COMPARISON ANALYSIS OF HIMAWARI 8, CHIRPS AND GSMaP DATA TO DETECT RAIN IN INDONESIA

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ABSTRACT

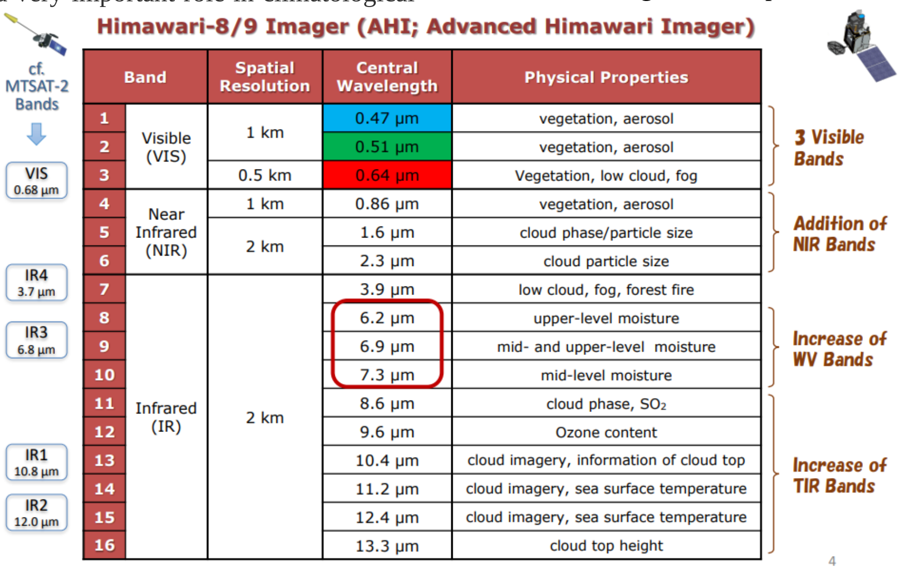
The need for rainfall data, especially for areas where the number of observation stations is not very close, is very important for local climate analysis activities. This data need can be met, one of which is from remote sensing data, such as Himawari 8. The Himawari 8 rainfall data are data derived using the INSAT Multi-Spectral Rainfall Algorithm (IMSRA) method based on the infrared channel on the Himawari 8 satellite. However, research on the IMSRA method was carried out using a case study of a region in India. Thus, validation is needed to determine the ability of Himawari 8 rainfall data to detect rain in Indonesia. The data used for comparison are CHIRPS and GSMaP rainfall data. In addition, BMKG rainfall data are used as benchmark data. The technique used for validation is using the Contingency Table method. The results of the validation show that the rain detection ability for Himawari 8 rainfall data is relatively good, namely 66% for 2019 and 85% for 2020. In addition, the ability to detect rain using Himawari 8 rainfall data is quite good compared to the ability to detect rain using CHIRPS rainfall data and GSMaP rainfall data.

Keywords: rainfall detection, Himawari 8 satellite, CHIRPS, GSMaP, contingency table

1. Introduction

Availability of rainfall data from surface observation stations in Indonesia; especially in several regions of Indonesia becomes very important, especially for disaster analysis. However, until now the availability and accuracy of observational data is still very limited, so the use of satellite data is very important and necessary. Global rainfall data with high accuracy has a very important role in climatological and hydrological analysis, especially for the purposes of disaster analysis [1]. The accuracy of rainfall data in Indonesia is not yet known, which encourages data validation by comparison with rainfall data from observation stations.

Remote sensing is the science of obtaining information about the surface of the earth without coming into direct contact with it [2]. Currently, remote sensing for atmospheric observations is very


Himawari-8/9 Imager (AHI; Advanced Himawari Imager)

Band		Spatial Resolution	Central Wavelength	Physical Properties
1	Visible (VIS)	1 km	0.47 μm	vegetation, aerosol
2			0.51 μm	vegetation, aerosol
3		0.5 km	0.64 μm	Vegetation, low cloud, fog
4	Near Infrared (NIR)	1 km	0.86 μm	vegetation, aerosol
5		2 km	1.6 μm	cloud phase/particle size
6			2.3 μm	cloud particle size
7	Infrared (IR)	2 km	3.9 μm	low cloud, fog, forest fire
8			6.2 μm	upper-level moisture
9			6.9 μm	mid- and upper-level moisture
10			7.3 μm	mid-level moisture
11			8.6 μm	cloud phase, SO_2
12			9.6 μm	Ozone content
13			10.4 μm	cloud imagery, information of cloud top
14			11.2 μm	cloud imagery, sea surface temperature
15			12.4 μm	cloud imagery, sea surface temperature
16			13.3 μm	cloud top height

Figure 1. Himawari 8 imagery specifications (source: Okamoto and JMA, 2016)

important [3], and one of them is to estimate rainfall. Accurate rainfall estimation techniques based on satellite data are quite interesting to study and develop (especially in Indonesia) because of the high temporal and spatial variability [4]. Satellite-based rainfall estimation results have been widely used [5], one of them using Himawari 8.

Himawari 8 is a geostationary satellite with wide coverage and real time which has 16 channels (three visible, three near-infrared, and ten infrared) with different wavelengths (Figure 1). This satellite is capable of providing data every 10 minutes with a spatial resolution of 2 km [6]. According to Hirose et al in 2019, Himawari 8 is the first geostationary satellite equipped with a 6.9 μm visible wave channel which allows for more detailed information about the distribution of visible waves in the middle to upper troposphere [1]. Hirose et al also stated that Himawari 8 data is expected to yield more detailed rainfall information to analyze the "warm type" rain in the Asian monsoon region as mentioned by Sohn et al in 2013 [1], [7].

