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Determination of Optimal Rain Gauge on The Coastal Region Use Coefficient Variation: Case Study in Makassar

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ABSTRACT The quality of rainfall data is highly significant in disaster analysis, ecology, and water resource management. However, the accuracy and quantity of rain gauges are often inadequate, especially for analyzing extreme events, including the Makassar City flood, in 2019. This inadequacy is due to several reasons, including rain gauges' inadequacy and insufficient distribution. This study, therefore, aims to analyze the requirements of optimal rain gauges, using coefficients of variation in various error levels, based on the latest rainfall data in several locations within Makassar City. Monthly and yearly rainfall observation data from 2010 to 2019 obtained at 5 locations were used to calculating the optimal rain gauge number. According to the results, the existing station has a 10% and 15% monthly and annual error, respectively. This region has 3 groups causing highly optimal rain gauges, and these are the first group comprising Paotere, Panaikang, as well as Biring Romang, while the second and third groups comprise Sudiang and Barombong. The northwest wind blows towards the coast and crosses these three places in a line, thus, causing rainfall intensity with a slight disparity, between the first group. Furthermore, the combination of these places resulted in low optimal rain gauge. However, the combination of the first group with the second and third lead to an increase in the optimal rain gauge number. The low elevation, proximity, and location of the first group's three locations in line with the rain-causing wind results in low optimal rain gauge. In the combination of the first, second, and third groups, additional gauges are required to obtain a 5% or 10% error. The rainfall intensity and position greatly influence the rain catchment in Makassar, and consequently, the optimal rain gauge number. In addition, the distance, topographical aspects, and the combined land-sea and monsoonal winds' factors must also be analyzed, in deploying equipment.

KEYWORDS Optimum rain gauge; Coefficient of variation; Rainfall; Coastal; Makassar.

1 INTRODUCTION

Weather stations' number and network significantly influence the rainfall accuracy of observation. The observation network determination is related to observation sites'shape and number. Thus, the problem of determining the number of stations not only involves accuracy (Cameron and Hunter, 2002), but also involves rain gauages'placements and numbers (Daskin, 1995; Church, 2002; Church and Murray, 2009). Generally, rain gauges generally are highly limited in number, therefore, this study was conducted the number of optimal rain gauges or ORG. Studies on ORG numbers were first conducted in the mid-20th century. In deploying new rain gauges, there is a need to eliminate redundant gauges or add to rain gauge network's inadequacy. Several studies have therefore attempted to develop a number of optimized rain gauge networks, based on different statistical approaches. Rycroft (1949) used the annual rainfall data and distance variance to determine the ORG number at Jonker shook catchment, and developed an equation for the ORG. Meanwhile, Ganguli et al., (1951) used the monthly rainfall's coefficient of distance variation to determine the number of rain gauges. An ORG in distance variations is determined using the coefficient of variation (Cv) concerning the desired accuracy (Ahuja, 1960; Adhikary et al., 2015; Ngene et al., 2015; Patel et al., 2016). Minimizing the kriging variance, is another method used to determine the ORG number (Prakash and Singh, 2000; Putthividhya and Tanaka, 2012; Wu et al., 2020). However, due to convenience in application, the Cv method remains widely applied.

The most representative rainfall is a measurement on the earth's surface, from the rain gauge (Ciach, 2003; Ciach et al., 2007). This measurement's result is no longer the potential rainfall but represents rainwater reaching the earth's surface. The rain gauge's location and distribution are also expected to represent the surrounding area. However, the earth's surface's condition is not homogeneous, and this caused the World Meteorological Organization (WMO) to determine the different rain gauge density, thus, a place is said to be representative or considered able to represent a certain area. Table 1 shows these representative conditions (WMO, 1994).

Table 1. Meteorological observation density standards according to WMO (WMO, 1994)

Surface	Minimum representative area (km^2/station)	
	Non-Recorded	Recorded
Coastal	900	9,000
Mountains	250	2,500
Interior plains	575	5,750
Hilly	575	5,750
Small Island	25	250
Urban Area	--	10–20
Polar/ Arid	10,000	100,000

According to Hu et al., (2013), rainfall data obtained from rain gauges are considered the most accurate, however, these data are limited and not homogenous (Xie and Arkin, 1997). Similarly, the number of rainfall measuring stations in Indonesia is highly insufficient. The Meteorology Climatology and Geophysics Agency, as a weather data measurement institution, only have 186 stations. This number is far below from the WMO standard, especially considering weather and topography complexities.

