Criteria Decision Analysis (Tekleyohannes et al., 2021),and Kagan method (Bakhtiari et al., 2021; Nandiasa et al., 2020; Nandiasa & Purwaning, 2021; Wu et al., 2020).

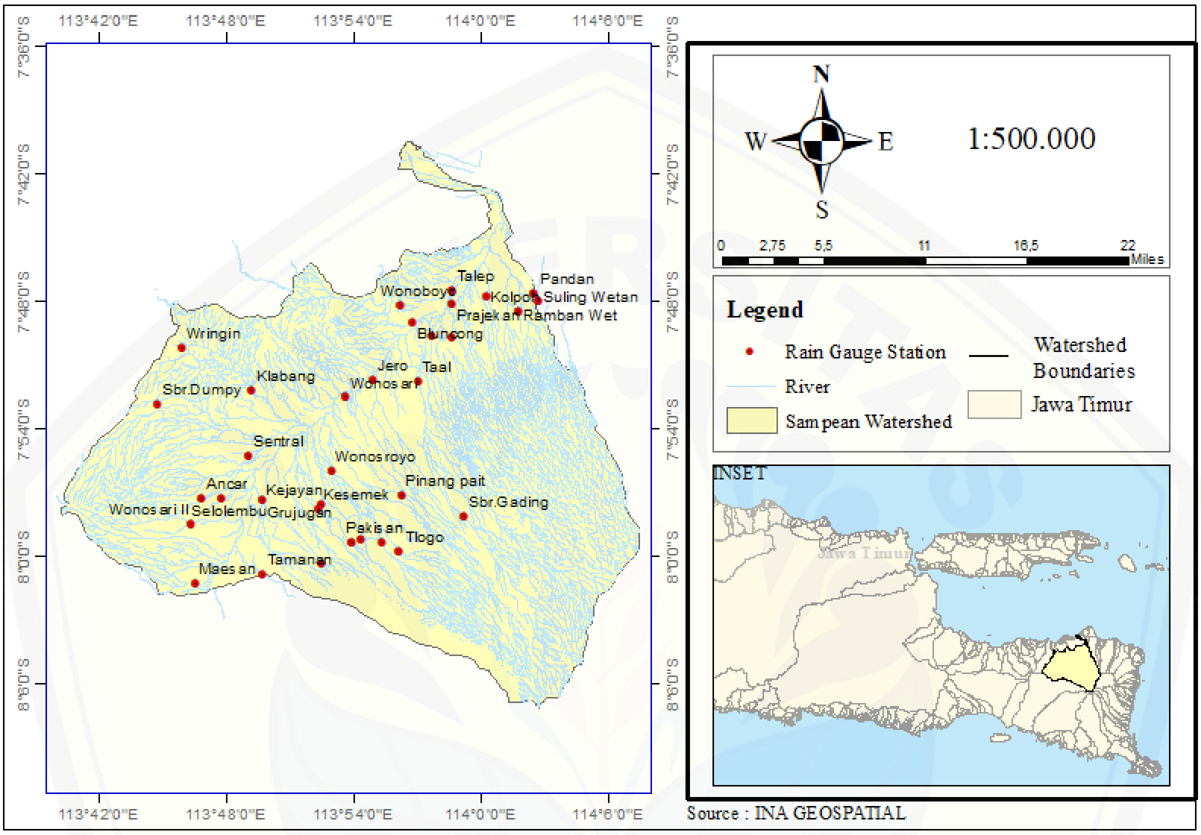
Kagan's (1972) approach can minimize rainfall estimation errors in the spatial correlation network between measuring stations. The measurement of the network density of each watershed used the Kagan method to determine the placement pattern and the number of gauge stations.This method can provide results in the form of coordinate points that become recommendations for rain station construction locations based on the Kagan triangles (Renaldhy et al., 2021). The calculation of network density using the Kagan method begins by determining the correlation coefficient between gauge stations in the month that has high rainfall intensity (wet season). Therefore, correlation analysis to evaluate the density of the field rain gauge network on variations in the aggregation of temporal rainfall data are required to be explored.