Several methods for estimating rainfall using satellite data have been developed. Suwarsono et al in 2009 found that the lower the cloud brightness temperature, the higher the rainfall, except for cirrus clouds which are not rain-producing clouds but have low temperatures [8]. Upadhyaya and Ramsankaran in 2013 developed a rainfall estimation method with the basic principle that cloud top temperature has an inverse relationship with the amount of rainfall produced from clouds based on infrared channel estimation on geostationary satellites [9]. The established estimating approach is simple, yet it is accurate. Other methods that can be used to estimate rainfall using satellite data include Auto Estimator (AE), Convective Stratiform Technique (CST), Convective Stratiform Technique modified (CSTm), Non-linear relations and non-linear inversions [10].

Availability of rainfall data from surface observation stations in Indonesia, especially in some areas of Indonesia, is still very limited so to overcome this, rainfall data from satellite data is needed. The need for this rainfall data can be fulfilled, one of which is from remote sensing data, such as Himawari 8. However, the accuracy of Himawari 8 satellite in generating rainfall data in Indonesia is unclear. As a result, the question is, how reliable is the Himawari 8 Satellite in detecting rain in Indonesia?

There are several approaches for comparing the capability or accuracy of satellite rainfall estimation data to station rainfall data. Dinku et al in 2007 assessed the capacity to estimate satellite rainfall using statistical analysis of mean error, root mean square error, efficiency score, and bias [11], Prakash et al in 2010 used statistics to analyze correlation coefficient, bias, standard deviation, and root mean square error [12], in addition, Sharifi et al and Reis et al use statistical analysis and categorization methods [13], [14]. Statistical analysis can determine how much satellite rainfall data deviates from observation station data, whereas categorical approaches can determine how well satellite data detect rain events.

To find out the ability of Himawari 8 rainfall data to detect rain in Indonesia and to meet the needs of rainfall data in Indonesia, this research analyzed the ability of Himawari 8 rainfall data (derived based on infrared channel 3 data using the INSAT Multi-Spectral Rainfall Algorithm /IMSRA) to detect rain in Indonesia at 163 Meteorological, Climatological, and Geophysical Agency (BMKG) station locations for 2019 and 161 BMKG station locations for 2020.

Analysis of rain detection capability was carried out using a Contingency Table by calculating the number of rain events that were successfully detected and failed to be detected by the satellite. The calculation will then be converted into a statistical index. The statistical index results from the Himawari 8 rainfall

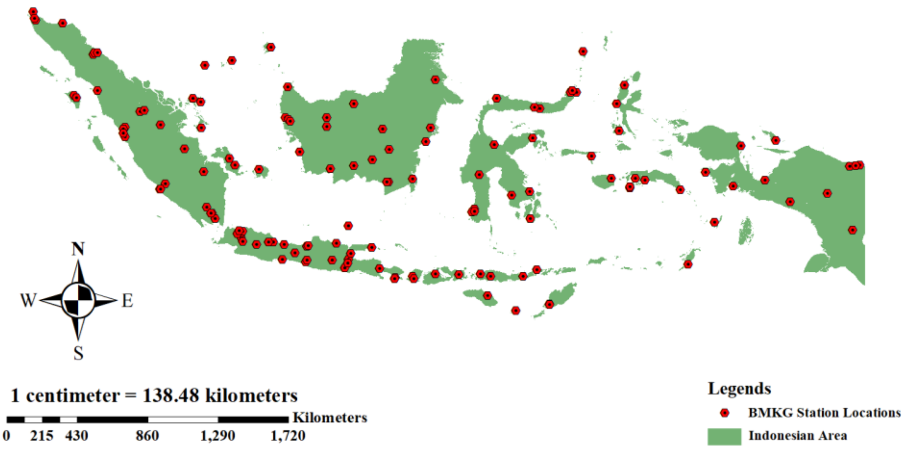


Figure 2. BMKG rainfall gauge station location (source: dataonline.bmkg.go.id)

data will be compared with the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) and Global Satellite Mapping of Precipitation (GSMaP) statistical indexes.

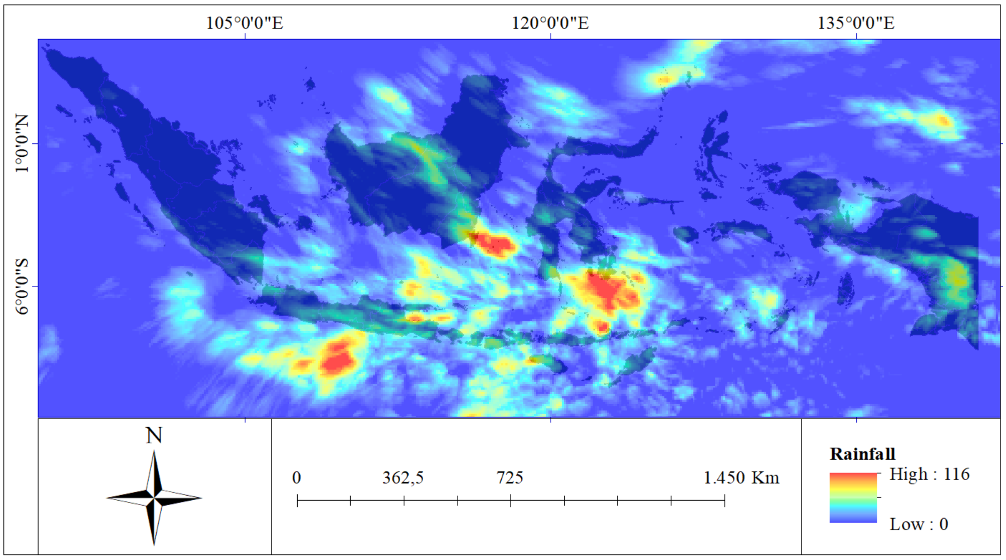


Figure 3. Himawari 8 rainfall (mm/day) for January 1, 2020 (source: modis-atalog.lapan.go.id/himawari-8)

