COMPARATIVE TEST OF SEVERAL RAINFALL ESTIMATION METHODS USING HIMAWARI-8 DATA

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Abstract. Indonesian society needs information on potential hydrometeorological disasters, therefore the development of rainfall estimation methods becomes an important research activities to support disaster risk reduction. Central Kalimantan were selected as research location for comparative test of rainfall estimation methods based on Himawari-8 IR1 (11µm) data, because it has area with cloud cover fairly intensive throughout the year. Some rainfall estimation methods tested in this research are AE, CST, CSTM, IMSRA. Non Linear Relation, and Non Linear Inversion. Each of these methods tends to have a weakness in the value of accuracy, so this research aims to determine the most accurate method to be applied in Palangkaraya (27 meters above sea level) city and Muratewe (60 meters above sea level) district in Central Kalimantan. The experiment was conducted during the period of highest rainfall in January and February 2016 by converting the temperature data cloud tops (IR1) into a precipitation with AE, CST, CSTM, IMSRA, Non Linear Relation and Non Linear Inversion method. Based on the results of quantitative analysis, it was known that IMSRA was the best method which can be applied in rainfall estimation in Muarateweh's and Palangka Raya's winter period. The Accuracy of all estimation methods decreased when it was applied in Palangka Raya at afternoon and in Muarateweh at night until early morning. The estimation method with the lowest score was the AE with an average MSE value > 90 and the best estimation method was IMSRA with MSE value <12.

Keywords: *estimation, rainfall, satellite, Palangka Raya, Muarateweh*

1 INTRODUCTION

Hydrometeorological disaster is the most often disaster in Indonesia. The vulnerability of hydrometeorological disaster makes information about potential hydrometeorological disasters is needed because it's related to disaster risk reduction effort. A wheather satellite, which has wider coverage and faster in generating data than in situ observation in weather stations, is used to monitor weather in Indonesia to provide atmospheric dynamic information that is related to early warning of extreme weather. It can generate cloud top brightness temperature data to determine the presence and type of clouds, and it also can be used to generate the amount of rainfall.

Until now, there are many rainfall estimation methods that have been developed in different regions around the world. Kind of estimation method which has simple algorithm but has good accuracy is estimation method based on geostationary satellite IR1 channel data that use basic principles that the temperature of cloud tops has an inverse relationship to the amount of rainfall generated from the cloud (Upadhyaya, 2013). Some methods for rainfall estimation using satellite data channel IR1 tested in this research are AE, CST, CSTM, IMSRA, Relation Non Linear and Non Linear Inversion.

AE method has a basic principle that the temperature of the cloud top has an inverse relationship with the amount of rainfall that would result in the same grid, which the lower the temperature of the cloud top will potentially cause the highest rainfall amount (Scherer and Hudlow, 1971; Scofield, 1987). The equation obtained from the AE method is the nonlinear regression relationship between the temperature of cloud top from channel 11 μm and precipitation product from weather radar. Vicente et al. (1998) examined the relationship between the cloud top temperature and precipitation by nonlinear regression relationship between the cloud top temperature IR channels in GOES-8 satellite and precipitation product from weather radar network in the Gulf of Mexico. In their research, Vicente et al. (1998) showed that AE method has good ability to estimate rainfall rate per hour in 3 storm systems examined in the research. But the AE method has the result that tends to underestimate the precipitation due to stratiform clouds. This is because AE was developed from research on strong convective systems with a short lifetime duration. This also causes AE method have good accuracy when it's used in the estimation of rainfall for 1 to 6 hours, but had poor results when it's applied in the estimation of the daily rainfall rate. Application of AE method in rainfall estimation in Papua (Indonesia) was studied by Suwarinoto (2012), which showed that AE method has a good ability to detect rain events in Papua with an accuracy above 70%.

Estimation method that has working principle as AE is a nonlinear relationship method. Nonlinear relationship method is the name from author to an estimation method formulated by Suwarsono et al. (2009). The research examined the relationship of cloud top temperature with rainfall of QMORPH in Bengawan Solo river area. QMORPH rainfall data obtained from the combination of satellites Low Earth Orbit (LEO) with passive microwave (PMW) instrument and geostationary satellite MTSAT-1R. In regression analysis and correlation between the brightness temperature of cloud and precipitation per-pixel, the brightness temperature of the cloud more than 280 K is considered to produce rainfall = 0 mm/hr. It is based on the analysis results in the research that highest limit temperature of the cloud tops that does not produce rain rainfall data based on QMORPH is 280 K. Then the relationships equation of cloud top temperature and rain QMORPH is generated by using marginal analysis.

