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Simulating Rainfall Seasonal Pattern in Kandangan Subregency Using Statistical Method

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Simulating Rainfall Seasonal Pattern in Kandangan Subregency Using Statistical Method

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Abstract. Rainfall is an important climate element which affects water resources availability in a certain area. Water resources availability itself are an important factor for human life. In this research, daily rainfall from 2014 to 2016 was statistically analyzed to obtain form and scale parameter for 2-parameter gamma distribution for each month. Then obtained parameter is clustered based on seasons resulting in four clusters. Then each obtained parameter within each cluster is modeled as dependent variable using simple linear regression with Sea Surface Temperature Anomaly over Nino 3,4 Zone as its independent variable. Those processes resulted in the regression model for each gamma distribution parameter and for each season. Then obtained model used and combined with random seed algorithm to simulate rainfall during 2017. Resulted rainfall showed that statistical model that had been built was capable to simulate the temporal pattern of rainfall although with underestimated rainfall value.

1. Introduction

Rainfall is an important climate element for human life [1]. The rainfall pattern of the certain region might influence some aspects of human life, such as cropping pattern, the cycle of disease [1], disaster management, industry, trades, and economical services [9]. Hence, sufficient capability to predict weather and climates especially rainfall pattern will give some benefits to human life, for both economic and non-economic sectors.

Despite its importance, the capability to predict rainfall especially for an equatorial region still not adequate enough for operational use. Indonesia region, for example, recent rainfall prediction model tend to have low Proportion Correct (PC), especially when used to simulate rainfall during wet seasons when rain occurrence become more frequencies [10]. Difficulties of rainfall prediction over equatorial region mainly caused by its complex atmosphere. Rainfall in Indonesia is affected by various planetary-scale atmospheric-oceanic dynamics, such as El-Nino Southern Oscillation (ENSO), Indian Ocean Dipole (IOD) [8], and Madden Julian Oscillation (MJO) [3]. Not only by planetary-scale dynamics, more localized atmospheric dynamics like small-scale convection and orographic induced circulations also have a significant effect on weather and rainfall. Hence, this research was conducted to arrange a method for simulating and predicting the regular pattern of rainfall using a method based on probability and statistics.

Gamma probability density function is one of probability density function (PDF) which widely used and most preferred to describe rainfall [5-7] suggested that gamma distribution have good fits with daily total rainfall distribution frequency. Not only for the normal daily pattern, but gamma probability density function also can be used to describe extreme rainfall event [6]. In this research, 2-

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parameter gamma probability density function was used to model the regular pattern of rainfall. In this research, simple linear regression analysis also used to build empirical prediction model of scale and form parameter of gamma PDF with Sea Surface Temperature Anomaly (SSTA) for Nino 3,4 and 4 regions as its independent variable.

Kandangan Subregency located in Temanggung Regency which part of Central Java. Kandangan Subregency located at 657 meters above sea level [4]. According to Center Bureau of Statistics [4], maximum air temperature at surface level in Kandangan can reach 30^{o}C whereas its minimum can be as low as 20^{o}C. Error! Reference source not found. shows the location map of Kandangan Subregency. Kandangan Subregency borders with Kedu and Gemawang Subregency for western part, Semarang Regency and Gemawang Subregency for northern part, Semarang Regency and Kaloran Subregency for eastern part, and Temanggung Subregency and Kaloran Subregency for southern part. To fulfill daily water needs, people in Kandangan Subregency tend to use local water resources, such as groundwater and springs. For agricultural needs, people in Kandangan Subregency also use local water resources in the form of irrigation and rain-dependent crop fields. Since local water resources are used for many purposes, its availability becomes important.