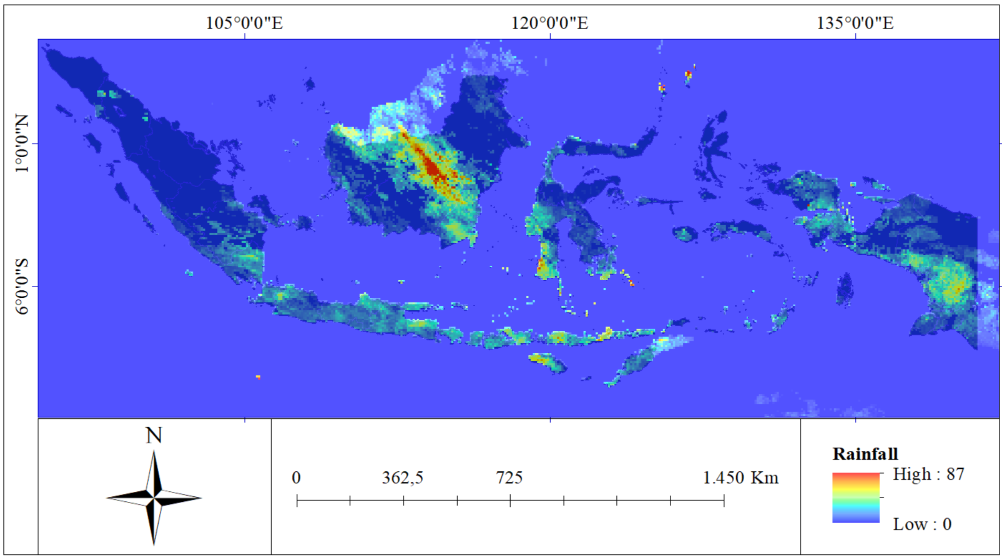


Figure 4. CHIRPS rainfall (mm/day) for January 1, 2020

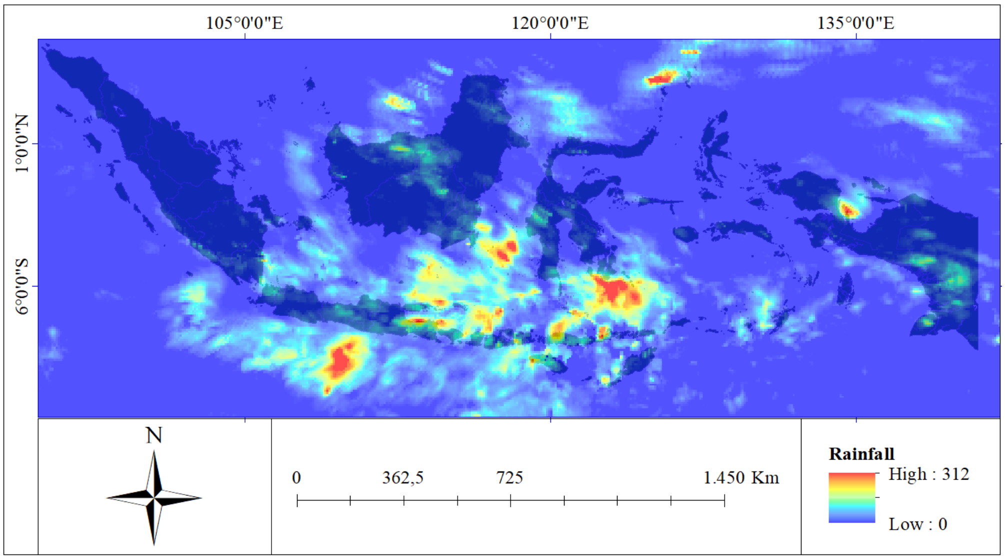


Figure 5. GSMaP rainfall (mm/day) for January 1, 2020 (source: sharaku.eorc.jaxa.jp/GSMaP)

2. Methods

This study necessitates the use of Himawari 8 rainfall data, CHIRPS rainfall data, and GSMaP rainfall data. Additionally, BMKG rainfall data will be utilized as a benchmark. All data are available online and open to the public so the data can be obtained free of charge. After all of the relevant data have been collected, the data are retrieved based on the coordinates of the locations of the BMKG stations. To make conclusions, the gathered data are processed and analyzed using the contingency table categorical approach. The statistical index values produced from contingency tables are used to draw conclusions. The capacity of the Himawari 8 to detect rain was tested in all areas of Indonesia using 163 BMKG stations. Figure 2 depicts the locations of these stations.

The LAPAN remote sensing earth station at Pekayon has been able to receive Himawari 8 Satellite data every 10 minutes in near real time for 14 channels on the Himawari 8 Satellite [15]. Thus, the Himawari 8 satellite data have been received by LAPAN, allowing the data to be downloaded immediately. The Himawari 8 data utilized in this investigation are infrared channel 3. The data on the channel are then converted into an estimated rainfall value using the IMSRA formula proposed by [16] namely

$$R = 8{,}613098e^{-\frac{TB-197{,}97}{15{,}7061}} \quad (1)$$

where R is the rainfall in $mm/hour$ and TB is the cloud top temperature in Kelvin while e is the Euler number. The resulting Himawari 8 rainfall estimation value sample can be seen in Figure 3.

Meanwhile, CHIRPS rainfall data are available at link data.chc.ucsb.edu/products/CHIRPS-2.0/. This sample data are shown in Figure 4. Furthermore, GSMaP rainfall data are obtained by downloading it on the Japan Aerospace Exploration Agency (JAXA) website by previously registering at link sharaku.eorc.jaxa.jp/GSMaP/registration.html. This sample data are shown in Figure 5. Finally, BMKG rainfall data may be accessed by downloading it from the BMKG website after completing the registration process via the following link dataonline.bmkg.go.id/register.