The next method is a nonlinear inversion method obtained from the experimental results by looking for an exponential relationship between cloud top temperature data from MTSAT satellite channel IR1 and surface rainfall in 2008 measured by an automatic rain measurement operated by LAPAN. This method was developed by Octari et al. (2015) which is based on mathematic equation obtained by using a nonlinear inverse modelling process so that result a empiric exponential equation that generates a nonlinear equation. In the research, time series of monthly rainfall estimation shows that there is a similar pattern between estimation result and observation, but the bias is too big enough. As for the estimation of diurnal pattern is pretty good though the value overestimates but there is a time shift peak of rainfall where the highest rainfall observation data occurred at 14:00 pm and the estimation data occurred at 17:00 pm.

Not as AE, non-linear relationships and non-linear inversion, for CST method cloud that will be estimated is separated into convective and stratiform clouds that are have different rainfall each other. Determining of cloud type is based on cloud top temperature gradient brightness value that were obtained from geostationary satellite data IR1 channel. Endarwin *et al.* (2014) modified CST method with a change rate of rainfall from convective and stratiform clouds. The results of research show that the accuracy of CST and CSTm applied in 23 research points spread in Java, Kalimantan, Sumatra and Sulawesi had detection accuracy of rainfall event in July 2011, November 2011, and January

2012 the method CST respectively 0,936, 0,658, and 0,689 while the method CSTm in the same month in a row is 0,974, 0,745, and 0,709.

The next method is IMSRA which is the result of research in India by Mishra et al. (2009) using TRMM Precipitation Radar (PR) data and satellite Kalpana-1 channel IR. In this method the rain/non-rain clouds is classified based on Roca et al. (2002) considering the value of BT IR and WV then calculate the regression equation to estimate 3-hourly or daily rainfall. This method also used in research Mishra et al. (2010) using Meteosat-IR and TRMM-PR data. Gairola (2011) applied IMSRA method Gairola with the result is IMSRA has good accuracy to estimate rain on area of tropical cyclone Aila in Bay of Bengal. In that research IMSRA good performance enough to estimate rainfall every three hours. Recorded rainfall estimation using IMSRA compared with observation of TRMM-3B42 has correlation coefficient 0.76, bias -0.235 and RMSE 1.73.

Six methods which are examined in this research have good accuracy when they are applied in the tropics on previous research so that wirh the condition in Indonesia that has high levels of hydrometeorological disaster vulnerability is very high, then the six rainfall estimation methods need to be tested in Indonesia so that it can be seen the best estimation method in order to the disaster risk reduction in Indonesia.

This research will discussed related to how the accuracy of six rainfall estimation methods to be applied in the region Central Kalimantan, what about difference in level of accuracy of rainfall estimation in Palangkaraya and Muarateweh, and what is the best rainfall estimation method that can be applied in Palangkaraya and Muarateweh.

This research aims to test of some methods of estimation of rainfall from satellite data Himawari-8 to obtain the best rainfall estimation method that can be applied in the Central Kalimantan region, especially in Palangkaraya and Muarateweh so hydrometeorological disaster can be identified to reduce disaster risk on those sites.

2 MATERIALS AND METHODOLOGY

2.1 Data

Data used in this research are Himawari-8 satellite IR1 channel data and GSMaP rainfall rate in January and February 2016. GSMaP data in this research are used as a validator of estimation result. This is because in these areas there are no hourly rainfall data.

Himawari-8 satellite channels IR1 data in January and February 2016 can be downloaded from http://weather.is.kochi-u.ac.jp/sat/GAME/ and calibrated by using calibrator data which can be downloaded from http://weather.is.kochi-u.ac.jp/sat/CAL/. Form GSMaP data can be downloaded from ftp://hokusai.eorc.jaxa.jp. Satellite data are generated to rainfall rate in Palangkaraya (2.23 LS - 113.939 BT; 27 meters above sea level) and Muarateweh (0.95 LS - 114.9 BT; 60 masl) (Figure 2-1).