Some research applied the Kagan method to design a rain gauge station network in Iran (Bakhtiari et al., 2021; Nazaripour et al., 2017). Optimization of rain gauge networks in the Jinjiang Basin concluded that the Kagan method improves the optimization level of rain gauge networks and provides a reference for such an optimization (Wu et al., 2020). Analysis of placement pattern and number of rain stations based on the equation of Kagan Rodda in Ciliwung Watershed (Nandiasa et al., 2020), evaluating database water resources in the Kabupaten Banyuwangi (Erwanto et al., 2016), assessing rain gauge rationalization by considering the criteria in determining the location of rain gauges (Renaldhy et al., 2021). Next, the research on the rationalization of the density of river basin gauge stations has been carried out based on daily rainfall data and variations in error rates (Abdaa et al., 2021). The results showed that the daily rainfall correlation between locations was relatively small. This was a result of the observed daily rainfall.

The selection of aggregated data can change the conclusions of an analysis result (Siegmund et al., 2020). Temporal aggregation is a process that varies from fine to coarse intervals. Temporal aggregation was necessary for various reasons, including closing save in data, data summary, and data size reduction for convenience processing (Cheng & Adepeju, 2014; Falconi et al., 2020). The effect of data aggregation on dispersion estimates in count data has been discussed that dispersion estimates can increase strongly after aggregation, an effect which we will demonstrate and quantify explicitly for some scenarios (Errington et al., 2021). The increase in dispersion estimates implies an inflation of the parameter standard errors, which, however, can be shown to serve a corrective purpose by comparison with random effect models. Several previous studies in evaluating the determination of the rain station network did not pay attention to variations in aggregated rain data. Based on the advantages of the variety of data aggregation, this study aims to compare the variety of data aggregation in the rain gauge station network analysis and evaluate the rain gauge network in the Sampean watershed.

2. Study Area

This research was conducted in the Sampean watershed with the upstream part located in Bondowoso Regency, while the downstream part was in Situbondo Regency. Geographically, the Sampean watershed is located at 7°41'30,'S-8°7'0" S and 113°40'30-14°6'0" E. The highest elevation in this watershed is Sumber Gading station 650,4 masl, and the lowest elevation is Kolpoh Station 98,5 masl. Sampean watershed has an area of 1244.1265 km^2 with 33 rain gauge stations. Sampean watershed map is shown in Figure 1.



Source : INA GEOSPATIAL

Figure 1. Sampean Watershed Mapping

This study used secondary data on daily, ten days, and monthly rainfall in the Sampean watershed from 2000-2020 with 33 rain gauge stations obtained from the UPT SDA (natural resources office) Sampean. Gauge stations in the Sampean watershed are listed in Table 1.

Table 1. Position of the gauge station network in the Sampean watershed

No	Gauge Station	Village	Location
1.	Ancar	Jetis	113,78083 E and -7,95444 S
2.	Bluncong	Pandak	113,94608 E and -7,81709 S
3.	Clangap	Alas Sumur	113,87505 E and -8,00584 S
4.	Glendengan	Botolinggo	113,97695 E and -7,82848 S
5.	Grujugan	Grujugan Lor	113,82877 E and -7,95611 S
6.	Jero	Kalitapen	113,91541 E and -7,86214 S
7.	Kejayan	Kejayan	113,87491 E and -7,96008 S
8.	Kesemek	Kesemek	113,87233 E and -7,96270 S
9.	Klabang	Klabang	113,82026 E and -7,87030 S
10.	Kolpoh	Sempol	114,00470 E and -7,79641 S
11.	Maesan	Maesan	113,77541 E and -8,02102 S
12.	Maskuning	Maskuningwetan	113,90613 E and -7,98664 S

No	Gauge Station	Village	Location
13.	Pakisan	Pakisan	113,92199 E and -7,98934 S
14.	Pandan	Suling wetan	114,04222 E and -7,79416 S
15.	Pinang pait	Pecalongan	113,93784 E and-7,95205 S
16.	Prajekan	Walidono	113,97685 E and-7,80240 S
17.	Pringduri	Besuk	113,96203 E and-7,82774 S
18.	Ramban Wet	Rambankulon	114,03000 E and-7,80823 S
19.	Sbr.Dumpyong	Sumber Dumpyong	113,74631 E and-7,88113 S
20.	Sbr.Gading	Sumber Gading	113,98749 E and-7,96885 S
21.	Selolembu	Jeruksoksok	113,79663 E and -7,95466 S
22.	Sentral	Badean	113,81765 E and -7,92166 S
23.	Sukokerto	Maskuningwetan	113,89830 E and-7,98914 S
24.	Suling Wetan	Suling wetan	114,04582 E and-7,79968 S
25.	Taal	Taal	113,95073 E and -7,86261 S
26.	Talep	Walidono	113,97729 E and -7,79188 S
27.	Tamanan	Tamanan	113,82802 E and-8,01390 S
28.	Tlogo	Tlogosari	113,93613 E and-7,99645 S
29.	Wonoboyo	Leprak	113,93638 E and-7,80305 S
30.	Wonosari	Wonosari	113,89383 E and-7,87477 S
31.	Wonosari II	Wonosari	113,77289 E and-7,97471 S
32.	Wonosroyo	Tumpeng	113,88268 E and -7,93356 S
33.	Wringin	Jatisari	113,76481 E and-7,83623 S

