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Evaluation of GSMaP Rainfall Data in the Aceh Region

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ABSTRACT

Rainfall measurement data in the field is quite limited, however, satellite data obtained by remote sensing methods are widely available. However, its accuracy must still be tested using observational rainfall data. The objective of this research was to validate GSMaP satellite estimated rainfall data with Automatic Rain Gauge (ARG) rainfall data at rain stations dispersed over Aceh Province's west-central region, as well as to identify the primary drivers for GSMaP data error. ARG and GSMaP data sources. A comparison of GSMaP data accuracy using a combination of Pearson and RMSE tests shows that GSMaP performance is very low in the dry and transition seasons and significantly better in the rainy season. GSMaP, on the other hand, is still unable to offer sufficient precise rainfall estimation data for each season. Meanwhile, a comparison by elevation shows that GSMaP data is not fully reliable.

KEYWORDS : ARGs, Pearson, RMSE, Satellite, West-central Aceh Province

INTRODUCTION

Sumatra Island has great rainfall variability. Rainfall in Sumatra is influenced by global and local weather and climatic factors as well as geographical factors such as regional topography [1], [2]. This rainfall variability can occur at annual, monthly, and even daily levels [3].

Bukit Barisan Sumatra (BBS), which extends across the central part of Sumatra, is one of the synoptic-scale geographic factors that influence cloud movement and distribution in Sumatra [4] – [8]. The same thing happens in the west-central region of Aceh Province, which is located in the northern part of Sumatra Island, where fluctuating rainfall is also found [9], [10].

Rainfall is the most important factor in meteorology since it influences many industries, including agriculture, tourism, and health [11]. Rainfall measurements at each observation station generate point rainfall data, which is thought to reflect rainfall within a particular radius. The length of this radius is determined by the topography of the area and the type of rain in the area, however owing to many issues, such as the expense of establishing and operating weather stations and challenging topography or natural circumstances, a limited number of rain observation stations are available [12], [13].

In the last few decades, this problem has been overcome by the development of rainfall prediction using weather observation satellites. One of them is the Global Satellite Mapping of Precipitation (GSMaP), a Japanese space agency project developed to measure global rainfall values.

However, the reliability of the data released by this satellite needs to be validated with data measured by surface rainfall measurement instrumentation. The rainfall value estimated by GSMaP and the rainfall value measured by instruments at the station may differ. This is because GSMaP satellites measure the intensity of infrared and microwave radiation scattered by clouds to predict the amount of rainfall that will fall to the surface, and the GSMaP data processing algorithm has not collected corrections that cause data errors due to very local factors [14], [15].

The topography of the west-central Aceh region is dominated by the influence of BBS, causing the number of operational rainfall gauges to be relatively low. This also underlies the need for this study. As a result, the need for rainfall data measured by weather satellites (in this case, GSMaP) really helps to complement the limited distribution of rain stations. However, GSMaP performance must be tested first by considering local factors such as topography that affect it [16].

The problem formulation in this study is to explore the compatibility of GSMaP estimation data with surface observation data due to the influence of topography and yearly seasons, as well as what causes data mistakes due to topography and seasonal variations. The objective of this study was to compare projected rainfall data from the GSMaP satellite to Automatic Rain Gauge (ARG) rainfall data at rain stations dispersed across Aceh Province's west-central region and to identify the primary factors for GSMaP data error.

METHODS

Research Area

A comparison of GSMaP rainfall data with ARG rainfall data was carried out in the western-central region of Aceh Province which is geographically located at 5°15'19"North 95°21'57"East to 2°08'21"North 98°08'39"East.