Determination of Palangkaraya and Muarateweh region as locations of this research is based on BNPB data during 2002 until 2015 in Central Kalimantan, which indicates that have occurred at least 101 flood events there. This is caused by the amount of rainfall is so high throughout the year in Central Kalimantan (> 5 mm/h). and area of Palangkaraya and Muarateweh are sites with the highest frequency of flood events in Central Kalimantan. In Addition, taking those locations are research location are also by their difference elevation so that there are differences characteristic of diurnal rainfall and by using the same estimation method is able to produce different levels of accuracy.

On the other hand, based on climatological data, Central Kalimantan has monsoonal rainfall pattern with a monthly averaged rainfall rate, which has one peak and one valley rain in the graph. The highest monthly rainfall in Kalimantan generally occurs in January and February so that in this research during January and February 2016 are chosen for time of study.

Figure 2-1: Research site in Central Kalimantan Province, Indonesia

2.2 Method

Figure 2-2 shows a flowchart for this research. In this research, the first step is conversion of cloud top temperature IR1 channel data into rainfall rate data based on six estimation methods tested in this research. Then extraction for estimating rainfall data and GSMaP data for coordinate of two research sites. Then analyzing the accuracy of estimated rainfall data based on GSMaP data. In the end, making conclusion related to accuracy of estimation methods.

2.2.1 Rainfall Estimation Method

a. AE

Exponential equation in AE method used in this research is based on Vicente et al. (1998) as below.

$$R = 1{,}1183\,.\,10^{11}\,exp(-3{,}6382\,.\,10^{-2}\,.\,T^{1.2}) \quad (2\text{-}1)$$

R is the rainfall rate in mm/h and T is the cloud top temperature on the same grid with R in Kelvin.

b. CST

In the first step in CST method is identifying the location of a convective core using the MTSAT2 IR1 channel. Identification of this convective core is done by looking Brightness Temperature (BT) to determine the lowest temperature T_{min}. If there is more than one T_{min} in a pixel, the closest to the center of the pixel is chosen as T_{min}. After that is a calculation of the slope parameter value (S) based the value of BT at a point estimated by 8 points surrounding the equation (Islam *et al.*, 2002):

$$S = k(T_{i-1,j-1} + T_{i-1,j} + T_{i+1,j+1} + T_{i+1,j} + T_{i,j-1} + T_{i,j+1} + T_{i+1,j-1} + T_{i-1,j+1} - 8T_{i,j}) \quad (2\text{-}2)$$

With i and j are coordinate where S is calculated and k=0.125.