3. Methods

Based on the same data source and time, this study's grouping rainfall data consisted of three types: daily, ten daily, and monthly. The advantages of this aggregation variation can be seen through the graph of the relationship between the rainfall correlation value and the distance between the locations of the gauge stations. Furthermore, the analysis of the distribution of gauge stations was carried out using the Kagan method. The advantages of a station network can be seen through alignment errors and interpolation errors.

3.1 Spatial rainfall correlation

Spatial correlation of rain data was used for precise distribution of rainfall data, such as modeling of rainfall flows etc. The correlation structure inherent in the data can be determined based on historical rainfall data for different durations. The rainfall correlation coefficient between locations can be calculated using the Eq. (1) (Nazaripour et al., 2017):

$$r(d) = r(0)e^{\frac{-d}{d_0}} \tag{1}$$

Where $r(d)$ is the rainfall correlation among two stations with distance d, d_0 is reference distance, $r(0)$ is correlation coefficient when zero distance.

3.2 Station Network Density

Several studies have used the Kagan method to optimize the density of the rain station network (Nandiasa & Purwaning, 2021; Nazaripour et al., 2017). The Kagan network produces several outputs, namely the relationship between the number of gauge stations needed and the level of alignment error and interpolation error, producing the optimal number and pattern of placement of gauge stations. If there are more existing gauge stations than the results of Kagan's calculation, not all gauge stations are used in the subsequent analysis, and gauge stations can be reduced. The selection is made by selecting the gauge station closest to the node that represents the Kagan network. If there are fewer rain stations than Kagan's calculation, it is necessary to add more gauge stations. However, in this study, the measure of the Kagan network is only used to determine the optimal number and placement of gauge stations as the basis for advanced analysis (Erwanto et al., 2016). Rain gauge stations that meet both number and distribution requirements are adjusted to the World Meteorological Organization (WMO), which provides guidelines for minimum network density in several areas. Two essential things in planning the network are the number of stations required and the location of the gauge stations (Abdaa et al., 2021), which are listed in Table 2.

Table 2. Minimum densities of station (area in km^2 per station) based on WMO

Physiographic Unit	Densities of station
Coastal	900
Mountains	250
Interior plains	575
Hilly/undulating	575
Small island	25
Polar /Arid	10.000

Source: Rodda (2011)

3.3 Kagan-Rodda method

Evaluation of the distribution of gauge stations is one way to obtain an efficient hydrological network, which effectively represents hydrological conditions in the river area. A simple way to find out the gauge station network was proposed by Kagan (1967), who has the advantage of determining the need for the number of stations and their placement pattern. With this method, the desired error in the network calculation can be determined, and the optimal number and placement pattern of gauge stations can be obtained. The determination of the measurement network proposed by Kagan (1967) used statistical analysis by relating network density to interpolation errors and smoothing errors (Bakhtiari et al., 2021). Eq. 2 –6 used are as follows:

$$P_1 = C_v\sqrt{\frac{1-r(0)+0{,}23\frac{\sqrt{A}}{d_0\sqrt{N}}}{N}} \tag{2}$$

$$P_2 = C_v\sqrt{\frac{1}{3}|1-r(0)|+0{,}52\frac{r(0)}{d_0}\sqrt{\frac{A}{N}}} \tag{3}$$