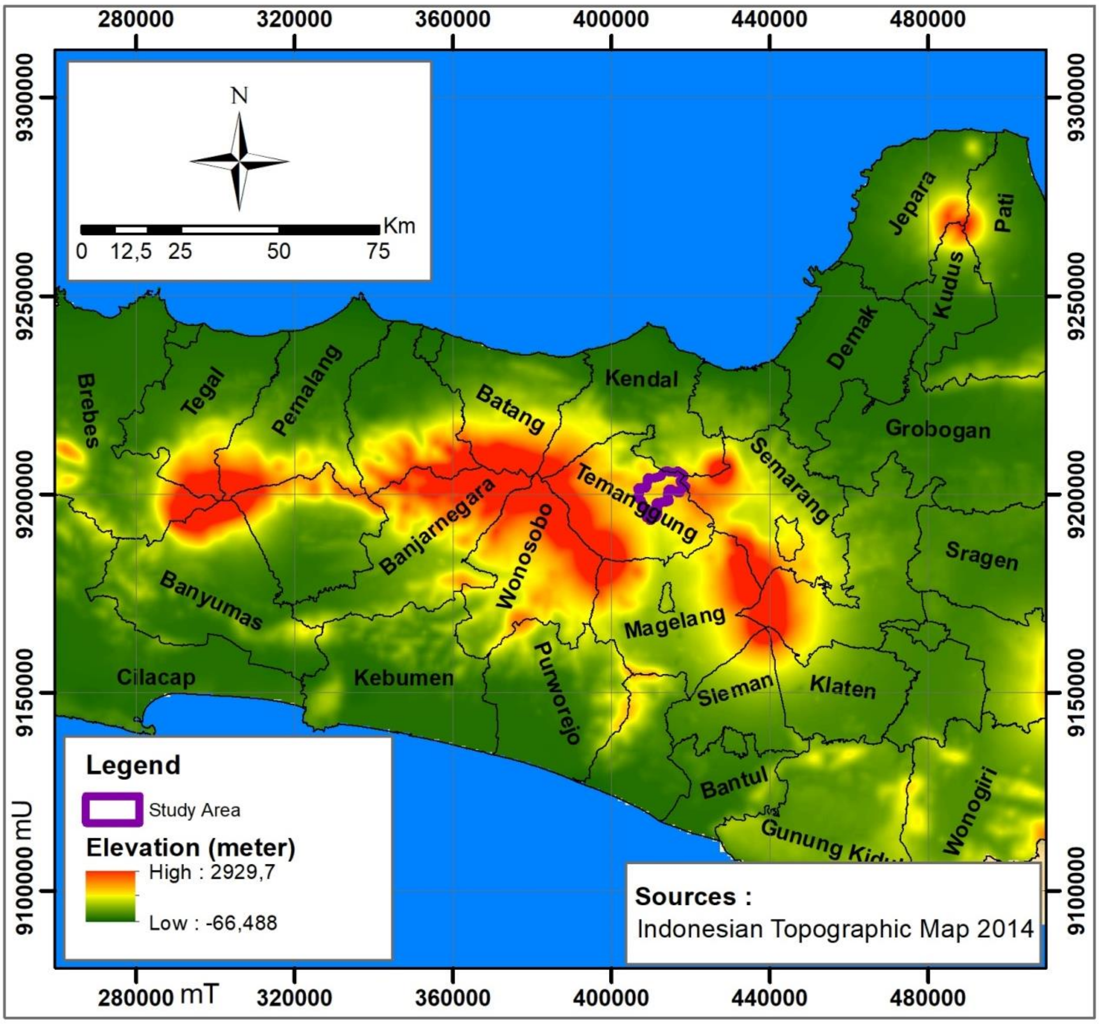

Figure 1. Border map of Kandangan Sub Regency

2. Methods

This research used a statistical method to model seasonal pattern of rainfall in Kandangan Subregency. In this research, rainfall was simulated based on its probability and regression analysis. Variable used to build a statistical model using regression analysis was rainfall and SSTA. Data used in this research was secondary data. Rainfall data of Kandangan Subregency was collected from direct rainfall measurement done by Kejora Limited Liability Company whereas SSTA data was gotten from National Oceanic and Atmospheric Administration (NOAA).