This analysis examined data from January 1, 2019 to December 31, 2020. All satellite rainfall data are provided in raster format, whereas BMKG rainfall data are presented in spreadsheet format, with BMKG station coordinates displayed. Data from BMKG stations on rainfall events were then compared to estimated rainfall data from Himawari 8, CHIRPS, and GSMaP.

To test the capacity of Himawari 8 rainfall estimation data to identify rain in Indonesia, the data were retrieved at the same location as the BMKG station. After the data have been properly extracted, it is ready for analysis. Sharifi et al in 2016 employed a contingency table to examine rainfall performance based on satellite estimations [13]. The table illustrates the frequency of rain occurrences based on satellite estimations. Table 1 depicts the construction of the contingency table.

Table 1. Structure of Contingency Table

		Sattelite/Model		
		Yes	**No**	**Total**
Rain-gauge	Yes	*Hits* (a)	*Misses* (c)	$a+c$
	No	*False alarms* (b)	*Correct negatives* (d)	$b+d$
	Total	$a+b$	$c+d$	$\boldsymbol{total}$

The rain gauge indicates that it will rain if the BMKG rainfall data exceed 0 mm/day. Meanwhile, the satellite/model predicts rain if the satellite's estimated rainfall data (Himawari 8, CHIRPS, and GSMaP) are larger than 0 mm/day. *Hits* occur when the BMKG and satellite rainfall data exceed 0 mm/day, indicating that the satellite successfully identified rain events. *False alarms* occur when the BMKG rainfall data are 0 mm/day but satellite rainfall data are greater than 0 mm/day, which means the satellite gives a false alarm for rain. *Misses* happen when the BMKG rainfall data are more than 0 mm/day but the satellite rainfall data are 0 mm/day, implying that the satellite misses rain events. Finally, a *correct negative* occurs when the BMKG and satellite rainfall data are both 0 mm/day, indicating that the satellite reports no rain and this is correct.

The assessment process was carried out for all satellite rainfall data (Himawari 8, CHIRPS and GSMaP) against rain-gauge data (BMKG rainfall) so that a total of three sets of contingency tables were produced. Using this table for daily rainfall data, the following various statistical indices are used to evaluate the performance of Himawari 8 rainfall data:

1. *Probability of Detection* (POD)
   POD indicates if satellite data successfully predicts rain events. The best POD score is 1 where

$$POD = \frac{a}{a+c}. \quad (2)$$

2. *False Alarms Ratio* (FAR)
   FAR states what fraction of events are predicted by satellite data but do not occur. The ideal score

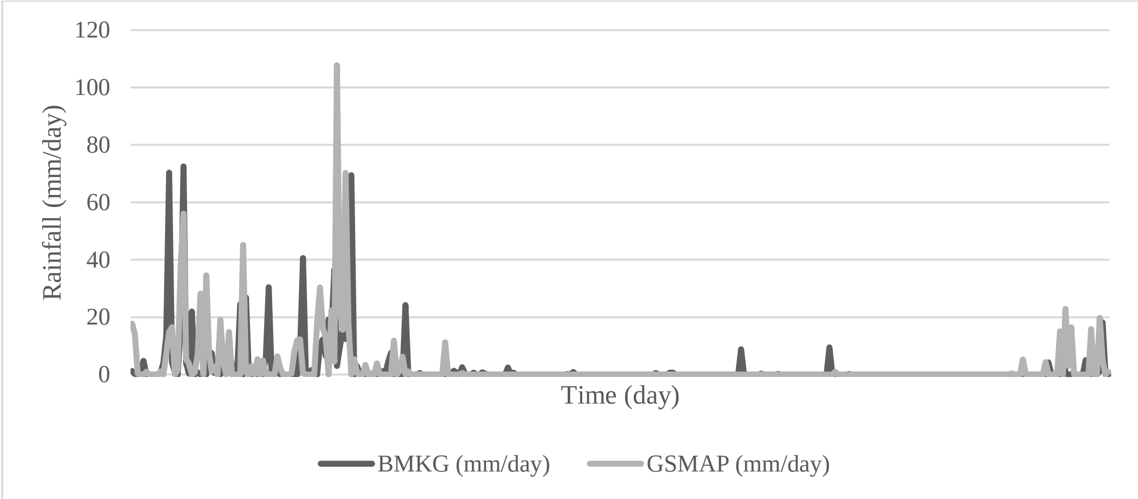


Figure 6. Comparison of BMKG and GSMaP rainfall data at the Denpasar Geophysics Station from 1 January 2019 to December 31, 2019

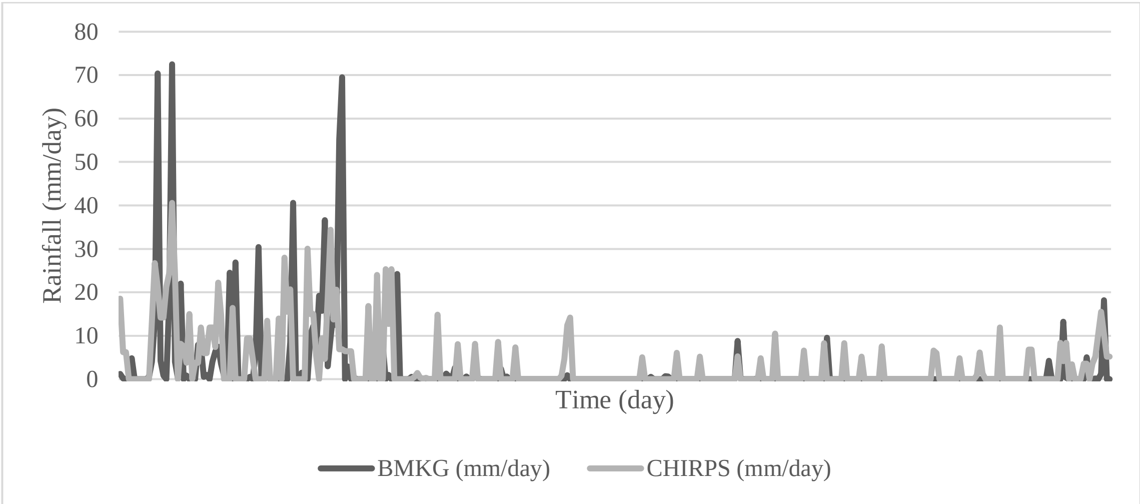


Figure 7. Comparison of BMKG and CHIRPS rainfall data at the Denpasar Geophysics Station from 1 January 2019 to December 31, 2019