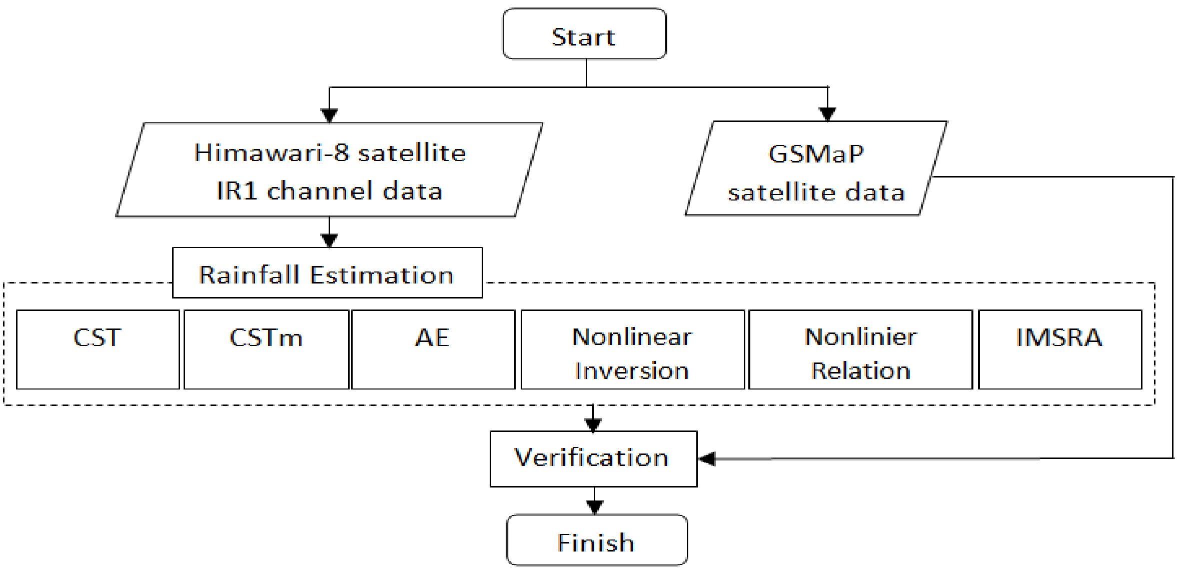


Figure 2-2: Research method flowchart

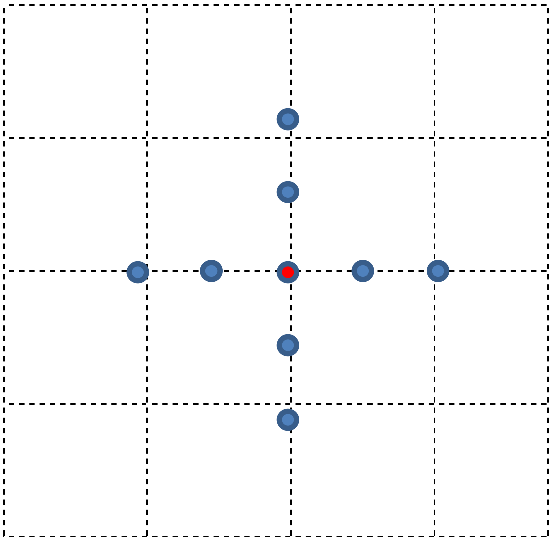


Figure 2-3: A Scheme of the 8 points used to determine the slope parameter

According to Goldenberg *et al.* (1990), in the identification of convective core, the S value must meet the following threshold.

$$S \geq exp\,[0.0826\,(T_{min} - 207) \qquad (2\text{-}3)$$

With S is slope parameter and Tmin is estimated temperature of the cloud top. After the type of cloud has known, the next step is determination of convective precipitation area (Ac) which based on Adler and Negri (1988) is formulated as follows:

$$\ln\,(A_c) = -0{,}0492.\,T_{min} + 15{,}27 \qquad (2\text{-}4)$$

The last step is to calculate the precipitation resulted from each cloud grid with the following equation (Islam et al., 2002):

$$Convective\ rainfall\ (mm) = c\,(Ac\ /\ A)\,T\,.Rc \qquad (2\text{-}5)$$

$$Stratiform\ rainfall\ (mm) = s\,(As\ /\ A)\,T\,.Rs \qquad (2\text{-}6)$$

With
c =amount of convective cell in a grid
Ac =convective rain area
A =average area for a pixel (km^2)
T =period in average (hour)
Rc =intensity of convective rain = 20 mm/hr
s =amount of stratiform cell in a grid
As =stratiform rain area
Rs =intensity of stratiform rain = 3,5 mm/hr

c. CSTm

CSTm is development of the CST by changing the intensity of the rainfall becomes Rc = 26 mm/hour and Rs = 0.8 mm/hour (Endarwin et al., 2014)

d. IMSRA

According to Gairola (2011), the regression equation in IMSRA method to estimate rainfall is:

$$R = 8.613098 * exp(-(TB - 197.97)/15.7061) \qquad (2\text{-}7)$$

With R is rainfall rate and TB is cloud top temperature of infrared (IR) channel.

e. Nonlinear Relation

The best equation proposed by Suwarsono *et al.*, (2009) is:

$$y = 2\,.\,10^{25}\,.\,x^{-10.256} \qquad (2\text{-}8)$$

With y (mm/hr) is rainfall rate and x (K degree) is cloud top temperature IR channel. The estimation result of that research has determination coefficient or R^2 = 0,9837.

f. Nonlinear Inversion

This method is proposed by Octari et al. (2015) which is based on mathematic equation obtained using a nonlinear inverse modelling process so that a empiric exponential equation as below:

$$y_{est} = 1{,}380462\,.\,10^{-7} e^{\frac{3789{,}518}{x}} \qquad (2\text{-}9)$$

y_{est} =dependent variable (rainfall rate)
x =independent variable (cloud top temperature)

2.2.2 Verification Method

Verification methods used in this research are correlation coefficient analysis and RMSE in diurnal variation. Both of these methods are used to analyze the relationship of estimated rainfall and GSMaP data and also to analyze the diurnal deviation value of estimation result related to GSMaP data.

3 RESULTS AND DISCUSSION

3.1 January 2016

Based on the result of cloud top temperature data processing from Himawari 8 satellite channel IR1, below is result of rainfall rate estimation for the month of January 2016 in Muarateweh.