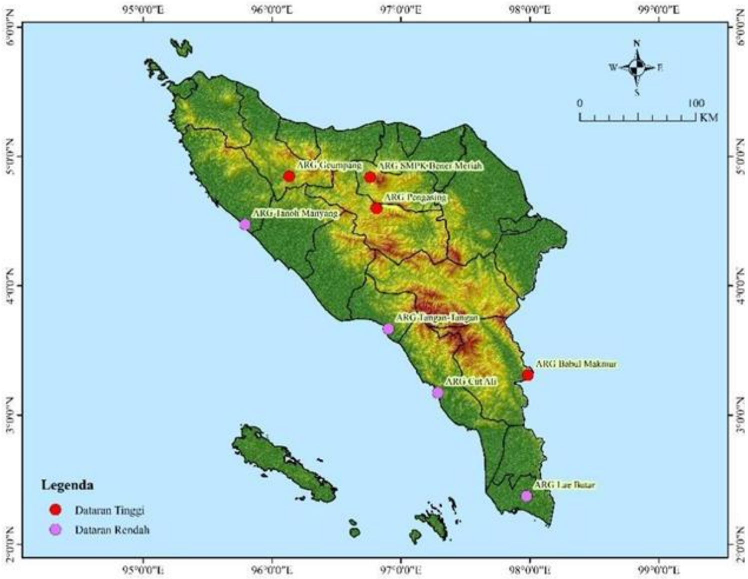


Figure 1. Research Area Map

The study area is divided into two division areas based on several considerations, including regional division based on differences in area topography, namely the lowland region (I) in western region of Aceh Province and the highland region (II) in the central region of Aceh Province. Each area is chosen for the presence of several rain stations. This division aims to analyze the performance of GSMaP satellites in estimating rainfall values due to the influence of altitude. The selection of the area takes into account climatological factors that support rainfall throughout the year [17].

ARG Rainfall Data

The surface rainfall data used is rainfall data measured by the BMKG's Automatic Rain Gauge (ARG) spread over 8 regencies in the west-central region of Aceh Province. The data obtained is in the form of daily data, which is then accumulated into monthly data. The data used in this study is for 2021. There are 4 stations taken from each region I and region II, so the total number of stations used is 8 (Table 1).

Table 1. ARG Rain Station

Stations Code	Regency	Region	North latitude (°)	East longitude (°)	Elevation (m)
ARG Cut Ali	Aceh Selatan	I	3.17356	97.28612	6
ARG Lae Butar	Aceh Singkil	I	2.37415	97.97392	30
ARG Tangan-Tangan	Aceh Barat Daya	I	3.66749	96.90368	6
ARG Tanoh Manyang	Aceh Jaya	I	4.47513	95.791555	5
ARG Geumpang	Pidie	II	4.84630	96.132658	500
ARG Pengasing	Aceh Tengah	II	4.59862	96.80948	1.228
ARG Babul Makmur	Aceh Tenggara	II	3.29773	97.9642	979
ARG SMPK Bener Meriah	Bener Meriah	II	4.84	96.761	1.327

GSMaP

GSMaP data is available on the Japan Aerospace Exploration Agency (JAXA) website and can be accessed at the URL http://sharaku.eorc.jaxa.jp/GSMaP/index.htm. GSMaP data has a temporal resolution in a 1-hour period (GSMaP_NRT Hourly) which contains rain intensity (mm/hour) for 1 day from 00:00–23:59 UTC with the data format as .npz. This daily rainfall data is in the form of a grid with a spatial resolution of 0.11° x 0.11° or a spatial area of around 12.21 square km is represented by one grid. The process of describing GSMaP data to suit the study area requires writing a Python script for data mining on the ARG coordinates taken.

GSMaP Estimated Rainfall Value

ARG rainfall data that is measured 24 hours has a temporal resolution that is automatically updated every 10 minutes. Rainfall per 10 minutes is accumulated into daily rainfall. Furthermore, the data used is the value of daily rainfall which is accumulated into monthly rainfall which is then used in this study.