2.1. Rain Probability

Rain probability was calculated to know about the chance of rain to occur for each month. In rainfall simulation, it was used as a parameter to determine frequency and number of rain occurred during the simulated time. Rain probability in this research is expressed as the ratio between the number of wet days (a day with rain occurrence) and a number of days. In this research, rain probability is calculated for each month resulting monthly rain probability.

2.2. Calculating 2-Parameter Gamma Distribution

2-Parameter Gamma PDF was used to express rainfall distribution. Shape (k) and scale (θ) parameter for gamma distribution was calculated using Eq (1) and Eq (2). In those equation, R represents mean of rainfall, r represents rainfall and σ represents standard deviation.

$$k = \left(\frac{\bar{R}}{\sigma r}\right)^2 \quad (1)$$

$$\theta = \frac{\bar{R}}{k} \quad (2)$$

2.3. Rain Probability and Rainfall Modell

Regression analysis was used to build a statistical model of rain probability and a gamma distribution of rainfall (shape and scale parameter). In this research, regression analysis was done using SSTA as an independent variable for all of the dependent variable. Before regression analysis was done for each variable, data was clustered based on its month into four class. Those classes were DJF (December, January, February), MAM (March, April, May), JJA (June, July, August), and SON (September, October, and November). Data were clustered as such to represents seasonal changes in Indonesia. Then, after clustered, each variable is modeled using equation (3) and (4) which adopted from [11]. In that equation, x is the independent variable, y are the independent variable, n is number of data, α_y and β_y are regression coeficient for dependent variable y.

$$\alpha_y = \frac{\sum y - \beta_y \sum y}{n} \quad (3)$$

$$\beta_y = \frac{n \sum yx - \sum y . \sum x}{n \sum x^2 - (x)^2} \quad (4)$$

2.4. Rainfall Simulation

After received the regression equation for rainfall probability and gamma distribution parameter, then those equations were used to simulate rainfall. In this research, simulated rainfall was daily rainfall. Rainfall simulation was started by simulating rainfall probability for each day and generating random seed during simulation time. In this research, generated random seed represented probability of rain not to happen on a certain day. Obtained rainfall probability and the random seed were used as a threshold to determine whether a certain day was a wet day or not. If on a certain day generated random seed is less than 1 minus rain probability, then that day was a wet day and vice versa. Then if the day was a wet day, a parameter of gamma distribution of rainfall simulated using received regression equation and SSTA data to obtain shape and scale parameter. After that, those received parameter used to simulate rainfall on that day by generating gamma distribution-based random value using equation (5) [2]. In Eq (5), $\Upsilon(k)$ represents gamma function. After daily rainfall was simulated, simulated daily rainfall was used to calculate monthly rainfall.

$$R(x) = \frac{e^{-x}/_{\theta}t^{k-1}}{\theta^k \Upsilon(k)} \quad (5)$$

3. Results and Discussion

3.1. Seasonal Pattern of Rainfall in Kandangan Subregency

Used rainfall data for 2014 to 2016 showed that yearly mean of rainfall in Kandangan Subregency was 3183.6 mm/year. Error! Reference source not found. shows monthly rainfall from 2014 to 2016. From the figure, it can be seen that there were two periods of rainfall peak in one year period. It occurred on January to April and November to December. Between those periods, there was a single period with low rainfall. Those patterns suggest that rainfall in Kandangan tend to have a monsoonal pattern.