$$L = 1{,}07\sqrt{\frac{A}{N}} \tag{4}$$

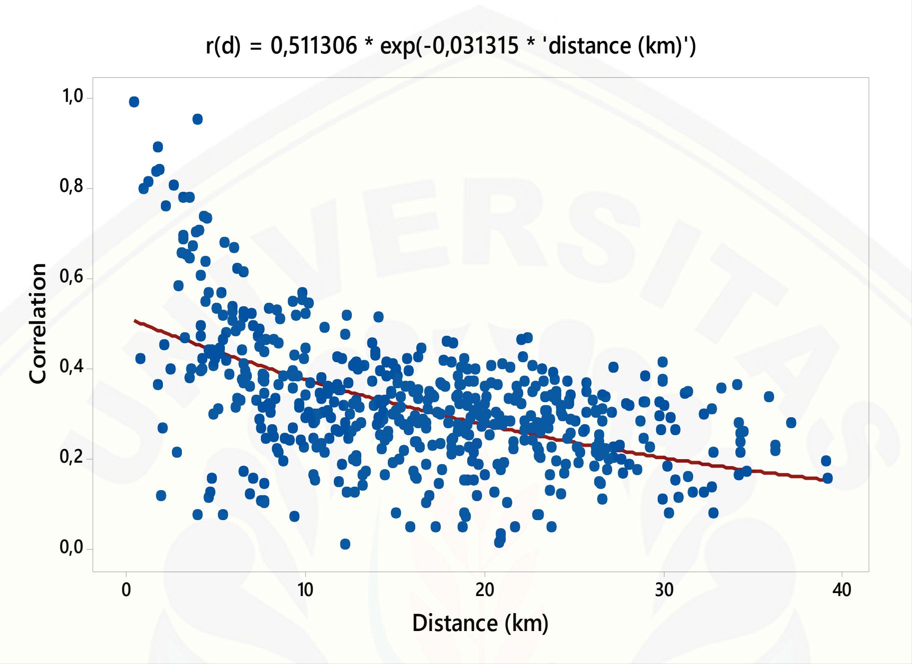
$$C_v = \frac{S}{\bar{x}} \tag{5}$$

Where P_1 is alignment error (%), P_2 is interpolation error (%), C_v is coefficient of variation, A is the watershed area (km^2), L is the distance between stations in an equilateral triangle, S is the standard deviation of rainfall in the Sampean watershed, and $\bar{x}$ is the average calculated rainfall in the Sampean watershed.

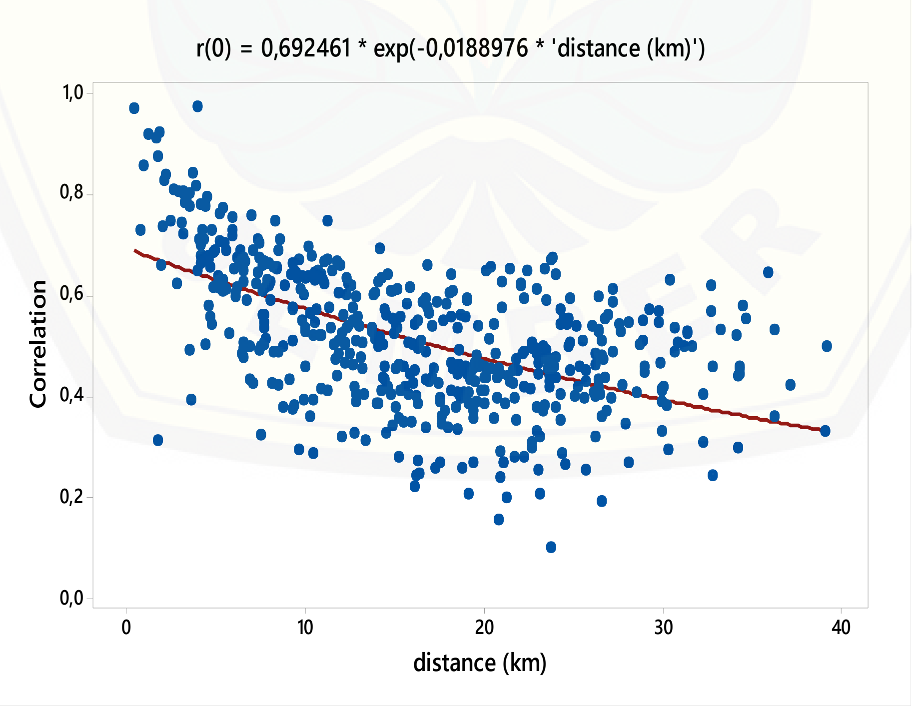
4. Results and Discussion

Before performing the Kagan analysis, preprocessing the data into daily, ten days, and monthly rainfall during the wet month was carried out. The wet season in Indonesia occurs between October and March. The division of rainfall data into several types according to different time intervals is called the data aggregation process (Cheng & Adepeju, 2014). The relationship between the distance between stations and the correlation is illustrated through a scatter diagram which is then formed by an exponential function as shown in Figure 2.