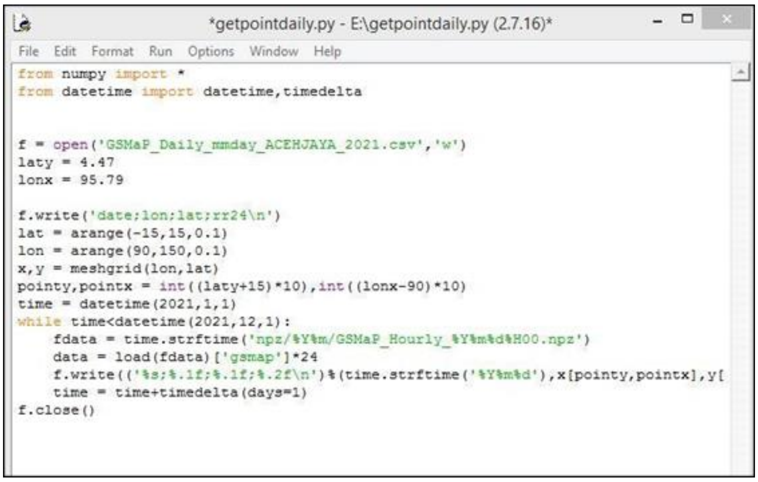


Figure 2. Coordinate Adjustment in Python

The downloaded data needs to be processed to describe the GSMaP data and the ARG data, which involves adjusting the GSMaP measurement points to the ARG coordinates on the surface. Selection of ARG coordinates can be done by creating a Python script. Next, the selection is made by adjusting the location of the latitude and longitude of the ARG point in the Python script.

Furthermore, GSMaP_NRT Hourly data is accumulated into daily rainfall data (GSMaP_NRT *Daily*) to adjust its temporal resolution with ARG data. GSMaP data and surface rainfall sourced from ARG are plotted based on time series. Rainfall is grouped into 3 periods in a year, namely rainfall in January representing the wet season, the peak of the dry season (August), and the transitional period from the dry season to the wet season (September). Then, an overall analysis is carried out between stations in the highlands and those in the lowlands.

Statistical Test

Pearson Correlation Coefficient

Pearson correlation comparison test was carried out to find the degree of closeness of the relationship between the two independent variables. These two variables do not necessarily state causation. Pearson correlation value can be searched by

$$r = \frac{\sum(x-\bar{x})(x-\bar{y})}{\sqrt{\sum(x-\bar{x})^2}\,\sqrt{\sum(y-\bar{y})^2}} \qquad (1)$$

where

r = Correlation coefficient,

x = ARG rainfall value,

y = GSMaP value.

Root Mean Square Error (MRSE)

The RMSE test is carried out to compare the level of reliability of the forecast results of a model (in this case the GSMaP rainfall estimate). RMSE is the quantity of error produced by a forecasting model. A small RMSE value means that the variation in the value produced by a forecasting model is close to the variation in the observed value. The RMSE formula is as follows:

$$\sqrt{\frac{\sum_{i=1}^{n}(y_i-\hat{y_l})^2}{n}} \qquad (2)$$

RESULTS AND DISCUSSION

ARG Rainfall Data

Observational rainfall data obtained from several ARGs in Region I and Region II yields the result that Region II has the highest rainfall throughout January, August, and September 2021. This can happen because Region II is a mountainous region and an area that faces the wind (*windward*).

The wind from the Indian Ocean generates a lot of water vapor. A small portion of this water vapor falls as rain in Region I, while most of it passes through Region I to descend in Region II due to cooling from being forced up into the higher air by the mountainous topography, which is a geographical characteristic of Region II. A comparison of the amount of rainfall in Regions I and II can be seen in Figure 3. For rainfall data in January, August, and September at each ARG station, it can be seen in Figure 4.