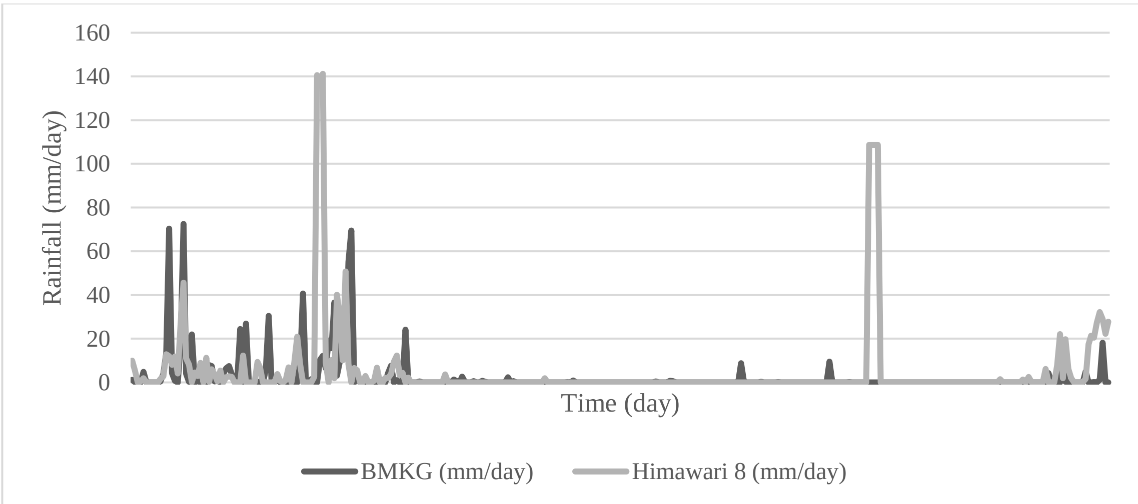


Figure 8. Comparison of BMKG and Himawari 8 rainfall data at the Denpasar Geophysics Station from 1 January 2019 to December 31, 2019

is 0 with

$$FAR = \frac{b}{a+b}. \tag{3}$$

3. *Critical Succes Index* (CSI)
   CSI states the extent to which satellite data predicting rain events corresponds to actual rain events. The best score for CSI is 1 with

$$CSI = \frac{a}{a+b+c}. \tag{4}$$

4. *Accuracy*
   Accuracy states the ratio of rain/no rain events that has been successfully predicted by satellite data. The best score for accuracy is 1 with

$$Accuracy = \frac{a+d}{total}. \tag{5}$$

5. *Bias*
   The bias explains how the frequency of satellite-predicted rain occurrences differs from the frequency of observed rain events. The bias value ranges from 0 to 1, with ∞ being the best. The bias equation is given by

$$Bias = \frac{a+b}{a+c}. \tag{6}$$

3. Result and Discussion

The process for obtaining contingency values as shown in Table 1 is carried out for all BMKG stations in Indonesia. The method for one of the BMKG station data, namely Denpasar Geophysics Station data, is shown below: Based on data at the Denpasar Geophysics Station (Figure 6 - Figure 8 for 2019 and Figure 9 - Figure 11 for 2020), using the process shown in Table 1, the contingency values for 2019 are obtained for GSMaP, CHIRPS, and Himawari 8, namely *hits* (*a*) of 32, 45 and 38; *false alarms* (*b*) of 34, 59 and 46; *misses* (*c*) of 41, 28 and 31; and *correct negatives* (*d*) of 250, 225 and 229.

Furthermore, for 2020 for GSMaP, CHIRPS and Himawari 8 data, the *hits* values (*a*) are 41, 57 and 79; *false alarms* (*b*) of 23, 45 and 53; *misses* (*c*) of 71, 55 and 33; and *correct negatives* (*d*) of 121, 99 and 91. The same process is carried out for all other BMKG stations (162 stations for 2019 and 160 stations for 2020) so that a contingency value will be obtained based on all BMKG stations in Indonesia.

2019. The results of data pairs for extracting daily rainfall values from 163 stations in 2019 are 52656 data pairs. Furthermore, the results of a comparison using the Contingency Table between the rainfall values of GSMaP, CHIRPS, and Himawari 8 with the rainfall values of the BMKG stations are presented in Table 2 - Table 4, while the results of statistical analysis for the performance test of each satellite rainfall data are presented in Table 5.

Table 2. Contingency Table of GSMaP and BMKG rainfall data for 2019

		GSMaP		
		Yes	**No**	**Total**
BMKG	**Yes**	10334	6987	17321
	No	9797	25538	35335
	Total	20131	32525	52656

Table 3. Contingency Table of CHIRPS and BMKG rainfall data for 2019

		CHIRPS		
		Yes	**No**	**Total**
BMKG	**Yes**	10393	6928	17321
	No	11019	24316	35335
	Total	21412	31244	52656

Table 4. Contingency Table of Himawari 8 and BMKG rainfall data for 2019

		Himawari 8		
		Yes	**No**	**Total**
BMKG	**Yes**	11404	5917	17321
	No	12314	23021	35335
	Total	23718	28938	52656

The results of the comparison between GSMaP and BMKG daily rainfall values for all rain events at all stations tested in 2019 are *hits* for GSMaP data occurring 10334 times, *false alarms* occurring 9797 times, *misses* occurring 6987 and *correct negatives* events occurring 25538 times (Table 2). A sample comparison of BMKG and GSMaP data at one of the stations (Denpasar Geophysics Station) for 2019 is presented in Figure 6.