The Makassar City is a plain area with a 0 to 5 degree slope, and flanked by two river estuaries, the Tallo and Jeneberang Rivers. In addition, the city's altitude varies between 1-25 meters above sea level. As a city bordering the sea, Makassar has a plain shoreline, and the land descends gradually into the sea. The city is also categorized as a coastal zone, due to the elevation criteria below 10 meters above sea level (McGranahan et al., 2007) and location within 100 km of shoreline (Small and Nicholls, 2003). Furthermore, the land-sea wind's influence is extremely strong on the beach and decreases inland, on Bawakaraeng Mountain. Located in the tropical region, the city's temperature is always warm, with an average annual value of 27.5^{0}C. Also, the city has an average rainfall around 3,137 mm, but has wide rainfall variation. During the dry season, only 15 mm on two days of rain are expected in August and September, while in wet season, over 530 mm per month of rainfall is expected between December and February.

The city's wide variation in rainfall presents a need to calculate the required optimal rainfall gauge and accuracy level. Based on WMO's coastal standard of one rain gauge in 9000 km^2, Makassar City rain guage density is currently sufficient. In addition to 3 rain gauges managed by BMKG, there are two rain gauges in cooperation with the Ministry of Agriculture. However, the city contains a densely populated area and is growing rapidly, therefore, the city is also an urban area is prone to hydro-meteorological disasters. Thus, there is a need to carefully calculate the rain gauge number. Any mistakes in determining the rain gauge number required for water management analysis and disasters is bound to cause large casualties and losses. Therefore, determining the optimal rain gauge amount is crucial. Makassar has proved to be an area prone to hydro-meteorological disasters, including floods, and even recorded one of the most severe floods in 2019. Based on rainfall records at the time, not all stations recorded extreme rainfall at the incidence's occurrence, thus, the sufficiency of the number of rainfall measurements in Makassar and surrounding areas is quite questionable. This is a coastal region; thus, the rainfall pattern influences monsoon circulation (Giarno et al., 2012). Also, due to the random rainfall distribution, the satellite rainfall estimation's accuracy tends to decrease (Giarno et al., 2018). Therefore, this study aims to evaluate the adequacy of optimal rain gauges in Makassar, using the coefficient of variation (*Cv*).

2 METHODS

This study utilized rainfall data in Makassar City, the South Sulawesi province's capital. Located on Sulawesi Island's southwest coast, this region is bordered to the east and west by mountains, and by the coast, respectively. Furthermore, the Makassar Strait is located in the west of the city, and in northern Pangkajene regency, while Maros and the Gowa regency are positioned in the east and south, respectively. The city has a land area of 175.7 km^2, comprising 15 districts, 153 villages, and populated by 1,663,479 people.

Also, the region has a relatively flat topography, with the highest elevation of 20 meters. As with the rest of Indonesia, monsoon onset as well as withdrawal in this region is highly dynamic (Giarno et al., 2012) and the detection of remote sensing to the precipitation varies in each place (Giarno et al., 2018). Also, the rainy season peaks from December to February, while the dry season peaks from July to September. Figure 1 shows this study used data 10 monthly rainfall data, from 2010 to 2019, obtained from 5 sites in Makassar, Paotere, Panaikang, Barombong, Biring Romang, and Sudiang.