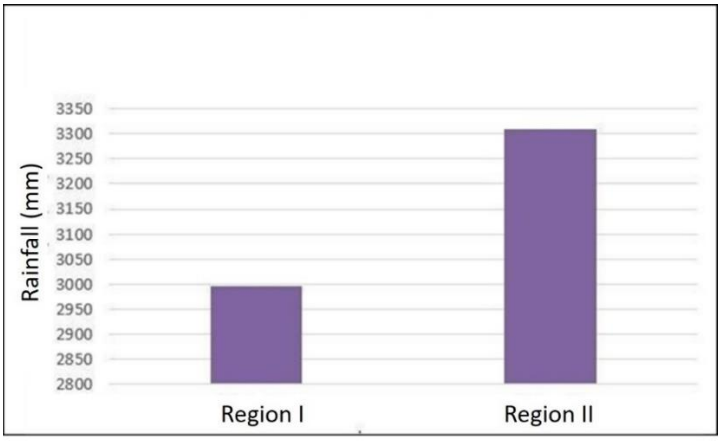
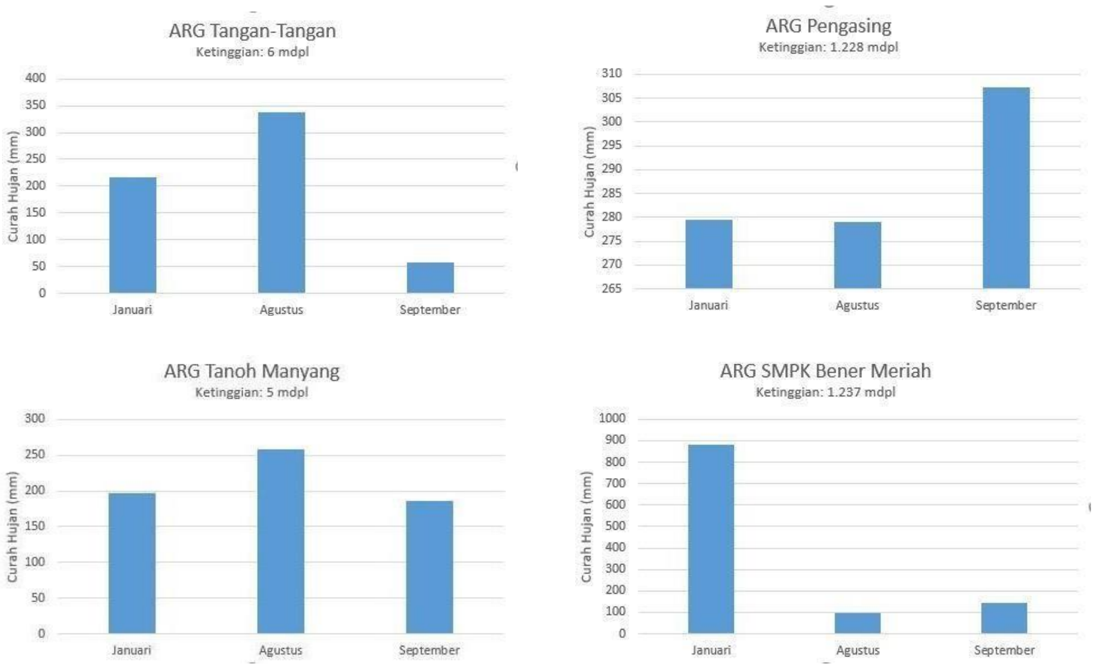