(a)



(b)



(c)

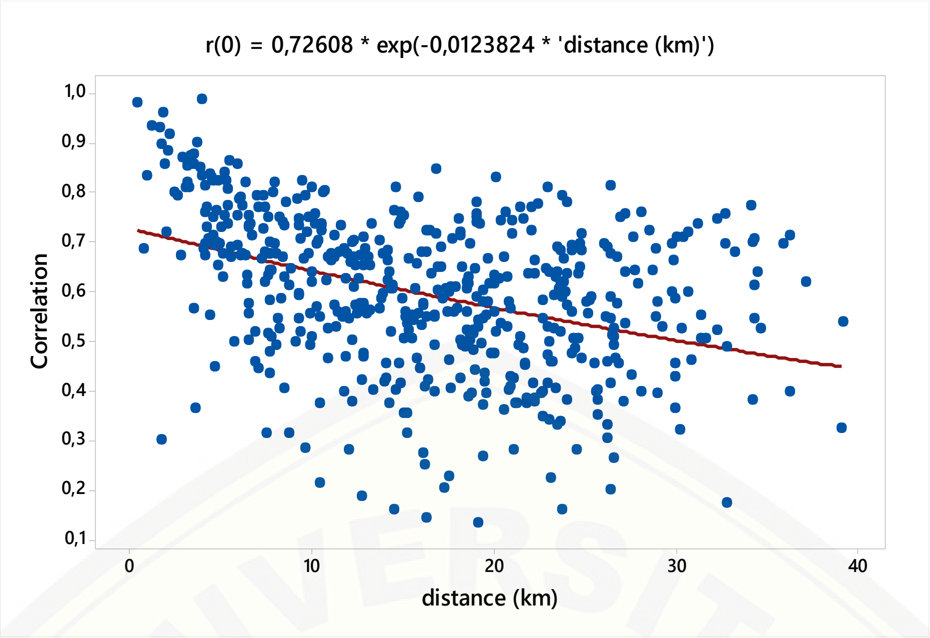


Figure 2. Correlation of rainfall data aggregation to the distance of gauge stations (a) daily (b) ten days (c) monthly

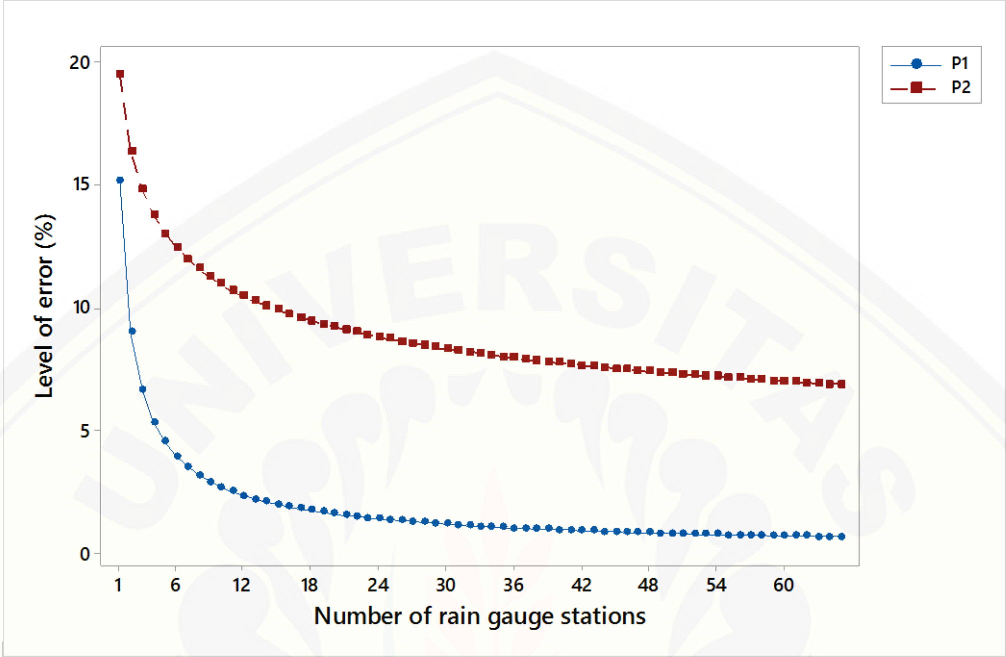
Figure 2 shows that the correlation coefficient decreases sharply in daily time intervals case. The three images also show that there is a very strong correlation of rainfall at close distances.The correlation value decreases to near zero as the distance increases. In addition, it can be seen that the scatter chart of data aggregation from daily to ten days and monthly levels are increasing. At the same time, it can also be seen that in general the slope of the scatter points becomes flattered when aggregating with longer time intervals. This indicates that the correlation distance for the monthly interval is stronger than for the ten-day and daily rainfall intervals.That is, a certain time interval can affect the results of basic estimates such as correlation and autocorrelation (Cheng & Adepeju, 2014; Mair & Fares, 2011). Therefore, it is necessary to evaluate the placement pattern of rain stations.