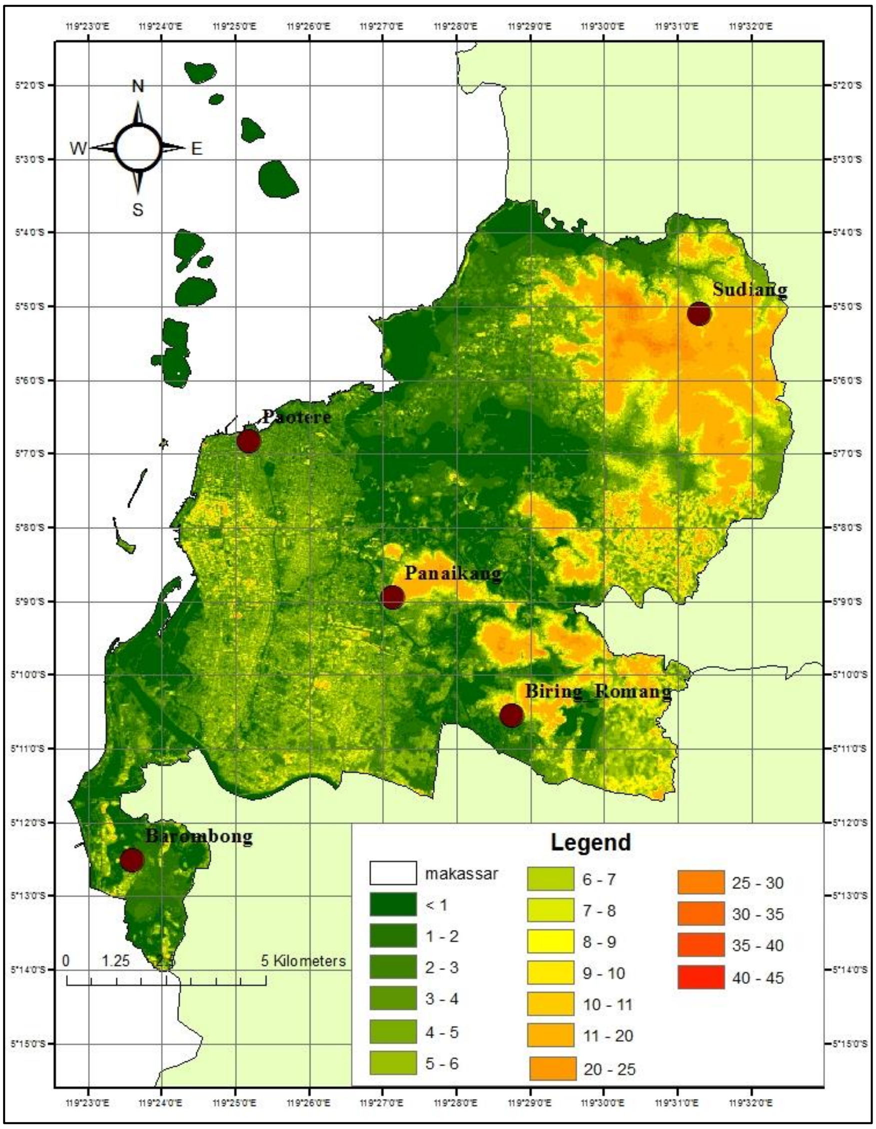

Figure 1. Topography (in meter) and rain gauges site in Makassar City

The determination of minimum rain gauge number depends on the destination. Based on the WMO standard, the amount of rain in Makassar is sufficient to support global weather analysis and modeling. However, in extreme phenomena, for instance, the in January 2019, the rainfall measurement results at the five stations are significantly different, especially between Barombong (346 mm) and Sudiang (1204 mm). This difference raises a question about the adequacy and accuracy of rain gauges in Makassar.

Generally, rainfall characteristics are presented using the proportion of events, mean, quantile, standard deviation, and coefficient of variation. These parameters are used for various analyses and this study only focuses on determining the optimal station number, only from the inter-station variance's statistical aspect. This method is suitable for plain areas, including Makassar City.

Due to the extremely high fluctuation in rain within Makassar, the rainfall data is bound to be analyzed using the optimal monthly and annual rain gauges, to determine the optimal rain gauge, changing over time. However, the data must first be validated, then each station's monthly and annual rainfall is calculated for each station. Prior to obtaining the optimal rain gauge number, the mean (average) and variance must be calculated. Subsequently, the relative standard deviation and the coefficient of variation are computed. The optimal rain gauge number is then obtained based on the coefficient of variation and the error level. Also, the number of locations is considered while determining the optimal rain gauge. For instance, the optimal rain guage is calculated for 5 locations, followed by the mean and variance using 5 locations. Similarly, with 4 locations, the mean and variance are calculated using 4 locations.

The arithmetically averaged total precipitation is recorded during a calendar day, month, or year. Meanwhile, the variance is a measure of variability, calculated from the average of squared deviations, obtained from the mean, and shows the data set's degree of spread. A more spread data implies a larger the variance. Rainfall is a highly volatile variable, with a mean value highly sensitive to data outliers. Therefore, variance and standard deviation must be included.

Based on the mean's definition, for instance, observational data x_i. Where N represents the data length, and i indicates monthly rainfall, the mean, μ is formulated, using Equation (1).

$$\mu = \frac{\sum_{i=1}^{N} X_i}{N} \quad (1)$$

In the probability and statistical theory, variance measures spreading. Thus, zero variance indicates all values are equal, while low or high variance indicates the data points tend to be very close to the average value (expected value), or very scattered, respectively, and these measurements tend to differ. The variance's square root is also called the standard deviation (σ) and is calculated using Equation (2).