Figure 3. Comparison of Total Rainfall (mm) in Regions I and II



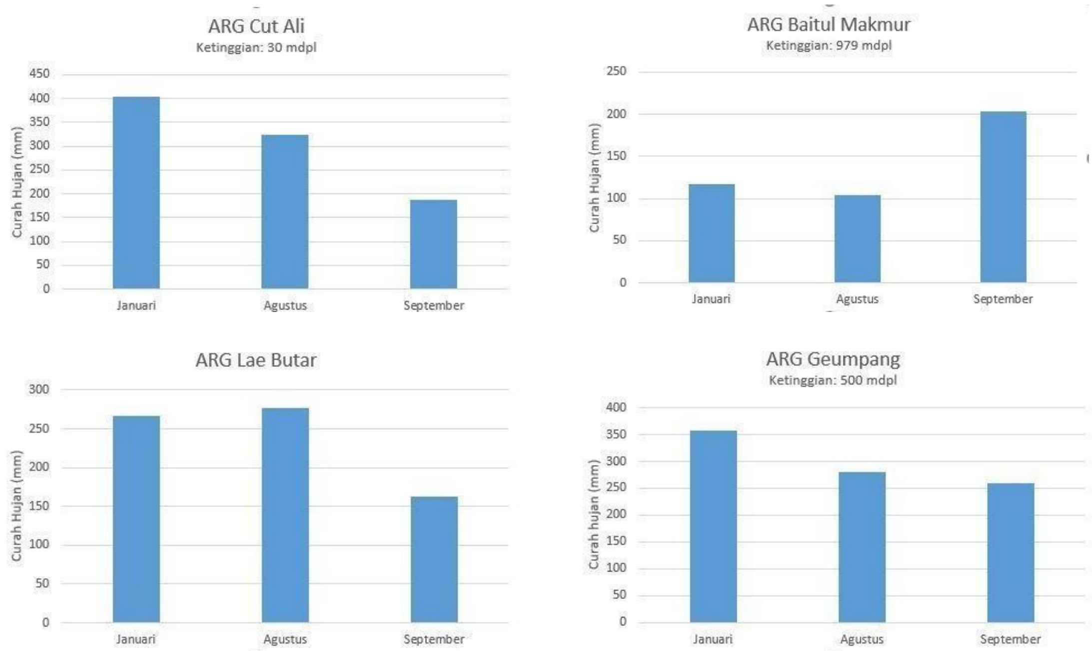


Figure 4. Rainfall (mm) with Altitude Location (Above Sea Level in Meters) in Each Region and Period

The three temporal variations, namely January-August-September, were chosen to test the validity of GSMap to ARG.

Figure 5 shows a graph of rainfall for the 2021 season. From the infographic, January has the highest rainfall.

This is a fact that the amount of rainfall in the west-central region of Aceh Province is dependent on the South Asian monsoon winds, which usually take place from October–January [18]. However, this does not rule out the possibility that high rain intensity can occur in the middle of the year in this region. The west-central region of Aceh Province is classified climatologically as a tropical climate area, which indirectly has rainfall throughout the year. The main rain clouds in this region come from the Indian Ocean. Therefore, every rain event in this region generally has a relationship with the surface temperature of the Indian Ocean [19].

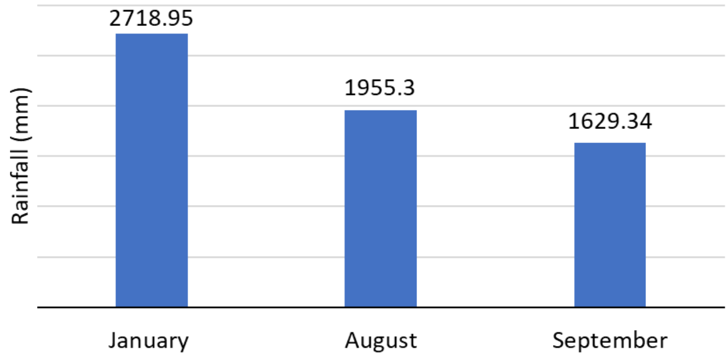


Figure 5. Total Rainfall (mm) in Each Season (January, August, and September 2021)

Comparison or ARG and GSMaP Rainfall

The comparison of ARG and GSMap rainfall is divided into two variations, namely based on altitude and seasonality. The amount of rainfall issued by the satellite is an indirect prediction of rainfall using microwave and infrared sensors, then the term "overestimate" is used if the amount of rain output from the satellite exceeds the amount of surface rain and "underestimate" if the amount of satellite rain is less than the amount of surface rain [20]. A visual comparison with a bar graph was performed to see the difference between the GSMaP estimate and the real value measured by ARG (Figure 6). The coefficient of determination (R^2) represents the percentage of the total variation in the fit between the GSMaP data as the dependent variable and the ARG data as the independent variable (Table 2).