The analysis of the placement pattern of gauge stations using the Kagan method is used to obtain the alignment errors and interpolation errors are listed in Table 3 and visualized in Figure 3. The values of $r(0)$ andd_0 are obtained through the exponential function of the correlation shown in Figure 2. Figure 3 shows that the alignment and interpolation errors in the three aggregation decrease exponentially with the increase in the number of stations. Based on the existing rain gauge network, the relative mean error of observed rainfalls is less than 5% in the study area. Nevertheless, the spatial interpolation error is a more important error criterion to achieve a network design (Nazaripour et al., 2017). The interpolation error is quite large for daily rainfall, exceeding 5%. For ten days and monthly rainfall have almost the same error graph. However, the percentage of error in the 10-day rainfall is higher than the monthly rainfall. It can be seen from the percentage of errors at 1 to 5 gauges.

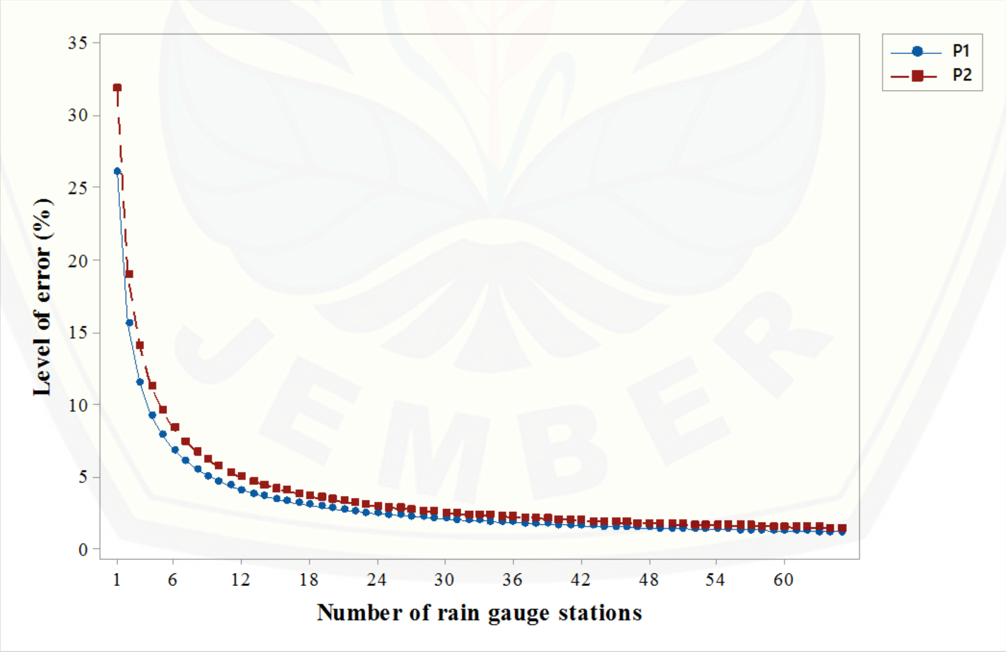
Error analysis of daily rainfall shows that the alignment error less than 5% occurs when the number of gauge stations is 5, but the interpolation error is still quite high. Even when there are 33 stations in the Sampean watershed, the interpolation error still exceeds 5%. If there are 15 gauge stations, the percentage of interpolation error is less than 10%. In contrast to the daily data, the 10 daily and monthly rainfall data managed to get an average and theinterpolation error rate of less than 5%. For 10 days of rainfall, there are 10 to 12 ideal gauge stations with an error rate of less than 5%, and a network density of less than 250 km^2/station for the mountainous region category. While the monthly data between 7-12 stations are optimal for the hydrological needs of the Sampean watershed.

As we know the construction of the station certainly requires time and money, therefore it would be better and more efficient if the gauge station was built as little as possible but could represent the hydrological conditions of the area. In this case, it can be seen that monthly rainfall produces gauge stations that are more efficient than 10 days rainfall and daily rainfall because 7 stations in the Sampean watershed have been able to meet WMO recommendations for mountainous areas of less than 250 km^2/station with an error rate of less than 5%.