Furthermore, for CHIRPS data, *hits* occurred 10393 times, *false alarms* occurred 11019 times, *misses* occurred 6928 times, and *correct negatives* events occurred 24316 times (Table 3). Figure 7 shows a sample comparison of BMKG and CHIRPS data from one of the sites (Denpasar Geophysics Station) for 2019. Finally, for Himawari 8 data, *hits* happened 11404 times, *false alarms* occurred 12314 times, *misses* occurred 5917 times, and *correct negatives* events occurred 23021 times (Table 4). Figure 8 shows a sample comparison of BMKG and Himawari 8 data from one of the sites (Denpasar Geophysics Station) in 2019.

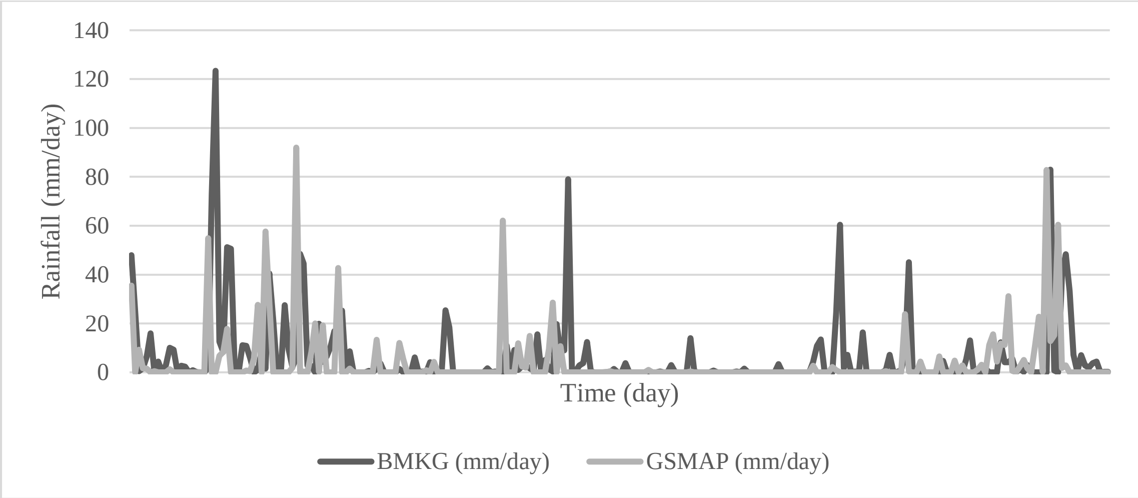


Figure 9. Comparison of BMKG and GSMaP rainfall data at the Denpasar Geophysics Station from 1 January 2020 to December 31, 2020

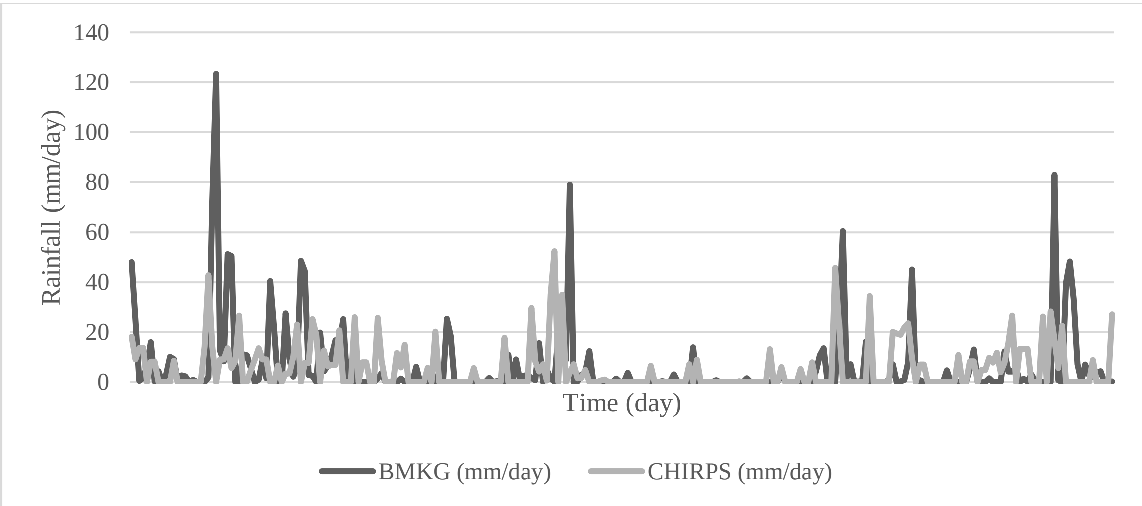


Figure 10. Comparison of BMKG and CHIRPS rainfall data at the Denpasar Geophysics Station from 1 January 2020 to December 31, 2020