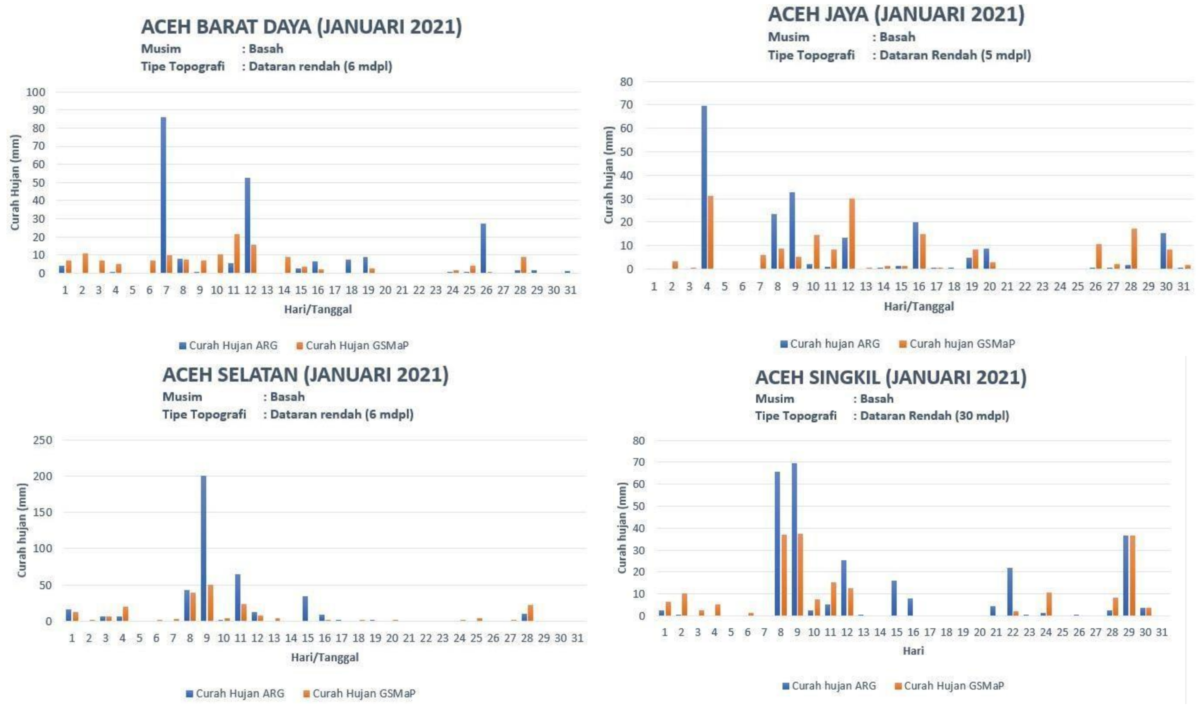


Figure 6. Comparison of Daily GSMaP and ARG Rainfall (mm) in Each Region I with the Season and Altitude Location (Above Sea Level in Meters)