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N}(x_i-\mu)^2}{N}} \quad (2)$$

In cases where the center range's distribution with respect to a portion of the data is calculated using quantile, the coefficient of variation (Cv), also called relative standard deviation (RSD), is often used to measure the spread's size, relative to the standard deviation. Cv is a statistical measure of data points' dispersion in a data series around the average and represents the standard deviation-average ratio. This parameter is used to compare the degree of variation from one data series to another, despite the significant differences between the averages. The Cv value is formulated using Equation (3).

$$Cv = \frac{\sigma}{\mu} \quad (3)$$

Meanwhile, the Cv is used to determine the optimal rain gauge number, N_O, at a certain error ε, using Equation (4).

$$N_O = \left(\frac{Cv}{\varepsilon}\right)^2 \quad (4)$$

Where, N_O represents the number optimal rain gauge number, and ε denotes the self-determined desired error, for instance, 5% and 10%. Equation (4) was widely tested using design rainfall with a return period (Al-Abadi and Al-Aboodi, 2014; Adhikary et al., 2015; Ngene, et al., 2015). While obtaining a Cv value, there is a need to know the data description, including the concentration and data distribution size. In this study, 5%, 10%, 15%, 20% and 25% error levels were examined.

3 RESULTS

The optimal rain gauges (N_O) number was calculated based on several possible combinations of rain gauges and respective error rates. Furthermore, the similarity in rainfall patterns and distance proximity were also considered in this calculation. From 5 locations, 4 possibilities exist, and these are a combination of 2, 3, 4 and 5 rain gauges, calculated using various error levels, 5% (Error_5), 10% (Error_10), 15% (Error_15), 20% (Error_20) and 25% (Error_25). Figures 2-5 show the boxplot graphic illustrating the monthly calculations results.

In this study, the rain gauge combination considers the possibility of a similarity in the rain guage's optimal result, thus, all possible combinations are calculated. Only one combination of 5 rain gauges is possible using all 5 locations, while for 4 locations only 3 combinations were used. Meanwhile, for 3 locations, only 5 combinations were counted, and the last 2 locations only used 5 combinations. Figure 2 shows the combination 2 of 5 sites discovered N_O in a 5% error level varies from 20 optimal rain gauges to only 2 required optimal rain gauges. Thus, a lower desired error level requires more rain gauges. In addition, the combination of 2 rain gauges in an error level (ε) of 5%, 10%, 15%, 20%, and 25% resulted in median N_O of 10, 5, 3, 3, and 2, respectively. The distribution of N_O is analyzed from the distance between the third and first quantiles, on the boxplot. Also, the 3rd quantile refers to the upper box limit, while the first counterpart refers to the lower box limit. The lower error level causes greater values in N_O and spreading, however, every researcher and government agency certainly prefer a low error level and optimal rain gauge.

Increasing the number of rain gauges used for observation helps improve accuracy. According to Figures 3, 4, and 5, in comparison to a combination of 2 gauges, combining 3, 4, and 5 gauges showed the error level significantly affects the number of rain gauges to be installed. The error level's effect was more significant on the median N_O, compared to the number of rain gauges combined. However, the number of combined gauges also affects N_O dispersion. The median for the combination of rain gauges 3, 4, and 5 is almost similar to the combination of 2 gauges, 10, 5, 3, 3, and 2, respectively. Differences between the third and first quantiles or range, rises directly proportional to the number of equipment used, especially in 5% error level. Conversely, the error level causes a reduction in range, thus, a high error causes an unchanged N_O value.

Table 3 shows the N_O's monthly variability, and this value also varies. The average optimal rain gauge is calculated for combinations used and grouped according to the error level and month. Based on this table, a low error level is required to augment gauges, otherwise, the existing rain gauges need to be reduced to a large error level. A comparison with higher error levels showed at least 6 or 7 gauges must be added at a 5% error. Similarly, decreasing rain gauge tends to cause a rise in error levels.

Table 2 shows the N_O in dry seasons within Makassar City, increased from June to September, based on the monthly N_O calculation. During dry season, precipitation in the city is highly random, compared to the rainy season, both in intensity and distribution. In the application of *Cv* formulation, the variance is to be increased, and consequently, the N_O. Furthermore, the value of ε used as a dividing factor is also bound to further increase N_O, because the value is a fraction below 1. Meanwhile, in error levels above 15%, the N_O change between dry and wet seasons is inconspicuous. The average optimal rain gauge number required to obtain a 5% error level changed from 7 to 15, between January and December. Therefore, constant rainfall during the rainy season makes No value lower, compared to the sparse rain in dry season.