(a)



(b)



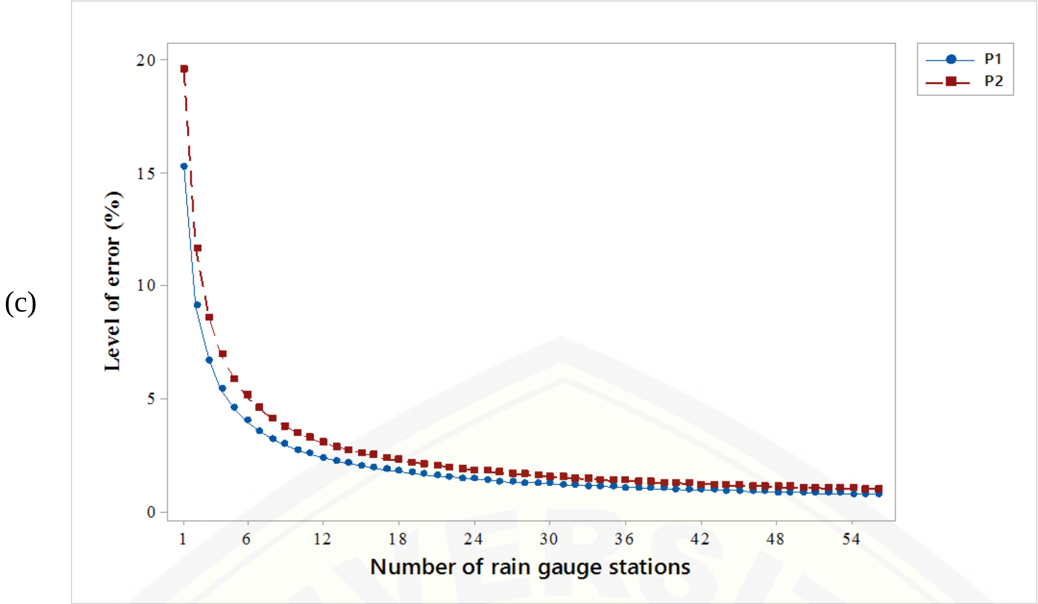


Figure 3. Graph of smoothing and interpolation errors for many gauge stations (a) daily (b) ten days (c) monthly

Based on Kagan's analysis and WMO recommendations regarding network density, the ideal Sampean watershed as a mountain area (Arifianto, 2019) has 7 rain stations with a distance between stations of 14,263 km. That is, there are 26 out of 33 that should not be needed. The location of the rain station based on the Kagan method in Figure 4 is shown by the vertices of an equilateral triangle. Several nodes are still empty or far from the rain station. Characteristically, the empty node area is mountainous, therefore a rain gauge station difficult be built. Sampean watershed has too many stations. Some stations are located nearby, such as Kejayan and Kesemek Stations, which are only less than 1 km away. This causes the gauge station position to be ineffective, therefore it needs to be reviewed. The same condition related to too many rain station networks in the watershed also occurs in the Kedunglarangan watershed with 16 rain gauges (Prawati & Dermawan, 2018) and in arid & semi-arid regions of Iran (Nazaripour et al., 2017).

Table 3. Analysis of gauge station position errors based on daily, ten days, monthly

No	C_v	$r(0)$	d_0	$P_1(\%)$	$P_2(\%)$	L(km)	Network Density (km^2/station)
Daily rainfall							
1	0.59	0.73	0.012	15.14	19.48	37.74	1244.14
2				9.00	16.38	26.69	622.07
3				6.64	14.80	21.79	414.71
4				5.35	13.77	18.87	311.03
5				4.53	13.03	16.88	248.83
6				3.95	12.45	15.41	207.36
7				3.52	11.98	14.26	177.73
8				3.18	11.58	13.34	155.52
9				2.91	11.25	12.58	138.24
10				2.69	10.95	11.93	124.41
11				2.51	10.70	11.38	113.10
12				2.35	10.47	10.89	103.68