Error! Reference source not found. also shows that there was a significant decrease in rainfall during May 2015 to October 2015. That rainfall decrease was greater if compared to another period. It might be caused by El-Nino with a strong intensity that happened since March 2015 to middle 2016. Error! Reference source not found. shows a graphic of Sea Surface Temperature Anomaly (SSTA) from January 2014 to December 2016 for Nino Zone 3,4. From the graphic, it can be is seen that there was high positive SSTA which happened during 2015 and up to middle 2016. Another unusual pattern that can bee seen from Error! Reference source not found. is a significant decrease of rainfall which happened on December 2016. But, unlike the previous case, the cause of this decline was not fully known. SSTA during the end of 2016 for Nino Zone 3,4 tend to had a negative value which indicated the occurrence of La-Nina event. Thus, rainfall decrease that occurred during the end of 2016 was expected to be caused by another causes.

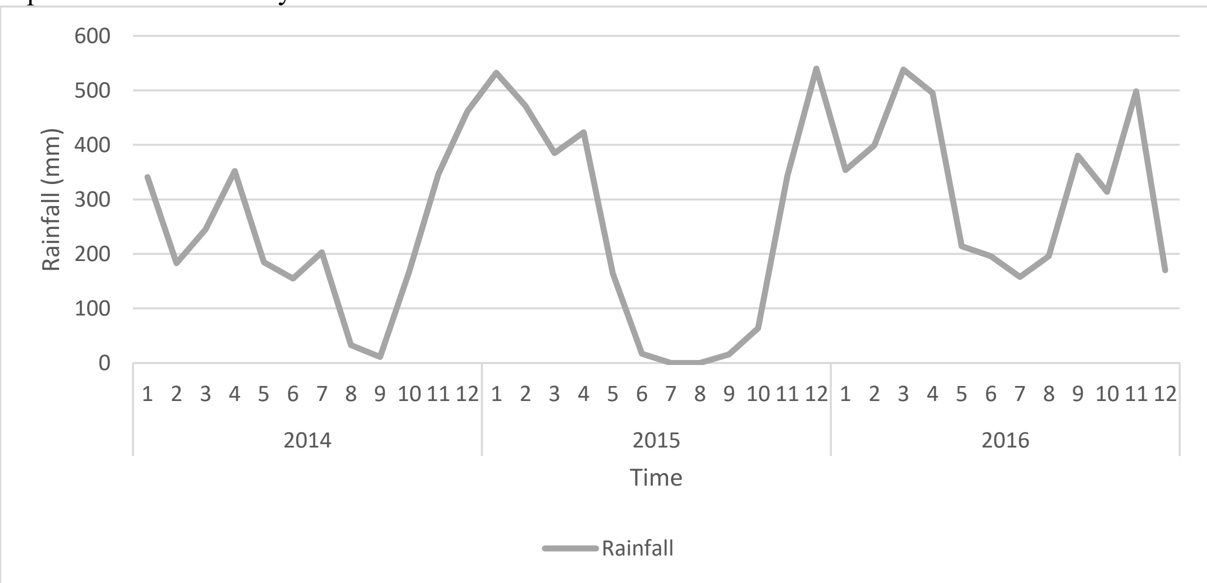

Figure 2. Graphic of Monthly Rainfall in Kandangan Subregency Periods 2014-2016

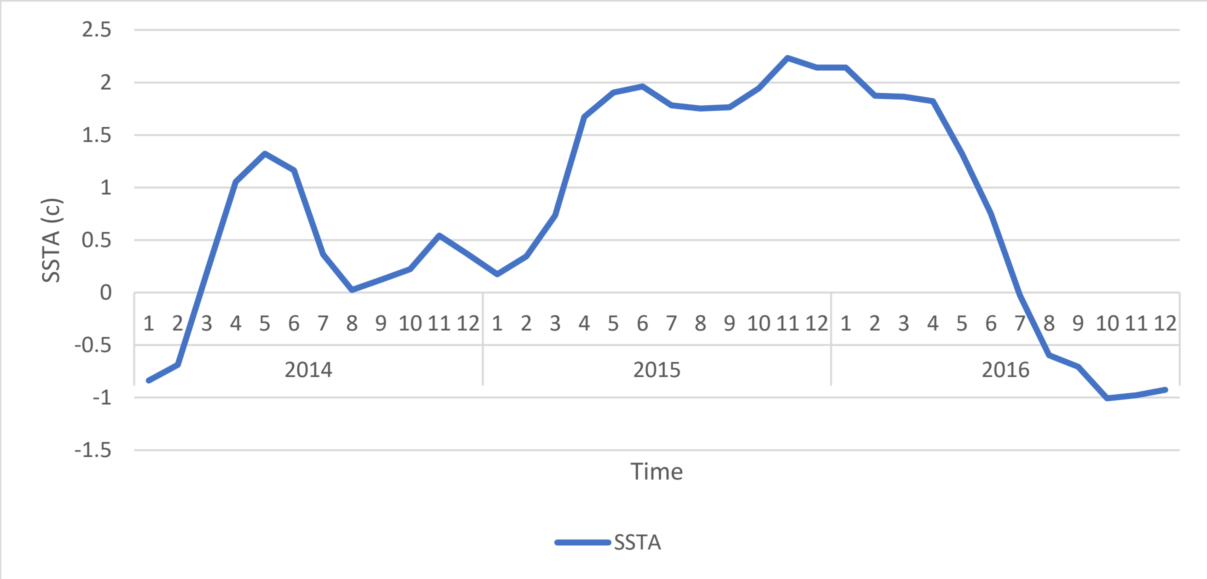

Figure 3. Graphic Sea Surface Temperature Anomaly for Nino Zone 3, 4 Periods 2014-2016

3.2. Rainfall Statistics

Table A1 shows resulted in statistic parameters of data. Probability calculation shows that rain was more likely to happen during DJF and MAM with probability of 0.47 and 0.44 for each period respectively. Meanwhile, a period with lowest rain probability was JJA with rain probability 0,15. It strengthens the previous statement that said rainfall in Kandangan Subregency tends to affect by monsoon.