Based on Figure 3-1, during January 2016 in Muarateweh, rainfall estimation using nonlinear relationship, AE and nonlinear inversion generally produces large enough in bias and tends to overestimate. It proves that 3 this method is less accurate when it's used to estimate rainfall rate in Muarateweh on January 2016. Based on Figure 3-1 above may also be known that cumuliform cloud types more often formed in the region Muarateweh than stratiform cloud types. This is because based on the research Vicente *et al.*, (1998), AE will tend to have underestimation for the rainfall from stratiform clouds.

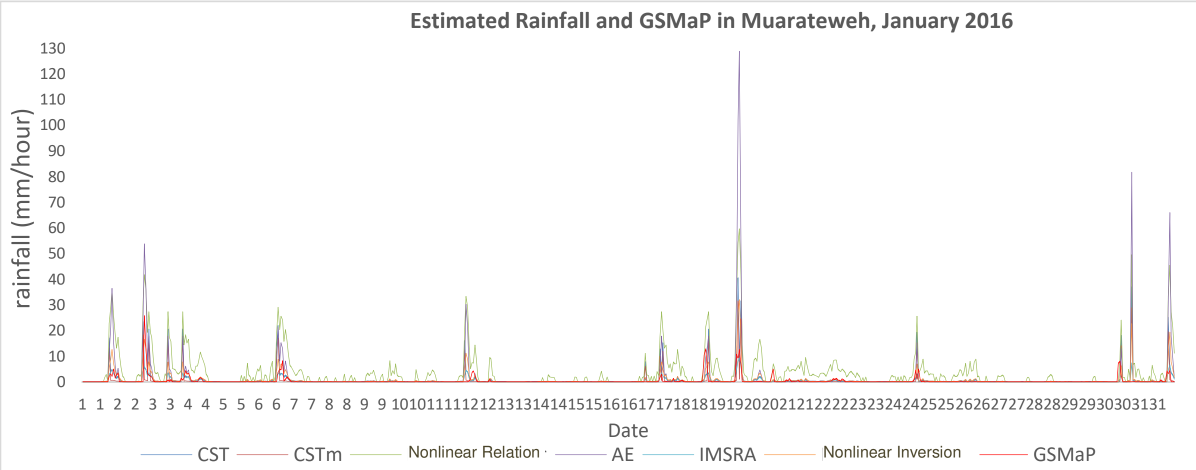
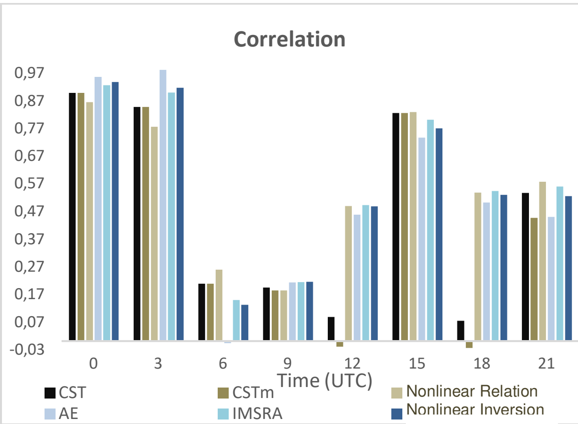


Figure 3-1: Graph of estimated rainfall and GSMaP in Muarateweh in January 2016



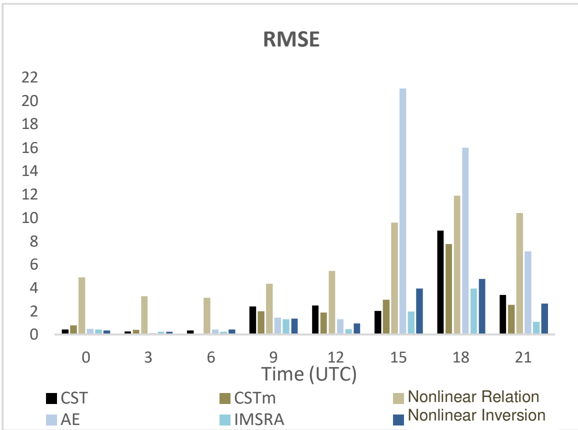


Figure 3-2: Graph of Correlation and RMSE between Estimated Rainfall and GSMaP in Muarateweh on Januari 2016