13				2.21	10.26	10.47	95.70
14				2.09	10.07	10.09	88.87
15				1.99	9.90	9.74	82.94
16				1.89	9.74	9.44	77.76
17				1.81	9.59	9.15	73.18
Ten days rainfall							
1	0.85	0.67	0.0086	26.131	31.83	37.74	1244.14
2				15.539	18.93	26.69	622.07
3				11.465	13.96	21.79	414.71
4				9.241	11.25	18.87	311.03
5				7.817	9.52	16.88	248.83
6				6.818	8.30	15.41	207.36
7				6.074	7.40	14.26	177.73
8				5.495	6.69	13.34	155.52
9				5.031	6.13	12.58	138.24
10				4.649	5.66	11.93	124.41
11				4.328	5.27	11.38	113.10
12				4.055	4.94	10.89	103.68
13				3.819	4.65	10.47	95.70
14				3.612	4.40	10.09	88.87
Monthly rainfall							
1	0.60	0.73	0.012	15.27	19.56	37.74	1244.14
2				9.08	11.63	26.69	622.07
3				6.70	8.58	21.79	414.71
4				5.40	6.91	18.87	311.03
5				4.57	5.85	16.88	248.83
6				3.98	5.10	15.41	207.36
7				3.55	4.54	14.26	177.73
8				3.21	4.11	13.34	155.52
9				2.94	3.76	12.58	138.24
10				2.72	3.48	11.93	124.41
11				2.53	3.24	11.38	113.10
12				2.37	3.03	10.89	103.68
13				2.23	2.86	10.47	95.70
14				2.11	2.70	10.09	88.87
15				2.00	2.57	9.74	82.94

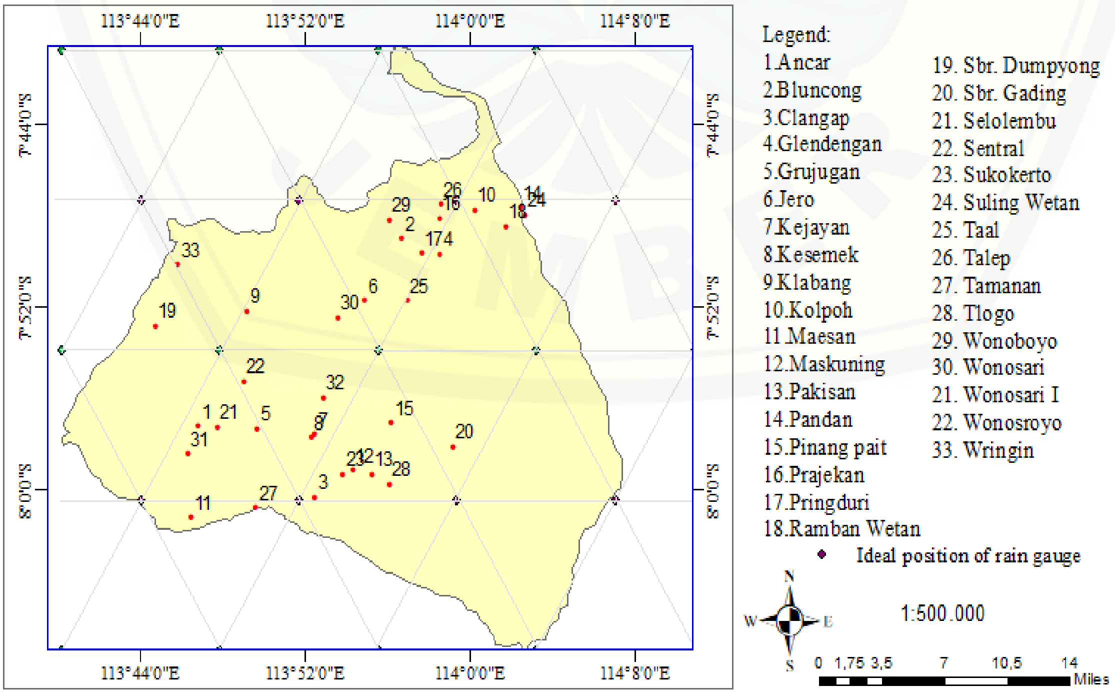


Figure 4. Kagan analysis through an equilateral triangle

5. Conclusion

The results of the study indicate that the temporal aggregation of rainfall data gives an effect on the basic statistics as correlation. The greater interval can increase the effectiveness of deployment with minimum error. Based on Kagan's analysis, there is an uneven distribution of gauge stations in the Sampean watershed even though the average and interpolation error in the monthly rainfall is less than 5%. It is this inequality that causes gauge stations to be inefficient. Two nodes are still empty and far from the gauge station. Therefore, it is necessary to shift or relocate several gauge stations to areas that match the coordinates of the Kagan node.

Conflict of Interest

The authors declare that there is no conflict of interest with any financial, personal, or other relationships with other people or organizations related to the material discussed in the article.

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