Table 1. Resulted Regression Coefficient

Model Class	Probability		Gamma Shape (k)		Gamma Scale (θ)	
	α	β	α	β	α	β
			Nino 3,4			
MAM	0.47	-0.01	0.45	-0.03	16.88	7.39
JJA	0.22	-0.09	0.20	-0.08	21.07	-6.85
SON	0.34	-0.08	0.32	-0.08	24.67	-1.64
DJF	0.47	0.01	0.35	0.02	37.68	2.81
			Nino 4			
MAM	0.46	-0.18	0.42	-0.12	27.35	-10.41
JJA	0.03	0.27	0.03	0.24	-2.60	39.31
SON	0.21	0.18	0.18	0.19	25.90	-3.54
DJF	0.47	0.00	0.35	-0.07	39.69	9.42

3.3. Rainfall Pattern Simulation for Kandangan Subregency Area

Monthly rainfall simulation was done based on method explained in section 2 for period 2017. Table 1. Resulted Regression Coefficient shows resulted in regression model, shows a plot of simulated rainfall and actual rainfall from secondary data, and
shows results of Mean Absolute Error (MAE) calculation for simulated rainfall. Simulation results and its error examination showed that built statistical model tend to underestimate the value of rainfall. It happened on both models built from Nino zone 4 and Nino zone 3,4. Further, it can be seen that

Table 2. Mean Absolute Error Calculation of Simulated Rainfall

Tahun	Bulan	Simulated Rainfall (mm)		Actual Rainfall (mm)	Absolute Error	
		Nino 4	Nino 3,4		Nino 4	Nino 3,4
2017	1	282.9	112.4	365.0	82.1	252.6
2017	2	269.8	221.1	461.0	191.2	239.9
2017	3	418.8	346.1	556.0	137.2	209.9
2017	4	85.1	89.5	377.0	291.9	287.5
2017	5	88.2	56.8	191.0	102.8	134.2
2017	6	32.3	45.7	168.0	135.7	122.3
2017	7	8.7	5.4	29.0	20.3	23.6
2017	8	1.0	0.0	0.0	1.0	0.0
2017	9	10.8	1.0	81.0	70.2	80.0
2017	10	9.3	2.0	200.0	190.7	198.0
2017	11	21.1	0.0	498.0	476.9	498.0
2017	12	338.6	199.8	172.0	166.6	27.8
Mean Absolute Error					155.5	172.8