Based on Figure 3-2, in terms of similarity of the diurnal pattern to the data GSMaP, all of estimation methods have the same general pattern that the highest correlation in the morning then decreases in the afternoon. Correlation coefficients increase again at night and decrease during the early morning, but not as significant as the afternoon-evening. It shows that in the morning, rainfall estimation and GSMaP on January 2016 has a pattern of increase/ decrease is almost same with a correlation coefficient >+0.77. And during the day until early evening, the relationship between pattern of rainfall estimation data and GSMaP is not so obvious as indicated by the correlation value <+0.27. Meanwhile, during night until early morning correlation coefficients >+0.35. Figure 3-2 also shows that the negative correlation (r> -0.03) occur at night for CSTm method which shows that estimated amount of rainfall increase, meanwhile GSMaP data decrease. Based on the diurnal variation of the correlation value, the best estimation method for Muarateweh region during January is IMSRA correlation value of about 0.67.

Based on RMSE data (Table 3-1), the greatest error of estimation occurs during the night until early morning for all estimation methods. The nonlinear relationship method shows the result with large deviation throughout the day and estimation data from AE method has the maximum deviation of the data. Whereas, a method with the lowest deviation value is IMSRA with RMSE values as below.

Table 3-1: RMSE of Rainfall Estimation in Muarateweh on Januari

CST	2.54
CSTm	2.32
Nonlinear relation	6.62
AE	6.01
IMSRA	1.22
Nonlinear inversion	1.85

Based on correlation value and RMSE, so that the best estimation method on January 2016 to be applied in Muarateweh is IMSRA.

Estimation result for Palangka Raya can be seen in Figure 3-3. Based on Figure 3-3, diurnal variation of the correlation between rainfall estimation and GSMaP is similar with data in Muarateweh to the general pattern is the highest correlation value during the morning and evening, and decline during the evening and early morning. But data in Palangka Raya have differences in the correlation values for 21 UTC that the correlation value of all estimation methods is negative r>-0.05. Based on the correlation coefficient, the best method which can be applied in Palangkaraya on January 2016 is IMSRA with correlation coefficient is +0.5.

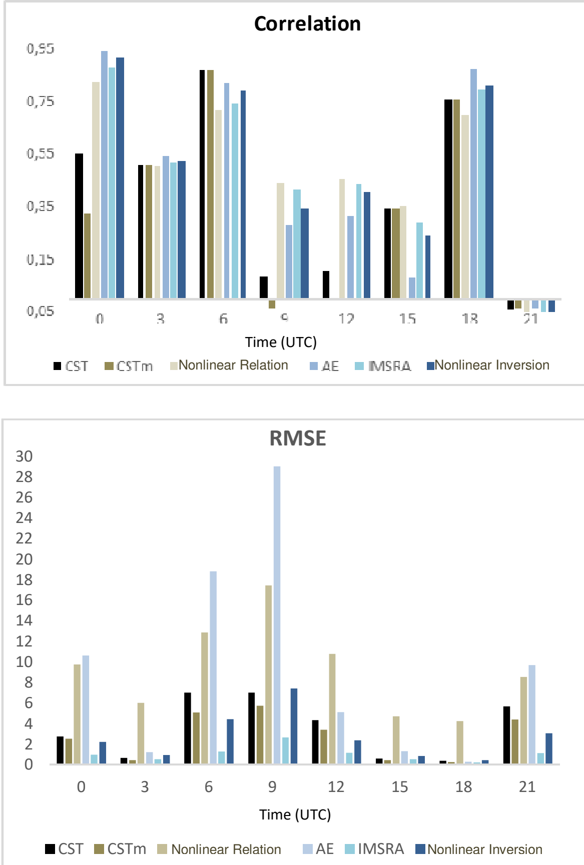


Figure 3-3: Graph of Correlation and RMSE between Estimated Rainfall and GSMaP in Palangka Raya on Januari 2016

Figure 3-3 also shows that the largest deviation occurs during daylight afternoon. AE method is a method with the largest deviation (RMSE = 9.5) and estimation methods with the smallest deviation is IMSRA (RMSE = 1.05). So that the best estimation method in the area of Palangka Raya on January 2016 that can be applied is IMSRA.