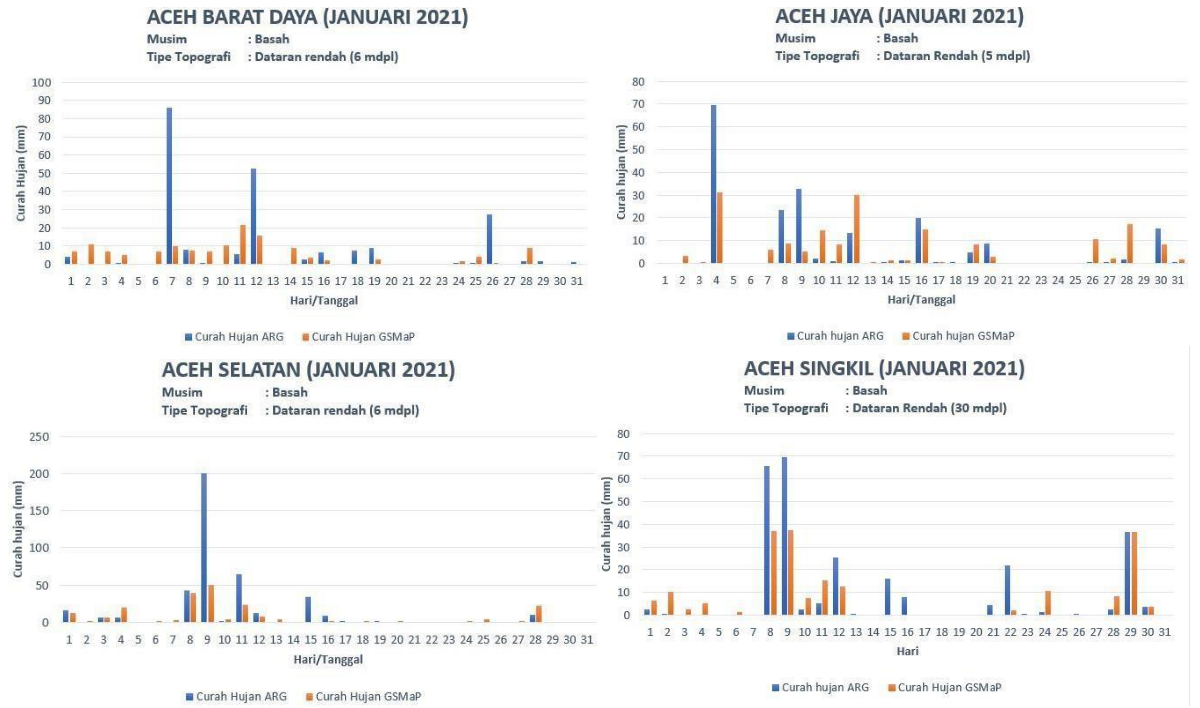


Figure 7. Comparison of Daily GSMaP and ARG Rainfall (mm) in Region II with the Season and Altitude Location (Above Sea Level in Meters)

Table 2. Coefficient of Determination of GSMaP Data on ARG Data

Observation Point	Region	Coefficient of Determination (R^2)		
		January	August	September
ARG Tangan-Tangan	I	0.115	0.359	0.085
ARG Tanoh Manyang	I	0.445	0.652	0.557
ARG Cut Ali	I	0.657	0.043	0.043
ARG Lae Butar	I	0.003	0.340	0.057
ARG Geumpang	II	0.003	0.172	0.003
ARG Babul Makmur	II	0.409	0.621	0.187
ARG Pengasing	II	0.120	0.013	0.320
ARG SMPK Bener Meriah	II	0.334	0.192	0.419

To determine the value of GSMaP data quality in predicting rainfall, the determination of data quality values is also carried out quantitatively using statistical parameters, namely the coefficient of determination, root mean square error test, and Pearson correlation (Tables 3, 4, and 5).

Table 3. Root Mean Square Error (RMSE) Test between ARG and GSMaP Data

ARG Placement Regency	Region	Month (season)	RMSE
		January (Wet)	17.1
Aceh Barat Daya	I	August (Dry)	13.3
		September (Transition)	13.7
		January (Wet)	10.5
Aceh Jaya	I	August (Dry)	14.8
		September (Transition)	7.1
		January (Wet)	29.3
Aceh Selatan	I	August (Dry)	21.3
		September (Transition)	21.2
		January (Wet)	7.3
Aceh Singkil	I	August (Dry)	9.8
		September (Transition)	7.1
		January (Wet)	7.8
Aceh Tenggara	II	August (Dry)	17.1
		September (Transition)	13.6
		January (Wet)	15.1
Aceh Tengah	II	August (Dry)	25.3
		September (Transition)	19.3
		January (Wet)	54.5
Bener Meriah	II	August (Dry)	20.4
		September (Transition)	14.9
		January (Wet)	18.2
Pidie	II	August (Dry)	13.4
		September (Transition)	11.1

Table 4. GSMaP Performance in Each Season and Region

ARG Placement Regency	Region	Month (season)	GSMaP performance
Aceh Barat Daya	I	January (Wet)	
		August (Dry)	
		September (Transition)	
Aceh Jaya	I	January (Wet)	
		August (Dry)	
		September (Transition)	
Aceh Selatan	I	January (Wet)	
		August (Dry)	
		September (Transition)	
Aceh Singkil	I	January (Wet)	
		August (Dry)	
		September (Transition)	
Aceh Tenggara	II	January (Wet)	
		August (Dry)	
		September (Transition)	
Aceh Tengah	II	January (Wet)	
		August (Dry)	
		September (Transition)	
Bener Meriah	II	January (Wet)	
		August (Dry)	
		September (Transition)	
Pidie	II	January (Wet)	
		August (Dry)	
		September (Transition)	

The level of correlation between ARG and GSMaP values is the estimated GSMaP value that is close to the rainfall value measured at ARG. The estimated value of the GSMaP satellite can be lower (underestimate) or higher (overestimated) than the value in ARG (Tables 6 and 7).