Table 3 shows the disparity annual precipitation affects N_O more, compared to the average monthly optimal rain gauge. For 5% error of N_O, 55 stations are required in averaging, and this sum is smaller for higher error. Currently, the N_O is available in 5 locations, and is only able to tolerate 15% error.

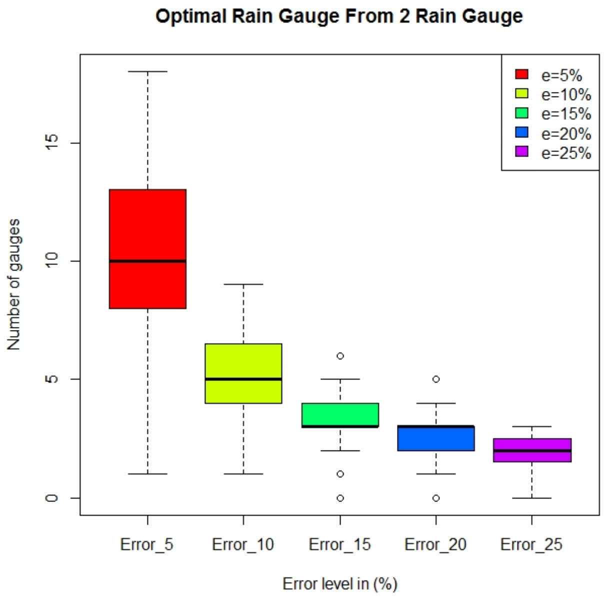

Figure 2. N_O combination of 2 rain gauges

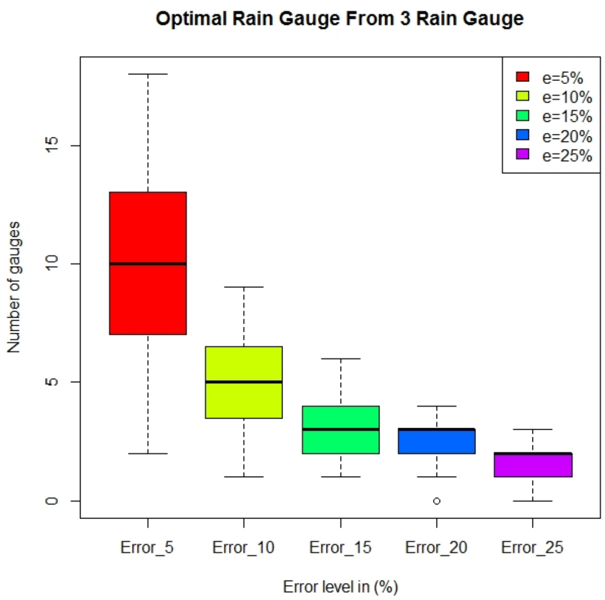

Figure 3. N_O combination of 3 rain gauges

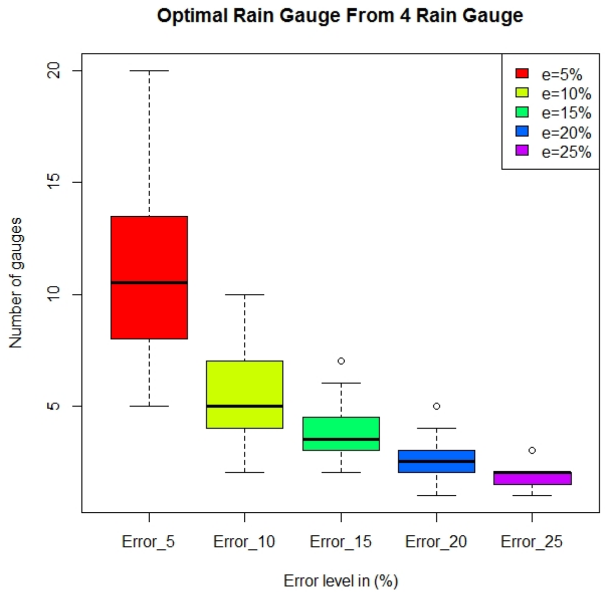

Figure 4. N_O combination of 4 rain gauges

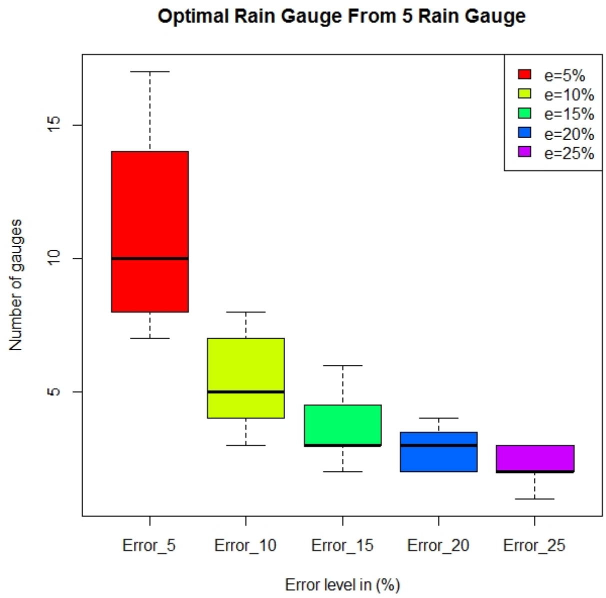

Figure 5. N_O combination of 5 rain gauges

In this study, all the five gauges were not deployed at the beach. Only Paotere and Barombong lie near the Makassar Strait, influenced by the land and sea wind system. The sea breeze blows from morning until late evening, while the land breeze blows at night (Oliver, 2004). Therefore, local wind influences rain in Makassar, thus, rainfall is possible for a whole day, both in dry and wet seasons. The distance between Sudiang and Panaikang is 6 km from the beach, while Biring Romang is situated 10 km from the beach. Table 4 shows the distance between stations.

Table 2. Average N_O in several error levels

Level error/ORG					
Month	5%	10%	15%	20%	25%
Jan	7	4	2	2	1
Peb	7	4	2	2	1
Mar	8	4	3	2	2
Apr	9	4	3	2	2
May	12	6	4	3	2
Jun	12	6	4	3	2
Jul	14	7	5	4	3
Aug	13	7	4	3	2
Sep	15	8	5	4	3
Oct	10	5	3	3	2
Nov	10	5	3	2	2
Dec	7	3	2	2	1

According to the table, the farthest distance, 19.78 km, is between Barombong and Sudiang, while Panaikang-Paotere are the closest stations, with a 4.24 km distance. The rainfall observed in Panaikang and Paotere recorded close rainfall intensities. Using the WMO standard, a station is