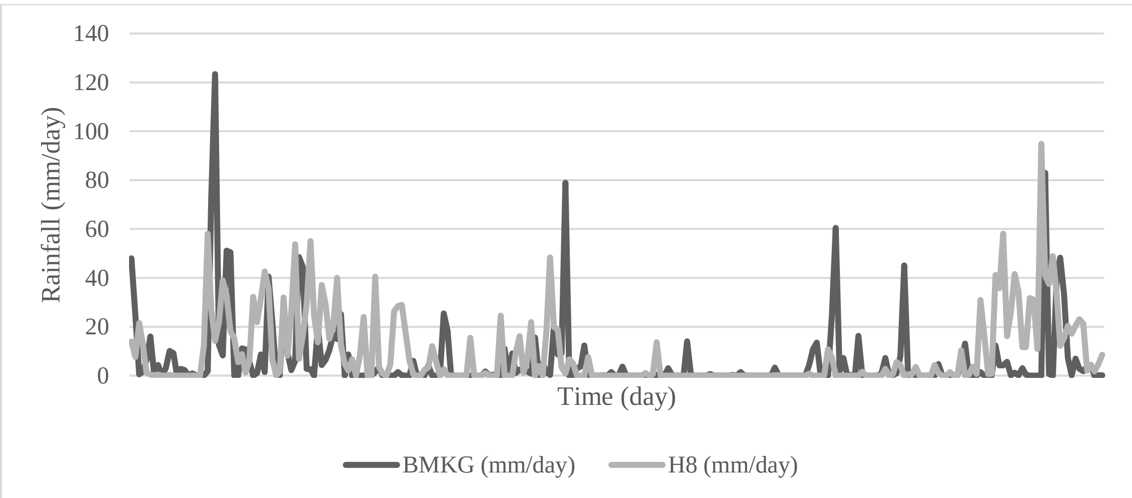


Figure 11. Comparison of BMKG and Himawari 8 rainfall data at the Denpasar Geophysics Station from 1 January 2020 to 31 December 2020

Table 5. Statistical Index recap for all rainfall data for 2019

Statistical Index	Rainfall data		
	GSMaP	CHIRPS	Himawari 8
POD	0.60	0.60	0.66
FAR	0.49	0.51	0.52
CSI	0.38	0.37	0.38
Accuracy	0.68	0.66	0.65
Bias	1.16	1.24	1.37

The maximum number of hit events (correct events) was attained by Himawari 8 (11404 events) when the rainfall values of GSMaP, CHIRPS, and Himawari 8 were compared to the BMKG rainfall data. Himawari 8 has a higher false alarm rate (12314 events) than GSMaP (9797 events) and CHIRPS (11019 events). This is also demonstrated by the statistical analysis findings in Table 5, which reveal that the Himawari 8 POD score (about 66%) is the greatest, but the FAR value (52%) is also greater when compared to GSMaP and CHIRPS. Furthermore, the accuracy of Himawari 8 (65%) is somewhat lower than that of GSMaP (68%) and CHIRPS (66%). Finally, the CSI value (38%) indicates the capacity of Himawari 8 to detect rain events, which is the same as GSMaP (38%) and greater than CHIRPS (37%), despite the bias rate of Himawari 8 (1.37) being higher than the others.

2020. The results of data pairs for extracting daily rainfall values from 161 stations in 2020 are 38,497 data pairs. Furthermore, the results of a comparison using the Contingency Table between the rainfall values of GSMaP, CHIRPS, and Himawari 8 with the rainfall values of the BMKG stations are presented in Table 6 - Table 8, while the results of statistical analysis for the performance test of each satellite rainfall data are presented in Table 9.

Table 6. Contingency Table of GSMaP and BMKG rainfall data for 2020

		GSMaP		
		Yes	**No**	**Total**
BMKG	**Yes**	14846	8705	23551
	No	5275	9671	14946
	Total	20121	18376	38497

Table 7. Contingency Table of CHIRPS and BMKG rainfall data for 2020

		CHIRPS		
		Yes	**No**	**Total**
BMKG	**Yes**	14554	8997	23551
	No	5900	9046	14946
	Total	20454	18043	38497

Table 8. Contingency Table of Himawari 8 and BMKG rainfall data for 2020

		Himawari 8		
		Yes	**No**	**Total**
BMKG	**Yes**	20102	3449	23551
	No	9419	5527	14946
	Total	29521	8976	38497

The comparison of GSMaP with BMKG daily rainfall values for all rain events at all stations examined in 2020 yields 14846 *hits*, 5275 *false alarms*, 8705 *misses*, and 9671 *correct negatives* occurrences (Table 6). Figure 9 depicts a sample comparison of BMKG and GSMaP data at one of the sites (Denpasar Geophysics Station) for 2020.

Furthermore, for CHIRPS data, *hits* occurred 14554 times, *false alarms* occurred 5900 times, *misses* occurred 8997 times, and *correct negatives* events occurred 9046 times (Table 7). Figure 10 shows a sample comparison of BMKG and CHIRPS data at one of the sites (Denpasar Geophysics Station) for 2020.

Finally, for Himawari 8 data, *hits* occurred 20102 times, *false alarms* occurred 9419 times, *misses* occurred 3449 times, and *correct negatives* events occurred 5527 times (Table 8). Figure 11 shows a sample comparison of BMKG and Himawari 8 data at one of the sites (Denpasar Geophysics Station) for 2020.

Table 9. Statistical Index recap for all rainfall data for 2020

Statistical Index	Data Curah Hujan		
	GSMaP	CHIRPS	Himawari 8
POD	0.63	0.81	0.85
FAR	0.26	0.29	0.32
CSI	0.52	0.49	0.61
Accuracy	0.64	0.61	0.67
Bias	0.85	0.87	1.25

The largest number of hit events (correct events) was attained by Himawari 8 (20102 events) when the rainfall values of GSMaP, CHIRPS, and Himawari 8 were compared to the BMKG rainfall data. Himawari 8 has a higher false alarm rate (9419 events) than

GSMaP (5275 events) and CHIRPS (5900 events). This is also demonstrated by the statistical analysis findings in Table 9, which reveal that the Himawari 8 POD score (about 85%) is the highest, but the FAR value (32%) is also higher when compared to GSMaP and CHIRPS. However, the overall accuracy of Himawari 8 (67%) is somewhat greater than that of GSMaP (64%) and CHIRPS (61%). Furthermore, as evidenced by the CSI value, Himawari 8 has a stronger capacity to detect rain occurrences (61%) than GSMaP (52%), and CHIRPS (49%), while having a larger bias rate (1.25).