Table 5. Difference between GSMaP and ARG Values in Region I

Regency	Month	ARG	GSMaP	Difference
	January	404.4	209.27	195.13
Aceh Selatan	August	323.2	338.56	-15.36
	September	310.6	157.79	152.81
	January	196.1	178.9	17.2
Aceh Jaya	August	258.6	236.97	21.63
	September	186.2	192.2	-6
	January	216	141.91	74.09
Aceh Barat Daya	August	337.58	431.22	-93.64
	September	57.79	247.93	-190.14
	January	266.25	196.73	69.52
Aceh Singkil	August	276.4	281.78	-5.38
	September	169.64	162.61	7.03

Table 6. Difference between GSMaP and ARG Values in Region II

Regency	Month	ARG	GSMaP	Difference
Aceh Tengah	January	279.5	241.04	38.46
	August	279.1	236.97	42.13
	September	307.17	192.2	114.97
Aceh tenggara	January	117	157.65	-40.65
	August	104.4	430.29	-325.89
	September	203.6	221.56	-17.96
Bener Meriah	January	882.1	233.37	648.73
	August	96.8	445.31	-348.51
	September	142.9	292.46	-149.56
Pidie	January	357.6	190.26	167.34
	August	279.8	324.22	-44.42
	September	259.07	183.63	75.44

Correlation According to Elevation Differences

The difference in values obtained by the GSMaP sensor is a result of the sensitivity of the sensor, which measures rainfall from microwave and infrared scattering in a cloudy atmosphere. Topography affects the characteristics of the collected rain clouds.

The results of the GSMaP estimation in all regions I during the study period showed that the quantity of weak performance was more dominant than the others by 42%, moderate performance by 8%, strong performance by 33%, and perfect performance by 17%. Meanwhile, the results are almost the same for high topography, with a poor performance of 50%, a moderate performance of 17%, a strong performance of 33%, and never showing perfect performance at all (0%). The data shows that the GSMaP satellite has a slightly better performance in the lowlands compared to the highlands. However, in general, these results reveal that GSMaP data is not fully reliable.

Correlation According to Seasonal Differences

Rain intensity and surface emissivity affect the performance of GSMaP satellites. The difference in the position of the sun is what causes changes in the seasons and the intensity of radiation received by the earth. GSMaP satellite performance is slightly better in the wet season. From 8 comparative samples spread over Regions I and II for 3 months of study samples, 24 results were obtained to compare the accuracy of GSMaP data through a combination of Pearson and RMSE correlation tests. The results can be seen in Table 7.

Table 7. GSMaP Performance Quantities in Each Season (x is Times)

Wet Season	3x	1x	2x	2x
Dry Season	4x	1x	3x	0x
Transition season	4x	1x	3x	0x

■ : weak; ■ : moderate; ■ : strong; ■ : perfect

From Table 7 it can be concluded that the performance of GSMaP is very poor in the dry and transition seasons, and slightly better in the wet season. However, overall GSMaP is still unable to provide sufficiently accurate rainfall estimation data.

CONCLUSION

According to the results of statistical analysis on ARG and GSMaP rainfall data in 8 sample regions in Aceh Province with varying topography and seasons, rainfall prediction with the GSMaP satellite has not been able to assess the influence of topography and seasonal changes in general. However, the association between ARG and GSMaP data can be noticed in specific circumstances of rain. These findings also show that when compared to GSMaP rainfall data, accumulated rainfall data in a Dasarian will add statistical inaccuracies. In lowland locations, the substantial discrepancy in values detected by ARG and GSMaP is attributable to the combination of sea level and land surface [21]. Meanwhile, the GSMaP data error problem that is frequently encountered in highland locations is caused by orographic rain, which has minimal ice in the sky above the orographic clouds [22].

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