able to represent 900 km^2 or 17 km a radius, thus, the distance between stations is at least 34 km. However, based on N_O calculations, the existing stations produce a maximal error monthly and annual error of 10% and 15%, respectively. To conclude this analysis, an N_O calculation was performed to detect the probability of the guage's deployment location. In this study, the average for the station pairs, Paotere Barombong, Biring Romang, Sudiang, and Panaikang, were calculated for 5% and 10% errors. Tables 5 and 6 show the results for each pair, calculated annually.

Table 3. Annual N_O values

Rain Gauge (RG)	N_O				
Level of error	5%	10%	15%	20%	25%
5RG	50	13	6	3	2
4RG	48	12	5	3	2
3RG	65	16	7	4	3
2RG	55	14	6	3	2
Average	55	14	6	3	2

Table 4. Distance between rainfall stations in Makassar

Sites	Barombong	Sudiang	Biring Romang	Panaikang	Paotere
Barombong	0.000 km	19.780 km	10.180 km	9.300 km	10.950 km
Sudiang	19.780 km	0.000 km	11.140 km	10.490 km	11.740 km
Biring Romang	10.180 km	11.140 km	0.000 km	4.240 km	9.550 km
Panaikang	9.300 km	10.490 km	4.240 km	0.000 km	5.310 km
Paotere	10.950 km	11.740 km	9.550 km	5.310 km	0.000 km

Table 5. N_O values calculated using 5% error level, among Paotere (PT), Barombong (BR), Biring Romang (BO), Sudiang (SD) and Panaikang (PK)

Year	BR-SD	BR-BO	PK-BR	PK-SD	PT-BO	PT-BR	PT-PK	PT-SD
2010	1	184	14	95	1	0	7	145
2011	5	71	2	85	0	0	1	104
2012	3	57	0	87	1	0	2	67
2013	90	69	0	254	4	1	2	221
2014	15	117	0	197	0	0	0	197
2015	1	125	0	100	4	1	2	77
2016	21	99	1	24	4	1	1	14
2017	78	107	0	2	1	0	1	0
2018	189	87	0	24	0	0	0	28
2019	204	101	1	39	1	0	5	17
Average	61	102	2	91	2	0	2	87

Table 6. N_O values calculated using 10% error level, among Paotere (PT), Barombong (BR), Biring Romang (BO), Sudiang (SD) and Panaikang (PK)