simulation error tend to be larger during the wet season and transition period from dry season to wet season. It implied that when rain becomes more frequent statistical model tends to become more prone to error. Besides, this underestimation might also be caused by the difference of monthly rainfall pattern between 2017 and monthly mean from 2014 to 2016. shows that during wet period monthly rainfall in 2017 tend to larger whereas in dry period monthly rainfall in 2017 tend to smaller.

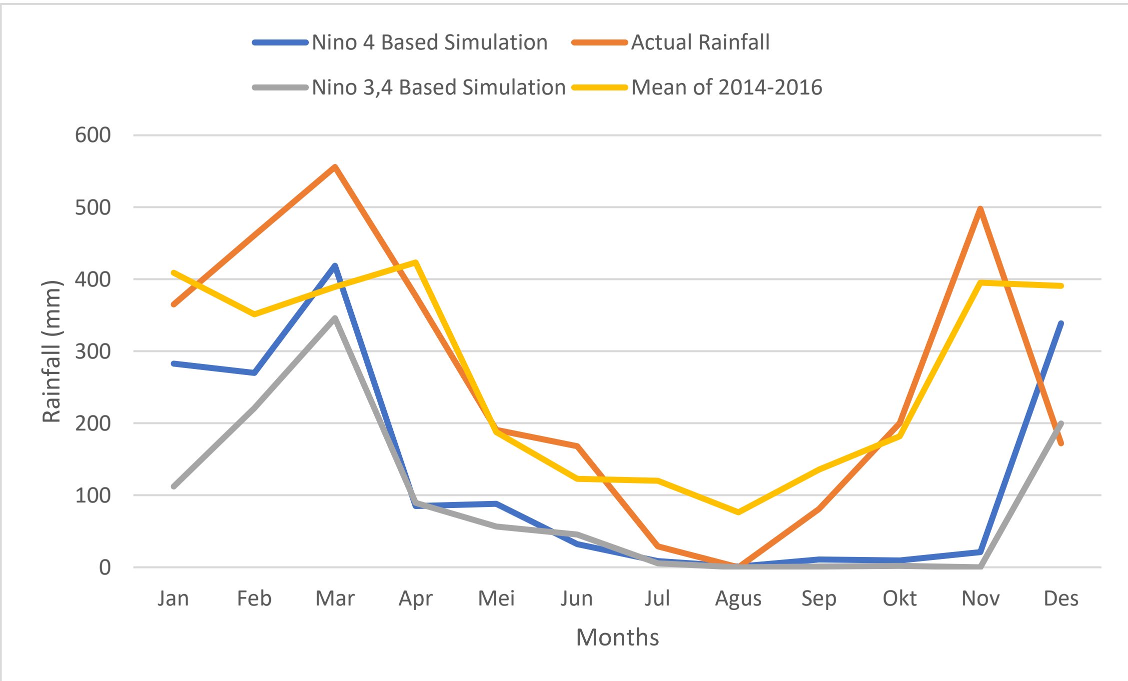

Figure 4. Graphic of Simulated Rainfall Period 2017

Although simulated rainfall tends to underestimate the actual value, simulated and actual rainfall tend to have similar seasonal pattern especially from January 2017 to August 2017. **Error! Reference**

source not found. and Error! Reference source not found.shows scatter plot between simulated and actual rainfall. Further, statistical correlation analysis using Spearman Correlation Analysis showed that simulated and actual rainfall is correlated with each other. The analyzed correlation value between rainfall simulated based on Nino zone 3,4 SSTA and actual rainfall was 0.504 whereas analyzed correlation value between rainfall simulated based on Nino zone 4 and SSTA was 0.629. That means that changes in actual rainfall tend to accomppanied by changes in simulated rainfall in the same direction. It implied that arranged statistical model was capable to simulate the seasonal pattern of rainfall in Kandangan Subregency.