Based on the data rainfall estimation on January 2016 in Muarateweh and Palangkaraya (Figure 3-3), there are significant differences related to the accuracy of estimation at both places. Rainfall estimation in Muarateweh produces data that are poor during night early morning while in Palangkaraya, the estimation result is not good enough during the day and evening. This distinction is very closely related to the topography of the region that also affect to the diurnal pattern of rainfall in both places. Here is a graph of the amount of rainfall per 3 hours at both sites.

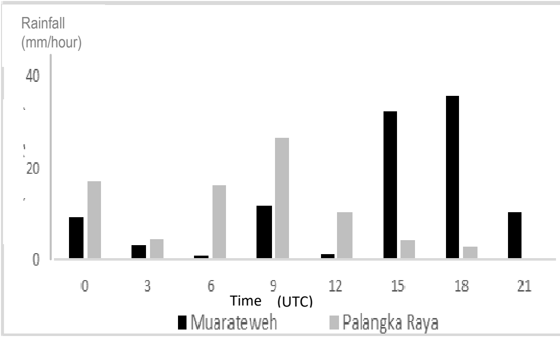


Figure 3-4: Timeseries of Total Rainfall from GSMaP Data in Muarateweh and Palangka Raya in January 2016

3.2 February 2016

The results of rainfall estimation in February 2016 can be seen in Figure 3-5.

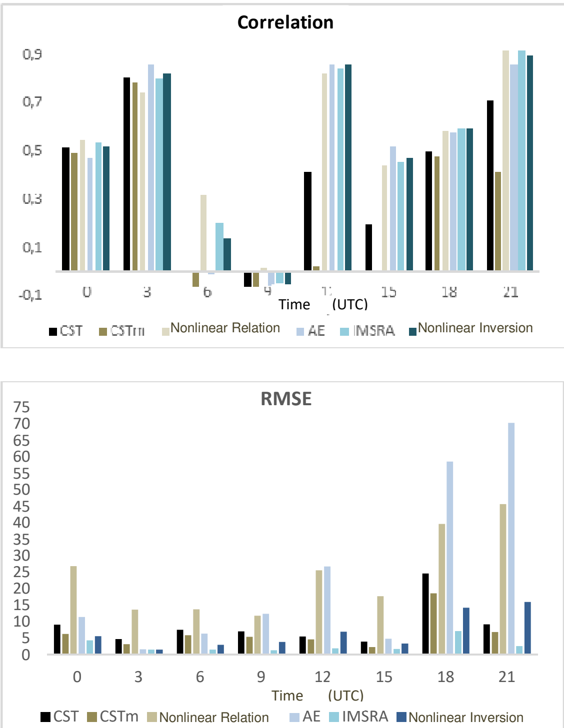


Figure 3-5: Graph of Correlation and RMSE between Estimated Rainfall and GSMaP on Muarateweh in February 2016

Figure 3-5 shows that the value of the data which correlates rainfall estimation and GSMaP on February in Muarateweh throughout the day is higher than the correlation coefficient in January. The difference is the RMSE value of the data estimation which is shifting in time of highest RMSE values. In January, the average RMSE of 6 estimation methods occured at 15-18 UTC, while in February the highest RMSE at 18-21 UTC. It shows that there are indications of seasonal influences that has impact to the results of the rainfall estimation in Muarateweh.

Based on the correlation can be seen that the best estimation method that can be applied in Muarateweh on February 2016 is nonlinear relationship method (r = + 0.55) and IMSRA (r = + 0.54), while the worst method because it has the lowest correlation value is CSTM (r = + 0.2). While based on RMSE, the best estimation method with the lowest deviation is IMSRA (RMSE = 2.8) and the worst methods a nonlinear relation (RMSE = 24.37).

The accuracy of the estimation of rainfall in Palangkaraya can be seen in the following graph (Figure 3-6). Based on Figure 3-6, the correlation between rainfall estimation and GSMaP in Palangka Raya show significant improvement compared with a correlation value in January, while the pattern of correlation values diurnalnya there are differences. The most striking difference is the correlation value at 21 UTC where in January, the correlation value is very low with the inverse relationship (negative correlation), while in February the correlation value is high enough in all of estimation methods, except CSTm which have low correlation value throughout the day on February.

As for kmowing how big the deviation value can be seen in the graph RMSE Figure 3-6. In that graph, it appears that the lowest accuracy in every estimation method also shifts in time. In January the value of the biggest mistakes is found in the estimation result in 6-12 UTC, while in February the biggest mistakes are found in 12-18 UTC.