Year	BR-SD	BR-BO	PK-BR	PK-SD	PT-BO	PT-BR	PT-PK	PT-SD
2010	0	46	4	24	0	0	2	36
2011	1	18	0	21	0	0	0	26
2012	1	14	0	22	0	0	0	17
2013	23	17	0	63	1	0	1	55
2014	4	29	0	49	0	0	0	49
2015	0	31	0	25	1	0	0	19
2016	5	25	0	6	1	0	0	4
2017	19	27	0	0	0	0	0	0
2018	47	22	0	6	0	0	0	7
2019	51	25	0	10	0	0	1	4
Average	15	25	0	23	0	0	0	22

Based on the table, there are at least three optimal rain gauge groups for a 5% error. Each group is identified by the significantly large optimal rain gauge number. For the first group, Paotere, Biring Romang, and Panaikang, the combination produced N_O with a value below or equal to 2. Meanwhile, the combination between the first group and gauges in Barombong with significantly large N_O, except Paotere-Biring Romang, with N_O of 2. Despite the differences between Biring Romang and Panaikang, the rainfall measurement results in Barombong do not differ significantly from Paotere. To obtain an accuracy of rainfall measurement at the 5% level, additional rain gauges ought to be installed between Barombong and Panaikang, or Barombong and Biring Romang. Meanwhile, the N_O resulted from combining this group with the rain gauge in Sudiang (above 60 gauges). Consequently, to obtain an error level of 5%, there a need to add gauges between this first group and Sudiang. Considering the average N_O in these three groups reached a minimum of 61, the number of equipment required to obtain a 5% error level is quite large. Also, the 10% error level results in the same grouping as the 5% level. The only difference is in the decreasing number of additional rain gauges required.

An analysis based on the distance to N_O showed the distance between Panaikang and Paotere is 5 km. Meanwhile, the distance between the first and second, first and third groups, as well as the second and third groups are all above 5 km. Based on the analysis above, new rain stations ought to be placed the first and second groups or between the first and third groups. This is because the location of Paotere, Biring Romang, and Panaikang are between Sudiang and Barombong. Therefore, to produce smaller error, a new rain station ought to be placed within 5 km.

4 DISCUSSION

A study by Ramage (1968) showed the change in water vapor from the wind blowing through the Indonesian region influences rainfall characteristics. The Asian prevailing wind emerges while the wind blows from west to north, and passes the vast rain-causing ocean, mainly in the equator's south. Conversely, in cases where the wind originates from the Australian mainland, dry air is carried, causing little rainfall in Indonesia. The Indonesian territory is significantly vast and is on both the equator's north and south sides. This country also has many mountains and islands; thus, the early rainy season's onset (monsoon onset) is not uniform (Giarno et al., 2012). Similarly, Makassar City, although located in a monsoonal area, due to the unique positioning close to Makassar Strait and mountainous Bawakaraeng, in the west and east, respectively, has the capacity to impact monsoon circulation. In addition, the rainfall fluctuation affects the optimal rain gauge number. In cases where rainfall is evenly distributed, the number of gauges required is lower, compared to places where rainfall differs in intensity with each location. This is because the optimal rain gauge calculation uses the variance and average rainfall, and this sis highly sensitive to differences in values between rain gauges. Generally, in January and December, the rainy season's peak in Makassar, rain falls evenly in all places, while during the dry season or transition, the reaching the earth's surface is often random.

In the coastal region, rainfall is also influenced by the wind propagation's speed and direction (Yang and Slingo, 2001; Liberti et al., 2001). The inland sea wind propagation's complexity increases, due to the monsoon wind flow's influence, where the propagation phase speed is about 3 m/s and 7 m/s, in the eastern and western monsoonal flow regimes, respectively (Ichikawa and Yasunari, 2006). This reciprocal relationship between the monsoon and the inland sea wind system affects the optimal rain gauge determination in Makassar. The gauges in this study, Paotere and Barombong, lies on the beach influenced by the land and sea wind system. Sea breezes occur in the morning until late evening, while land breezes occur at night (Oliver, 2004). The local wind influences rainfall pattern in Makassar, thus rainfall is possible for an entire day, both in dry and wet seasons.