4. Conclusion

In general, the ability to detect rain events from Himawari 8, GSMaP, and CHIRPS data is better in 2020 compared to the ability to detect rain in 2019. This is thought to be related to the El Nino events in 2019 and La Nina in 2020. In particular, in those two years, it was concluded that the Himawari 8, CHIRPS and GSMaP rainfall data have their respective capabilities in detecting rain that occurs in Indonesia. This can be seen from the statistical index value of each satellite data. Although in terms of probability of detection and critical success, the Himawari 8 index data has advantages compared to other data, the GSMaP and CHIRPS data show a smaller false alarm ratio and bias than the Himawari 8 data. In addition, the accuracy value of the Himawari 8 data is better than other data for 2019 but GSMaP and CHIPRS show better values for 2020 data. This indicates the need for further studies using longer time series.

Acknowledgments

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References

[1] H. HIROSE, S. SHIGE, M. K. YAMAMOTO, and A. HIGUCHI, "High Temporal Rainfall Estimations from Himawari-8 Multiband Observations Using the Random-Forest Machine-Learning Method," *J. Meteorol. Soc. Japan. Ser. II*, vol. 97, no. 3, pp. 689–710, 2019, doi: 10.2151/jmsj.2019-040.

[2] J. Bühl *et al.*, "Remote Sensing," *Meteorol. Monogr.*, vol. 58, pp. 10.1-10.21, Jan. 2017, doi: 10.1175/AMSMONOGRAPHS-D-16-0015.1.

[3] N. Ayasha, "A COMPARISON OF RAINFALL ESTIMATION USING HIMAWARI-8 SATELLITE DATA IN DIFFERENT INDONESIAN TOPOGRAPHIES," *Int. J. Remote Sens. Earth Sci.*, vol. 17, no. 2, p. 189, Mar. 2021, doi: 10.30536/j.ijreses.2020.v17.a3441.

[4] W. F. Krajewski, G. J. Ciach, and E. Habib, "An analysis of small-scale rainfall variability in different climatic regimes," *Hydrol. Sci. J.*, vol. 48, no. 2, pp. 151–162, Apr. 2003, doi: 10.1623/hysj.48.2.151.44694.

[5] J. Guo *et al.*, "Aerosol-induced changes in the vertical structure of precipitation: a perspective of TRMM precipitation radar," *Atmos. Chem. Phys.*, vol. 18, no. 18, pp. 13329–13343, Sep. 2018, doi: 10.5194/acp-18-13329-2018.

[6] K. BESSHO *et al.*, "An Introduction to Himawari-8/9— Japan’s New-Generation Geostationary Meteorological Satellites," *J. Meteorol. Soc. Japan. Ser. II*, vol. 94, no. 2, pp. 151–183, 2016, doi: 10.2151/jmsj.2016-009.

[7] B. J. Sohn, G.-H. Ryu, H.-J. Song, and M.-L. Ou, "Characteristic Features of Warm-Type Rain Producing Heavy Rainfall over the Korean Peninsula Inferred from TRMM Measurements," *Mon. Weather Rev.*, vol. 141, no. 11, pp. 3873–3888, Nov. 2013, doi: 10.1175/MWR-D-13-00075.1.

[8] P. Suwarsono, A. D. S. Kusumaning, and M. Kartasamita, "Penentuan Hubungan Antara Suhu Kecerahan dangan MTSAT dengan Curah Hujan Data QMORPH," *J. Penginderaan Jauh*, vol. 6, no. 1, pp. 32–42, 2009, [Online]. Available: http://jurnal.lapan.go.id/index.php/jurnal_inderaja/article/view/1184/1062.

[9] S. Upadhyaya and R. Ramsankaran, "Review of satellite remote sensing data based rainfall estimation methods," *Hydro 2013 Int.*, no. December, pp. 1–16, 2013.

[10] N. Alfuadi, "Interkomparasi Teknik Estimasi Curah Hujan," *Pros. SNSA*, pp. 151–162, 2016.

[11] T. Dinku, P. Ceccato, E. Grover-Kopec, M. Lemma, S. J. Connor, and C. F. Ropelewski, "Validation of satellite rainfall products over East Africa's complex topography," *Int. J. Remote Sens.*, vol. 28, no. 7, pp. 1503–1526, Apr. 2007, doi: 10.1080/01431160600954688.

[12] S. Prakash, C. Mahesh, R. M. Gairola, and P. K. Pal, "Estimation of Indian summer monsoon rainfall using Kalpana-1 VHRR data and its validation using rain gauge and GPCP data," *Meteorol. Atmos. Phys.*, vol. 110, no. 1–2, pp. 45–57, Dec. 2010, doi:

10.1007/s00703-010-0106-8.

[13] E. Sharifi, R. Steinacker, and B. Saghafian, “Assessment of GPM-IMERG and other precipitation products against gauge data under different topographic and climatic conditions in Iran: Preliminary results,” *Remote Sens.*, vol. 8, no. 2, 2016, doi: 10.3390/rs8020135.

[14] J. B. C. dos Reis, C. D. Rennó, and E. S. S. Lopes, “Validation of satellite rainfall products over a mountainouswatershed in a humid subtropical climate region of Brazil,” *Remote Sens.*, vol. 9, no. 12, 2017, doi: 10.3390/rs9121240.

[15] A. Indradjad, B. A. M. Pratiknyo, and H. Gunawan, “Study of Development and Upgrading Remote Sensing Ground Station System for Receiving Satellite Himawari 8 in LAPAN Pekayon,” 2015.

[16] A. K. Mishra, R. M. Gairola, A. K. Varma, and V. K. Agarwal, “Improved rainfall estimation over the Indian region using satellite infrared technique,” *Adv. Sp. Res.*, vol. 48, no. 1, pp. 49–55, Jul. 2011, doi: 10.1016/j.asr.2011.02.016.