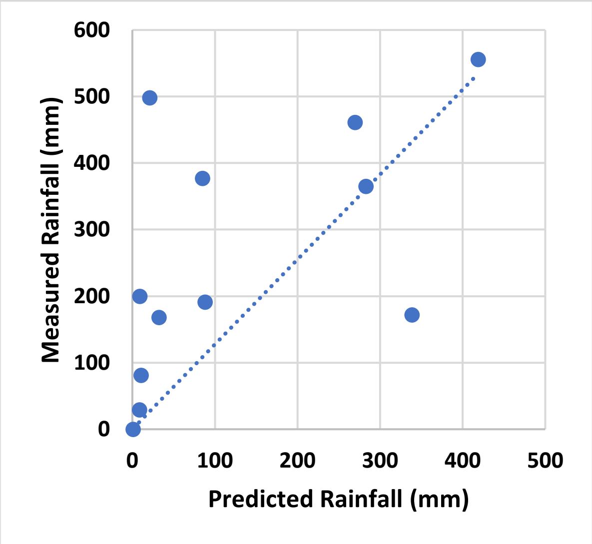

Figure 5. Scatter plot of Nino 4 based rainfall simulation and actual rainfall

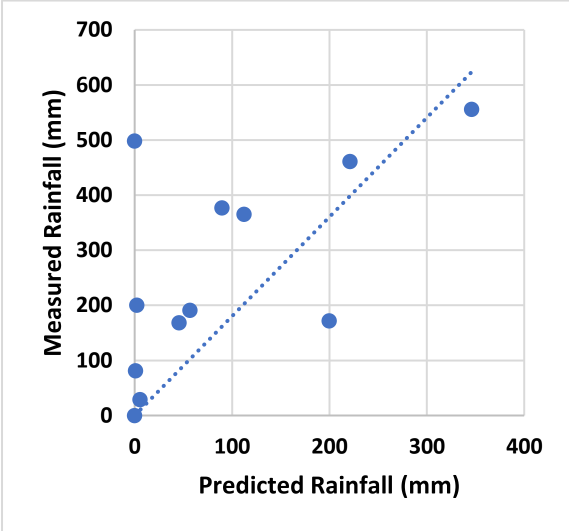

Figure 6. Scatter plot of Nino 3,4 based rainfall simulation and actual rainfall

Although previous analysis indicated that model used capable to simulate the seasonal pattern of rainfall, there was a period when used model failed to simulate rainfall pattern. Those periods were SON. Used statistical model tends to fail to simulate increasing rainfall which happens during this period. Rainfall increasing simulated by the statistical model was too low compared to its actual increasing. It was expected to be caused by a transition period which normally to occur during this period. Another failure happened in December 2017. Simulated rainfall showed that used statistical model can't predict rainfall decline which occurs during these periods.

4. Conclusion

Rainfall in Kandangan Subregency during 2017 was simulated using a statistical model. Resulted rainfall showed that used statistical model tend to underestimate rainfall especially during the wet season and transition period from dry season to wet season with mean absolute error 155.5 and 172.8 for Nino 4 and Nino 3.4 scheme respectively. Simulation result also showed that used statistical model was capable to simulate seasonal changes of rainfall with correlation value 0,504 and 0,629 for Nino 3,4 and 4 scheme respectively although there were periods when statistical model failed to simulate seasonal changes of rainfall.

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6. Appendices

Table A1. Statistical Parameter of Rainfall

Seasons	Probability	Gamma Shape	Gamma Scale
DJF	0.5	0.4	39.1
MAM	0.4	0.4	26.6
JJA	0.2	0.1	15.6
SON	0.3	0.3	23.9

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