Furthermore, the test performed with 5% level shows optimal rain gauge amount between Paotere and Barombong is 2, and with an even smaller annual value. Meanwhile, the rain gauge test in Sudiang shows the optimal rain gauge value is significantly large. This means the rainfall between Paotere and Panaikang is significantly different from Sudiang, thus, a rain gauge must be added between these two places. Also, the test results show there is a difference between Barombong and Sudiang, where the optimal rain gauge between Barombong and Paotere and Panaikang is minute but calculated by the significantly large Biring Romang. The optimal rain gauge between Sudiang and Paotere, Panaikang, and Biring Romang were also very large. Based on the analysis of rain events, the Asian Monsoon winds carry a lot of water vapor and cause rain blowing from the northwest. During the rainy season, the Asian monsoon winds first reach Makassar Beach, located in the Paotere area, then moves to Panaikang and Biring Romang. These three places are parallel to the northwest, where the dominant monsoon winds are directed landward. Rainfall begins in Paotere, on the beach, then spreads towards Panaikang, and finally to Biring Romang, causing the three places to have the same rainfall pattern, resulting in a small calculation of the optimal rainfall gauge. These three places also have a relatively similar altitude of below 5 meters.

Conversely, Sudiang and Barombong have slightly different characteristics, compared to Paotere, Panaikang, and Biring Romang. The Sudiang elevation is higher, compared to other stations, causing changes in wind direction and rain, in this location. According to Figure 1, the winds carrying water vapor from the northwest are to be influenced by the land, thus, rain in Sudiang is different from Paotere. A calculation of the optimal rain gauge also supports this analysis, stating the optimal rain gauge amount is large, while combining Sudiang with these three locations. Conversely, the optimal rainfall gauge values for Paotere and Panaikang are small, but are significantly large, paired with Biring Romang. Rainfall beginning in Paotere, is bound to spread towards Panaikang and Biring Romang, causing the three places to have the same rain pattern, thus, producing a small and optimal rainfall gauge. Both stations are on the beach, however, Barombong is in the south of Paotere. Rain in tropical Indonesia is significantly random, therefore, Barombong has a different northwest monsoon direction from Paotere. In addition, these three locations' altitudes are below 5 meters. Meanwhile, Sudiang and Barombong have slightly different waters because the winds coming from different beaches are not parallel to Paotere.

In some cases, the coast's shape also affects rainfall (Al Fahmi et al., 2019). The convex land shape causes the wind to converge, while the concave shape causes wind propagation divergence. Paotere is in a relatively convex area, in cases where the wind blows from the northwest, and is therefore bound to have slightly higher rainfall, compared to Barombong, in a significantly convex area (Figure 1). The Paotere beach's convex shape causes convergence in the Panaikang and Biring Romang areas and causes rainfall to remain high in both areas. Furthermore, this area is closer to the mountains, and these also have an impact on rainfall, due to winds from the mountains in the afternoon. Consequently, the rain pattern in Barombong is different from Biring Romang, leading to an increase in the optimal rain gauge value. The land-sea wind's combined impact's magnitude also requires further studies, using the monsoon propagation and land-sea wind system (Yang and Slingo, 2001; Liberti et al., 2001; Ichikawa and Yasunari, 2006). Similarly, topographic aspects must also be considered, in selecting the location of the rain gauge to be installed (Prakash and Singh, 2000; Putthividhya and Tanaka, 2012; Wu et al., 2020).

5 CONCLUSION

According to the meteorology and statistics aspect, the optimal rain gauge is inversely proportional to the error level, thus, a small rain gauge amount leads to high error level. The rainfall intensity with a slight disparity between Paotere, Biring Romang, and Panaikang also has the capacity to cause the combination among these locations to result in a similar optimal rain gauge amount, and these are also called the first group. In addition, the dominant wind blows from the northwest towards the coast, then crosses these three places in a line towards the Bawakareng Mountains. The three locations' low elevation and relative proximity also results in low optimal rain gauge. The other group is Sudiang as well as Barombong as the second and third groups, and this is the optimal rain gauge calculated, using the first group and the additional gauges required to obtain a 5% or 10% error level.

Based on monthly rainfall data, the optimal raingauge at 5% and 10% error levels are 10 and 5 units or sites, respectively. This means the existing station has a 10% error level. Furthermore, longer rainfall duration causes an increase in the optimal rain gauge number. The number of optimal rain gauges for annual data at 5%, 10%, and 15% error level are 55, 14, and 6 units, respectively. Therefore, the existing rain gauge locations have an error level above 15%. In the addition of gauges to increase the rainfall observation's accuracy, the distance and combination of the rain's nature must be considered. A new rain gauge ought to be placed between the first and second groups or between the first and third groups, at a 5 km distance from the existing station. Also, the topographic aspects, as well as the land-sea and monsoonal winds'combined effects, require further analysis, in deploying new rain gauges.

DISCLAIMER

The authors declare no conflict of interest.

AVAILABILITY OF DATA AND MATERIALS

All data are available from the author.

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