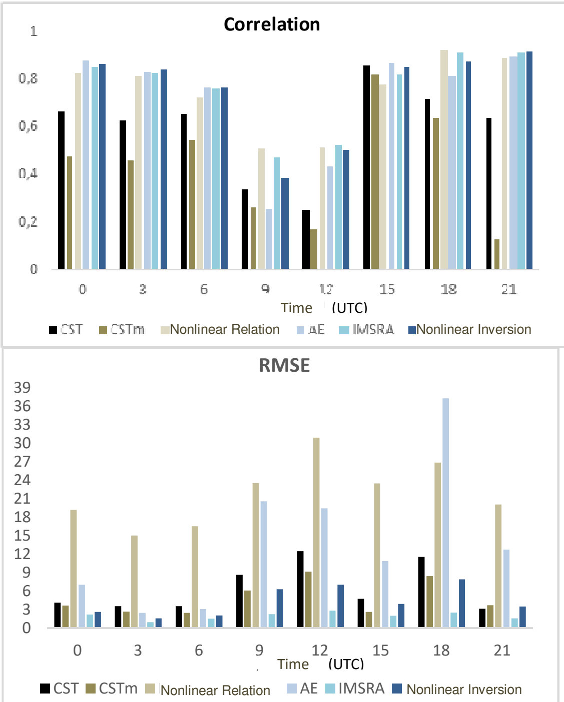


Figure 3-6: Graph of Correlation and RMSE between Estimated Rainfall and GSMaP in Palangka Raya in February 2016

Based on the correlation coefficient, the best estimation method to be applied in Palangkaraya on February 2016 is IMSRA (r = + 0.76) and worst method is CSTM (r = + 0.44). Meanwhile, based on RMSE, estimation method with the highest accuracy is IMSRA (RMSE = 1.94) and the worst method with the greatest deviation value is nonlinear relationship (RMSE = 21.92).

On the pattern of RMSE values per 3 hours during February 2016 in Palangka Raya and Muarateweh there are differences as in January 2016. Six rainfall estimation methods used in this study are decreasing in accuracy when they are applied in Muarateweh at dawn while in Palangka Raya decreasing are accuracy at night. If Figure 3-6 is observed and associated with Figure 3-7 wich is a graph of total rainfall rate in both of places during February 2016, a decrease in the accuracy of estimation of the sixth method occurs when the highest rainfall are diurnal. In Muarateweh, the highest rainfall occurred in the early morning, which corresponds to RMSE increasing. It's also for Palangka Raya total rainfall data where rainfall is highest at night and increasing value of RMSE was also at the time.

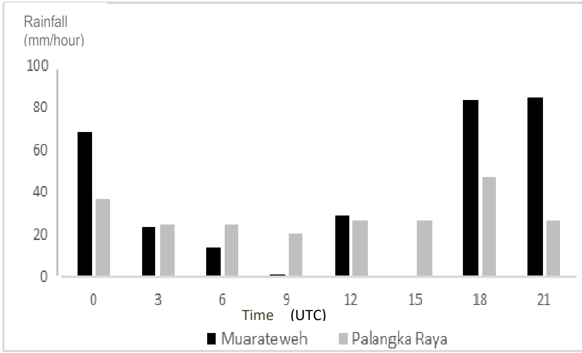


Figure 3-7: Timeseries of Total Rainfall from GSMaP Data in Muarateweh and Palangka Raya in February 2016

4 CONCLUSION

The best method that can be applied in the rainfall estimation at the rainy season in Muarateweh and Palangkaraya is IMSRA. All of the methods examined in this research had better accuracy when they are used at the time except the time of diurnal highest rainfall (RMSE<4,0), whereas at the time of rainfall diurnal reached the highest value, the accuracy of rainfall estimation methods tend to decrease. This shows that six methods are poor to estimate rainfall rate in Palangkaraya during afternoon (RMSE= 9,0) and in Muaratewe during night until early morning (RMSE= 13,1). The estimation method with the lowest score is AE with the accuracy in average MSE>90 and the best estimation method is IMSRA with MSE value <12.

Related to decreasing the accuracy of estimation methods during the time of diurnal highest rainfall, need to do a further research to discuss about the causes of decreasing accuracy of estimation methods so that will be know correction of every method to improve its accuracy.

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